

2001

Effects of Energy Source and Soil Reaction on Redox, Soil Color, and Sesquioxide Transformation for the Moreland and Sharkey Soils.

Jang-hung Huang
Louisiana State University and Agricultural & Mechanical College

Follow this and additional works at: https://digitalcommons.lsu.edu/gradschool_disstheses

Recommended Citation

Huang, Jang-hung, "Effects of Energy Source and Soil Reaction on Redox, Soil Color, and Sesquioxide Transformation for the Moreland and Sharkey Soils." (2001). *LSU Historical Dissertations and Theses*. 345.

https://digitalcommons.lsu.edu/gradschool_disstheses/345

This Dissertation is brought to you for free and open access by the Graduate School at LSU Digital Commons. It has been accepted for inclusion in LSU Historical Dissertations and Theses by an authorized administrator of LSU Digital Commons. For more information, please contact gradetd@lsu.edu.

INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

ProQuest Information and Learning
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
800-521-0600

UMI[®]

**EFFECTS OF ENERGY SOURCE AND SOIL REACTION ON REDOX, SOIL
COLOR, AND SESQUIOXIDE TRANSFORMATION FOR THE MORELAND
AND SHARKEY SOILS**

A Dissertation

**Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
In partial fulfillment of the
requirements for the degree of
Doctor of Philosophy**

In

The Department of Agronomy

by

Jang-Hung Huang

B.S., National Chungshing University, Taiwan, 1985

M.S., National Taiwan University, Taiwan, 1990

August 2001

UMI Number: 3021434

UMI[®]

UMI Microform 3021434

Copyright 2001 by Bell & Howell Information and Learning Company.

All rights reserved. This microform edition is protected against
unauthorized copying under Title 17, United States Code.

Bell & Howell Information and Learning Company
300 North Zeeb Road
P.O. Box 1346
Ann Arbor, MI 48106-1346

ACKNOWLEDGMENTS

I would like to express my deep appreciation to Dr. Wayne H. Hudnall for his assistance, guidance, and support during my study at the Agronomy Department, Louisiana State University. My gratitude also extends to Dr. Hudnall's family, his wife, Callalya, and his son, Eric, for their concern and friendship.

I am especially grateful to my graduate committee, Dr. William H. Pattrick, Jr, Dr. Ray E. Ferrell, Jr, Dr. Robert P. Gambrell, Dr. Vincent LiCata, and Mr. Jerry J. Daigle, for their guidance and time in reviewing my dissertation manuscript.

I sincerely wish to thank Mr. Chiang-Kun Lin for his friendship and financial support. I also want to thank Asfaw Bekele and Jackie Prudente, fellow graduate students and colleagues, for their assistance and support. I am thankful to Dr. Stephen Bretzius for editing my dissertation draft.

Finally, thanks my family.

TABLE OF CONTENTS

ACKNOWLEDGMENTS.....	ii
ABSTRACT.....	v
CHAPTER 1. SOIL AQUIC CONDITIONS AND HYDRIC SOILS: A LITTERATURE REVIEW.....	1
1.1. Introduction.....	1
1.2. Soil Color Relative to Fe Oxides and Wetness Conditions..	5
1.3. Elements of Soil Aquic Conditions and Hydric Soils.....	7
1.3.1. Saturation.....	8
1.3.2. Reduction.....	9
1.3.3. Redoximorphic Features.....	12
1.3.4. Hydric Soils.....	13
1.4. Factors Affecting Redoximorphic Features.....	14
1.4.1. Microorganisms and Organic Carbon.....	14
1.4.2. Oxygen.....	16
1.4.3. Parent Materials, pH, and Fe Minerals.....	17
1.4.4. Temperature.....	19
1.5. Problems Associated with Chroma ≤ 2	20
CHAPTER 2. EFFECTS OF 10 G/KG SUCROSE AND ADJUSTED pH ON Eh, pH, AND Fe TRANSFORMATION.....	22
2.1. Introduction.....	22
2.1.1. Redox Interfaces.....	23
2.1.2. Respiration.....	23
2.1.3. Fermentation.....	24
2.1.4. Selective Chemical Dissolution.....	25
2.2. Materials and Methods.....	28
2.2.1. Background Information of Two Studied Soils.....	28
2.2.2. Incubation Procedures.....	31
2.2.3. Analysis Methods.....	34
2.3. Results.....	35
2.3.1. pH.....	35
2.3.2. Eh.....	61
2.3.3. Mn and Fe in Soil Solution.....	83
2.3.4. Selective Chemical Dissolution Analysis.....	89
2.3.5. Soil Colors.....	103
2.3.6. Summary.....	112
2.4. Discussion and Conclusions.....	120
2.4.1. pH.....	120
2.4.2. Eh.....	127
2.4.3. Mn and Fe in Soil Solution.....	133
2.4.4. Fe Oxide Transformation.....	136
2.4.5. Soil Colors.....	140

CHAPTER 3. THE EFFECTS OF DIFFERENT SUCROSE CONCENTRATIONS ON THE CHANGES OF pH, Eh, Fe TRANSFORMATION, AND SOIL COLORS.....	142
3.1. Introduction.....	142
3.2. Materials and Methods.....	144
3.2.1. Materials.....	144
3.2.2. Analysis Methods.....	144
3.3. Results.....	145
3.3.1. pH.....	145
3.3.2. Eh.....	158
3.3.3. Mn and Fe in Soil Solution.....	172
3.3.4. Selective Chemical Dissolution Analysis.....	176
3.3.5. Organic Carbon.....	185
3.3.6. Soil Colors.....	192
3.3.7. Summary.....	201
3.4. Discussion and Conclusions.....	212
3.4.1. pH.....	212
3.4.2. Eh and Organic Carbon.....	215
3.4.3. Fe Oxide Transformation.....	219
3.4.4. Soil Colors.....	223
CHAPTER 4. THE CHANGES OF Eh, pH, SOLUBLE ORGANIC CARBON, Fe, AND Mn CONCENTRATIONS IN THE INTERSTITIAL WATER AT THREE DIFFERENT DEPTHS.....	230
4.1. Introduction.....	230
4.2. Materials and Methods.....	232
4.2.1. Materials.....	232
4.2.2. Incubation Procedures.....	232
4.2.3. Chemical and Mineralogical Analysis.....	233
4.3. Results.....	235
4.3.1. pH.....	235
4.3.2. Eh.....	239
4.3.3. Mn and Fe in Soil Solution.....	244
4.3.4. Organic Carbon.....	253
4.3.5. X-Ray Diffraction.....	256
4.3.6. Summary.....	258
4.4. Discussion and Conclusions.....	264
CHAPTER 5. SUMMARY AND CONCLUSIONS.....	275
REFERENCES.....	278
VITA.....	291

ABSTRACT

Moreland clay (very fine, smectitic, thermic, Oxyaquic Hapluderts) derived from Red River alluvium does not exhibit redoximorphic features, though it is saturated for more than 2 months during the growing season. Sharkey clay (very-fine, smectitic, thermic Chromic Epiaquerts) derived from the Mississippi River alluvium exhibits redoximorphic features. The objectives of this study were to determine the effects of energy sources and adjusted pH on Eh, pH, and iron transformation on these two Vertisols in Louisiana.

Laboratory analysis was used to evaluate the factors controlling the formation of redoximorphic features. The first experiment was designed to predict the effects of 10 mg/kg sucrose and adjusted pH on the changes in Eh and pH during alternating saturation and drying treatments. DCB, acid-oxalate, and sodium pyrophosphate reagents were used to evaluate iron transformation. The second experiment evaluated different sucrose concentration effects, from 0.25 to 20 mg/kg, on pH and Eh. Methods used to evaluate organic carbon were also tested. The third laboratory experiment measured the redox potentials and chemical properties of the interstitial water at three different depths to correlate the relationship among Eh, pH, and redoxic couples while evaluating the reduction sequence and Fe oxide stability.

Results indicated that: 1) Mn and Fe can't be reduced in soils with an insufficient energy source, and pH and soil color did not change during 3 weeks of flooding; 2) soil pH and Eh were controlled by the concentrations of organic carbon, types and concentrations of inorganic compounds, and

fermentation; 3) selective chemical analysis can evaluate Fe transformation; 4) three different methods used to evaluate the concentrations of organic carbon failed to explain the change in Eh; 5) Eh, pH, and the concentration of Fe and Mn ions in the interstitial water failed to satisfy the Nernst equation; and 6) anaerobic microbes used nearby inorganic compounds as electron acceptors.

CHAPTER 1.

SOIL AQUIC CONDITIONS AND HYDRIC SOILS: A LITERATURE REVIEW

1.1. Introduction

The development of soils for non-agricultural uses has rapidly increased in recent years. For many non-agricultural soils use, the water table is the most significant factor. To assist planners in making land use decisions, identification of detailed soil wetness is needed. Without precise prediction of the soil moisture regime, incorrect evaluations of the land use potential of the soils may result. Identification of seasonal saturation is not only important for timber and crop management, but also for determining soil suitability of on-site waste disposal, septic tank filter fields, sewage lagoons, cemeteries, homes with basements, and building foundations (Vepraskas and Wilding, 1983a; Evans and Franzmeier, 1986). Usually soil wetness and aquic moisture regimes are inferred from soil colors and redoximorphic features (Griffin et al., 1992). One major problem arising from this practice is the inability to identify seasonal saturation and aquic moisture regimes because the morphological criteria alone is inadequate for making most land uses interpretations (Mausbach, 1992).

Soil color is a result of Fe and Mn oxide-hydroxide composition and quantity, soil moisture, organic matter, and the composition of the sand and silt fractions. Among these factors, Fe is the most important contribution because it is the fourth most abundant element in Earth's crust and the formation of different Fe minerals is related to soil saturation and aeration conditions.

Schwertmann (1993) indicated that Fe oxides are useful field indicators of pedogenetic environments for three reasons: (i) they include several minerals, (ii) these minerals have different colors, and, (iii) the type of mineral formed is influenced by the environment. Soil color is obviously and easily discriminated by the eye. Thus, it has been used historically to differentiate soil drainage in soil survey and classification. Low chroma (≤ 2) soil colors may indicate poor soil drainage conditions (Soil Survey Staff, 1998).

Soil hydrology is the factor that drives the development of hydromorphic features, saturation, and reduction in wet soils (Mausbach and Richardson, 1994). When an unsaturated soil is submerged, the gaseous diffusion of oxygen into the soil is retarded by the water. The aerobic organisms consume the trapped oxygen within a few hours and become quiescent or die (Ponnamperuma et al., 1967). Soil reduction will take place after the following conditions are met simultaneously: (i) the absence of an O_2 supply, (ii) the presence of organic matter, and (iii) the presence of anaerobic microorganisms in an environment suitable for their growth (Bouma, 1983). Facultative or strictly anaerobic organisms utilize oxidized compounds such as nitrate, manganic oxides, ferric oxides, sulfate and organic carbon as electron acceptors. The choice of an alternative electron acceptor is related to the net energy gain from the electron transfer and availability. In saturated soils, reduction of Fe^{3+} oxides by microbes only happens after oxygen, nitrate, and Mn^{4+} have been reduced (Ponnamperuma, 1972).

Mineral stability, pH, availability of nutrients, toxicity of specific chemical species and electrical conductivity significantly change after soils are saturated by water. Thus, it is very important to investigate the chemical, physical, and mineralogical behaviors of soils after saturation and reduction. Reduction can be measured directly with a platinum electrode or indirectly by a staining test. In the context of Soil Taxonomy (Soil Survey Staff, 1998), only the reduction-oxidation of Fe is considered because reduced Fe produces visible redoximorphic features that are identifiable in field. Redoximorphic features used as soil classification criteria for the aquic soil moisture regime can be misleading if used for inference for drainage conditions because soil saturation may occur for a long period without the development of mottling or soil colors with chroma ≤ 2 (Franzmeier et al., 1983; Vepraskas and Wilding, 1983a,b,c).

Sharkey soils are derived from Mississippi River alluvium and Moreland soils are from Red River alluvium. Sharkey soils (10YR-2.5Y) are dominated by amorphous Fe, and Moreland soils (5YR) have hematite as the predominant Fe oxide mineral. Data from instrumented sites in Louisiana tend to support a very-fine, smectitic, thermic Chromic Epiaquerts taxonomic classification for the Sharkey series (Hudnall and Patterson, 1997). However, similar Sharkey soils in Mississippi have been challenged by Pettry and Switzer (1996) on the basis that the aquic soil colors are relict, negative reaction to α , α' dipyridyl, and absence of reduced conditions during the growing season. Moreland soils lacking low soil chroma and/or positive reaction to α , α' -dipyridyl, and then were classified as very-fine, smectitic, thermic Oxyaquic Hapluderts. Hudnall et

al. (1990) showed that the Moreland soils and similar soils formed in Red River alluvium reacted to α , α' dipyridyl dye, and the Moreland soils are classified as very fine, smectitic, thermic, Oxyaquic Hapludert. The reason why most Moreland soils do not exhibit redoximorphic features and/or Fe reduction remains unknown. The scope of this dissertation is to investigate the causes controlling the formation of redoximorphic features in both the Sharkey and Moreland soils.

The primary objectives of this dissertation are to relate soil morphology, soil color, pH, redox potential, and chemical properties to redoximorphic features and soil-forming process of two widely distributed Vertisols formed from Red River and Mississippi River alluvium in Louisiana.

1. To evaluate the alternation of pH and redox potentials by artificially changing the original pH to 5, 6, and 7 with and without the addition of 10 mg/kg sucrose (by soil weight).
2. To evaluate the morphological implications due to the differences in Fe transformations and soil components after treatments.
3. To determine the effects of different sucrose concentrations from 20 to 0.25 mg/kg on redox potentials, pH, and distribution and formation of Fe minerals.
4. To determine the effects of selective chemical dissolution and mineral stability after pH and sucrose treatments.
5. To test and refine the Nernst equation, specifically to identify the threshold of Fe and Mn reduction.

6. To test the sequential reduction of Fe and Mn oxides in Moreland and Sharkey soils.

1.2. Soil Color Relative to Fe Oxides and Wetness Conditions

The ubiquitous presence of Fe oxides (51 g kg^{-1} Fe in the earth's crust) leads to the coloration of most soils (Schwertmann, 1993). Schwertmann and Taylor (1977) noted that the hue of subsurface soil is a function of the type and proportion of the Fe oxides. Secondary Fe oxides are the most important pigmenting agents in soils having a low content of organic matter and Mn oxides. Visual and spectrophotometric measurement of soil color can be used to identify hematite, goethite, and lepidocrocite with a relatively high reliability (Torrent et al., 1983; Schenost and Schwertmann, 1999). Chromas 2 or less are not limited to saturated and reduced soils. Bouma (1983) and Smith (1983) noted that redoximorphic features related to contemporaneous pedogenic processes can't be distinguished from those attributed to relict pedogenic events. The redoximorphic features could be from relict soil moisture regimes, which no longer reflect present drainage conditions (Vepraskas and Bouma, 1976; Dudal, 1992). Moreover, low chroma mottling without seasonal high water tables can also be observed in stratified soils, whose fine textured layer had enough water to become reduced and mottled and coarse textured layer remained unsaturated (Vepraskas, et al., 1974; Clothier, et al., 1978). Soil color can be used to infer previous environmental conditions if it is relic, or can reflect current weathering and pedogenesis (Brown, 1970). However, soil color

varies with concentration, crystal size, degree of cementation, and isomorphic substitution of Fe (Schwertmann, 1993).

Hematite can be readily identified in a soil if the hue is 7.5-5YR or redder (Schwertmann et al., 1982). Scheffer et al. (1958, cited from Torrent et al., 1983) found that only 1.7% hematite could give a soil a red color because hematite is usually finely divided and only small amounts can impart intense bright red coloration (Schwertmann et al., 1977). A small quantity (10 g kg^{-1}) of hematite in a soil containing 30 g kg^{-1} goethite can markedly redden a soil from 2.5Y to 5YR. Soils containing goethite exclusively have a hue of 10YR or yellower (Schwertmann et al., 1982; Torrent et al., 1983). Soils with a hue of 7.5YR and a value ≥ 6 owe their orange color to lepidocrocite. Ferrihydrite can be distinguished from goethite by its redder hue (5-7.5YR) and from lepidocrocite by its lower value (≤ 6) (Schwertmann, 1993). However, these typical Fe-oxide colors may not be recognized if masked by the dark colors of organic matter and Mn oxides.

In aerobic soils, Fe oxides are primarily formed at the site of the Fe source and reflect the homogeneous Fe distribution. Fe oxides can be reduced by microbial respiration under anaerobic conditions. Hydric soils are commonly reduced and Fe enters solution as Fe^{2+} in poorly drained soils (Blodgett et al., 1993). The reduced and mobile Fe^{2+} may move to aerobic zones and oxidize to form new Fe oxides resulting in heterogeneous Fe distribution (Schwertmann, 1993). Thus, the color mottling forms after the redistribution of Fe oxides. Mottles, associated with the reduction, mobilization, and precipitation of Fe and

Mn, are often used by soil scientists as an indicator of the internal drainage status of a soil profile (Clothier et al., 1978). Bouma (1983) stated that soil color and mottling are primarily a function of Fe reduction, which requires anaerobic conditions, an energy source (i.e., organic matter), and a viable population of Fe-reducing bacteria.

A chroma of 2 or less is the most consistent mark of alternating saturation-reduction left in a soil associated with soil wetness conditions (Veneman et al., 1976; Franzmeier et al., 1983; Comerma, 1985) and is used to define aquic moisture regimes (Soil Survey Staff, 1998). Low chroma mottling and gray colors result from a gleying process that involves saturation of the soil with water for long periods. The gray soil color is produced primarily by the natural color of sand, silt, and clay particles (Ponnamperuma, 1972). Bloomfield (1950; 1951) suggested gleyed soil color resulted from unmasking of soil material by the removal of Fe oxide coatings to expose the mineral grains and the reduced Fe may be present as an Fe-organic complex. Daniels et al. (1961) noted neutral and gley hues relate to the presence of Fe^{2+} . This implies a reducing regime that is virtually free of dissolved oxygen (Daniels et al., 1973). Soils with small amounts of Fe oxides exhibit soil colors between grayish, greenish, or white indicating either little or no weathering or the complete removal of Fe oxides following their reduction by microbial respiration (Schwertmann, 1993).

1.3. Elements of Soil Aquic Conditions and Hydric Soils

A soil's moisture regime must be known before the soil can be classified. Of the six moisture regimes defined in Soil Taxonomy, the definitions of aquic

moisture regime and aquic condition are probably the most unclear. Aquic moisture regime occurs in soils that are periodically saturated with groundwater or has a capillary fringe for sufficient periods to cause the soils to be anaerobic within the moisture control section. The duration of the anaerobic conditions is not specified (Soil Survey Staff, 1998). When comparisons are made among soils with fluctuating water table, redox potentials, and soil colors, a problem arises because the definition of aquic moisture regime is based on the soil being virtually free of dissolved O₂. To have aquic conditions, three properties must occur simultaneously: (i) depth and patterns of saturation, such as Episaturation, Endosaturation, and Anthric saturation, (ii) occurrence of reduced Fe, and (iii) presence of redoximorphic features, such as redox concentrations, redox depletion, reduced matrix, and a positive reaction to an α , α' -dipyridyl solution. These three characteristics are used to define taxa at the suborder, great group, and subgroup levels in Soil Taxonomy (Soil Survey Staff, 1998), but duration is not specified. The depth for soils to be classified as aquic at the suborder level is that the redoximorphic features appear within 50 cm of the mineral soil surface. At the great group or subgroup levels the redoximorphic features are within 100 cm of the mineral soil surface. To define consistently the depth and duration at which saturation and reduction occur, and morphological inference may help in determining and managing wet soils.

1.3.1. Saturation

Saturation is characterized by zero or positive pressure in the soil water as observed in an unlined auger hole, or verified by piezometers or tensiometers

(Zobeck and Ritchie, 1984; Soil Survey Staff, 1998). Saturation of a soil occurs during periods when inputs from precipitation, ground water, and seepage-flow sources exceed evapotranspiration and drainage. Upon saturation, soil microorganisms quickly consume gaseous oxygen entrapped in soil pores and dissolved oxygen in the soil pore water. Oxygen can't be replenished below the top few centimeters even though it could be available from irrigation or precipitation.

Saturation of a soil with water can cause drastic changes in the normal chemical and biological reactions in the soil. These changes are a result of oxygen depletion by the aerobic microbes immediately after the soil is saturated (Turner and Patrick, 1968) and the activity of anaerobic bacteria, which is termed anaerobiosis. Anaerobiosis is influenced not only by the onset and duration of saturated conditions, but also by the availability of an energy source and suitable temperatures to support appreciable microbial activity (e.g., $\geq 5^{\circ}\text{C}$) (Bouma, 1983; Soil Survey Staff, 1998). Saturation only is the prerequisite for reduction and mottle formation. Microsites may be saturated and anaerobiosis may be occurring at these microsites. This is especially true for fine and very fine textured soils.

1.3.2. Reduction

When oxygen is depleted in the soil, microorganisms can use alternative electron acceptors to support their respiration. Reduction occurs when inorganic oxidants, such as Fe^{3+} or Mn^{4+} , accept electrons from the oxidation of

organic matter. Oxidation of organic matter in a saturated soil depends largely upon a myriad of anaerobic microorganisms.

Patrick (1980) referred to the relative ease of reduction as the intensity factor and the amount of the redox couples undergoing reduction as the capacity factor. Patrick and Mahapatra (1968) suggested four levels of redox conditions, highly reduced, reduced, moderately reduced, and oxidized, depend on the values of redox potential measured by a platinum electrode in soils. Redox potential has a quantitative relationship with oxidized and reduced Fe in solution unless they are complexed with organic matter (Olumo et al., 1973). Redox potential is a quantitative measure of electron availability and indicates intensity of oxidation or reduction in both chemical and biological systems (Gambrell and Patrick; 1978). Redox potential of a soil can be expressed as electron activity or pE (Sposito, 1989). Since the Fe systems are the most important redox couples in soils, the measurements of redox potential can provide insight into the relationship between Fe reduction and formation of mottling in seasonally saturated soils (Cogger et al., 1992). However, he also argued that redox potential values are limited because there are no widely accepted methods to measure and interpret field redox potentials.

In oxidized systems, the fact that they are poorly poised results in lowering the stability, reproducibility, and usefulness for redox measurements. In addition, measured redox potential values are relatively insensitive to changes in dissolved O₂ between 0.21 and 0.0021 atm (Ponnamperuma, 1972; Liu and Narasimhan, 1989). Callebaut et al. (1982) and Ransom and Smeck (1986)

noted that redox potential did not reflect the soil aeration status in oxygen-rich environments. As the activities of redox couples increase the soil poise, stability and reproducibility increase, thus resulting in more useful application of redox potentials in flooded soils (Bohn, 1971).

Under equilibrium conditions, redox potentials and pH are related to the activity of Fe^{2+} and Fe^{3+} species by the Nernst equation. Theoretically, redox and pH measurements can be used to predict when soil conditions are suitable for Fe reduction and oxidation. However, soil is a dynamic system receiving continual inputs of O_2 and organic matter. It is seldom at redox equilibrium. Field soils never reach oxidation-reduction equilibrium (Bohn, 1971; Barlett and James, 1995) and the activities and redox potentials measured in soil solution may be kinetically constrained (Liu and Narasimhan, 1989). Bohn (1971) contended that redox potentials are a mixed potential in most natural systems and are quantitatively unrelated to the theoretical Nernst distribution of ion reduction-oxidation status. The nonequilibrium conditions result in redox potentials from mixed couples of electron donors and acceptors rather than from pure couples such as Fe^{2+} - Fe^{3+} (Bohn, 1971). Soil heterogeneity also affects the reproducibility of measured redox potential. However, measured redox potentials seem to be the best method to measure and quantify the reduction-oxidation status of soils.

Another method of determining reduced conditions in waterlogged soils is the staining test. The staining test is a colorimetric method that indicates the presence of reduced Fe in the soil. Soil reduction can be identified by direct

measurement of redox potentials or indirectly by the presence of ferrous Fe determined by α, α' dipyridyl solution in 1-normal ammonium-acetate solution (Childs, 1981; Faulkner et al., 1989; Soil Survey Staff, 1998). The test of soil reduction for ferrous Fe is consistent with the definition of aquic condition in that Fe is the only element considered for reducing conditions. Faulkner et al. (1989) noted that the interpretation of ferrous Fe test is critical to properly assess the saturation and reduction status of a soil. Concentrations $> 1 \text{ mg kg}^{-1}$ indicate the presence of Fe^{2+} and reduction. However, the redox staining test methods are only qualitative indicators of reduction because Fe-organic complexes may affect the accuracy of the staining test as discussed by Childs (1981). Bartlett and James (1995) also contended that the test results vary with time and location. It is only accurate to the particular sample being tested at the point in time of testing.

1.3.3. Redoximorphic Features

Redoximorphic features associated with wetness result from the reduction and oxidation of Fe and Mn after saturation and desaturation. The reduced Fe and Mn are mobile and redistributed within a soil profile. Certain redox patterns occur as a function of patterns where the ion-carrying water moves through the soil, and of the location of aerated zones in the soil. Redoximorphic features includes redox concentrations, redox depletions, reduced matrix, and a positive reaction to α, α' -dipyridyl solution. Redox concentrations result in the formation of masses, concretions, or nodules formed in situ. Redox depletion forms when Fe and Mn are stripped out. Reduced matrix refer to soil matrix which has a

low chroma in situ undergoes a change in hue or chroma within 30 minutes after the soil material has been exposed to air. All of these features are associated with soil wetness conditions and are used as criteria for aquic conditions (Soil Survey Staff, 1998). These morphological features are used because Fe is relatively abundant in soil constituents and the effects of alternating oxidation-reduction on the changes of Fe minerals can be reflected in the soil morphology. The specific redoximorphic features based upon Fe transformations can readily serve as morphological indicators of seasonally saturated and reducing soil conditions (Vepraskas, 1992). When redoximorphic features are not present, a positive reaction to α,α' -dipyridyl dye solution can be supplemented to meet the requirements for redoximorphic features (Soil Survey Staff, 1998).

The formation of redoximorphic features is limited in soils with low amounts of soluble organic carbon, high pH, low temperature, low amount of Fe parent material, or aerated groundwater. For examples, soils formed from Pleistocene terrace red soils, whose Fe oxides are at an advanced stage of crystallization and resistant to reduction under waterlogged conditions, can not easily form redoximorphic features (Mitsuchi, 1992). Blume and Schlichting (1985) reported that wetland soils might lack redoximorphic features when the soil water is rich in O₂ or poor in organic matter.

1.3.4. Hydric Soils

Hydric soils are defined as soils that are saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions in the

upper part (Federal Register, 1994). To identify hydric soils in the field the National Technical Committee for Hydric Soils (NTCHS) recommends the use of field indicators (USDA-NRCS, 1998). According to the definition, saturation for a week or longer is considered a minimum amount of time for a soil to develop anaerobic conditions. However, duration of saturation is not the only factor that affects the oxidation-reduction characteristics of a soil. Hurt and Puckett (1992) failed to find a correlation between wetlands and hydric soils in Florida. The criteria based on soil morphology encounter the same problems as the definition of aquic condition.

1.4. Factors Affecting Redoximorphic Features

It is widely accepted that the requirements for reduction in soils are the (i) presence of microorganisms and an energy source, (ii) absence of oxygen, (iii) certain amount of Fe in the parent material and suitable pH (< 8.2), and (iv) soil temperatures sufficient for anaerobic microbial activity.

1.4.1. Microorganisms and Organic Carbon

Redoximorphic features are widely present in poorly-drained soils indicating the Fe-reducing bacteria are distributed ubiquitously throughout many soil profiles. Ottow and Glathe (1971) isolated 71 species of Fe-reducing facultative bacteria from three different gleyed subsoils. Some obligate anaerobic bacteria also can reduce ferric Fe to ferrous Fe (Ottow, 1970).

A supply of highly reducing organic carbon from the surface soil is an essential factor for the development of redoximorphic features (Okazaki and Wada, 1976, cited from Mitsuchi, 1992). Daniels et al. (1973) believed that the

oxygen consumption in saturated soils was attributed to the oxidation of soluble organic carbon. Couto et al. (1985) proposed that the lack of an energy source for microbial activity within subsurface soils was the most important factor preventing Fe reduction in some Oxisols in Brazil. Berner (1981), Macedo and Bryant (1989), Bryant and Macedo (1990), Bigham et al. (1991), Buol and Camargo (1992), Cogger and Kennedy (1992), and Hudnall and Wilding (1992) also suggested that soils low in organic carbon resulted in limiting reduction of Fe-oxides because there was no available energy source for microbial activity. The amount of soluble Fe in a soil increases as organic matter increase because organic matter provides an energy source for the microbes. The soluble Fe concentration is derived from dissolution of Fe-humus complexes, leading to further dissolution of Fe oxyhydroxides (Bao, 1985). Gilliam and Gambrell (1978) and Lowrance and Smittle (1998) indicated that NO_3^- reduction was limited when there was low organic matter or carbon availability. Stanford et al. (1975) found that denitrification rates correlated better with a soluble fraction of soil C rather than with total soil carbon. Smid and Beauchamp (1976) found that denitrification was not influenced by temperatures, but denitrification largely increased when carbon availability was not a limited factor under aerobic incubation conditions.

Daniels and Buol (1992) estimated a dissolved organic carbon concentration of 10 mg L^{-1} was needed to provide enough energy for the reduction of NO_3^- , Mn, and Fe. The additions of 0.4 mg C L^{-1} had no effect on the reduction of nitrate in a microcosm experiment (Obenhuber and Lowrance,

1991). Total soil organic carbon does not correlate well with reduction because most of organic carbon is resistant to utilization by microorganisms (Couto et al., 1985). The organic matter present in the lower horizons is probably not sufficiently abundant and is too stable for the reduction process to occur during the waterlogging period (Couto et al., 1985).

1.4.2. Oxygen

When a soil is submerged, gas exchange between soil and air is drastically curtailed. The diffusion of oxygen in water is 10,000 times slower than that of oxygen in gas-filled pores (Howeler and Bouldin, 1971; Ponnamperna, 1972). The anaerobic bacteria use NO_3^- , Mn^{4+} , Fe^{3+} , and SO_4^{2-} as electron acceptors only after aerobic microorganisms use up the dissolved oxygen (Connell and Patrick, 1968; Patrick and Mahapatra, 1968; Ponnamperna, 1972; Gilliam et al., 1979; Faulkner et al., 1989). Rainwater is essentially oxygen saturated, 10 mg/L or more, when it reaches the ground (Daniels et al., 1973). Rainfall aerates soil water and delays Fe reduction (Vepraskas and Wilding, 1983a; Buol and Camargo, 1992).

The crucial values of dissolved oxygen to affect reduction have been reported by several authors. Scott and Evans (1955) reported a limit of $5 \mu\text{mol kg}^{-1}$ after which O_2 concentration decreases rapidly to zero and Eh declines to the reduced range. According to Turner and Patrick (1968), O_2 has been depleted at redox potentials $< +420 \text{ mV}$. There is little or no O_2 diffusion when O_2 content was $\leq 6\%$ (Callebaut et al., 1982). $\text{O}_2 \leq 50 \text{ mg L}^{-1}$ was selected as a breakpoint between oxidizing and reducing conditions (Faulkner and Patrick,

1992). Cogger and Kennedy (1992) reported that reduction is inhibited when dissolved oxygen levels are > 5 mg/L. Once the dissolved oxygen values were reduced to 0.2 mg/L or less, the Eh decreased rapidly in the ground water of some North Carolina Aquults and Udults, which was reported by Daniels et al. (1973). Soils with dissolved O_2 content < 1 mg/kg for significant periods displayed grayest in color indicating the reduction of Fe (Evans and Franzmeier, 1986). White et al. (1990) stated that 2 μ g/L dissolved oxygen concentration in water was the detection limit of most oxygen probes. In summary, the measurement of dissolved oxygen is another tool to indicate the oxidation-reduction of soils.

1.4.3. Parent Materials, pH, and Fe Minerals

Soil color inherited from parent material is another important consideration to interfere the identification of redoximorphic features. Soils developed in red parent materials in which hematite is the dominant Fe oxyhydroxide, may limit the formation of redoximorphic features (Lindbo, 1997). In addition, soils with pH higher than 8 or those that lack Fe oxide minerals may not develop mottles or low chroma colors. For example, saturated sandy soils without redoximorphic features were cited by Fanning et al. (1973, 1992). Conversely, aerated soils may exhibit redoximorphic features, such as when the parent material (e.g., shale, mudstone) is rich in reductates (Blume and Schlichting, 1985).

Reduction of Fe and Mn oxides consumes protons and electrons indicating that pH and availability of organic substance will affect the reduction of Fe and

Mn in soils. The transformations of Fe and Mn are controlled by pH, redox potential, and the kinds and concentrations of other chemical species which can be predicted from stability diagrams (Collins and Buol, 1970a; Olomu et al., 1973). Eh and pH measurements are very useful to characterize the stability of Fe and Mn minerals (Garrels and Christ, 1965; Lindsay, 1972; Barnum, 1982). Collins and Buol (1970 a, b), Bohn (1971), Ponnampereuma (1972), Gotoh and Patrick (1974), and Patrick (1980) have developed redox equilibria and stability diagrams of the relationship among pH, Eh, and Fe reduction. Many researchers tried to verify this relationship in natural soils, but all attempts have failed (Jeffery, 1961; Ponnampereuma and Castro, 1964; Bohn, 1968, 1969). The reasons for this are twofold. Firstly, the solid phase of Fe compounds may be a mixture of amorphous and crystallized forms and may co-exist or may be co-precipitated with other elements. This makes it difficult to identify the amount and species of Fe minerals. The second problem is that a variety of reactions proceed simultaneously in soils, which makes it very difficult to calculate the activity of ferric and ferrous Fe species, a parameter needed in calculations based upon the Nernst equation.

It is reasonable to predict the stability of different Fe minerals under certain conditions by applying the Eh, pH, and standard redox potentials for different Fe species. Many researchers approached the problem similarly, but presented different conclusions for Fe mineral stability. Munch and Ottow (1980) and Wahid and Kamalam (1993) noted that amorphous Fe was preferentially reduced by Fe-reducing bacteria in advance of more stable Fe. The reduced

Fe, mediated by microorganisms, was converted to amorphous forms (Wahid and Kamalam, 1993). Those results supported Ponnamperna's (1972) findings that the lower the crystallinity, the more the pedogenic Fe oxides may be reduced. However, Munch et al. (1978) found that crystalline Fe rather than amorphous Fe became reduced preferentially by Fe-reducing bacteria. The crystalline Fe seemed to be attacked first by Fe-reducing bacteria in soils that contained a low amount of amorphous Fe (Munch and Ottow, 1980). Macedo and Bryant (1987, 1989) demonstrated the preferential reduction of hematite over Al-substituted goethite in the presence of a seasonally high water table. Bigham et al. (1991) also found hematite to be unstable, which was the source of Fe for the pedogenetic formation of goethite and other Fe. Goethite was more stable than hematite in weakly-reduced systems and is the most common form of Fe in many soils (Buol and Camargo, 1992). In summary, there are conflicting conclusions regarding the stability of Fe oxides from different authors, methods, and studying sites.

1.4.4. Temperature

Soil temperature is an important consideration because of its effect on biological activity in soils. Soil temperatures below biological zero (5 °C) inhibit microbial activity and reduction in saturated soils (Daniel et al., 1971; Soil Survey Staff, 1998). Below 5°C, biological activity within soils is assumed to be insignificant, but as soil temperature increases, the rate of biological activity will accelerate (Pickering and Veneman, 1984). Cogger and Kennedy (1992) found that reduction rate was greatly slowed at 4°C and 9°C compared to 15 °C.

Franzmier et al. (1983) found that soil saturated by ground water during cold season might inhibit reduction. The microbes can reduce the ferric Fe quickly during the coming spring if soils are still saturated. Gilliam and Gambrell (1978) noted that temperature had little influence on NO_3^- reduction because soluble organic carbon was the primary factor in NO_3^- reduction. Dobos et al. (1990) noted that temperature had little effect on mottle chroma when no organic carbon was added, and the increase from 15° to 25° was not always associated with a graying of mottles when organic carbon was added. The temperature of biological zero has been questioned. Evidence presented by Ping et al. (1992) indicated that microbial activity persists in permafrost ($< 0^\circ\text{C}$) soils of Alaska and these soils meet all criteria of reduced soils except temperature.

1.5. Problems Associated with Chroma ≤ 2

It is impractical to measure the soil moisture regime directly through long-term monitoring because the measurements of moisture regimes are costly and time consuming. The redoximorphic features of wetness used as diagnostic properties are reflected by the reduction of Fe and Mn, which can be judged visually in the field. Thus, the absence or presence of redoximorphic features becomes a very important characteristic to infer soil drainage conditions. Soils that have chroma of 2 or less are usually considered as poorly drained soils. Daniels et al. (1971) found that the formation of chroma 2 was closely related to the change and duration of a ground water table. Veneman et al., (1976) associated occurrence of mottles with chroma of two or less with

saturation of soils during some period of the year in a Wisconsin toposequence. He concluded that the occurrence of low chroma correlated with the duration of saturation. Simonson and Boersma (1972) also correlated water table fluctuations with profile features in western Oregon. However, the formation of redoximorphic features was dominated by the redox chemistry of the site, which was controlled by several different variables, including organic carbon, pH, parent material, temperature, Fe-Mn content and species, and saturation duration. Thus, saturation and morphological properties are not always correlated.

Several studies give evidence of these problems. Franzmeier et al. (1983) reported seasonally saturated soils with chroma colors > 2 in Indiana. Vepraskas and Wilding (1983b) investigated a toposequence of four seasonally saturated Alfisols in southern Texas, but only two met the criteria of chroma 2 or less. They further recommended that mottles with chroma 3 or less be used as criteria for southern Texas soils. The unreliable criteria of chroma 2 or less were also reported by several authors (Daniels et al., 1973; Pickering and Veneman, 1984; Couto et al., 1985; Evans and Franzmeier, 1986; Buol and Camargo, 1992; Cogger and Kennedy, 1992; Mokma and Sprecher, 1994). This was attributed to soil saturation without Fe reduction and mottle formation.

CHAPTER 2.

EFFECTS OF 10 G/KG SUCROSE AND ADJUSTED pH ON Eh, pH, AND Fe TRANSFORMATION

2.1. Introduction

The pH of acid and alkaline water-saturated, reduced soils tended to converge to a value of 7 (Patrick and Mikkelesen, 1971; Ponnampersuma, 1972). Stanford et al. (1975) found that soils with a pH 5.3 initially tended to become less acidic, whereas the pH of alkaline and calcareous soils tended to decrease after submergence. Berner (1981) noted that the pH of most marine and non-marine soils was relatively stable between pH 6 and 8 and that more than 90% of the soil pH measurements were between pH 6.5 and 7.5. An initial pH decrease in both water saturated acid and alkaline soils was attributed to increased microbial activity and the production of CO₂ as a result of microbial respiration. Water restricted the diffusion of gases into flooded soils and CO₂ was produced by the bacteria within the soils. The subsequent pH increase of acid soils was due to the reduction of inorganic compounds. The pH values of saturated calcareous and sodic soils were lower than those of aerobic soils due to the accumulation of CO₂. The pH of saturated alkaline soils responded to the partial pressure change of CO₂ (Ponnampersuma et al., 1966; Ponnampersuma, 1972). The soil pH stabilized at 6.5 to 7.0 when organic matter was not limited. The pH of some organically poor alkali soils (O.M. < 4 mg/kg) rarely decreased below 8.5 (Moorman and Breemen, 1978).

The threshold reduction potentials for Fe and Mn have been shown to be pH dependent. It was necessary to characterize pH changes from interstitial

water until the soil pH reaches equilibrium. This equilibrium required microbial activity and this activity in soils was limited not by the supply of nitrogen, phosphorous, or other inorganic nutrients but by the paucity of readily utilizable organic nutrients (Alexander, 1977). The water-soluble fraction contained the least resistant components and was readily metabolized, which served as an electron source to facilitate reduction. The objectives of this experiment were to test the effects of pH and the addition of 10 g/kg sucrose on the changes of redox potential, pH, soil color, and iron oxide transformation among different horizons within profiles and between the Moreland clay and Sharkey clay soils.

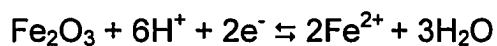
2.1.1. Redox Interfaces

The saturated soil and the water become three separate entities after a soil is submerged (Bartlett and James, 1993). The first was the water and the atmosphere interface. The water was partially oxygenated due to contact with the atmosphere. The second was the interstitial water immediately below the water-air interface and was almost devoid of O₂. Although thin, it efficiently prevented the diffusion of O₂ into the water. The third was soil below the water-soil interface and was anaerobic and served as the source of electron donors. Anaerobic microorganisms within the saturated soil reduces Fe and Mn, which diffuse into the water-air interface because of a concentration gradient and re-oxidizes as Fe³⁺ and Mn⁴⁺ oxides.

2.1.2. Respiration

Respiration is an adenosine triphosphate (ATP) generation metabolic process that uses either inorganic or organic compounds as electron donors

and an inorganic compound as the electron acceptor (Alexander, 1977; Barner, 1983). Soil microbes need an energy source (organic carbon) to maintain their metabolic activity. The choice of an alternative electron acceptor is related to both the net energy gained from the electron transfer and availability (Bohn et al., 1985). Initially, microbes use the most energetically favored species. In aerated soils, microbes use oxygen as an electron acceptor through a process known as aerobic respiration. Aerobic respiration oxidizes the organic substrate to CO₂ and water, releasing approximately ten times or more free energy per mole of glucose consumed than from the fermentative processes (Barner, 1983). After soil submergence, no oxygen is available for microbial aerobic respiration. Other inorganic compounds become the electron acceptors, e.g. ferric, manganic oxides, or sulfate, for anaerobic respiration. The energy yield of anaerobic respiration is lower than that of aerobic respiration (Alexander, 1977). Anaerobic respiration consumes hydrogen ions, resulting in an increased soil pH (Garrels and Christ, 1965; Collins and Buol, 1970a; Lindsay, 1972; Ponnamperna, 1972; Bohn et al., 1985). This reaction is shown as follows using reduction of hematite:



2.1.3. Fermentation

Fermentation is another metabolic process from which microbes gain energy when a soil is anaerobic. In contrast to anaerobic respiration, microbes use organic matter as an electron acceptor during fermentation instead of inorganic compounds. Fermentation involves the catabolism of an organic

compound to compounds whose average oxidation charge of carbon is the same as that of the initial organic compound but whose total energy content is lower. For example, when glucose is broken down into ethanol and carbon dioxide, the oxidation charge of carbon for glucose is zero while those of ethanol and carbon dioxide are -2 and $+4$, respectively. The reaction is shown as follows:



The average oxidation charge of carbon for the reactants and products is the same. The microorganisms that produce fermentation are either facultative or strict anaerobes. The important fermentation products included ethanol, butanol, acetone and acetic, butyric, formic, gluconic, itaconic, lactic, and succinic acid (Alexander, 1977; Barner, 1983; Lockwood, 1979). The types and concentrations of organic acids that accumulated within soils varies widely depending upon the type and quantity of fermentative microbes. Fermentation is an important hydrogen ion producer when soils with abundant organic matter are saturated. The soil pH will decrease when fermentation is the major anaerobic process. The Mn and Fe reducing microbes gaining less energy per electron transfer could not compete with fermentors, such as *Bacillus* and *Clostridia*, for fermentable substrate (Lovley, 1992).

2.1.4. Selective Chemical Dissolution

Crystalline and non-crystalline iron phases in soils are very difficult to separate. Non-crystalline clay minerals have a larger specific surface area and a higher chemical reactivity. These materials are more sensitive to chemical

dissolution than are crystalline clay minerals. Selective dissolution can determine non-crystalline clay and soil constituents (Hayashi and Yamada, 1990; Wada, 1989). These methods used dithionite-citrate-bicarbonate (DCB), sodium pyrophosphate, and acid ammonium oxalate as dissolution agents. Sodium pyrophosphate estimates the amount of organic-Fe complex noted as Fe_p , acid ammonium oxalate estimates the amount of poorly crystalline inorganic and organic Fe complex forms noted as Fe_o , and DCB estimates the total concentration of free Fe oxide noted as Fe_d .

Pyrophosphate has been used to study the movement of iron and associated organic matter between soil horizons (Bascomb, 1968; Mckeague, 1967). The results were used to define the spodic horizon (Mckeague and Schuppli, 1982; Soil Survey Staff, 1975) and andic soil properties (Soil Survey Staff, 1998). Loveland and Digby (1984) suggested that extraction with 0.1 M sodium pyrophosphate at pH 10, followed by high-speed centrifugation (RCF 20,000) for 10 minutes was the most analytically reliable method. Potassium pyrophosphate may peptize finely divided hydrous amorphous oxides in soils and is thus not suitable (Bascomb, 1968). Jarvis (1984) reported that the proportion of Mn extracted by pyrophosphate was correlated with the organic carbon contents and that DCB extraction was well correlated with reducible Mn. Mn extracted by oxalate extractions exaggerated the amount of Mn by dissolving primary and secondary soil materials containing Mn and Mn oxides.

Amorphous Fe hydroxides and poorly crystalline Fe minerals are quite easily and quickly dissolved by an oxalate solution. Poorly soluble stable

compounds released large quantities of Fe_2O_3 after a prolonged reaction with an oxalate solution. Highly insoluble, stable Fe oxides, such as hematite, released virtually no iron after a prolonged reaction with an oxalate solution. The oxalate extraction dissolved much of the Fe and Al from the amorphous materials but very little from the crystalline oxides, whereas the DCB extraction dissolved a large proportion of the crystalline iron oxides together with most of the amorphous materials (McKeague and Day, 1966). Kellerman and Tsyurupa (1965) ascribed the effect of oxalate solution on well-crystallized Fe hydroxides and oxides and some silicates to the complexing capacity of the oxalate ion. Arshad et al. (1972) found that oxalate and dithionite had some extraction limitations for soils containing 30% or more trioctahedral clay minerals.

DCB extraction fairly well isolated the total pedogenic free Fe oxides (Mehra and Jackson, 1960). The difference between total Fe (Fe_t) and dithionite soluble Fe (Fe_d) approximated the silicate Fe (Fe_{t-d}) in non-calcareous soils unless significant amounts of magnetite were present. Blume and Schwertmann (1969) used different extracting methods, including DCB and Tamm's oxalate method, to evaluate the pedogenesis of Mn, Fe, and Al oxides in soil profiles. Kodama and Wang (1989) found that the ratio of Fe extracted by acid oxalate to Fe extracted by DCB was nearly uniform for most of the clay samples from B and C horizons, indicating that almost all free Fe existed in non-crystalline forms. Arshad et al. (1972) and Pawluk (1972) argued that factors such as particle size, the speed of shaking, and temperature, as well as the degree and type of crystallinity, affected the results of Fe extracted by acid

oxalate and DCB. They suggested that such data should serve as general guidelines rather than absolute indices of Fe quantities.

2.2. Materials and Methods

2.2.1. Background Information of Two Studied Soils

Moreland Soil

The sampled site for Moreland soil (Moreland clay, very fine, montmorillonitic, thermic, super active Typic Epiaquert) was located at 31° 50' 47.6"N, 93° 11' 9.9"W in Natchitoches Parish, Louisiana. Moreland soils occur on floodplains. They were formed in clayey sediments transported by streams from Permian red beds via the Red River. Most of these soils are protected from flooding today by levees. Typically they are level. The mean annual temperature ranges from 14 to 21 °C and the mean annual precipitation ranges from 965 to 1470 mm. A seasonal high water table is within 45 cm of the soil surface from December to April. The Moreland soils are seasonally waterlogged within 75 cm of the soil surface despite their lack of low (≤ 2) chroma colors within this depth. Flooding is rare but can occur under abnormal or catastrophic conditions, less than once in 10 years and at anytime during the year. This soil has very high shrink-swell potential.

The Moreland soil was separated into four horizons, Ap, 0 to 15; Bw, 15 to 40; Bkss, 40 to 65; and Bss, 65 to 100 cm. Selected morphological, physical, and chemical properties are shown in Table 2.1. Organic carbon was 7.62 g/kg concentrated at the surface horizon and decreased with depth to approximately

Table 2.1. Selected morphological, physical, and chemical characteristics of the Moreland and Sharkey pedons.

Horizons	Depth cm	Matrix color	Mottles	Texture	pH	Organic carbon ---g/kg--
<u>Moreland</u>						
Ap	0- 15	5YR 3/3		clay	7.4	7.62
Bw	15- 40	5YR 3/3		clay	7.5	5.04
Bkss	40- 65	5YR 3/3	N 5/	clay	7.8	5.22
Bss	65-100	5YR 3/3		clay	7.7	6.54
<u>Sharkey</u>						
Ap1	0- 12	2.5Y 3/2	2.5Y 4/1	clay	6.3	16.0
Ap2	12- 25	2.5Y 4/2	10YR 5/6 2.5Y 4/4	clay	6.4	9.54
Bssg1	25- 50	2.5Y 4/1	10YR 5/6 2.5Y 4/4	clay	6.7	9.24
Bssg2	50-100	2.5Y 4/1	10YR 5/6 2.5Y 4/4	clay	6.8	8.34

6.54 g/kg in the Bss horizon. The irregular carbon distribution in different horizons was probably due to different flooding alluvium or fresh organic carbon either carried by wind when the soil was cracked during the dry season or washed in by rainfall. The pH values increased with soil depth from 7.4 to 7.8 due to the presence of carbonate. The Bkss horizon had the highest concentrations of calcium carbonate. Carbonate, a common cementing reagent in Red River parent materials, accumulated in the Bkss horizon, indicating that waterlogging depleted carbonate from the upper soil and concentrated it in the lower soil strata during the dry seasons (Blodgett et al., 1993). Black soft Mn masses (N 5/0) were observed as coating on the surface of large voids within the Bkss horizon, indicating that Mn reduced during rainy seasons and moved into through the interfaces of slickensides and oxidized within lower horizons due to either a higher pH or water deficient. All the sampled horizons had a

Munsell hue of 5YR with a value of 4 and a chroma of 3 (dark reddish brown) and no low (≤ 2) chroma colors. Weak hydromorphism was expressed within the Moreland soils by Mn translocation and a lack of low chroma. The chroma of Moreland soil was not low enough to reflect its aquic properties at either the suborder or subgroup levels.

Sharkey Soil

The latitude and longitude of the Sharkey soil (Sharkey clay, very-fine, smectitic, thermic Chromic Epiaquerts) in Madison Parish, Louisiana are 32° 26' 19.51"N, 91° 9' 55.64"W. Sharkey soils are identified as clayey, expansive soils occurring on nearly level topography on lower parts of natural levees, terraces, and flood plains of the Mississippi River and its tributaries. They formed in clayey alluvium that is predominantly smectitic with clay contents of 60 to 90% in the subsoils. These soils are classed as poorly drained with slow surface runoff and low permeability. The slope is normally less than 1 percent, but ranges to 5 percent. The mean annual temperature ranges from 16 to 21 °C. The mean annual precipitation ranges from 1140 to 1650 mm. A seasonally high water table occurs at a depth of 0 to 60 cm from December to April. Wetness causes poor aeration and restricts plant root development. This soil cracks when dry and seals over when wet. Monitoring data from sites in Louisiana suggested that Sharkey soils have episaturation (Hudnall and Patterson, 1997).

The profile was separated into four horizons: Ap1, 0 to 12; Ap2, 12 to 25; Bssg1, 25 to 50; and Bssg2, 50 to 100 cm. Selected morphological, physical,

and chemical properties are shown in Table 2.1. Organic carbon decreased with depth from a maximum concentration of 16.0 g/Kg in the Ap1 horizon to 8.34 mg/kg within the Bssg2 horizon. Soil pH ranged from 6.3 to 6.8 and increased from upper to lower horizons. Smectite was the predominant clay mineral in all horizons. The surface Munsell color was 2.5Y 3/2 (very dark grayish brown) with 2.5Y 4/1 (dark gray) redoximorphic features. Soil chroma decreased with increased depth. All horizons of the Sharkey soil showed low chromas (≤ 2), indicating that Sharkey soil experienced significant periods of alternating oxidation and reduction conditions necessary for the formation of redoximorphic features.

2.2.2. Incubation Procedures

Soil with or without the addition of 10 g/kg (by soil weight) was used in combination with imposed pH levels of 5.0, 6.0, 7.0, and natural pH. The effects on reduction with or without the addition of 10 g/kg sucrose were studied using 300 g soil samples from each horizon of the Moreland and Sharkey soils that had been adjusted to a desired pH value by addition of either 0.1N HCl or 0.1N NaOH. Equilibrium for the adjusted soil pH was assumed when two successive pH readings taken within 24 hours did not differ more than 0.1 unit. After agitation on a reciprocating shaker for 16 hours under aerated conditions, the sample with or without the addition of sucrose was placed into incubation box fifteen cm in diameter and six cm in height. The soil was covered with H₂O three cm above the soil surface. Incubation boxes were

sealed to prevent excessive evaporation. There were two replications per treatment.

Faulkner et al. (1989) reported that epoxy-sealed electrodes had a useful life of only about one year in wetland soils. The glass electrode was selected to use in the laboratory. Construction of the platinum (Pt) glass electrodes followed the procedures outlined by Szogi and Hudnall (1991). Prior to installation in the incubation box, the Pt electrodes were platinized and tested in a poised ferrous ammonium sulfate-ferric ammonium sulfate solution and discarded if not accurate within ± 10 mV of 430 mV (Light, 1972). However, Cogger et al. (1992) noted that this solution was so strongly poised that even unsatisfactory electrodes would sometimes give accurate readings. The flowchart of incubation procedures is shown in Figure 2.1. Pt electrodes were installed in triplicate near the bottom of the soil and connected to a data logger. A calomel reference electrode was used as a reference electrode. Redox potential readings were obtained at 10-min intervals and averaged hourly. The redox potential values were adjusted by adding +244 mV to a datalogger reading that bases the redox potential on the standard hydrogen reference electrode (SHE). Each incubation box was connected by a KCl-saturated agar salt bridge. Soil pH value was measured for 9 days consecutively and then every other day during the three weeks of incubation. The three-week incubation period was to simulate a long-term flooding condition in fields.

The soil solution was sampled using a disposal pipette after three weeks. About 100 g of saturated soil were sampled from each incubation box and

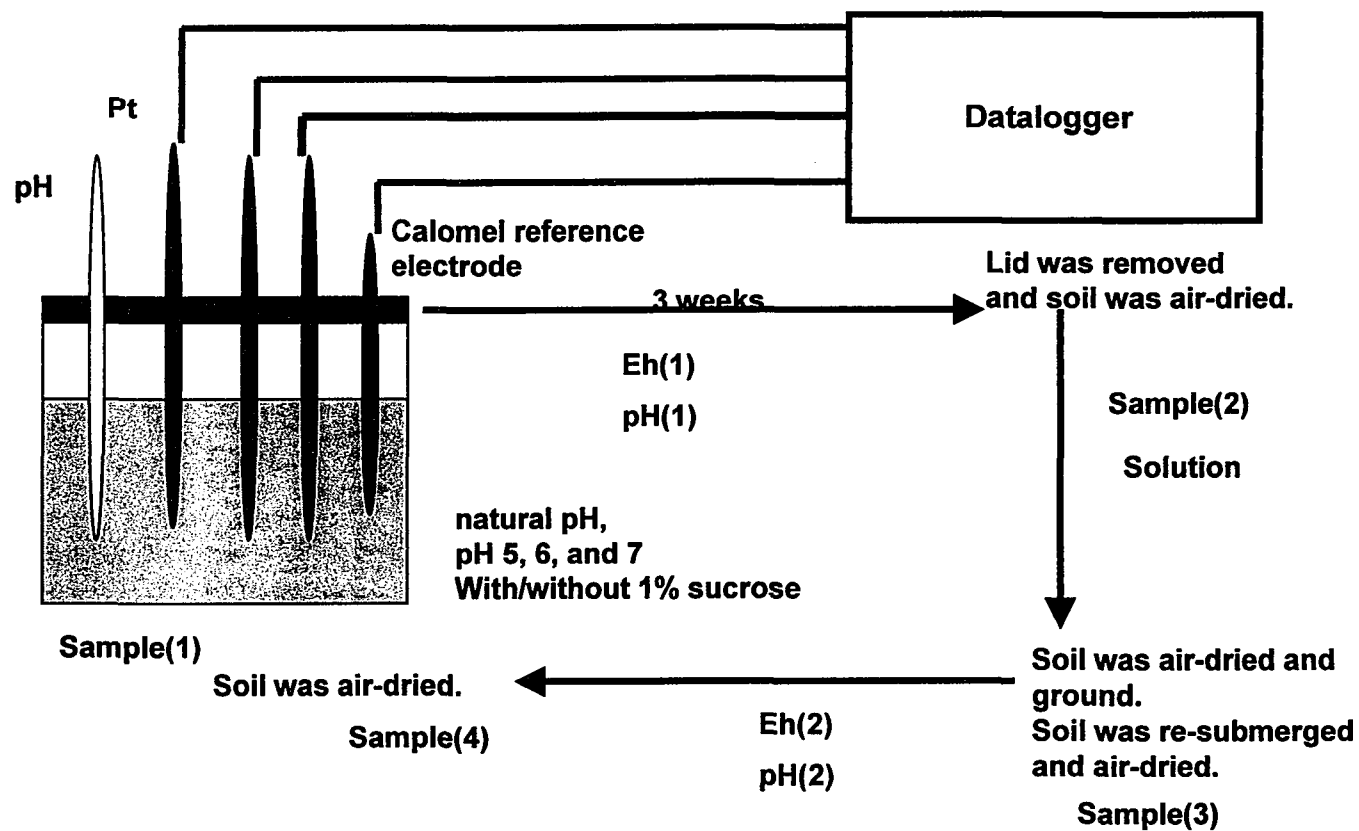


Figure 2.1. The flow chart of experimental procedures.

freeze-dried to prevent further oxidation-reduction by microorganisms. The remainder of the soil was air-dried in the incubation box. After being air-dried or freeze-dried, about 50 g of dried soil were sampled and used for further analysis. The soil sample was ground in a ceramic mortar with a pestle and passed through a 1.00 mm sieve. The Pt electrodes were cleaned and tested for the second saturation and drying experiments.

The remaining air-dried soils were reinstalled into the incubation box without lid. Soils were saturated by water again. The re-saturation treatment was to mimic a short-term submergence in fields. The redox potential was recorded during the second saturation period. The pH values were measured manually every 24-hour for 7 days consecutively. The soils were allowed to air dry within the box. Once air-dried, the soils were ground and passed through a 1.00 mm sieve.

2.2.3. Analysis Methods

The Fe and Mn in soil solution sampled with a pipette after a 3-week incubation were filtered through Whatman No. 42 filter paper. An aliquot of filtrate was immediately acidified by a drop of concentrated nitrate to keep the Fe^{2+} and Mn^{2+} in soluble forms and all samples were stored at 4°C within a refrigerator until analyzed. The Fe and Mn in the soil solution were measured by inductively coupled plasma spectroscopy (ICP).

The freeze-dried and air-dried soils sampled during different stages were crushed, passed through a 1 mm sieve, and stored in an air-tight plastic container for further chemical analysis.

Sodium pyrophosphate extractions were performed with the Loveland and Digby (1984) method. Acid ammonium oxalate extractable Fe and Mn were obtained using the McKeague and Day (1966) method. The DCB extractable Fe and Mn were determined by the Mehra and Jackson (1960) method. All the Fe extracted by different reagents was measured by ICP.

Soil colors after drying were photographed, determined, and recorded through methods developed by the Soil Survey Staff (1998) using Munsell Soil Color charts.

2.3. Results

2.3.1. pH

Moreland Soil

The notations for the Moreland soil with different treatments are presented in Tables 2.2.1 and 2.2.2. The temporal pH changes for the Ap horizon are illustrated in Figure 2.2.1. The pH for the M.Ap.01 and M.Ap.71 treatments decreased at an almost imperceptible rate from pH 7.4 and 7.0 to pH of 7.2 and 6.9 during 21 days of flooding, respectively. The maximum pH decrease was less than 0.3 pH units for both soils. The pH for the M.Ap.51 treatment increased from pH 5.0 to 5.4 within 48 hours and then remained constant for 21 days. The pH for the M.Ap.61 treatment did not appreciably change during the experiment.

The pH for the M.Ap.S01 treatment decreased from 7.4 to 6.4 within 24 hours and to pH 6.0 within 72 hours. The pH remained at 6.0 for 21 days. The pH for the M.Ap.S01 and the M.Ap.S71 treatments was similar. The pH for

Table 2.2.1. Treatment explanation for the Moreland soil during the first incubation period.

Treatment abbreviation	Treatments
M.Ap.01	Moreland, Ap horizon, natural pH, without sucrose, first incubation.
M.Ap.71	Moreland, Ap horizon, adjusted pH 7, without sucrose, first incubation.
M.Ap.61	Moreland, Ap horizon, adjusted pH 6, without sucrose, first incubation.
M.Ap.51	Moreland, Ap horizon, adjusted pH 5, without sucrose, first incubation.
M.Ap.S01	Moreland, Ap horizon, natural pH, with sucrose, first incubation.
M.Ap.S71	Moreland, Ap horizon, adjusted pH 7, with sucrose, first incubation.
M.Ap.S61	Moreland, Ap horizon, adjusted pH 6, with sucrose, first incubation.
M.Ap.S51	Moreland, Ap horizon, adjusted pH 5, with sucrose, first incubation.
M.Bw.01	Moreland, Bw horizon, natural pH, without sucrose, first incubation.
M.Bw.71	Moreland, Bw horizon, adjusted pH 7, without sucrose, first incubation.
M.Bw.61	Moreland, Bw horizon, adjusted pH 6, without sucrose, first incubation.
M.Bw.51	Moreland, Bw horizon, adjusted pH 5, without sucrose, first incubation.
M.Bw.S01	Moreland, Bw horizon, natural pH, with sucrose, first incubation.
M.Bw.S71	Moreland, Bw horizon, adjusted pH 7, with sucrose, first incubation.
M.Bw.S61	Moreland, Bw horizon, adjusted pH 6, with sucrose, first incubation.
M.Bw.S51	Moreland, Bw horizon, adjusted pH 5, with sucrose, first incubation.
M.Bkss.01	Moreland, Bkss horizon, natural pH, without sucrose, first incubation.
M.Bkss.71	Moreland, Bkss horizon, adjusted pH 7, without sucrose, first incubation.
M.Bkss.61	Moreland, Bkss horizon, adjusted pH 6, without sucrose, first incubation.
M.Bkss.51	Moreland, Bkss horizon, adjusted pH 5, without sucrose, first incubation.
M.Bkss.S01	Moreland, Bkss horizon, natural pH, with sucrose, first incubation.
M.Bkss.S71	Moreland, Bkss horizon, adjusted pH 7, with sucrose, first incubation.
M.Bkss.S61	Moreland, Bkss horizon, adjusted pH 6, with sucrose, first incubation.
M.Bkss.S51	Moreland, Bkss horizon, adjusted pH 5, with sucrose, first incubation.
M.Bss.01	Moreland, Bss horizon, natural pH, without sucrose, first incubation.
M.Bss.71	Moreland, Bss horizon, adjusted pH 7, without sucrose, first incubation.
M.Bss.61	Moreland, Bss horizon, adjusted pH 6, without sucrose, first incubation.
M.Bss.51	Moreland, Bss horizon, adjusted pH 5, without sucrose, first incubation.
M.Bss.S01	Moreland, Bss horizon, natural pH, with sucrose, first incubation.
M.Bss.S71	Moreland, Bss horizon, adjusted pH 7, with sucrose, first incubation.
M.Bss.S61	Moreland, Bss horizon, adjusted pH 6, with sucrose, first incubation.
M.Bss.S51	Moreland, Bss horizon, adjusted pH 5, with sucrose, first incubation.

Table 2.2.2. Treatment explanation for the Moreland soil during the second incubation period.

Treatment abbreviation	Treatments
M.Ap.02	Moreland, Ap horizon, natural pH, without sucrose, second incubation.
M.Ap.72	Moreland, Ap horizon, adjusted pH 7, without sucrose, second incubation.
M.Ap.62	Moreland, Ap horizon, adjusted pH 6, without sucrose, second incubation.
M.Ap.52	Moreland, Ap horizon, adjusted pH 5, without sucrose, second incubation.
M.Ap.S02	Moreland, Ap horizon, natural pH, with sucrose, second incubation.
M.Ap.S72	Moreland, Ap horizon, adjusted pH 7, with sucrose, second incubation.
M.Ap.S62	Moreland, Ap horizon, adjusted pH 6, with sucrose, second incubation.
M.Ap.S52	Moreland, Ap horizon, adjusted pH 5, with sucrose, second incubation.
M.Bw.02	Moreland, Bw horizon, natural pH, without sucrose, second incubation.
M.Bw.72	Moreland, Bw horizon, adjusted pH 7, without sucrose, second incubation.
M.Bw.62	Moreland, Bw horizon, adjusted pH 6, without sucrose, second incubation.
M.Bw.52	Moreland, Bw horizon, adjusted pH 5, without sucrose, second incubation.
M.Bw.S02	Moreland, Bw horizon, natural pH, with sucrose, second incubation.
M.Bw.S72	Moreland, Bw horizon, adjusted pH 7, with sucrose, second incubation.
M.Bw.S62	Moreland, Bw horizon, adjusted pH 6, with sucrose, second incubation.
M.Bw.S52	Moreland, Bw horizon, adjusted pH 5, with sucrose, second incubation.
M.Bkss.02	Moreland, Bkss horizon, natural pH, without sucrose, second incubation.
M.Bkss.72	Moreland, Bkss horizon, adjusted pH 7, without sucrose, second incubation.
M.Bkss.62	Moreland, Bkss horizon, adjusted pH 6, without sucrose, second incubation.
M.Bkss.52	Moreland, Bkss horizon, adjusted pH 5, without sucrose, second incubation.
M.Bkss.S02	Moreland, Bkss horizon, natural pH, with sucrose, second incubation.
M.Bkss.S72	Moreland, Bkss horizon, adjusted pH 7, with sucrose, second incubation.
M.Bkss.S62	Moreland, Bkss horizon, adjusted pH 6, with sucrose, second incubation.
M.Bkss.S52	Moreland, Bkss horizon, adjusted pH 5, with sucrose, second incubation.
M.Bss.02	Moreland, Bss horizon, natural pH, without sucrose, second incubation.
M.Bss.72	Moreland, Bss horizon, adjusted pH 7, without sucrose, second incubation.
M.Bss.62	Moreland, Bss horizon, adjusted pH 6, without sucrose, second incubation.
M.Bss.52	Moreland, Bss horizon, adjusted pH 5, without sucrose, second incubation.
M.Bss.S02	Moreland, Bss horizon, natural pH, with sucrose, second incubation.
M.Bss.S72	Moreland, Bss horizon, adjusted pH 7, with sucrose, second incubation.
M.Bss.S62	Moreland, Bss horizon, adjusted pH 6, with sucrose, second incubation.
M.Bss.S52	Moreland, Bss horizon, adjusted pH 5, with sucrose, second incubation.

38

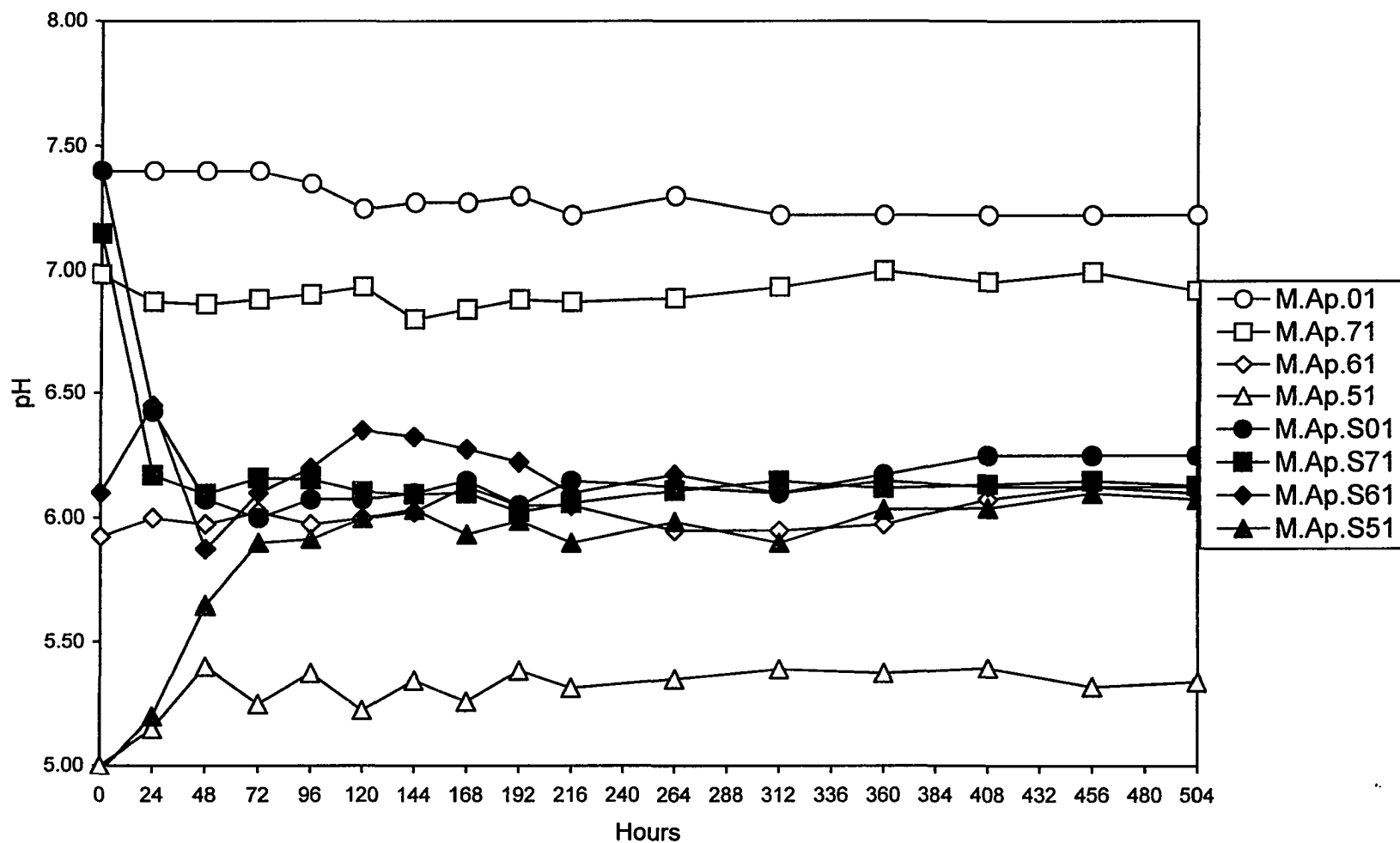


Figure 2.2.1. Mean pH values of the Ap horizon for the Moreland soil during the first incubation periods.

the M.Ap.S71 treatment decreased to 6.2 and remained at this pH for the duration of the experiment. The pH for the M.Ap.S61 treatment increased from 5.9 to 6.5 within 24 hours and then decreased to 5.9 within 48 hours. It stabilized at approximately pH 6.1 for the remainder of the experiment. The pH for the M.Ap.S51 treatment increased from 5.0 to 5.9 within 72 hours and remained at 6.1 for the duration of the experiment.

The temporal distributions of pH for the Bw horizon with different treatments were similar to those of the Ap horizon (Fig. 2.2.2). The pH for the M.Bw.01 and M.Bw.71 treatments was similar to those of the Ap horizon. They did not change for 21 days. The M.Bw.61 treatment increased gradually from pH 6.0 to 6.5, and the M.Bw.51 treatment increased from pH 5.1 to 5.6. The rates of decrease for the M.Ap.S01 and M.Ap.S71 treatments were greater than that of the M.Bw.S01 and M.Bw.S71 treatments. The pH for the M.Bw.S01 and M.Bw.S71 treatments did not change within 24 hours but decreased to pH 6.4 and 6.2 within 48 hours and gradually decreased to pH 6.1 and 6.0, respectively. The M.Bw.S61 treatment increased from pH 6.2 to 6.5 within 24 hours and gradually decreased to 5.9 during the experiment. The pH increased at a moderate rate from 5.1 to 5.9 for the M.Bw.S51 treatment within 96 hours and remained constant for the remainder of the experiment.

The pH for the Bkss and Bss horizons (Fig. 2.2.3 and 2.2.4) showed trends similar to those of the Bw horizon except for the M.Bkss.5S treatment. The pH for the M.Bkss.5S treatment increased from 5.0 to 5.3 within 24 hours and decreased gradually to 5.0 during 21 days of submergence. The pH for the

40

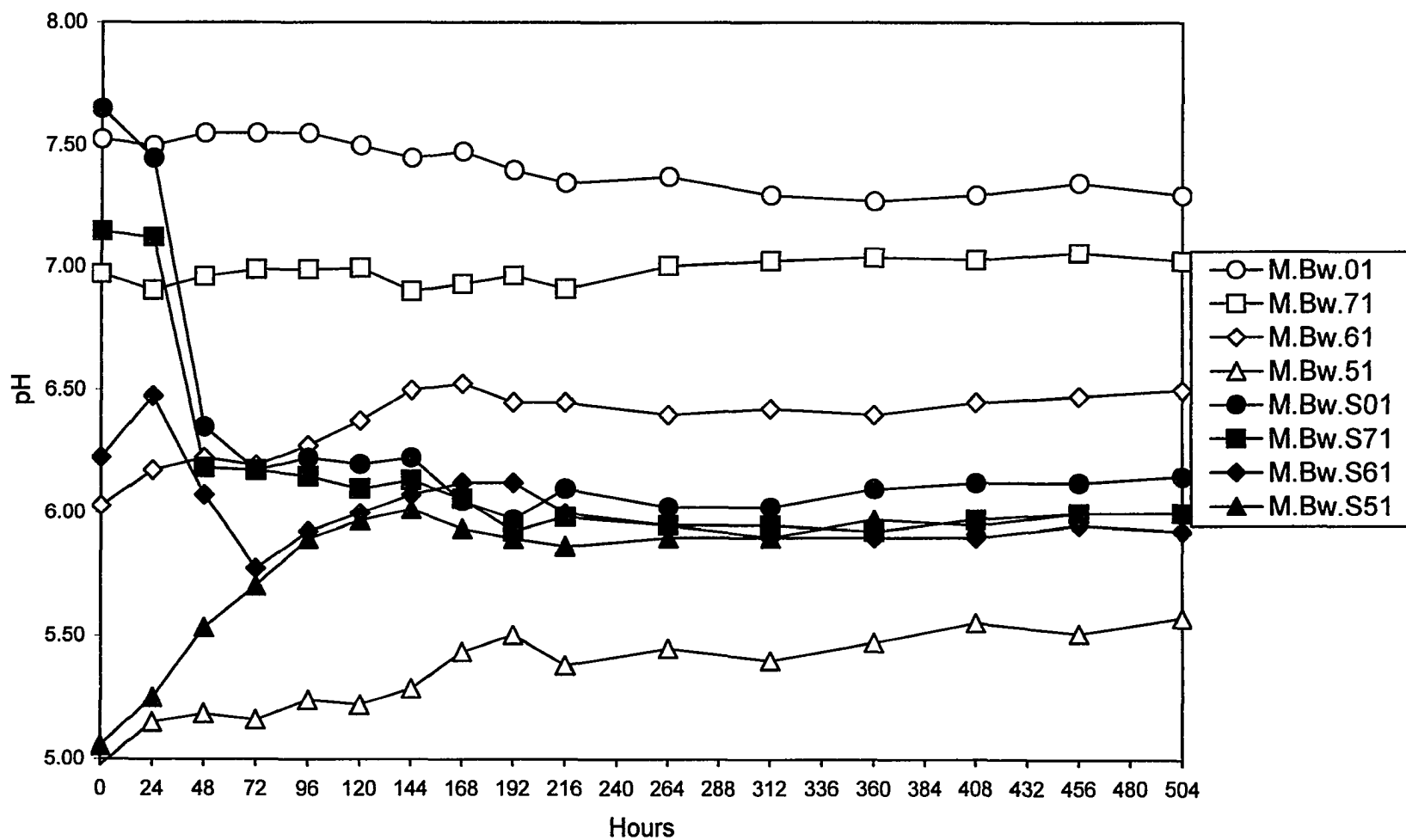


Figure 2.2.2. Mean pH values of the Bw horizon for the Moreland soil during the first incubation period.

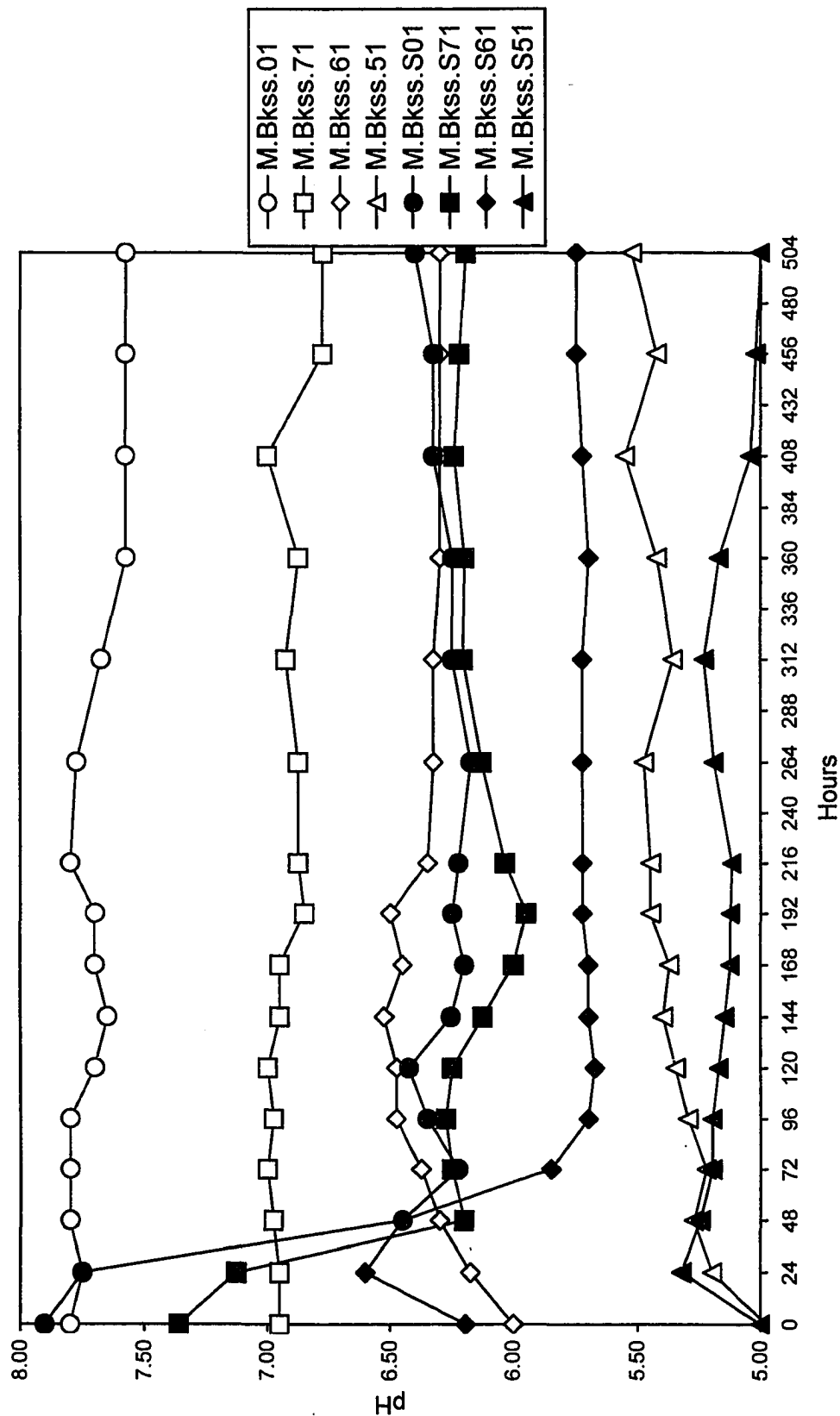


Figure 2.2.3. Mean pH values of the Bkss horizon for the Moreland soil during the first incubation period.

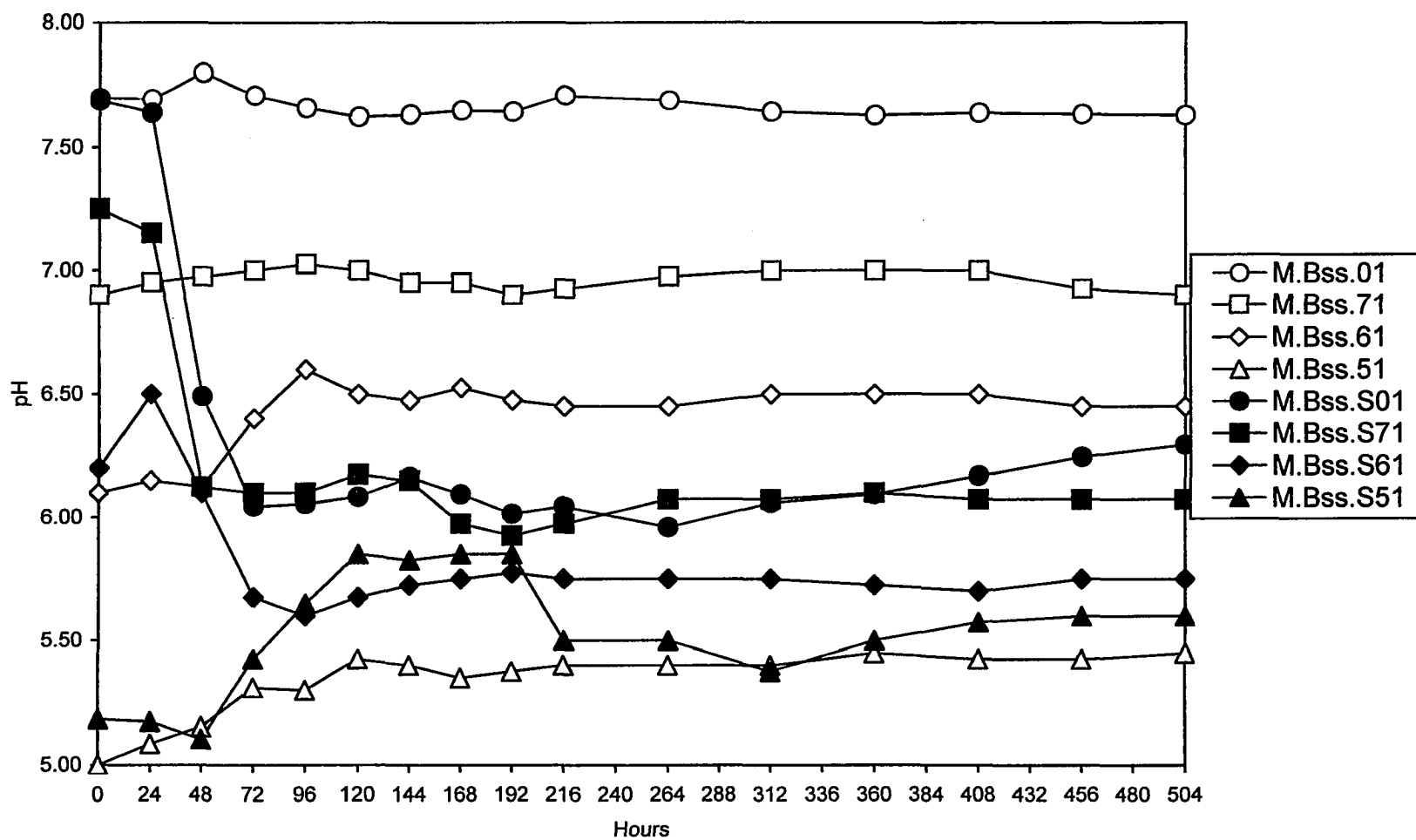


Figure 2.2.4. Mean pH values of the Bkss horizon for the Moreland soil during the first incubation period.

M.Bss.S51 treatment showed a similar trend to that of the M.Bkss.S51 treatment, but the rate of increase was greater. The pH for the M.Bss.S51 treatment increased to 5.9 within 96 hours and gradually decreased to 5.6 for the duration of submergence.

Figure 2.2.5 shows the pH for the M.Ap.02, M.Ap.72, M.Ap.62, and M.Ap.52 treatments after drying and re-saturation. The pH values measured at the beginning of re-saturation of the different treatments without the addition of sucrose were not appreciably different from the final pH values from the first incubation period. The pH was 6.9 for the M.Ap.71 treatment and 7.1 for the M.Ap.72 treatment. The pH for the Bw, Bkss, and Bss horizons (Fig. 2.2.6, 2.2.7, and 2.2.8) showed similar trends except for the pH adjusted to 5 Bkss and Bss horizons. The M.Bkss.52 treatment increased from pH 5.5 to 5.9 after drying and re-saturation. The temporal pH changes for natural pH and pH adjusted to 7 and 6 for all horizons without sucrose treatment did not change during the seven-day measurement (Fig. 2.2.5, 2.2.6, 2.2.7, and 2.2.8). The pH adjusted to 5 treatment for all horizons gradually increased about 0.4 units during 168 hours.

The pH increased more than 0.5 units for the natural pH and pH adjusted to 7 horizons treated with sucrose as compared to previous pH readings during the first incubation experiment (Fig. 2.2.5, 2.2.6, 2.2.7, and 2.2.8). The pH for the M.Ap1.S62, M.Bw.S62, and M.Bss.S62 treatments did not change after drying. However, the pH for the M.Bkss.S62 treatment increased from 5.8 to 6.4. The pH did not change for the M.Ap.S52, M.Bw.S52, and M.Bss.S52

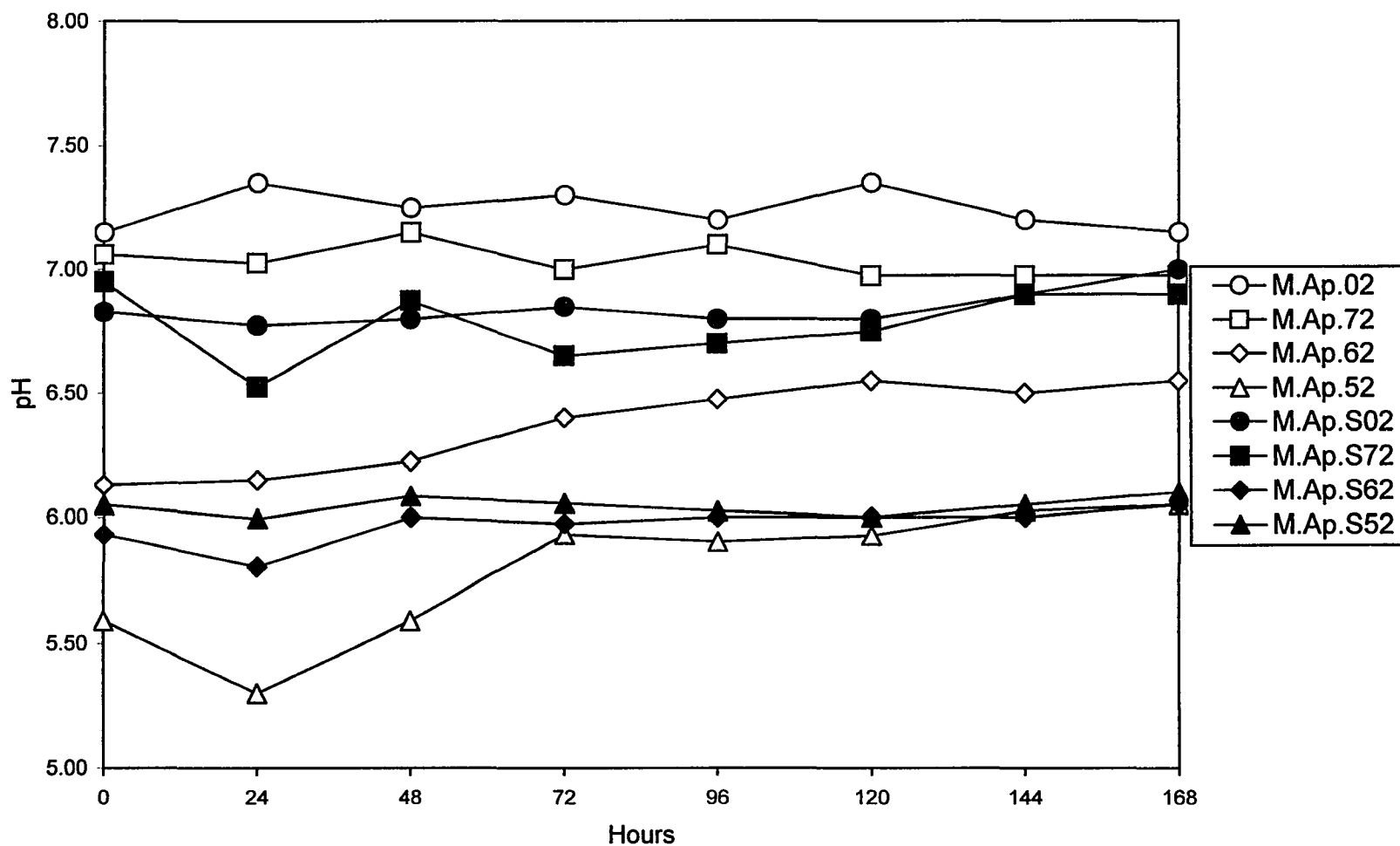


Figure 2.2.5. Mean pH values of the Ap horizon for the Moreland soil during the re-saturation period.

45

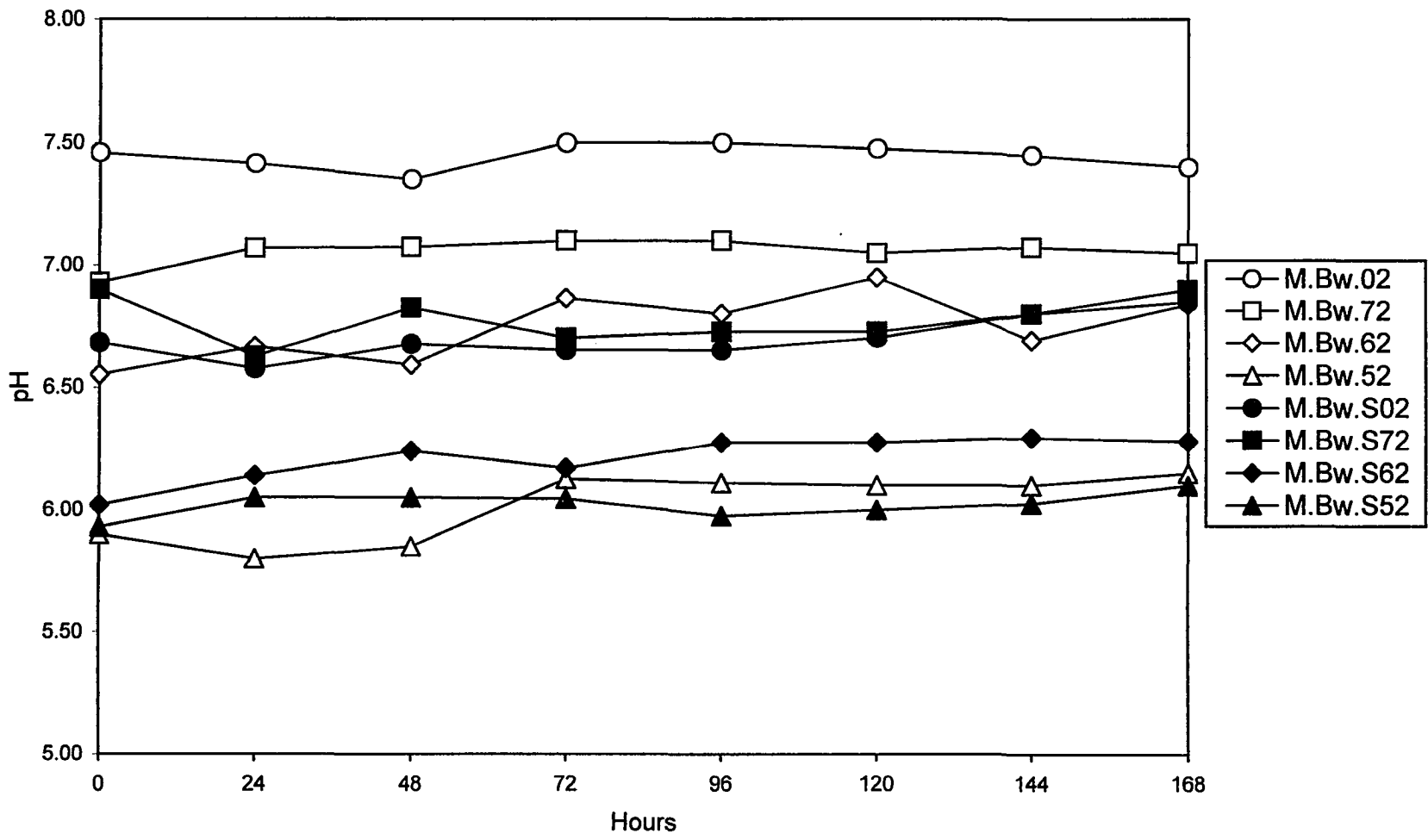


Figure 2.2.6. Mean pH values of the Bw horizon for the Moreland soil during the re-saturation period.

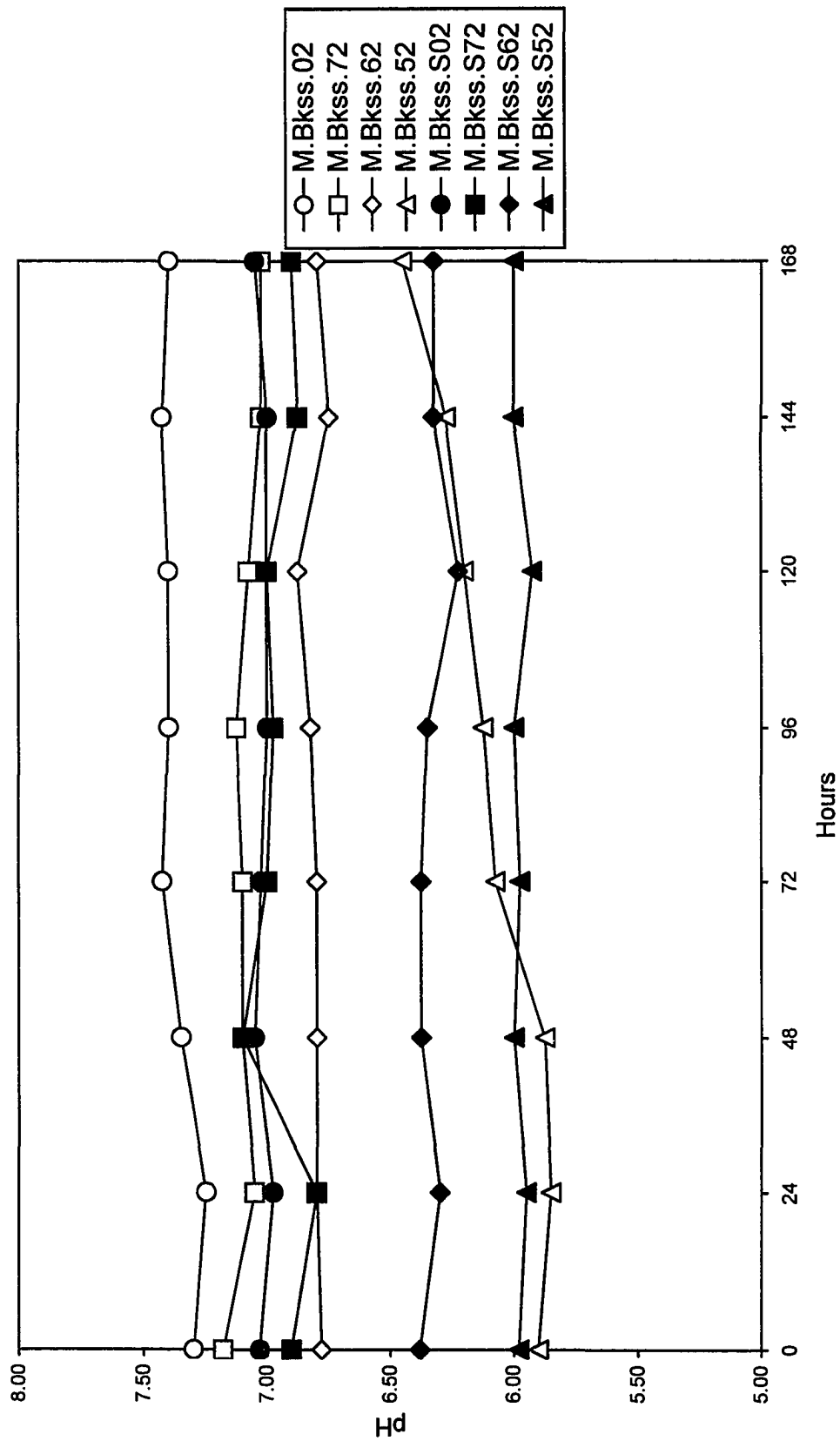


Figure 2.2.7. Mean pH values of the Bkss horizon for the Moreland soil during the re-saturation period.

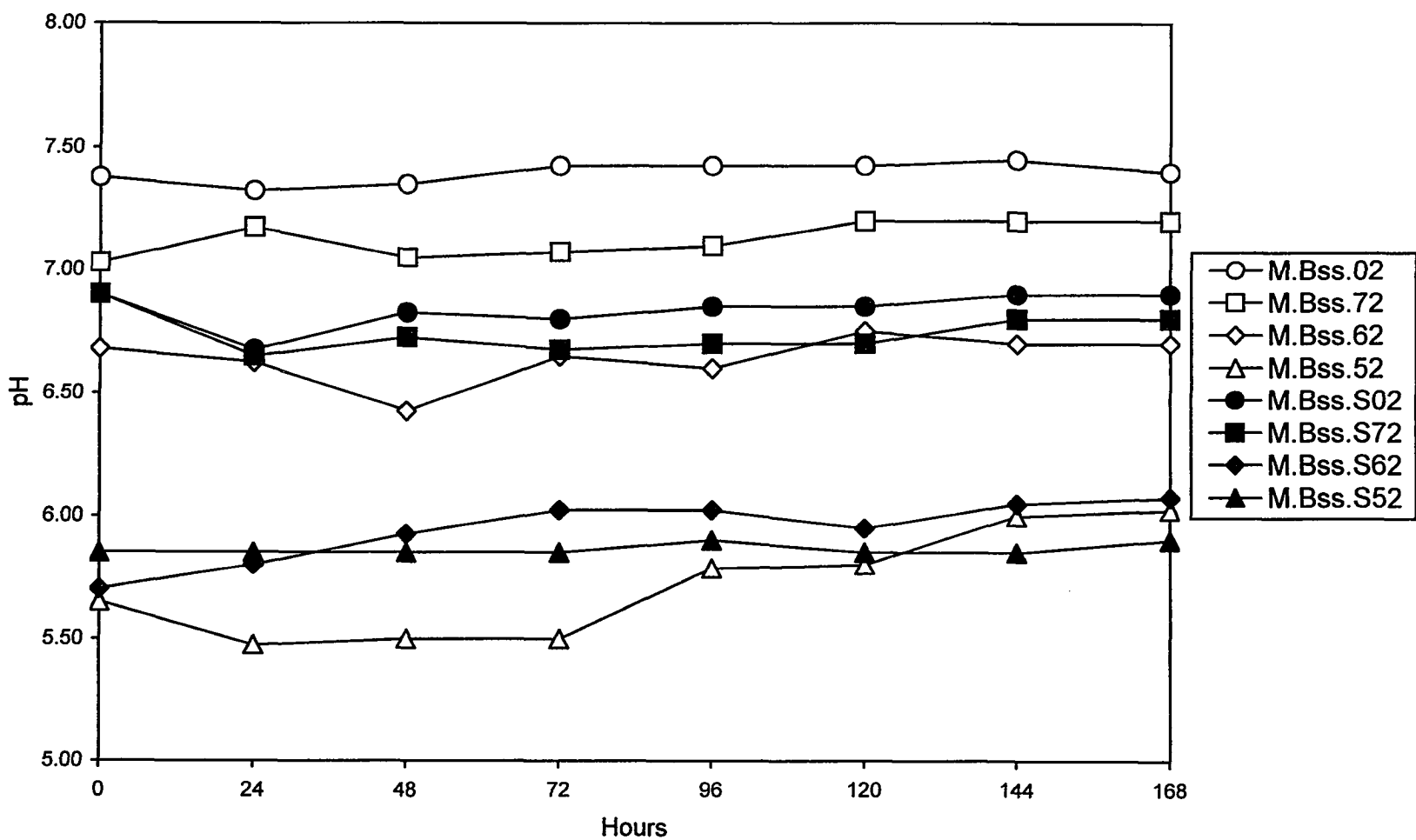


Figure 2.2.8. Mean values of the Bss horizon for the Moreland soil during the re-saturation period.

treatments as compared to previous pH readings during the first incubation experiment. However, the pH for the M.Bkss.S52 treatment increased from 5.0 to 6.0. The pH for all horizons with sucrose and different pH treatments did not change during 7 days of re-saturation.

Sharkey Soil

The notations for the Sharkey soil with different treatments are shown in Tables 2.2.3 and 2.2.4. The pH for the S.Ap1.01 treatment decreased gradually from 6.3 to 5.9 after 21 days (Fig. 2.2.9). The pH for the S.Ap1.71 treatment decreased from 7.0 to 6.6 within 48 hours and remained at 6.5 during the experiment. The pH for the S.Ap1.61 treatment did not change for 21 days. The pH for the S.Ap1.51 treatment increased from pH 5.1 to 5.4 during 21 days of flooding.

The pH for the S.Ap1.S01 treatment decreased from 6.4 to 5.7 within 24 hours and decreased to 5.1 within 48 hours (Fig. 2.2.9). It increased gradually to pH 5.7 during the experiment. The pH for the S.Ap1.S71 treatment showed a similar trend to those of S.Ap1.S01 treatment. The pH for the S.Ap1.S71 treatment decreased from 7.2 to 6.3 within 24 hours. The decreased pH was 0.9 units within 24 hours. It reached a minimum pH value of 5.8 within 48 hours and gradually increased to 6.3 during the experiment. The pH values were about 0.6 units higher for the S.Ap1.S71 treatment than for the S.Ap1.S01 treatment during the same period. The pH for the S.Ap1.S61 decreased from 6.2 to 5.8 with 24 hours and to 5.4 within 48 hours. It remained constant for the duration of the experiment. The pH for the S.Ap1.S51 treatment decreased

Table 2.2.3. Treatment explanation for the Sharkey soil during the first incubation period.

Treatment abbreviation	Treatments
S.Ap.01	Sharkey, Ap1 horizon, natural pH, without sucrose, first incubation.
S.Ap.71	Sharkey, Ap1 horizon, adjusted pH 7, without sucrose, first incubation.
S.Ap.61	Sharkey, Ap1 horizon, adjusted pH 6, without sucrose, first incubation.
S.Ap.51	Sharkey, Ap1 horizon, adjusted pH 5, without sucrose, first incubation.
S.Ap.S01	Sharkey, Ap1 horizon, natural pH, with sucrose, first incubation.
S.Ap.S71	Sharkey, Ap1 horizon, adjusted pH 7, with sucrose, first incubation.
S.Ap.S61	Sharkey, Ap1 horizon, adjusted pH 6, with sucrose, first incubation.
S.Ap.S51	Sharkey, Ap1 horizon, adjusted pH 5, with sucrose, first incubation.
S.Bw.01	Sharkey, Ap2 horizon, natural pH, without sucrose, first incubation.
S.Bw.71	Sharkey, Ap2 horizon, adjusted pH 7, without sucrose, first incubation.
S.Bw.61	Sharkey, Ap2 horizon, adjusted pH 6, without sucrose, first incubation.
S.Bw.51	Sharkey, Ap2 horizon, adjusted pH 5, without sucrose, first incubation.
S.Bw.S01	Sharkey, Ap2 horizon, natural pH, with sucrose, first incubation.
S.Bw.S71	Sharkey, Ap2 horizon, adjusted pH 7, with sucrose, first incubation.
S.Bw.S61	Sharkey, Ap2 horizon, adjusted pH 6, with sucrose, first incubation.
S.Bw.S51	Sharkey, Ap2 horizon, adjusted pH 5, with sucrose, first incubation.
S.Bkss.01	Sharkey, Bssg1 horizon, natural pH, without sucrose, first incubation.
S.Bkss.71	Sharkey, Bssg1 horizon, adjusted pH 7, without sucrose, first incubation.
S.Bkss.61	Sharkey, Bssg1 horizon, adjusted pH 6, without sucrose, first incubation.
S.Bkss.51	Sharkey, Bssg1 horizon, adjusted pH 5, without sucrose, first incubation.
S.Bkss.S01	Sharkey, Bssg1 horizon, natural pH, with sucrose, first incubation.
S.Bkss.S71	Sharkey, Bssg1 horizon, adjusted pH 7, with sucrose, first incubation.
S.Bkss.S61	Sharkey, Bssg1 horizon, adjusted pH 6, with sucrose, first incubation.
S.Bkss.S51	Sharkey, Bssg1 horizon, adjusted pH 5, with sucrose, first incubation.
S.Bss.01	Sharkey, Bssg2 horizon, natural pH, without sucrose, first incubation.
S.Bss.71	Sharkey, Bssg2 horizon, adjusted pH 7, without sucrose, first incubation.
S.Bss.61	Sharkey, Bssg2 horizon, adjusted pH 6, without sucrose, first incubation.
S.Bss.51	Sharkey, Bssg2 horizon, adjusted pH 5, without sucrose, first incubation.
S.Bss.S01	Sharkey, Bssg2 horizon, natural pH, with sucrose, first incubation.
S.Bss.S71	Sharkey, Bssg2 horizon, adjusted pH 7, with sucrose, first incubation.
S.Bss.S61	Sharkey, Bssg2 horizon, adjusted pH 6, with sucrose, first incubation.
S.Bss.S51	Sharkey, Bssg2 horizon, adjusted pH 5, with sucrose, first incubation.

Table 2.2.4. Treatment explanation for the Sharkey soil during the second incubation period.

Treatment abbreviation	Treatments
S.Ap.02	Sharkey, Ap1 horizon, natural pH, without sucrose, second incubation.
S.Ap.72	Sharkey, Ap1 horizon, adjusted pH 7, without sucrose, second incubation.
S.Ap.62	Sharkey, Ap1 horizon, adjusted pH 6, without sucrose, second incubation.
S.Ap.52	Sharkey, Ap1 horizon, adjusted pH 5, without sucrose, second incubation.
S.Ap.S02	Sharkey, Ap1 horizon, natural pH, with sucrose, second incubation.
S.Ap.S72	Sharkey, Ap1 horizon, adjusted pH 7, with sucrose, second incubation.
S.Ap.S62	Sharkey, Ap1 horizon, adjusted pH 6, with sucrose, second incubation.
S.Ap.S52	Sharkey, Ap1 horizon, adjusted pH 5, with sucrose, second incubation.
S.Bw.02	Sharkey, Ap2 horizon, natural pH, without sucrose, second incubation.
S.Bw.72	Sharkey, Ap2 horizon, adjusted pH 7, without sucrose, second incubation.
S.Bw.62	Sharkey, Ap2 horizon, adjusted pH 6, without sucrose, second incubation.
S.Bw.52	Sharkey, Ap2 horizon, adjusted pH 5, without sucrose, second incubation.
S.Bw.S02	Sharkey, Ap2 horizon, natural pH, with sucrose, second incubation.
S.Bw.S72	Sharkey, Ap2 horizon, adjusted pH 7, with sucrose, second incubation.
S.Bw.S62	Sharkey, Ap2 horizon, adjusted pH 6, with sucrose, second incubation.
S.Bw.S52	Sharkey, Ap2 horizon, adjusted pH 5, with sucrose, second incubation.
S.Bkss.02	Sharkey, Bssg1 horizon, natural pH, without sucrose, second incubation.
S.Bkss.72	Sharkey, Bssg1 horizon, adjusted pH 7, without sucrose, second incubation.
S.Bkss.62	Sharkey, Bssg1 horizon, adjusted pH 6, without sucrose, second incubation.
S.Bkss.52	Sharkey, Bssg1 horizon, adjusted pH 5, without sucrose, second incubation.
S.Bkss.S02	Sharkey, Bssg1 horizon, natural pH, with sucrose, second incubation.
S.Bkss.S72	Sharkey, Bssg1 horizon, adjusted pH 7, with sucrose, second incubation.
S.Bkss.S62	Sharkey, Bssg1 horizon, adjusted pH 6, with sucrose, second incubation.
S.Bkss.S52	Sharkey, Bssg1 horizon, adjusted pH 5, with sucrose, second incubation.
S.Bss.02	Sharkey, Bssg2 horizon, natural pH, without sucrose, second incubation.
S.Bss.72	Sharkey, Bssg2 horizon, adjusted pH 7, without sucrose, second incubation.
S.Bss.62	Sharkey, Bssg2 horizon, adjusted pH 6, without sucrose, second incubation.
S.Bss.52	Sharkey, Bssg2 horizon, adjusted pH 5, without sucrose, second incubation.
S.Bss.S02	Sharkey, Bssg2 horizon, natural pH, with sucrose, second incubation.
S.Bss.S72	Sharkey, Bssg2 horizon, adjusted pH 7, with sucrose, second incubation.
S.Bss.S62	Sharkey, Bssg2 horizon, adjusted pH 6, with sucrose, second incubation.
S.Bss.S52	Sharkey, Bssg2 horizon, adjusted pH 5, with sucrose, second incubation.

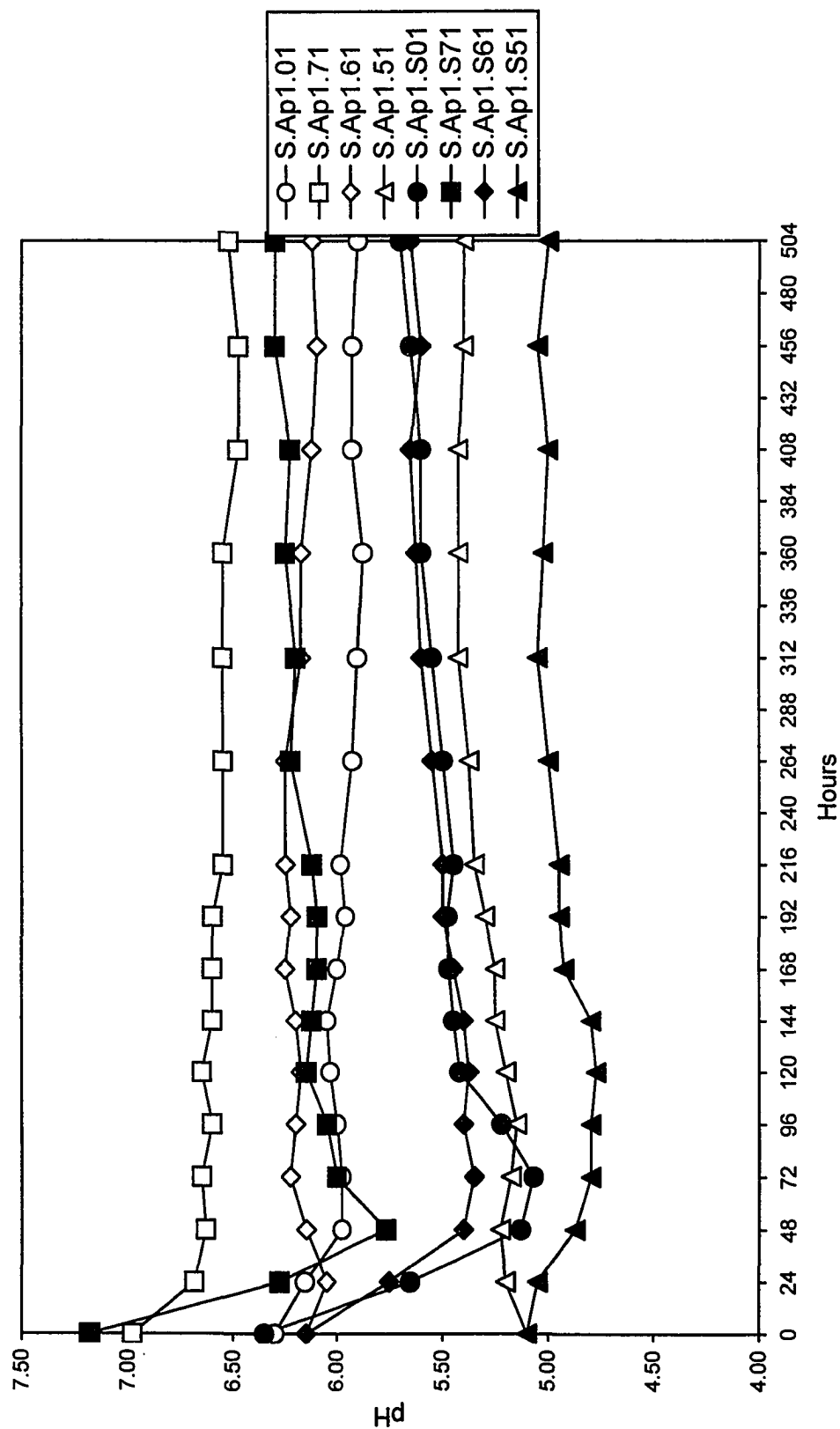


Figure 2.2.9. Mean pH values of the Ap1 horizon for the Sharkey soil during the first incubation periods.

slowly from 5.1 to 4.8 within 72 hours and fluctuated around 5.0 for the duration of submergence.

The pH for the Ap2 horizon without the addition of sucrose showed trends similar to those of the Ap1 horizon (Fig. 2.2.10). The pH for the S.Ap2.S01 and S.Ap2.S71 treatments was similar to those of the S.Ap1.S01 and S.Ap1.S71 treatments. However, the pH readings measured for the S.Ap2.S01 and S.Ap2.S71 treatments were 5.3 and 6.1, which were lower than those of S.Ap1.S01 and S.Ap1.S71 treatments by the end of the experiment. The pH for the S.Ap2.S61 treatment decreased from 6.2 to 5.6 within 24 hours and then increased gradually to 5.7 for 21 days. The pH of the S.Ap2.S61 treatment showed the same trend as that of the S.Ap2.S51 treatment. It decreased gradually from 5.1 to 4.9 within 48 hours and gradually increased to 5.3 for the remainder duration of the experiment.

Figures 2.2.11 and 2.2.12 show the temporal change for the Bssg1 and Bssg2 horizons with different treatments. The pH for the S.Bssg1.01 treatment decreased gradually from 6.7 to 6.2 (Fig. 2.2.11), but the pH of S.Bssg2.01 treatment did not change (Fig. 2.2.12) for 21 days. The pH for the pH adjusted to 7 and 6 Bssg1 and Bssg2 horizons also did not change. The pH for the S.Bssg1.51 and S.Bssg2.51 treatments increased from 5.1 to 5.6 by the end of the experiment.

The pH for the S.Bssg1.S01 treatment decreased from 6.8 to 6.1 within 24 hours and to 4.9 within 72 hours (Fig. 2.2.11). It remained constant during 21 days of submergence. The same results were observed for the pH of the

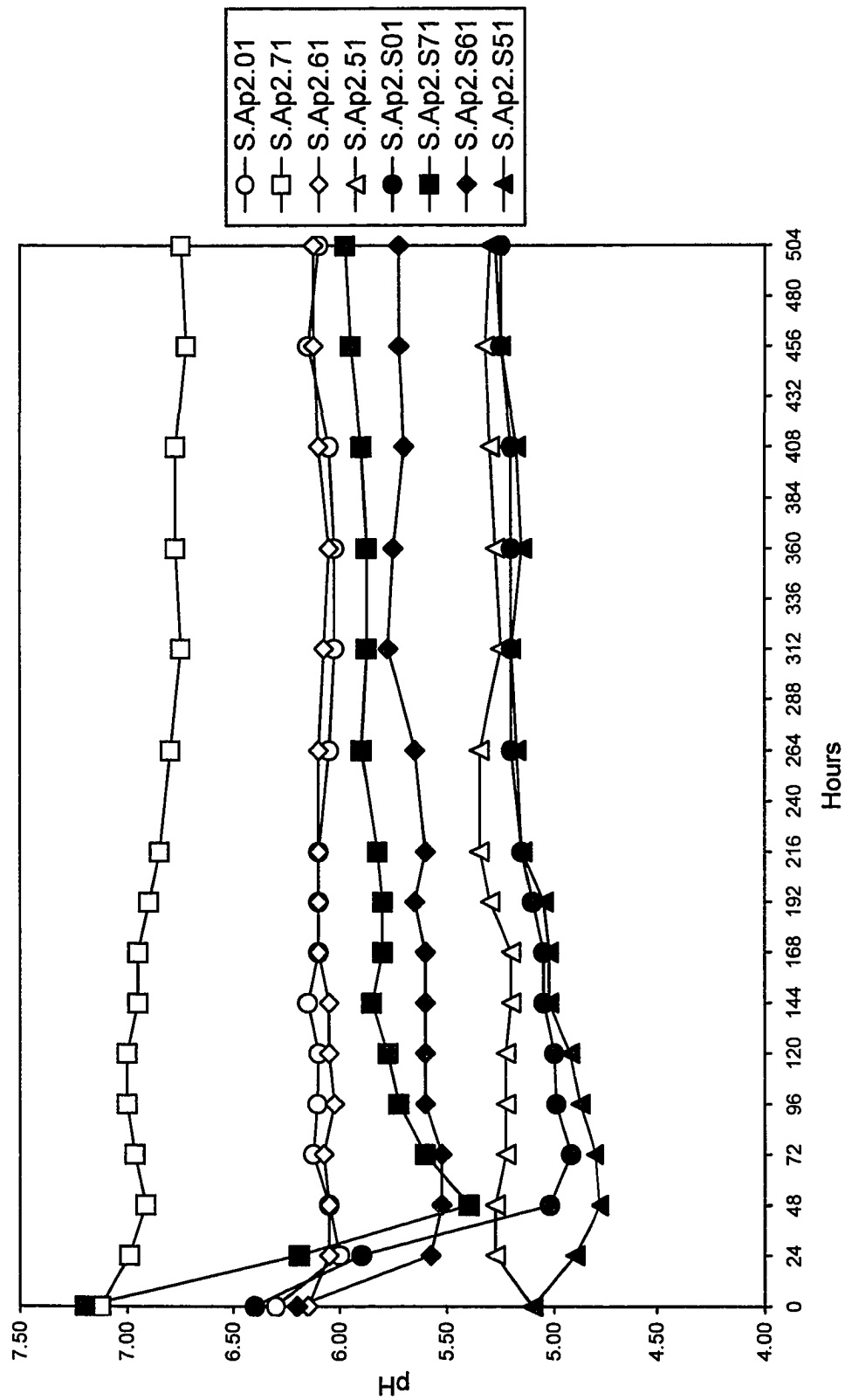


Figure 2.2.10. Mean pH values of the Ap2 horizon for the Sharkey soil during the first incubation periods.

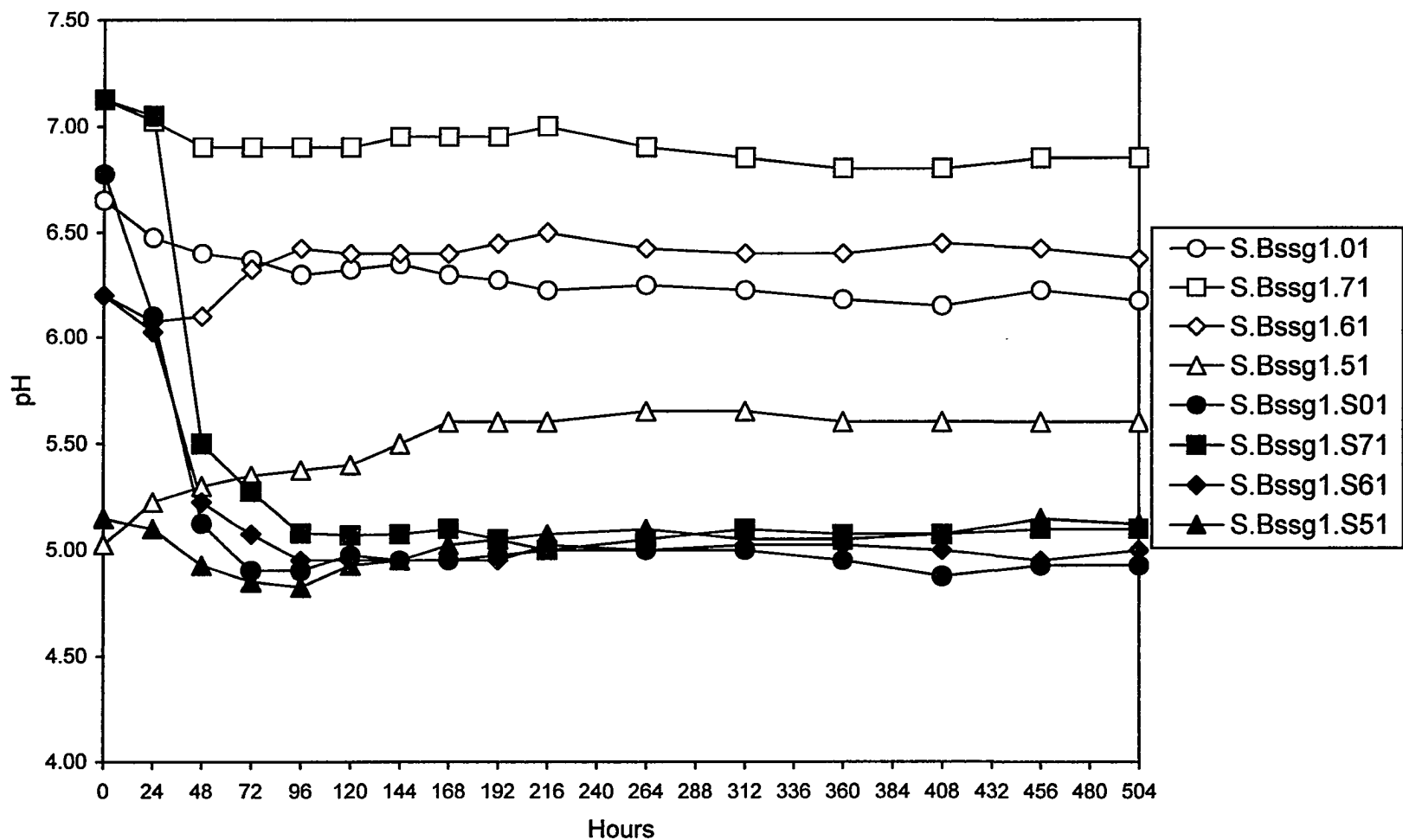


Figure 2.2.11. Mean pH values of the Bssg1 horizon for the Sharkey soil during the first incubation periods.

55

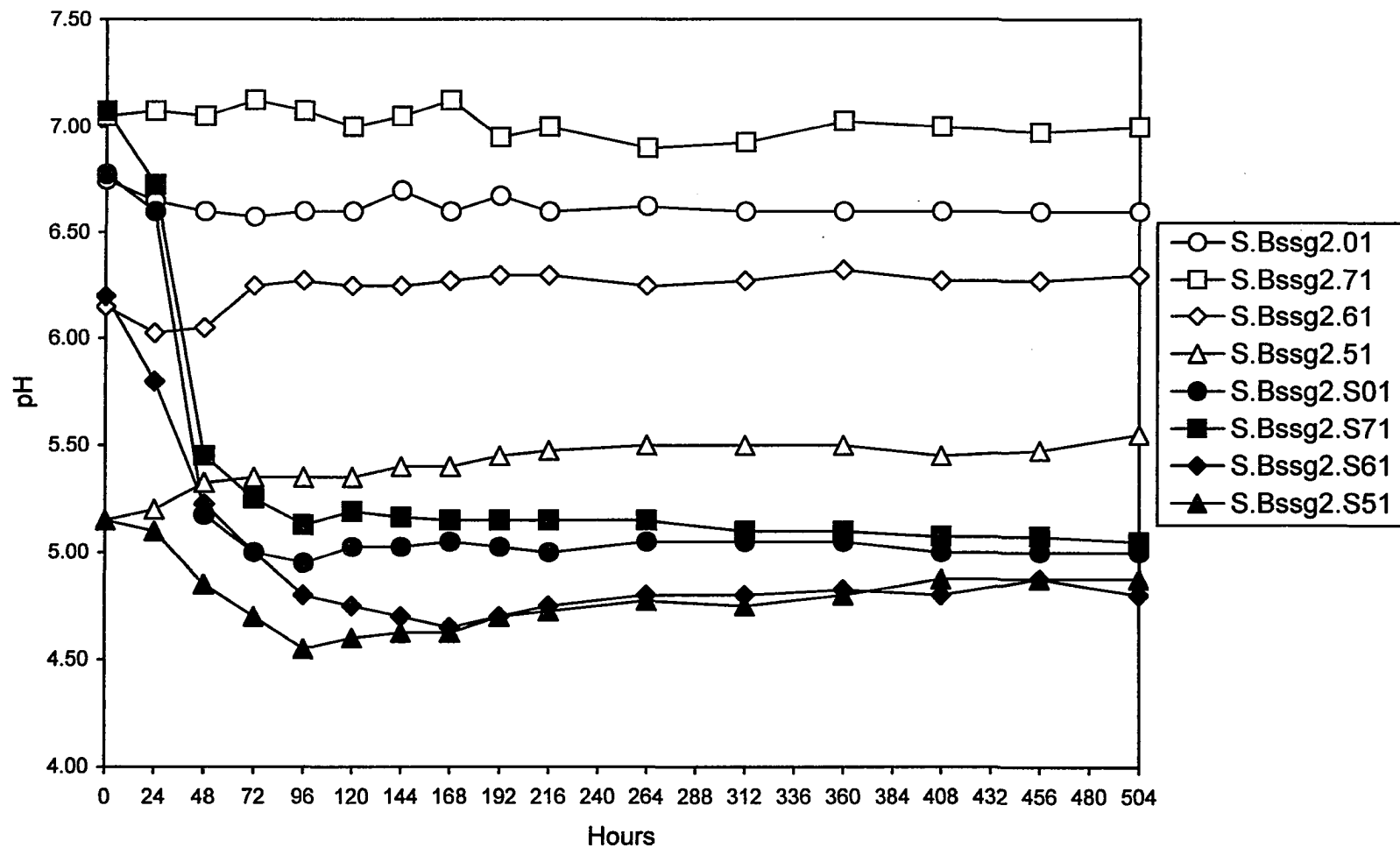


Figure 2.2.12. Mean pH values of the Bssg2 horizon for the Sharkey soil during the first incubation periods.

S.Bssg2.S01 treatment (Fig. 2.2.12). The pH for the S.Bssg1.S71 treatment decreased from 7.1 to 5.2 within 48 hours and remained constant during the experiment. The S.Bssg1.S61 treatment decreased from pH 6.2 to 5.2 within 48 hours and stabilized for the remainder of submergence. The pH for the S.Bssg2.S71 and S.Bssg2.S61 treatments showed the similar trend to those of the S.Bssg1.S71 and S.Bssg1.S61 treatments, respectively. The pH for the S.Bssg1.S51 and S.Bssg2.S51 treatments was similar. The pH for the S.Bssg1.S51 treatment decreased from 5.1 to 4.8 within 48 hours and then increased gradually to 5.1 during the experiment.

After re-saturation, the pH for the S.Ap1.02 and S.Ap1.62 treatments remained approximately pH 6.1 for 7-day re-saturation period (Fig. 2.2.13). However, the pH decreased from 6.9 to 6.4 for the S.Ap1.72 treatment and increased from 5.2 to 5.6 for the S.Ap1.52 treatment. The pH did not change during re-saturation for the Ap2 horizon with no sucrose treatment (Fig. 2.2.14). The pH decreased about 0.3 units for the different pH treatments of the Bssg1 and Bssg2 horizons without sucrose during the re-saturation period except for the S.Bssg1.02 treatment (Fig. 2.2.15 and 2.2.16). The pH increased 0.3 units for the Bssg1 and Bssg2 horizon with no sucrose treatment during the 7-day re-saturation period.

The pH increased approximately 0.4 units for the S.Ap1.S02, S.Ap2.S02, and S.Ap2.S72 treatments as compared to the last readings from the first incubation period. The pH for the S.Ag1.S02 treatment increased from 5.7 to 6.2. However, the S.Ap1.S62, S.Ap1.S52, S.Ap2.S62, and, S.Ap2.S52

57

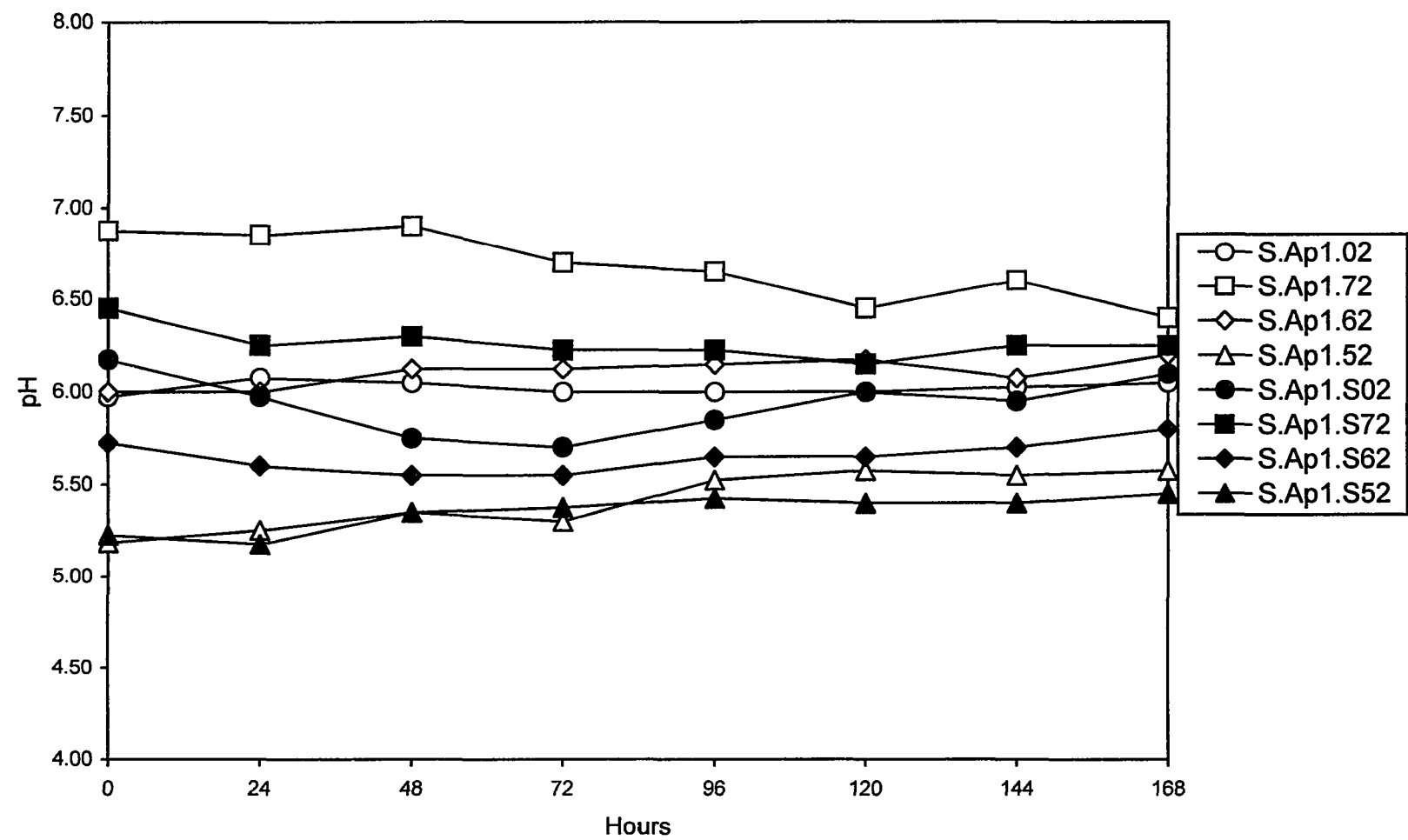


Figure 2.2.13. Mean pH values of the Ap1 horizon for the Sharkey soil during the re-saturation period.

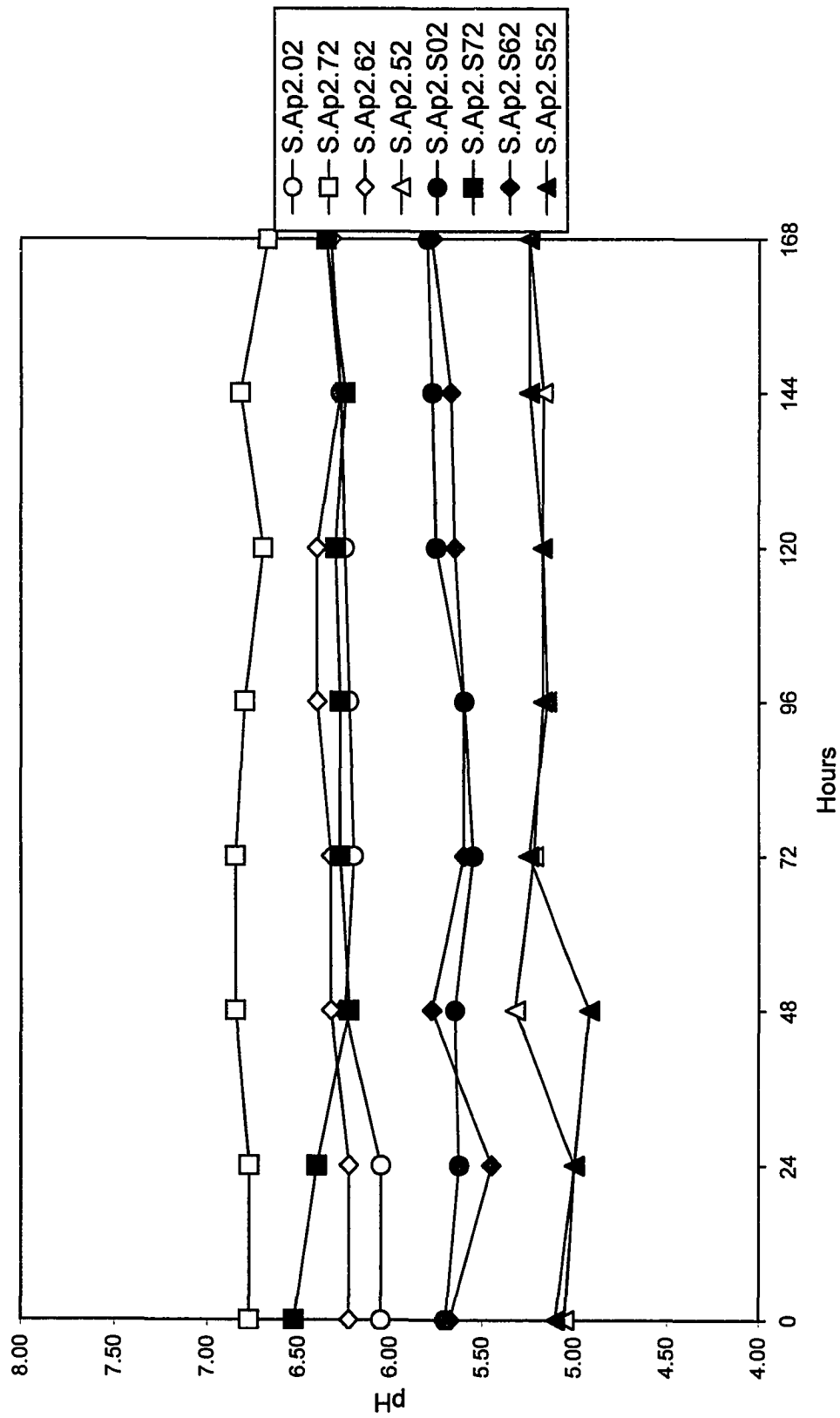


Figure 2.2.14. Mean pH values of the Ap2 horizon for the Sharkey soil during the re-saturation period.

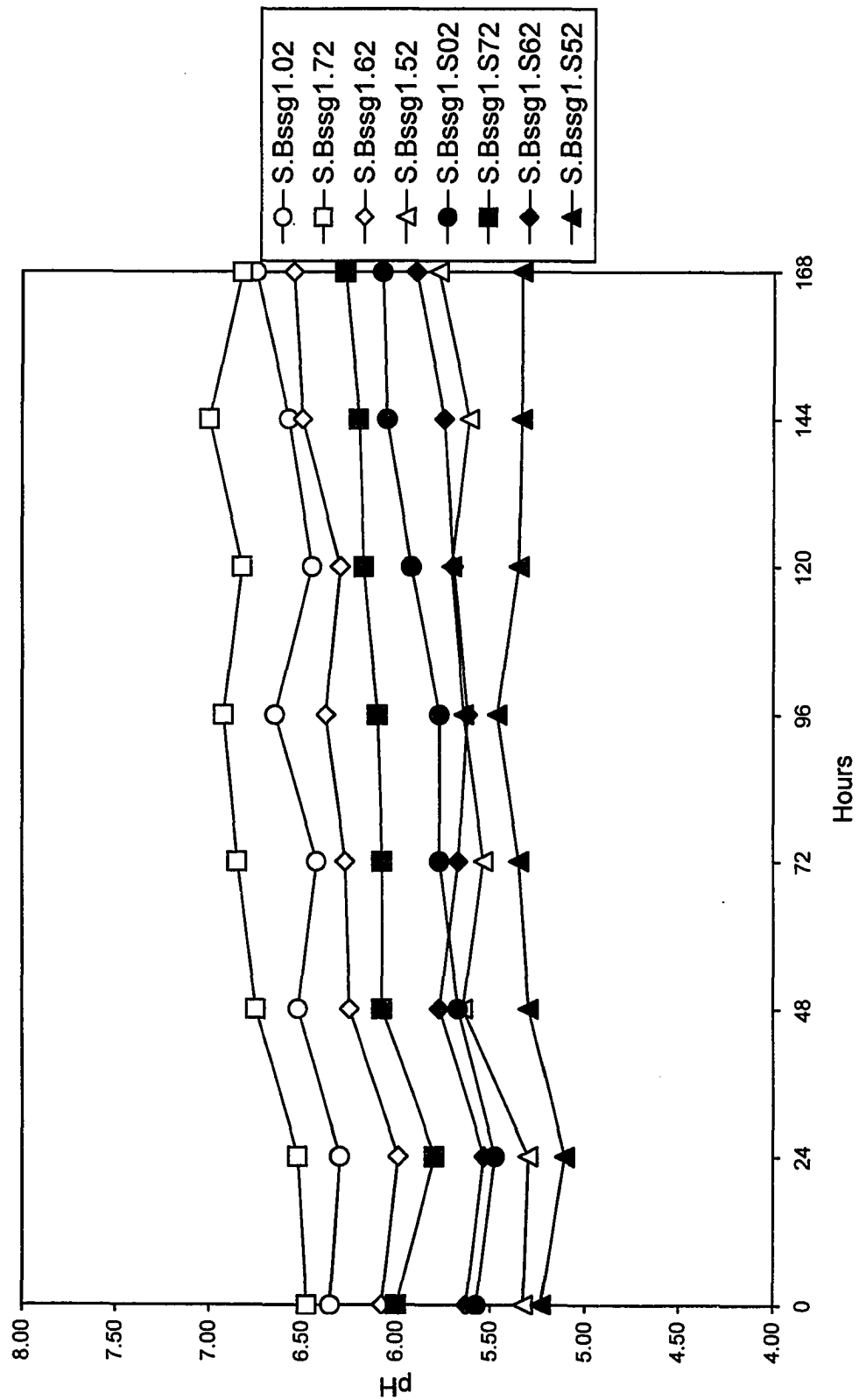


Figure 2.2.15. Mean pH values of the Bssg1 horizon for the Sharkey soil during the re-saturation period.

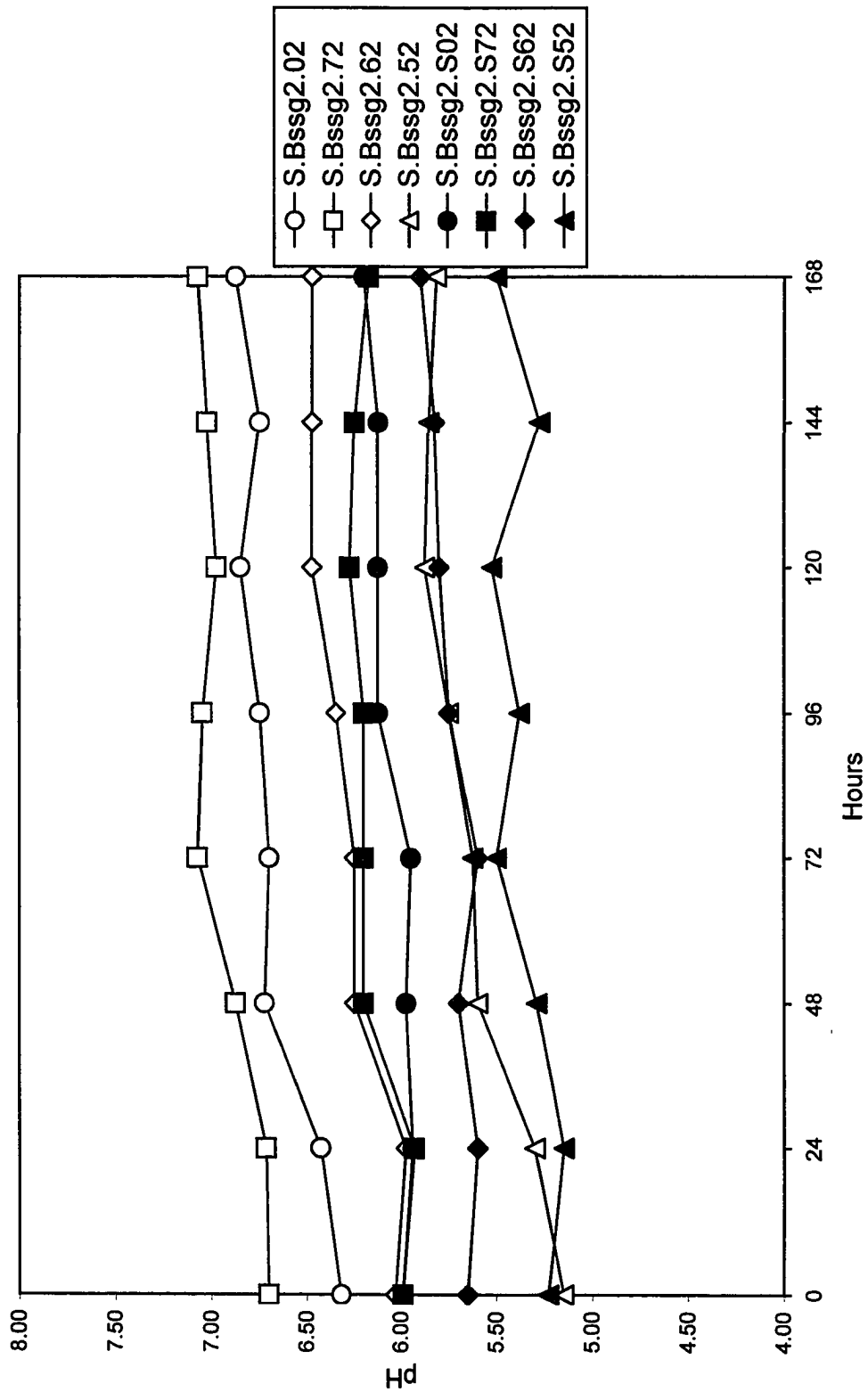


Figure 2.2.16. Mean pH values of the Bssg2 horizon for the Sharkey soil during the re-saturation period.

treatments did not change. The pH for the different pH soils of the Ag1 and Ag2 horizons treated with sucrose did not change during the 7-day re-saturation. The pH for the Bssg1 and Bssg2 horizons treated with sucrose was 0.6 units higher than its previous readings except for the pH adjusted to 5 treatment.

2.3.2. Eh

Moreland Soil

Temporal Eh changes for the Ap horizon with different treatments during the first incubation period are presented in Figure 2.3.1. The Eh for the M.Ap.01 treatment decreased gradually from 590 to 230 mV, and the M.Ap.71 treatment decreased from 580 to 300 mV during 21 days of incubation. The Eh for the M.Ap.61 treatment was similar to that of the M.Ap.51 treatment. The Eh for the M.Ap.51 treatment did not change and remained above 490 mV during the experiment. Based upon the results of Patrick and Jugsujinda (1992), the critical Eh for Mn and Fe to be reduced was 200 and 100 mV at pH 6.5, respectively. The redox potential was also adjusted by a factor of -59 mV/pH (Callebaut et al., 1982). Neither Mn nor Fe was reduced in the Ap horizon with no sucrose treatment.

The Eh for the different pH Ap horizons treated with sucrose showed a bimodal distribution (Fig. 2.3.1). The Eh for the M.Ap.S01 treatment decreased from 350 to -320 mV within 24 hours and gradually increased to -110 mV within 168 hours. It continued to increase to 60 mV within 216 hours and decreased again asymptotically to -220 mV during the experiment. The Eh for the M.Ap.S71, M.Ap.S61, and M.Ap.S51 treatments was similar to that of the

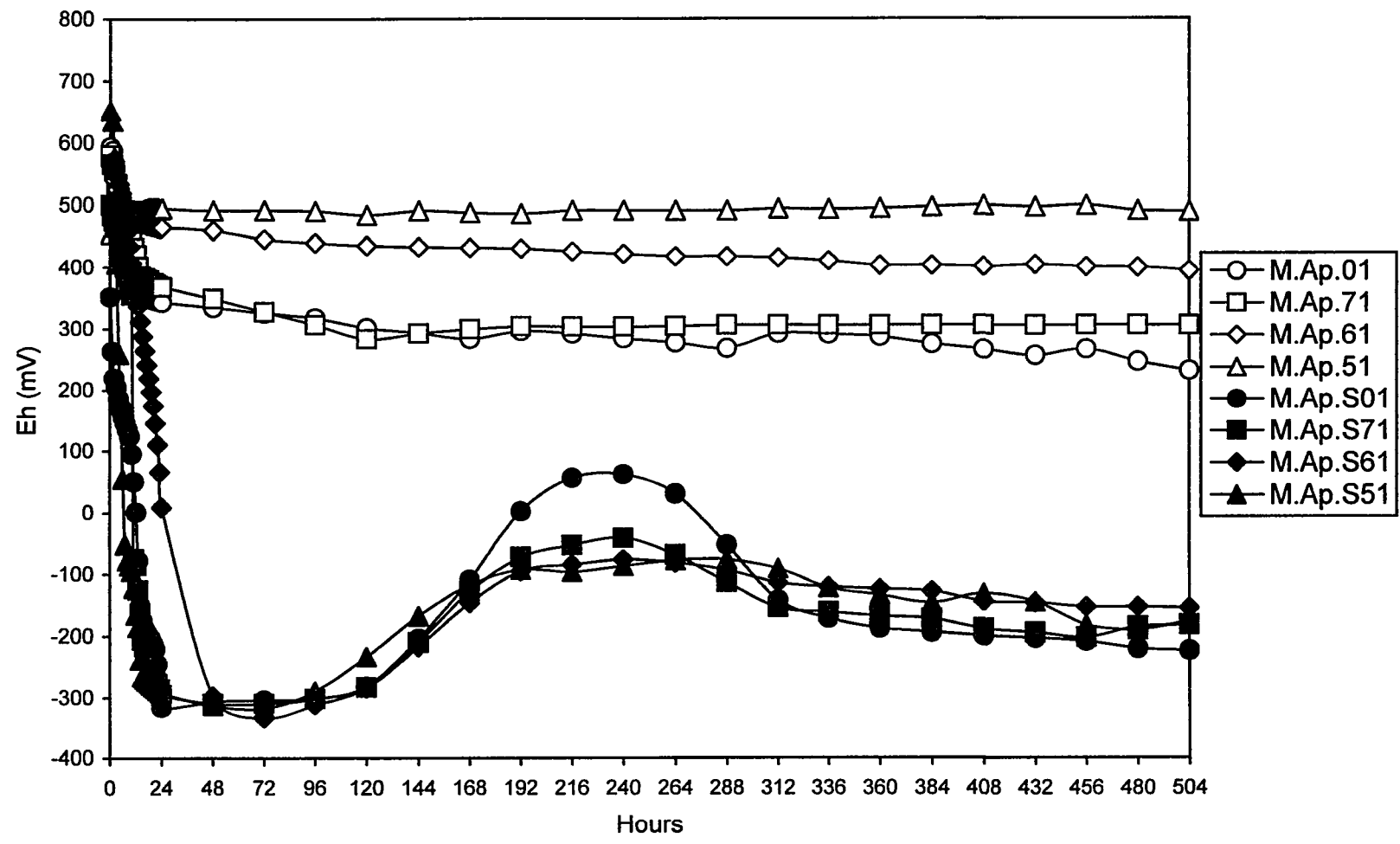


Figure 2.3.1. Mean redox potentials of the Ap horizon for the Moreland soil during the first incubation period.

M.Ap.S01 treatment. However, the Eh reached maximum values of -40, -80, and -80 mV within 240 hours for the M.Ap.S71, M.Ap.S61, and M.Ap.S51 treatments, respectively. After the maximum Eh was reached, the Eh decreased from -80 to -180 mV for the M.Ap.S51 treatment by the end of submergence. The Fe and Mn oxides were reduced for the Ap horizon treated with sucrose.

The Eh for the M.Bw.01, M.Bw.71, M.Bw.61, and M.Bw.51 treatments remained steady at 380, 440, 511, and 570 mV during 21 days of incubation (Fig. 2.3.2). Neither Mn nor Fe was reduced from the Bw horizon when no sucrose was added. The Eh for the M.Bw.S01, M.Bw.S71, and M.Bw.S61 treatments showed a bimodal distribution (Fig. 2.3.2). The Eh for the M.Bw.S01 treatment decreased from 450 to -160 mV within 24 hours and gradually decreased to -300 mV within 96 hours. It increased to 0 mV within 216 hours and then decreased to -160 mV during the experiment. The Eh for the M.Bw.S71 and M.Bw.S61 treatments was similar to that of M.Bw.S01 treatment. However, the rate of increasing Eh for the M.Bw.61 and M.Bw.51 treatments was slower than that of the M.Bw.S01 treatment after the minimum Eh was reached. The maximum Eh for the M.Bw.S01 treatment was 0 mV, which was higher than those of the M.Bw.61 and M.Bw.51 treatments. The Eh for the M.Bw.S51 treatment was different from other pH treatments. It decreased from 490 to -320 mV within 48 hours and increased gradually to -80 mV during the remainder of the 21-day incubation.

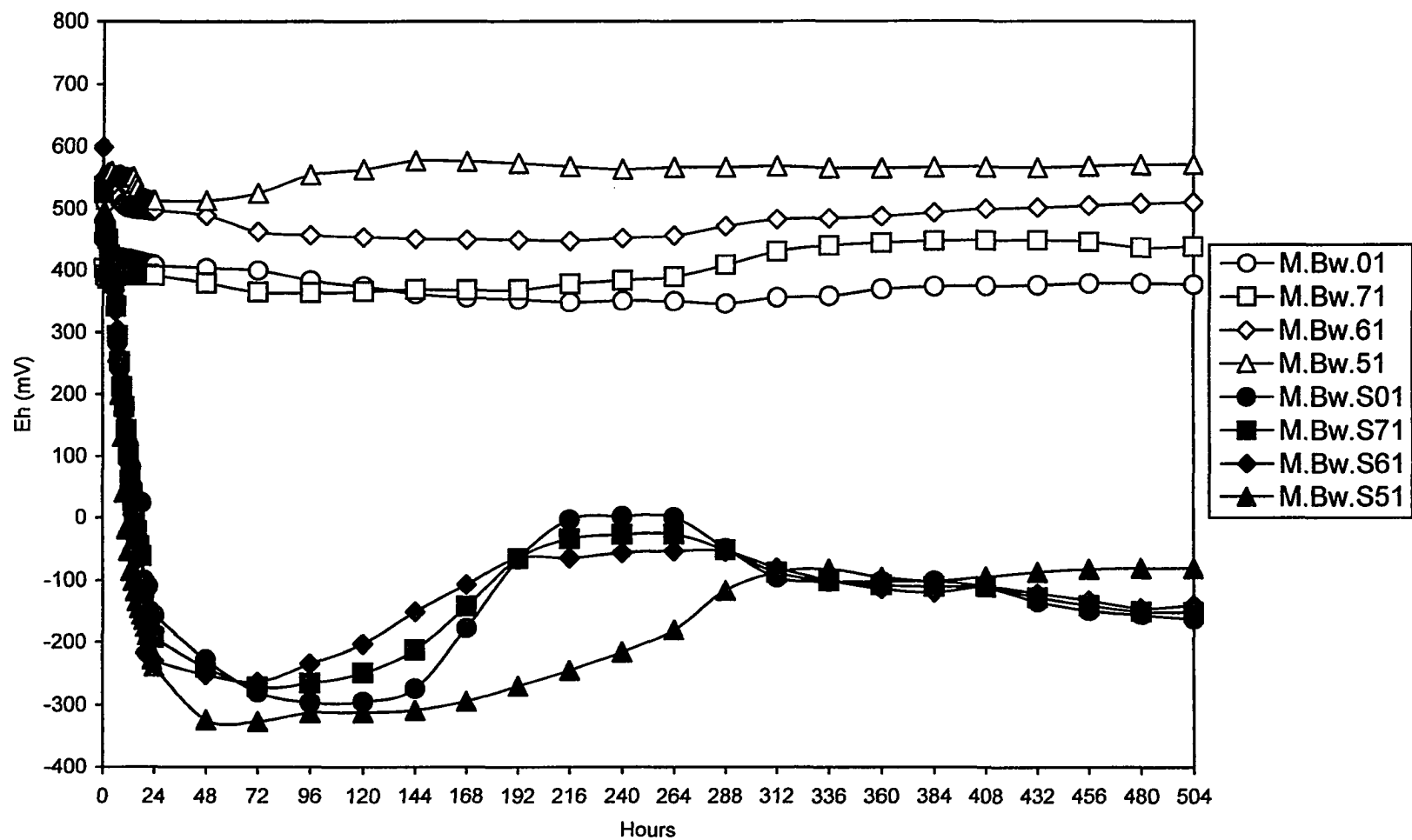


Figure 2.3.2. Mean redox potentials of the Bw horizon for the Moreland soil during the first incubation period.

The Eh showed a gradual decrease from 360 to 280 mV for the M.Bkss.01 treatment (Fig. 2.3.3). The Eh for the M.Bkss.71, M.Bkss.61, and M.Bkss.51 treatments did not change and remained above 300 mV for the experiment. The Eh for the M.Bkss.S01 treatment showed a bimodal distribution and was similar to that of the M.Bw.S01 treatment. The Eh for the M.Bkss.S71 and M.Bkss.S61 treatments showed a bimodal distribution. After the Eh reached –300 mV within 96 hours for the M.Bkss.S71 treatment, it increased and attained a maximum Eh value of –60 mV within 408 hours. It decreased to –120 mV during the experiment. The Eh for the M.Bkss.S51 treatment decreased to its minimum value of –250 mV within 72 hours and then gradually increased to 170 mV for 21 days.

The Eh for the M.Bss.01, M.Bss.71, M.Bss.61, and M.Bss.51 treatments did not change and ranged from 300 to 570 mV during the experiment (Fig. 2.3.4). The Eh for the M.Bss.S01 treatment was similar to that of the M.Bkss.S01 treatment. The Eh for the M.Bss.S71, M.Bss.S61, and M.Bss.S51 treatments was similar to that of M.Bkss.S51 treatment. The Eh for the M.Bss.S71 treatment decreased to –300 mV within 72 hours and then increased gradually to –50 mV during the experiment.

The results of Eh for the Ap horizon with different treatments during the re-saturation period are shown in Figure 2.3.5. The Eh for the M.Ap.02, M.Ap.72, M.Ap.62, and M.Ap.52 treatments had similar trends. The Eh for the M.Ap.02 treatment decreased gradually to 180 mV within 216 hours and increased

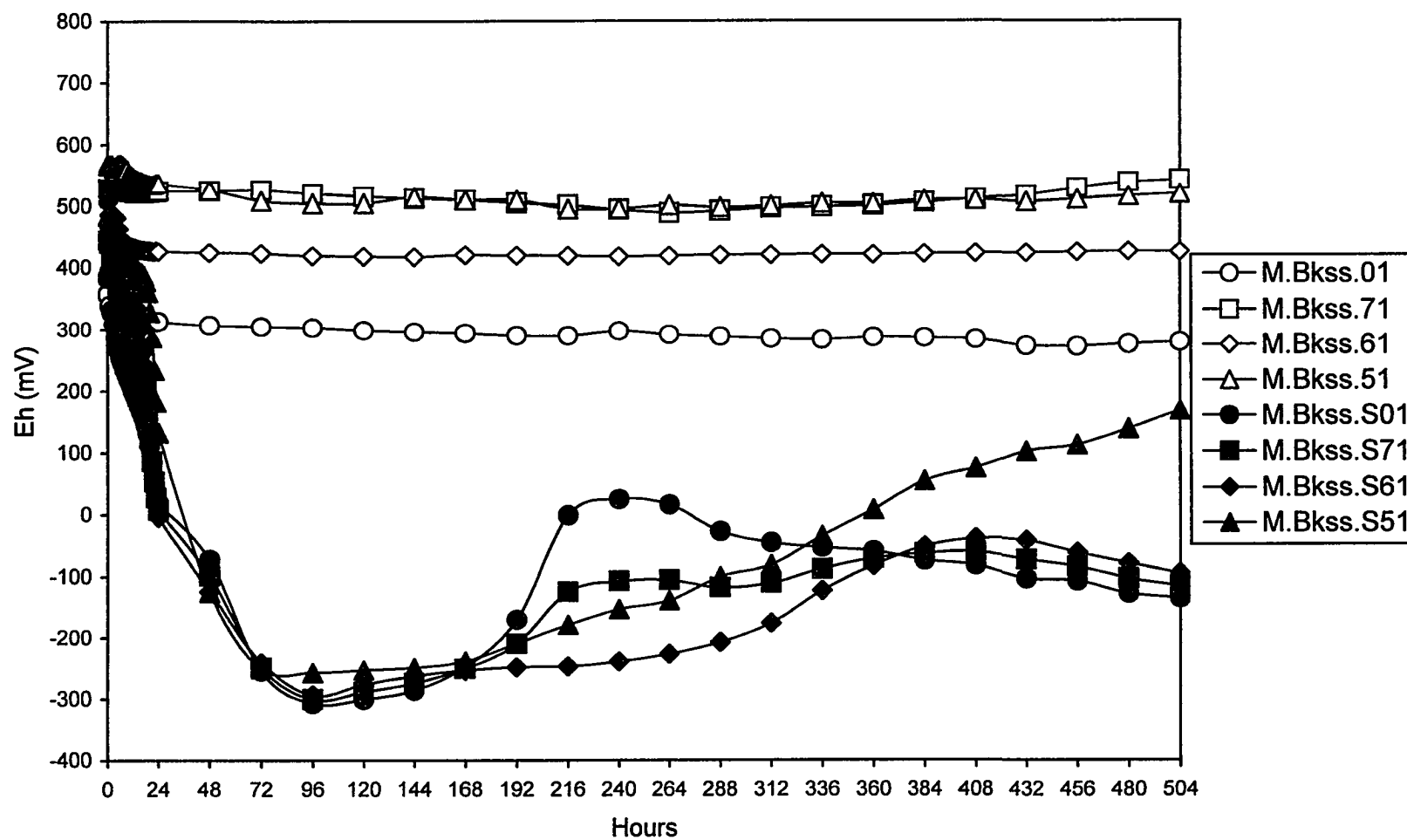


Figure 2.3.3. Mean redox potentials of the Bkss horizon for the Moreland soil during the first incubation period.

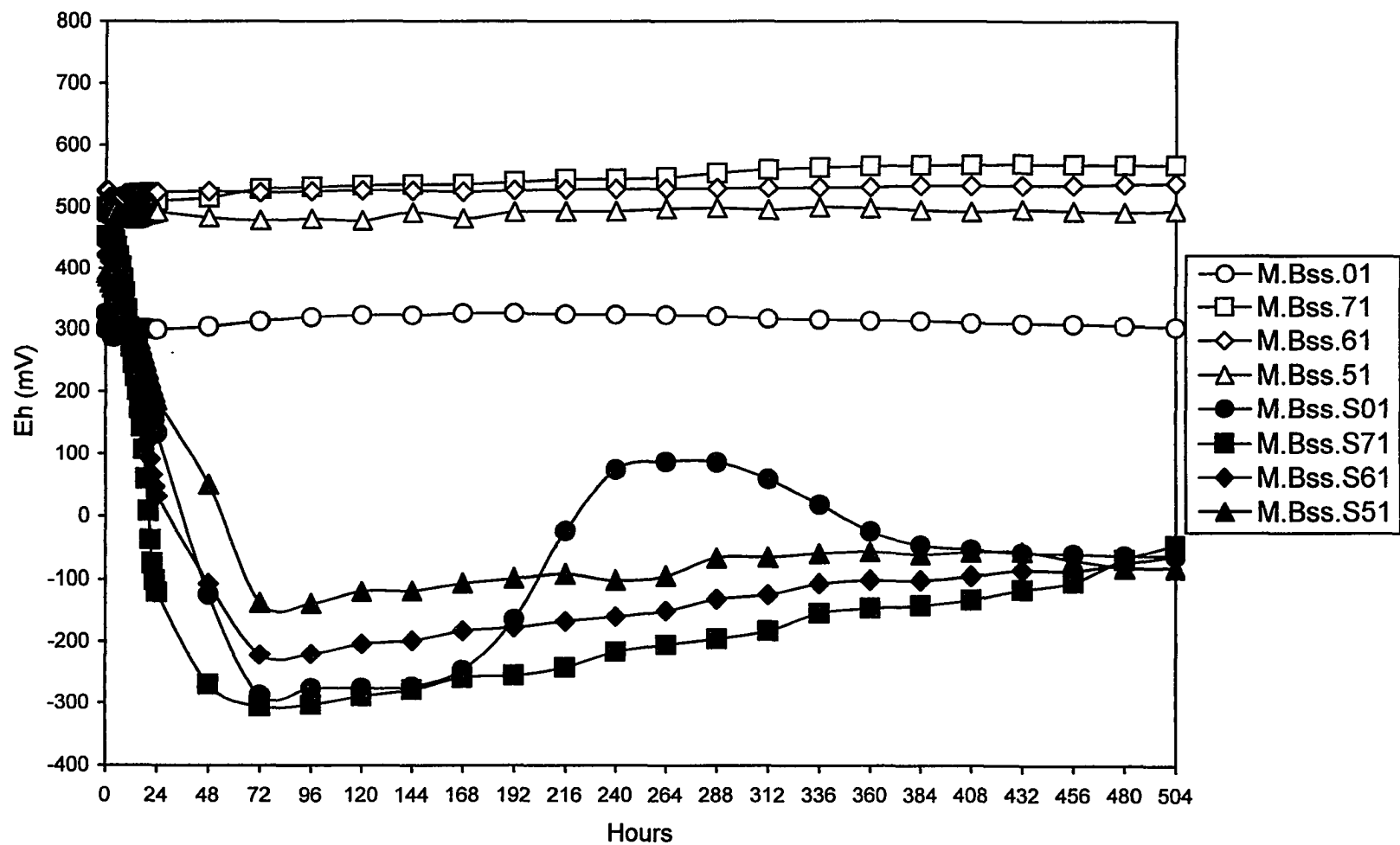


Figure 2.3.4. Mean redox potentials of the Bss horizon for the Moreland soil during the first incubation period.

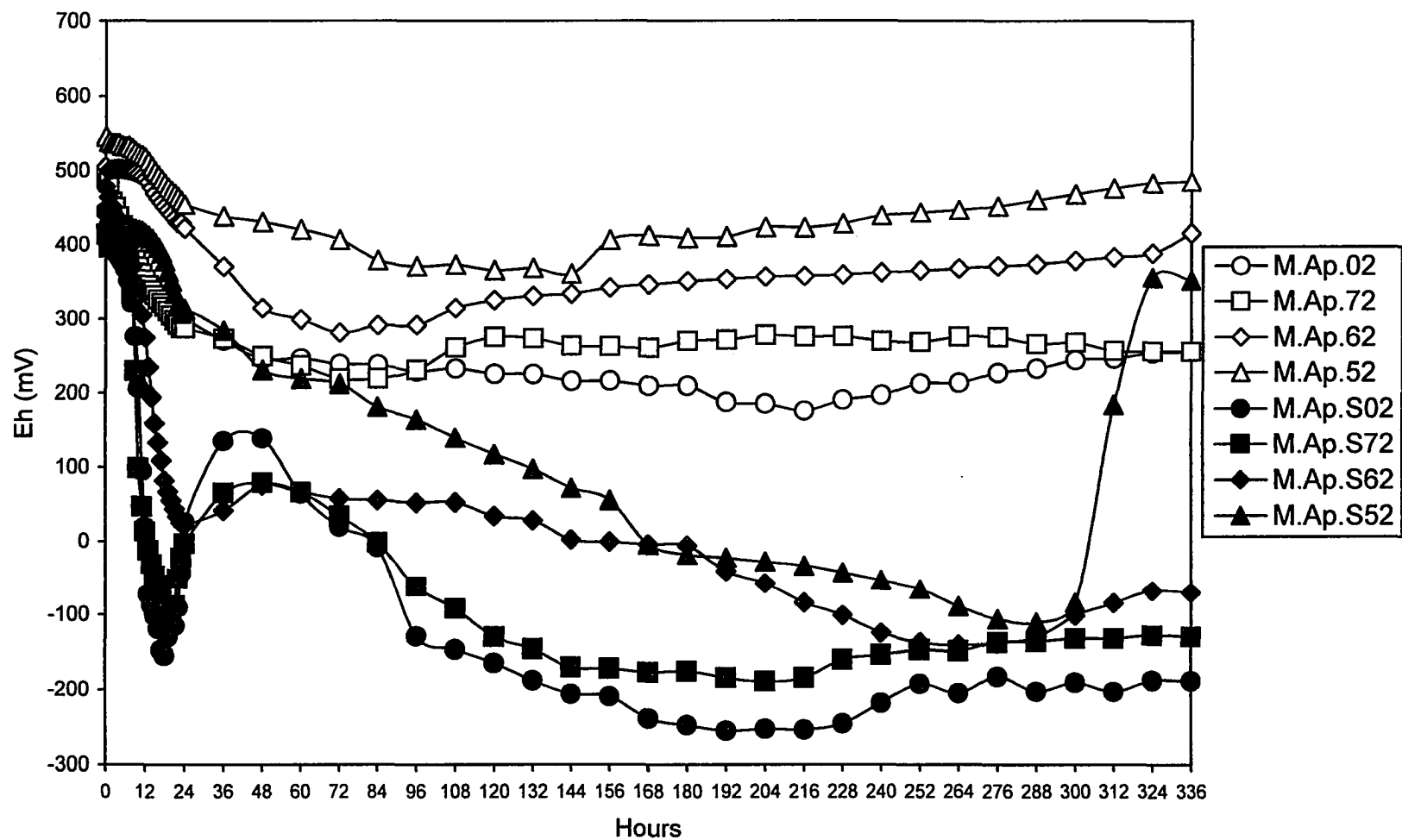


Figure 2.3.5. Mean redox potentials of the Ap horizon for the Moreland soil during the re-saturation period.

gradually to 260 mV during the remainder of re-saturation. The rate of decreasing Eh for the M.Ap.02 treatment was lower during the re-saturation period than that of the M.Ap.01 treatment during the first incubation period. The Mn oxides were probably reduced during the re-saturation period, but the Eh was too high for Fe to be reduced. The Eh for the M.Ap.S02 and M.Ap.S72 treatments showed a bimodal distribution. The Eh for the M.Ap.S02 treatment decreased to approximately -160 mV within 16 hours and then increased to 140 mV within 36 hours. Thereafter, the Eh decreased gradually to -250 mV within 180 hours and showed an increasing trend again during the experiment. The Eh for the M.Ap.S72 treatment was similar to that of the M.Ap.S02 treatment. The Eh for the M.Ap.S62 treatment decreased from 480 to 20 mV within 24 hours and then increased to 80 mV within 48 hours. It decreased gradually to -140 mV during the remainder of re-saturation. The Eh for the M.Ap.S52 treatment showed a gradual decreasing trend to -100 mV during the experiment. After soils were air-dried, oxygen was reintroduced and the Eh increased drastically with no transition period. Both the Mn and Fe would be reduced for the Ap horizon treated with sucrose during the re-saturation period.

The Eh for the Bw horizons with no sucrose treatment during re-saturation was similar to that of the Ap horizons (Fig. 2.3.6). The Eh for the M.Bw.S02 and M.Bw.S72 treatments showed a bimodal distribution. The Eh for the M.Bw.S02 treatment decreased from 490 to -60 mV within 36 hours and increased to -10 mV within 72 hours. It decreased gradually to -160 mV during the remainder of the experiment. The Eh for the M.Bw.S62 and M.Bw.S52

70

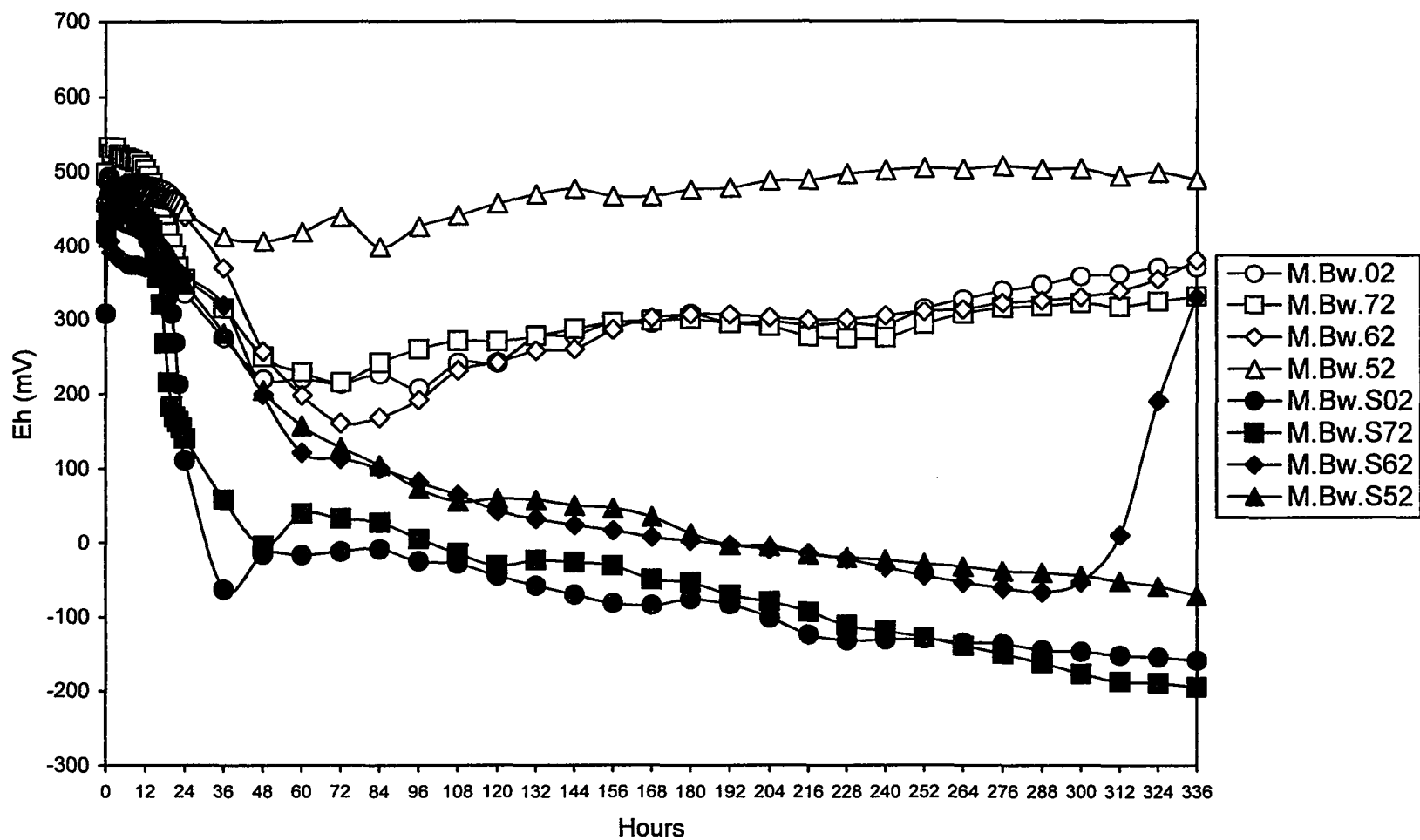


Figure 2.3.6. Mean redox potentials of the Bw horizon for the Moreland soil during the re-saturation period.

treatments decreased gradually from 410 mV to –50 mV during the re-saturation period.

The Eh for different pH treatments of the Bkss and Bss horizons with no sucrose treatment was similar (Fig. 2.3.7 and 2.3.8). It decreased to approximately 300 mV within 48 hours and stabilized during the remainder of re-saturation. The pH 5 treatment seemed to show greater Eh values than those of higher pH treatments. The Eh for the M.Bkss.S02 treatment decreased to 0 mV within 48 hours and gradually decreased to –250 mV during the experiment. The Eh for the M.Bss.S02 and M.Bss.S72 treatments showed similar trends to that of M.Bkss.S02 treatment. The Eh decreased from 410 to –70 mV for the M.Bkss.S62 treatment and from 510 to –50 mV for the M.Bkss.S62 treatment during the re-saturation period.

Sharkey Soil

The Eh for the Ap1 horizon of the Sharkey soil with different treatments during the first incubation period is presented in Figure 2.3.9. The Eh decreased from 290 mV to 120 mV for the S.Ap1.01 treatment and from 210 mV to 30 mV for the S.Ap1.71 treatment. The Eh for the S.Ap1.61 and S.Ap1.51 treatments at the end of the 21-day incubation was 210 and 360 mV, respectively. The higher pH treatment seemed to have a lower Eh than did the lower pH treatment. Both Mn and Fe would be reduced for the S.Ap1.01 and S.Ap1.71 treatments, but the S.Ap1.61 and S.Ap1.51 treatments would not be reduced with respect to neither Mn nor Fe.

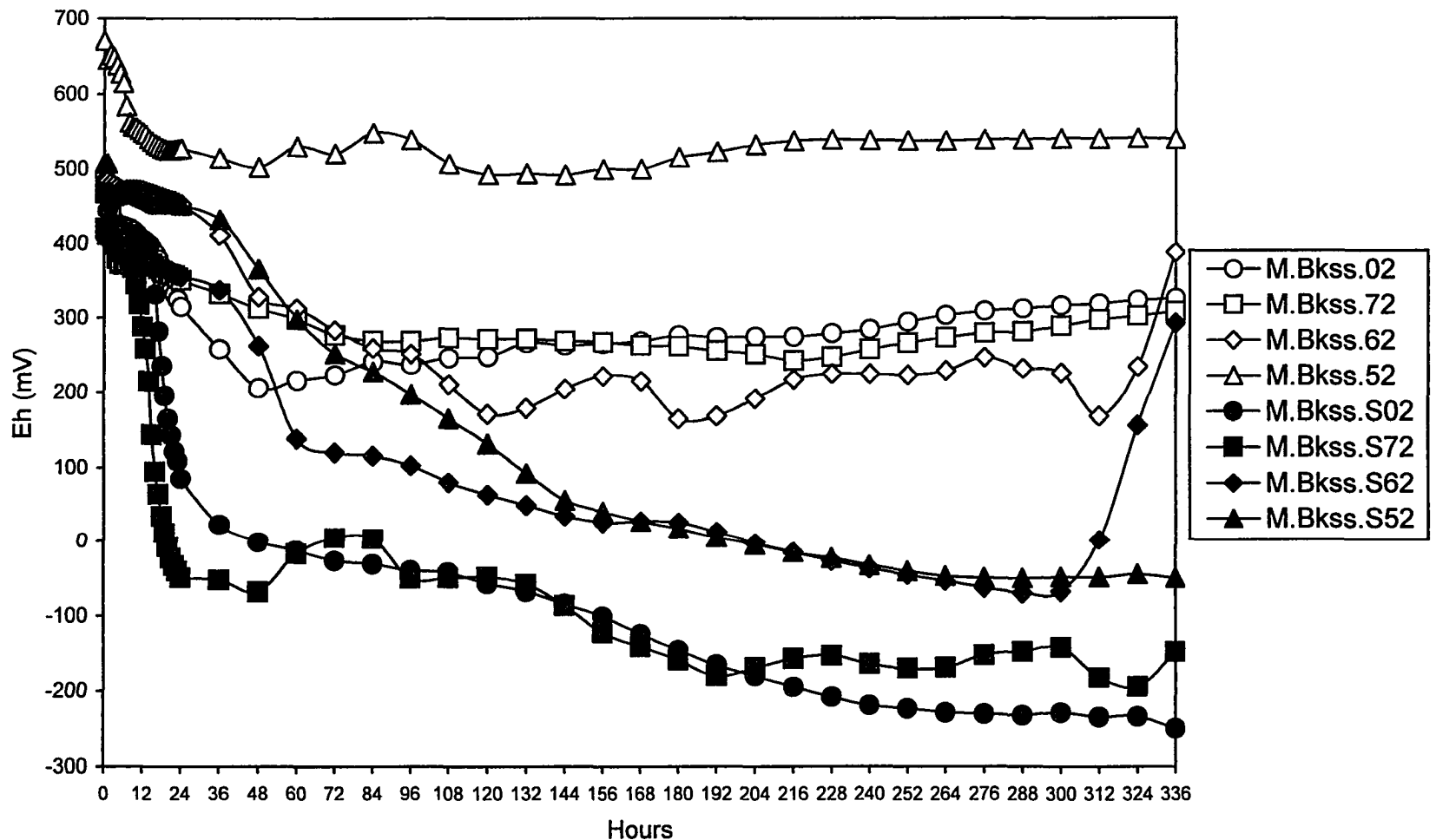


Figure 2.3.7. Mean redox potentials of the Bkss horizon for the Moreland soil during the re-saturation period.

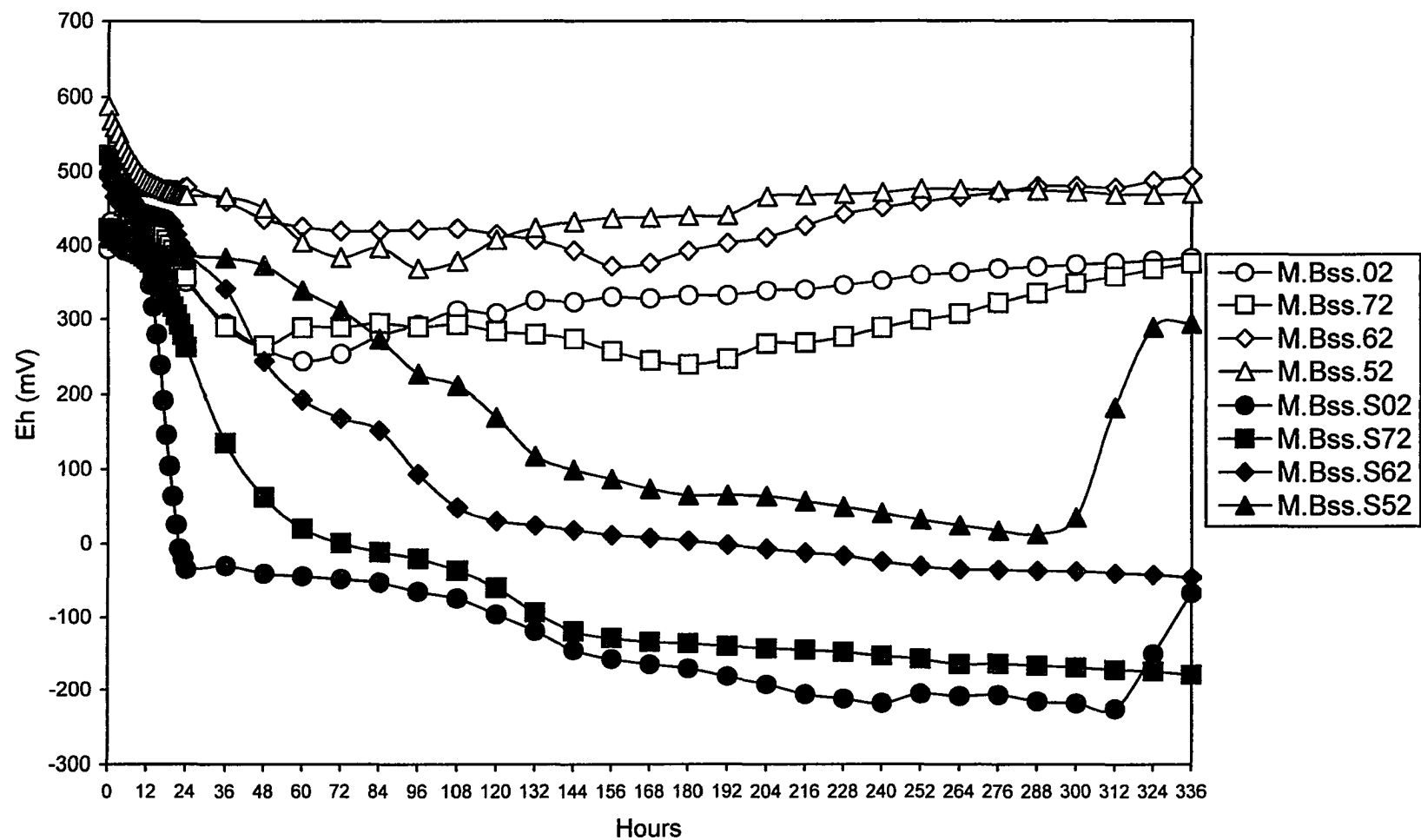


Figure 2.3.8. Mean redox potentials of the Bss horizon for the Moreland soil during the re-saturation period.

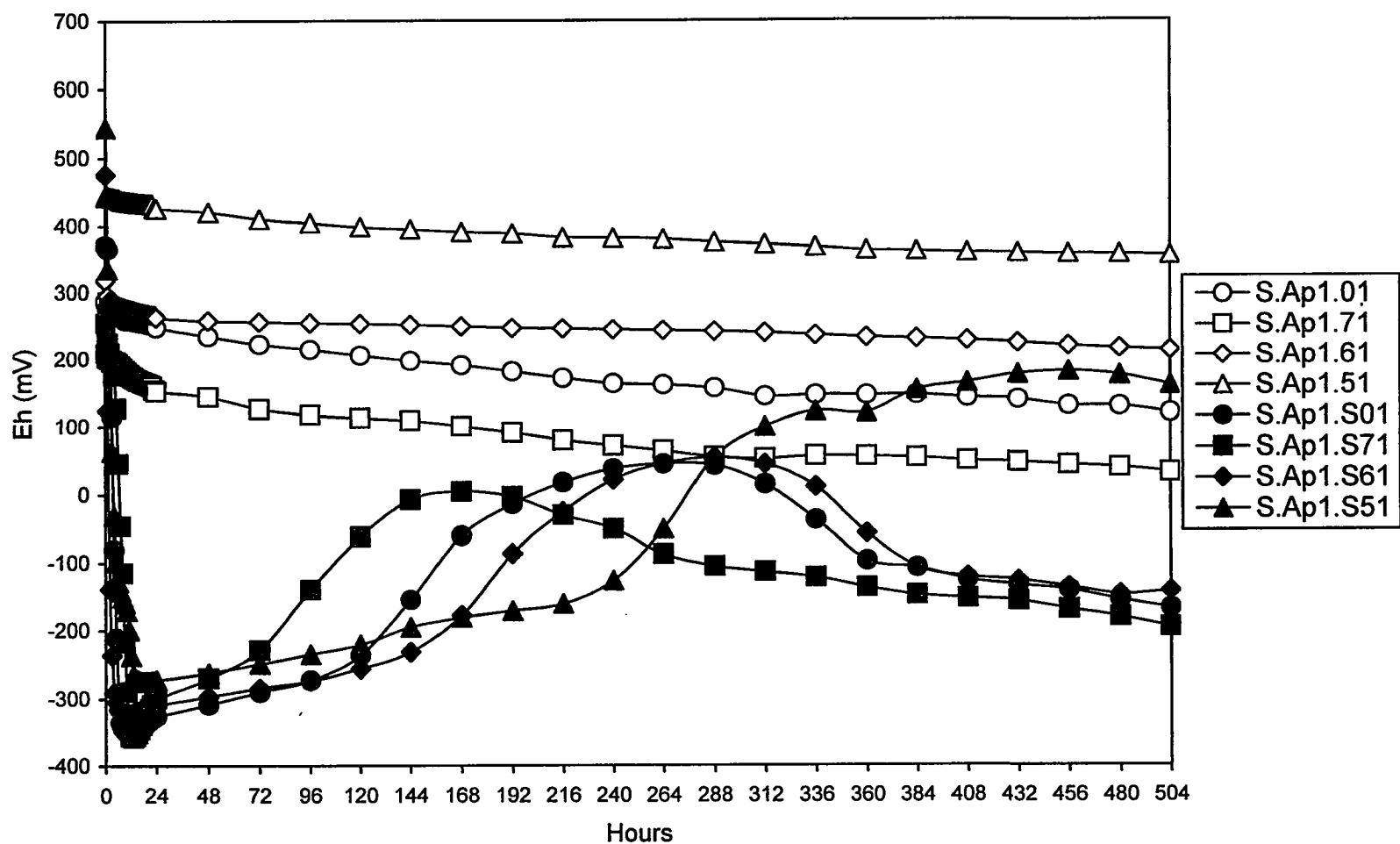


Figure 2.3.9. Mean Eh values of the Ap1 horizon for the Sharkey soil during the first incubation periods.

The Eh for the Ap1 horizon of the Sharkey soil treated with sucrose showed a bimodal distribution (Fig. 2.3.9). The Eh for the S.Ap1.S01 treatment decreased from 370 to -330 mV within 24 hours. It increased and reached a maximum value of 50 mV within 264 hours. It decreased again to -170 mV during the experiment. The Eh for the S.Ap1.S71 and S.Ap1.S61 treatments showed a similar trend to that of the S.Ap1.S01 treatment. However, the time needed for the S.Ap1.S71 treatment to reach the maximum Eh was 168 hours, which was quicker than for the S.Ap1.S01 treatment. The S.Ap1.S61 treatment required 288 hours to attain the maximum Eh. The distribution of Eh for the S.Ap1.S51 treatment was different from the S.Ap1.S01, S.Ap1.S71, and S.Ap1.S61 treatments. The Eh for the S.Ap1.S51 treatment decreased from 540 mV to -270 mV within 24 hours and gradually increased to 180 mV during the remainder of submergence. The Eh was low enough for Mn and Fe to be reduced within the Ap1 horizon treated with sucrose.

The distribution of the Eh for the different pH of the Ap2 horizon with no sucrose treatment was similar to that of the Ap1 horizons during the first incubation period (Fig. 2.3.10). Mn and Fe would only be reduced by the S.Ap2.71 treatment. The bimodal distribution of the Eh was observed within the Ap2 horizon treated with sucrose. The Eh for the S.Ap2.S01 and S.Ap2.S71 treatments was similar. The Eh for the S.Ap2.S01 treatment decreased from 420 to -310 mV within 24 hours. It increased and reached a maximum value of -20 mV within 264 hours. It decreased again to -150 mV during the experiment. The S.Ap2.S61 and S.Ap1.S51 treatments showed a similar trend.

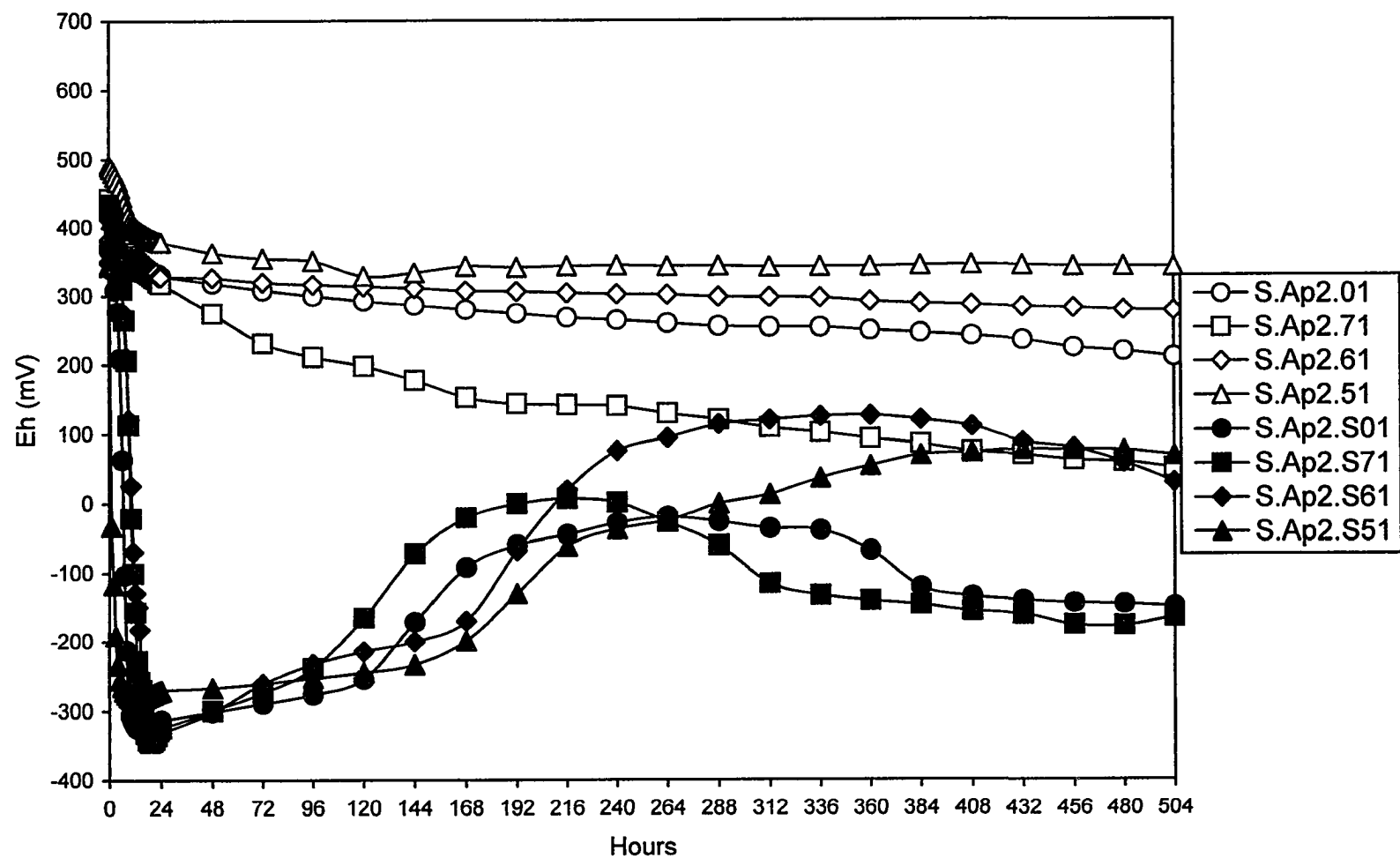


Figure 2.3.10. Mean Eh values of the Ap2 horizon for the Sharkey soil during the first incubation periods.

After the Eh of the S.Ap1.S61 treatment reached a minimum of –330 mV within 24 hours, it increased gradually within 168 hours. The rate of increasing was greater after 168 hours and increased to 120 mV within 312 hours. It decreased to 30 mV for the duration of incubation.

The Eh did not appreciably change for the different pH treatments of the Bssg1 and Bssg2 horizons with no sucrose treatment during the experiment (Fig. 2.3.11 and 2.3.12). The Eh for the pH adjusted to 7 and natural pH Bssg1 and Bssg2 horizons was above 300 mV for 21 days. The Eh's for the pH adjusted to 6 and 5 Bssg1 and Bssg2 horizons were above 500 mV during the experiment. The Eh was too high for Mn and Fe to be reduced within the Bssg1 and Bssg2 horizons without sucrose treatment. The Eh for the Bssg1 and Bssg2 horizons with sucrose treatment was different from that of the Ag1 and Ag2 horizons treated with sucrose (Fig. 2.3.11 and 2.3.12). The time required for the Eh to increase was much longer for the Bssg1 and Bssg2 horizons than for the same pH treatment of the Ag1 horizon. The Eh for the S.Bssg1.S51 treatment decreased from 410 to – 260 mV within 48 hours and gradually increased to 80 mV during the remainder of incubation (Fig. 2.3.11). The S.Bssg1.S61 treatment showed a similar trend but a lower Eh value as compared to that of the S.Bssg1.S51 treatment. The Eh for the S.Bssg1.S01 and S.Bssg1.S71 treatments was lower than that of the S.Bssg1.S51 and S.Bssg1.S61 treatments. The Eh for the different pH treatments of the Bssg2 horizons treated with sucrose was similar to each other (Fig. 2.3.12). They were also similar to those of the Bssg1 horizon treated with sucrose.

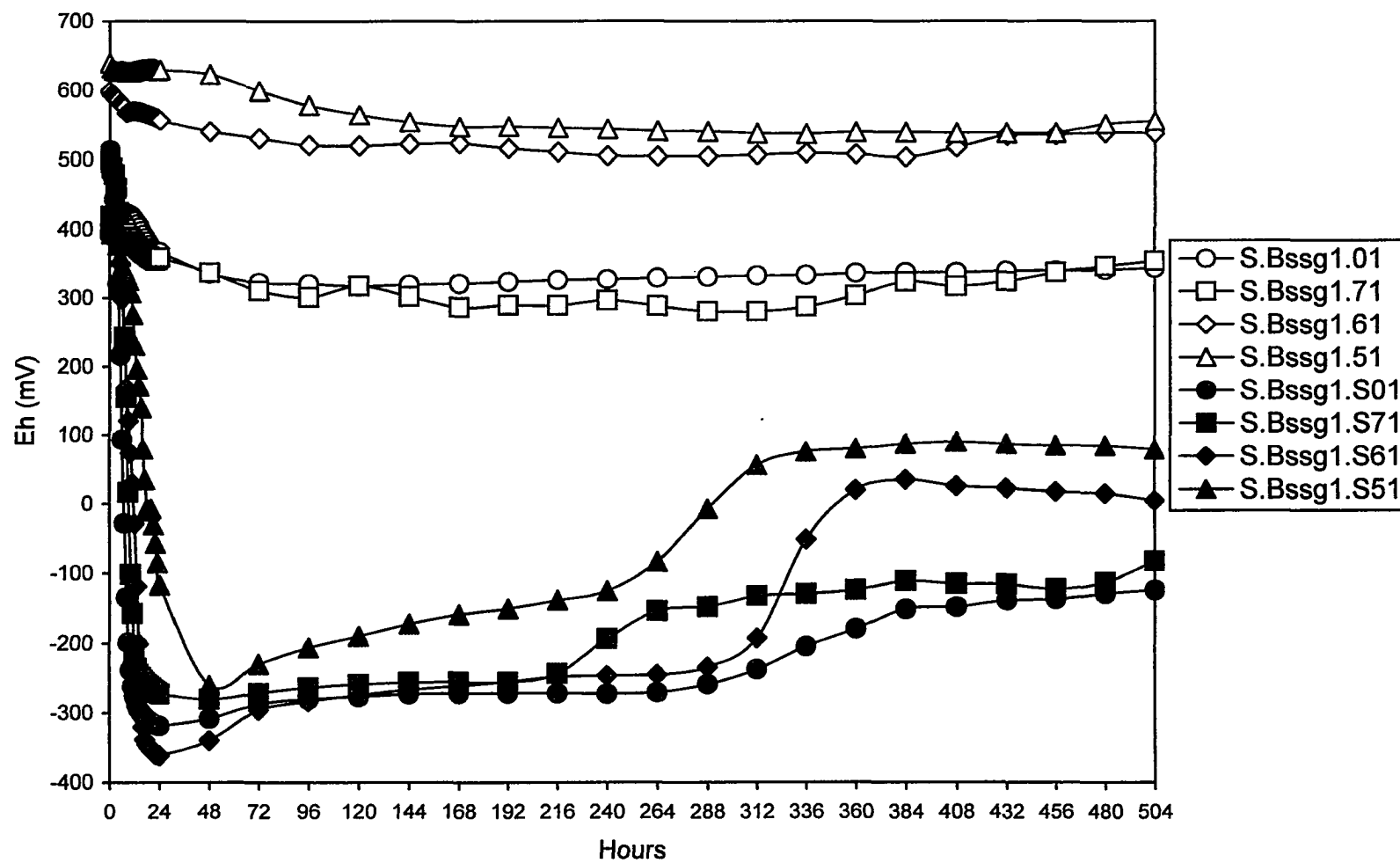


Figure 2.3.11. Mean Eh values of the Bssg1 horizon for the Sharkey soil during the first incubation periods.

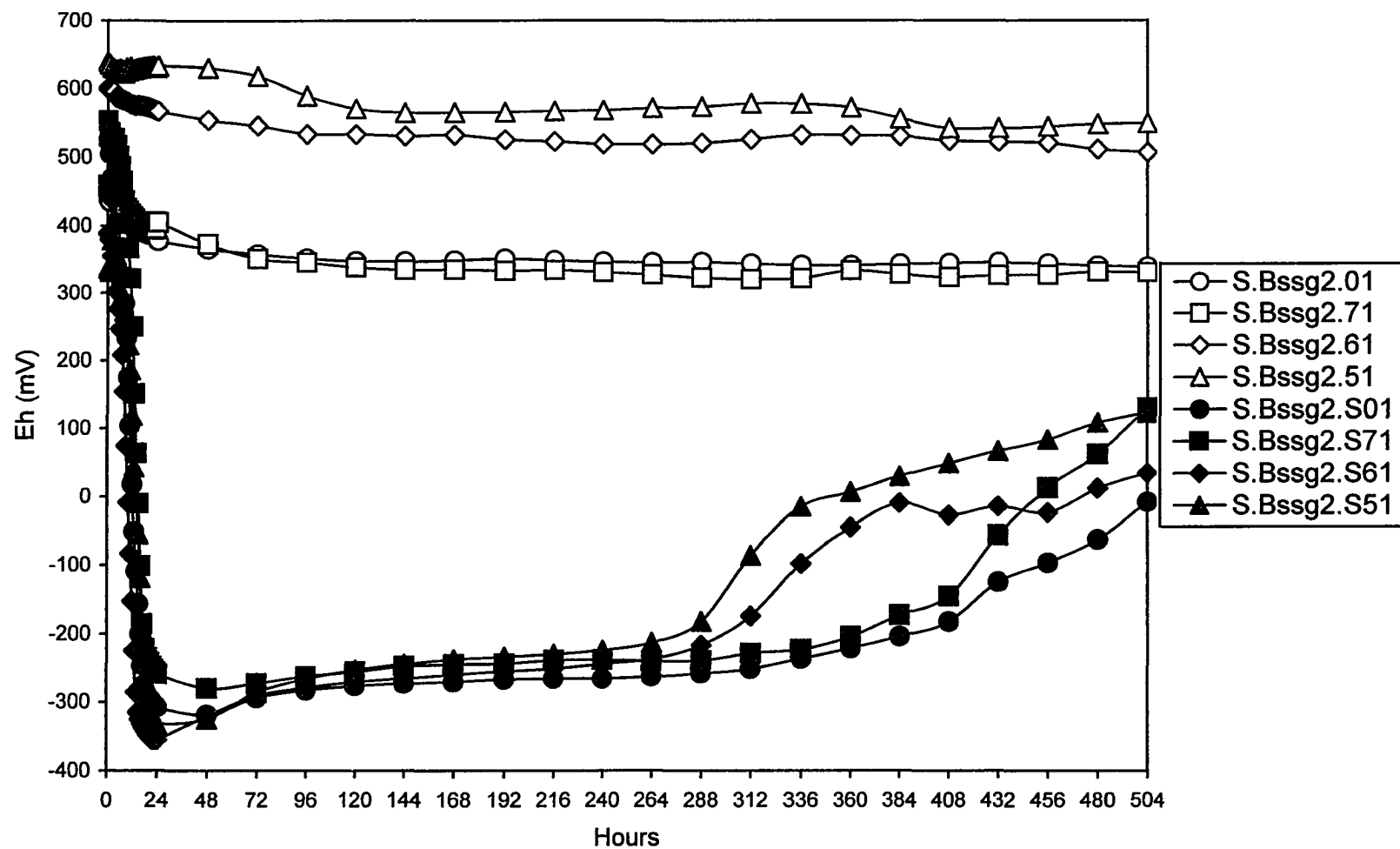


Figure 2.3.12. Mean Eh values of the Bssg2 horizon for the Sharkey soil during the first incubation periods.

The Eh for the Ap1 horizon of the Sharkey soil with different treatments during the re-saturation period is shown in Figure 2.3.13. The Eh for the S.Ap1.02 treatment decreased from 270 to 150 mV within 24 hours and then decreased gradually to 100 mV during the experiment. The Eh for the S.Ap1.72, S.Ap1.62, and S.Ap1.52 treatments had a similar trend as that of S.Ap1.02 treatment, but the Eh was higher for the pH 5 and 6 treatments than that of the natural pH and pH 7 treatments. The S.Ap1.02 and S.Ap1.72 treatments would reduce Mn and Fe, but the S.Ap1.52 and S.Ap1.62 treatments could not reduce the Mn and Fe. The bimodal distribution of the Eh for the Ap1 horizon treated with sucrose was observed during re-saturation (Fig. 2.3.13). The Eh for the S.Ap1.S02 treatment decreased from 480 to -110 mV within 48 hours and then increased to 140 mV within 96 hours. It decreased again to -170 mV for the experiment. The Eh for the S.Ap1.S72, S.Ap1.S62, and S.Ap1.S52 treatments was similar to that of the S.Ap1.S02 treatment. However, the Eh for the S.Ap1.S52 treatment reached a maximum Eh of 240 mV within 96 hours.

Like the Eh of the Ap1 horizon, the Eh for the S.Ap2.02 and S.Ap2.72 treatments decreased gradually from 440 to 210 mV for the S.Ap1.02 treatment and from 520 to 220 mV during the experiment (Fig. 2.3.14). The Eh was low enough for the S.Ap2.02 and S.Ap2.72 treatments to reduce Mn but not Fe. The Eh for the S.Ap2.62 and S.Ap2.52 treatments did not appreciably change and remained above 400 mV during the re-saturation period. The Eh for the Ap2 horizon treated with sucrose showed a bimodal distribution. The Eh for

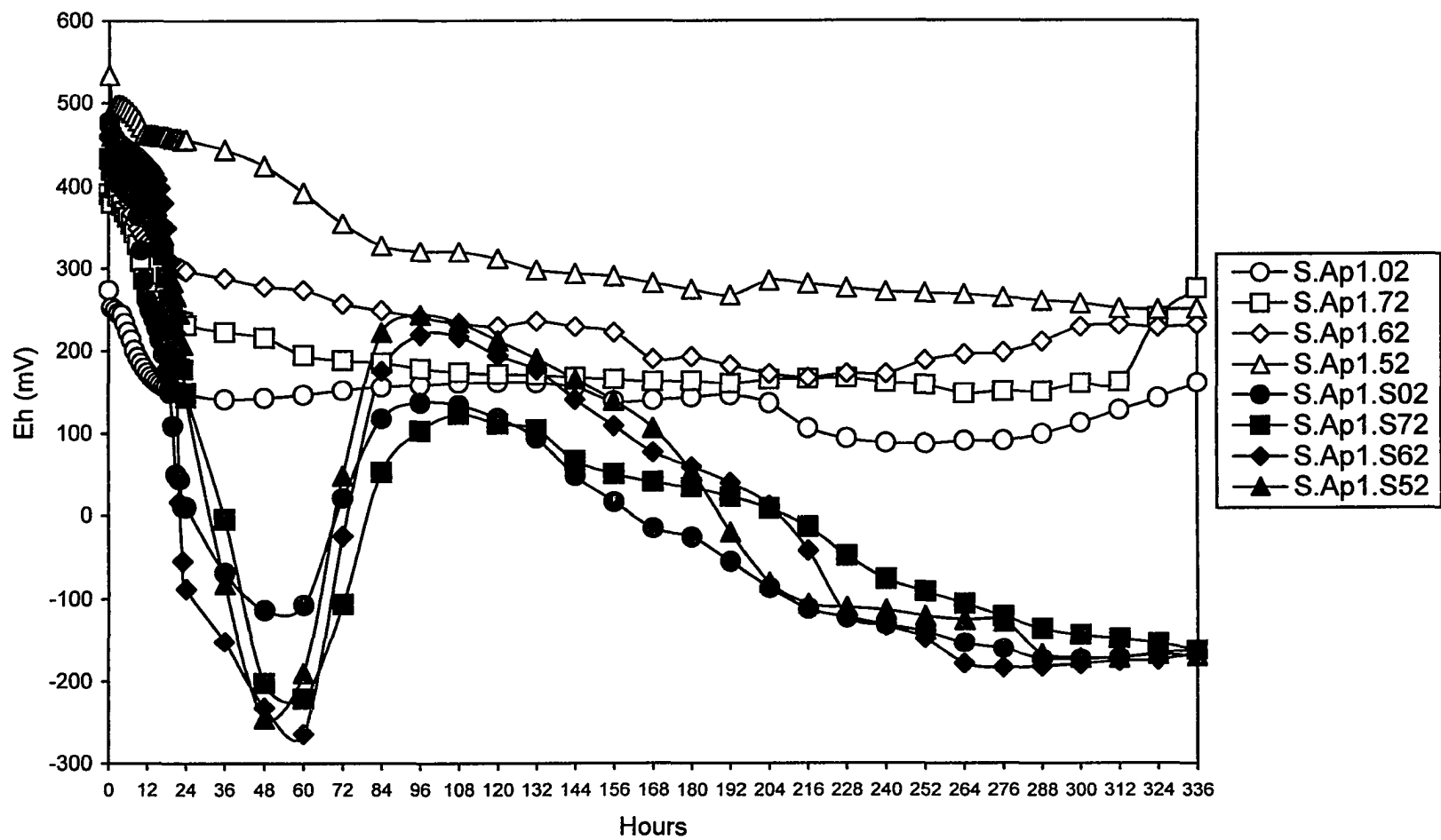


Figure 2.3.13. Mean redox potentials of the Ap1 horizon for the Sharkey soil during the re-saturation period.

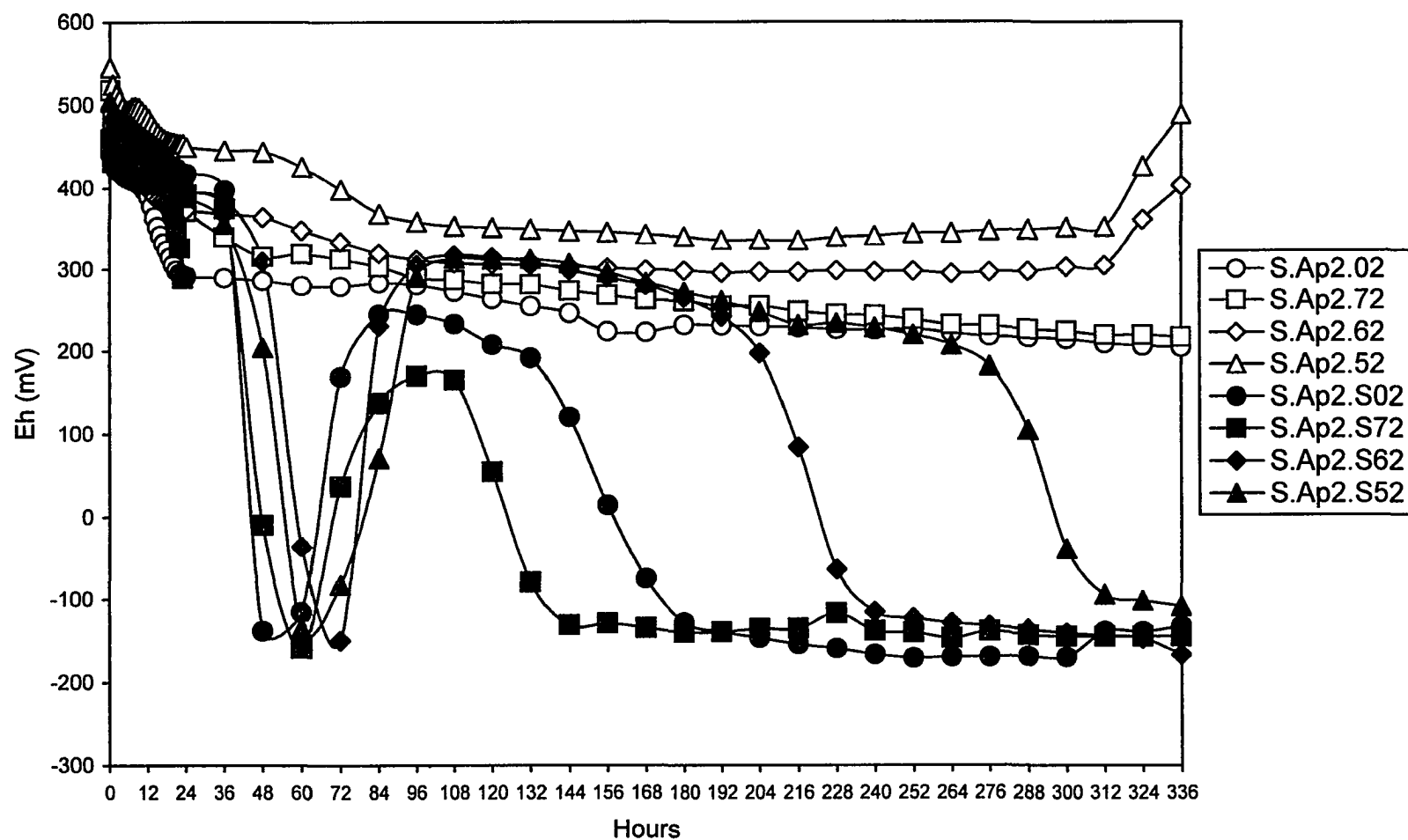


Figure 2.3.14. Mean redox potentials of the Ap2 horizon for the Sharkey soil during the re-saturation period.

the S.Ap2.S02 treatment decreased from 440 to –140 mV within 48 hours. It increased to 250 mV within 84 hours and then decreased to –170 mV during the remainder of re-saturation. The Eh for the S.Ap2.S72, S.Ap2.S62, and S.Ap2.S52 treatments was similar to those of the S.Ap2.S02 treatment. The lower the pH treatment, the higher the Eh attained by the soil. For example, the maximum Eh was 170 mV for the S.Ap2.S72 treatment and 320 mV for the S.Ap2.S62 treatment. The Eh for the S.Ap2.S62 treatment remained 320 mV for 120 hours and then decreased to –160 mV during the experiment. The S.Ap2.S72 treatment remained less than 24 hours at a maximum Eh of 170 mV.

The Eh for the Bssg1 and Bssg2 horizons with no sucrose treatment showed gradual decreasing trends during the re-saturation period (Fig. 2.3.15 and 2.3.16). The Eh was above 270 mV for the different pH treatments of the Bssg1 and Bssg2 horizons with no sucrose treatment. Both Mn and Fe would not be reduced within the range of Eh recorded. The Eh for the different pH treatments of the Bssg1 and Bssg2 horizons treated with sucrose was similar to that of the Ap2 horizon corresponding with the same pH treatment (Fig. 2.3.15 and 2.3.16).

2.3.3. Mn and Fe in Soil Solution

Moreland Soil

The concentrations of Mn ions in the Moreland soil are presented in Table 2.3.1. The Mn was less than 0.05 mg/L for the natural pH, and pH adjusted to 6 and 7 treatments. It increased to 2.09 mg/L or more for the pH adjusted to 5

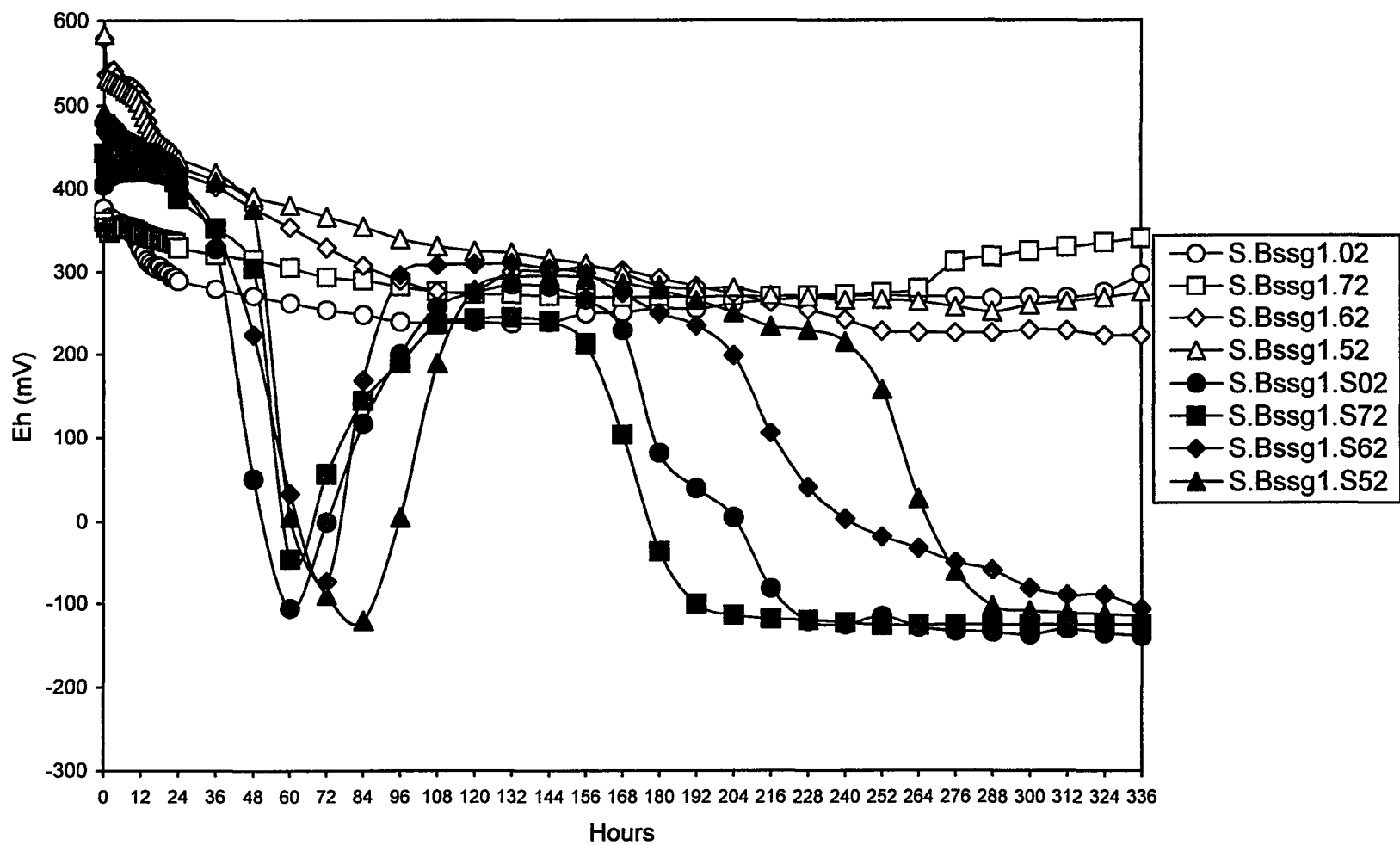


Figure 2.3.15. Mean redox potentials of the Bssg1 horizon for the Sharkey soil during the re-saturation period.

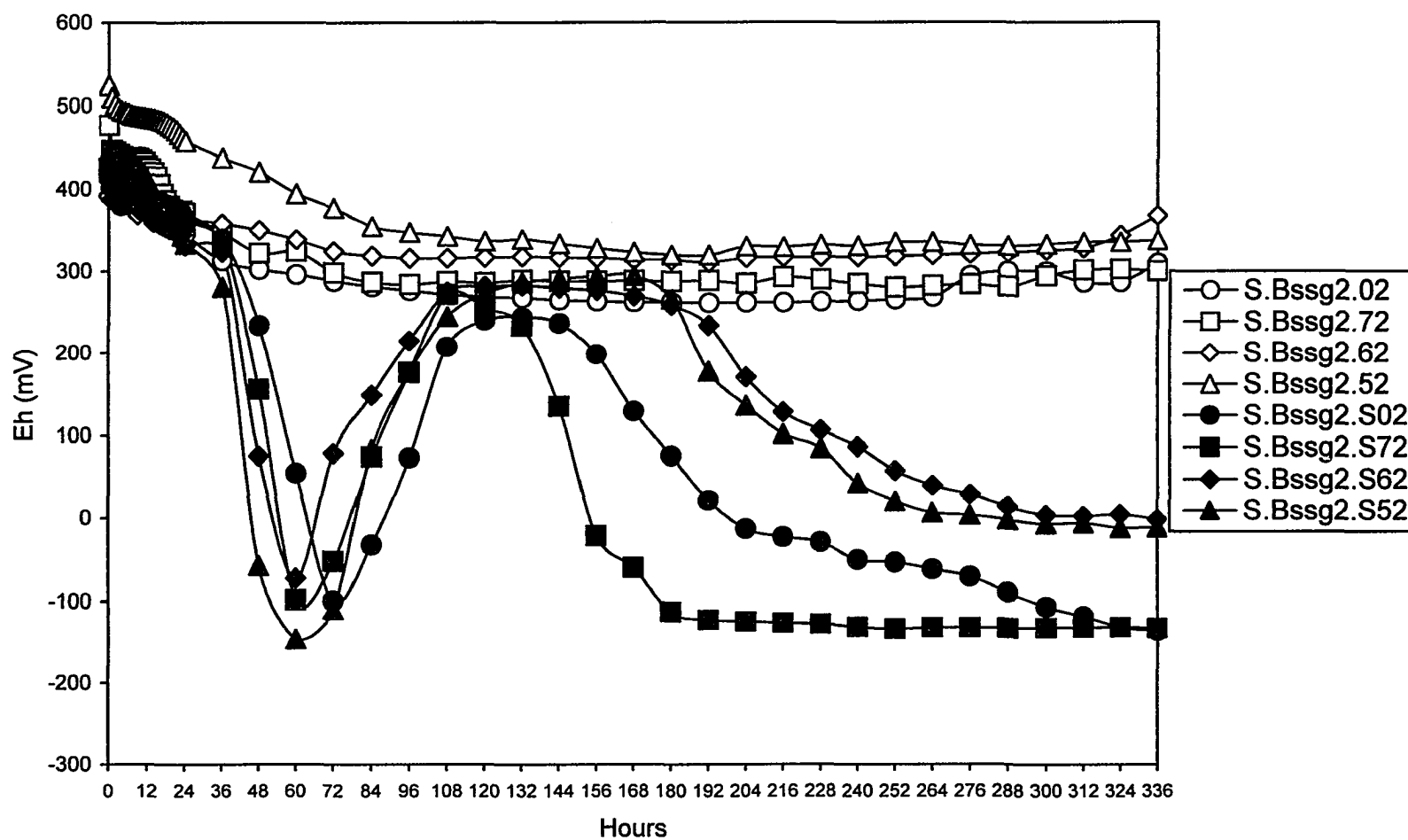


Figure 2.3.16. Mean redox potentials of the Bssg2 horizon for the Sharkey soil during the re-saturation period.

Table 2.3.1. Concentrations of Mn ions for the Moreland and Sharkey soils in soil solution.

Horizons and treatments	Mn ions -----mg/L-----	Horizons and treatments	Mn ions -----mg/L-----
M.Ap.0 ¹	0.03 ± 0.00	S.Ap1.0	0.01 ± 0.00
M.Ap.7	0.02 ± 0.00	S.Ap1.7	0.01 ± 0.01
M.Ap.6	0.02 ± 0.00	S.Ap1.6	0.02 ± 0.00
M.Ap.5	6.87 ± 0.19	S.Ap1.5	0.45 ± 0.01
M.Ap.0S ²	42.7 ± 4.22	S.Ap1.0S	29.0 ± 6.89
M.Ap.7S	58.3 ± 12.2	S.Ap1.7S	24.7 ± 2.74
M.Ap.6S	62.3 ± 7.00	S.Ap1.6S	31.3 ± 1.94
M.Ap.5S	69.0 ± 0.86	S.Ap1.5S	38.0 ± 0.77
M.Bw.0	0.03 ± 0.00	S.Ap2.0	0.03 ± 0.01
M.Bw.7	0.02 ± 0.00	S.Ap2.7	0.02 ± 0.00
M.Bw.6	0.02 ± 0.00	S.Ap2.6	0.06 ± 0.00
M.Bw.5	2.09 ± 0.08	S.Ap2.5	0.47 ± 0.09
M.Bw.0S	42.4 ± 5.82	S.Ap2.0S	21.3 ± 0.50
M.Bw.7S	62.4 ± 0.38	S.Ap2.7S	16.9 ± 0.03
M.Bw.6S	82.3 ± 6.10	S.Ap2.6S	29.8 ± 1.70
M.Bw.5S	99.2 ± 3.29	S.Ap2.5S	37.7 ± 2.09
M.Bkss.0	0.02 ± 0.00	S.Bssg1.0	0.02 ± 0.01
M.Bkss.7	0.02 ± 0.00	S.Bssg1.7	0.01 ± 0.00
M.Bkss.6	0.06 ± 0.01	S.Bssg1.6	0.01 ± 0.00
M.Bkss.5	11.8 ± 0.45	S.Bssg1.5	0.01 ± 0.00
M.Bkss.0S	31.1 ± 0.11	S.Bssg1.0S	8.44 ± 0.22
M.Bkss.7S	49.9 ± 0.90	S.Bssg1.7S	5.43 ± 0.51
M.Bkss.6S	85.1 ± 5.39	S.Bssg1.6S	6.09 ± 0.34
M.Bkss.5S	101 ± 2.91	S.Bssg1.5S	9.25 ± 0.10
M.Bss.0	0.03 ± 0.00	S.Bssg2.0	0.01 ± 0.00
M.Bss.7	0.02 ± 0.00	S.Bssg2.7	0.01 ± 0.00
M.Bss.6	0.03 ± 0.00	S.Bssg2.6	0.01 ± 0.00
M.Bss.5	6.73 ± 0.01	S.Bssg2.5	0.02 ± 0.00
M.Bss.0S	14.7 ± 0.11	S.Bssg2.0S	5.20 ± 0.95
M.Bss.7S	27.3 ± 1.89	S.Bssg2.7S	4.71 ± 0.37
M.Bss.6S	62.5 ± 0.28	S.Bssg2.6S	5.98 ± 0.93
M.Bss.5S	76.8 ± 1.60	S.Bssg2.5S	6.80 ± 0.01

¹: 0: natural pH; 7: pH 7; 6: pH 6; 5: pH 5.

²: S: with the addition of 10 g/kg sucrose.

treatment. The Mn for the M.Bkss.5 treatment was as high as 11.8 mg/L, which corresponded to its morphological property where there were the highest concentrations of soft Mn mass (Table 2.1). The Mn of the pH adjusted to 5 treatment was higher than that of other horizons with no sucrose treatment. The Fe for all horizons without the addition of sucrose was almost negligible even though the soil pH adjusted to 5 (Table 2.3.2). The Fe ranged from 0.1 to 0.2 mg/L for all horizons with no sucrose treatment. The pH treatments had no effect upon the Fe in soil solution.

The concentrations of both Mn and Fe ions increased with sucrose treatment. The Mn increased from 0.03 to 42.7 mg/L and the Fe increased from 0.11 to 17.1 mg/L for the M.Ap.0S treatment. The pH effect increased the Mn and Fe with decreased pH treatment. The Mn increased from 42.7 mg/L for the M.Ap.0S treatment to 69.0 mg/L for the M.Ap.5S treatment. The Fe increased from 17.1 mg/L for the M.Ap.0S treatment to 186 mg/L for the M.Ap.5S treatment. The Bw, Bkss, and Bss horizons had a similar trend to that of the Ap horizon.

Sharkey Soil

The distribution of Mn and Fe ions in the Sharkey soil was similar to that of the Moreland soil (Tables 2.3.1 and 2.3.2). The Mn increased with decreased pH values for the S.Ap1.5 and S.Ap2.5 treatments. It increased from 0.01 mg/L for the S.Ap1.0 treatment to 0.45 mg/L for the S.Ap1.5 treatment. The Mn did not change for the S.Bssg1.5 and S.Bssg2.5 treatments. The pH

Table 2.3.2. Concentrations of Fe ions for the Moreland and Sharkey soils in soil solution.

Horizons and treatments	Fe ions	Horizons and treatments	Fe ions
	-----mg/L-----		-----mg/L-----
M.Ap.0 ¹	0.11 ± 0.01	S.Ap1.0	0.12 ± 0.00
M.Ap.7	0.10 ± 0.00	S.Ap1.7	0.08 ± 0.00
M.Ap.6	0.10 ± 0.00	S.Ap1.6	0.14 ± 0.01
M.Ap.5	0.14 ± 0.02	S.Ap1.5	0.19 ± 0.01
M.Ap.0S ²	17.1 ± 1.41	S.Ap1.0S	56.9 ± 4.20
M.Ap.7S	100 ± 5.49	S.Ap1.7S	51.4 ± 0.04
M.Ap.6S	143 ± 12.3	S.Ap1.6S	114 ± 15.8
M.Ap.5S	186 ± 5.83	S.Ap1.5S	126 ± 3.83
M.Bw.0	0.08 ± 0.01	S.Ap2.0	0.17 ± 0.02
M.Bw.7	0.08 ± 0.00	S.Ap2.7	0.14 ± 0.00
M.Bw.6	0.09 ± 0.00	S.Ap2.6	0.24 ± 0.03
M.Bw.5	0.10 ± 0.01	S.Ap2.5	0.27 ± 0.01
M.Bw.0S	33.8 ± 3.30	S.Ap2.0S	115 ± 6.31
M.Bw.7S	118 ± 0.79	S.Ap2.7S	70.7 ± 0.20
M.Bw.6S	235 ± 10.3	S.Ap2.6S	137 ± 14.5
M.Bw.5S	299 ± 4.06	S.Ap2.5S	247 ± 11.0
M.Bkss.0	0.16 ± 0.00	S.Bssg1.0	0.16 ± 0.01
M.Bkss.7	0.17 ± 0.00	S.Bssg1.7	0.13 ± 0.02
M.Bkss.6	0.17 ± 0.00	S.Bssg1.6	0.15 ± 0.01
M.Bkss.5	0.19 ± 0.00	S.Bssg1.5	0.21 ± 0.05
M.Bkss.0S	29.0 ± 1.65	S.Bssg1.0S	100 ± 2.01
M.Bkss.7S	115 ± 5.35	S.Bssg1.7S	61.4 ± 0.89
M.Bkss.6S	227 ± 1.11	S.Bssg1.6S	112 ± 5.86
M.Bkss.5S	259 ± 17.5	S.Bssg1.5S	172 ± 17.7
M.Bss.0	0.15 ± 0.00	S.Bssg2.0	0.13 ± 0.01
M.Bss.7	0.16 ± 0.05	S.Bssg2.7	0.08 ± 0.00
M.Bss.6	0.16 ± 0.00	S.Bssg2.6	0.14 ± 0.02
M.Bss.5	0.17 ± 0.00	S.Bssg2.5	0.18 ± 0.01
M.Bss.0S	49.5 ± 4.04	S.Bssg2.0S	64.5 ± 2.46
M.Bss.7S	135 ± 24.5	S.Bssg2.7S	50.7 ± 1.11
M.Bss.6S	285 ± 4.65	S.Bssg2.6S	49.2 ± 14.2
M.Bss.5S	349 ± 21.6	S.Bssg2.5S	121 ± 18.0

¹: 0: natural pH; 7: pH 7; 6: pH 6; 5: pH 5.

²: S: with the addition of 10 g/kg sucrose.

treatment had no effect upon the Fe for the soils with no sucrose treatment. It ranged from 0.08 to 0.27 mg/L for all the horizons with no sucrose treatment.

The Mn for the Ap1 and Ap2 horizons treated with sucrose was higher than that of the Bssg1 and Bssg2 horizons. The Mn increased from 0.01 mg/L for the S.Ap1.0 treatment to 29.0 mg/L for the S.Ap1.0S treatment. The Mn only increased from 0.02 for the S.Bssg1.0 treatment to 8.44 mg/L for the S.Bssg1.0S treatment. The Mn increased with decreased pH treatment. The Mn for the pH adjusted to 5 soils treated with sucrose was higher than that of other pH treatments. There was no difference for the natural, pH 6, and pH 7 treatments. The Mn was 29.0 mg/L for the S.Ap1.0S treatment and 38.0 mg/L for the S.Ap1.5S treatment. The distribution of Fe ions in soil solutions showed a similar trend to that of Mn ions. The Fe increased with decreased pH treatment. The Ap2 horizon with sucrose treatment had a higher concentration of Fe ions than did the other horizons with the same pH treatment.

2.3.4. Selective Chemical Dissolution Analysis

Moreland Soil

The concentrations of Fe extracted by the three chemical dissolution methods for the Moreland soil are presented in Table 2.4.1. The Fe extracted by DCB approximated the combined contents of amorphous forms of Fe and crystalline Fe. The sodium pyrophosphate extractable Fe (Fe_p) represented Fe-humus complex forms. Fe extracted by oxalate (Fe_o) represented organic and inorganic Fe forms. The difference between oxalate-extractable Fe (Fe_o) and

Table 2.4.1. Amounts of Fe and Mn extracted by three chemical dissolution methods for the Moreland soil.

Horizons and treatments	Fe _d ⁴	Mn _d	Fe _p ⁵	Fe _o ⁶	Fe _{o-p}	Fe _{d-o}
	-----mg/kg-----					
M.Ap.0 ¹ (1) ²	12721 ± 157	686 ± 3	248 ± 15	4774 ± 62	4526 ± 45	7947 ± 120
M.Ap.0(2)			429 ± 14	4768 ± 28	4339 ± 16	7953 ± 113
M.Ap.0(3)			412 ± 4	4929 ± 24	4517 ± 12	7792 ± 121
M.Ap.0(4)			445 ± 3	4882 ± 26	4437 ± 13	7839 ± 113
M.Ap.0S ³ (2)			1794 ± 35	5594 ± 68	3800 ± 38	7127 ± 129
M.Ap.0S(3)			891 ± 12	6589 ± 91	5698 ± 46	6131 ± 113
M.Ap.0S(4)			887 ± 10	6662 ± 60	5775 ± 30	6059 ± 119
M.Ap.7(1)			358 ± 15	4602 ± 7	4244 ± 11	8119 ± 111
M.Ap.7(2)			411 ± 8	4606 ± 172	4195 ± 86	8114 ± 165
M.Ap.7(3)			363 ± 9	4247 ± 25	3884 ± 13	8473 ± 112
M.Ap.7(4)			393 ± 12	3991 ± 153	3598 ± 77	8730 ± 113
M.Ap.7S(2)			1798 ± 30	5671 ± 21	3873 ± 18	7050 ± 115
M.Ap.7S(3)			851 ± 23	6660 ± 39	5809 ± 23	6061 ± 155
M.Ap.7S(4)			680 ± 8	6512 ± 70	5832 ± 35	6209 ± 122
M.Ap.6(1)			390 ± 14	4596 ± 4	4206 ± 10	8125 ± 111
M.Ap.6(2)			403 ± 14	4579 ± 19	4176 ± 12	8142 ± 112
M.Ap.6(3)			488 ± 4	4568 ± 45	4080 ± 23	8153 ± 117
M.Ap.6(4)			458 ± 2	4063 ± 87	3605 ± 44	8658 ± 116
M.Ap.6S(2)			2168 ± 33	6142 ± 50	3974 ± 30	6579 ± 123
M.Ap.6S(3)			1656 ± 11	6575 ± 74	4919 ± 37	6146 ± 127
M.Ap.6S(4)			1469 ± 10	6675 ± 37	5206 ± 19	6046 ± 114
M.Ap.5(1)			500 ± 19	4539 ± 15	4039 ± 18	8181 ± 112
M.Ap.5(2)			509 ± 21	4541 ± 25	4032 ± 16	8180 ± 113
M.Ap.5(3)			581 ± 2	4611 ± 35	4030 ± 18	8110 ± 120
M.Ap.5(4)			474 ± 5	4156 ± 139	3682 ± 70	8546 ± 114
M.Ap.5S(2)			2440 ± 47	6172 ± 62	3732 ± 39	6549 ± 144
M.Ap.5S(3)			1463 ± 17	6982 ± 129	5519 ± 65	5739 ± 148
M.Ap.5S(4)			998 ± 15	6751 ± 41	5753 ± 22	5970 ± 115

(Table 2.4.1 continued)

Horizons and treatments	Fe _d	Mn _d	Fe _p	Fe _o	Fe _{o-p}	Fe _{d-o}
	-----mg/kg-----					
M.Bw.0(1)	12612 ± 91	673 ± 15	113 ± 1	4407 ± 40	4294 ± 28	8205 ± 70
M.Bw.0(2)			245 ± 6	4560 ± 22	4315 ± 11	8052 ± 66
M.Bw.0(3)			279 ± 7	4536 ± 36	4257 ± 18	8076 ± 69
M.Bw.0(4)			257 ± 1	4564 ± 22	4307 ± 11	8048 ± 66
M.Bw.0S(2)			1801 ± 56	5497 ± 180	3696 ± 94	7116 ± 142
M.Bw.0S(3)			825 ± 13	7069 ± 162	6244 ± 81	5543 ± 131
M.Bw.0S(4)			820 ± 4	7382 ± 16	6562 ± 8	5230 ± 65
M.Bw.7(1)			215 ± 15	4458 ± 8	4243 ± 12	8154 ± 64
M.Bw.7(2)			240 ± 8	4544 ± 40	4304 ± 20	8068 ± 70
M.Bw.7(3)			208 ± 3	4053 ± 21	3845 ± 11	8559 ± 66
M.Bw.7(4)			245 ± 7	3910 ± 20	3665 ± 11	8702 ± 66
M.Bw.7S(2)			1768 ± 71	5712 ± 98	3944 ± 60	6900 ± 94
M.Bw.7S(3)			880 ± 15	6326 ± 61	5446 ± 31	6286 ± 77
M.Bw.7S(4)			688 ± 4	6344 ± 7	5656 ± 4	6268 ± 64
M.Bw.6(1)			258 ± 1	4111 ± 42	3853 ± 30	8501 ± 71
M.Bw.6(2)			236 ± 5	4199 ± 31	3964 ± 16	8413 ± 68
M.Bw.6(3)			294 ± 7	4290 ± 21	3996 ± 11	8322 ± 66
M.Bw.6(4)			305 ± 1	4052 ± 12	3747 ± 6	8560 ± 65
M.Bw.6S(2)			1912 ± 53	5193 ± 72	3281 ± 45	7420 ± 82
M.Bw.6S(3)			1294 ± 13	5648 ± 55	4354 ± 28	6964 ± 75
M.Bw.6S(4)			955 ± 3	5634 ± 76	4679 ± 38	6978 ± 84
M.Bw.5(1)			277 ± 3	4147 ± 35	3870 ± 25	8466 ± 69
M.Bw.5(2)			305 ± 5	4118 ± 33	3813 ± 17	8494 ± 68
M.Bw.5(3)			337 ± 3	4229 ± 25	3892 ± 12	8383 ± 67
M.Bw.5(4)			317 ± 3	3932 ± 15	3615 ± 8	8680 ± 65
M.Bw.5S(2)			2298 ± 23	5566 ± 70	3268 ± 37	7046 ± 81
M.Bw.5S(3)			1338 ± 66	6303 ± 226	4965 ± 117	6309 ± 172
M.Bw.5S(4)			1003 ± 25	5864 ± 130	4861 ± 66	6748 ± 112

(Table 2.4.1 continued)

Horizons and treatments	Fe _d	Mn _d	Fe _p	Fe _o	Fe _{o-p}	Fe _{d-o}
	-----mg/kg-----					
M.Bkss.0(1)	12303±28	543± 5	107 ± 5	3900 ± 86	3793 ± 61	8403 ± 64
M.Bkss.0(2)			204 ± 2	3875 ± 17	3671 ± 9	8427 ± 23
M.Bkss.0(3)			155 ± 8	3915 ± 18	3760 ± 10	8387 ± 24
M.Bkss.0(4)			156 ± 5	3832 ± 45	3676 ± 23	8471 ± 38
M.Bkss.0S(2)			1805 ±124	5171 ±128	3366 ± 89	7131 ± 93
M.Bkss.0S(3)			792 ± 24	5866 ± 84	5074 ± 43	6437 ± 62
M.Bkss.0S(4)			749 ± 9	6101 ±109	5352 ± 55	6202 ± 80
M.Bkss.7(1)			163 ± 4	3587 ± 36	3424 ± 26	8716 ± 32
M.Bkss.7(2)			210 ± 3	3774 ± 37	3564 ± 18	8528 ± 33
M.Bkss.7(3)			143 ± 3	3341 ± 23	3198 ± 11	8971 ± 26
M.Bkss.7(4)			157 ± 3	3196 ± 50	3039 ± 25	9106 ± 41
M.Bkss.7S(2)			1963 ± 30	5225 ±142	3262 ± 73	7078 ±102
M.Bkss.7S(3)			674 ± 9	5869 ±122	5195 ± 61	6434 ± 88
M.Bkss.7S(4)			625 ± 35	5711 ±151	5086 ± 77	6592 ±108
M.Bkss.6(1)			226 ± 4	3990 ± 58	3764 ± 41	8313 ± 45
M.Bkss.6(2)			239 ± 2	4014 ± 29	3775 ± 15	8289 ± 29
M.Bkss.6(3)			255 ± 7	4024 ± 49	3769 ± 25	8279 ± 40
M.Bkss.6(4)			216 ± 5	3951 ± 17	3735 ± 9	8352 ± 23
M.Bkss.6S(2)			1512 ±117	4565 ± 59	3053 ± 65	7738 ± 46
M.Bkss.6S(3)			1015 ± 22	4949 ± 16	3934 ± 14	7354 ± 23
M.Bkss.6S(4)			879 ± 8	4890 ± 62	4011 ± 31	7413 ± 48
M.Bkss.5(1)			235 ± 3	3727 ± 69	3492 ± 49	8576 ± 53
M.Bkss.5(2)			282 ± 11	3866 ± 20	3584 ± 11	8436 ± 24
M.Bkss.5(3)			327 ± 6	3950 ± 32	3623 ± 16	8352 ± 30
M.Bkss.5(4)			288 ± 11	3566 ± 46	3278 ± 24	8737 ± 38
M.Bkss.5S(2)			798 ± 7	4294 ± 14	3496 ± 8	8008 ± 22
M.Bkss.5S(3)			870 ± 44	4559 ± 37	3689 ± 29	7743 ± 33
M.Bkss.5S(4)			706 ± 9	4550 ± 33	3844 ± 17	7753 ± 31

(Table 2.4.1 continued)

Horizons and treatments	Fe _d	Mn _d	Fe _p	Fe _o	Fe _{o-p}	Fe _{d-o}
	-----mg/kg-----					
M.Bss.0(1)	11909 ± 174	603±6	244 ± 34	6042 ± 82	5798 ± 63	5867 ±136
M.Bss.0(2)			371 ± 11	6033 ± 64	5662 ± 32	5876 ±131
M.Bss.0(3)			430 ± 34	6161 ± 40	5731 ± 26	5748 ±126
M.Bss.0(4)			417 ± 15	5971 ± 10	5554 ± 9	5938 ±123
M.Bss.0S(2)			1946 ± 39	6405 ±131	4459 ± 68	5504 ±204
M.Bss.0S(3)			827 ± 13	6550 ±101	5723 ± 51	5359 ±142
M.Bss.0S(4)			831 ± 9	6705 ±131	5874 ± 65	5204 ±154
M.Bss.7(1)			275 ± 18	4979 ± 75	4704 ± 55	6930 ±134
M.Bss.7(2)			368 ± 12	5143 ± 44	4775 ± 23	6766 ±127
M.Bss.7(3)			343 ± 9	5010 ± 68	4667 ± 34	6899 ±132
M.Bss.7(4)			354 ± 5	4783 ± 39	4429 ± 20	7126 ±126
M.Bss.7S(2)			2030 ± 28	5554 ±167	3524 ± 86	6355 ±225
M.Bss.7S(3)			1121 ± 46	5745 ± 82	4624 ± 47	6164 ±136
M.Bss.7S(4)			1044 ± 32	5701 ± 56	4657 ± 32	6208 ±129
M.Bss.6(1)			355 ± 31	4726 ± 64	4371 ± 51	7183 ±131
M.Bss.6(2)			371 ± 11	4929 ± 44	4558 ± 23	6980 ±127
M.Bss.6(3)			413 ± 32	4762 ± 18	4349 ± 19	7147 ±123
M.Bss.6(4)			472 ± 14	4451 ± 30	3979 ± 16	7458 ±125
M.Bss.6S(2)			2074 ± 36	5652 ± 68	3578 ± 38	6257 ±132
M.Bss.6S(3)			1352 ± 12	5869 ± 62	4517 ± 32	6040 ±130
M.Bss.6S(4)			1303 ± 8	5819 ± 36	4516 ± 19	6090 ±125
M.Bss.5(1)			354 ± 8	5593 ± 6	5239 ± 7	6316 ±123
M.Bss.5(2)			431 ± 22	5641 ± 55	5210 ± 30	6268 ±129
M.Bss.5(3)			494 ± 9	5841 ± 59	5347 ± 26	6068 ±130
M.Bss.5(4)			523 ± 3	5390 ±134	4867 ± 67	6519 ±155
M.Bss.5S(2)			2191 ± 49	6272 ±142	4081 ± 85	5637 ±336
M.Bss.5S(3)			1475 ± 49	6272 ±134	4797 ± 26	5637 ±123
M.Bss.5S(4)			1230 ± 26	6275 ± 42	5045 ± 25	5634 ±126

¹: 0: natural pH; 7: pH 7; 6: pH 6; 5: pH 5.

²: (1): before incubation; (2): after incubation and freeze-dry; (3): first drying; (4): second drying.

³: S: with the addition of 10 g/kg sucrose.

⁴: Fe_d: Fe extracted by DCB.

⁵: Fe_p: Fe extracted by sodium pyrophosphate.

⁶: Fe_o: Fe extracted by acid-oxalate.

pyrophosphate soluble Fe (Fe_p) approximated the inorganic Fe (Fe_{o-p}). The difference between Fe_d and Fe_o estimated the crystalline Fe (Fe_{d-o}).

The DCB-extractable Fe (Fe_d) before incubation represented the total free Fe. It was assumed that no Fe was loss during the experimental procedures. From the results, there was not much difference in Fe_d concentration among the different horizons. The total free Fe concentration ranged from 11,900 to 12,700 mg/kg. The Mn_d concentration ranged between 540 and 690 mg/kg for the four horizons.

The data shows that the M.Ap.0 treatment having the highest concentrations of pyrophosphate-extractable Fe (Fe_p) was consistent with its high organic carbon contents (Table 2.1). The Fe_p for all horizons increased with the decreasing pH treatment. The Fe_p increased from 248 for the M.Ap.0(1) treatment to 363 mg/kg for the M.Ap.7(1) treatment and to 500 mg/kg for the M.Ap.5(1) treatment. Except for the natural pH treatment, the Fe_p did not change for the soils with no sucrose treatment during 21 days of incubation. The Fe_p increased from 248 for the M.Ap.0(1) treatment to 429 mg/kg for the M.Ap.0(2) treatment. It did not change after the first and second drying treatments. The Fe_p was 412 mg/kg for the M.Ap.0(3) treatment and 445 mg/kg for the M.Ap.0(4) treatment. Other horizons with different pH treatments showed a similar trend.

The Fe_p increased for all soils treated with sucrose after they were incubated for three weeks and freeze-dried. The Fe_p decreased after the first drying treatment. The Fe_p increased from 248 mg/kg for the M.Ap.0(1)

treatment to 1,794 mg/kg for the M.Ap.0S(2) treatment and then decreased to 891 mg/kg for the M.Ap.0S(3) treatment. After the second drying treatment, the decrease Fe_p was lower than after the first drying treatment. It decreased from 891 mg/kg for the M.Ap.0S(3) treatment to 887 mg/kg for the M.Ap.0S(4) treatment. The decreased pH treatment seemed to increase the Fe_p after the soils were freeze-dried. The Fe_p was 2,440 mg/kg for the M.Ap.5S(2) treatment as compared to 1,794 mg/kg for the M.Ap.0S(2) treatment. However, it did not follow the trend of the M.Bkss.6S(2) and M.Bkss.5S(2) treatments. The Fe_p was 1,963 mg/kg for the M.Bkss.7S(2) treatment and 798 mg/kg for the M.Bkss.5S(2) treatment.

The oxalate-extractable Fe (Fe_o) concentrations of the soils without the addition of sucrose did not change after alternating saturation and drying treatments (Table 2.4.1). An increase in the Fe_o for soils treated with sucrose was observed for the freeze-dry treatment. It showed a tendency similar to that of the increasing Fe_p . However, the absolute increase Fe_o was lower than that of the increase Fe_p . The Fe_o for the M.Ap.0S(2) treatment increased 820 mg/kg but the Fe_p increased 1,546 mg/kg. This phenomenon was more apparent for the Bss horizon, which had the highest Fe_o . The Fe_o did not change after the second drying treatment as compared to the first drying treatment. The Fe_o changed from 6,589 mg/kg for the M.Ap.0S(3) treatment to 6,662 mg/kg for the M.Ap.0S(4) treatment.

The concentrations of inorganic amorphous Fe oxides were based upon the difference between Fe extracted by oxalate and by pyrophosphate ($Fe_o - Fe_p$).

This value indicates the concentration of inorganic amorphous Fe. From the results in Table 2.4.1, the Fe_{o-p} did not change for the soils with no sucrose treatment during different sampling periods. It decreased for the soils treated with sucrose after the 21-day incubation and freeze-dry treatments. The Fe_{o-p} increased for the first drying treatment. The Fe_{o-p} did not change after the second drying treatment. The Fe_{o-p} decreased from 4,526 mg/kg for the M.Ap.0(1) treatment to 3,800 mg/kg for the M.Ap.0S(2) treatment after the freeze-dry treatment. It increased to 5,698 mg/kg for the M.Ap.0S(3) treatment after the first drying treatment. The Fe_{o-p} was 5,775 mg/kg for the M.Ap.0S(4) treatment after the second drying treatment.

The concentrations of crystalline Fe forms were represented by Fe_{d-o} . The Fe_{d-o} did not change for the soils with no sucrose treatment during different treatments. The Fe_{d-o} decreased for all soils treated with sucrose after they were incubated for three weeks and freeze-dried. A decrease Fe_{d-o} was observed after the first drying treatment. The Fe_{d-o} increased from 7,947 mg/kg for the M.Ap.0(1) treatment to 7,127 mg/kg for the M.Ap.0S(2) treatment and then decreased to 6,131 mg/kg for the M.Ap.0S(3) treatment. After the second drying treatment, the Fe_{d-o} did not change.

Sharkey Soil

The concentrations of Mn_d and Fe_d for the Sharkey soil before submergence are presented in Table 2.4.2. The Fe_d for four different horizons ranged approximately from 8,100 to 8,700 mg/kg. The Mn_d concentration ranged

Table 2.4.2. Amounts of Fe and Mn extracted by three chemical dissolution methods for the Sharkey soil.

Horizons and treatments	Fe _d ⁴	Mn _d	Fe _p ⁵	Fe _o ⁶	Fe _{o-p}	Fe _{d-o}
	-----mg/kg-----					
S.Ap1.0 ¹ (1) ²	8378 ±22	432 ± 6	1167 ± 2	8047 ±212	6880± 150	331±151
S.Ap1.0(2)			1176 ± 16	8159 ± 41	6983± 31	219± 33
S.Ap1.0(3)			1124 ± 26	8058 ± 35	6934± 31	320± 29
S.Ap1.0(4)			1121 ± 24	7837 ± 52	6716± 40	541± 40
S.Ap1.0S ³ (2)			2710 ± 14	8083 ±243	5373± 172	294±173
S.Ap1.0S(3)			2180 ± 73	7964 ±154	5784± 121	413±110
S.Ap1.0S(4)			2084 ± 55	7800 ± 60	5716± 57	578± 45
S.Ap1.7(1)			1175 ± 25	7955 ±137	6780± 98	423± 98
S.Ap1.7(2)			1200 ± 14	8022 ± 27	6823± 22	355± 25
S.Ap1.7(3)			1159 ± 24	7742 ±107	6583± 78	636± 77
S.Ap1.7(4)			1150 ± 10	7786 ± 76	6635± 54	592± 56
S.Ap1.7S(2)			2740 ± 14	7757 ± 68	5018± 49	620± 50
S.Ap1.7S(3)			2254 ± 53	7653 ±213	5399± 155	724±152
S.Ap1.7S(4)			1927 ± 94	7783 ±253	5855± 191	595±179
S.Ap1.6(1)			1288 ± 30	8333 ± 85	7045± 64	44± 62
S.Ap1.6(2)			1378 ±109	8257 ± 76	6879± 94	120± 56
S.Ap1.6(3)			1382 ± 17	7852 ±124	6469± 88	526± 89
S.Ap1.6(4)			1244 ± 29	7854 ± 28	6610± 29	524± 25
S.Ap1.6S(2)			3103 ± 89	8583 ± 53	5480± 73	-205± 41
S.Ap1.6S(3)			2419 ± 59	7400 ±171	4981± 128	978±122
S.Ap1.6S(4)			1711 ± 11	7461 ±342	5749± 242	917±243
S.Ap1.5(1)			1503 ± 25	8334 ± 31	6831± 28	44± 27
S.Ap1.5(2)			1463 ± 14	8296 ± 27	6833± 21	82± 25
S.Ap1.5(3)			1250 ± 9	7791 ± 52	6541± 37	586± 40
S.Ap1.5(4)			1293 ± 29	7425 ±102	6132± 75	953± 74
S.Ap1.5S(2)			2892 ± 79	8207 ± 82	5315± 81	171± 60
S.Ap1.5S(3)			2178 ± 69	7653 ±137	5475± 109	724± 98
S.Ap1.5S(4)			1794 ± 7	7448 ± 70	5699± 50	930± 52

(Table 2.4.2 continued)

Horizons and treatments	Fe _d	Mn _d	Fe _p	Fe _o	Fe _{o-p}	Fe _{d-o}
	-----mg/kg-----					
S.Ap2.0(1)	8618 ± 46	547 ± 14	1231 ± 10	8174 ± 99	6943 ± 70	444 ± 77
S.Ap2.0(2)			1242 ± 11	8345 ± 121	7103 ± 86	273 ± 92
S.Ap2.0(3)			1176 ± 8	8274 ± 56	7098 ± 40	344 ± 51
S.Ap2.0(4)			1121 ± 24	8132 ± 78	7011 ± 57	485 ± 64
S.Ap2.0S(2)			2439 ± 6	8143 ± 317	5704 ± 224	475 ± 226
S.Ap2.0S(3)			1947 ± 12	8137 ± 222	6190 ± 157	481 ± 160
S.Ap2.0S(4)			1854 ± 6	7967 ± 212	6112 ± 150	651 ± 153
S.Ap2.7(1)			1057 ± 6	8047 ± 133	6991 ± 94	570 ± 100
S.Ap2.7(2)			1092 ± 17	8038 ± 152	6946 ± 108	580 ± 112
S.Ap2.7(3)			1083 ± 14	7869 ± 81	6786 ± 58	749 ± 65
S.Ap2.7(4)			1046 ± 12	7985 ± 75	6939 ± 54	633 ± 62
S.Ap2.7S(2)			2596 ± 22	7788 ± 146	5192 ± 105	830 ± 108
S.Ap2.7S(3)			1931 ± 23	8097 ± 99	6166 ± 72	520 ± 77
S.Ap2.7S(4)			1756 ± 25	8021 ± 39	6265 ± 33	597 ± 42
S.Ap2.6(1)			1458 ± 41	8159 ± 64	6701 ± 54	459 ± 56
S.Ap2.6(2)			1609 ± 13	8310 ± 34	6701 ± 26	308 ± 40
S.Ap2.6(3)			1596 ± 11	7963 ± 56	6367 ± 41	655 ± 51
S.Ap2.6(4)			1469 ± 31	8103 ± 26	6634 ± 29	515 ± 37
S.Ap2.6S(2)			3699 ± 103	8340 ± 105	4641 ± 104	278 ± 81
S.Ap2.6S(3)			2672 ± 24	7945 ± 271	5272 ± 193	673 ± 194
S.Ap2.6S(4)			2089 ± 47	8078 ± 244	5989 ± 176	540 ± 176
S.Ap2.5(1)			1675 ± 37	8569 ± 1	6894 ± 26	49 ± 32
S.Ap2.5(2)			1749 ± 25	8268 ± 67	6518 ± 51	350 ± 57
S.Ap2.5(3)			1395 ± 11	7959 ± 115	6564 ± 82	658 ± 88
S.Ap2.5(4)			1430 ± 18	7734 ± 81	6305 ± 59	884 ± 66
S.Ap2.5S(2)			3437 ± 24	8288 ± 133	4852 ± 95	329 ± 99
S.Ap2.5S(3)			2705 ± 133	7961 ± 112	5256 ± 123	657 ± 86
S.Ap2.5S(4)			1822 ± 99	7671 ± 57	5849 ± 81	947 ± 52

(Table 2.4.2 continued)

Horizons and treatments	Fe _d	Mn _d	Fe _p	Fe _o	Fe _{o-p}	Fe _{d-o}
	-----mg/kg-----					
S.Bssg1.0(1)	8691 ± 44	350±16	981 ± 3	8190 ±104	7209 ± 73	501 ± 80
S.Bssg1.0(2)			1008 ± 10	8274 ± 53	7266 ± 38	416 ± 49
S.Bssg1.0(3)			985 ± 9	8061 ±135	7077 ± 96	629 ±101
S.Bssg1.0(4)			958 ± 23	8031 ± 69	7073 ± 51	660 ± 58
S.Bssg1.0S(2)			1960 ± 23	8172 ±117	6212 ± 84	519 ± 88
S.Bssg1.0S(3)			1695 ± 22	7972 ± 34	6277 ± 29	719 ± 39
S.Bssg1.0S(4)			1515 ± 14	8091 ± 55	6576 ± 40	600 ± 50
S.Bssg1.7(1)			951 ± 27	8130 ± 35	7178 ± 31	561 ± 40
S.Bssg1.7(2)			1023 ± 35	8015 ± 69	6992 ± 55	676 ± 58
S.Bssg1.7(3)			1011 ± 9	8018 ± 17	7006 ± 14	673 ± 34
S.Bssg1.7(4)			989 ± 18	8051 ± 39	7061 ± 30	640 ± 41
S.Bssg1.7S(2)			1926 ± 26	8141 ±364	6216 ±258	549 ±259
S.Bssg1.7S(3)			1542 ± 8	7946 ±110	6405 ± 78	744 ± 84
S.Bssg1.7S(4)			1126 ± 14	8026 ± 51	6899 ± 38	665 ± 48
S.Bssg1.6(1)			1347 ± 31	8570 ± 16	7223 ± 25	121 ± 33
S.Bssg1.6(2)			1337 ± 20	8598 ± 53	7261 ± 40	93 ± 49
S.Bssg1.6(3)			1293 ± 42	8302 ± 75	7009 ± 60	389 ± 61
S.Bssg1.6(4)			1262 ± 48	8465 ± 53	7203 ± 51	226 ± 49
S.Bssg1.6S(2)			2391 ± 25	8499 ± 40	6108 ± 33	191 ± 42
S.Bssg1.6S(3)			2200 ± 38	8471 ± 68	6271 ± 55	220 ± 57
S.Bssg1.6S(4)			1671 ± 17	8484 ±117	6813 ± 84	207 ± 89
S.Bssg1.5(1)			1469 ± 8	8374 ± 85	6905 ± 60	317 ± 68
S.Bssg1.5(2)			1546 ± 21	8278 ± 71	6732 ± 53	412 ± 59
S.Bssg1.5(3)			1253 ± 11	8224 ±103	6970 ± 73	467 ± 79
S.Bssg1.5(4)			1291 ± 20	8150 ±129	6814 ± 93	586 ± 97
S.Bssg1.5S(2)			2836 ±157	8097 ±118	5261 ±139	594 ± 89
S.Bssg1.5S(3)			2469 ± 82	8154 ± 88	5686 ± 85	536 ± 70
S.Bssg1.5S(4)			2001 ± 28	7864 ±148	5863 ±107	827 ±109

(Table 2.4.2 continued)

Horizons and treatments	Fe _d	Mn _d	Fe _p	Fe _o	Fe _{o-p}	Fe _{d-o}
	-----mg/kg-----					
S.Bssg2.0(1)	8081 ± 4	328 ± 7	858 ± 10	7232 ± 151	6374 ± 107	848 ± 107
S.Bssg2.0(2)			886 ± 5	7322 ± 56	6436 ± 40	759 ± 40
S.Bssg2.0(3)			848 ± 8	6945 ± 60	6097 ± 43	1136 ± 43
S.Bssg2.0(4)			808 ± 9	7057 ± 48	6249 ± 34	1024 ± 34
S.Bssg2.0S(2)			1897 ± 19	7415 ± 276	5518 ± 195	666 ± 195
S.Bssg2.0S(3)			1294 ± 15	7145 ± 60	5851 ± 44	936 ± 43
S.Bssg2.0S(4)			1254 ± 10	7237 ± 119	5983 ± 84	844 ± 84
S.Bssg2.7(1)			848 ± 11	6818 ± 95	5969 ± 68	263 ± 68
S.Bssg2.7(2)			858 ± 9	6744 ± 38	5886 ± 27	1337 ± 27
S.Bssg2.7(3)			833 ± 11	6788 ± 78	5955 ± 55	1293 ± 55
S.Bssg2.7(4)			867 ± 2	6853 ± 46	5987 ± 33	1227 ± 33
S.Bssg2.7S(2)			1907 ± 43	6878 ± 99	4970 ± 76	1203 ± 70
S.Bssg2.7S(3)			1346 ± 26	6914 ± 116	5568 ± 84	1167 ± 82
S.Bssg2.7S(4)			1316 ± 12	6770 ± 78	5454 ± 56	1310 ± 56
S.Bssg2.6(1)			1046 ± 24	6547 ± 127	5500 ± 92	1534 ± 90
S.Bssg2.6(2)			1051 ± 7	6633 ± 110	5583 ± 78	1447 ± 78
S.Bssg2.6(3)			1026 ± 56	6621 ± 258	5595 ± 187	1460 ± 183
S.Bssg2.6(4)			1028 ± 24	7037 ± 137	6009 ± 98	1044 ± 97
S.Bssg2.6S(2)			2099 ± 50	6527 ± 54	4428 ± 52	1553 ± 39
S.Bssg2.6S(3)			1708 ± 20	6525 ± 48	4817 ± 36	1555 ± 34
S.Bssg2.6S(4)			1414 ± 42	6781 ± 74	5368 ± 60	1299 ± 53
S.Bssg2.5(1)			1287 ± 93	7120 ± 211	5833 ± 163	961 ± 149
S.Bssg2.5(2)			1303 ± 28	7118 ± 80	5815 ± 60	963 ± 56
S.Bssg2.5(3)			1072 ± 31	6950 ± 51	5878 ± 42	1130 ± 36
S.Bssg2.5(4)			1103 ± 15	6509 ± 111	5407 ± 79	1571 ± 78
S.Bssg2.5S(2)			2048 ± 28	6807 ± 155	4759 ± 111	1274 ± 109
S.Bssg2.5S(3)			1831 ± 38	6661 ± 159	4830 ± 116	1420 ± 112
S.Bssg2.5S(4)			1752 ± 8	6621 ± 85	4869 ± 61	1459 ± 60

¹: 0: natural pH; 7: pH 7; 6: pH 6; 5: pH 5.

²: (1): before incubation; (2): after incubation and freeze-dry; (3): first drying; (4): second drying.

³: S: with the addition of 10 g/kg sucrose.

⁴: Fe_d: Fe extracted by DCB.

⁵: Fe_p: Fe extracted by sodium pyrophosphate.

⁶: Fe_o: Fe extracted by acid-oxalate.

between 330 and 550 mg/kg. The Mn_d for the Bssg1 and Bssg2 horizons was approximately 100 mg/kg lower than that of the Ap1 and Ap2 horizons.

The Fe_p for the soils with no sucrose treatment did not appreciably change after the freeze-dry, first drying, nor second drying treatments. The Fe_p for the S.Ap1.0(1) treatment was 1,167 mg/kg. It did not change for the S.Ap1.0(2) treatment. The Fe_p was 1,124 mg/kg for the S.Ap1.0(3) treatment and 1,121 mg/kg for the S.Ap1.0(4) treatment. The Fe_p for the Ap2, Bssg1, and Bssg2 horizons with the same pH treatment showed similar trends to that of the Ap1 horizon. It did not change during different sampling periods. The S.Ap2.0(2) treatment had the highest amounts of Fe_p but was not different from that of the S.Ap1.0(2) treatment. The Fe_p decreased with the increasing depth. It was 858 mg/kg for the S.Bssg2.0(2) treatment.

The Fe_p increased with the addition of sucrose from 1,167 mg/kg for the S.Ap1.0(1) treatment to 2,710 mg/kg for the S.Ap1.0S(2) treatment. The increase in Fe_p after the freeze-dry treatment confirmed that the freeze-dry treatment prevented the activity of microbes. The Fe_p decreased after the first drying treatment from 2,710 mg/kg for the S.Ap1.0S(2) treatment to 2,180 mg/kg for the S.Ap1.0S(3) treatment. The Fe_p was 2,084 mg/kg for the S.Ap1.0S(4) treatment, indicating no appreciable difference between the first and second drying treatments. The Fe_p for other horizons with different pH treatments was similar to that of the Ap1 horizon.

The Fe_o for all Sharkey horizons was very close to that of the Fe_d (Table 2.4.2), indicating that amorphous Fe was the predominant Fe form. The Fe_d

was 8,378 mg/kg and the Fe_o was 8,047 mg/kg for the S.Ap1.0(1) treatment. This means that 90% of the total Fe was amorphous. The distribution of Fe_o for the soils with different pH treatments sampled during different periods did not change. The Fe_o for the S.Ap1.0(1) treatment was 8,047 mg/kg. It was 8,159 mg/kg for the S.Ap1.0(2) treatment and 8,257 mg/kg for the S.Ap1.6(2) treatment. The Fe_o did not apparently change with sucrose treatment. It remained constant for soils with sucrose treatment sampled for the freeze-dry, first drying, and second drying treatments. The Fe_o was 8,083 mg/kg for the S.Ap1.0S(2) treatment and 7,964 mg/kg for the S.Ap1.6S(2) treatment. Other horizons showed a similar trend to that of the Ap1 horizon.

The Fe_{o-p} did not change for the soils with no sucrose treatment during different sampling periods. The Fe_{o-p} was 6,880 mg/kg for the S.Ap1.0(1) treatment. It ranged from 6,720 to 6,990 mg/kg for the Ap1 horizon sampled after the freeze-dry, first drying, and second drying treatments. The Fe_{o-p} appreciably decreased for the soils treated with sucrose and freeze-dried. The Fe_{o-p} decreased from 6,880 mg/kg for the S.Ap1.0(1) treatment to 5,373 mg/kg for the S.Ap1.0S(2) treatment. The Fe_{o-p} did not significantly change after the first and second drying treatments. It was 5,784 mg/kg for the S.Ap1.0S(3) and 5,716 mg/kg for the S.Ap1.0S(4) treatment. The distribution of Fe_{o-p} for other horizons with different treatments was similar to that of the Ap1 horizon.

The crystalline forms of Fe in the Sharkey soil ranged approximately from 4 to 10%. The Bssg2 had the highest Fe_{o-p} . The changes in Fe_{o-p} were irregular

for the Sharkey soil with or without sucrose treatment during different sampling periods.

2.3.5. Soil Colors

Moreland Soil

The Moreland soil, before incubation, had a dark reddish brown color (5YR 3/3, dry) and did not have low chroma redoximorphic features associated with wetness. The matrix colors for soils without the addition of sucrose and with different pH treatments after the first drying treatment was 5YR 3/3, identical to the color of the initial soil (Table 2.5.1).

Thin fragile Fe oxide films were observed immediately above the water surface during the 3-week incubation except for the M.Bkss.51S treatment. An apparent change in the color treated with sucrose was detected after the first drying treatment (Table 2.5.1). The predominant matrix color below the soil surface was dark reddish brown (5YR 3/3, dry), corresponding to the color of the initial material. Most of the alternations occurred on the soil surface, 30% or more of which consisted of distinct, reddish and yellowish hues with high and low chroma redoximorphic features (10R to 7.5YR 3 to 5/3 to 6, dry) after the first drying treatment. Some of the redoximorphic features (7.5YR) occurring on the soil surface were formed during the first drying period.

Yellowish red to yellow hue with low chroma (7.5YR to 2.5Y 4 to 3/1 to 2, dry) extending about 2 mm into the soil surface was observed in all soils treated with sucrose. The matrix colors of the M.Bkss.51S treatment below the soil surface were changed to faint brown (10YR 4/3) but without the

Table 2.5.1 Soil colors for the Moreland soil after the first drying treatment.

Horizon and treatments	Descriptions (dry color)
M.Ap.0 ¹ 1 ²	5YR 3/3.
M.Ap.71	5YR 3/3.
M.Ap.61	5YR 3/3.
M.Ap.51	5YR 3/3.
M.Ap.01S ³	5YR 3/3 with many ⁴ 5YR 3/4 and 2.5YR 3/6 on the soil surface and 1 mm 7.5YR 4/2 below the soil surface.
M.Ap.71S	5YR 3/3 with many 2.5YR 3/6, common 2.5YR 5/2, and few 7.5YR 4/3 on the soil surface and 1 mm 10YR 3/1 below the soil surface.
M.Ap.61S	5YR 3/3 with many 2.5YR 3/6, few 7.5YR 3/4, and few 5YR 3/4 on the soil surface and 1 mm 2.5Y 4/2 below the soil surface.
M.Ap.51S	5YR 3/3 with many 10R 3/4 and few 7.5YR 1/4 on the soil surface and 1 mm 10YR 4/2 below the soil surface.
M.Bw.01	5YR 3/3.
M.Bw.71	5YR 3/3.
M.Bw.61	5YR 3/3.
M.Bw.51	5YR 3/3.
M.Bw.01S	5YR 3/3 with many 5YR 3/4 and common 2.5YR 3/4 on the soil surface and 1 mm 10YR 4/1 below the soil surface.
M.Bw.71S	5YR 3/3 with many 2.5YR 3/6 and common 2.5YR 4/6 on the soil surface and 1 mm 10YR 3/1 below the soil surface.
M.Bw.61S	5YR 3/3 with many 2.5YR 3/6 and common 7.5YR 4/6 on the soil surface and 1 mm 10YR 3/2 below the soil surface.
M.Bw.51S	5YR 3/3 with many 10R 3/6, and common 2.5YR 3/6 and 3/4 on the soil surface and 1 mm 10YR 3/2 below the soil surface.

(Table 2.5.1 continued)

Horizon and treatments	Descriptions (dry color)
M.Bkss.01	5YR 3/3.
M.Bkss.71	5YR 3/3.
M.Bkss.61	5YR 3/3.
M.Bkss.51	5YR 3/3.
M.Bkss.01S	5YR 3/3 with many 5YR 3/4 and common 2.5YR 3/4 on the soil surface and 1 mm 10YR 4/1 below the soil surface.
M.Bkss.71S	5YR 3/3 with many 2.5YR 2.5/3, common 2.5YR 3/4, and 5YR 4/2 on the soil surface and 1 mm 10YR 4/1 below the soil surface.
M.Bkss.61S	5YR 3/3 with many 2.5YR 3/6 and common 7.5YR 4/6 on the soil surface and 1mm 10YR 4/2 below the soil surface.
M.Bkss.51S	5YR 3/3 with many 7.5YR 5/4, common 5YR 3/3, and few 2.5YR 4/6 on the soil surface and faint 10YR 4/3 below the soil surface.
M.Bss.01	5YR 3/3.
M.Bss.71	5YR 3/3.
M.Bss.61	5YR 3/3.
M.Bss.51	5YR 3/3.
M.Bss.01S	5YR 3/3 with many 5YR 3/4 and common 2.5YR 3/4 on the soil surface and 1 mm 10YR 4/1 below the soil surface.
M.Bss.71S	5YR 3/3 with many 10R 3/6, and common 5YR 3/8 and 4/4 on the soil surface and 1 mm 10YR 3/2 below the soil surface.
M.Bss.61S	5YR 3/3 with many 2.5YR 3/6 and common 7.5YR 3/4 on the soil surface and 1 mm 10YR 3/2 below the soil surface.
M.Bss.51S	5YR 3/3 with many 5YR 4/4 and 5YR 4/6, and common 2.5YR 3/6 on the soil surface and 1 mm 10YR 4/2 below the soil surface.

¹: 0: natural pH; 7: pH 7; 6: pH6; 5: pH 5.

²: First drying treatment.

³: With sucrose treatment.

⁴: few: < 2%; common: 2 ~ 20%; many: > 20%.

appearance of low chroma redoximorphic features. Redoximorphic features above the soil surface for the M.Bkss.51S treatment were formed during drying period.

Soil colors approximated the colors of the original soils after they were ground and mixed. The soils with no sucrose treatment did not change after re-saturation and the second drying treatment (Table 2.5.2). Many yellowish red hues with high chroma redoximorphic features (7.5 to 10YR 3 to 4/4 to 6) were observed on the surfaces of soils treated with sucrose. Only the S.Ap.01S treatment had few 7.5YR 2.5/1 (black) redoximorphic features on the soil surface.

Sharkey Soil

The original colors of Sharkey soil were grayish brown (2.5Y 5/2). The soil colors remained unchanged after the first drying treatment except for the S.Ap1.01 and S.Ap1.71 treatments (Table 2.5.3). Yellow (2.5Y 7/6) and brownish yellow (10YR 6/6) colors formed on the S.Ap1.01 and S.Ap1.71 soil surfaces, respectively.

With the exception of the S.Bssg1.51S, S.Bssg1.61S, S.Bssg2.51S, and S.Bssg2.61S treatments, thin, fragile Fe oxide films formed above the water surface during the 3-week incubation. The Fe oxide films had reddish colors (2.5YR to 10YR 3 to 7/6 to 8). Some reddish and yellowish redoximorphic features with high values and chroma (10YR to 2.5Y 5 to 7/4 to 8) appeared on the S.Bssg1.51S, S.Bssg1.61S, S.Bssg2.51S, and S.Bssg2.61S surfaces.

Table 2.5.2. Soil colors for the Moreland soil after the second drying treatment.

Horizon and treatments	Descriptions (dry color)
M.Ap.0 ¹ 2 ²	5YR 3/3.
M.Ap.72	5YR 3/3.
M.Ap.62	5YR 3/3.
M.Ap.52	5YR 3/3.
M.Ap.02S ³	5YR 3/3 with many ⁴ 7.5YR 4/4 and few 7.5YR 2.5/1 on the soil surface.
M.Ap.72S	5YR 3/3 with many 7.5YR 4/4 on the soil surface.
M.Ap.62S	5YR 3/3 with many 7.5YR 4/4 on the soil surface.
M.Ap.52S	5YR 3/3 with many 7.5YR 3/4 on the soil surface.
M.Bw.02	5YR 3/3.
M.Bw.72	5YR 3/3.
M.Bw.62	5YR 3/3.
M.Bw.52	5YR 3/3.
M.Bw.02S	5YR 3/3 with many 7.5YR 4/6 on the soil surface.
M.Bw.72S	5YR 3/3 with many 7.5YR 4/3 on the soil surface.
M.Bw.62S	5YR 3/3 with many 7.5YR 4/4 on the soil surface.
M.Bw.52S	5YR 3/3 with many 10YR 3/4 on the soil surface.
M.Bk.02	5YR 3/3.
M.Bk.72	5YR 3/3.
M.Bk.62	5YR 3/3.
M.Bk.52	5YR 3/3.
M.Bk.02S	5YR 3/3 with many 7.5YR 4/6 on the soil surface.
M.Bk.72S	5YR 3/3 with many 7.5YR 4/6 on the soil surface.
M.Bk.62S	5YR 3/3 with many 10YR 3/6 on the soil surface.
M.Bk.52S	5YR 3/3 with many 10YR 3/4 on the soil surface.
M.Bss.02	5YR 3/3.
M.Bss.72	5YR 3/3.
M.Bss.62	5YR 3/3.
M.Bss.52	5YR 3/3.
M.Bss.02S	5YR 3/3 with many 7.5YR 4/4 and few 7.5YR 4/3 on the soil surface.
M.Bss.72S	5YR 3/3 with many 10YR 3/4 and few 7.5YR 4/6 on the soil surface.
M.Bss.62S	5YR 3/3 with many 10YR 3/6 on the soil surface.
M.Bss.52S	5YR 3/3 with many 10YR 3/4 on the soil surface.

¹: 0: natural pH; 7: pH 7; 6: pH6; 5: pH 5.

²: Second drying treatment.

³: With sucrose treatment.

⁴: few: < 2%; common: 2 ~ 20%; many: > 20%.

Table 2.5.3. Soil colors for the Sharkey soil after the first drying treatment.

Horizon and treatments	Descriptions (dry color)
S.Ap1.0 ¹²	2.5Y 5/2 with few ⁴ 2.5Y 7/6 on the soil surface.
S.Ap1.71	2.5Y 5/2 with common 10YR 6/6 on the soil surface.
S.Ap1.61	2.5Y 5/2.
S.Ap1.51	2.5Y 5/2.
S.Ap1.01S ³	2.5Y 5/2 with many 2.5YR 3/6 and 5YR 5/6, and common 2.5Y 5/6 on the soil surface and 1.5 mm 2.5Y 5/1 below the soil surface.
S.Ap1.71S	2.5Y 5/2 with many 5YR 6/8 and 10YR 6/8, few 2.5YR 3/6 and 7.5YR 6/8 on the soil surface and 1.5-2 mm 2.5Y 5/1 below the soil surface.
S.Ap1.61S	2.5Y 5/2 with many 5YR 3/4 and 7.5YR 6/6, and few 10YR 5/6 on surface and 1 mm 2.5Y 5/1 below the soil surface.
S.Ap1.51S	2.5Y 5/2 with many 5YR 4/6 and 10YR 6/6 on the soil surface and 1mm 2.5Y 6/1 below the soil surface.
S.Ap2.01	2.5Y 5/2.
S.Ap2.71	2.5Y 5/2.
S.Ap2.61	2.5Y 5/2.
S.Ap2.51	2.5Y 5/2.
S.Ap2.01S	2.5Y 5/2 with many 7.5YR 6/8 and 10 YR 6/8, and few 2.5YR 3/6 on the soil surface and 1 mm 2.5Y 5/1 below the soil surface.
S.Ap2.71S	2.5Y 5/2 with many 5YR 3/4 and 7.5YR 6/8, and few 10YR 5/6 on the soil surface and 1 mm 2.5Y 5/1 below the soil surface.
S.Ap2.61S	2.5Y 5/2 with many 7.5YR 6/8 and 10YR 7/8 on the soil surface and 1 mm 2.5Y 5/1 below the soil surface.
S.Ap2.51S	2.5Y 5/2 with many 10YR 6/8 and few 5YR 4/6 on the soil surface and 1mm 2.5Y 6/1 below the soil surface.

(Table 2.5.3 continued)

Horizon and treatments	Descriptions (dry color)
S.Bssg1.01	2.5Y 5/2.
S.Bssg1.71	2.5Y 5/2.
S.Bssg1.61	2.5Y 5/2.
S.Bssg1.51	2.5Y 5/2.
S.Bssg1.01S	2.5Y 5/2 with many 10YR 7/6 and 10 YR 6/8, and few 7.5YR 6/8 on the soil surface and 1 mm 2.5Y 5/1 below the soil surface.
S.Bssg1.71S	2.5Y 5/2 with many 10YR 6/8 and 10YR 5/6, common 7.5YR 5/4, and few 5YR 5/8 on the soil surface and 1 mm 2.5 Y 5/1 below the soil surface.
S.Bssg1.61S	2.5Y 5/2 with many 10YR 7/8 and 2.5Y 6/8 on the soil surface and 1 mm 2.5Y 5/1 below the soil surface.
S.Bssg1.51S	2.5Y 5/2 with many 2.5Y 7/8 and few 10YR 5/6 on the soil surface and 1mm 2.5Y 6/1 below the soil surface.
S.Bssg2.01	2.5Y 5/2.
S.Bssg2.71	2.5Y 5/2.
S.Bssg2.61	2.5Y 5/2.
S.Bssg2.51	2.5Y 5/2.
S.Bssg2.01S	2.5Y 5/2 with many 10YR 7/8, and common 7.5YR 6/8 and 2.5Y 5/4 on the soil surface and 1 mm 2.5Y 5/1 below the soil surface.
S.Bssg2.71S	2.5Y 5/2 with many 10YR 6/8 and common 10YR 7/6, and few 10YR 5/6 on surface and 1 mm 2.5Y 5/1 below the soil surface.
S.Bssg2.61S	2.5Y 5/2 with many 5Y 6/6, common 2.5 YR 7/6, and few 10YR 6/8 on the soil surface and 1 mm 2.5Y 6/1 below the soil surface.
S.Bssg2.51S	2.5Y 5/2 with many 2.5Y 6/6 and few 7.5YR 6/8 and 1 mm 2.5Y 6/1 below the soil surface.

¹. 0: natural pH; 7: pH 7; 6: pH6; 5: pH 5.

². First drying treatment.

³. With sucrose treatment.

⁴. few: < 2%; common: 2 ~ 20%; many: > 20%.

The S.Bssg1.51S, S.Bssg1.61S, S.Bssg2.51S, and S.Bssg2.61S treatments had more yellowish redoximorphic features on the soil surface than did the S.Bssg1.01S, S.Bssg1.71S, S.Bssg2.01S, and S.Bssg2.71S treatments. The S.Bssg2.71S treatment had many 10YR 6/8, common 10YR 7/6, and few 10YR 5/6 redoximorphic features on the soil surface, but the S.Bssg2.61S treatment had many 5Y 6/6, common 2.5 YR 7/6, and few 10YR 6/8 redoximorphic features.

A yellow hue with low chroma (2.5Y 5 to 6/1) penetrating 1 to 2 mm into the soil surface was observed in soils treated with sucrose after the first drying treatment. The S.Ap1.71S treatment had low chroma 1.5 to 2 mm in thickness. Low chroma redoximorphic features formed on the surface of all soils treated with sucrose.

No redoximorphic features were formed after the second drying treatment for the Sharkey soil with no sucrose treatment (Table 2.5.4). The matrix color was grayish brown (2.5Y 5/2). There were no fragile Fe oxide films on the water surface for soils treated with sucrose during the re-saturation period. Redoximorphic features with yellowish (2.5Y) or reddish hues (5YR to 10YR) appeared on the soil surface after the second drying treatment. The Ap1 and Ap2 horizons treated with sucrose had more reddish redoximorphic features (5YR to 10YR) than did the Bssg1 and Bssg2 horizons (2.5Y to 10YR). The soils with pH adjusted to 5 or 6 had a reddish hue as compared to those with pH adjusted to 7 or natural pH soils. The S.Ap1.52S treatment had

Table 2.5.4. Soil colors for the Sharkey soil after the second drying treatment.

Horizon and treatments	Descriptions (dry color)
S.Ap1.0 ¹ 2 ²	2.5Y 5/2.
S.Ap1.72	2.5Y 5/2.
S.Ap1.62	2.5Y 5/2.
S.Ap1.52	2.5Y 5/2.
S.Ap1.02S ³	2.5Y 5/2 with many ⁴ 10YR 6/8 on the soil surface.
S.Ap1.72S	2.5Y 5/2 with common 10YR 6/6 and few 10YR 6/8 and 2.5Y 5/3 on the soil surface.
S.Ap1.62S	2.5Y 5/2 with many 5YR 4/6 and 7.5YR 5/8 on the soil surface.
S.Ap1.52S	2.5Y 5/2 with many 7.5YR 6/8 and few 5YR 5/8 on the soil surface.
S.Ap2.02	2.5Y 5/2.
S.Ap2.72	2.5Y 5/2.
S.Ap2.62	2.5Y 5/2.
S.Ap2.52	2.5Y 5/2.
S.Ap2.02S	2.5Y 5/2 with many 10YR 5/8 on the soil surface.
S.Ap2.72S	2.5Y 5/2 with many 10YR 6/3 on the soil surface.
S.Ap2.62S	2.5Y 5/2 with many 7.5YR 5/8 on the soil surface.
S.Ap2.52S	2.5Y 5/2 with many 7.5YR 5/8 on the soil surface.
S.Bssg1.02	2.5Y 5/2.
S.Bssg1.72	2.5Y 5/2.
S.Bssg1.62	2.5Y 5/2.
S.Bssg1.52	2.5Y 5/2.
S.Bssg1.02S	2.5Y 5/2 with many 2.5Y 5/3 on the soil surface.
S.Bssg1.72S	2.5Y 5/2 with many 2.5Y 5/3 on the soil surface.
S.Bssg1.62S	2.5Y 5/2 with many 10YR 6/8 and 10YR 6/6 on the soil surface.
S.Bssg1.52S	2.5Y 5/2 with many 10YR 5/6 and few 10YR 4/6 on the soil surface.
S.Bssg2.02	2.5Y 5/2.
S.Bssg2.72	2.5Y 5/2.
S.Bssg2.62	2.5Y 5/2.
S.Bssg2.52	2.5Y 5/2.
S.Bssg2.02S	2.5Y 5/2 with common 2.5Y 5/3 on the soil surface.
S.Bssg2.72S	2.5Y 5/2 with many 2.5Y 5/3 on the soil surface.
S.Bssg2.62S	2.5Y 5/2 with many 7.5YR 6/8 on the soil surface.
S.Bssg2.52S	2.5Y 5/2 with many 10YR 6/8 on the soil surface.

¹: 0: natural pH; 7: pH 7; 6: pH6; 5: pH 5.

²: Second drying treatment.

³: With sucrose treatment.

⁴: few: < 2%; common: 2 ~ 20%; many: > 20%.

redoximorphic features with hue (5 to 7.5YR), but the S.Ap1.02S treatment had 10YR redoximorphic features.

2.3.6. Summary

A summary of pH versus time for the Moreland clay Ap horizon with and without sucrose is presented in Fig 2.2.1. Without sufficient energy, the pH did not appreciably change. With the addition of sucrose, fermentation was the major microbial process, which is noted by a lowering of the pH because of the production of organic acids. These results were obtained for all the horizons and treatments. A similar trend was observed for the Sharkey clay Ap1 horizon (Fig. 2.2.9). The Eh values were not affected by pH, but were by the addition of sucrose. Without the addition of sucrose, the measured Eh values, regardless of pH, were never below the threshold values for the reduction of Mn and Fe (Fig. 2.3.1).

The Sharkey soil Ap horizon organic carbon content was determined to be 16.0 g/kg. There was sufficient energy greater for the reduction of Mn and Fe for some treatments. There was a pH effect in that when the pH was lowered to pH 5 and 6, the redox potential was greater than the redox threshold for the both Mn and Fe (Fig. 2.3.1). The redox threshold also obtained for the natural pH (6.4) and pH 7 treatments without sucrose. The process responsible for this is not understood and requires additional investigation.

Both Mn and Fe were reduced in all sucrose added treatments. The Eh time dependant curves for the Moreland Ap horizon showed a bimodal distribution that were pH dependant, i. e. as pH decreased more Mn and Fe were

solubilized (Fig. 2.4.1 and 2.4.2). This showed the interaction of pH and energy. As pH decreases and energy increases, reduction of both Mn and Fe increase, thus increased quantity of Mn and Fe in solution. Similar trends were observed for the Sharkey Ap1 horizon (Fig. 2.4.3 and 2.4.4).

The data for the DCB, pyrophosphate, and oxalate Fe extractions for the Ap horizon Moreland soil are presented in Fig. 2.5.1. Note that if the sample is freeze-dried, which represents rapid drying, without an opportunity for oxidation, and consistently greater than those treatments that were allowed to dry slowly. The quantity of crystalline Fe decreases with each wetting and drying cycle (Fe_{d-o}). It is noted that if there is a sufficient energy of SOC, complexes with carbon, which decreases with each successive drying treatment.

The Fe oxide dissolution data for the Ap1 horizon for the Sharkey soil are presented in Fig. 2.5.2. Note that there are two dominant components of Fe, amorphous organic and amorphous inorganic, with virtually no crystalline phase of Fe.

There was no soil color change for any treatment except those in which sucrose was added for the Moreland soil. There were many, fine redox depletion and concentration within the upper 1 mm of the surface for all horizons. However, since the amount of energy would be limited to the surface horizon in the field, redoximorphic features would not be expected to form in the Moreland soil. It is possible that both depletions and concentrations might form along ped faces and along slickenside faces during some years when

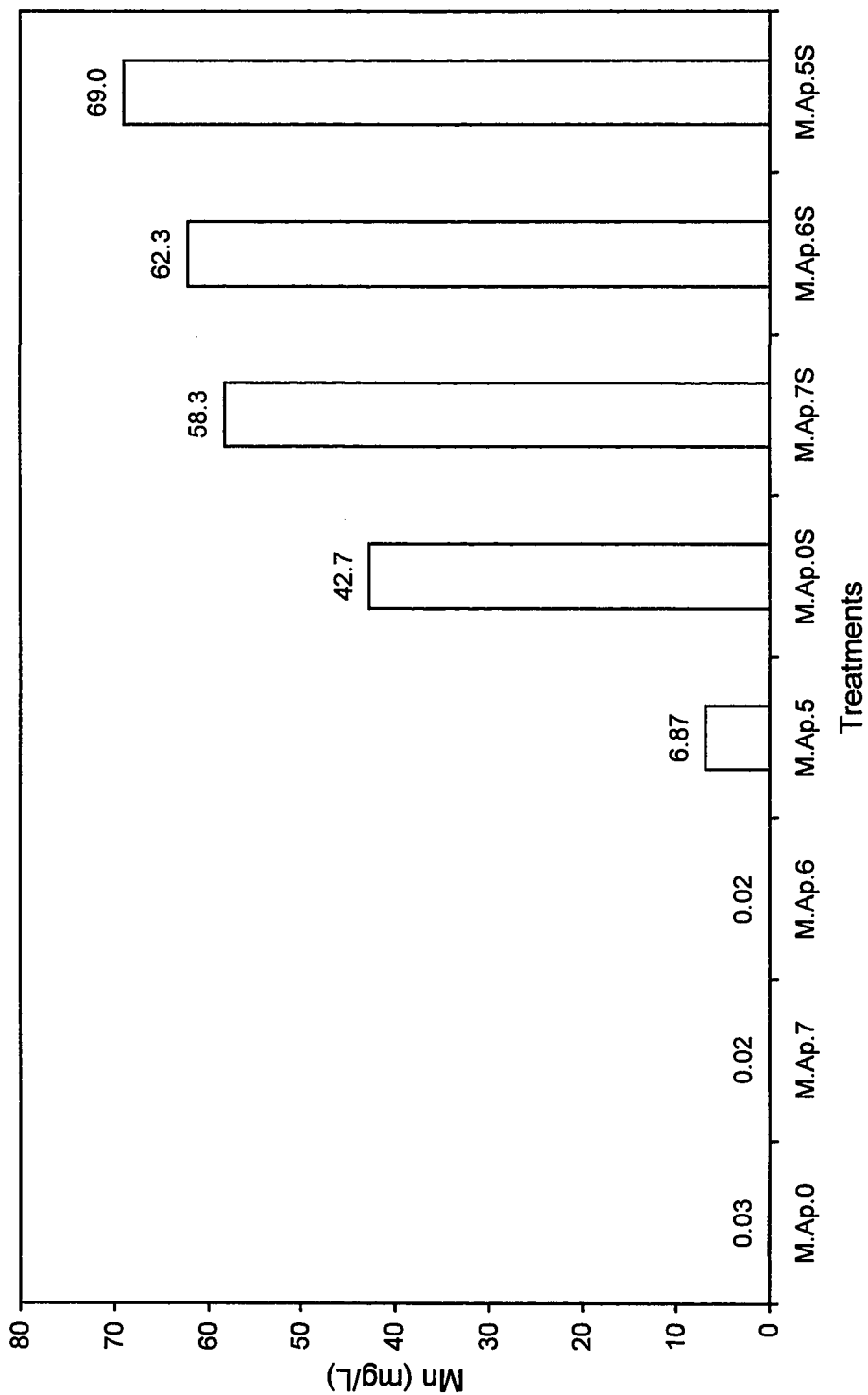


Fig. 2.4.1. Mn in soil solution versus pH for the Moreland soil Ap horizon with or without sucrose.

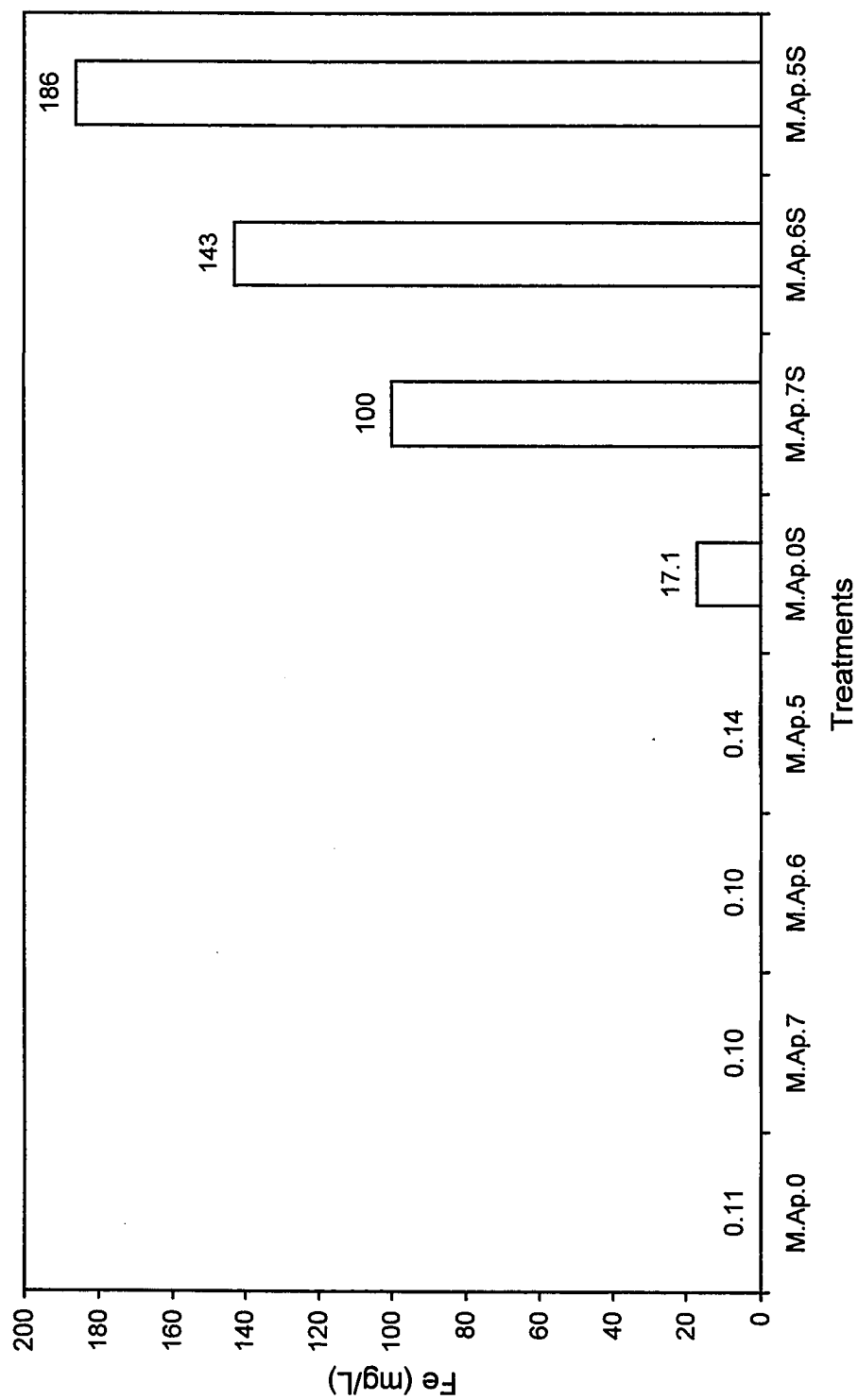


Fig. 2.4.2. Fe in soil solution versus pH for the Moreland soil Ap horizon with or without sucrose.

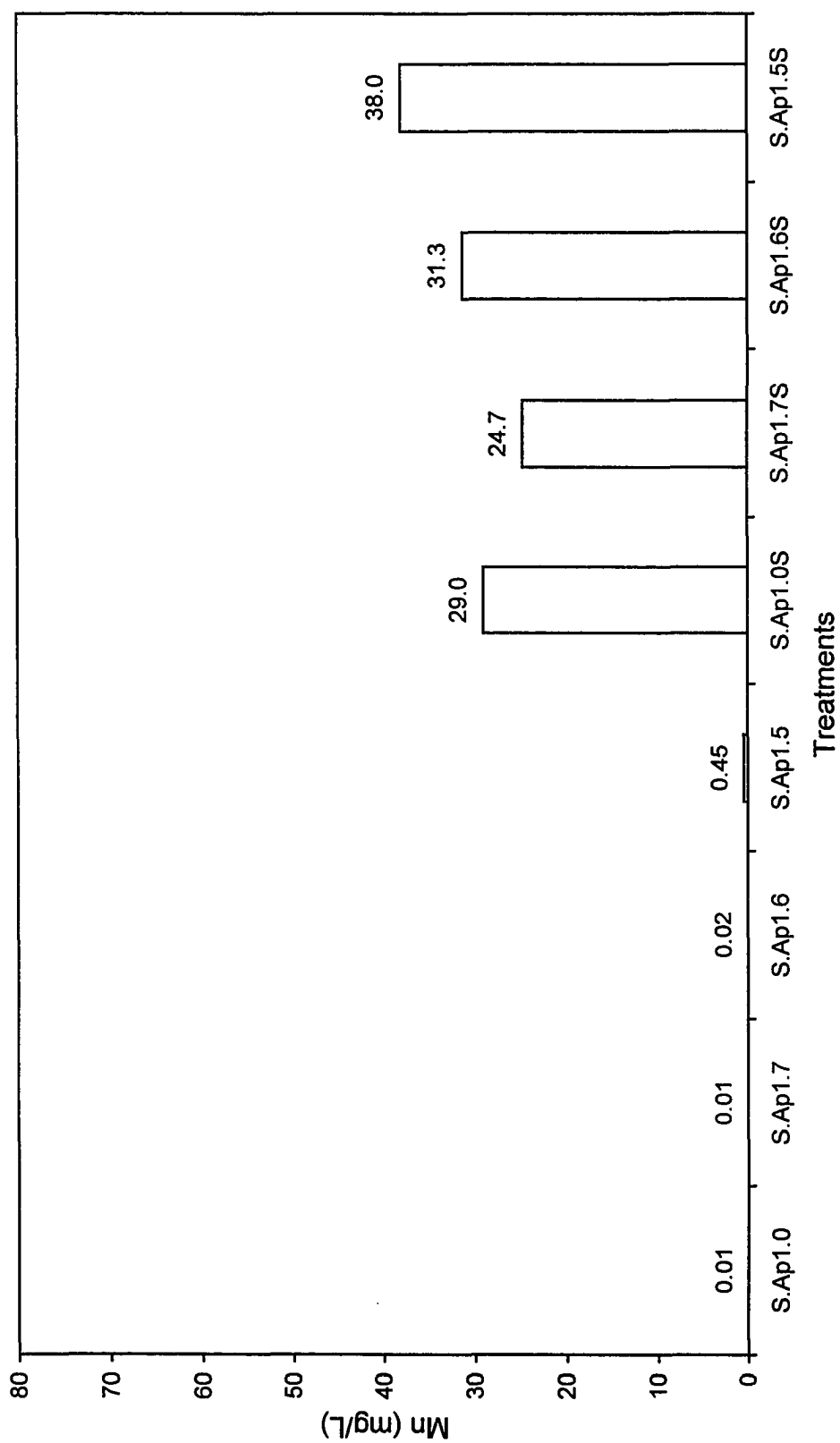


Fig. 2.4.3. Mn in soil solution versus pH for the Sharkey soil Ap1 horizon with or without sucrose.

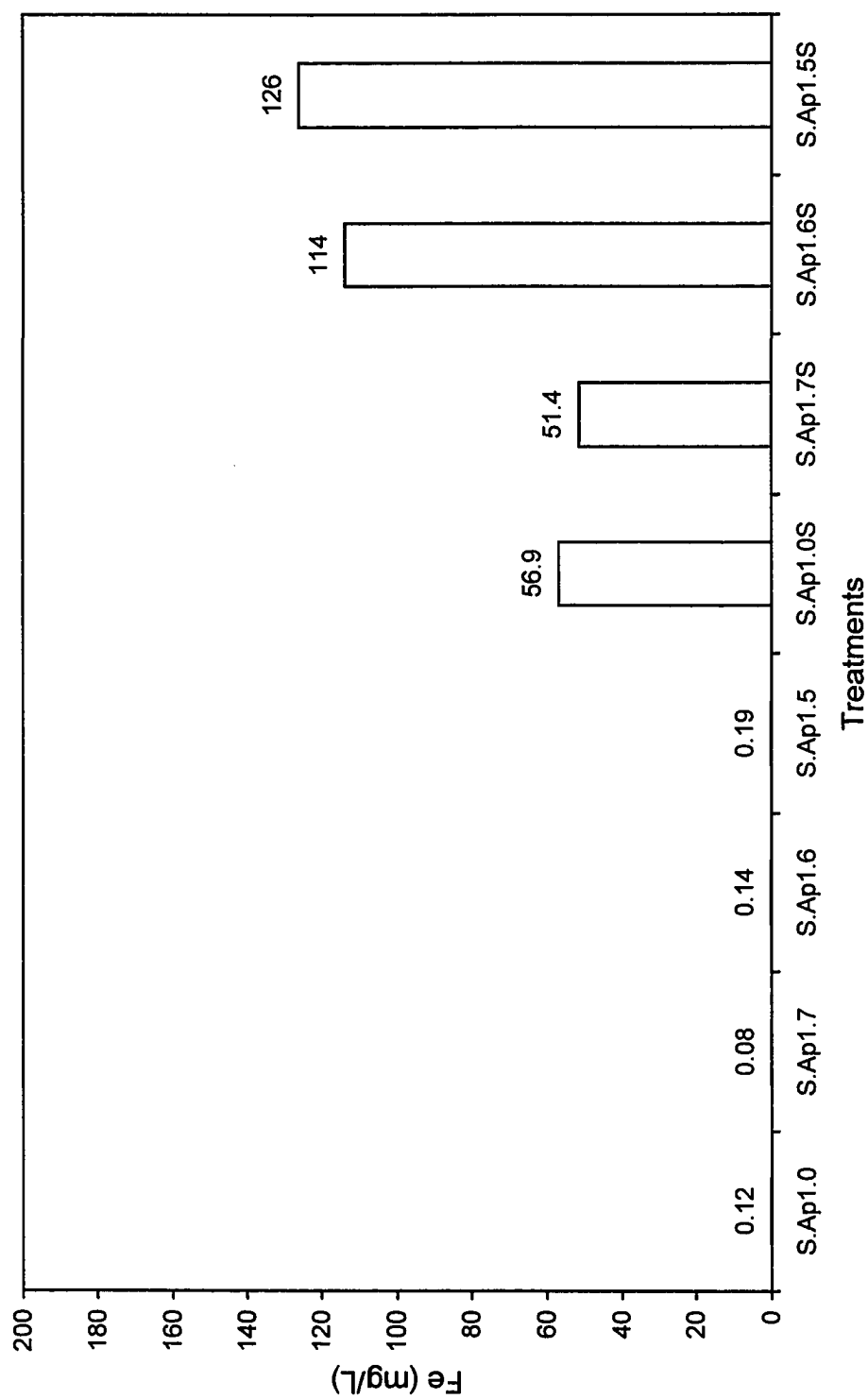


Fig. 2.4.4. Fe in soil solution versus pH for the Sharkey soil Ap1 horizon with or without sucrose.

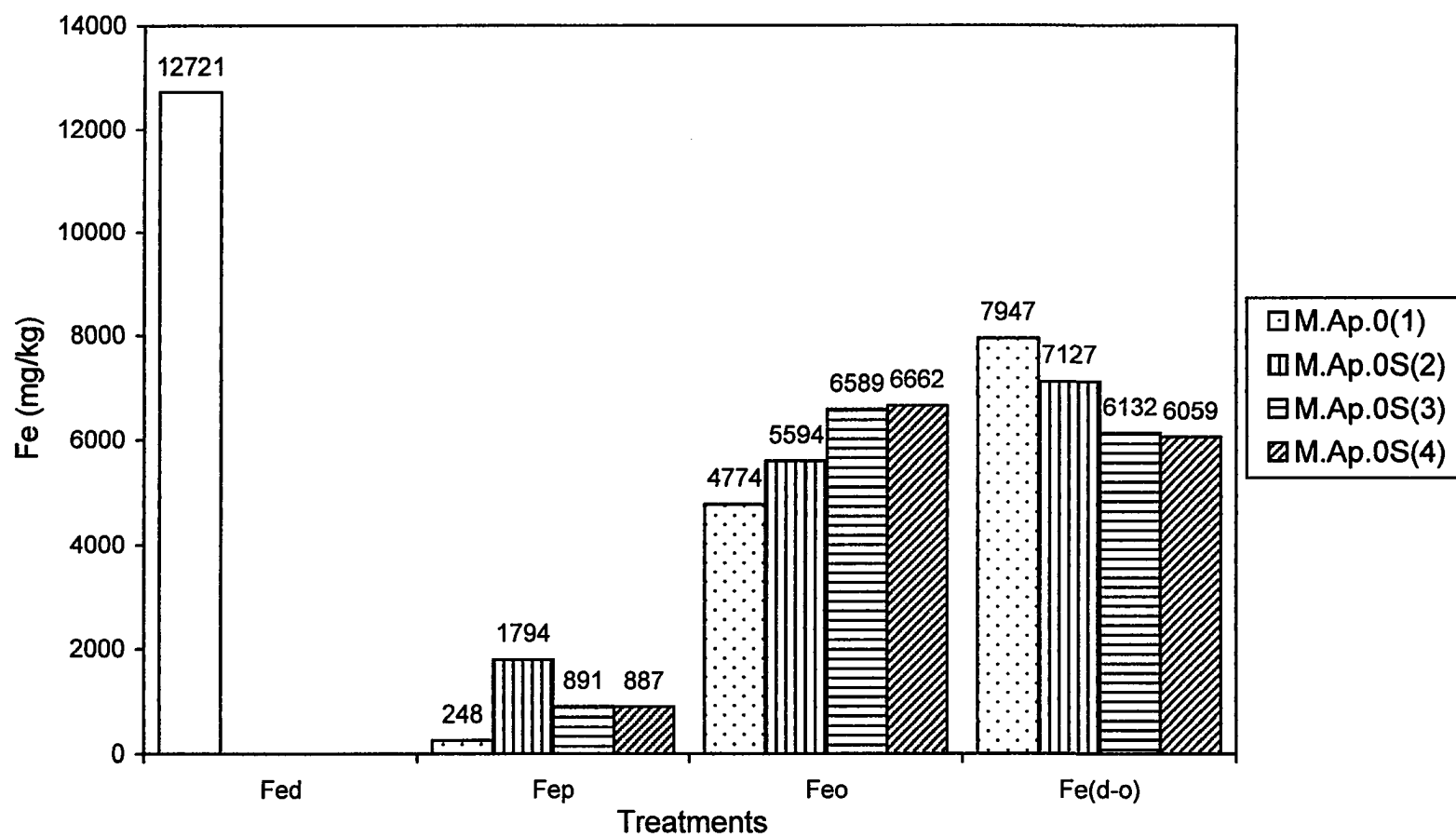


Fig. 2.5.1. Fe concentrations extracted by different chemical reagents for the natural pH Ap horizon of the Moreland soil.

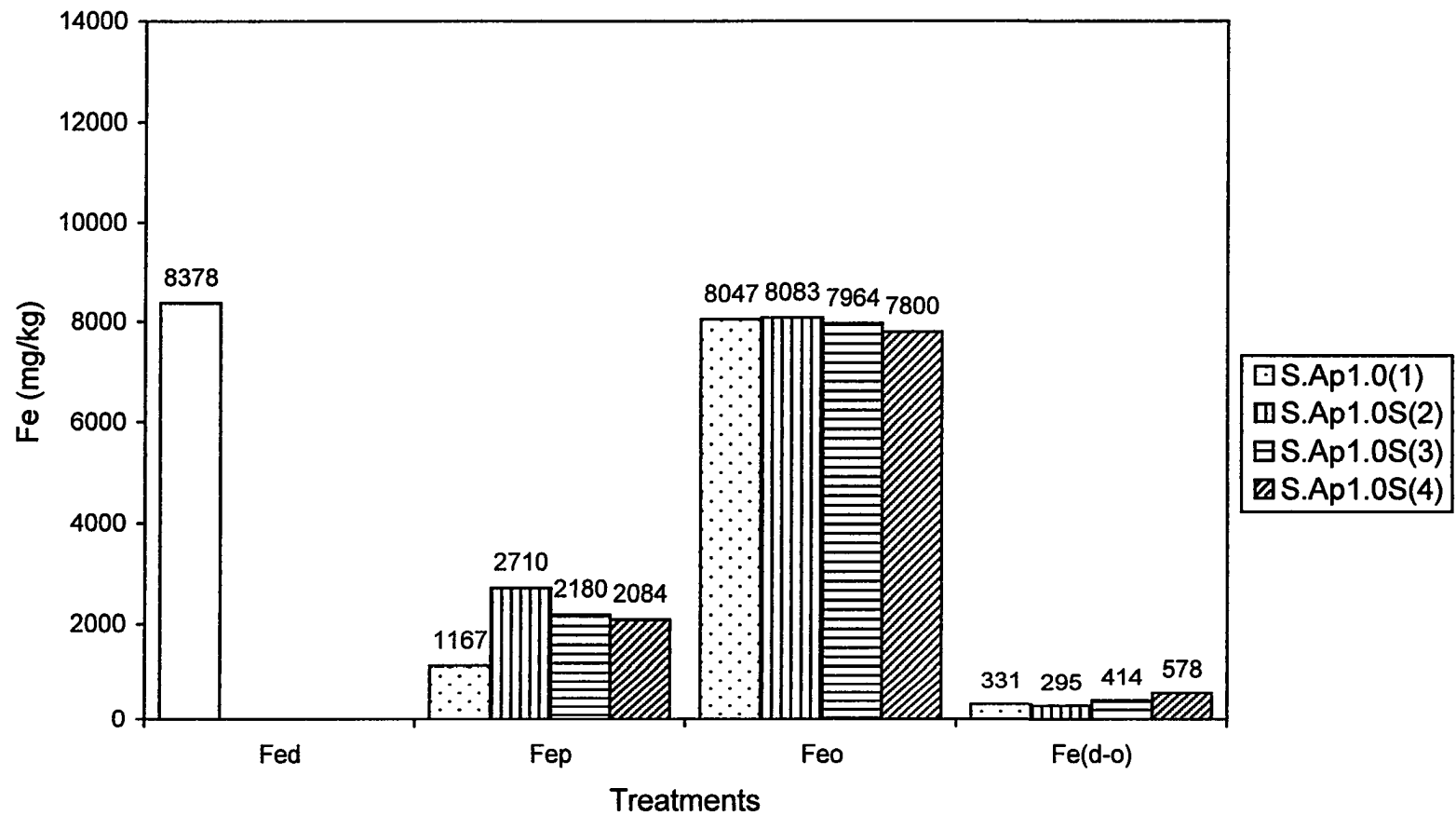


Fig. 2.5.2. Fe concentrations extracted by different chemical reagents for the natural pH Ap1 horizon of the Sharkey soil.

there was an abundant supply of plant debris. However, since the pH of the lower horizon is approximately 8, redoximorphic features are not likely to form, but both Mn and Fe may precipitate as a function of the increased pH.

The soil colors of the Sharkey remained unchanged except Ap1 horizon, which had a sufficient source of OC. All sucrose added treatment showed both redox depletions and concentrations during the first wetting and drying cycle, but not for any subsequent wetting and drying cycles. Two major differences were noted between the Moreland and Sharkey soils. Moreland soils will not form redoximorphic features nor change color because there was no sufficient energy source. The Moreland soil contains Fe in these phase, amorphous organic, amorphous inorganic and crystalline in the form of hematite. The Sharkey soil contains only the first two phases.

2.4. Discussion and Conclusions

2.4.1. pH

First Incubation Period

The pH for the M.Ap.01 and M.Ap.71 treatments after 21 days of submergence decreased from 7.4 and 7.0 to 7.2 and 6.9, respectively (Fig. 2.2.1). A slight decrease in pH presumably resulted from the CO₂ produced by bacteria (Ponnamperuma, 1966) and not from the reduction of Mn or Fe (Vepraskas and Wilding, 1983b). The pH for the M.Ap.61 and M.Ap.51 treatments gradually increased to 6.1 and 5.3 after 21 days. This increase in pH was due to the buffering capacity of the soil and the soil was not at pH 5 or 6 equilibrium after the soil was adjusted with HCl to their pH's. These pH

treated soils did not approach pH 7.0 because there was not sufficient OC to serve as an energy source. The results differed from the conclusions of Berner (1981), Patrick and Mikkelesen (1971), Ponnampereuma (1966, 1972), Stanford et al. (1975), and Yu (1991), all of whom indicated that the pH of alkaline or acidic flooded soils invariably approached 7.0. The pH for other horizons of the Moreland soil with different pH treatments showed the same trends as those of the Ap horizon (Fig. 2.2.2, 2.2.3, and 2.2.4). The pH did not approach 7.0 during the 21 days of incubation.

The pH for the different Sharkey treatments with no sucrose showed a similar trend to that of the Moreland soil and did not approach 7.0 after 21 days of incubation (Fig. 2.2.9, 2.2.10, 2.2.11, and 2.2.12). A decrease in pH for the S.Ap1.01 treatment was caused by the production of CO₂ during the decomposition of OC (16.0 g/kg) present (Table 2.1). The amount of pH decrease was greater than that of the Moreland soil due to greater OC within the Ap1 horizons of the Sharkey soil. The decreasing rate of pH for the S.Ap1.71 treatment was greater than that of the S.Ap1.01 treatment because OC was solubilized by hydroxyl ions. The production of carbon dioxide for the S.Ap1.71 treatment was greater than that of the S.Ap1.01 treatment, resulting in decreased pH. The pH for the Ag2, Bssg1, and Bssg2 horizons with natural pH and pH adjusted to 7 and no sucrose added showed a slower rate of decrease (Fig. 2.2.10, 2.2.11, and 2.2.12) due to the presence of less and more stable OC (Ponnampereuma, 1966, 1972; Couto et al., 1985). The pH for the pH adjusted to 5 and 6 soils with no sucrose increased slightly because of

the soil buffering capacity as discussed for the Moreland soil adjusted to pH 5 and 6 with no sucrose treatment.

The pH for the M.Ap.S01 treatment decreased from 7.4 to 6.4 within 24 hours and remained constant at 6.1 for the duration of the first incubation period (Fig. 2.2.1). The rapidly decreasing pH was attributed to increases in organic acids and CO₂, which were OC fermentation byproducts resulting from digestion by fermentative bacteria (Lovley, 1992). The amount of H⁺ produced by fermentation was greater than that consumed by the reduction of Fe or Mn as indicated by the presence of Fe and Mn ions in the soil solution after 21 days of incubation (Table 2.3.1).

The distribution of the pH for the M.Bw.S01, M.Bkss.S01, and M.Bss.S01 treatments were similar to that of the M.Ap.S01 treatment (Fig. 2.2.2, 2.2.3, and 2.2.4). However, the rate of decrease in pH for the M.Ap.S01 treatment was greater than that of other horizons. This was presumably due to the surface horizon having more OC. The pH for the M.Ap.S71, M.Bw.S71, M.Bkss.S71, and M.Bss.S71 treatments showed a similar tendency to that of the M.Ap.S01 treatment.

The pH for the M.Ap.S61 treatment increased from 5.9 to 6.45 within 24 hours and then decreased to 5.9 after 48 hours (Fig. 2.2.1). The pH stabilized at 6.1 for the remainder of incubation. Anaerobic bacteria consumed both organic and inorganic compounds. The rapid pH increase within 24 hours was due to the greater availability of active Mn and Fe as electron acceptors after the addition of 0.1N HCl increased their solubility. The amount of H⁺ consumed

by anaerobic respiration was greater than that produced by fermentation. As a result, the pH increased within 24 hours. After readily reducible Fe^{3+} and Mn^{4+} were depleted, the organic compounds acted as major electron acceptors (fermentation), resulting in a decreased pH. Some poorly crystalline Mn and Fe dissolved after the pH decreased due to fermentation and became the electron acceptors causing the pH to increase. The pH for the M.Bw.S61, M.Bkss.S61, and M.Bss.S61 treatments was similar to that of the M.Ap.S61 treatment.

The pH for the M.Ap.S51 treatment increased from 5.0 to 5.9 within 72 hours and remained at 6.1 for the remainder of incubation (Fig. 2.2.1). The distribution of the pH was different from that of the M.Ap.S01, M.Ap.S71, and M.Ap.S61 treatments. The pH 5 treatment increased the solubility of Mn and Fe inorganic compounds resulting in a greater concentration of Mn and Fe than were present in the pH adjusted to 6 and 7 soils. The amount of H^+ produced by fermentation was less than that consumed by the reduction of Mn or Fe, resulting in a net pH increase for the experiment. However, the soil pH was 6.1 after 21 days of incubation and did not approach to pH 7.0 as reported by Ponnamperna (1966, 1972), Patrick and Mikkelesen (1971), (Standford et al., 1975), Berner (1981), and Yu (1991). The distribution of the pH for the M.Bkss.S51 and M.Bss.S51 treatments (Fig. 2.2.3 and 2.2.4) was both similar to and different from that of the M.Ap.S51 and M.Bw.S51 treatments. The M.Bkss.S51 and M.Bss.S51 treatments had lower pH values than those of the M.Ap.S51 and M.Bw.S51 treatments during the 21-day of incubation. The pH for the M.Bkss.S51 treatment increased from 5.0 to 5.3 within 24 hours and

then decreased gradually to 5.0 after 3 weeks. The decreased pH was due to the organic acids produced by fermentative bacteria using OC instead of inorganic oxidants as electron acceptors. The Bkss horizon had the highest amount of calcium carbonate (Table 2.6), and was dissolved by 0.1 N HCl when the soil pH was adjusted to pH 5. The high concentration of Ca^{2+} ions in soil solutions competed with the Fe^{2+} for the OC. The bond formed between Ca^{2+} and OC is formed easier than that formed between Fe^{2+} and OC (Norvell, 1988). Fermentative bacteria could easily attack Ca-humus complexes. As a result, a greater fermentation reaction prevailed and the pH decreased for the Bkss horizon.

The distribution of pH for the Sharkey soil treated with sucrose during the first incubation period was similar to that of Moreland soil and was also controlled by fermentation and anaerobic respiration (Fig. 2.2.9, 2.2.10, 2.2.11, 2.2.12). However, the distribution of the pH for the Sharkey soil was lower than that of the Moreland soil with the same pH treatment. The pH after 3 weeks of incubation was 6.2 for the M.Bw.01S treatment (Fig. 2.2.2) and 5.3 for the S.Ap2.01S treatment (Fig. 2.2.10). The availability of Mn presumably controlled the pH. The concentration of Mn in soil solution was 42.4 mg/L for the M.Bw.0S treatment and 21.3 mg/L for the S.Ap2.0S treatment (Table 2.3.1). The pH of the S.Ap2.01S treatment was 5.3 higher than that of the S.Bssg1.S01 (Fig. 2.2.11). The concentration of Mn in soil solution was 8.44 mg/L for the Bssg1 horizon (Table 2.3.1).

Table 2.6. Concentrations of Ca and Mg ions in soil solutions for the Moreland soil after incubation.

Horizons and treatments	Ca	Mg	Horizons and treatments	Ca	Mg
	-----mg/L-----			-----mg/L-----	
M.Ap.0 ¹	2263	1050	M.Bkss.0	1513	715
M.Ap.7	3991	1952	M.Bkss.7	6872	2849
M.Ap.6	5368	2952	M.Bkss.6	39452	9876
M.Ap.5	10731	4370	M.Bkss.5	84042	17628
M.Ap.0S ²	7341	3575	M.Bkss.0S	9604	3741
M.Ap.7S	11898	5149	M.Bkss.7S	16558	5431
M.Ap.6S	12000	5199	M.Bkss.6S	46253	10987
M.Ap.5S	12064	5298	M.Bkss.5S	85511	19153
M.Bw.0	2372	1070	M.Bss.0	1616	828
M.Bw.7	4971	2063	M.Bss.7	4207	1984
M.Bw.6	10002	6235	M.Bss.6	10153	5284
M.Bw.5	22096	8002	M.Bss.5	35852	11363
M.Bw.0S	9561	3724	M.Bss.0S	8847	3925
M.Bw.7S	12233	4828	M.Bss.7S	13825	5195
M.Bw.6S	18356	8011	M.Bss.6S	20954	7235
M.Bw.5S	25791	9504	M.Bss.5S	34954	11343

¹: 0:natural pH; 7: pH 7; 6: pH 6; 5: pH 5.

²: S: with the addition of 10 g/kg sucrose.

Second Saturation Period

The pH for the natural pH and pH adjusted to 7 Moreland soil with no sucrose treatment after re-saturation did not change and remained approximately the same as the original pH's. The pH for the pH adjusted to 5 and 6 Moreland soil with no sucrose treatment slightly increased after re-saturation (Fig. 2.2.5, 2.2.6, 2.2.7, and 2.2.8). The very-clayey soil seemed to irreversibly absorb the added H⁺ ions after the first drying treatment. Except for the M.Bkss.52 and M.Bss.52 treatments (Fig. 2.2.7 and 2.2.8), the pH did not change for different pH Moreland soil with no sucrose treatments during the re-saturation period. The pH increased from 5.9 to 6.5 for the M.Bkss.52

treatment and from 5.6 to 6.0 for the M.Bss.52 treatment. This was ascribed to the non-equilibrium soil state and the presence of residual calcium carbonate. The pH for the different pH Sharkey soil with no sucrose treatment did not change during the re-saturation period (Fig. 2.2.13, 2.2.14, 2.2.15, and 2.2.16).

The pH resulted from a competition between the oxidation of organic acid and re-oxidation of ferrous Fe and manganous Mn after the first drying treatment (Ponnamperuma et al., 1967; Brinkman, 1970; Miller, 1983). The increased pH was 0.5 or more units for the natural pH and pH adjusted to 7 Moreland soil treated with sucrose than for the pH adjusted to 5 and 6 soils after the first drying treatment. This increase was due to greater reduced Mn and Fe in the pH adjusted to 5 and 6 treatments, resulting in more protons during the drying treatment. The Mn and Fe were 42.7 and 17.1 mg/L respectively for the M.Ap.0S treatment and 69.0 and 186 mg/L for the M.Ap.5 treatment. The pH for the M.Bkss.S52 treatment increased from 5.0 to 6.0 which was higher than that of other horizons adjusted to pH 5 due to greater fermentation during the first incubation period. The pH did not change for the Moreland soil with no sucrose treatment, indicating lower energy sources during the re-saturation period. The distribution of the pH for the Sharkey soil was similar to that of the Moreland soil during the re-saturation period in that the pH did not change.

2.4.2. Eh

First Incubation Period

The Eh for the Moreland soil with no sucrose treatment during the first incubation period ranged from approximately 250 to 600 mV (Fig. 2.3.1, 2.3.2, 2.3.3, and 2.3.4). The Eh was not low enough to indicate that either Mn or Fe would reduce. The lack of reduction was predicted from Eh-pH stability diagrams and from previous studies (Daniels et al., 1973; Gotoh and Patrick, 1974). Neither Mn nor Fe reduction occurred for the Moreland soil (Patrick and Jugsujinda, 1992). The low amount of bio-available OC in the Moreland soil was the major factor prohibiting the reduction of Mn and Fe (Daniels et al., 1973; Couto et al., 1985; Mokma and Sprecher, 1994). When OC content was not at levels high enough to sustain high levels of microbial activity in the soil, then the Eh remained above 300mV and the formation of redoximorphic features did not develop, a phenomena that was consistent with the morphological properties of Moreland soil in the field.

Except for the S.Ap1.01, S.Ap1.71, and S.Ap2.71 treatments, the Eh was too high for all other Sharkey soil with no sucrose and pH treatments for Fe to reduce during the 21-day incubation (Fig. 2.3.9, 2.3.10, 2.3.11, and 2.3.12). The initial concentration of OC was 16.0 g/kg for the Ap1 horizon. This concentration of OC provided a sufficient energy source for Mn and Fe to reduce, indicating that the redoximorphic features should do and form within the surface horizon of the Sharkey soil. The formation of redoximorphic features within the S.Ap1.01 and S.Ap.71 treatments also confirmed this fact

(Table 2.5.3). The Eh for the S.Ap2.71 treatment was lower than that of the S.Ap2.01 treatment, implying that the addition of NaOH increased the availability of OC for microbes, and this increased availability resulted in the lowest Eh for the soils adjusted to pH 7.

The addition of HCl increased the availability of Mn and Fe, which consumed more electrons, and resulted in bio-available OC being exhausted during the pH adjustment period. Thus, the pH adjusted to 5 and 6 treatments had a higher Eh distribution than did the natural pH and pH adjusted to 7 treatments. The OC in the Bssg1 and Bssg2 horizons was presumably too stable and low for Mn and Fe to reduce.

The distribution of the Eh for the M.Ap.S01 treatment showed a bimodal distribution (Fig. 2.3.1). The Eh decreased to a minimum of -300 mV within 24 hours and then increased to 100 mV within 240 hours. The Eh decreased again asymptotically to -160 mV during the 21-day incubation. Ponnampersuma (1972) described the same bimodal distribution of Eh without further interpretation. The intense Eh decrease was triggered by the supply of sucrose to fermentative bacteria as a energy source. The decrease in Eh was most likely accompanied by the microbial reduction of Fe and Mn in the soil. The Eh increased presumably because available organic C was deficient for fermentative bacteria and the reduction of Mn and Fe by Mn- and Fe-reducing bacteria. Once the fermentative bacteria had more limited sources of energy, their activity diminished and the Eh began to increase, equilibrating at around 100 mV. The quantity of reducible Mn and Fe was limited and fermentative

bacteria propagated again within 168 hours, resulting in a decreasing Eh thereafter. The Eh for the M.Ap.S71, M.Ap.S61, and M.Ap.S51 treatments was similar to that of the M.Ap.S01 treatment. The Eh reached the maximum values of 0, -100, and -100 mV for the pH 7, 6, and 5 treatments, respectively. It seemed that the lower pH treatment facilitated fermentation, resulting in a lower maximum Eh for the M.Ap.S51 treatment.

The explanation for bimodal distribution involves two phenomena: i) aggregate stability and ii) competition between bacteria. The Eh decreased after the addition of sucrose due to the fermentation. The Eh increased thereafter because of the reduction of Mn and Fe, consuming electrons. The Ap1 horizon is subjected to alternating saturation and drying, resulting in higher stable Mn and Fe and/or micro aggregates, which are less effected by the pH adjusted to 6 and 7 treatments. The Mn- and Fe- reducing bacteria needed more energy to reduce Mn and Fe formed as coating or concretions. Insufficient reducible Mn and Fe limited Mn- and Fe-reducing bacteria resulting in lowering their activity and the Eh decreased. The distribution of the Eh was attributed to the competition between fermentation and anaerobic respiration. The subsurface horizons with less stable aggregate showed a gradual decreasing trend.

The M.Bw.S51 treatment showed a gradual Eh distribution (Fig. 2.3.2). This phenomenon was more pronounced for the pH treatment adjusted to 5, 6, and 7 of the Bss horizon (Fig. 2.3.4) because this horizon had a greater amount of Fe_o , approximately 6,000 g/kg, than the other horizons that ranged from 3,900

to 4,700 mg/kg (Table 2.4.1). The Eh for the M.Bkss.S51 decreased to –125 mV within 48 hours and then increased gradually to 170 mV during 21 days. Based upon the pH, the Bkss horizon had a greater fermentation during the incubation period, indicating greater OC loss by way of CO₂. Without an energy source, the Eh increased during the incubation period. Patrick (1980) noted that soils with greater amounts of amorphous Mn and Fe that could be readily used as electron acceptors retarded the additional decrease of Eh. This phenomenon could be used to explain the distribution of the Eh for the M.Bss.S51, M.Bss.S61, and M.Bss.S71 treatments. Due to greater reduction of Mn and Fe, the Eh was greater for the M.Bss.S51 treatment than for the M.Bss.S71 treatment.

Except for the S.Ap1.S01, S.Ap1.S71, S.Ap1.S61, S.Ap2.S01, and S.Ap2.S71 treatments, the Eh did not show a bimodal distribution during the first incubation period (Fig. 2.3.9 and 2.3.10). The lower pH treatment increased fermentation reaction. The time required to increase the Eh was less for the S.Ap1.S01 treatment than for the S.Ap1.S61 treatment. However, the pH adjusted to 5 treatment increased the quantity of reducible Mn and Fe, resulting in a higher Eh for the S.Ap1.S51 treatment. The distribution of Eh for the different pH Bssg1 and Bssg2 horizons treated with sucrose was similar to that of the S.Ap1.S51 treatment (Fig. 2.3.11 and 2.3.12). The S.Bssg2.S51 treatment had a greater Eh than did the S.Bssg2.S01 treatment due to a greater quantity of reducible Mn and Fe.

Second Saturation Period

The Eh for the M.Ap.02 treatment after re-saturation (Fig. 2.3.5) decreased gradually and reached the reducing condition for Mn below a critical value of 250 mV at pH 7. The decreasing Eh was due to more available OC transformed from part of the resistant decomposable OC after alternative saturation and drying treatment. Franzluebbers, et al. (2000) reported that the flush of CO₂ during the first day following re-wetting of dried soil was related to both soil microbial biomass C and potentially mineralizable C and N in eight soils from Texas. The Eh was limited within a rather narrow range and increased gradually after the soil was air-dried. The low OC contents of soils resulted in limited microbial activity where Eh was not low enough to reduce Fe. The Eh for the M.Ap.72, M.Ap.62, and M.Ap.52 treatments was greater than that of the M.Ap.02 treatment. This difference can be ascribed to the loss of OC during the pH adjustment period. The Eh for other horizons of Moreland soil with no sucrose treatment was above the reduction threshold to reduce Mn and Fe (Fig. 2.3.6, 2.3.7, and 2.3.8).

The Eh for the S.Ap1.02 treatment during the re-saturation period decreased gradually to 90 mV, which was less than the threshold to reduce Mn and Fe (Fig. 2.3.13). The Eh for other horizons of the Sharkey soil with no sucrose treatment was above the reduction threshold to reduce Mn and Fe due to the insufficient and stable OC (Fig. 2.3.14, 2.3.15, and 2.3.16).

The distribution of the Eh for the M.Ap.S02 and M.Ap.S72 treatments was bimodal (Fig. 2.3.5). The Eh for the M.Ap.S02 treatment decreased to

approximately -180 mV, reaching below the Fe reduction threshold within 12 hours. The lowest minimum Eh was -180 mV for the M.Ap.S02 treatment, which was greater than -260 mV for the M.Ap.S01 treatment. This was because of less OC and more amorphous Mn and Fe used as alternative electron acceptors. The increased amorphous Fe partially resulted from the transformation of crystalline Fe oxides during the first incubation and drying treatments (Dowling et al., 1991). Consequently, the increase in Eh during the first few days was due to the decreasing population of fermentative microbes and effects of increased non-crystalline Mn or Fe. A decrease in Eh was observed again, indicating that a lack of reducible Mn and Fe and an increased population of fermentative bacteria. The Eh remained at this level until drying. While the treatments were drying, oxygen was reintroduced and the Eh sharply increased. The Eh for the M.Ap.S52 and M.Ap.S62 treatments decreased gradually during the re-saturation period. The distribution of the Eh for the M.Ap.S52 treatment was higher than that of the M.Ap.S72 treatment, indicating greater concentrations of amorphous Mn and Fe were available to accept electrons. The Eh for other horizons of the Moreland soil showed similar trends to that of the M.Ap.S52 treatment (Fig. 2.3.6, 2.3.7, and 2.3.8).

The distribution of Eh for the S.Ap1.S02 treatment (Fig. 2.3.13) was bimodal and similar to that of the S.Ap1.S01 treatment (Fig. 2.3.9). However, the minimum and maximum Eh were greater for the S.Ap1.S02 treatment due to fewer energy sources and greater concentration of readily reducible Mn and Fe. The S.Ap1.S52 treatment had the same distribution of Eh as the

S.Ap1.S02 treatment. The maximum Eh was greater for the S.Ap1.S52 treatment due to a greater quantity of readily reducible Mn and Fe. The minimum Eh was less for the Ap1 horizon than other horizons due to a greater OC content within the Ap1 horizon. The Eh for the different pH Ap2, Bssg1, and Bssg2 horizons treated with sucrose was similar to each other (Fig. 2.3.14, 2.3.15, and 2.3.16). Samples adjusted to pH 5 remained at the maximum Eh longer than did higher pH treatments due to more freshly amorphous Mn and Fe produced during the first incubation and drying treatments.

2.4.3. Mn and Fe in Soil Solution

A large quantity of reducible Mn and Fe transform into exchangeable and water soluble Fe and Mn under a low pH and Eh (Gotoh and Patrick, 1972; 1974; Sparrow and Uren, 1981). The concentrations of Fe and Mn ions in soil solutions were measured at the end of the first incubation period to estimate the redox environment needed for the reduction of Fe and Mn.

The concentrations of Mn ions significantly increased in the pH adjusted to 5 horizons of Moreland soil with no sucrose treatment (Table 2.3.1). The Mn increased from 0.03 mg/L for the M.Ap.0 treatment to 6.87 mg/L for the M.Ap.5 treatment. Low pH and Eh can enhance the conversion of the oxidized Mn to both the water soluble and exchangeable forms even under aeration conditions (Gotoh and Patrick, 1972). This trend was more pronounced for Mn than for Fe (Olomu et al., 1972). The Mn in the M.Bkss.5 treatment was as high as 11.8 mg/L, which corresponded to its profile morphological property where there were greater soft Mn masses. The high concentration of Ca^{2+} ions in the Bkss

soil solution could compete the exchangeable sites of clay particles with Mn^{2+} ions, which also presumably resulted in greater Mn^{2+} concentration in Bkss soil solution. Based on the result of Eh, it was too high for Mn to reduce. Therefore, the increased concentrations of Mn ions were mainly due to the abiotic dissolution from oxidized Mn rather than the reduction of Mn by microorganisms. The Mn^{2+} was very low at pH levels of 6 or more, indicating that there was no Mn reduction or abiotic dissolution. The same conclusions were also supported by a greater Eh. The greater quantity of Mn in the Moreland soil is probably another factor that prohibits the formation of redoximorphic features since Mn is reduced at a greater Eh.

The Mn in the Sharkey soil with no sucrose treatment increased with decreasing pH treatment. The Mn increased from 0.01 mg/L for the S.Ap1.0 treatment to 0.45 mg/L for the S.Ap1.5 treatment. The Mn in the pH 5 Sharkey soil was less than that of the pH 5 Moreland soil due to lower total Mn (Mn_d) in the Sharkey soil (Tables 2.4.1 and 2.4.2), even though the Eh was low enough to reduce Mn in the Ap1 horizon. The Mn was 6.87 mg/L for the M.Ap.5 treatment and 0.45 mg/L for the S.Ap1.5 treatment. Another possibility to explain this lower Mn in the Sharkey soil might be that the Mn co-precipitated with Fe and was not dissolved by acidification.

The concentration of Fe for the Moreland soil with no sucrose treatment was negligible (approximately 0.14 mg/L) even when the soil pH was as low as 5 (Table 2.3.2). Vepraskas and Wilding (1983b) found that the total dissolved Fe contents in the groundwater were consistently less than 3 mg/L in those

studied soils where the reduction of Fe was low. The low Fe corresponds to the high Eh. Macedo and Bryant (1989) reported that no microbial growth and no evidence of Fe reduction was observed in soils low in OC. The distributions of the Eh for the S.Ap1.0 and S.Ap1.7 treatments were low for Fe to reduce during the first incubation period, but the Fe was not significantly different from other lower pH treatments. This indicates that the concentration of reduced Fe was either too low and/or absorbed onto exchangeable sites (Gotoh and Patrick, 1974; Sparrow and Uren, 1981).

From the results of Tables 2.3.1 and 2.3.2, soil pH did not seem to limit the microbial activity responsible for the reduction because Mn and Fe increased with decreased pH treatments treated with sucrose for the same horizon. The Mn increased with decreasing pH treatment, indicating that Mn was not completely reduced at the higher pH conditions before microbes begin to use Fe as an electron acceptor. The Mn in the Moreland soil treated with sucrose was greater than that of the Sharkey soil with the same treatment. The Mn was 42.7 g/L for the M.Ap.0S treatment and 29.0 mg/L for the S.Ap1.0S treatment. The lower Mn in the Bssg1 and Bssg2 horizons of the Sharkey soil was assumed to be an important factor that controlled the pH during incubation. The rate of decreasing pH was greater for the Bssg1 horizon than for the Ap1 horizon (Fig. 2.2.9 and 2.2.11). The Fe was mainly in the form of Fe^{2+} because Fe^{3+} ion was only present in low pH and high Eh environments. Blume and Schlichting (1985), Olomu et al. (1973), and Schwab and Lindsay (1983) found that most soluble Fe in flooded soils was complexed with OC because organic

acids were readily produced under anaerobic conditions (Stevenson and Fitch, 1986). The greater Fe and Mn at pH 5 might be due to H^+ and Al^{3+} ions displacing Fe^{2+} and Mn^{2+} ions from the exchange sites of clay to the soil solution (Gotoh and Patrick, 1972; 1974). Amorphous Fe was the main Fe form in the Sharkey soil, and crystalline Fe was the major Fe form in the Moreland soil (Tables 2.4.1 and 2.4.2). The microbes required more energy to reduce crystalline Fe. However, the Fe in the Moreland soil was greater than that of the Sharkey soil, implying that the types of Fe did not affect the Fe in an energy rich environment.

2.4.4. Fe Oxide Transformation

Free Fe ranged from amorphous to crystalline forms and possessed a spectrum of energy levels that comprised a continuum from readily extractable to extremely non-extractable Fe (Schwertmann, 1973). The influence of chemical dissolution reagents by sodium pyrophosphate, acid oxalate, and DCB extraction may not fully account for difference in the amorphous and crystalline Fe oxide forms. Nevertheless, the relationship between different chemical dissolution reagents has been confirmed for different soils and experimental approaches (McKeague and Day, 1966; McKeague et al., 1971; Pawluk, 1972). Under anaerobic conditions, Fe oxides will be transformed into different forms, but silicate minerals will not be affected by microbial respiration. From the samples after sucrose and pH treatments, therefore, valuable information about Fe transformation introduced by chemical dissolution reagents before and after different treatments can be inferred.

However, the interpretation that follows remain speculative since it is based upon Fe_p , Fe_o , and Fe_d data, which is assumed to be reliable measures of the quantity of organic, inorganic amorphous, and crystalline Fe.

With successive pH treatment, the Fe_p increased, indicating that the 0.1 HCl treatments dissolved some inorganic Fe (Table 2.4.1). The Fe_p increased from 248 mg/kg for the M.Ap.0(1) treatment to 500 mg/kg for the M.Ap.5(1) treatment. The slight increase in Fe_p with incubation for the Moreland soil showed that little Fe reduction occurred even though the OC content was very low. The Fe_p increased from 248 mg/kg for the M.Ap.0(1) treatment to 429 mg/kg for the M.Ap.0(2) treatment. However, the Eh showed that no Fe reduction was occurring (Fig. 2.3.1). The concentration of Fe_p ranged from 860 to 1,170 mg/kg in the natural pH Sharkey soil, which was much greater than that of the Moreland soil (Tables 2.4.1 and 2.4.2). The distribution of Fe_p for the Sharkey soil showed a similar trend to the Moreland soil.

The Fe_p increased with sucrose treatments for the Moreland and Sharkey soils after the 3-week incubation (Tables 2.4.1 and 2.4.2). This suggests that the reduction of Fe significantly increased when microorganisms had a sufficient energy source. The increased Fe_p resulted from the reduction of amorphous and/or crystalline inorganic Fe. The Fe_p increased with decreased pH treatments, indicating that lowering the pH increases the solubility of inorganic Fe oxides for microbes to use as electron acceptors. The Fe from the soil solution for the pH 5 treatment showed similar tendencies (Tables 2.3.1 and 2.3.2). However, the Fe_p from the pH adjusted to 5 and 6 for the Bkss

horizons of Moreland soil did not increase with decreasing pH treatments. This was presumably due to more active fermentation during incubation periods because of greater Ca^{2+} ions competing with humus for Fe^{2+} . The Fe_p decreased immediately after the first drying treatment, indicating that aerobic microorganisms were responsible for breaking down the Fe-organic complexes during the drying period. The Fe released from the Fe-organic complexes transformed into an inorganic Fe form that could not be dissolved with sodium pyrophosphate (Dowling et al., 1991). After the re-saturation and second drying treatments, the Fe_p decreased but much less than during the first drying treatment. The Fe_p increased from 248 mg/kg for the M.Ap.0(1) treatment to 1,794 mg/kg for the M.Ap.0S(2) treatment and then decreased to 891 mg/kg for the M.Ap.0S(3) treatment. It decreased from 891 mg/kg for the M.Ap.0S(3) treatment to 887 mg/kg for the M.Ap.0S(4) treatment.

The Fe_o did not change for the Moreland and Sharkey soil when sucrose was not added to the samples (Tables 2.4.1 and 2.4.2). An increase in the Fe_o for the Moreland soil treated with sucrose was observed after the 3-week incubation showing a similar tendency to the increase in Fe_p content (Table 2.4.1). However, the overall increase Fe_o was less than the increase in Fe_p , indicating the sodium pyrophosphate dissolved a portion of the inorganic amorphous Fe (Wada, 1989). Comparing the Fe_o for the Moreland soil with sucrose treatment before and after the first incubation, I conclude that some of the increased Fe_o was from the reduction of crystalline Fe; otherwise, the Fe_o after incubation would be the same as before the first incubation. The Fe_o for

the Moreland soil increased after the first drying treatment, indicating a continuous reduction of crystalline Fe forms before the soils were air-dried. After the re-saturation and second drying treatments, the Fe_o increased for some treatments and decreased for others. For those treatments in which the Fe_o increased, the Fe was bound via an Fe chelate. The decrease resulted from Fe either being incorporated as an amorphous Fe complex or into an ordered Fe crystalline phase. The formation of these components that result during slow drying have been reported by Mckeague et al. (1971) and Willett et al. (1992). The Fe_o did not change for the Sharkey soil treated with sucrose because amorphous Fe comprised more than 90% of the total Fe (Table 2.4.2).

The concentration of inorganic amorphous Fe was based upon the difference between Fe extracted by oxalate and by pyrophosphate ($Fe_o - Fe_p$). This difference explains the amount of inorganic amorphous Fe present after different treatments. The Fe_{o-p} did not change for the Moreland and Sharkey soils when no sucrose was added, suggesting no reduction of Fe. The Fe_{o-p} decreased for the Moreland and Sharkey soils treated with sucrose after the first incubation period, indicating that some inorganic amorphous Fe was transformed into organic amorphous forms (Tables 2.4.1 and 2.4.2). After the first drying treatment, the Fe_{o-p} for the soils with sucrose treatment increased and was greater than before the first incubation, showing that the Fe-humus complexes transformed into inorganic amorphous Fe forms. After the re-saturation and second drying treatments, the Fe_{o-p} did not change. This means that the newly formed amorphous inorganic Fe were the major electron

acceptors. Based on the above results, the crystalline and amorphous inorganic Fe in the Moreland soil were reduced simultaneously during the experiment. The results from Fe_{d-o} data decreased for the Moreland soil treated with sucrose after the freeze-dry and first drying treatments confirmed that amorphous and crystalline Fe were reduced simultaneously.

2.4.5. Soil Colors

The matrix color for the Moreland soil with no sucrose treatment after the first and second drying treatments was 5YR 3/3, which was identical to the color of the initial soil (Tables 2.5.1 and 2.5.2). This unchanged color suggests that no Fe reduction occurred even though the soil pH was as low as pH 5. The redoximorphic features observed for the S.Ap1.01 and S.Ap.71 treatments with greater OC indicate that the lack of an energy source for microbial activity was the most important factor preventing the reduction of Mn and Fe.

Thin, fragile Fe oxide films on the water surface were observed near the end of the 3-week incubation for most Moreland and Sharkey soils treated with sucrose. The presence of Fe oxide hydrates on the water surface suggests that reduced Fe diffused to the surface layer from the pool of electrons within the soils (Bartlett and James, 1993). No Fe oxide film was observed for soils whose pH was lower than 5. There were no films because of the low pH of the soil solution, which prevented the precipitation of Fe. Low chroma extending into the soil surface was observed in all soils. The low chromas were limited to the soil surface because these clayey soils impeded the diffusion of SOC into the bottom soil matrix. After the re-saturation and second drying treatments,

many yellowish hues with high chroma redoximorphic features were observed on the surface of soils treated with sucrose (Table 2.6), indicating that Fe reduction occurred during re-saturation, which is consistent with the results of Eh. However, the intensity of reduction was far less than during the first incubation period due to lower usable energy sources.

CHAPTER 3.

THE EFFECTS OF DIFFERENT SUCROSE CONCENTRATIONS ON THE CHANGES OF pH, Eh, Fe TRANSFORMATION, AND SOIL COLORS

3.1. Introduction

The reduction of Fe or Mn oxides depended mainly on: (i) the quantity of easily decomposable organic matter (OM) (Alexander, 1977), (ii) the pH and Eh status of the soil at the time of flooding (Ponnamperuma, 1972), (iii) the presence of other oxidants (Patrick and Jugsujinda, 1992), and (iv) the amount, crystallinity and particle size of the pedogenic free Fe(III) oxides (Munch et al., 1978). Of these, soluble organic carbon (SOC) was the most important attribute (Alexander, 1977). The absence of Fe reduction in soils that lacked an energy source or oxidizable OM was reported by Franzmeier et al. (1983), Couto et al. (1985), Bryant and Macedo (1990), and Jacob et al. (1997). The organic carbon (OC) was an energy source for microbes and may interact with clay and metallic ions. The interaction was attributed to O-functional groups such as COOH, O-, phenolic-, alcoholic, enolic-OH, and C=O structures of various types (Mortland; 1986; Schnitzer, 1986; Stevenson and Fitch, 1986).

The kind and quantity of other oxidants such as Fe and Mn were the second most important attribute. Clay minerals were the source of Fe because clay minerals containing Fe were more vulnerable to acids (Schnitzer, 1986). The Fe ion with high positive valence and strong coordination ability were more susceptible to organic acids than weakly coordinated ones (e.g. Ca and Mn) (McBride ,1978; Camerlynck and Kiekens, 1982). Fe availability in soils seemed to be highly dependent upon organic acids. The Fe^{2+} activity in soil

with high OM was suppressed by the formation of organic complexes and the Fe^{3+} oxides reduction was enhanced (Bao, 1985). Organic acids strongly interfered with the activity of Fe in soil solution and influenced the types, crystallinity, and crystal morphology of oxides (Schwertmann et al., 1986).

Reduction rates in soils correlated better with SOC than with total soil carbon because much of the total carbon was highly resistant to decomposition. Glucose-C extracted from soils provided an index of C sources that were relatively susceptible to decomposition (Stanford et al., 1975). SOC or other OM sources have been used to maintain microbial activities for microcosm experiments (Daniel et al., 1973; Gotoh and Patrick, 1974; Smid and Beauchamp, 1976; Gilliam and Gambrell, 1978; Munch et al., 1978; Munch and Ottow, 1980; Bergman et al., 2000). Obenhuber and Lowerance (1991) and Daniel and Buol (1992) estimated different concentrations of dissolved OC necessary for the reduction of NO_3^- , Mn^{4+} , and Fe^{3+} . Dobos et al. (1990) investigated the effects of three levels of alfalfa (3.2, 9.6, and 15.4 g kg^{-1}) on color changes in an Alfisol. He found that the hue became more yellow and chroma decreased with increasing concentrations of OC. The amount of decomposable organic materials exerted a dominant influence on pH and critical redox potentials for Fe and Mn reduction, but the transformation of Fe minerals was still uncertain. The first objective of this study was to investigate the effects of sucrose upon pH, threshold redox potentials for Fe and Mn reduction, and the transformation of Fe oxide minerals. The second objective

was to compare the Moreland and Sharkey soils treated with different sucrose concentrations.

3.2. Materials and Methods

3.2.1. Materials

The surface horizons of Moreland and Sharkey soils were selected for this study. The natural pH for the Moreland and Sharkey soils was 7.4 and 6.4, respectively. Two soil pHs were used: the natural pH and pH 5 created by adding 0.1 N HCl. Seven concentrations of sucrose based on soil weight were used: 20, 10, 5, 2.5, 1, 0.5, and 0.25 g/kg. The incubation procedures were the same as those described in Chapter 2.

3.2.2. Analysis Methods

The analysis of Fe and Mn in soil solutions and the methods of selective chemical dissolution were described in Chapter 2.

Total organic carbon (TOC) was measured with a LECO CN-2000 Carbon-analyser using a temperature of 1100°F. SOC was extracted by cold water using the method of Lu et al. (2000). The same method quantified SOC in soil solutions.

Soil color was determined at the end of incubation using Munsell Soil Color charts and spectral reflectance using a Chroma Meter, Minolta Corporation CR-200, quantitative soil color Munsell notation.

3.3. Results

3.3.1. pH

Moreland Soil

The notations for Moreland soil with different sucrose treatments are presented in Table 3.1.1. Figure 3.1.1 shows the temporal pH changes for the Moreland soil with different levels of sucrose treatment during the first incubation period. The pH for the M.01.20g/kg treatment decreased from 7.6 to 7.1 within 24 hours and steadily decreased to pH 5.5 within 48 hours. The pH increased gradually to 5.9 during the remainder of 21 days of incubation. The decreasing pH for the M.01.10g/kg treatment was greater within 24 hours than that of the M.01.20g/kg treatment. The pH for the M.01.10g/kg treatment decreased from 7.6 to 5.9 within 24 hours and to 5.6 within 48 hours. It gradually increased to 6.2 during 21 days. The pH for the M.01.5g/kg treatment was less pronounced than for the M.01.20g/kg and M.01.10g/kg treatments. The pH decreased to 6.0 within 96 hours and increased to 6.7 during the experiment. The pH for the M.01.2.5g/kg treatment decreased to 6.6 within 72 hours and gradually increased to 7.0 during 21 days. The pH for the M.01.1g/kg, M.01.0.5g/kg, and M.01.0.25g/kg treatments was similar. The pH decreased gradually to 7.0 and remained at this pH for the duration of the experiment.

The samples were air-dried and re-saturated. The pH increased 0.4 units from 5.9 to 6.3 for the M.02.20g/kg treatment and from 6.2 to 6.8 for the M.02.10g/kg treatment at the beginning of re-saturation (Fig. 3.1.2). The pH for

Table 3.1.1. Treatment explanation for the Moreland soil during the first and second incubation period.

Treatment abbreviation	Treatments
M.01.20g/kg	Moreland, natural pH, first incubation, with 20g/kg sucrose.
M.01.10g/kg	Moreland, natural pH, first incubation, with 10g/kg sucrose.
M.01.5g/kg	Moreland, natural pH, first incubation, with 5g/kg sucrose.
M.01.2.5g/kg	Moreland, natural pH, first incubation, with 2.5g/kg sucrose.
M.01.1g/kg	Moreland, natural pH, first incubation, with 1g/kg sucrose.
M.01.0.5g/kg	Moreland, natural pH, first incubation, with 0.5g/kg sucrose.
M.01.0.25g/kg	Moreland, natural pH, first incubation, with 0.25g/kg sucrose.
M.02.20g/kg	Moreland, natural pH, second incubation, with 20g/kg sucrose.
M.02.10g/kg	Moreland, natural pH, second incubation, with 10g/kg sucrose.
M.02.5g/kg	Moreland, natural pH, second incubation, with 5g/kg sucrose.
M.02.2.5g/kg	Moreland, natural pH, second incubation, with 2.5g/kg sucrose.
M.02.1g/kg	Moreland, natural pH, second incubation, with 1g/kg sucrose.
M.02.0.5g/kg	Moreland, natural pH, second incubation, with 0.5g/kg sucrose.
M.02.0.25g/kg	Moreland, natural pH, second incubation, with 0.25g/kg sucrose.
M.51.20g/kg	Moreland, pH 5, first incubation, with 20g/kg sucrose.
M.51.10g/kg	Moreland, pH 5, first incubation, with 10g/kg sucrose.
M.51.5g/kg	Moreland, pH 5, first incubation, with 5g/kg sucrose.
M.51.2.5g/kg	Moreland, pH 5, first incubation, with 2.5g/kg sucrose.
M.51.1g/kg	Moreland, pH 5, first incubation, with 1g/kg sucrose.
M.51.0.5g/kg	Moreland, pH 5, first incubation, with 0.5g/kg sucrose.
M.51.0.25g/kg	Moreland, pH 5, first incubation, with 0.25g/kg sucrose.
M.52.20g/kg	Moreland, pH 5, second incubation, with 20g/kg sucrose.
M.52.10g/kg	Moreland, pH 5, second incubation, with 10g/kg sucrose.
M.52.5g/kg	Moreland, pH 5, second incubation, with 5g/kg sucrose.
M.52.2.5g/kg	Moreland, pH 5, second incubation, with 2.5g/kg sucrose.
M.52.1g/kg	Moreland, pH 5, second incubation, with 1g/kg sucrose.
M.52.0.5g/kg	Moreland, pH 5, second incubation, with 0.5g/kg sucrose.
M.52.0.25g/kg	Moreland, pH 5, second incubation, with 0.25g/kg sucrose.

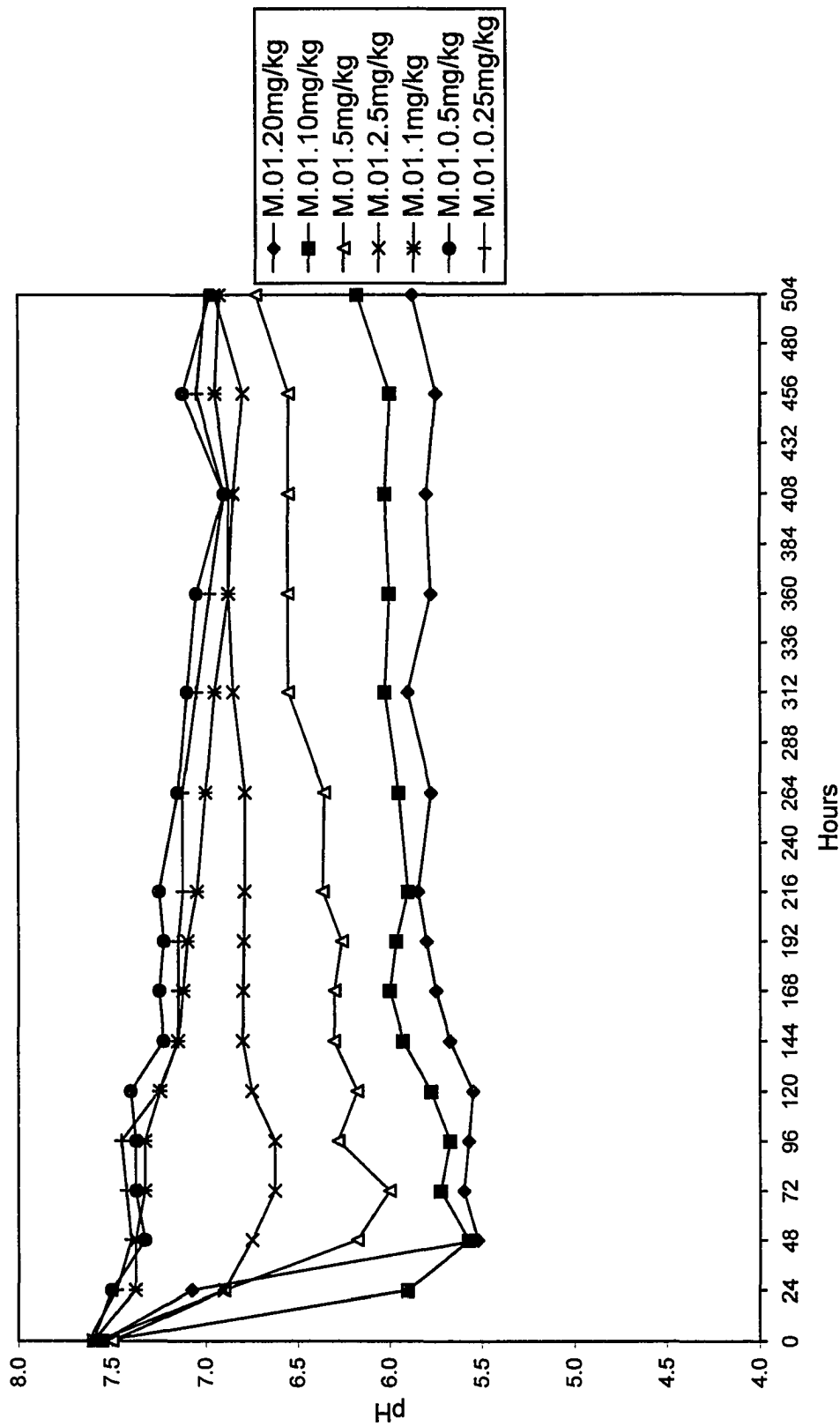


Figure 3.1.1. Mean pH values of the natural pH Moreland soil during the first incubation period.

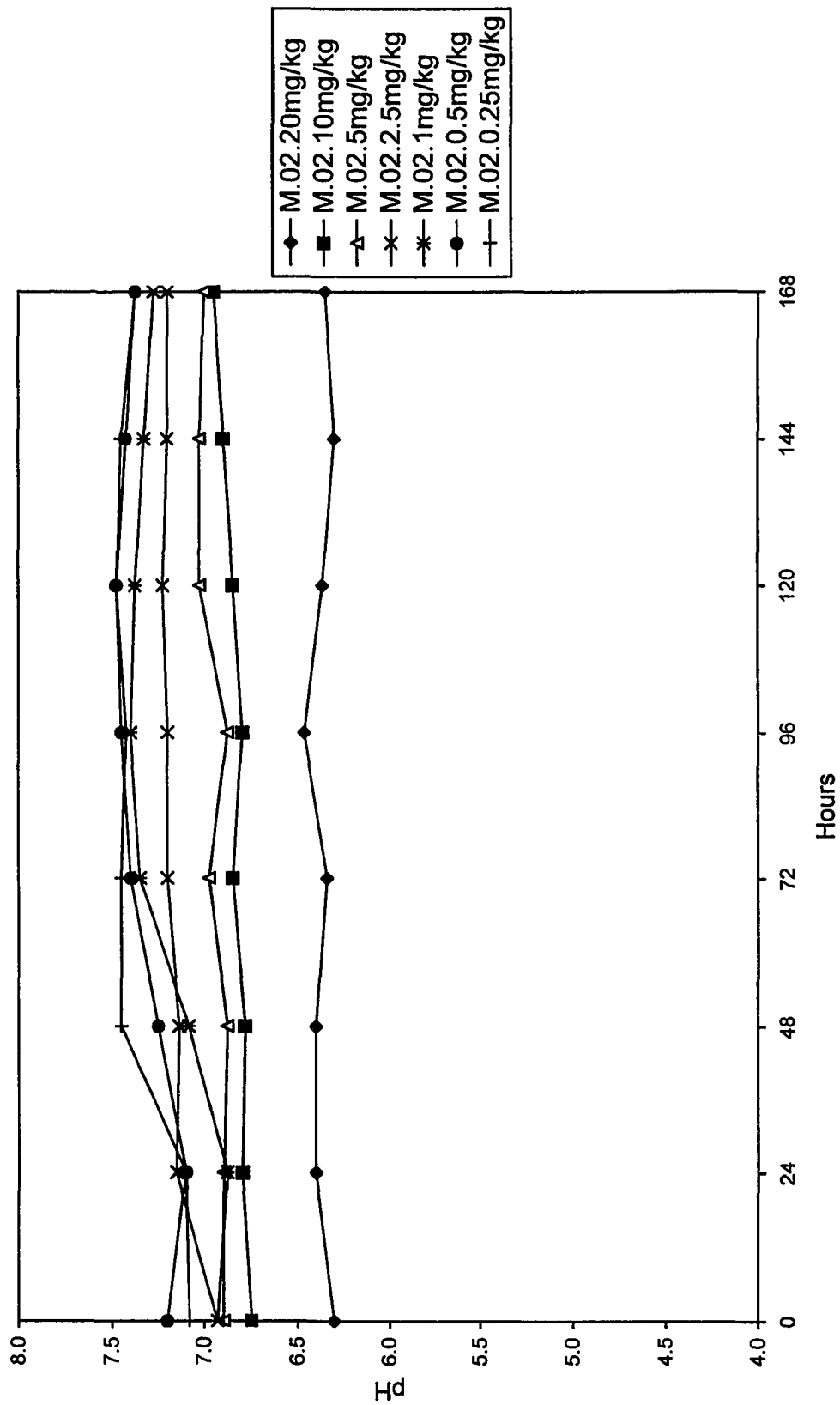


Figure 3.1.2. Mean pH values of the natural pH Moreland soil during the re-saturation period.

the M.02.20g/kg treatment remained stable at pH 6.4 during the re-saturation period. The pH for the M.02.5g/kg, M.02.2.5g/kg, M.02.1g/kg, M.02.0.5g/kg, and M.02.0.25g/kg did not appreciably change during the experiment. Soil pH approached 7.3 for soils treated with less than 2.5 g/kg sucrose.

The pH for the pH 5 Moreland soil treated with different levels of sucrose is presented in Fig. 3.1.3. The pH for the M.51.20g/kg treatment increased from pH 5.1 to 5.5 within 72 hours and stabilized at approximately 5.5 for the duration of the experiment. The pH's for the M.51.10g/kg, M.51.5g/kg, and, M.51.2.5g/kg treatments were consistent with that of the M.51.20g/kg treatment. The pH values measured at the end of incubation were 5.8, 5.9, and 6.2 for the M.51.10g/kg, M.51.5g/kg, and, M.51.2.5g/kg treatments, respectively. The pH for the soils treated with the less than 1 g/kg sucrose was the same as that of M.51.20g/kg treatment. The pH increased gradually from 5.0 to 5.8 for the M.51.1g/kg treatment, from 5.0 to 5.4 for the M.51.0.5g/kg treatment, and from 5.0 to 5.4 for the M.51.0.25g/kg treatment. The soil pH did not change for all treatments with less than 1 g/kg sucrose during the re-saturation period (Fig. 3.1.4).

Sharkey Soil

The notations for the Sharkey soil with different treatments are presented in Table 3.1.2. The pH's for Sharkey soil with different sucrose treatments during the first incubation period are shown in Figure 3.1.5. The pH decreased within 72 hours with increasing rate of sucrose. The pH for the S.01.20g/kg treatment

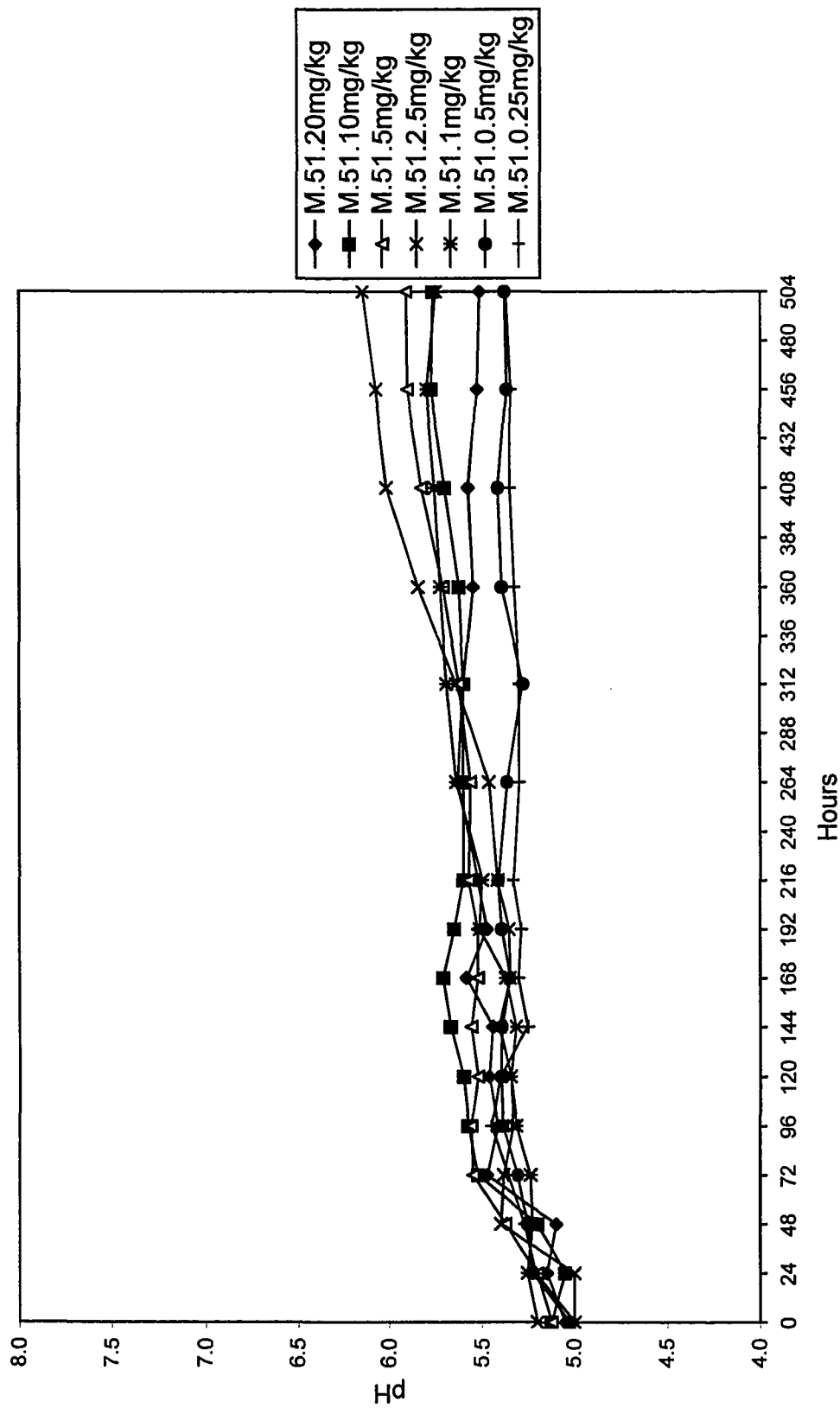


Figure 3.1.3. Mean pH values of the pH 5 Moreland soil during the first incubation period.

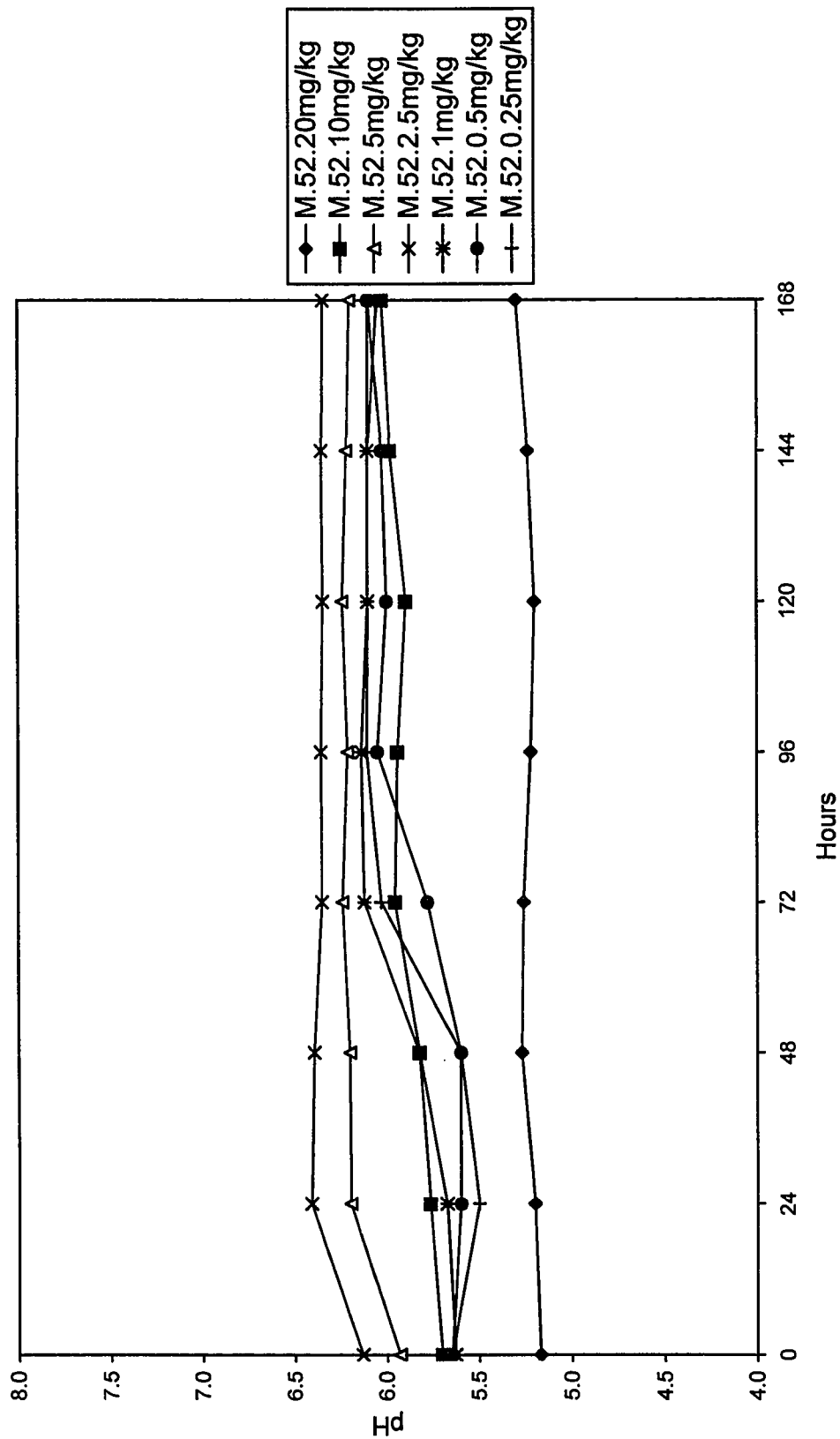


Figure 3.1.4. Mean pH values of the pH 5 Moreland soil during the re-saturation period.

Table 3.1.2. Treatment explanation for the Sharkey soil during the first and second incubation period.

Treatment abbreviation	Treatments
S.01.20g/kg	Sharkey, natural pH, first incubation, with 20g/kg sucrose.
S.01.10g/kg	Sharkey, natural pH, first incubation, with 10g/kg sucrose.
S.01.5g/kg	Sharkey, natural pH, first incubation, with 5g/kg sucrose.
S.01.2.5g/kg	Sharkey, natural pH, first incubation, with 2.5g/kg sucrose.
S.01.1g/kg	Sharkey, natural pH, first incubation, with 1g/kg sucrose.
S.01.0.5g/kg	Sharkey, natural pH, first incubation, with 0.5g/kg sucrose.
S.01.0.25g/kg	Sharkey, natural pH, first incubation, with 0.25g/kg sucrose.
S.02.20g/kg	Sharkey, natural pH, second incubation, with 20g/kg sucrose.
S.02.10g/kg	Sharkey, natural pH, second incubation, with 10g/kg sucrose.
S.02.5g/kg	Sharkey, natural pH, second incubation, with 5g/kg sucrose.
S.02.2.5g/kg	Sharkey, natural pH, second incubation, with 2.5g/kg sucrose.
S.02.1g/kg	Sharkey, natural pH, second incubation, with 1g/kg sucrose.
S.02.0.5g/kg	Sharkey, natural pH, second incubation, with 0.5g/kg sucrose.
S.02.0.25g/kg	Sharkey, natural pH, second incubation, with 0.25g/kg sucrose.
S.51.20g/kg	Sharkey, pH 5, first incubation, with 20g/kg sucrose.
S.51.10g/kg	Sharkey, pH 5, first incubation, with 10g/kg sucrose.
S.51.5g/kg	Sharkey, pH 5, first incubation, with 5g/kg sucrose.
S.51.2.5g/kg	Sharkey, pH 5, first incubation, with 2.5g/kg sucrose.
S.51.1g/kg	Sharkey, pH 5, first incubation, with 1g/kg sucrose.
S.51.0.5g/kg	Sharkey, pH 5, first incubation, with 0.5g/kg sucrose.
S.51.0.25g/kg	Sharkey, pH 5, first incubation, with 0.25g/kg sucrose.
S.52.20g/kg	Sharkey, pH 5, second incubation, with 20g/kg sucrose.
S.52.10g/kg	Sharkey, pH 5, second incubation, with 10g/kg sucrose.
S.52.5g/kg	Sharkey, pH 5, second incubation, with 5g/kg sucrose.
S.52.2.5g/kg	Sharkey, pH 5, second incubation, with 2.5g/kg sucrose.
S.52.1g/kg	Sharkey, pH 5, second incubation, with 1g/kg sucrose.
S.52.0.5g/kg	Sharkey, pH 5, second incubation, with 0.5g/kg sucrose.
S.52.0.25g/kg	Sharkey, pH 5, second incubation, with 0.25g/kg sucrose.

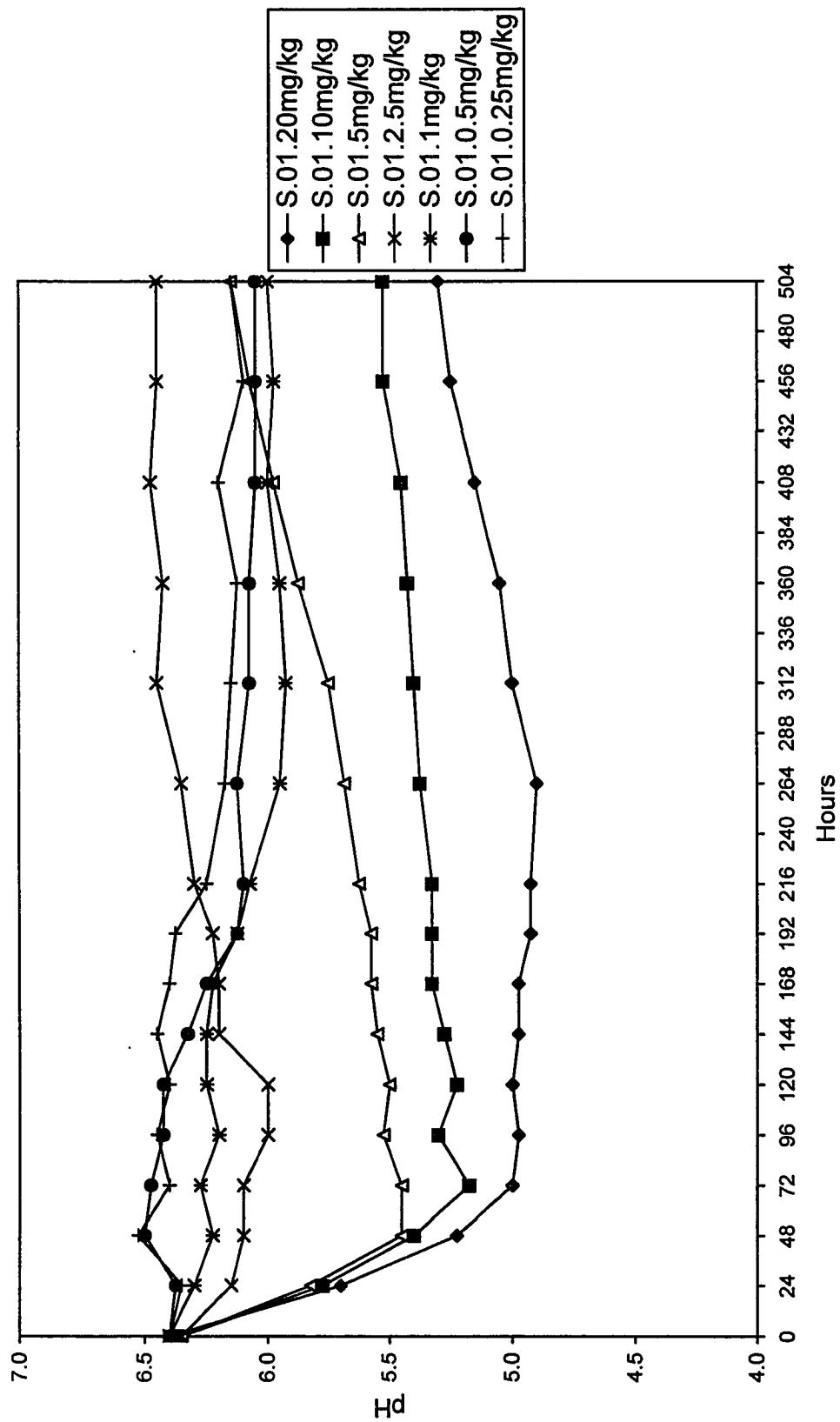


Figure 3.1.5. Mean pH values of the natural pH Sharkey soil during the first incubation period.

decreased from 6.4 to 5.7 within 24 hours and continued to decrease to 5.0 within 72 hours. It remained constant at 5.3 for the remainder of the incubation period. The pH's for the S.01.10g/kg, S.01.5g/kg, and S.01.2.5g/kg treatments was similar to that of S.01.20g/kg treatment. The pH decreased from 6.4 to 5.2 for the S.01.10g/kg treatment and from 6.4 to 6.1 for the S.01.2.5g/kg treatment within 72 hours. After soil pH reached a minimum value, the pH began to increase gradually. The pH was 5.3, 5.5, 6.2, and 6.5 for the S.01.20g/kg, S.01.10g/kg, S.01.5g/kg, and S.01.2.5g/kg treatments after 21 days. The pH for the S.01.1g/kg, S.01.0.5g/kg, and S.01.0.25g/kg treatments gradually decreased during the first incubation period. Soil pH decreased from 6.4 to approximately 6.1 for the S.01.1g/kg, S.01.0.5g/kg, and S.01.0.25g/kg treatments, respectively. The pH did not change for the natural pH Sharkey soil with different sucrose treatments after drying and re-saturation (Fig. 3.1.6).

The changes in pH for the pH adjusted to 5 Sharkey soil during the first incubation period are shown in Figure 3.1.7. The pH for both the S.51.20g/kg and S.51.10g/kg treatments decreased from 5.1 to 4.7 within 96 hours and remained constant at 4.7 for the remainder of the incubation period. The pH for the S.51.5g/kg treatment remained constant for 21 days. The pH for the S.51.2.5g/kg treatment gradually increased from 5.0 to 5.5. The pH for the S.51.1g/kg, S.51.0.5g/kg, and S.51.0.25g/kg treatments remained constant for 21 days.

Soil pH increased approximately 0.2 units for the S.52.20g/kg treatment during re-saturation and drying (Fig. 3.1.8). The pH increased 0.5 and 0.2 units

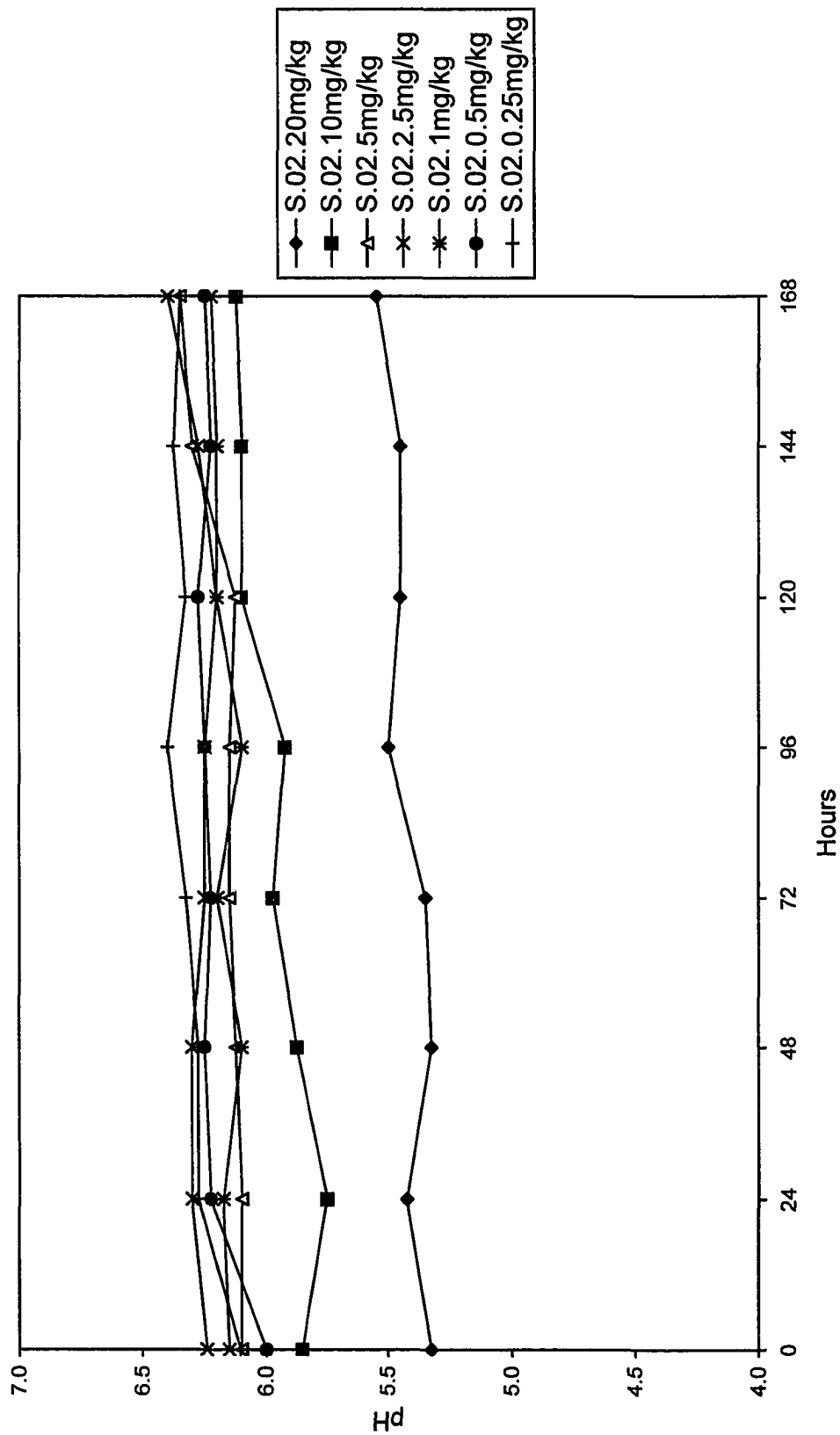


Figure 3.1.6. Mean pH values of the natural pH Sharkey soil during the re-saturation period.

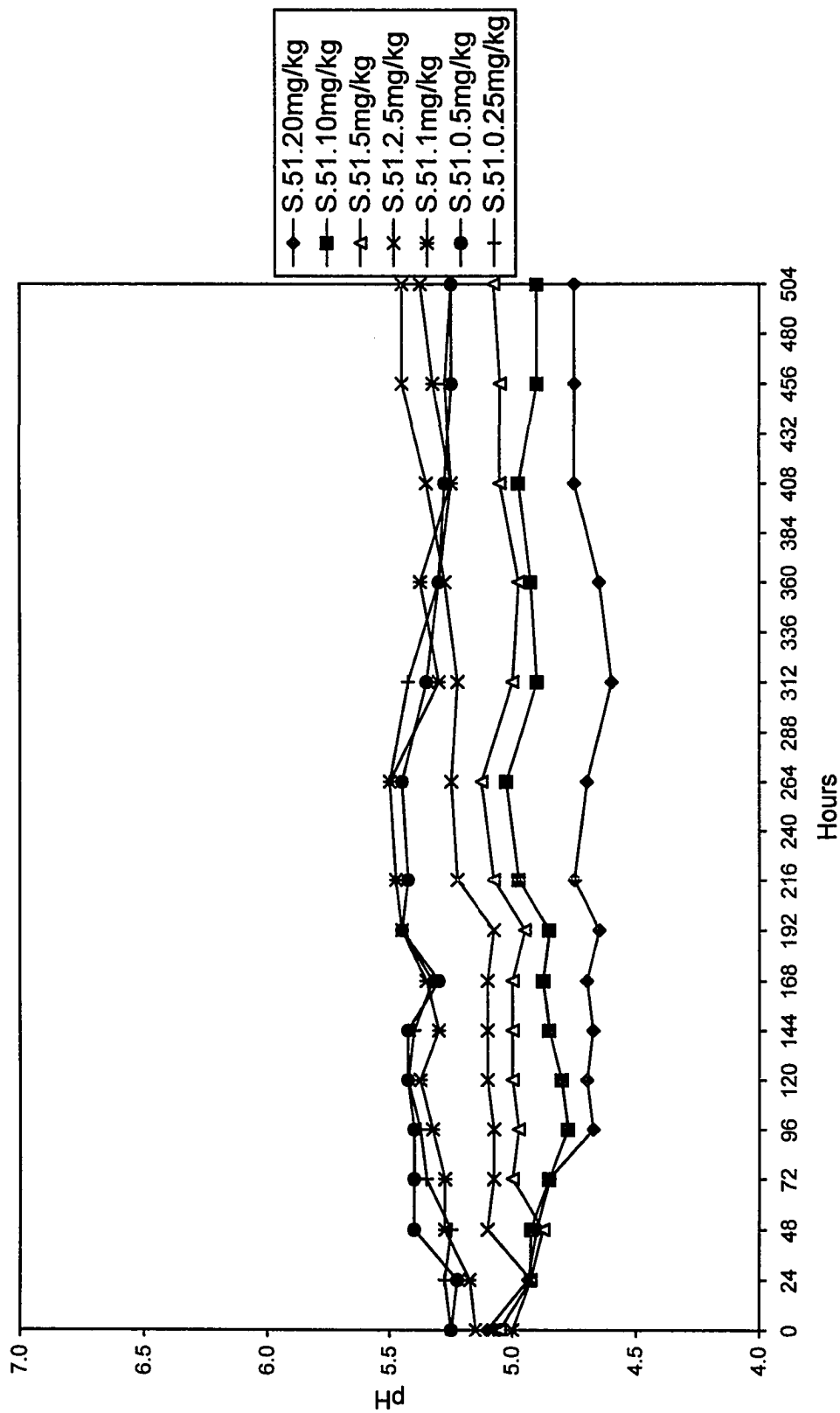


Figure 3.1.7. Mean pH values of the pH 5 Sharkey soil during the first incubation period.

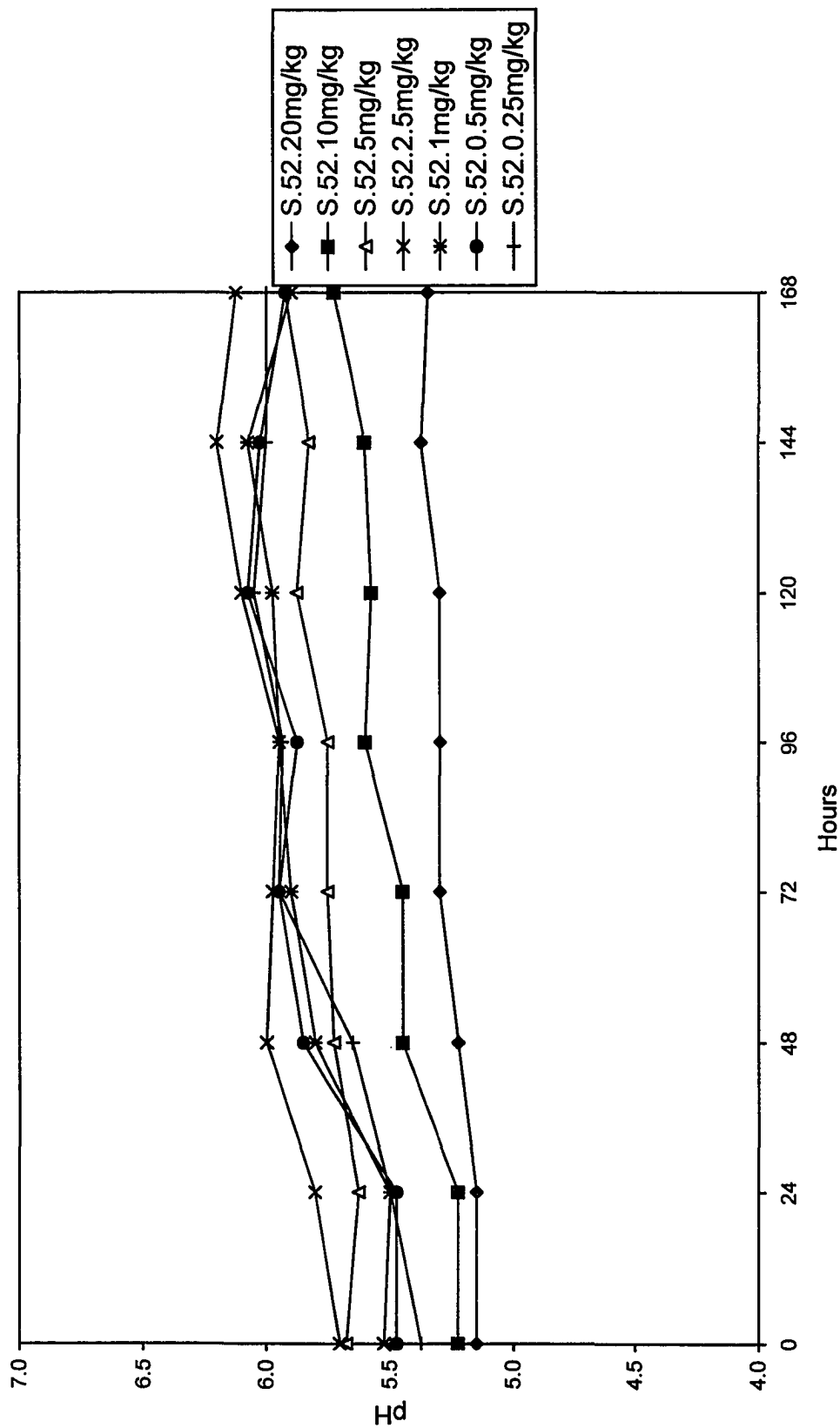


Figure 3.1.8. Mean pH values of the pH 5 Sharkey soil during the re-saturation period.

for the S.52.10g/kg and S.52.5g/kg treatments, respectively. The pH for the soils with the 2.5g/kg or less sucrose increased more than 0.4 units.

3.3.2. Eh

Moreland Soil

Data from Figure 3.2.1 show effects of sucrose concentrations on Eh during the first incubation period for the natural pH Moreland soil. Except for the M.01.0.25g/kg treatment, the distribution of Eh for the natural Moreland soil treated with different sucrose showed a bimodal distribution during first saturation (Fig. 3.2.1). The Eh for the M.01.20g/kg treatment decreased from 490 to –310 mV within 12 hours and increased gradually from –300 to –200 after 144 hours. The Eh increased after 144 hours of incubation to a maximum value of –10 mV after 336 hours, decreasing to –70 mV after 21 days. The redox potential of the M.01.20g/kg treatment would likely continue to decrease if the monitoring period was extended. The Eh for the M.01.10g/kg, M.01.5g/kg, M.01.2.5g/kg, and M.01.20g/kg treatments was similar to that of M.01.20g/kg treatment. However, less time was needed to increase the Eh for the lower sucrose treatment after the minimum Eh was reached. The M.01.10g/kg treatment took 120 hours to increase Eh compared to 24 hours for the M.01.2.5g/kg treatment.

The Eh for the M.01.1g/kg treatment decreased from 510 mV to –270 mV within 24 hours. It increased to 60 mV within 72 hours and remained constant for the duration of the experiment. The Eh for the M.01.0.5g/kg treatment decreased from 620 to 110 mV within 24 hours and increased to 240 mV within

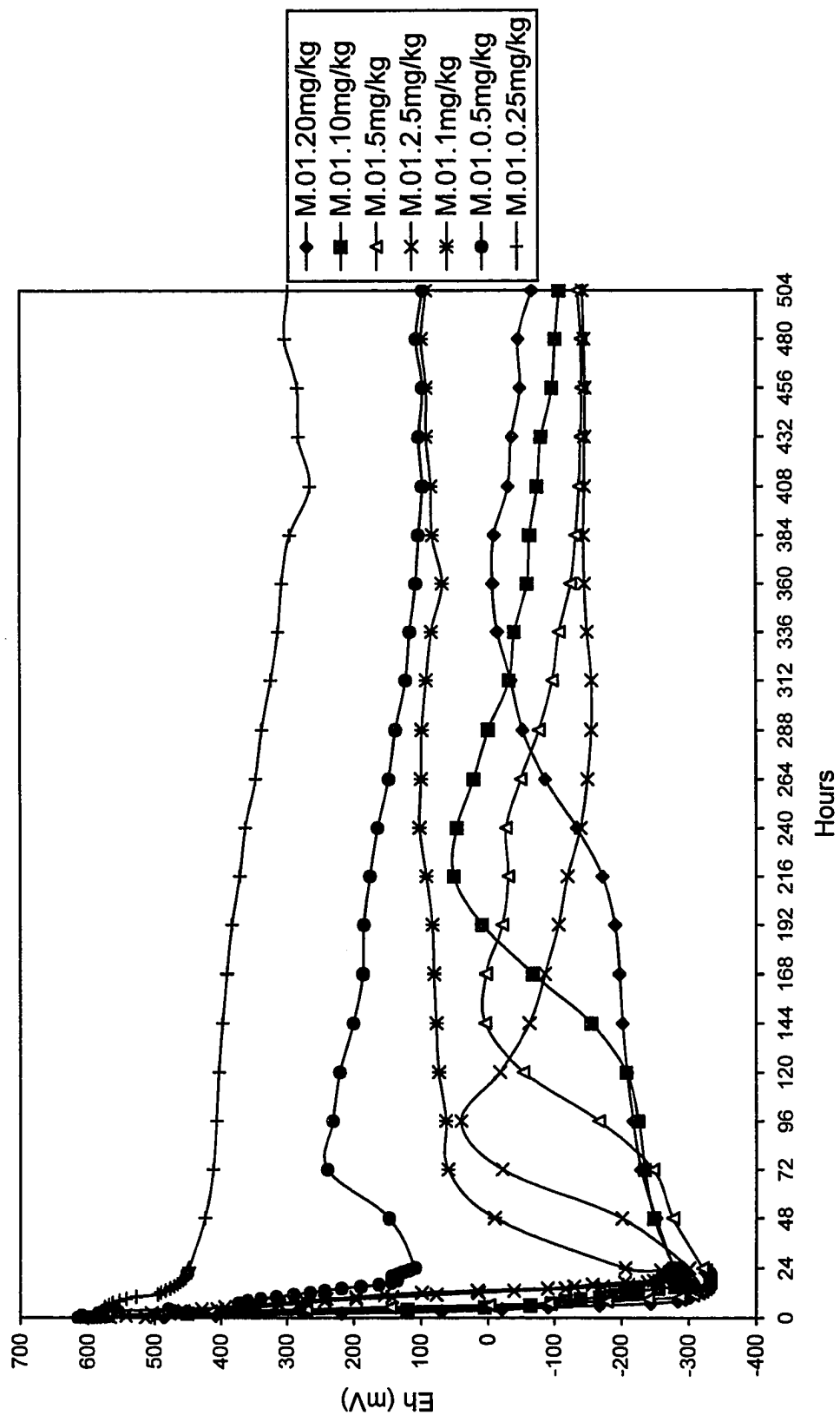


Figure 3.2.1. Mean redox potentials of the natural pH Moreland soil during the first incubation period.

72 hours. It decreased gradually to 100 mV for the remaining 21 days of flooding. The Eh for the M.01.0.25g/kg treatment decreased from 580 to 450 mV within 24 hours and decreased gradually to 300 mV after 21 days. Based upon the results of Patrick and Jugsujinda (1992), the critical Eh for reducing Mn and Fe oxides was 200 and 100 mV at pH 6.5, respectively. The redox potential can be adjusted by a factor of -59 mV/pH (Callebaut et al., 1982). Both Mn and Fe oxides were reduced for soils with 0.5 g/kg or more sucrose. Neither Mn nor Fe reduced for the M.01.0.25g/kg treatment after 21 days.

Figure 3.2.2 shows the Eh for the natural pH Moreland soil during the re-saturation period. The soils with 0.25 g/kg or more sucrose showed a bimodal distribution. The Eh for the M.02.20g/kg treatment decreased from 460 to 90 mV within 20 hours and increased to 140 mV within 36 hours. The Eh decreased to -120 mV within 96 hours and to -200 mV for the remainder of re-saturation period. The Eh for the M.02.10g/kg treatment was similar to that of M.02.20g/kg treatment. The Eh for the M.02.10g/kg treatment remained constant at -120 mV during the experiment. The Eh for the M.02.5g/kg and M.02.2.5g/kg treatments were similar to that of M.02.10g/kg treatment. However, the Eh began to increase for the M.02.5g/kg and M.02.2.5g/kg treatments within 156 and 192 hours, respectively. The Eh for the M.02.1g/kg and M.02.0.5g/kg treatments was similar. The Eh for the M.02.1g/kg treatment decreased from 510 to 290 mV within 24 hours and decreased gradually to 160 mV before the soil was air-dried. The Eh for the M.02.0.25g/kg treatment decreased gradually from 450 mV to 260 mV during the experiment. Mn oxide

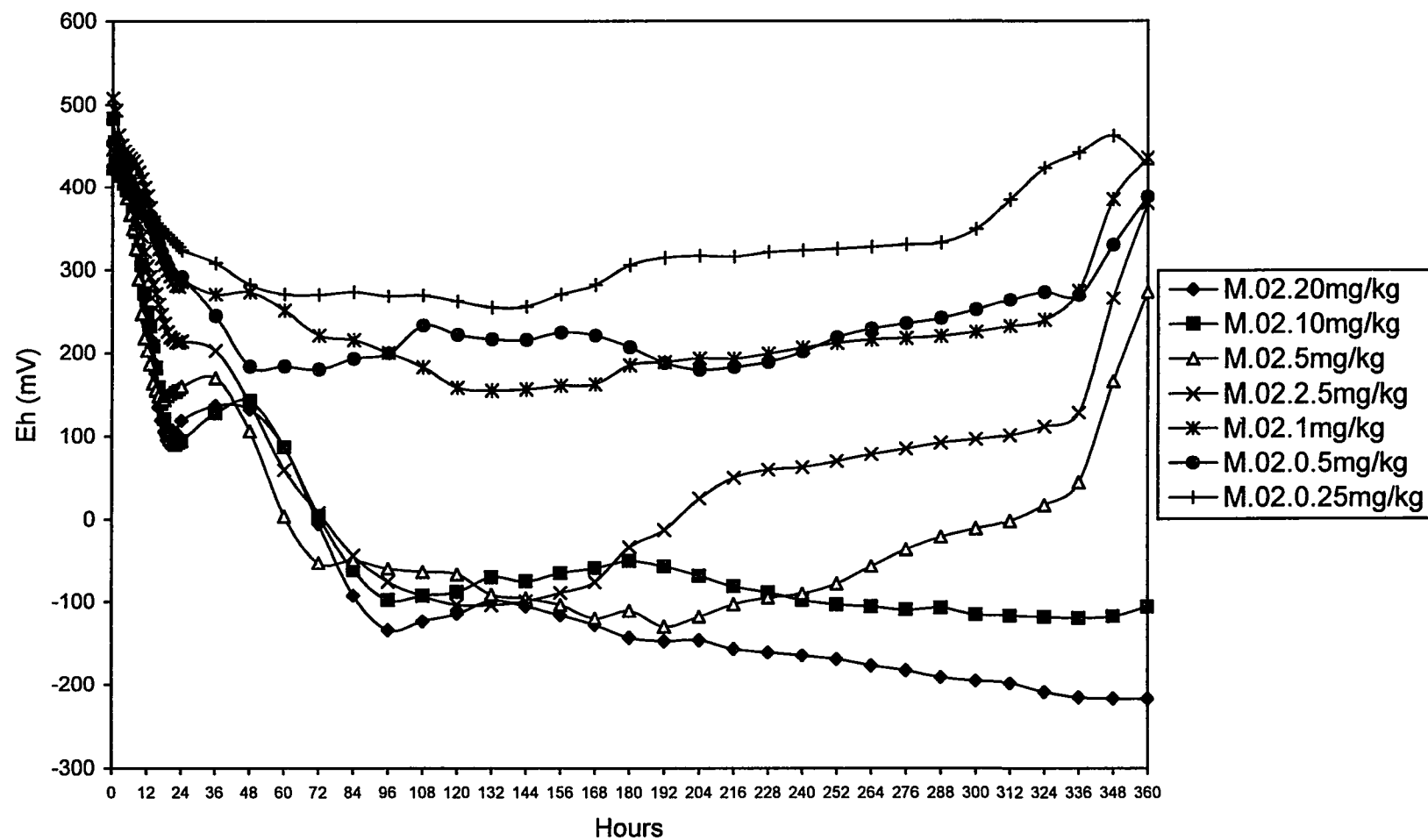


Figure 3.2.2. Mean redox potentials of the natural pH Moreland soil during the re-saturation period.

minerals were reduced for the soils with 0.5 g/kg or more sucrose. Fe oxide minerals were reduced for the soil with 2.5 g/kg or more sucrose.

The Eh during the first incubation period for the Moreland soil adjusted to pH 5 (Fig. 3.2.3) is similar to that of natural pH soil. All the soils with different sucrose treatments showed a bimodal distribution. The Eh for the M.51.20g/kg treatment decreased from 420 to –300 mV within 24 hours and increased gradually to –60 mV during 21 days of flooding. The Eh would likely to continued to decrease if the incubation period were extended. The distributions of Eh for the M.51.10g/kg, M.51.5g/kg, and M.51.2.5g/kg treatments were similar to those of the M.01.10g/kg, M.01.5g/kg, and M.01.2.5g/kg treatments. The maximum Eh attained by the M.51.10g/kg, M.51.5g/kg, and M.51.2.5g/kg treatments were –20, 60, and 160 mV higher than those of the M.01.10g/kg, M.01.5g/kg, and M.01.2.5g/kg treatments, respectively. The maximum Eh for the M.51.2.5g/kg treatment was 160 mV as compared to 40 mV of M.01.2.5g/kg treatment. The Eh for the M.51.0.5g/kg treatment decreased from 480 to –50 mV within 24 hours and increased to 320 mV within 72 hours. It remained at approximately 300 mV during the experiment. The Eh for the M.51.0.25g/kg treatment was similar to that of M.51.0.5g/kg treatment but took 48 hours to reach the minimum Eh of 30 mV. After the minimum Eh was reached, it increased to approximately 350 mV within 96 hours and remained constant for 21 days. Neither Mn nor Fe oxide minerals could be reduced for soil adjusted to pH 5 and treated with sucrose 0.5 g/kg or less.

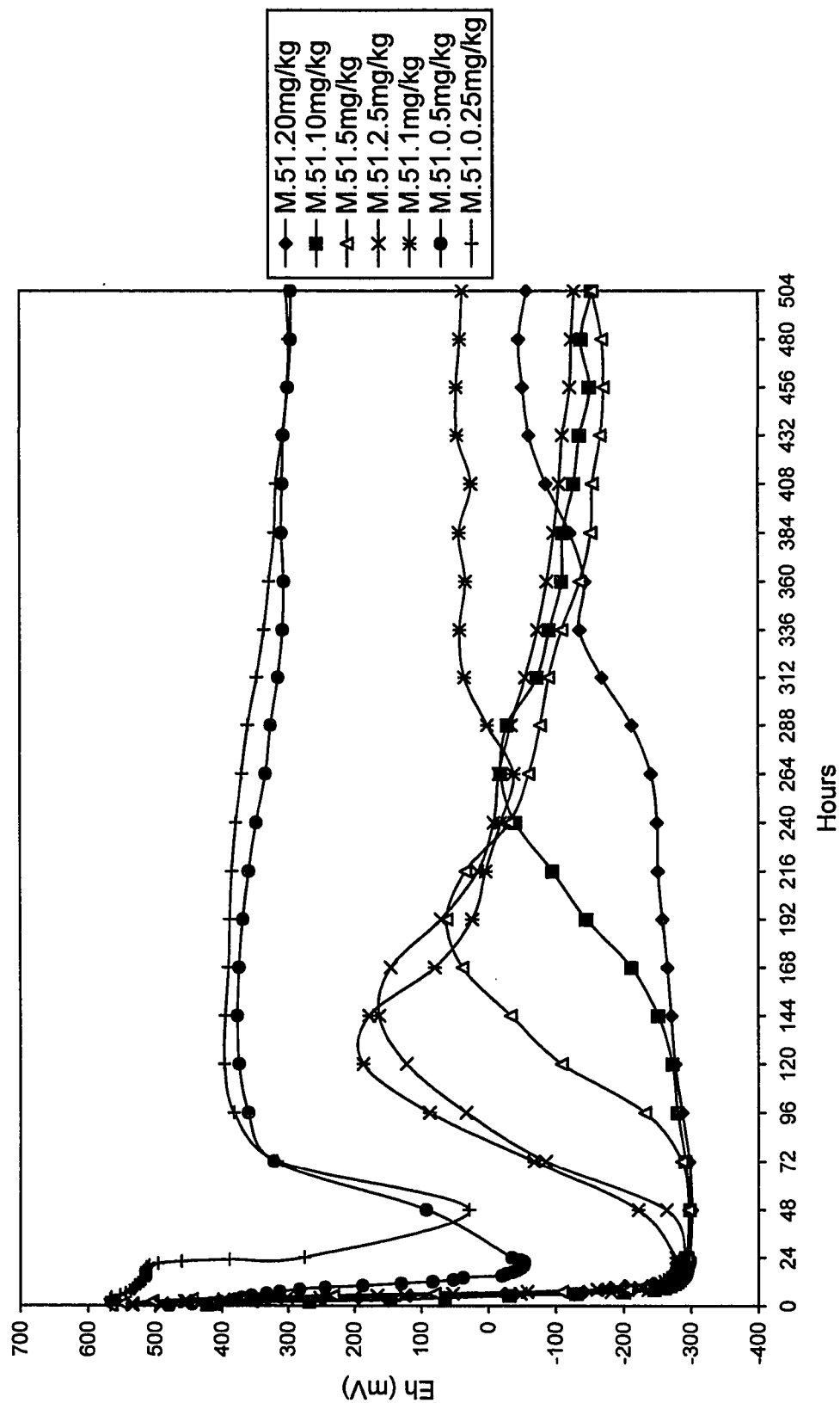


Figure 3.2.3. Mean redox potentials of the pH 5 Moreland soil during the first incubation period.

Temporal Eh changes during the re-saturation period for the Moreland soil adjusted to pH 5 are presented in Figure 3.2.4. Soils with 0.5 g/kg or more sucrose showed a bimodal distribution. The Eh for the M.52.20g/kg treatment decreased from 430 to -210 mV within 72 hours and increased to 60 mV within 108 hours. The Eh continuously decreased to -200 mV. The M.52.10g/kg, M.52.5g/kg, and M.52.2.5g/kg treatments showed a similar decreasing trend during the re-saturation period. The M.52.10g/kg treatment had a lower minimum Eh than the M.52.5g/kg and M.52.2.5g/kg treatments. The minimum Eh was -130, 60, and 60 mV for the M.52.10g/kg, M.52.5g/kg, and M.52.2.5g/kg treatments, respectively. The Eh for the M.52.1g/kg treatment decreased from 450 mV to 200 mV within 24 hours and to 110 mV within 72 hours. It increased to 430 mV before the soils were air-dried. The Eh for the M.52.0.5g/kg treatment was similar to that of M.52.1g/kg treatment. The Eh for the M.52.0.25g/kg treatment showed the slowest rate of decrease from 550 mV to 310 mV after 144 hours. The M.52.0.25g/kg treatment was the only treatment in which Mn and Fe would not be reduced.

Sharkey Soil

Temporal changes in redox potential for the natural pH Sharkey soil during the first incubation period are presented in Fig. 3.2.5. The Eh's for the S.01.20g/kg, S.01.10g/kg, S.01.5g/kg, and S.01.2.5g/kg treatments were similar to those of the M.01.20g/kg, M.01.10g/kg, M.01.5g/kg, and M.01.2.5g/kg treatments, respectively. Soils with 1 g/kg or more sucrose

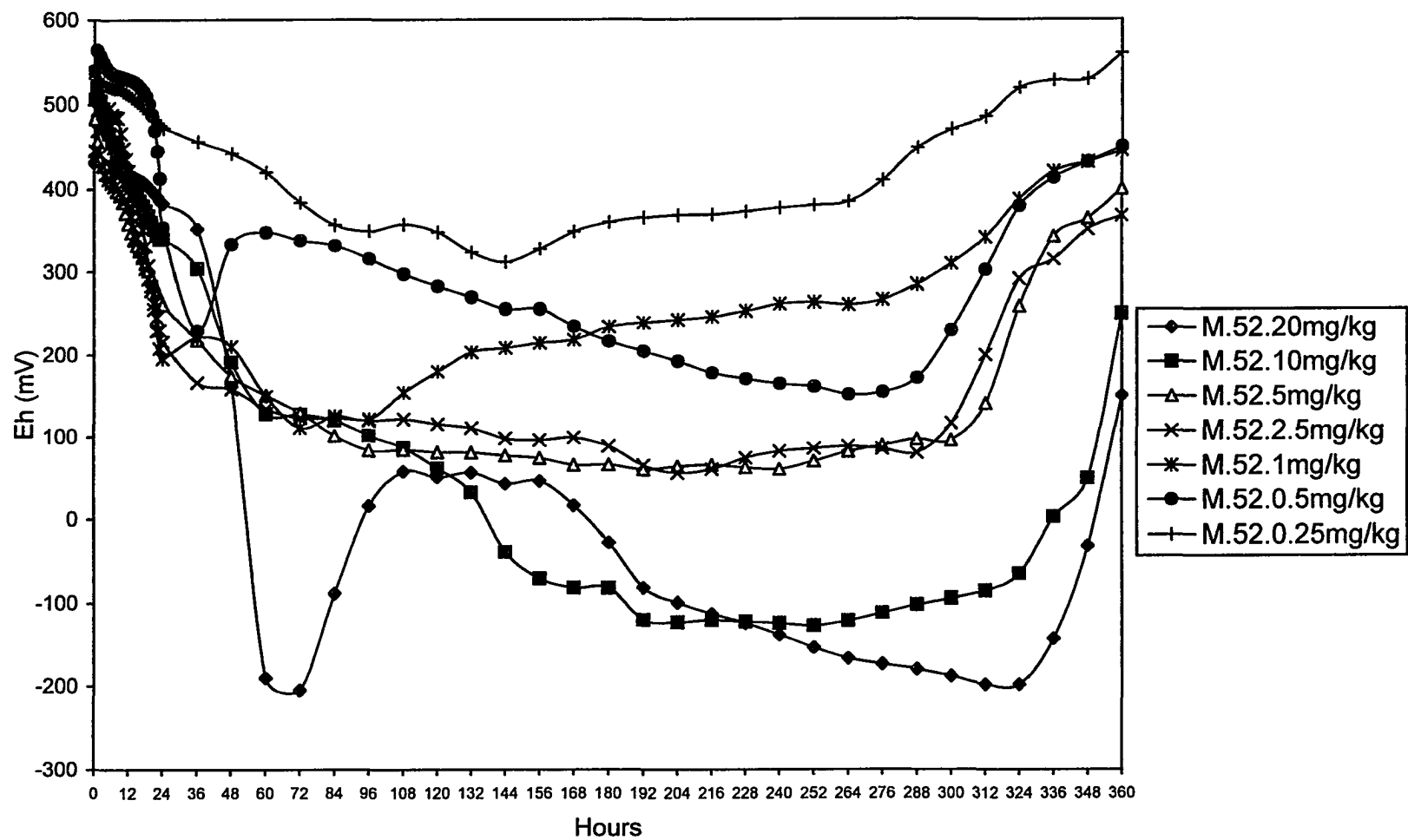


Figure 3.2.4. Mean redox potentials of the pH 5 Moreland soil during the re-saturation period.

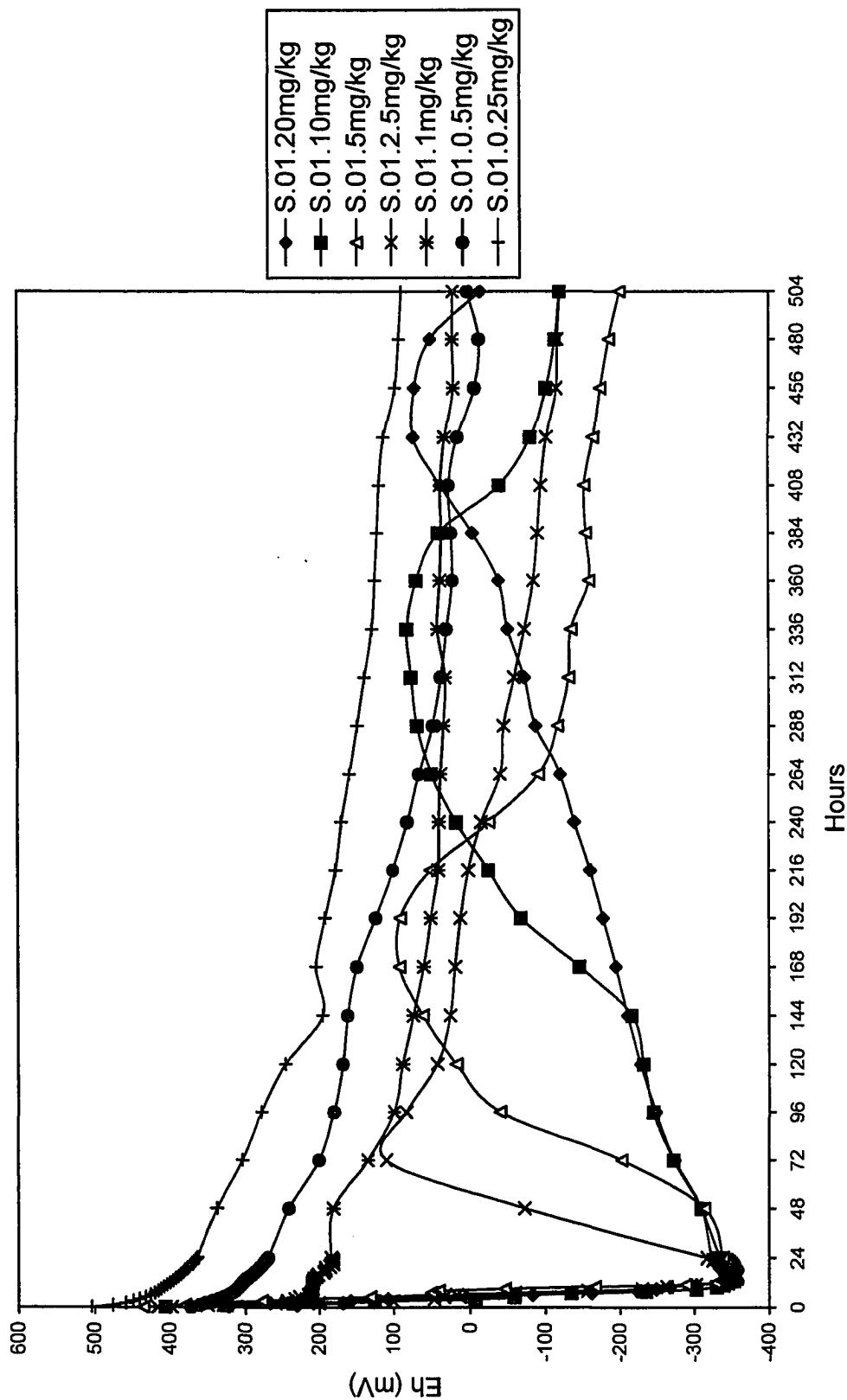


Figure 3.2.5. Mean redox potentials of the natural pH Sharkey soil during the first incubation period.

showed a bimodal distribution. The Eh for the S.01.10g/kg treatment decreased from 410 to –350 mV within 24 hours and gradually increased to –220 mV within 144 hours. The rate of increase in Eh was higher within 288 hours and reached a maximum of 70 mV. The Eh decreased again to –120 mV during the 21 days of incubation. The time required for the Eh to increase was different for treatments with different concentrations of sucrose. The more sucrose added to the soil, the more time needed to increase.

The Eh for the S.01.1g/kg, S.01.0.5g/kg, and S.01.0.25g/kg treatments decreased gradually during the experiment. The Eh decreased from 500 mV to 90 mV for the S.01.0.25g/kg treatment after 21 days. The Eh's were sufficiently low within all treatments that Mn and Fe could be reduced.

The Eh for the S.02.20g/kg, S.02.10g/kg, S.02.5g/kg, S.02.2.5g/kg, S.02.1g/kg, and S.02.0.5g/kg treatments showed a similar pattern during the re-saturation period (Fig. 3.2.6). Except for the S.02.0.25g/kg, the Eh showed a bimodal distribution. Soils with greater amounts of sucrose attained lower Eh during the re-saturation period, but took more time to reach a minimum Eh. The Eh for S.02.20g/kg treatment reached a minimum of –260 mV within 72 hours, and the S.02.5g/kg treatment reached a minimum of –170 mV within 24 hours. The Eh for the S.02.0.25g/kg treatment showed a gradual decrease from 440 to –30 mV. Mn and Fe could be reduced during all the treatments.

The temporal changes in Eh for the Sharkey soil adjusted to pH 5 were similar to those of natural pH Sharkey soil (Fig. 3.2.7). The bimodal distribution of Eh was observed for the soils with 0.5 g/kg or more sucrose. However, there

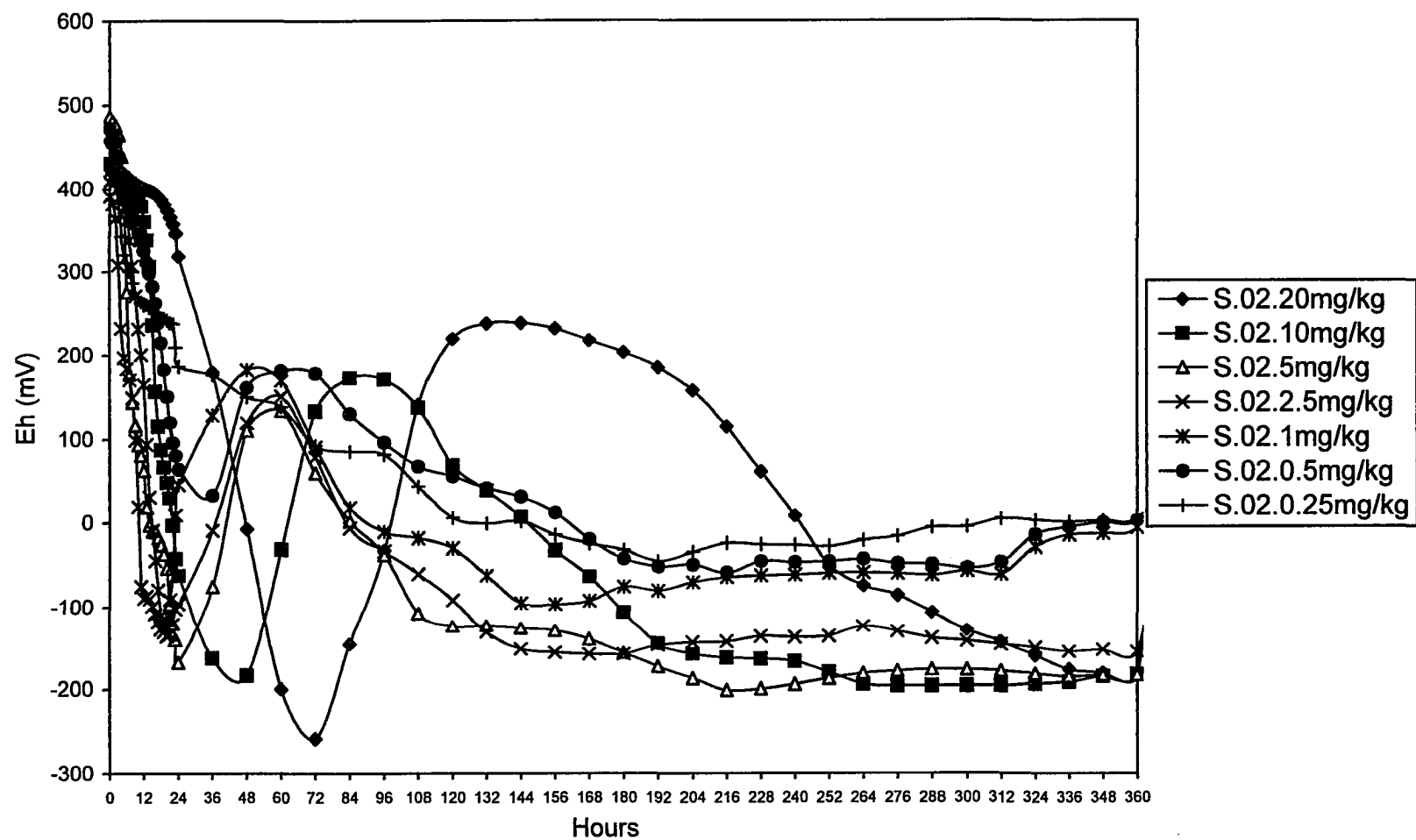


Figure 3.2.6. Mean redox potentials of the natural pH Sharkey soil during the re-saturation period.

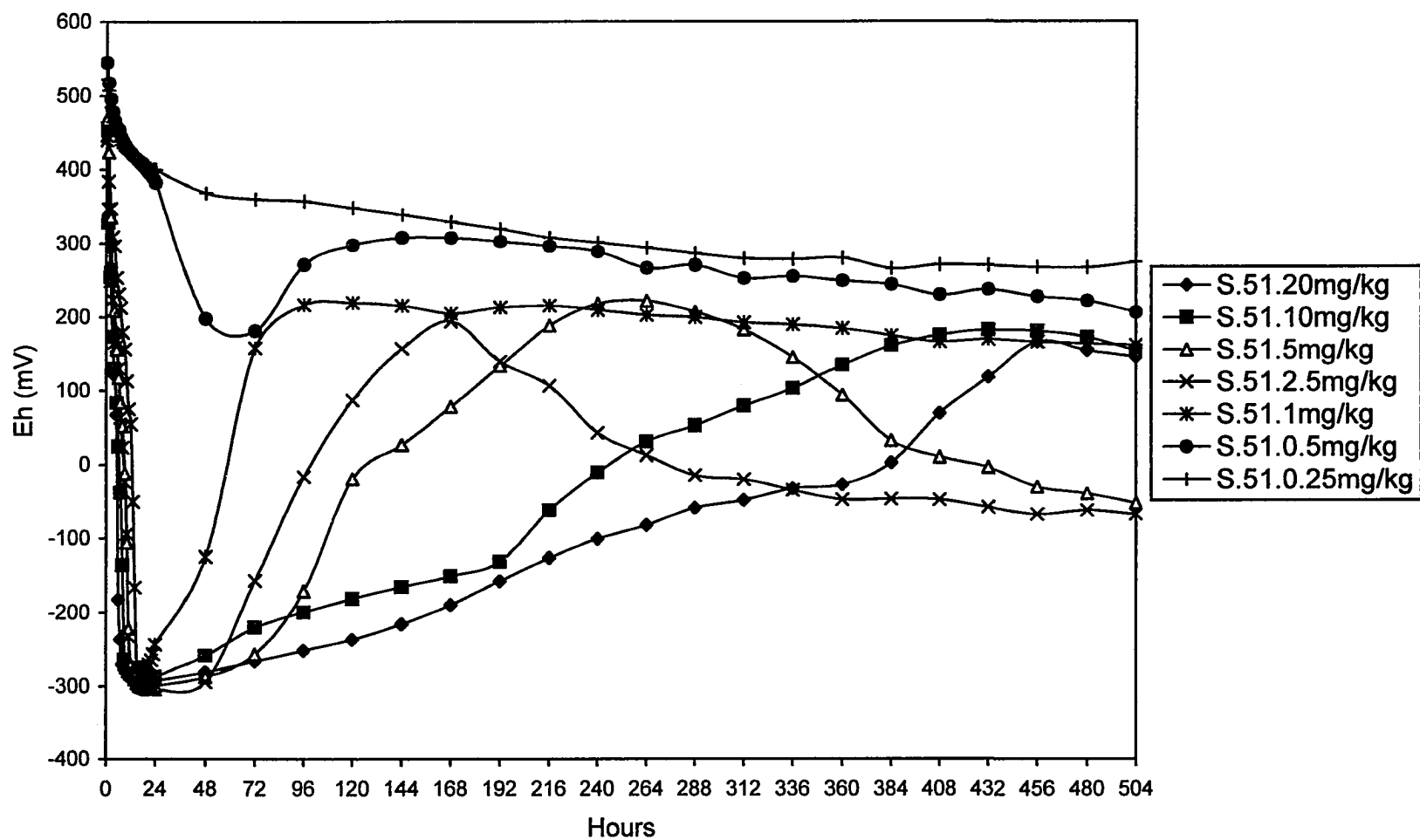


Figure 3.2.7. Mean redox potentials of the pH 5 Sharkey soil during the first incubation period.

were several dissimilarities between natural and adjusted pH soils. First, the minimum Eh was slightly lower for the natural pH treatments. The minimum Eh was -300mV for the S.51.20g/kg, S.51.10g/kg, S.51.5g/kg, and S.51.2.5g/kg treatments but was -350 mV for the S.01.20g/kg, S.01.10g/kg, S.01.5g/kg, and S.01.2.5g/kg treatments. Second, the maximum Eh for the pH adjusted to 5 Sharkey soils was higher than that of natural pH Sharkey soil. The maximum redox potential for S.51.20g/kg, S.51.10g/kg, S.51.5g/kg, and S.51.2.5g/kg treatments was approximately 200 mV as compared to 100 mV for the S.01.20g/kg, S.01.10g/kg, S.01.5g/kg, and S.01.2.5g/kg treatments. Finally, the Eh for the S.51.1g/kg treatment immediately decreased after the soil was flooded, but the S.01.1g/kg treatment decreased gradually. Mn could be reduced within those soils with 0.5 g/kg or more sucrose. Fe could be reduced for those treatments with 1 g/kg or more sucrose.

The distributions of redox potential during the re-saturation period for the Sharkey soil adjusted to pH 5 were similar to those of natural pH Sharkey soil after re-saturation (Fig. 3.2.8). The major difference between the natural and adjusted pH soils was that the S.52.20g/kg and S.52.10g/kg treatments maintained their maximum redox potentials for more time than did the natural pH treatments. The S.52.20g/kg treatment stayed approximately 120 hours at maximum Eh (290 mV), but the S.02.20g/kg treatment lasted only 72 hours before beginning to decrease. Within all the treatments Mn and Fe oxide could be reduced during the experiment.

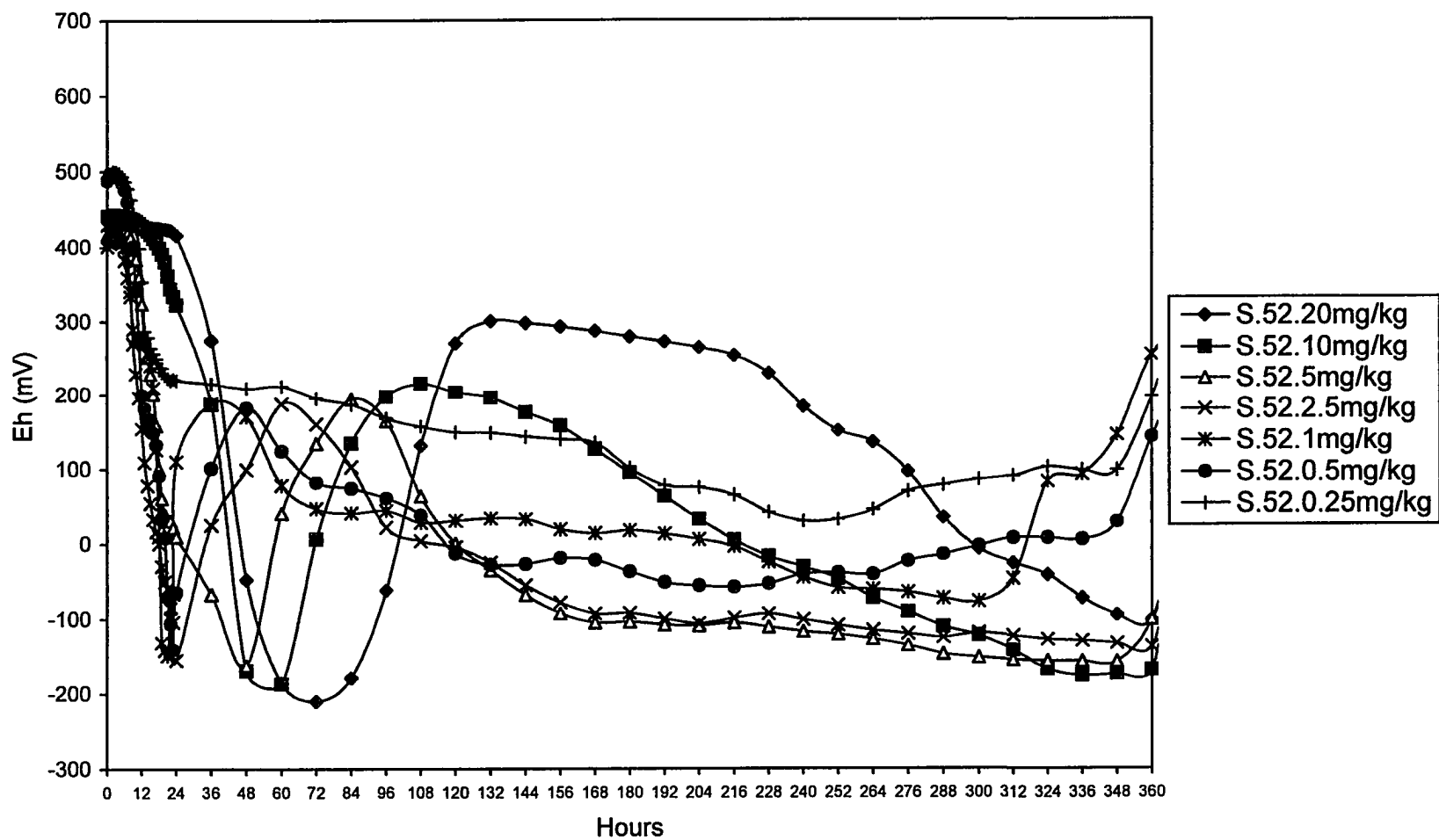


Figure 3.2.8. Mean redox potentials of the pH 5 Sharkey soil during the re-saturation period.

3.3.3. Mn and Fe in Soil Solution

Moreland Soil

Analytical data for the concentrations of Mn ions in the Moreland soil after three weeks of submergence are given in Table 3.2.1. The concentration of Mn ions was 54.2 mg/L for the M.0.20g/kg treatment, which was significantly greater than all other natural pH treatments. The Mn decreased with lower amounts of sucrose added to the soil. The Mn was 5.37 mg/L for the M.0.2.5g/kg treatment. There was no significant difference in Mn for the natural pH treatment with 2.5 g/kg or less sucrose. The Mn was negligible for the treatment with 1 g/kg or less sucrose. The Mn increased with the pH adjusted to 5 treatment. With the same sucrose treatment, the pH adjusted to 5 soils with 2.5 g/kg or more sucrose had a significantly greater Mn than those of the natural pH treatments. The Mn was 99.6 mg/L for the M.5.20g/kg treatment as compared to 54.2 mg/L for the M.0.20g/kg treatment. The Mn increased with increasing concentration of sucrose. The Mn for the M.5.1g/kg treatment was 11.7 mg/L significantly greater than that of M.5.0.5g/kg and M.5.0.25g/kg treatments. The Mn was significantly greater for the natural pH treatments with 5 g/kg or more sucrose and for the treatments adjusted to pH 5 with 2.5 g/kg or greater sucrose.

Like Mn, the concentrations of Fe in soil solution increased with increased sucrose treatment (Table 3.2.2). The Fe was 216 mg/L for the M.0.20g/kg treatment as compared to 4.48 mg/L for the M.0.5g/kg treatment. The increase in Fe was significantly greater for natural pH soils with 10 g/kg or more sucrose

Table 3.2.1. Concentrations of Mn ions for the Moreland soil in soil solution.

Horizons and treatments	Mn ions
	-----mg/L-----
M.0 ¹ .20g/kg ²	54.2 ± 0.54B ³
M.1g/kg	34.5 ± 5.88C
M.0.5g/kg	12.7 ± 1.89D
M.0.2.5g/kg	5.37 ± 0.82DE
M.0.1g/kg	0.12 ± 0.04E
M.0.0.5g/kg	0.12 ± 0.04E
M.0.0.25g/kg	0.12 ± 0.03E
M.5.20g/kg	99.6 ± 12.9A
M.5.10g/kg	65.5 ± 2.61B
M.5.5g/kg	57.6 ± 4.08B
M.5.2.5g/kg	32.2 ± 1.18C
M.5.1g/kg	11.7 ± 0.46DE
M.5.0.5g/kg	3.25 ± 0.75E
M.5.0.25g/kg	3.40 ± 0.20E

¹: 0:natural pH; 5: pH 5.

²: Amount of sucrose added.

³: The same capital letter is not significantly different (LSMEANS pairwise comparison, $\alpha = 0.05$).

Table 3.2.2. Concentrations of Fe ions for the Moreland soil in soil solution.

Horizons and treatments	Fe ions
	-----mg/L-----
M.0 ¹ .20g/kg ²	216 ± 21.8B ³
M.1g/kg	32.8 ± 1.75E
M.0.5g/kg	4.48 ± 2.21F
M.0.2.5g/kg	1.61 ± 0.46F
M.0.1g/kg	0.18 ± 0.02F
M.0.0.5g/kg	0.14 ± 0.00F
M.0.0.25g/kg	0.08 ± 0.02F
M.5.20g/kg	494 ± 12.2A
M.5.10g/kg	154 ± 1.44C
M.5.5g/kg	85.6 ± 2.08D
M.5.2.5g/kg	13.1 ± 3.90EF
M.5.1g/kg	0.16 ± 0.08F
M.5.0.5g/kg	0.16 ± 0.10F
M.5.0.25g/kg	0.08 ± 0.01F

¹: 0:natural pH; 5: pH 5.

²: Amount of sucrose added.

³: The same capital letter is not significantly different (LSMEANS pairwise comparison, $\alpha = 0.05$).

and pH adjusted to 5 soils with 5 g/kg or more sucrose. The Fe was 494 mg/L for the M.5.20g/kg treatment and 216 mg/L for the M.0.20g/kg treatment, respectively. The Fe was significantly higher for the pH adjusted to 5 soils with 5 g/kg or more sucrose than that of natural pH soils with the same sucrose. The Fe did not significantly change for the natural pH treatments with 5 g/kg or less and pH 5 treatments with 2.5 g/kg or less sucrose, respectively. The Fe for the natural pH treatment was greater than Mn only if the added sucrose concentration was as high as 20 g/kg. The Fe was 216 mg/L greater as compared to the Mn of 54.2 mg/L for the M.0.20g/kg treatment. The Mn was greater than the Fe for the M.0.5g/kg and M.0.2.5g/kg treatments. However, the Mn was less than the Fe for the soil with 2.5 g/kg or less sucrose.

Sharkey Soil

The distributions of Mn and Fe ions in the Sharkey soil were similar to those of Moreland soil (Tables 3.2.3 and 3.2.4). The Mn and Fe increased with increased sucrose concentrations and in the treatments adjusted to pH 5. The Mn was 25.8 mg/L for the S.0.20g/kg treatment and decreased to 1.36 mg/L for the S.0.2.5g/kg treatment. The Mn was significantly high for the pH adjusted to 5 soils with 2.5 g/kg or more sucrose than that of natural pH soils with the same sucrose. The Mn was 49.6 mg/L for the S.5.20g/kg treatment as compared to 25.8 mg/L for the S.0.20g/kg treatment. The distribution of Fe was similar to that of Mn. The Fe was significantly greater for natural pH soils with 10 g/kg or more sucrose and pH adjusted to 5 soils with 2.5g/kg or more sucrose. The critical sucrose concentration for the significant difference of Fe

Table 3.2.3. Concentrations of Mn ions for the Sharkey soil in soil solution.

Horizons and treatments	Mn ions
	-----mg/L-----
S.0 ¹ .20g/kg ²	25.8 ± 3.35C ³
S.1g/kg	21.5 ± 0.01D
S.0.5g/kg	8.13 ± 0.70F
S.0.2.5g/kg	1.36 ± 0.01G
S.0.1g/kg	0.07 ± 0.03G
S.0.0.5g/kg	0.04 ± 0.01G
S.0.0.25g/kg	0.04 ± 0.00G
S.5.20g/kg	49.6 ± 1.24A
S.5.10g/kg	34.3 ± 0.93B
S.5.5g/kg	25.1 ± 0.43C
S.5.2.5g/kg	12.7 ± 1.48E
S.5.1g/kg	0.41 ± 0.11G
S.5.0.5g/kg	0.40 ± 0.03G
S.5.0.25g/kg	0.40 ± 0.01G

¹: 0:natural pH; 5: pH 5.

²: Amount of sucrose added.

³: The same capital letter is not significantly different
(LSMEANS pairwise comparison, $\alpha = 0.05$).

Table 3.2.4. Concentrations of Fe ions for the Sharkey soil in soil solution.

Horizons and treatments	Fe ions
	-----mg/L-----
S.0 ¹ .20g/kg ²	214 ± 7.82B ³
S.1g/kg	56.8 ± 1.65D
S.0.5g/kg	16.8 ± 2.29EF
S.0.2.5g/kg	1.65 ± 0.22F
S.0.1g/kg	0.13 ± 0.02F
S.0.0.5g/kg	0.12 ± 0.01F
S.0.0.25g/kg	0.13 ± 0.00F
S.5.20g/kg	323 ± 15.2A
S.5.10g/kg	137 ± 0.26C
S.5.5g/kg	67.3 ± 7.41D
S.5.2.5g/kg	24.3 ± 1.11E
S.5.1g/kg	0.23 ± 0.02F
S.5.0.5g/kg	0.18 ± 0.00F
S.5.0.25g/kg	0.19 ± 0.00F

¹: 0:natural pH; 5: pH 5.

²: Amount of sucrose added.

³: The same capital letter is not significantly different
(LSMEANS pairwise comparison, $\alpha = 0.05$).

ions in the soil solution was 10 g/kg for the natural pH treatments and was 2.5 g/kg for the pH 5 treatments. Very little Mn and Fe ions were observed in soils receiving sucrose of 1 g/kg or less. The Mn and Fe were as low as 0.4 and 0.2 mg/L, respectively. The Fe was greater than the Mn for both the natural pH and pH adjusted to 5 treatments with 2.5 g/kg or more sucrose.

The Mn in the natural pH Sharkey soil with sucrose 2.5 g/kg or more was lower than that of the Moreland soil. This was more apparent for the soils adjusted to pH 5 treatment. Both the Moreland and Sharkey soils with 1 g/kg or less sucrose had no difference in Fe. The rate of increasing Fe was higher than that of Mn for the Moreland and Sharkey soils with increased sucrose treatment. The natural pH Sharkey soil with 2.5 to 10 g/kg sucrose had a greater Fe than that of the Moreland soil with same sucrose. However, the pH adjusted to 5 Moreland soil with 5 g/kg or more sucrose had a greater Fe than that of the pH 5 Sharkey soil with same sucrose treatment.

3.3.4. Selective Chemical Dissolution Analysis

Moreland Soil

Pyrophosphate-extractable Fe (Fe_p) increased for both the natural pH and pH 5 Moreland soil with different sucrose concentrations during 3 weeks of incubation (Table 3.3.1). The Fe_p increased with increased sucrose treatment during 21 days of flooding. The Fe_p increased from 354 mg/kg for the M.0.0g/kg(1) treatment to 2,596 mg/kg for the M.0.20g/kg(2) treatment and to 1,159 mg/kg for the M.0.2.5g/kg(2) treatment. This confirmed that the freeze-

Table 3.3.1. Amounts of Fe for the Moreland soil extracted by three chemical dissolution methods.

Horizons and treatments	Fe _d ⁴	Fe _p ⁵	Fe _o ⁶	Fe _{o-p}	Fe _{d-o}
	mg/kg				
M.0 ¹ .0g/kg ² (1) ³	12580 ± 20	354 ± 11	4567 ± 172	4213 ± 122	8013 ± 123
M.0.20g/kg(2)		2596 ± 84	6242 ± 259	3646 ± 136	6338 ± 184
M.0.20g/kg(3)		1036 ± 12	6922 ± 106	5886 ± 54	5658 ± 77
M.0.20g/kg(4)		954 ± 14	6884 ± 93	5930 ± 47	5696 ± 67
M.1g/kg(2)		1868 ± 68	5585 ± 128	3717 ± 72	6995 ± 91
M.1g/kg(3)		925 ± 9	6385 ± 101	5460 ± 51	6195 ± 73
M.1g/kg(4)		755 ± 5	6400 ± 87	5645 ± 44	6180 ± 63
M.0.5g/kg(2)		1457 ± 9	5463 ± 61	4006 ± 31	7117 ± 45
M.0.5g/kg(3)		955 ± 10	5663 ± 61	4708 ± 31	6917 ± 46
M.0.5g/kg(4)		782 ± 17	5700 ± 37	4918 ± 21	6880 ± 30
M.0.2.5g/kg(2)		1159 ± 26	5303 ± 131	4144 ± 67	7277 ± 94
M.0.2.5g/kg(3)		877 ± 7	5449 ± 65	4572 ± 33	7131 ± 48
M.0.2.5g/kg(4)		735 ± 3	5208 ± 71	4473 ± 36	7372 ± 52
M.0.1g/kg(2)		571 ± 7	4953 ± 104	4382 ± 52	7627 ± 75
M.0.1g/kg(3)		423 ± 6	4968 ± 49	4545 ± 25	7612 ± 37
M.0.1g/kg(4)		401 ± 4	4855 ± 49	4454 ± 25	7725 ± 37
M.0.0.5g/kg(2)		400 ± 7	4714 ± 76	4314 ± 38	7866 ± 55
M.0.0.5g/kg(3)		360 ± 15	4752 ± 39	4392 ± 21	7828 ± 31
M.0.0.5g/kg(4)		407 ± 5	4700 ± 17	4293 ± 9	7880 ± 18
M.0.0.25g/kg(2)		390 ± 2	4600 ± 84	4210 ± 42	7980 ± 61
M.0.0.25g/kg(3)		346 ± 7	4612 ± 131	4266 ± 66	7968 ± 94
M.0.0.25g/kg(4)		355 ± 1	4562 ± 250	4207 ± 125	8018 ± 177

(Table 3.3.1 continued)

Horizons and treatments	Fe _d	Fe _p	Fe _o	Fe _{o-p}	Fe _{d-o}
	mg/kg				
M.5 ¹ .0g/kg ² (1) ³	12567 ± 36	404 ± 7	4854 ± 81	4450 ± 58	7713 ± 63
M.5.20g/kg(2)		2628 ± 128	6603 ± 86	3975 ± 118	5964 ± 66
M.5.20g/kg(3)		1319 ± 80	7004 ± 74	5685 ± 77	5563 ± 58
M.5.20g/kg(4)		1033 ± 40	6973 ± 161	5940 ± 83	5594 ± 116
M.5.10g/kg(2)		2182 ± 10	6391 ± 41	4209 ± 120	6176 ± 38
M.5.10g/kg(3)		920 ± 10	6600 ± 62	5680 ± 51	5967 ± 51
M.5.10g/kg(4)		878 ± 31	6625 ± 50	5747 ± 29	5942 ± 43
M.5.5g/kg(2)		1787 ± 11	5985 ± 59	4198 ± 35	6582 ± 49
M.5.5g/kg(3)		914 ± 7	6000 ± 39	5086 ± 20	6567 ± 37
M.5.5g/kg(4)		802 ± 11	5965 ± 94	5163 ± 47	6602 ± 71
M.5.2.5g/kg(2)		1256 ± 9	5521 ± 85	4265 ± 92	7046 ± 65
M.5.2.5g/kg(3)		833 ± 12	5562 ± 79	4729 ± 40	7005 ± 61
M.5.2.5g/kg(4)		554 ± 5	5555 ± 129	5001 ± 65	7012 ± 95
M.5.1g/kg(2)		773 ± 2	5325 ± 222	4552 ± 111	7242 ± 159
M.5.1g/kg(3)		546 ± 4	5418 ± 110	4872 ± 55	7149 ± 82
M.5.1g/kg(4)		556 ± 13	5491 ± 95	4935 ± 48	7076 ± 72
M.5.0.5g/kg(2)		652 ± 7	5195 ± 179	4543 ± 90	7372 ± 129
M.5.0.5g/kg(3)		545 ± 5	5138 ± 51	4593 ± 26	7429 ± 44
M.5.0.5g/kg(4)		539 ± 6	5141 ± 181	4602 ± 90	7426 ± 130
M.5.0.25g/kg(2)		463 ± 5	4952 ± 41	4489 ± 21	7615 ± 38
M.5.0.25g/kg(3)		429 ± 2	5021 ± 111	4592 ± 55	7545 ± 82
M.5.0.25g/kg(4)		445 ± 7	5003 ± 137	4558 ± 68	7564 ± 100

¹: 0: natural pH; 5: pH 5.

²: Amount of sucrose added.

³: (1): before incubation; (2): after incubation and freeze dry; (3): first drying; (4): second drying.

⁴: Fe_d: Fe extracted by DCB.

⁵: Fe_p: Fe extracted by sodium pyrophosphate.

⁶: Fe_o: Fe extracted by acid-oxalate.

dry treatment prevented further oxidation of organic matter. The increase in Fe_p was not apparent for soils treated with 1 g/kg or less sucrose. The Fe_p was 423 mg/kg for the M.0.1g/kg(2) treatment as compared to 354 mg/kg for the M.0.0g/kg(1) treatment.

After the first drying treatment, the Fe_p decreased significantly for the soils receiving 2.5 g/kg or more sucrose. The Fe_p decreased from 2,596 mg/kg for the M.0.20g/kg(2) treatment to 1,036 mg/kg for the M.0.20g/kg(3) treatment. It decreased from 1,159 mg/kg for the M.0.2.5g/kg(2) treatment to 877 mg/kg for the M.0.2.5g/kg(3) treatment. The decrease after the first drying treatment was negligible for the soil with 0.5 g/kg sucrose. The Fe_p decreased from 400 to 360 mg/kg for the M.0.0.5g/kg(3) treatment. The Fe_p continuously decreased after the second drying treatment. The Fe_p decreased from 1,036 for the M.0.20g/kg(3) treatment to 954 mg/kg for the M.0.20g/kg(4) treatment. The decreased Fe_p after the second drying treatment was far less than that of the first drying treatment. The difference in Fe_p was 1,560 mg/kg between the M.0.20g/kg(2) and M.0.20g/kg(3) treatments but only 82 mg/kg between the M.0.20g/kg(3) and M.0.20g/kg(4) treatments. The Fe_p did not appreciably change for the soil with 0.5 g/kg or less sucrose between the first and second drying treatments.

The soils adjusted to pH 5 showed trends similar to natural pH soils sampled during different periods (Table 3.3.1). The Fe_p for the treatments adjusted to pH 5 was greater than that of natural pH soils with 1 g/kg or less sucrose during different periods.

The amounts of oxalate-extractable Fe (Fe_o) for the Moreland soil are presented in Table 3.3.1. An increase in Fe_o was observed for the natural pH soils with 2.5 g/kg or more sucrose after the freeze-dry treatment. The Fe_o increase from 4,567 mg/kg for the M.0.0g/kg(1) treatment to 6,242 mg/kg for the M.0.20g/kg(2) treatment and to 5,303 mg/kg for the M.0.2.5g/kg(2) treatment.

The Fe_o continuously increased after the first drying treatment. The Fe_o increased from 6,242 mg/kg for the M.0.20g/kg(2) treatment to 6,922 mg/kg for the M.0.20g/kg(3) treatment. There was no apparent difference in Fe_o for the soil receiving sucrose 5 g/kg or less between the freeze-dry and the first drying treatments. The Fe_o increased from 4,953 mg/kg for the M.0.1g/kg(3) treatment to 4,968 mg/kg for the M.0.1g/kg(4) treatment. The difference in Fe_o was insignificant between the first and second drying treatments even though the soil received a 20 g/kg sucrose treatment. A similar tendency was observed in Fe_o for soils adjusted to pH 5 (Table 3.3.1).

The Fe_{o-p} decreased after soils were freeze-dried but was not apparently for the soil with 5 g/kg or less sucrose (Table 3.3.1). The Fe_{o-p} decreased from 4,213 mg/kg for the M.0.0g/kg(1) treatment to 3,646 mg/kg for the M.0.20g/kg(2) treatment and was unchanged for the M.0.0.5g/kg(2) treatment. The Fe_{o-p} appreciably increased for the soils receiving 2.5 g/kg or more sucrose for the first drying treatment. The Fe_{o-p} increased from 3,646 mg/kg for the M.0.20g/kg(2) treatment to 5,886 mg/kg for the M.0.20g/kg(3) treatment. The Fe_{o-p} did not change in for all treatments between the first and second

drying treatments. The distribution of Fe_{o-p} for soils adjusted to pH 5 was similar to that of natural pH soils.

The Fe_{d-o} represented the concentration of crystalline Fe form (McKeague and Day, 1966). Approximately 2/3 total Fe was composed of crystalline Fe form in the Moreland soil. The Fe_{d-o} decreased after the freeze-dry treatment with increased sucrose treatment for the natural pH soils. The Fe_{d-o} decreased from 8,013 mg/kg for the M.0.20g/kg(1) treatment to 6,338 mg/kg for the M.0.20g/kg(2) treatment and to 7,277 mg/kg for the M.0.2.5g/kg(2) treatment. The Fe_{d-o} did not appreciably change for the soils with 0.5 g/kg or less sucrose. The Fe_{d-o} continuously decreased after the first drying treatment. The Fe_{d-o} decreased from 6,338 mg/kg for the M.0.20g/kg(2) treatment to 5,658 mg/kg for the M.0.20g/kg(3) treatment. It did not change after the second drying treatment. The distribution of Fe_{d-o} for soils adjusted to pH 5 was similar to that of natural pH soils. The Fe_{d-o} for the soils adjusted to pH 5 was less than that of natural pH soils with the same sucrose during different sampling periods. The Fe_{d-o} was 6,338 mg/kg for the M.0.20g/kg(2) treatment as compared to 5,964 mg/kg for the M.5.20g/kg(2) treatment.

Sharkey Soil

The concentrations of Fe extracted by DCB, sodium pyrophosphate, and acid oxalate for the Sharkey soil are presented in Table 3.3.2. The data showed that the Fe_p increased with increased sucrose concentrations after the freeze-dry treatment. The Fe_p increased from 1,250 mg/kg for the S.0.0g/kg(1) treatment to 3,737 mg/kg for the S.0.20g/kg(2) treatment. The increased Fe_p

Table 3.3.2. Amounts of Fe for the Sharkey soil extracted by three chemical dissolution methods.

Horizons and treatments	Fe _d ⁴	Fe _p ⁵	Fe _o ⁶	Fe _{o-p}	Fe _{d-o}
	-----mg/kg-----				
S.0 ¹ .0g/kg ² (1) ³	7696 ±160	1250 ±173	7753 ±114	6504±147	-58 ±139
S.0.20g/kg (2)		3737 ±170	7879 ± 29	4142±122	-184 ±115
S.0.20g/kg(3)		2467 ± 78	7492 ± 50	5025± 66	204 ±119
S.0.20g/kg(4)		2398 ±135	7332 ±118	4934±126	364 ±141
S.1g/kg(2)		2541 ± 43	7943 ±109	5402± 83	-248 ±137
S.1g/kg(3)		2145 ±159	7592 ±198	5447±180	103 ±180
S.1g/kg(4)		2184 ± 71	7476 ±199	5292±150	219 ±181
S.0.5g/kg(2)		2551 ± 23	7746 ±116	5195± 84	-51 ±140
S.0.5g/kg(3)		2357 ± 44	7614 ±139	5258±103	81 ±150
S.0.5g/kg(4)		2065 ± 72	7609 ± 41	5544± 58	87 ±117
S.0.2.5g/kg(2)		2241 ±105	7771 ±120	5529±113	-75 ±141
S.0.2.5g/kg(3)		2129 ±110	7832 ± 13	5703± 79	-137 ±114
S.0.2.5g/kg(4)		1981 ± 34	7619 ±109	5638± 81	77 ±137
S.0.1g/kg(2)		1571 ± 49	7611 ±147	6040±110	85 ±154
S.0.1g/kg(3)		1404 ± 53	7619 ±129	6215± 99	77 ±145
S.0.1g/kg(4)		1174 ± 20	7504 ± 33	6330± 27	191 ±116
S.0.0.5g/kg(2)		1517 ± 50	7744 ±145	6228±109	-49 ±153
S.0.0.5g/kg(3)		1110 ± 59	7815 ± 72	6705± 66	-120 ±124
S.0.0.5g/kg(4)		970 ± 87	7678 ± 52	6708± 72	18 ±119
S.0.0.25g/kg(2)		1349 ± 13	7829 ± 20	6479± 17	-133 ±114
S.0.0.25g/kg(3)		1065 ± 45	7835 ± 15	6770± 34	-139 ±114
S.0.0.25g/kg(4)		1110 ± 54	7841 ±205	6731±150	-145 ±184

(Table 3.3.2 continued)

Horizons and treatments	Fe _d	Fe _p	Fe _o	Fe _{o-p}	Fe _{d-o}
	-----mg/kg-----				
S.5 ¹ .0g/kg ² (1) ³	7767 ±118	1247 ± 25	7719 ±120	6472 ± 86	48 ±119
S.5.20g/kg(2)		3239 ± 18	7941 ±137	4702 ± 98	-174 ±128
S.5.20g/kg(3)		2497 ± 23	7706 ± 85	5210 ± 62	61 ±103
S.5.20g/kg(4)		2208 ± 25	7670 ±100	5462 ± 73	97 ±109
S.5.10g/kg(2)		2513 ± 34	7545 ± 96	5032 ± 72	223 ±108
S.5.10g/kg(3)		2228 ± 13	7600 ±167	5371 ±119	168 ±145
S.5.10g/kg(4)		2074 ± 33	7620 ± 54	5546 ± 45	147 ± 92
S.5.5g/kg(2)		2299 ± 43	7606 ±112	5307 ± 84	162 ±115
S.5.5g/kg(3)		2042 ± 18	7462 ± 24	5420 ± 21	305 ± 85
S.5.5g/kg(4)		1988 ± 22	7547 ±165	5560 ±118	220 ±143
S.5.2.5g/kg(2)		2092 ± 26	7560 ±100	5486 ± 73	207 ±109
S.5.2.5g/kg(3)		1936 ± 74	7596 ±177	5660 ±135	172 ±150
S.5.2.5g/kg(4)		1859 ± 68	7568 ±170	5709 ±130	200 ±146
S.5.1g/kg(2)		1656 ± 14	7637 ±100	5981 ± 71	130 ±109
S.5.1g/kg(3)		1350 ± 13	7567 ±167	6217 ±119	200 ±145
S.5.1g/kg(4)		1325 ± 23	7529 ±149	6204 ±107	238 ±134
S.5.0.5g/kg(2)		1496 ± 56	7773 ±109	6276 ± 87	-5 ±114
S.5.0.5g/kg(3)		1256 ± 18	7914 ± 67	6658 ± 49	-147 ± 96
S.5.0.5g/kg(4)		1141 ± 37	7838 ± 16	6697 ± 29	-71 ± 84
S.5.0.25g/kg(2)		1292 ± 59	7954 ± 85	6663 ± 73	-187 ±103
S.5.0.25g/kg(3)		1218 ± 7	7750 ± 59	6533 ± 42	17 ± 93
S.5.0.25g/kg(4)		1110 ± 43	7845 ± 88	6735 ± 69	-78 ±104

¹: 0:natural pH; 5: pH 5.²: Amount of sucrose added.³: (1): before incubation; (2): after incubation and freeze dry; (3): first drying; (4): second drying.⁴: Fe_d: Fe extracted by DCB.⁵: Fe_p: Fe extracted by sodium pyrophosphate.⁶: Fe_o: Fe extracted by acid-oxalate.

was insignificant for the soil treated with 1 g/kg or less sucrose. The Fe_p was 1,571 mg/kg for the S.0.1g/kg(2) treatment.

The Fe_p showed a decreasing trend after the first drying treatment. It decreased from 3,737 mg/kg for the S.0.20g/kg(3) to 2,467 mg/kg for the S.0.20g/kg(3) treatment. The decrease in Fe_p was not appreciably different for the soil with 5 g/kg or less sucrose. The Fe_p was unchanged between the first and second drying treatment. The distributions of Fe_p sampled during different periods for the soils adjusted to pH 5 were similar to those of the natural pH treatments (Table 3.3.2). No significant effect of pH adjustment upon Fe_p was detected.

There was no apparent difference in Fe_o for the natural pH and pH adjusted to 5 treatments sampled during the freeze-dry, first drying, and second drying treatment (Table 3.3.2). The inorganic Fe concentration was estimated by the difference of $Fe_o - Fe_p$. The original concentration of Fe_{o-p} was 6,500 mg/kg for the S.0.0g/kg(1) and S.5.0g/kg(1) treatments. The Fe_{o-p} decreased with increased sucrose concentrations after the freeze-dry treatment. The Fe_{o-p} decreased from 6,500 mg/kg to 4,142 mg/kg for the S.0.20g/kg(2) treatment. It did not appreciably change for both pH treatments with 0.5g/kg or less sucrose. The Fe_{o-p} did not apparently increase after the first drying treatment except in the S.0.20g/kg(3) and S.5.20g/kg(3) treatments. The Fe_{o-p} increased from 4,142 mg/kg for the S.0.20g/kg(2) treatment to 5,025 mg/kg for the S.0.20g/kg(3) treatment. There was no apparent difference in Fe_{o-p} between the first and second drying treatments.

Based on the ratio of Fe_{d-o} to Fe_d , the concentration of crystalline forms in the Sharkey soil was negligible. The amorphous Fe was the predominant Fe form in the Sharkey soil. The Fe_{d-o} did not change for the natural pH and pH adjusted to 5 Sharkey soil with different sucrose treatments sampled during different periods.

3.3.5. Organic Carbon

Moreland Soil

The amounts of total organic carbon (TOC) and soluble organic carbon (SOC) extracted by cold water for the Moreland soil are shown in Table 3.4.1. The original concentration of TOC for the M.0.0g/kg(1) treatment was 9.6 g/kg. Soils with greater amounts of added sucrose were expected to have a greater TOC. The TOC increased from 9.6 to 13.3 g/kg for the M.0.20g/kg(2) treatment. The TOC decreased after the first drying treatment. It decreased from 13.3 to 11.1 g/kg for the M.0.20g/kg(3) treatment. The TOC between the first and second drying treatments had no appreciable difference. The TOC was 9.9 g/kg for the M.0.2.5g/kg(3) and 9.7 g/kg for the M.0.2.5g/kg(4) treatment, respectively. Soils with 2.5 g/kg or less sucrose were not different in TOC (<0.5 g/kg) during different periods. The TOC for soils with 10 g/kg or less sucrose treatment after the first and second drying treatments had almost the same concentration as the M.0.0g/kg(1) treatment. The TOC for the Moreland soil adjusted to pH 5 was similar to that of natural pH soils, but the TOC was approximately 0.8 g/kg less than that of natural pH soil (Table 3.4.1).

Table 3.4.1. Total organic carbon and soluble organic carbon extracted by water for the Moreland soil.

Horizons and treatments	Total organic carbon	Soluble organic carbon
	-----g/kg-----	
M.0 ¹ .0g/kg ² (1) ³	9.6 ± 0.0	0.22 ± 0.01
M.0.20g/kg(2)	13.3 ± 0.3	0.68 ± 0.23
M.0.20g/kg(3)	11.1 ± 0.0	0.27 ± 0.04
M.0.20g/kg(4)	11.1 ± 0.4	0.26 ± 0.05
M.1g/kg(2)	11.3 ± 0.4	0.33 ± 0.03
M.1g/kg(3)	9.9 ± 0.2	0.25 ± 0.02
M.1g/kg(4)	9.7 ± 0.1	0.23 ± 0.04
M.0.5g/kg(2)	10.5 ± 0.3	0.25 ± 0.03
M.0.5g/kg(3)	9.7 ± 0.1	0.23 ± 0.01
M.0.5g/kg(4)	9.8 ± 0.2	0.22 ± 0.01
M.0.2.5g/kg(2)	10.1 ± 0.3	0.22 ± 0.02
M.0.2.5g/kg(3)	9.9 ± 0.3	0.19 ± 0.03
M.0.2.5g/kg(4)	9.5 ± 0.1	0.20 ± 0.04
M.0.1g/kg(2)	10.0 ± 0.2	0.21 ± 0.02
M.0.1g/kg(3)	9.6 ± 0.5	0.18 ± 0.01
M.0.1g/kg(4)	9.3 ± 0.2	0.19 ± 0.02
M.0.0.5g/kg(2)	9.9 ± 0.1	0.20 ± 0.03
M.0.0.5g/kg(3)	9.7 ± 0.3	0.20 ± 0.01
M.0.0.5g/kg(4)	9.6 ± 0.1	0.18 ± 0.02
M.0.0.25g/kg(2)	9.9 ± 0.5	0.19 ± 0.04
M.0.0.25g/kg(3)	9.0 ± 0.0	0.15 ± 0.06
M.0.0.25g/kg(4)	9.3 ± 0.3	0.17 ± 0.05

(Table 3.4.1 continued)

Horizons and treatments	Total organic carbon	Soluble organic carbon
	-----g/kg-----	
M.5 ¹ .0g/kg ² (1) ³	9.2 ± 0.0	0.20 ± 0.02
M.5.20g/kg(2)	12.7 ± 0.3	0.70 ± 0.14
M.5.20g/kg(3)	10.4 ± 0.1	0.28 ± 0.03
M.5.20g/kg(4)	10.3 ± 0.2	0.25 ± 0.06
M.5.10g/kg(2)	10.6 ± 0.1	0.39 ± 0.02
M.5.10g/kg(3)	9.9 ± 0.2	0.25 ± 0.04
M.5.10g/kg(4)	9.8 ± 0.0	0.22 ± 0.02
M.5.5g/kg(2)	10.4 ± 0.1	0.27 ± 0.04
M.5.5g/kg(3)	9.2 ± 0.0	0.24 ± 0.05
M.5.5g/kg(4)	9.3 ± 0.2	0.21 ± 0.03
M.5.2.5g/kg(2)	10.4 ± 1.3	0.26 ± 0.06
M.5.2.5g/kg(3)	9.2 ± 0.2	0.22 ± 0.05
M.5.2.5g/kg(4)	9.1 ± 0.1	0.20 ± 0.06
M.5.1g/kg(2)	9.8 ± 0.2	0.22 ± 0.05
M.5.1g/kg(3)	9.0 ± 0.0	0.21 ± 0.03
M.5.1g/kg(4)	8.8 ± 0.1	0.18 ± 0.01
M.5.0.5g/kg(2)	9.3 ± 0.1	0.20 ± 0.03
M.5.0.5g/kg(3)	9.0 ± 0.1	0.16 ± 0.06
M.5.0.5g/kg(4)	9.0 ± 0.0	0.18 ± 0.02
M.5.0.25g/kg(2)	9.3 ± 0.0	0.18 ± 0.04
M.5.0.25g/kg(3)	9.3 ± 0.2	0.17 ± 0.07
M.5.0.25g/kg(4)	9.0 ± 0.0	0.16 ± 0.04

¹: 0:natural pH; 5: pH 5.

²: Amount of sucrose added.

³: (1): without the addition of sucrose; (2): freeze-dry;
(3): first drying; 4th: second drying.

The distributions of SOC extracted by cold water for the Moreland soil showed the same trends as those of TOC (Table 3.4.1). The concentration of SOC for the M.0.0g/kg(1) treatment was 0.22 g/kg. It increased to 0.68 g/kg for the M.0.20g/kg(2) treatment and to 0.33 g/kg for the M.0.10g/kg(2) treatment. The SOC was not different for soils with 5 g/kg or less sucrose at different periods. The SOC for the soils adjusted to pH 5 was similar to that of the natural pH soil (Table 3.4.1).

Table 3.4.2 presents the concentrations of SOC in soil solution after 3 weeks of incubation. The SOC in solution decreased with decreased sucrose. The SOC was 456 mg/L for the M.0.20g/kg treatment and 56.2 mg/L for the M.0.2.5g/kg treatment. The SOC ranged from 37.4 to 56.2 mg/L for the M.0.2.5g/kg, M.0.1g/kg, M.0.0.5g/kg, and M.0.0.25g/kg treatments. The SOC was not significantly different for soils with 5 g/kg or less sucrose. The distribution of SOC for the soils adjusted to pH 5 was similar to that of the natural pH soil (Table 3.4.2).

Sharkey Soil

The concentration of TOC for the S.0.0g/kg(1) treatment was 19.6 g/kg greater than that of the M.0.0g/kg(1) treatment (Table 3.4.3). The TOC increased with increased sucrose after the freeze-dry treatment. It increased from 19.6 g/kg for the S.0.0g/kg(1) treatment to 25.3 mg/kg for the S.0.20g/kg(2) treatment. The TOC was not apparently different for the soil with 2.5 g/kg or less sucrose. The TOC decreased for the S.0.20g/kg(3), S.1g/kg(3), and S.0.5g/kg(3) treatments. It did not change for the soil with 2.5 g/kg or less

Table 3.4.2. Concentrations of soluble organic carbon in soil solution for the Moreland soil.

Horizons and treatments	Soluble organic carbon
	-----mg/L-----
M.0 ¹ .20g/kg ²	456 ± 23.3A ³
M.1g/kg	173 ± 58.7C
M.0.5g/kg	101 ± 11.5CD
M.0.2.5g/kg	56.2 ± 4.86D
M.0.1g/kg	48.6 ± 1.39D
M.0.0.5g/kg	45.1 ± 0.69D
M.0.0.25g/kg	37.4 ± 0.00D
M.5.20g/kg	345 ± 36.1B
M.5.10g/kg	142 ± 63.7C
M.5.5g/kg	98.7 ± 1.03D
M.5.2.5g/kg	48.1 ± 0.69D
M.5.1g/kg	41.5 ± 1.03D
M.5.0.5g/kg	40.5 ± 3.44D
M.5.0.25g/kg	37.7 ± 0.69D

¹: 0:natural pH; 5: pH 5.

²: Amount of sucrose added.

³: The same capital letter is not significantly different (LSMEANS pairwise comparison, $\alpha = 0.05$).

sucrose. There was no appreciable difference in the TOC between the first and second drying treatment. The distribution of TOC for the soils adjusted to pH 5 was similar to that of natural pH soils (Table 3.4.3).

The distribution of SOC extracted by cold water was similar to that of TOC sampled during different periods (Table 3.4.3). The SOC increased with increased sucrose after the freeze-dry treatment. It decreased after the first and second drying treatments. The difference in SOC was not apparent for the soil with 5 g/kg or less sucrose during different periods.

Table 3.4.4 presents the concentrations of SOC in the Sharkey soil solutions after 3 weeks of incubation. The SOC increased with increased

Table 3.4.3. Total organic carbon and soluble organic carbon extracted by water for the Sharkey soil.

Horizons and treatments	Total organic carbon	Soluble organic carbon
	-----g/kg-----	
S.0 ¹ .0g/kg ² (1) ³	19.6 ± 0.4	0.31 ± 0.01
S.0.20g/kg(2)	25.3 ± 0.1	1.24 ± 0.26
S.0.20g/kg(3)	21.8 ± 0.6	0.66 ± 0.15
S.0.20g/kg(4)	20.0 ± 0.4	0.36 ± 0.04
S.1g/kg(2)	23.4 ± 0.0	0.62 ± 0.07
S.1g/kg(3)	21.1 ± 0.9	0.40 ± 0.08
S.1g/kg(4)	19.6 ± 0.1	0.28 ± 0.01
S.0.5g/kg(2)	21.8 ± 0.3	0.46 ± 0.07
S.0.5g/kg(3)	19.9 ± 0.4	0.44 ± 0.04
S.0.5g/kg(4)	18.7 ± 0.2	0.26 ± 0.01
S.0.2.5g/kg(2)	20.4 ± 0.9	0.45 ± 0.04
S.0.2.5g/kg(3)	19.7 ± 0.9	0.36 ± 0.02
S.0.2.5g/kg(4)	19.4 ± 0.3	0.26 ± 0.01
S.0.1g/kg(2)	20.5 ± 0.2	0.33 ± 0.07
S.0.1g/kg(3)	20.2 ± 1.0	0.34 ± 0.00
S.0.1g/kg(4)	18.3 ± 0.0	0.24 ± 0.06
S.0.0.5g/kg(2)	20.3 ± 0.9	0.37 ± 0.01
S.0.0.5g/kg(3)	19.5 ± 0.6	0.33 ± 0.01
S.0.0.5g/kg(4)	19.5 ± 0.4	0.29 ± 0.06
S.0.0.25g/kg(2)	20.3 ± 1.4	0.31 ± 0.02
S.0.0.25g/kg(3)	19.0 ± 0.3	0.30 ± 0.01
S.0.0.25g/kg(4)	19.2 ± 0.4	0.30 ± 0.04

(Table 3.4.3 continued)

Horizons and treatments	Total organic carbon	Soluble organic carbon
	-----g/kg-----	
S.5 ¹ .0g/kg ² (1) ³	19.1 ± 0.9	0.23 ± 0.00
S.5.20g/kg(2)	22.7 ± 0.5	0.77 ± 0.01
S.5.20g/kg(3)	21.5 ± 0.6	0.30 ± 0.00
S.5.20g/kg(4)	19.9 ± 0.2	0.30 ± 0.01
S.5.10g/kg(2)	22.6 ± 1.4	0.52 ± 0.02
S.5.10g/kg(3)	20.1 ± 0.2	0.26 ± 0.01
S.5.10g/kg(4)	19.5 ± 0.2	0.26 ± 0.00
S.5.5g/kg(2)	21.0 ± 0.3	0.51 ± 0.02
S.5.5g/kg(3)	19.7 ± 0.6	0.24 ± 0.02
S.5.5g/kg(4)	19.3 ± 0.7	0.24 ± 0.01
S.5.2.5g/kg(2)	20.5 ± 1.2	0.37 ± 0.05
S.5.2.5g/kg(3)	19.9 ± 0.7	0.24 ± 0.02
S.5.2.5g/kg(4)	19.0 ± 0.0	0.22 ± 0.00
S.5.1g/kg(2)	20.0 ± 0.0	0.32 ± 0.03
S.5.1g/kg(3)	18.9 ± 0.1	0.23 ± 0.04
S.5.1g/kg(4)	19.1 ± 0.3	0.24 ± 0.01
S.5.0.5g/kg(2)	20.7 ± 0.5	0.31 ± 0.02
S.5.0.5g/kg(3)	19.9 ± 0.2	0.25 ± 0.00
S.5.0.5g/kg(4)	19.0 ± 0.2	0.23 ± 0.00
S.5.0.25g/kg(2)	19.9 ± 0.5	0.26 ± 0.01
S.5.0.25g/kg(3)	20.1 ± 0.6	0.24 ± 0.00
S.5.0.25g/kg(4)	18.5 ± 0.2	0.23 ± 0.01

¹: 0: natural pH; 5: pH 5.

²: Amount of sucrose added.

³: (1): without the addition of sucrose; (2): freeze-dry;
(3): first drying; 4th: second drying.

Table 3.4.4. Concentrations of soluble organic carbon in soil solution for the Sharkey soil.

Horizons and treatments	Soluble organic carbon
	-----mg/L-----
S.0 ¹ .20g/kg ²	408 ± 81.1A ³
S.1g/kg	202 ± 23.0B
S.0.5g/kg	131 ± 40.7BC
S.0.2.5g/kg	78.6 ± 4.52C
S.0.1g/kg	55.3 ± 10.4C
S.0.0.5g/kg	47.7 ± 1.39C
S.0.0.25g/kg	45.6 ± 2.09C
S.5.20g/kg	408 ± 19.0A
S.5.10g/kg	200 ± 19.3B
S.5.5g/kg	113 ± 1.72C
S.5.2.5g/kg	68.2 ± 1.72C
S.5.1g/kg	56.4 ± 1.03C
S.5.0.5g/kg	51.6 ± 0.34C
S.5.0.25g/kg	52.0 ± 0.69C

¹: 0:natural pH; 5: pH 5.

²: Amount of added sucrose.

³: The same capital letter is not significantly different (LSMEANS pairwise comparison, $\alpha = 0.05$).

sucrose concentrations. It was 408 mg/L for the S.0.20g/kg treatment and 78.6 mg/L for the S.0.2.5g/kg treatment. There was no significant difference for the soil with 5 g/kg or less sucrose. No apparent effect of adjusted pH upon the SOC concentration was detected.

3.3.6. Soil Colors

Moreland Soil

Dry soil colors for the Moreland soil using the Munsell Color charts after the first and second drying treatments are presented in Tables 3.5.1 and 3.5.2. Before incubation the natural pH and pH 5 Moreland soil had a dark reddish brown hue (5YR 3/3) without any redoximorphic features.

Table 3.5.1. Colors of the Moreland soil after the first drying treatment.

Horizon and treatments	Descriptions (dry color)
M.0 ¹ 1 ² .20g/kg ³	5YR 3/3 with many 2.5YR 3/4, common 5YR 5/6, and few 7.5YR 6/6 on the soil surface and 2mm 7.5YR 5/2 below the soil surface.
M.01.10g/kg	5YR 3/3 with many 7.5YR 5/6, common 2.5 YR 4/6, and few 7.5YR 6/6 on the soil surface and 1mm 7.5YR 5/2 below the soil surface.
M.01.5g/kg	5YR 3/3 with many 10YR 6/6, common 2.5YR 4/6, and few 5YR 7/4 on the soil surface and 0.5mm 7.5YR 5/2 below the soil surface.
M.01.2.5g/kg	5YR 3/3 with common 7.5YR 6/4 and few 10YR 6/4 on the soil surface.
M.01.1g/kg	5YR 3/3.
M.01.0.5g/kg	5YR 3/3.
M.01.0.25g/kg	5YR 3/3.
M.51.20g/kg	5YR 3/3 with many 2.5YR 3/6, common 5YR 5/8, and few 7.5YR 6/6 on the soil surface and 3mm 10YR 6/2 below the soil surface.
M.51.10g/kg	5YR 3/3 with many 2.5YR 3/4, common 5YR 5/8, and few 7.5YR 6/6 on the soil surface and 1mm 10YR 5/2 below the soil surface.
M.51.5g/kg	5YR 3/3 with many 2.5YR 3/4, common 5YR 5/8, and few 7.5YR 6/6 on the soil surface and 0.5mm 10YR 6/2 below the soil surface.
M.51.2.5g/kg	5YR 3/3 with common 7.5YR 6/8 and few 5YR 5/8 on the soil surface.
M.51.1g/kg	5YR 3/3 with few 7.5YR 6/3 on the soil surface.
M.51.0.5g/kg	5YR 3/3
M.51.0.25g/kg	5YR 3/3

¹: 0:natural pH; 5: pH 5.

²: First drying treatment

³: Amount of sucrose added.

Table 3.5.2. Colors of the Moreland soil after the second air-dry treatment.

Horizon and treatments	Descriptions (dry color)
M.0 ¹ 2 ² .20g/kg ³	5YR 3/3 with many 7.5YR 5/6 on the soil surface.
M.02.10g/kg	5YR 3/3 with many 7.5YR 5/6 on the soil surface.
M.02.5g/kg	5YR 3/3
M.02.2.5g/kg	5YR 3/3
M.02.1g/kg	5YR 3/3
M.02.0.5g/kg	5YR 3/3
M.02.0.25g/kg	5YR 3/3
M.52.20g/kg	5YR 3/3 with many 7.5YR 5/4 on the soil surface.
M.52.10g/kg	5YR 3/3 with many 7.5YR 5/6 on the soil surface.
M.52.5g/kg	5YR 3/3
M.52.2.5g/kg	5YR 3/3
M.52.1g/kg	5YR 3/3
M.52.0.5g/kg	5YR 3/3
M.52.0.25g/kg	5YR 3/3

¹: 0: natural pH; 5: pH 5.

²: Second air-dry treatment

³: Amount of sucrose added.

The predominant matrix color after the first drying treatment was dark reddish brown (5YR 3/3) for the M.01.20g/kg treatment, consistent with the color of the initial material (Table 3.5.1). The M.01.20g/kg treatment was abundant with many dark reddish brown (2.5YR 3/4), common yellowish red (5YR 5/6), and few reddish yellow (7.5YR 6/6) redoximorphic features on the soil surface. Brown hue with low chroma (7.5YR 5/2) penetrated 2 mm into the soil surface after the first drying treatment. Redoximorphic features formed on the soil surface that was more yellowish (7.5YR) for the M.01.10g/kg treatment. The formation of low chroma (7.5YR 5/2) extending 1 mm into the soil surface was observed. The redoximorphic features were predominantly brownish yellow (10YR 6/6) for the M.01.5g/kg treatment. Low chroma was detected on the soil surface but was less distinct than that of the M.01.10g/kg treatment. No low chroma redoximorphic features (≤ 2) were observed for the soils treated

with 2.5 g/kg or less sucrose. Common light brown (7.5YR 6/4) and few yellowish brown (10YR 6/4) redoximorphic features formed on the soil surface of the M.01.2.5g/kg treatment. Soils with 1 g/kg or less sucrose did not form any redoximorphic features on the surface.

The redoximorphic features formed on the soil surface of the Moreland soil adjusted to pH 5 after the first drying treatment were similar to those of the natural pH soils (Table 3.5.1). The predominant hues of the redoximorphic features on the soil surface of the M.51.10g/kg and M.51.5g/kg treatments (2.5YR 3/4 to 3/6) were more red than that of the M.01.10g/kg and M.01.5g/kg treatments (7.5 to 10YR 5/6 to 6/6). The depth of low chroma (10YR 5/2 to 6/2) into the soil surface decreased with decreased sucrose concentrations. No redoximorphic features with chroma less than or equal to 2 for soils adjusted to pH 5 was observed for treatments with 5 g/kg sucrose or less. Few light brown redoximorphic features formed on the soil surface of the M.51.1g/kg treatment. No redoximorphic features were detected on the soil surface of the M.51.0.5g/kg and M.51.0.25g/kg treatments.

The formations of redoximorphic features for the natural pH and pH adjusted to 5 Moreland soil after the second drying treatment were significantly less than after the first drying period (Table 3.5.2). Brown or strong brown hues (7.5YR 5/4 to 5/6) were observed on the soil surface of the M.02.20g/kg, M.02.5g/kg, M.52.20g/kg, and M.52.10g/kg treatments after the second drying treatment. Soil with 5 g/kg or less sucrose did not form any mottles on the soil surface after the second drying treatment.

Dry colors of crushed and homogenized soils with different sucrose treatments were measured using a reflectance spectrometer after the freeze-dry, first drying, and second drying treatments (Table 3.5.3). The original color of the natural pH soil matrices was 5.7YR 4.7/3.6 before incubation. A yellowish hue and the lowest chromas (6.5YR and 3.2) occurred in the M.0.20g/kg soil after the freeze-dry treatment. The hues were redder and chromas were lower with the increased sucrose treatments. The hue was 6.5YR and the chroma was 3.2 for the M.0.20g/kg treatment. The hue and chroma were 6.1YR and 3.5 for the M.0.2.5g/kg treatment. The colors of the M.0.1g/kg, M.0.2.5g/kg, and M.0.2.5g/kg treatments remained unchanged (5.7YR 4.7/3.6 to 4.8/3.6) after the freeze-dry treatment.

The chroma did not significantly change after the first drying treatment except for the M.0.20g/kg and M.1g/kg treatments. The chroma increased from 3.2 to 3.6 for the M.0.20g/kg treatment. The chroma decreased after the second drying treatment but hues did not change. The hue remained 6.6YR but the chroma changed from 3.6 to 3.3 for the M.0.20g/kg treatment after the second drying treatment.

The changes in soil colors for the soils adjusted to pH 5 were similar to those of the natural pH soils (Table 3.5.3). The original color for the M.5.0g/kg treatment (5.4YR 4.7/3.7) before incubation was more reddish than that of the natural pH soil (5.7YR 4.7/3.6). The hue was more yellowish and chroma was lower for the M.5.20g/kg, M.5.10g/kg, and M.5.5g/kg treatments after the freeze-dry treatment. It did not change for soils with 2.5 g/kg or less sucrose.

Table 3.5.3. Soil colors of the Moreland and Sharkey soils measured by reflectance spectrometer.

Horizons and treatments	Original color	Freeze-dry	First drying	Second drying
Descriptions (dry color)				
M.0 ¹ .0g/kg ²	5.7YR 4.7/3.6			
M.0.20g/kg		6.5YR 4.7/3.2	6.6YR 4.7/3.6	6.6YR 4.5/3.3
M.1g/kg		6.3YR 4.6/3.3	6.5YR 4.6/3.5	6.5YR 4.5/3.3
M.0.5g/kg		6.1YR 4.7/3.4	6.2YR 4.5/3.5	6.1YR 4.4/3.3
M.0.2.5g/kg		6.1YR 4.8/3.5	6.1YR 4.6/3.5	6.0YR 4.4/3.4
M.0.1g/kg		5.7YR 4.8/3.6	6.0YR 4.5/3.6	5.8YR 4.3/3.4
M.0.0.5g/kg		5.7YR 4.7/3.6	5.9YR 4.5/3.6	5.8YR 4.3/3.4
M.0.0.25g/kg		5.7YR 4.7/3.6	5.9YR 4.3/3.6	5.9YR 4.2/3.4
M.5.0g/kg	5.4YR 4.7/3.7			
M.5.20g/kg		6.4YR 5.0/3.4	6.5YR 4.8/3.6	6.4YR 4.5/3.4
M.5.10g/kg		6.1YR 4.8/3.5	6.2YR 4.7/3.6	6.1YR 4.4/3.4
M.5.5g/kg		5.9YR 4.8/3.6	6.0YR 4.7/3.7	5.9YR 4.4/3.4
M.5.2.5g/kg		5.6YR 4.9/3.7	5.8YR 4.6/3.7	5.8YR 4.3/3.4
M.5.1g/kg		5.5YR 4.7/3.7	5.6YR 4.5/3.7	5.6YR 4.2/3.4
M.5.0.5g/kg		5.5YR 4.8/3.7	5.6YR 4.5/3.7	5.5YR 4.2/3.4
M.5.0.25g/kg		5.5YR 4.8/3.7	5.6YR 4.4/3.7	5.5YR 4.3/3.4
S.0 ¹ .0g/kg ²	0.1Y 5.1/1.8			
S.0.20g/kg		0.7Y 5.0/1.6	0.5Y 5.0/1.7	0.5Y 4.6/1.6
S.1g/kg		0.5Y 4.9/1.6	0.5Y 4.9/1.6	0.5Y 4.6/1.6
S.0.5g/kg		0.4Y 5.0/1.9	0.4Y 5.0/1.6	0.4Y 4.7/1.6
S.0.2.5g/kg		0.3Y 5.0/1.8	0.3Y 4.9/1.6	0.3Y 4.6/1.6
S.0.1g/kg		0.2Y 5.2/1.9	0.2Y 5.0/1.8	0.2Y 4.4/1.6
S.0.0.5g/kg		0.2Y 5.1/1.9	0.2Y 5.0/1.9	0.1Y 4.7/1.7
S.0.0.25g/kg		0.1Y 5.2/1.9	0.1Y 5.0/1.9	0.1Y 4.6/1.7
S.5.0g/kg	0.1Y 5.1/1.9			
S.5.20g/kg		0.7Y 5.3/1.6	0.5Y 5.0/1.8	0.5Y 4.8/1.7
S.5.10g/kg		0.6Y 5.3/1.7	0.5Y 5.0/1.6	0.5Y 4.9/1.5
S.5.5g/kg		0.4Y 5.3/1.7	0.4Y 5.0/1.6	0.5Y 4.8/1.5
S.5.2.5g/kg		0.5Y 5.4/1.7	0.4Y 4.9/1.6	0.4Y 4.8/1.5
S.5.1g/kg		0.1Y 5.3/1.9	0.1Y 5.0/1.8	0.1Y 4.7/1.7
S.5.0.5g/kg		0.1Y 5.3/1.9	0.1Y 4.9/1.9	0.1Y 4.7/1.7
S.5.0.25g/kg		0.1Y 5.2/1.9	0.1Y 4.9/1.8	0.1Y 4.7/1.8

¹: 0: natural pH; 5: pH 5.

²: amount of sucrose added.

The hue and chroma did not appreciably change between the first and second drying treatments.

Sharkey Soil

The matrix color for the Sharkey soil was grayish brown (2.5Y 5/2) before incubation. The soil color changes for the Sharkey soil after the first drying treatment are compiled in Table 3.5.4. Many light red (2.5YR 7/8), common yellowish red (5YR 4/6) and strong brown (7.5YR 5/8), and few light yellowish brown (2.5Y 6/4) redoximorphic features formed on the soil surface of the S.01.20g/kg treatment. The predominant hues of the redoximorphic features on the soil surface were less reddish with decreased sucrose concentrations. The distinct hue of the redoximorphic features was yellowish red (5YR 4/6) for the S.01.10g/kg treatment and reddish yellow (7.5YR 6/8) for the S.01.5g/kg treatment. Pale yellow (2.5Y 8/2) was detected on the soil surface of the S.01.0.25g/kg treatment. A color of gray (2.5Y 5/1) extending 2 mm into the soil surface was observed. The thickness of gray hue penetrating into the soil surface decreased with decreased sucrose concentrations. It was 0.5mm thick for the S.01.5g/kg treatment.

The soil color changes in the pH adjusted to 5 Sharkey soil were similar to that of the natural pH soils (Table 3.5.4). The reddish redoximorphic features decreased and yellowish redoximorphic features increased with decreased sucrose concentrations. The predominant redoximorphic features were light red (2.5YR 6/8) and yellowish red (5YR 5/8) for the S.51.20g/kg and S.51.5g/kg treatments, respectively. Light brownish gray (2.5Y 6-7/2)

Table 3.5.4. Colors of the Sharkey soil after the first drying treatment.

Horizon and treatments	Descriptions (dry color)
S.0 ¹ 1 ² .20g/kg ³	2.5Y 5/2 with many 2.5YR 7/8 and common 5YR 4/6, 7.5YR 5/8, and 2.5Y 6/4 on the soil surface and 2 mm 2.5Y 4/1 below the soil surface.
S.01.10g/kg	2.5Y 5/2 with many 5YR 4/6 and common 10YR 6/4 and 2.5Y 6/3 on the soil surface and 1 mm 2.5Y 5/1 below the soil surface.
S.01.5g/kg	2.5Y 5/2 with many 7.5YR 6/8, common 5YR 4/6, 7.5YR 5/8, and few 5YR 7/4 on the soil surface and 0.5 mm 2.5Y 5/1 below the soil surface.
S.01.2.5g/kg	2.5Y 5/2 with few 10YR 8/2, 10YR 8/6, 2.5Y 7/4, and 8/6 on the soil surface.
S.01.1g/kg	2.5Y 5/2 with common 2.5Y 8/2 and few 10YR 7/8 on the soil surface.
S.01.0.5g/kg	2.5Y 5/2 with common 2.5Y 8/2 on the soil surface.
S.01.0.25g/kg	2.5Y 5/2 with common 2.5Y 8/2 on the soil surface.
S.51.20g/kg	2.5Y 5/2 with many 2.5YR 6/8, common 2.5Y 5/3, and few 10YR 5/8 on the soil surface and 2.5 mm 2.5Y 5/1 below the soil surface.
S.51.10g/kg	2.5Y 5/2 with many 5YR 5/8 and common 7.5YR 6/8 and 2.5Y 6/3 on the soil surface and 1 mm 2.5Y 6/1 below the soil surface.
S.51.5g/kg	2.5Y 5/2 with many 5YR 5/8, common 7.5YR 6/8, and few 2.5Y 6/3 on the soil surface and 0.5mm 2.5Y 5/1 below the soil surface.
S.51.2.5g/kg	2.5Y 5/2 with common 10YR 7/8 and 7.5YR 5/8, and few 2.5Y 6/3 and 2.5Y 4/2 on the soil surface.
S.51.1g/kg	2.5Y 5/2 with common 2.5Y 7/2 and few 10YR 7/8 on the soil surface.
S.51.0.5g/kg	2.5Y 5/2 with common 2.5Y 7/2 on the soil surface.
S.51.0.25g/kg	2.5Y 5/2 with common 2.5Y 6/2 on the soil surface.

¹. 0:natural pH; 5: pH 5.

². First drying treatment

³. Amount of sucrose added.

redoximorphic features formed on the soil surface of soils with 1 g/kg or less sucrose. A gray hue (2.5Y 5/1 to 6/1) extending into the soil surface occurred in the S.51.20g/kg, S.51.10g/kg, and S.51.5g/kg treatments.

Fewer reddish redoximorphic features formed for the natural pH Sharkey soil after the second drying treatment (Table 3.5.5) than after the first drying treatment. Strong brown (7.5YR 5/8) redoximorphic features on the soil surface were predominant for the S.02.20g/kg treatment. The hue of the redoximorphic features was more yellowish with decreased sucrose concentrations. Soils with sucrose less than 2.5 g/kg did not form redoximorphic features on the soil surface. The formation of redoximorphic features for the soils adjusted to pH 5 was similar to that of the natural pH soils. The hue of redoximorphic features was more reddish for soils adjusted to pH 5 than for the natural pH soil with the

Table 3.5.5. Colors of the Sharkey soil after the second drying treatment.

Horizon and treatments	Descriptions (dry color)
S.0 ¹ 2 ² .20g/kg ³	2.5Y 5/2 with many 7.5YR 5/8 and few 2.5 YR 4/6 and 10YR 5/6 on the soil surface.
S.02.10g/kg	2.5Y 5/2 with many 10YR 5/8 on the soil surface.
S.02.5g/kg	2.5Y 5/2 with many 2.5Y 6/4 and few 10YR 6/6 on the soil surface.
S.02.2.5g/kg	2.5Y 5/2 with few 10YR 5/6 on the soil surface.
S.02.1g/kg	2.5Y 5/2
S.02.0.5g/kg	2.5Y 5/2
S.02.0.25g/kg	2.5Y 5/2
S.52.20g/kg	2.5Y 5/2 with many 2.5YR 3/6 and common 10YR 5/6 and 2.5Y 4/4 on the soil surface.
S.52.10g/kg	2.5Y 5/2 with many 7.5YR 6/8 on the soil surface.
S.52.5g/kg	2.5Y 5/2 with few 10YR 6/8 on the soil surface.
S.52.2.5g/kg	2.5Y 5/2 with few 2.5Y 6/8 on the soil surface.
S.52.1g/kg	2.5Y 5/2
S.52.0.5g/kg	2.5Y 5/2
S.52.0.25g/kg	2.5Y 5/2

¹: 0: natural pH; 5: pH 5.

²: Second drying treatment

³: Amount of sucrose added.

same sucrose concentration. The color of the redoximorphic features was reddish yellow (7.5YR 6/8) for the S.52.10g/kg treatment and yellowish brown (10YR 5/8) for the S.02.10g/kg treatment. No color change was observed for the natural pH and pH adjusted to 5 soils after the second drying treatment.

Crushed soil colors for the Sharkey soil using a reflectance spectrometer after the freeze-dry, first drying, and second drying treatments are presented in Table 3.5.3. The original color of natural pH soil matrices was 0.1Y 5.1/1.8. The hue was more yellowish with increased sucrose concentrations after the freeze-dry treatment. The hue changed from 0.1Y into 0.7Y for the S.0.20g/kg treatment and was 0.3Y for the S.0.25g/kg treatment. The chroma did not change after the freeze-dry treatment except for the S.0.20g/kg and S.1g/kg treatments. The hue changed from 0.7Y to 0.5Y for the S.0.20g/kg treatment after the first drying treatment but remained constant for other treatments. The hue and chroma did not appreciably change after the second drying treatment from those of the first drying treatment.

The soil color changes for the soil adjusted to pH 5 were similar to that of the natural pH treatments (Table 3.5.3). The hue was more yellowish with increased sucrose concentrations, but there was no change for the treatment with 1 g/kg sucrose or less.

3.3.7. Summary

The chapter presented results for the seven sucrose concentrations (20, 10, 5, 2.5, 1.0, 0.5, and 0.25 g/kg) at two pH levels; natural (Moreland 7.4, Sharkey 6.4) and pH 5.0 effects on redox thresholds for Mn and Fe dissolution for two

wetting and drying cycles. The purpose was to see what concentrations of SOC are necessary for Mn and Fe to reduce and what would happen if the pH was lowered to pH 5 due to weathering, primarily leaching. The Ap horizon from both the Moreland and Sharkey soils were used for this experiment.

The pH of all the natural pH samples decreased, but both rate and quantity were sucrose concentration dependant, i.e. the greater the sucrose concentration, the greater was the pH decreased (Fig. 3.1.1). Conversely, the pH of all the pH 5 treatments increased (Fig. 3.1.3). The magnitude of pH decrease was proportional to the amount of fermentation. This is consistent with the finding presented in Chapter 2 in that fermentation is a major process that is often not reported for the redox reactions. The pH increased during drying which is typical when a field sample is dried because of the oxidation of organic acids. The pH of the pH 5 treated soil increased with increasing sucrose treatment except for the 1 g/kg sucrose treatment, which did not change. The Moreland soil is highly buffered and the samples equilibrated at pH 5 tended to attain their buffered pH (approximately pH 7.4), but did not because of the organic acids produced during fermentation. When the sucrose concentration was equal to and less than 1 g/kg, neither fermentation nor reduction occurred and the pH slightly increased. The pH of the natural Sharkey soil decreased with increasing concentration of sucrose due to fermentation (Fig. 3.1.5). The pH did not change after drying and re-saturation. The Sharkey soil has a lower buffered soil pH and the final pH's of the first wetting cycle were essentially 6.4. The pH of the pH 5 treated Sharkey soil

treatments of 20 and 10 g/kg sucrose decreased due to fermentation. The pH of the 5 g/kg treatment remained constant and the pH of the 2.5 g/kg treatment increased. This occurred for two reasons. First, the amount of SOC available for fermentation was too low and second, the SOC was used to reduce inorganic Mn and Fe; which raised the pH. The pH of other treatments remained constant (Fig. 3.1.7).

The Eh values versus concentrations showed that 0.5 g/kg of sucrose is required for Mn and Fe to reduce irregardless of pH for the Moreland soil (Fig. 3.2.1 and 3.2.3). The threshold sucrose value for the Sharkey soil was 1 g/kg (Fig. 3.2.5 and 3.2.7). This is because the natural pH is lower and the Fe is in either an amorphous organic or inorganic form, which is more readily reduced.

The soil solution and dissolution data are similar as those presented in Chapter 2. The quantity of Mn and Fe in soil solution increased with both increasing sucrose concentration and decreased pH for the Moreland and Sharkey soils (Fig. 3.3.1, 3.3.2, 3.3.3 and 3.3.4). The Fe_o increased with both increasing sucrose concentration for the Moreland soil (Fig. 3.4.1 and 3.4.2) and the amount is governed by the dissolution of hematite. Since no crystalline Fe was detected in the Sharkey soil, the Fe_o remained unchanged with sucrose treatments (Fig. 3.4.3 and 3.4.4).

For the Moreland soil, redox depletions formed within the surface of the 20, 10, and 5 g/kg natural pH and pH 5 treatment. Redoximorphic features (redox concentrations) did not form within the natural pH treatment with 1 g/kg sucrose or less and for the pH 5 treatment with 0.5 g/kg sucrose or less.

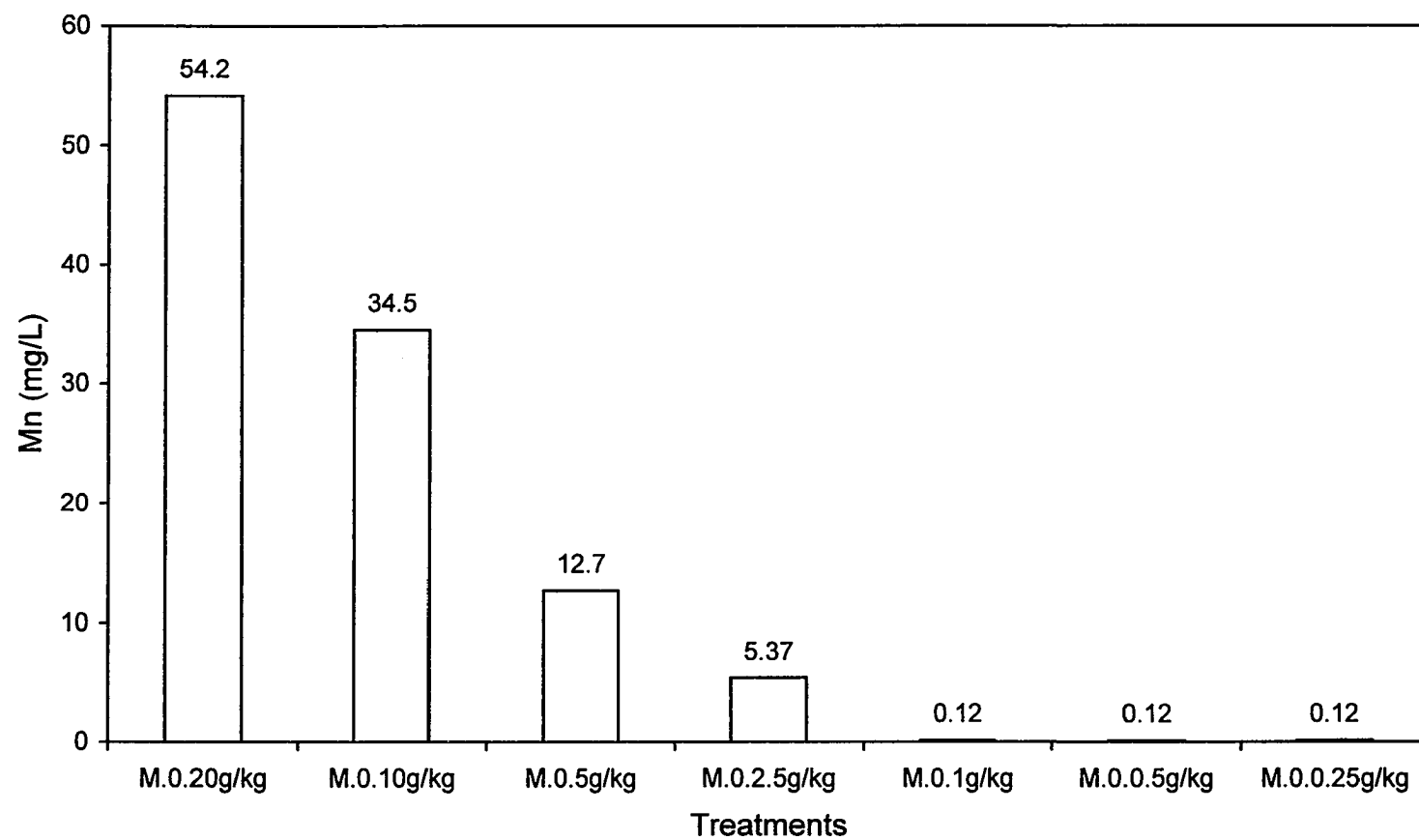


Fig. 3.3.1. Mn in soil solution for the natural pH Ap horizon of the Moreland soil with different sucrose concentrations.

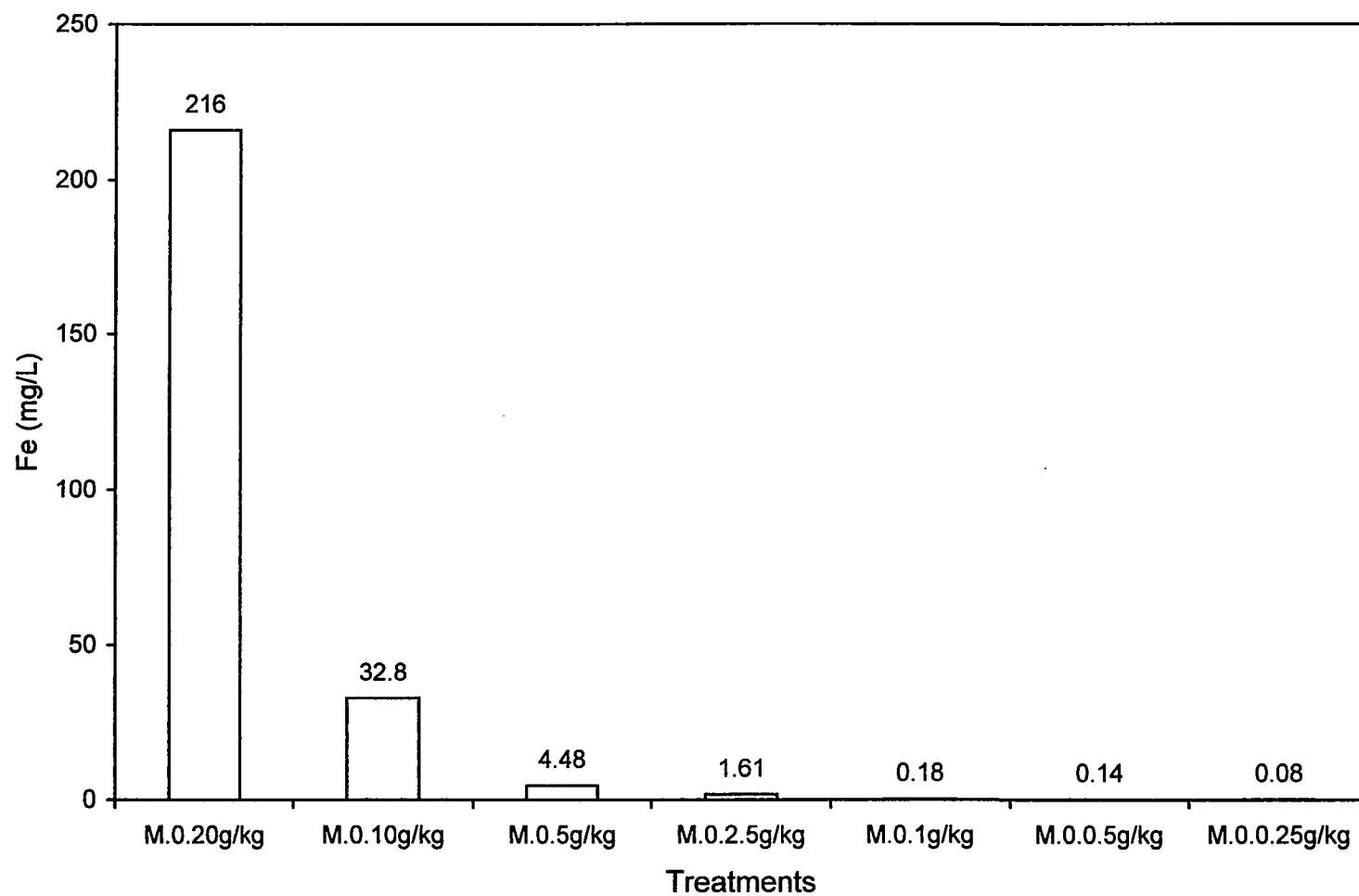


Fig. 3.3.2. Fe in soil solution for the natural pH Ap horizon of the Moreland soil with different sucrose concentrations.

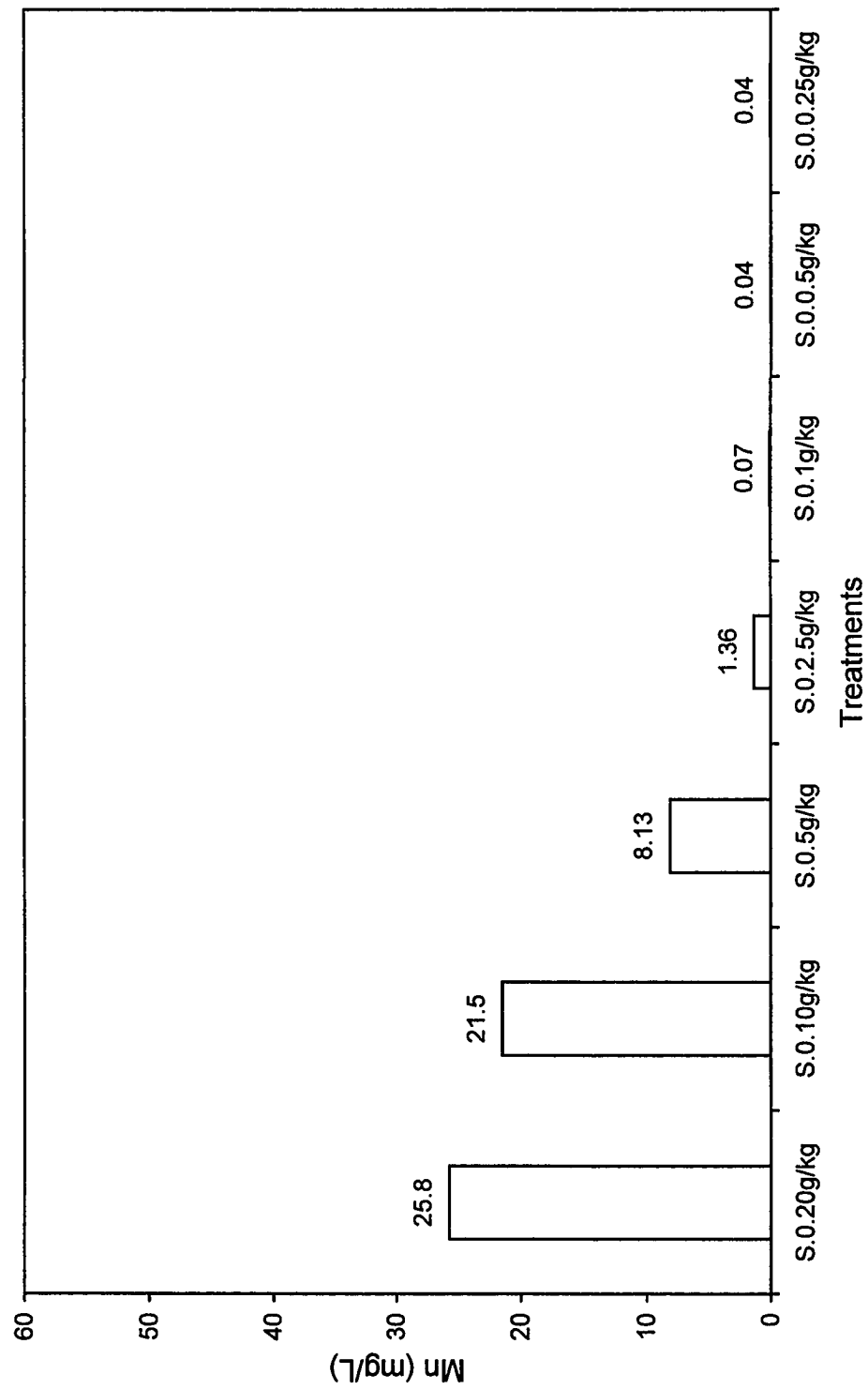


Fig. 3.3.3. Mn in soil solution for the natural pH Ap1 horizon of the Sharkey soil with different sucrose concentrations.

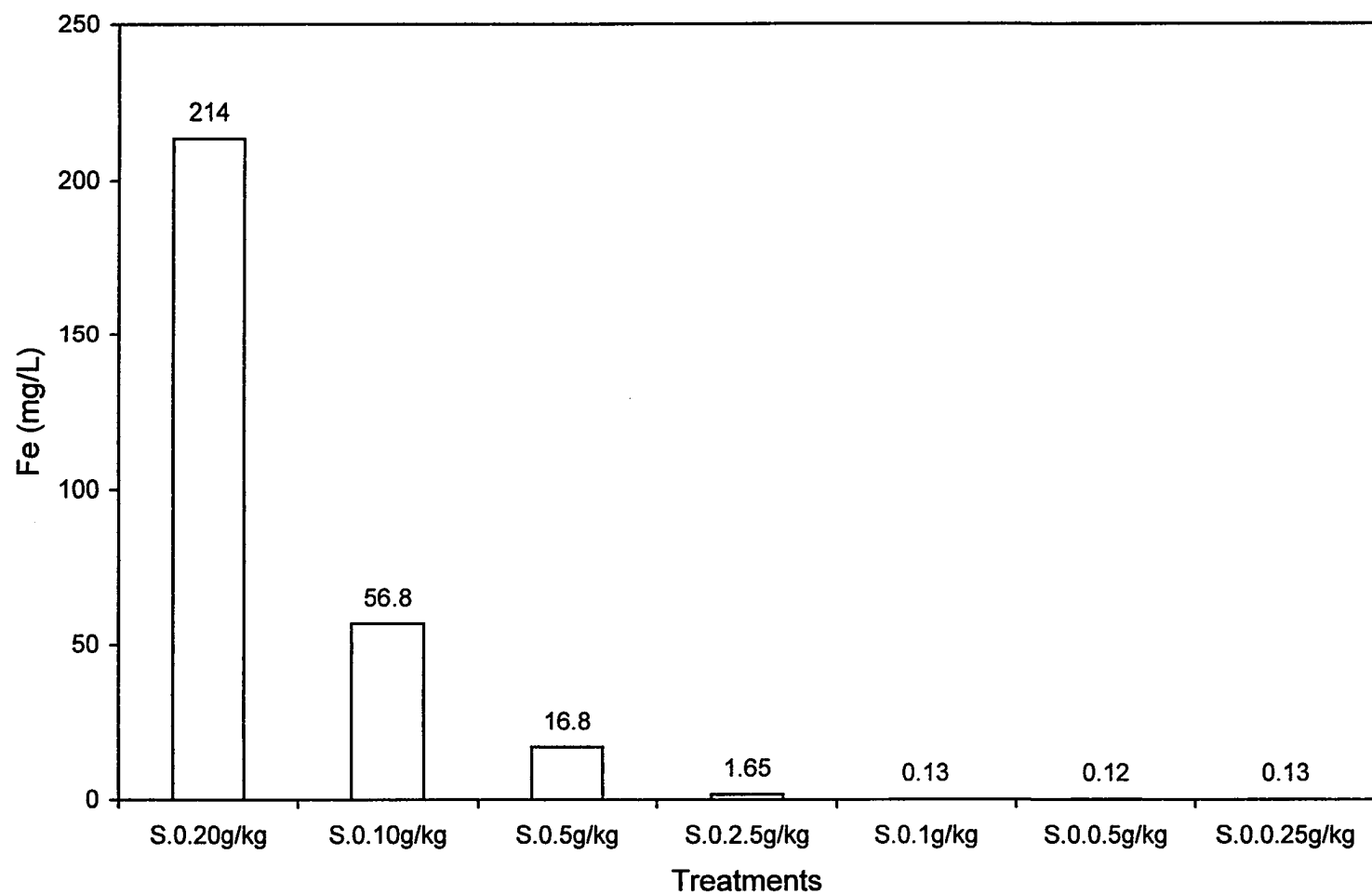


Fig. 3.3.4. Fe in soil solution for the natural pH Ap1 horizon of the Sharkey soil with different sucrose concentrations.

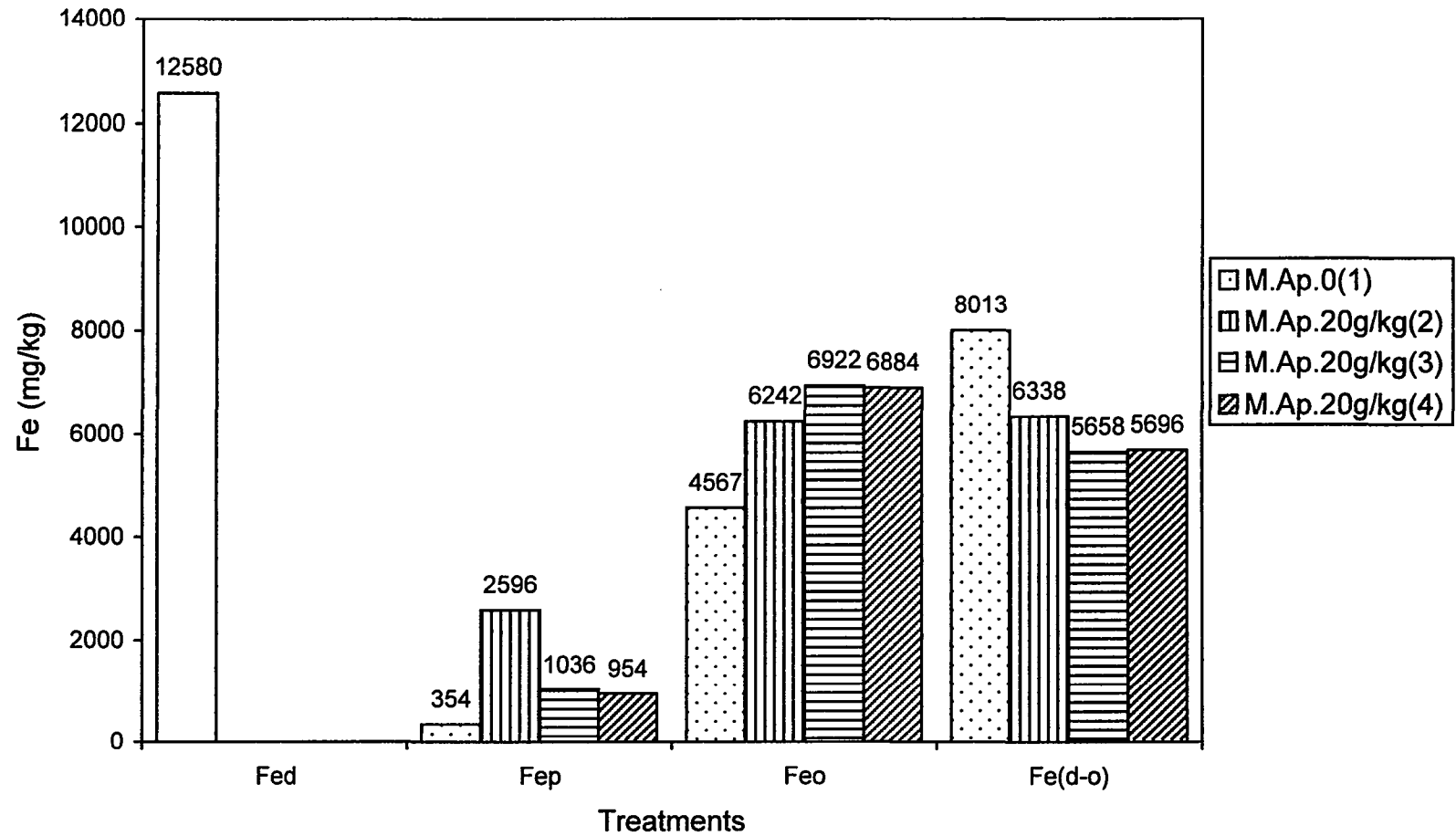


Fig. 3.4.1. Fe concentrations extracted by different chemical reagents for the natural pH Ap horizon of the Moreland soil with 20g/kg sucrose.

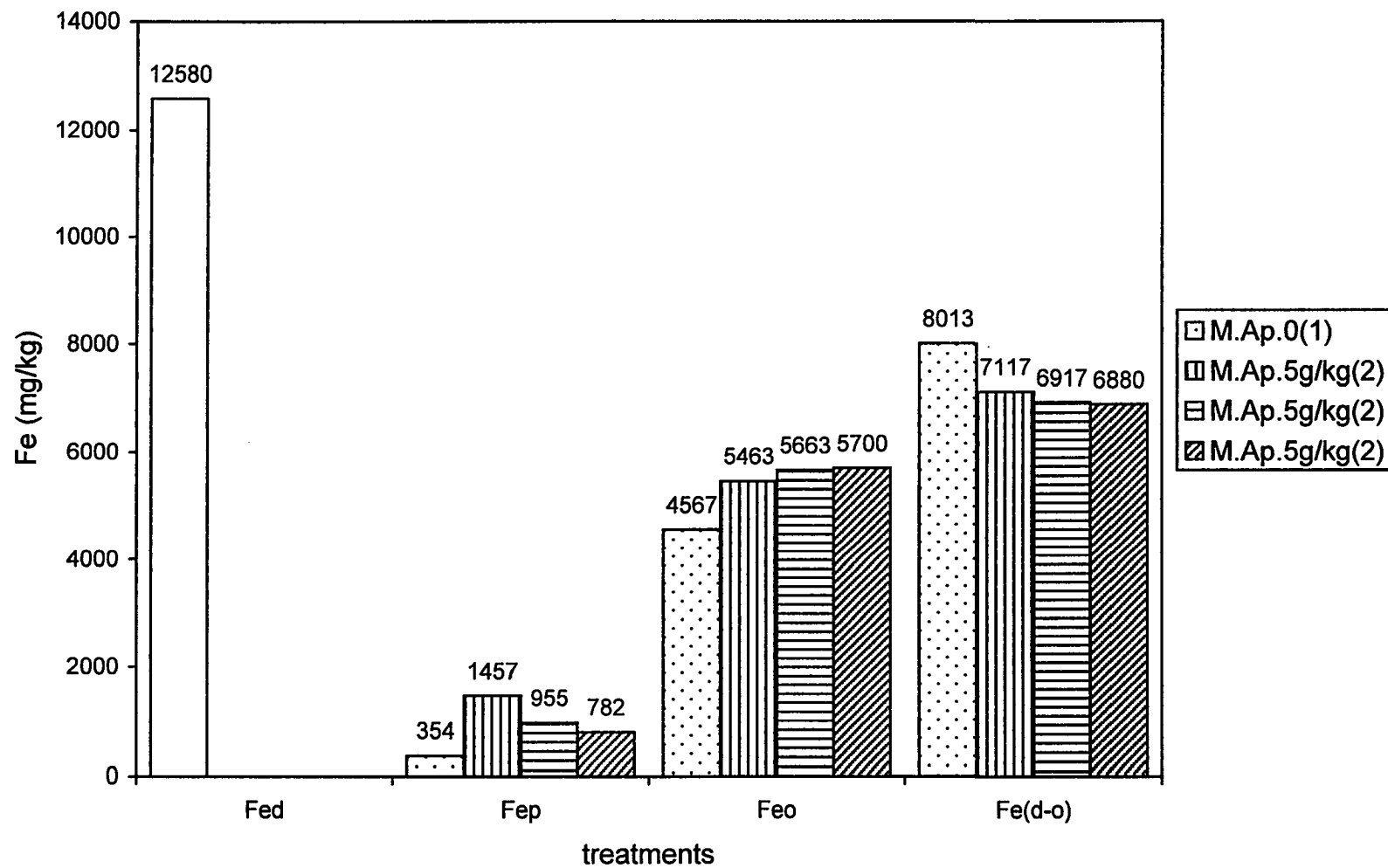


Fig. 3.4.2. Fe concentrations extracted by different chemical reagents for the natural pH Ap horizon of the Moreland soil with 5g/kg sucrose.

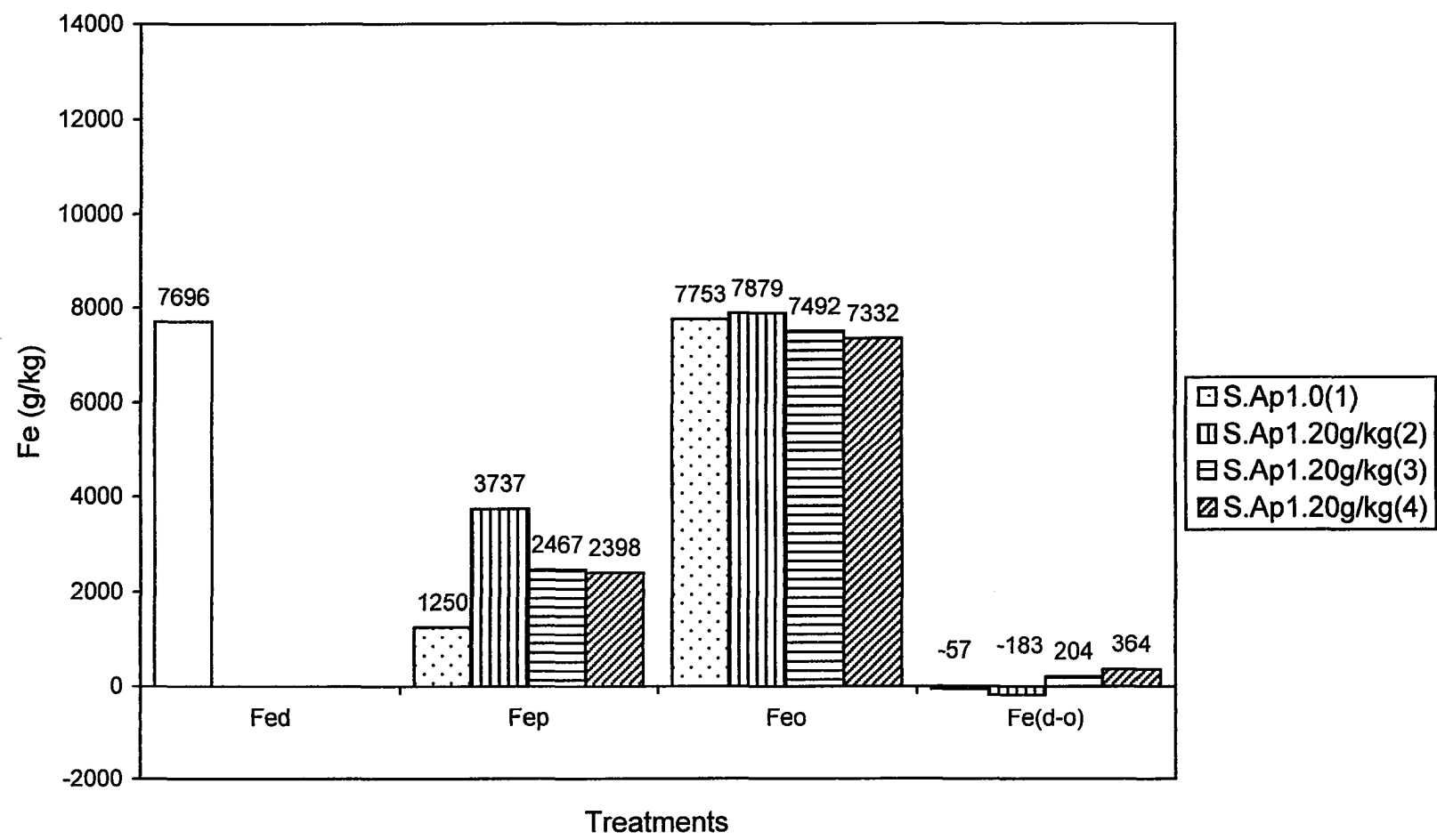


Fig. 3.4.3. Fe concentrations extracted by different chemical reagents for the natural pH Ap1 horizon of the Sharkey soil with 20g/kg sucrose.

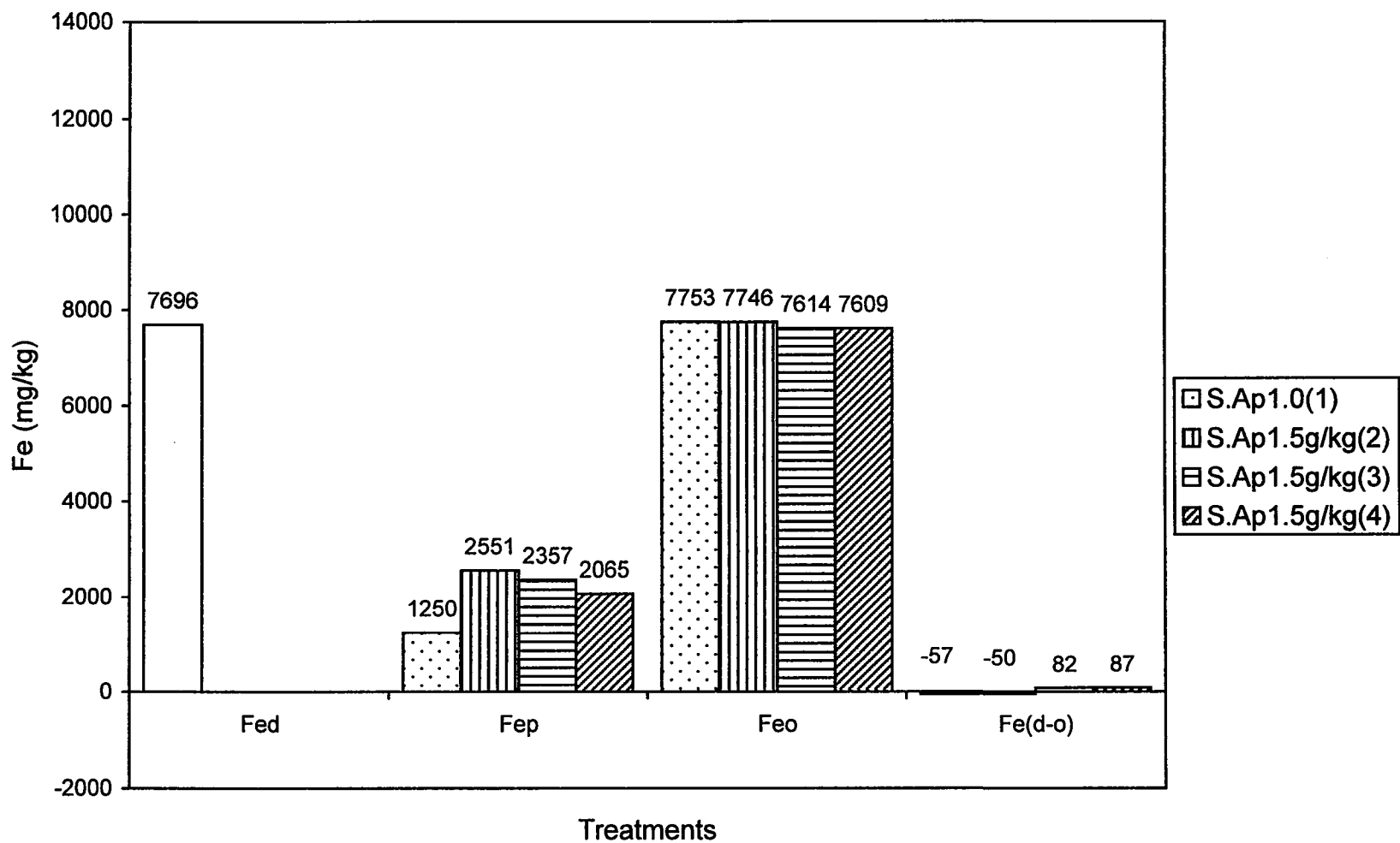


Fig. 3.4.4. Fe concentrations extracted by different chemical reagents for the natural pH Ap1 horizon of the Sharkey soil with 5g/kg sucrose.

Redoximorphic features (redox concentrations) formed within all treatments of the Sharkey soil. Some treatments showed more pronounced features. For example, amount of chroma change (lower chroma) increased with increasing sucrose during the first incubation. There was less change or no change for the second incubation except for the 5 g/kg and greater sucrose concentration for the natural pH or pH 5 adjusted treatments.

3.4. Discussion and Conclusions

3.4.1. pH

Based on the results in Chapter 2, anaerobic respiration and fermentation were the main mechanisms that controlled the pH. The pH of soils treated with 10 g/kg sucrose did not confirm previous research, indicating that acidic or alkaline soils approached a pH of 7.0 after submergence (Ponnamperuma, 1966, 1972; Patrick and Mikkelesen, 1971; Stanford et al., 1975; Berner, 1981; Yu, 1991). Therefore, different sucrose concentrations were used to evaluate their effects on pH.

Except for the M.01.2.5g/kg, M.01.1g/kg, M.01.0.5g/kg, and M.01.0.25g/kg treatments, the pH did not approach 7.0 during 21 days of incubation (Fig. 3.1.1). The rate of decrease in pH within 48 hours for the natural pH Moreland and Sharkey soils with 5 g/kg or more sucrose was greater than that of lower sucrose treatments. This reflected the influence of organic acids and CO₂ produced during the intensive decomposition of sucrose resulting in the lowering of pH (Lovley, 1992). The reduction of Fe and Mn oxides was possibly suppressed at the beginning of incubation because of the competition of

energy between fermentative and Fe-reducing bacteria. Bowman and Focht (1974) found that a high C/N ratio or high glucose concentration (1.8%) retarded denitrification and decreased soil pH. A decrease in pH within 48 hours could increase the solubility of Mn and Fe oxides. The increase in available metabolic byproducts of fermentative bacteria also stimulated the Fe-reducing bacteria to use inorganic compounds as electron acceptors, consuming the protons and electrons produced by fermentation. The pH showed an increasing trend after a minimum pH value was attained, indicating that anaerobic respiration strongly controlled the increased pH. However, the pH did not approach 7.0 during the experiment. The pH for the natural pH Moreland soil with 1 g/kg or less sucrose decreased to approximately 7.0. This gradual decrease in pH was a result of increasing carbon dioxide concentration (Ponnamperuma, 1966). The natural pH Sharkey soil with 2.5 g/kg or less sucrose did not approach 7.0 during the first incubation period (Fig. 3.1.5). This was presumably due to its greater exchangeable acid, lower SOC, and shorter incubation time.

The pH for the Moreland soil adjusted to pH 5 with 1 g/kg or more sucrose gradually increased during the first incubation period (Fig. 3.1.3). The pH 5 treatment increased the solubility of Mn and Fe oxides (Lindsay, 1972). Because of greater concentrations of active Fe and Mn, the reduction of Fe and Mn was more pronounced than in the natural pH soils. The protons consumed by anaerobiosis were therefore greater than that produced by fermentation, resulting in an increased pH. The Moreland soil with 2.5 g/kg

sucrose reached the highest pH of 6.2 after 3 weeks of submergence. The increased pH was lower for soils with more than 2.5 g/kg sucrose, indicating that fermentation was the main factor inhibiting the increase in pH. The increased pH was lower for soils treated with 1 g/kg or less sucrose. This was due to the lack of a sufficient energy source for microbes to reduce Mn and/or Fe and increase pH (Berner, 1981; Couto et al, 1985; Bryant and Macedo, 1990; Cogger and Kennedy, 1992)

The pH for the Sharkey soil adjusted to pH 5 was similar to that of the pH 5 Moreland soil (Fig. 3.1.6). However, the pH was lower when compared to the pH 5 Moreland soil with the same sucrose treatment due to lower amounts of Mn oxides in the Sharkey soil even though the Sharkey soil had greater amounts of amorphous Fe (Tables 3.3.1 and 3.3.2). A pH 5 treatment readily brought Mn into the soil solution even under aeration conditions (Gotoh and Patrick, 1972). This trend was more pronounced for Mn than for Fe (Olomu et al., 1972).

Mn and Fe ions dissolved in soil water and absorbed in exchangeable forms were detached from the exchange sites and oxidized after the drying treatment (Ponnamperuma et al., 1967; Brinkman, 1970; Miller, 1983). The oxidation of Mn and Fe released H^+ ions, decreasing the pH. The increase in pH during the re-saturation period for the natural pH Moreland soil with 10 g/kg or more sucrose was attributed to the oxidation of organic acids produced by fermentation during the first incubation period (Fig. 3.1.2). The oxidation of water soluble and exchangeable Mn and Fe ions produced exchangeable H^+

which could also be neutralized by any bicarbonates still present (Breemen, 1975). The natural pH Moreland soil with 10 g/kg or less sucrose approached a pH of 7.0 during the second saturation period. The reduction of Mn and Fe was much greater for the pH 5 treatment than for the natural pH soils (Tables 3.2.1 and 3.2.2), indicating that the protons produced by the oxidation of Mn and Fe after the first drying treatment were also greater. As a result, the pH for the Moreland soil adjusted to pH 5 during the re-saturation period was close to their pH at the end of the first incubation (Fig. 3.1.4). The pH for the Sharkey soil with different pH treatments during the re-saturation period was similar to that of the Moreland soil (Fig. 3.1.7 and 3.1.8). Except for the S.02.20g/kg treatment, the pH for the natural pH treatment with other sucrose concentrations was close to its natural pH at a value of 6.3. The pH for the soils adjusted to pH 5 was approximately 6.1. The increase in pH was due to proton consumption from anaerobic respiration during the re-saturation period.

3.4.2. Eh and Organic Carbon

The addition of 10 g/kg sucrose was high enough to effect the reduction of Mn and Fe in both Moreland and Sharkey soils. The concentration of SOC necessary for the reduction of Mn and Fe is still uncertain. This section considers the relationship among different sucrose concentrations, changes in Eh, and the reduction of Mn and Fe oxides.

The distributions of the Eh for the natural pH soils with 0.5 g/kg or more sucrose were observed (Fig. 3.2.1). The bimodal distribution was presumably due to the competition of anaerobic respiration and fermentation. The addition

of sucrose caused the rapid growth of fermentative bacteria (Lovley, 1992), resulting in a decrease in Eh. During this period, the metabolic products of fermentative bacteria facilitated the activity of Fe-reducing bacteria, resulting in electrons consumed by anaerobic respiration, increasing Eh. When the readily reducible inorganic Fe became a limiting factor, Fe-reducing microbes began to die or become quiescent; thus, the Eh decreased. The quantities and qualities of bio-available energy sources and readily available Mn and Fe controlled the bimodal distribution of Eh. Based on the results of Eh, the Mn and Fe were reduced within the natural pH soils with 2.5 g/kg or more sucrose (Patrick and Jugsujinda, 1992). The Eh for the M.01.0.25g/kg treatment gradually decreased from 600 mV to a value of 350 mV after 21 days, indicating that no Fe or Mn reduction took place. This was attributed to a lower energy source. Mn was reduced for the M.01.0.5g/kg and M.01.1g/kg treatments because the Eh was as low as 100 mV. The Eh for the natural pH Moreland soil with 2.5 g/kg or more sucrose did reach the critical Eh to reduce either Mn or Fe during the experiment.

The distribution of the Eh for the Moreland soil adjusted to pH 5 was similar to that of the natural pH soil (Fig. 3.2.3). One of the main differences in Eh for the natural pH and pH 5 treatments was the time required for the Eh to increase. The Eh for the pH 5 treatment always lagged behind the natural pH soils treated with the same amount of sucrose. This was attributed to increased fermentation. As a result, the survival time increased for fermentative bacteria, extending the time needed to increase the Eh. The second difference was the

distribution of Eh for the M.51.0.25g/kg and M.51.0.5g/kg treatments, which showed a greater rate of decreasing Eh within 48 hours due to lower pH as compared to that of the M.01.0.25g/kg and M.01.0.5g/kg treatments. The final difference was the broader bimodal distribution of Eh for the pH 5 treatment. This indicated that the pH 5 treatment had a greater electron buffer capacity or reducible Fe, deferring the decrease in Eh.

The Eh showed that both Mn and Fe could be reduced by the natural pH Sharkey soil with different sucrose treatments (Fig. 3.2.5). This was due to a greater energy source and amorphous Fe (Tables 3.3.2 and 3.4.3). The distribution of Eh for the natural pH and pH adjusted to 5 Sharkey soil was similar to that of the Moreland soil. The difference in the Eh among the Sharkey soil was also influenced by different concentrations of bio-available SOC, indicating that SOC was the main factor controlling the Eh. Treatments with a greater SOC had a greater reducing intensity and maintained a longer reducing condition than did treatments with lower concentrations. The distribution of the pH adjusted to 5 Sharkey soil was similar to that of the natural pH treatments but had a maximum Eh at 200 mV and a broader bimodal distribution than did the natural pH Sharkey treatments (Fig. 3.2.7). This was ascribed to a greater quantity of active Fe and Mn within the pH 5 treatment.

The rate of Eh decrease was slower for the natural pH and pH 5 Moreland treatments during the re-saturation period than during the first saturation period (Fig. 3.2.2 and 3.2.4). The bimodal distribution of Eh was also less clear. This was probably due to a lower remaining SOC concentration (Table 3.4.2) and

greater newly formed reducible Mn and Fe (Table 3.3.1) during the re-saturation period. The Eh for the natural pH Moreland soil with 1 g/kg or less sucrose was not low enough to reduce Fe and Mn. The Mn and Fe were reduced for the Moreland soil adjusted to pH 5 with 0.5 g/kg or more sucrose. This suggested that the pH 5 treatment, resulting in greater concentration of reducible Mn and Fe, was another controlling factor of reduction. The distributions of the Eh for the natural pH and pH 5 Sharkey soil during the re-saturation period were similar but differed from those of the Moreland soil (Fig. 3.2.6 and 3.2.8). The minimum Eh attained by the S.02.20g/kg treatment was -200 mV, which was higher than that of the first saturation period, implying less SOC during the re-saturation period (Table 3.4.3). The rate of decrease in Eh was less with increased sucrose treatment. The rate of decreasing Eh for the S.02.20g/kg treatment was slower than that of the S.02.10g/kg treatment. This was probably because OC was incorporated and transformed into more complex forms by aerobic bacteria during the drying period. The quantity of complexed OC increased with each increasing increment of sucrose. As a result, it took more time for fermentative bacteria to use those complex organic carbons as an energy source. Another explanation involved greater reducible Mn or Fe within the S.02.20g/kg treatment, which delayed the decreasing Eh. The Sharkey soil adjusted to pH 5 had a broader bimodal distribution of Eh due to greater available active Mn and Fe. The Eh for the S.02.0.5g/kg, S.02.0.25g/kg, S.52.0.5g/kg, and S.52.0.25g/kg treatments was less than that of the S.01.0.5g/kg, S.01.0.25g/kg, S.51.0.5g/kg, and S.51.0.25g/kg

treatments, respectively. This was due to the re-wetting of dried soil, which increased the microbial biomass C and potentially mineralizable C and N (Franzlubbers et al., 2000). Based on the results of Eh, both Mn and Fe were reduced in both the natural pH and pH adjusted to 5 Sharkey soil during the re-saturation period, suggesting that the Sharkey soil should exhibit redoximorphic features in the field.

TOC and SOC extracted by cold water were used to correlate the relationship between energy sources and the Eh (Tables 3.4.1 and 3.4.3). Both TOC and SOC decreased with decreased sucrose treatment and with the freeze-dry, first drying, and second drying treatments. No evidence showed the effects of TOC or SOC on the Eh. The concentration of TOC and SOC for the M.0.2.5g/kg(2) treatment was 10.1 and 0.22 g/kg, respectively. The TOC was 9.9 g/kg and SOC was 0.19 g/kg for the M.0.0.25g/kg(2) treatment. However, the Eh was -200 mV and 350 mV for the M.01.2.5g/kg and M.01.0.25g/kg treatments, respectively. Results of SAS LSMEANS pairwise comparison ($\alpha=0.05$) also revealed no significant difference in SOC for 0.25 g/kg to 5 g/kg Moreland and Sharkey soils (Tables 3.4.2 and 3.4.4). The TOC, SOC extracted by water, and SOC in the soil solution did not explain the Eh.

3.4.3. Fe Oxide Transformation

Reduction of Fe in soils was principally a biochemical process (Ottow, 1970). The Fe reduced by anaerobiosis complexed with organic acids, which can be extracted by sodium pyrophosphate. The Fe_p for the natural pH and pH adjusted to 5 Moreland soil increased with increasing sucrose rates after 3

weeks of incubation (Table 3.3.1). The added sucrose not only increased the activities of anaerobic microbes (Fig. 3.2.1 and 3.2.3) but also promoted the chelation ability with reduced Fe (Bao, 1985), of which both increased the reduction of Fe. An increasing Fe_p indicated that Fe_p could be produced at the expense of either amorphous or crystalline inorganic Fe forms after 21 days of incubation. The Fe_p for the M.0.0.25g/kg(2) treatment increased during the incubation period, suggesting that only a small quantity of Fe was reduced. However, the redox potential remained high (300 mV) and negligible Fe (0.08 mg/L) was observed in soil solution (Table 3.2.2). After the first drying period, the Fe_p for the Moreland soil treated with 1 g/kg or more sucrose decreased from 571 to 423 mg/kg for the M.0.1g/kg treatment and from 2,596 to 1,036 mg/kg for the M.0.20g/kg treatment. This was due to some specialized aerobic microbes that were able to utilize organic complexed Fe and release it in a finely inorganic hydrous form (Stone, 1997). After alternating saturation and drying treatments, the forms of Fe-organic compounds became less bio-degradable, thus more stable and not as easily attacked by aerobic microbes. This causes an insignificant decrease in Fe_p between the first and second drying treatments. The Fe_p for the pH 5 Moreland soil was similar to that of the natural pH soil (Table 3.3.2). However, the Fe_p was always greater for the pH adjusted to 5 treatments than in the natural pH treatments with the same sucrose. This was attributed to an increase in the solubility and availability of Fe as electron acceptors for the soils adjusted pH to 5. The distribution of the Fe_p for the natural pH and pH adjusted to 5 Sharkey soil was the same as that

of the Moreland soil with different pH treatments (Table 3.3.2). However, the original concentration of Fe_p for the Sharkey soil was greater than that of the Moreland soil. This corresponded to its greater OC content and implied that the Sharkey soils were more susceptible to reduction.

An increase in the Fe_o was observed for the natural pH Moreland soil with 2.5 g/kg or more sucrose after incubation. The increased Fe_o was ascribed to an increased Fe_p because oxalate dissolved both organic and inorganic amorphous Fe (Wada, 1989). As compared with the Fe_o of the M.0.0g/kg(1) treatment, the increased Fe_o after 21 days of incubation partially resulted from the reduction of crystalline Fe. The Fe_o increased after the first drying period, indicating that there were still enough organic compounds for the anaerobic microbes to reduce the crystalline Fe. There was no apparent difference in the Fe_o for all soils with different sucrose treatments between the first drying and second drying treatments even though the results of Eh were low enough to reduce Fe during the re-saturation period. Fe complexed with organic compounds transformed into amorphous inorganic Fe when the soil was air-dried, and was readily used as an electron acceptor when the soil was re-saturated. Thus, the Fe_o did not increase between the first and second drying treatments.

There was no difference in the Fe_o for the natural pH and pH adjusted to 5 Sharkey soil (Table 3.3.2), since the amorphous Fe was the main Fe form. This was also confirmed by the data of Fe_{d-o} . The Fe_o also did not increase with increasing sucrose treatment. It seemed that the Fe transformation was limited

to the transformation between organic and inorganic amorphous forms. The pH adjusted to 5 treatment did not have a greater Fe_o than the natural pH treatment, indicating that the Fe transformation was limited to the transformation between organic and inorganic amorphous forms.

From the results of Table 3.3.2, the Fe_{o-p} decreased with increasing sucrose rates for the natural pH and pH adjusted to 5 Moreland soil after the freeze-dry treatment. This indicated that the amorphous inorganic Fe was partially transformed into Fe-humus complexed forms during 3 weeks of incubation. The increased Fe_{o-p} for treatments with 2.5 g/kg or more sucrose after the first drying treatment meant that Fe-humus complexed forms transformed into amorphous inorganic Fe forms during drying. There was no difference in Fe_{o-p} between the first and second drying treatments, indicating that an energy source was the limiting factor resulting in no further reduction of crystalline Fe and newly formed amorphous Fe was preferentially reduced during re-saturation. The distribution of the Fe_{o-p} for the Sharkey soil was similar to that of the Moreland soil. However, the decreased Fe_{o-p} was greater after the freeze-dry treatment for the Sharkey soil when the same sucrose treatments were compared for the Moreland soil. This suggested that more amorphous inorganic Fe was transformed into Fe-humus complexed forms due to limited crystalline Fe in Sharkey soil. Based upon the data of the Fe_{d-o} , there was almost no crystalline Fe in the Sharkey soil (Table 3.3.2).

The Mn and Fe in soil solutions increased with increased sucrose for both the Moreland and Sharkey soils with different pH treatments (Tables 3.2.1,

3.2.2, 3.2.3, and 3.2.4). The increased Mn and Fe concentrations were greater for the Moreland soil adjusted to pH 5 than in the natural pH treatments. The greater Mn and Fe for the Moreland soil adjusted to pH 5 were due to increased Mn and Fe solubility or the greater Eh required to reduce Mn and Fe (Garrels and Christ, 1965; Lindsay, 1972; Barnum, 1982). The concentration of Mn in natural pH Moreland soil solution was lower than that of pH 5 treatment with the same sucrose, as expected. The Mn was 54.2 mg/L for the M.0.20g/kg treatment and 99.6 mg/L for the M.5.20g/kg treatment. That was because the pH 5 treatment increased water-soluble manganese at the expense of exchangeable form (Gotoh and Patrick, 1972). The Mn and Fe in the soil solution were lower for the natural pH Sharkey soil than for soils adjusted to pH 5 with the same sucrose treatment. The Fe was 214 mg/L for the S.0.20g/kg treatment and 323 mg/L for the S.5.20g/kg treatment. This is consistent with the findings of Olomu et al. (1972) indicating that the concentrations of Mn and Fe in soil solution increases as pH decreases. The main difference was that the Mn was less in the Sharkey soil than in the Moreland soil. The Mn was 99.6 mg/L for the M.5.20g/kg treatment and 49.6 mg/L for the S.5.20g/kg treatment. The lower Mn in the Sharkey soil was thought to be the factor resulting in lower pH in the Sharkey soil during the 21 days of submergence.

3.4.4. Soil Colors

The predominant matrix color was dark reddish brown (5YR 3/3) for the M.01.20g/kg treatment, consistent with the initial soil color after the first drying treatment (Table 3.5.1). However, the soil surface had many 2.5YR 3/4,

common 5YR 5/6, and few 7.5YR 6/6 redoximorphic features. The formation of redoximorphic features on the soil surface was from the re-oxidization of Fe^{2+} ions during the incubation period. The water-soluble Fe^{2+} ions migrated away from the locus of production through a concentration gradient and came in contact with the oxygenated water surface (Harmsen and Breemen, 1975). As a result, Fe^{2+} ions oxidized to Fe^{3+} and formed either amorphous Fe grains or short-ordered crystalline forms. More Fe^{2+} ions in the soil solution oxidized to Fe^{3+} and precipitated as redoximorphic features onto soil surface with each increment of sucrose were observed. The reddish redoximorphic features decreased and yellowish redoximorphic features increased with decreased sucrose for the natural pH Moreland soil. No formation of redoximorphic features was observed on the soil surface or within the matrix for the soils with 1 g/kg or less sucrose, indicating that OC was the main factor affecting the changes of soil colors. Dobos et al. (1990) found that a decrease in the chroma of redoximorphic features and matrix colors was due to increased OC concentrations. Redoximorphic features for the M.01.2.5g/kg treatment did not meet the 2 or less chroma color requirement for redox depletions. However, it was believed that these redoximorphic features formed as a result of preferential reduction and the removal of Fe within zones of the reddish brown (5YR 3/3) matrixes. The redoximorphic features formed on the soil surface for the Moreland soil adjusted to 5 were similar to those of the natural pH soils. The hues of redoximorphic features for the soil adjusted to pH 5 were redder than those of the natural pH soils with the same sucrose treatment. The hue of

redoximorphic features was 2.5YR for the M.51.10g/kg treatment and 7.5YR for the M.01.10g/kg treatment. This indicated that more Fe was reduced within the soils adjusted to pH 5 during the incubation period and re-oxidized after the first drying period. This was consistent with the results of greater Fe concentrations in soil solution (Table 3.2.2) and Fe_o (Table 3.3.1) for pH 5 treatments. No redoximorphic features were observed for the M.0.1g/kg treatment. However, the light brown (7.5YR 6/3) that formed on the soil surface for M.5.1g/kg treatment also meant that more Fe were reduced by the pH 5 soil.

The soil color change for the Sharkey soil was similar to those of the Moreland soil. The increased presence of reddish redoximorphic features with increased sucrose treatment was observed for the natural pH and pH adjusted to pH 5 Sharkey soil after the first drying treatment (Table 3.5.4). However, common light brownish gray to pale yellow (2.5Y 6 to 8/2) redoximorphic features formed within the natural pH and pH adjusted to 5 Sharkey soil with sucrose as low as 0.25 g/kg. This was due to greater concentrations of organic carbon and more easily reducible Fe in the Sharkey soil (Tables 3.3.2 and 3.4.3).

A brown color (7.5 YR 5/2) extending 2 mm into the Moreland soil surface was observed for the natural pH soil with 20 g/kg sucrose after the first drying treatment (Table 3.5.1). These zones of low chroma below the soil surface were referred to as neoalbans (Venemen et al., 1976). The neoalbans appeared to be distinct zones of low Fe content as compared to the color of the

initial matrix and redoximorphic features above the soil surface. This region was also identified as an Fe depletion zone in the Keys to Soil Taxonomy (Soil Survey Staff, 1998). The brown depletion zones corresponded to areas adjacent to the soil surface in which reductive dissolution of hematite had occurred. The extension of low chroma into the soil surface decreased with decreased sucrose. The changes in soil colors for the soils adjusted to pH 5 showed the same trends. No redoximorphic features with chroma less than or equal to 2 for the natural pH and pH 5 treatments were observed in soils with 2.5 g/kg or less sucrose. The formation and the extent of low chroma were controlled by the concentration of energy sources.

Low chroma (≤ 1) neoalban was observed on the soil surface for the natural pH and pH adjusted to 5 Sharkey soil with 5 g/kg or more sucrose. The abundance of low chroma redoximorphic features similar to those of the Moreland soil increased with increased sucrose treatment. The sucrose facilitated the reduction of Fe in both the Sharkey and Moreland soils.

Only natural pH Moreland soil with 20 g/kg sucrose and pH adjusted to 5 Moreland soil with 20 and 10 g/kg sucrose formed redoximorphic features on the soil surface after the re-saturation and second drying treatments (Table 3.5.2). The formation of redoximorphic features in the natural pH and pH adjusted to 5 soils was less than during the first drying period due to the lack of an energy source with which microbes might reduce Fe. Another plausible explanation was that the Mn became preferential electron acceptors resulting in a lower reduction of Fe in an environment deficient in energy sources. The

low chroma redoximorphic features disappeared after the re-saturation and drying periods due to being effectively masked by finely divided hematite(Schwertmann et al., 1977).

Due to lower energy sources during the re-saturation period, the abundance of redoximorphic features decreased in the natural pH and pH adjusted to 5 Sharkey soil after the second drying treatment (Table 3.5.5). The critical threshold sucrose concentration for the natural pH and pH adjusted to 5 Sharkey soil to form the redoximorphic features after the second drying treatment was 2.5 g/kg, which was lower than that of the Moreland soil. This suggested that there was a greater amounts readily reducible Fe in the Sharkey soil than in the Moreland soil.

The color of the natural pH soil matrixes were strongly influenced by energy sources with hue ranging from 5.7 to 6.5YR and chroma ranging from 3.6 to 3.2 with increased sucrose after the freeze-dry treatment (Table 3.5.3). These differences in hue were consistent with increasing sucrose concentrations. The yellowish hue (6.5 and 6.4YR) and lowest chromas (3.2 and 3.4) occurred for the M.0.20g/kg and M.5.20g/kg treatments. However, the colors of the natural pH soils with less than 1 g/kg sucrose remained unchanged (5.7YR) after 3 weeks of incubation due to a low energy source. The 1 g/kg or less sucrose treatments of the natural pH soils was an insufficient energy source for the microbes to reduce Fe. The soils with pH 5 treatment showed a redder color (5.4YR) than did the natural pH soils. This was ascribed to the acidification resulting in a differential dissolution of fine-sized Fe particles; thus, the average

hue increased. Color designations of Munsell value and chroma for dry, crushed pH adjusted to 5 soils after the freeze-dry treatment correlated with increased sucrose. The hue of M.5.0.25g/kg treatment showed yellowish (5.5YR), but the chroma was unchanged as compared to that of the original pH 5 treatment (5.4YR), indicating that the threshold sucrose concentration required to reduce Fe was lower for the pH 5 treatment.

The hues were yellowish and chromas were higher for both the natural pH and pH 5 Moreland soil after the first drying treatment (Table 3.5.3). This indicated that more Fe was reduced between the incubation and first drying periods resulting in more yellowish hues. An increase in chroma was generally attributed to increasing Fe^{3+} from Fe^{2+} in soil solution re-oxidized during the drying period. The increase in Fe_o after the first drying treatment also affirmed the result (Table 3.3.1). The hues after re-saturation and the second drying treatments became more reddish for the natural pH soils with 5 g/kg or less sucrose and for the pH adjusted to 5 treatments with 20 g/kg or less sucrose. The soils with lower sucrose treatments were more reddish, indicating that less Fe was reduced during the re-saturation treatment. Thus, the hues were more easily masked by the original soil matrix colors.

The original hue of natural pH and pH 5 Sharkey soil was 0.1Y (Table 3.5.3). The hues of crushed Sharkey soil with 0.25 or more sucrose was more yellowish than that of the original treatment during the freeze-dry, first drying, and second drying treatments (Table 3.5.3). The hue was 0.7Y, 0.5Y, and 0.5Y for the S.0.20g/kg treatment during the freeze-dry, first drying, and second

drying treatments, respectively. The hue was redder for the S.0.20g/kg treatment after the first drying treatment than the freeze-dry treatment. This indicated that the reduced Fe transformed into other oxidized Fe forms, presumably Fe-humus complex forms or newly formed fresh amorphous inorganic Fe. The chroma did not apparently change during different treatments because of the low chroma (≤ 1.9) of the original soil.

CHAPTER 4.

THE CHANGES OF Eh, pH, SOLUBLE ORGANIC CARBON, Fe, AND Mn CONCENTRATIONS IN THE INTERSTITIAL WATER AT THREE DIFFERENT DEPTHS

4.1. Introduction

It is widely accepted that the physio-chemical behavior of Mn and Fe in natural systems is largely controlled by fluctuations in the Eh-pH environment. Eh measurements with Pt electrodes were considered inaccurate because of the characteristic non-equilibrium of soil redox reactions and the heterogeneity of soil (Bohn, 1971; Cogger et al., 1992).

Natural systems do not reach oxidation-reduction equilibrium because of the continual addition of electron donors by oxidizable organic compounds. At non-equilibrium, the redox potential is a mixed potential and does not relate to the Nernst equation (Bohn, 1971).

Variability among measurements of electrodes was often large, due primarily to microsites in soil (Meek and Grass, 1975; Callebaut et al., 1982; Cogger and Kennedy, 1992; Cogger et al., 1992). The redox potential did not reflect the soil aeration status in oxygen-rich environments because of poor poise properties (Ponnamperuma, 1972; Callebaut et al., 1982). Cogger et al. (1992) claimed that theoretical estimates of Fe reduction based on measured redox potentials were inappropriate. The disparity between the actual concentration of Fe in solution and that theoretically predicted by measured Eh and pH was due to the formation of Fe-humus complexes (Olomu et al., 1973; Schnitzer, 1986; Schwertmann et al., 1986; Stevenson and Fitch, 1986).

Despite these shortcomings, the redox potential is the only measurement to assess the oxidation-reduction status of soil.

Soil pH tends to approach 7 when soil were submerged by water for a period of time (Ponnamperuma, 1966; 1972; Patrick and Mikkelesen, 1971; Stanford et al., 1975; Berner, 1981; Yu, 1991). The pH results from Chapters 2 and 3 did not support the same conclusion after 3 weeks of incubation. Ponnamperuma (1966) observed that the pH values of the soil solution were higher than soil pH values at the beginning of submergence but appreciably lower for the soil solution when the redox potential indicated apparent reduction. This was attributed to the accumulation of carbon dioxide in the soil solution and was described in terms of the inversion of suspension effect.

As bacteria decompose organic matter in saturated soil, they produce organic chemicals that reduce O_2 to H_2O , NO_3^- to N_2 , Mn^{4+} to Mn^{2+} , and Fe^{3+} to Fe^{2+} , respectively. These chemical reactions occur in sequence, with O_2 being reduced first, then NO_3^- , manganic Mn, and finally ferric Fe. The step-by-step order of redox reactions from the most energetically efficient to the least efficient constitutes a redox sequence (Connell and Patrick, 1968; Patrick and Mahapatra, 1968; Turner and Patrick, 1968; Ponnamperuma, 1972; Stanford, 1975; Patrick, 1980; Bohn, 1985; Patrick and Jugsujinda, 1992). Bohn (1985) considered that the choice of an alternative electron acceptor was related to the net energy gain from the electron transfer and the acceptors' availability in soil. Munch and Ottow (1978) concluded that the crystalline Fe oxides were dissolved preferentially rather than amorphous Fe forms under reducing

conditions. Munch and Ottow (1982, cited in Schwertmann et al., 1986) found that Fe reduction was considerably suppressed by inserting a semi-permeable membrane between the Fe and bacteria in strongly reduced conditions. This suppression was due to the lack of a “ferrireductase” system to overcome the energy barrier. The conclusion regarding the reduction sequence differed with authors, methods, and studying sites.

The objective of this research was to monitor the changes in pH, Mn and Fe contents in the interstitial water and soil Eh at three different depths to evaluate the reduction sequence and mineral stability.

4.2. Materials and Methods

4.2.1. Materials

The Moreland and Sharkey surface horizons were selected for the study materials without any pH adjustment and adjustment to pH 5. Natural pH for the Moreland and Sharkey soil was 7.4 and 6.4, respectively. Equilibrium status for the soil adjusted to pH 5 was assumed when two successive pH readings taken within 24 hours did not differ by more than 0.1 unit.

4.2.2. Incubation Procedures

A plastic incubation box (18.5 cm in length and 17.0 cm in diameter) was used with a total volume of approximately 4.2 L. Holes were drilled in the incubation box at 9.5, 12.5, and 16.5 cm from the lid in order to install ceramic cups for collecting the interstitial water for chemical analyses. Two types of porous ceramic cups were installed. One set of porous ceramic cups (8 cm in length and 1 cm in diameter) was installed at 9.5 cm. Another set of porous

ceramic cups (7 cm in length and 2 cm in diameter) was installed at 12.5 and 16.5 cm. All porous ceramic cups were sealed with silicon gel. Each incubation box was sealed with a plastic lid. Holes were drilled into the lid to admit electrodes and supply 10 g/kg sucrose (by solution). Four replicate electrodes were placed through the lid to depths of 9.5, 12.5, and 16.5 cm comparable to the sampling positions of ceramic cups. The experimental incubation system is shown in Figure 4.1.

About 1 Kg soil with 10 g/kg sucrose (by soil weight) was agitated on a reciprocating shaker in aerobic conditions for 16 hours. The ratio of water to soil was approximately 4 to 1. After agitation, the soil suspension was immediately poured into the incubation box and the soil matrix was kept at a height of 9.5 cm. The soil was amended with a 10 g/kg sucrose solution 9 cm above the soil surface. The incubation boxes were sealed with a lid. Redox potential measurements followed the methods described in Chapter 2. Approximately 2 mL of the interstitial water was sampled every 24 hours for chemical analysis for 3 weeks.

4.2.3. Chemical and Mineralogical Analysis

The pH of the interstitial water was measured immediately after sampling. The interstitial water was instantly diluted by distilled water to 10 fold and acidified by an aliquot of concentrated sulfuric acid for the analysis of soluble organic carbon, Fe, and Mn. The analytical methods were described in Chapter 3.

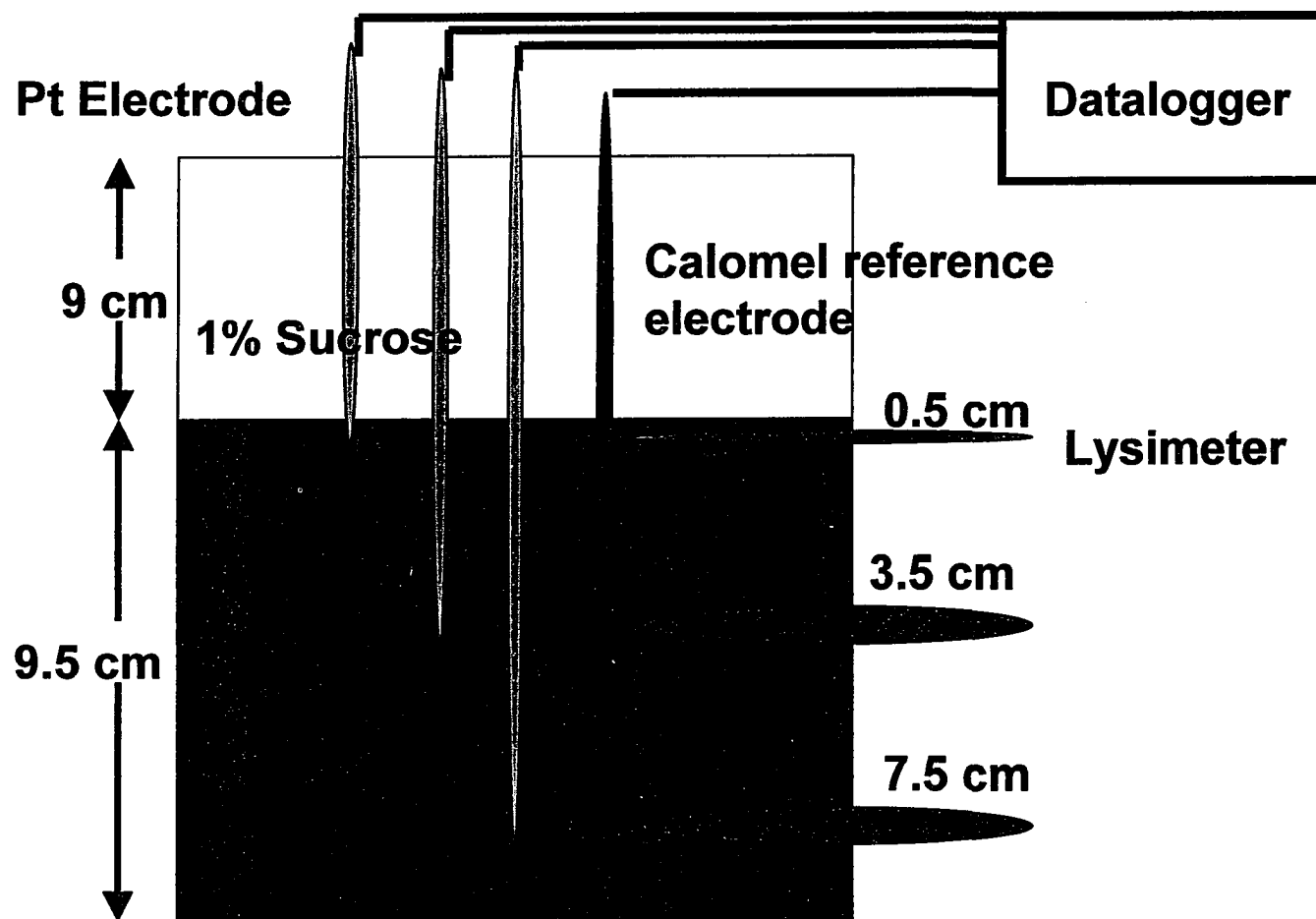


Fig. 4.1. The installation of lysimeters for studying interstitial water and Pt electrodes at three different depths.

X-ray diffraction patterns were obtained from the soil sampled from 0.5 and 7.5 cm below the surface of Moreland and Sharkey soil after 21 days of incubation. The soil was freeze-dried and grounded to pass through a 2 mm sieve. Powder mounts were prepared using a plexiglass holder by backfilling and then gently pressing the samples against hand-ground slides to minimize preferred orientation. The diffractograms were obtained from powder mounts at 40 kV and 25 mA using CuK α radiation and a fixed counting time of 100s/0.05 degree 2 θ on a Philips XRG-3000 diffractometer.

4.3. Results

4.3.1. pH

Moreland Soil

The notations for the Moreland soil with different treatments are presented in Table 4.1. Temporal pH changes for the natural pH Moreland soil are illustrated in Figure 4.2.1. The pH at the M.0.(0.5) position decreased from 7.4 to 7.2 within 24 hours and to 6.2 within 48 hours. The pH continued to decrease to 5.9 within 96 hours and stabilized at 5.7 for the remainder of the monitoring period. The pH at the M.0.(3.5) position did not change within 24 hours. It decreased to pH 6.4 within 48 hours and remained constant during the experiment. The pH at the M.0.(7.5) position increased from 7.4 to 7.7 within 24 hours. It decreased to pH 6.7 within 48 hours and continuously decreased to pH 6.3 within 120 hours. The pH increased from 6.3 to approximately 7.0 during the remainder of the experiment. The pH value measured at the end of

incubation was 5.8, 6.3, and 6.9 for the M.0.(0.5), M.0.(3.5), and M.0.(7.5) treatments, respectively.

Table 4.1. Treatment explanation for the Moreland and Sharkey soil.

Treatment abbreviation	Treatments
M.0(0.5)	Moreland, natural pH, installed at 0.5 cm below soil the surface.
M.0(3.5)	Moreland, natural pH, installed at 3.5 cm below the soil surface.
M.0(7.5)	Moreland, natural pH, installed at 7.5 cm below the soil surface.
M.5(0.5)	Moreland, adjusted to pH 5, installed at 0.5 cm below the soil surface.
M.5(3.5)	Moreland, adjusted to pH 5, installed at 3.5 cm below the soil surface.
M.5(7.5)	Moreland, adjusted to pH 5, installed at 7.5 cm below the soil surface.
S.0(0.5)	Sharkey, natural pH, installed at 0.5 cm below the soil surface.
S.0(3.5)	Sharkey, natural pH, installed at 3.5 cm below the soil surface.
S.0(7.5)	Sharkey, natural pH, installed at 7.5 cm below the soil surface.
S.5(0.5)	Sharkey, adjusted to pH 5, installed at 0.5 cm below the soil surface.
S.5(3.5)	Sharkey, adjusted to pH 5, installed at 3.5 cm below the soil surface.
S.5(7.5)	Sharkey, adjusted to pH 5, installed at 7.5 cm below the soil surface.

The pH of the interstitial water was 7.1 for the pH adjusted to 5 Moreland soil after 24-hour agitation. The pH at the M.5.(0.5) position decreased from 7.1 to 6.8 within 24 hours and continued to decrease to 5.8 within 48 hours (Fig. 4.2.1). It further decreased to 5.2 within 96 hours and stabilized at approximately 4.8 for the remainder of the experiment. The pH at the M.5.(3.5) position decreased to 6.4 within 48 hours. It decreased gradually to pH 5.8 during the incubation period. The pH at the M.5.(7.5) position decreased from 7.1 to 6.8 within 24 hours and continued to decrease to 6.1 within 72 hours. It increased gradually to 6.9 during the remainder of the experiment.

Sharkey Soil

The pH of the interstitial water was 7.4 and 7.2 for the natural pH and pH adjusted to 5 Sharkey soil after 24-hour agitation. The pH at the S.0.(0.5) position decreased from 7.4 to 5.3 within 48 hours and remained constant for 21 days (Fig. 4.2.2). The pH at the S.0.(3.5) position did not change within 24

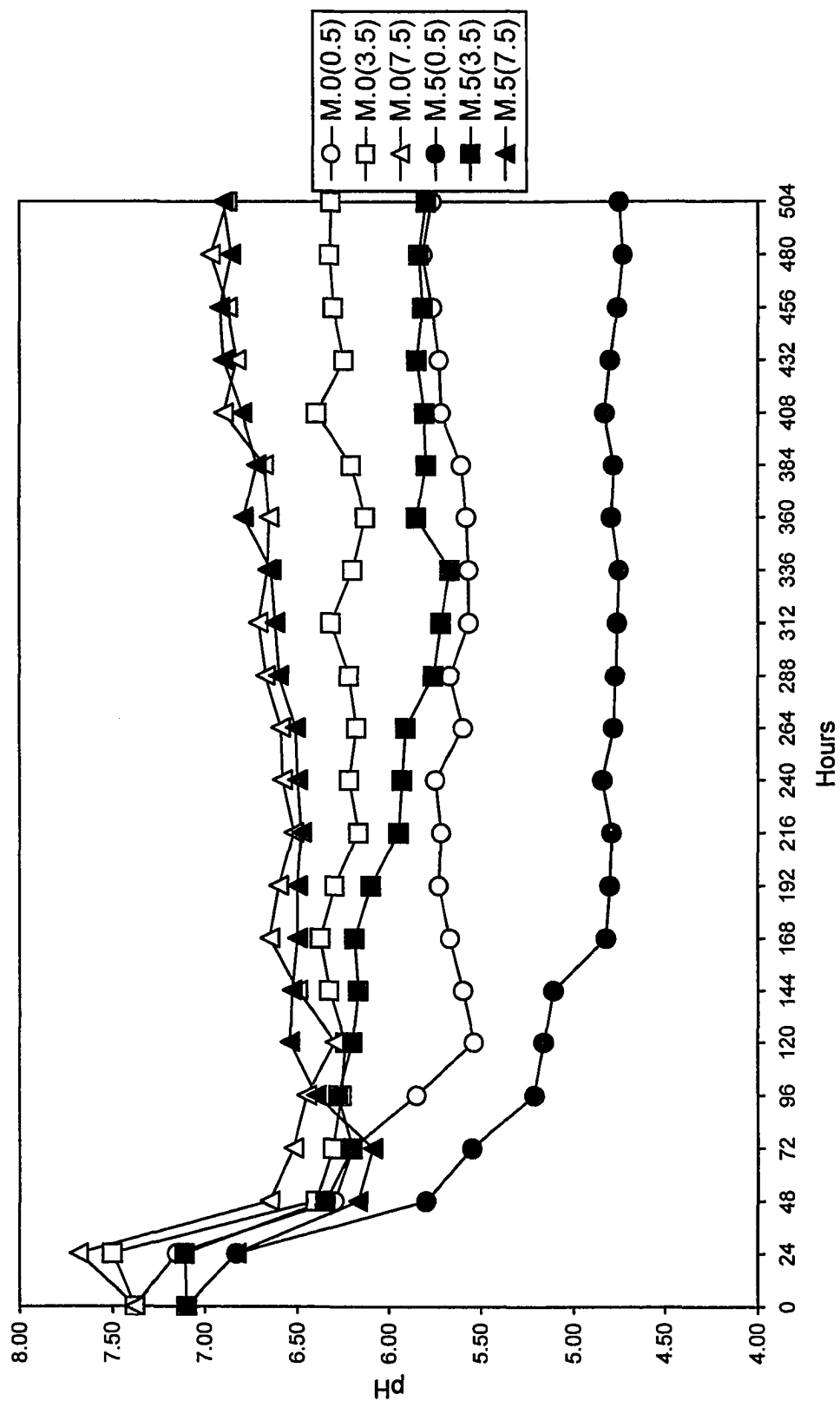


Fig. 4.2.1. Mean pH of the natural pH and pH adjusted to 5 Moreland soil at different depths sampled at 24-hour intervals.

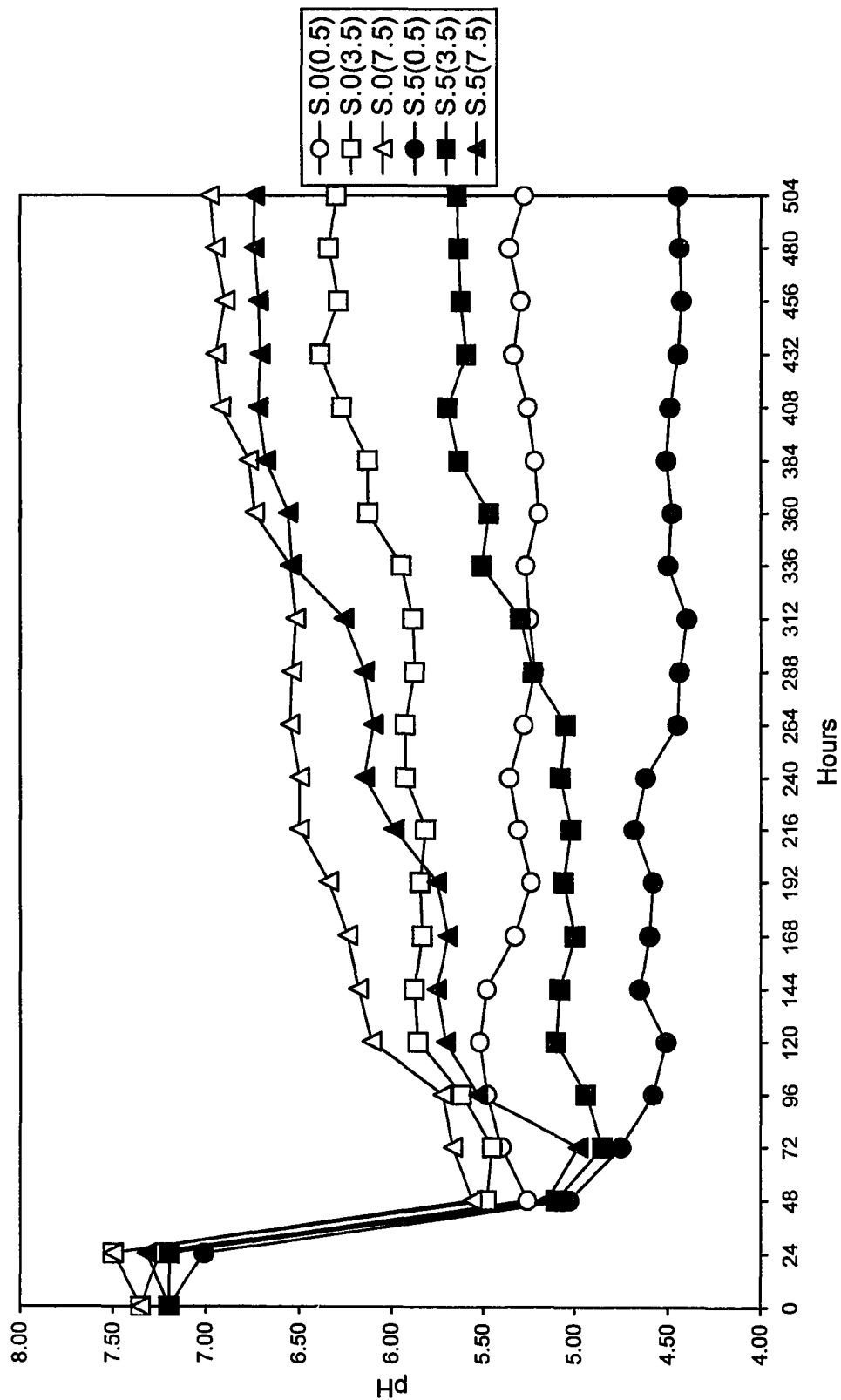


Fig. 4.2.2. Mean pH of the natural pH and pH adjusted to 5 Sharkey soil at different depths sampled at 24-hour intervals.

hours and decreased from 7.5 to 5.5 within 48 hours. It began to increase gradually to pH 5.9 after 120 hours and attained a value of 6.3 during the experiment. The pH at the S.0.(7.5) position decreased from 7.4 to 5.6 within 48 hours. It increased gradually to pH 7.0 for the duration of the experiment. The S.0.(7.5) position had a greater increasing rate of pH as compared to that of the S.0.(3.5) position after 96 hours.

Temporal distributions of pH for the Sharkey soil adjusted to pH 5 observed at different depths were similar to those of the natural pH Sharkey soil (Fig. 4.2.2). The pH at the S.5.(0.5) position decreased from 7.2 to 5.0 within 48 hours and continued to decrease to pH 4.5 within 120 hours. It stabilized at approximately 4.5 for the experiment. The pH at the S.5.(3.5) position was very similar to that of pH at the S.5.(0.5) position within 72 hours. It decreased from pH 7.2 to 4.9 within 72 hours but increased gradually to pH 5.7 when the experiment was terminated. The pH at the S.5.(7.5) position was similar to that of the S.5.(0.5) position within 72 hours. The pH at the S.5.(7.5) position decreased from 7.2 to 5.0 within 72 hours and increased gradually to 6.7 after 21 days. The rate of increasing pH was higher for the S.5.(7.5) position than for the S.5.(3.5) position after 72 hours of incubation.

4.3.2. Eh

Moreland Soil

Temporal Eh changes for the natural pH Moreland soil during 3 weeks of incubation are presented in Figure 4.3.1. The distributions of the Eh were bimodal for the M.0(0.5), M.0(3.5), and M.0(7.5) positions. The Eh at the

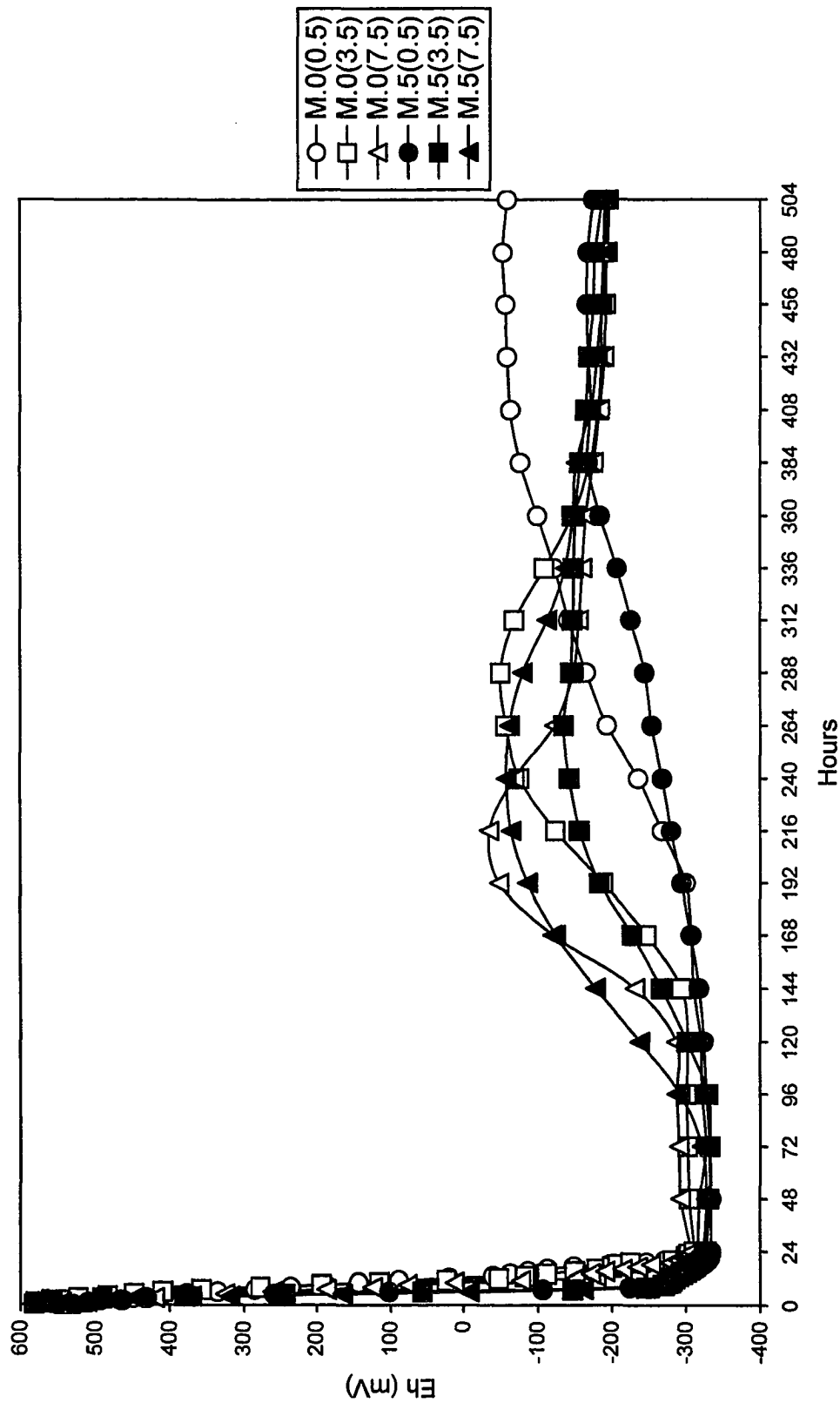


Fig. 4.3.1. Mean Eh of the natural pH and pH adjusted to 5 Moreland soil at different depths sampled at 24-hour intervals.

M.0.(0.5) position decreased from 530 to -320 mV within 24 hours. It increased gradually to -300 mV within 192 hours. The rate of increasing Eh was greater after 192 hours. The Eh attained a value of -60mV during the experiment. The Eh would decrease more if the monitoring period were extended. The Eh at the M.0.(3.5) position was similar to that of the M.0.(0.5) position within 144 hours. The Eh decreased from 530 mV to -310 mV within 24 hours and remained constant until 144 hours. It increased to a maximum of -50 mV within 288 hours. The Eh decreased again after 288 hours and reached -180 mV for the duration of the experiment. The Eh at the M.0.(7.5) position was similar to that of M.0.(3.5) position within 120 hours. The Eh increased within 120 hours and the rate of increasing Eh was greater than that of the M.0.(3.5) position. The Eh at the M.0.(7.5) position increased from -300 mV to a maximum of -30 mV within 216 hours. As with the Eh of the M.0.(3.5) position, a decrease in Eh was observed again after the maximum value was attained. It decreased to -180 mV within 384 hours and did not appreciably change for the duration of experiment. The Eh was low enough to reduce Mn and Fe for all natural pH soil during the experiment (Patrick and Jugsujinda, 1992).

The bimodal distribution of the Eh was observed for pH adjusted to 5 soil installed at different positions. The Eh at the M.5.(0.5) position decreased from 530 to -320 mV within 24 hours and remained constant until 120 hours (Fig. 4.3.1). It gradually increased to -50 mV during the experiment. The Eh decreased from 580 to -330 mV at the M.5.(3.5) position within 24 hours and remained constant within 96 hours. The Eh increased gradually to a maximum

value of -140 mV within 264 hours and decreased to -190 mV for the remainder of the experiment. The Eh at the M.5.(7.5) position was similar to that of the M.5.(3.5) position. After the minimum -320 mV was attained within 24 hours, the Eh began to increase gradually after 72 hours. The rate of increasing Eh was greater than that of the M.5.(3.5) position between 72 and 240 hours of incubation. The Eh increased to -60 mV at the M.5.(7.5) position within 240 hours. It began to decrease to -200 mV during the remainder of the experiment. The maximum value of Eh at the M.5.(0.5), M.5.(3.5), and M.5.(7.5) positions during 3 weeks of incubation was -170 , -140 , and -58 mV, respectively. The Mn and Fe were reduced during the monitoring period.

Sharkey Soil

The Eh shows a bimodal distribution for the natural pH Sharkey soil at three different depths (Fig. 4.3.2). The Eh at the S.0.(0.5) position decreased from 370 to -320 mV within 24 hours and began to increase gradually. It attained -80 mV within 264 hours and showed a slowly decreasing trend to -110 mV during 21 days of incubation. The Eh decreased from 460 to -320 mV within 24 hours at the S.0.(3.5) position. The increasing rate of Eh was greater than that of the S.0.(0.5) position after 48 hours. The Eh increased to -70 mV within 216 hours and decrease gradually to -200 mV for the remainder of the experiment. The distribution of Eh at the S.0.(7.5) position was similar to that of the S.0.(3.5) position. The Eh at the S.0.(7.5) position decreased from 410 to -330 mV within 24 hours and slightly increased to -300 mV within 48 hours. The rate

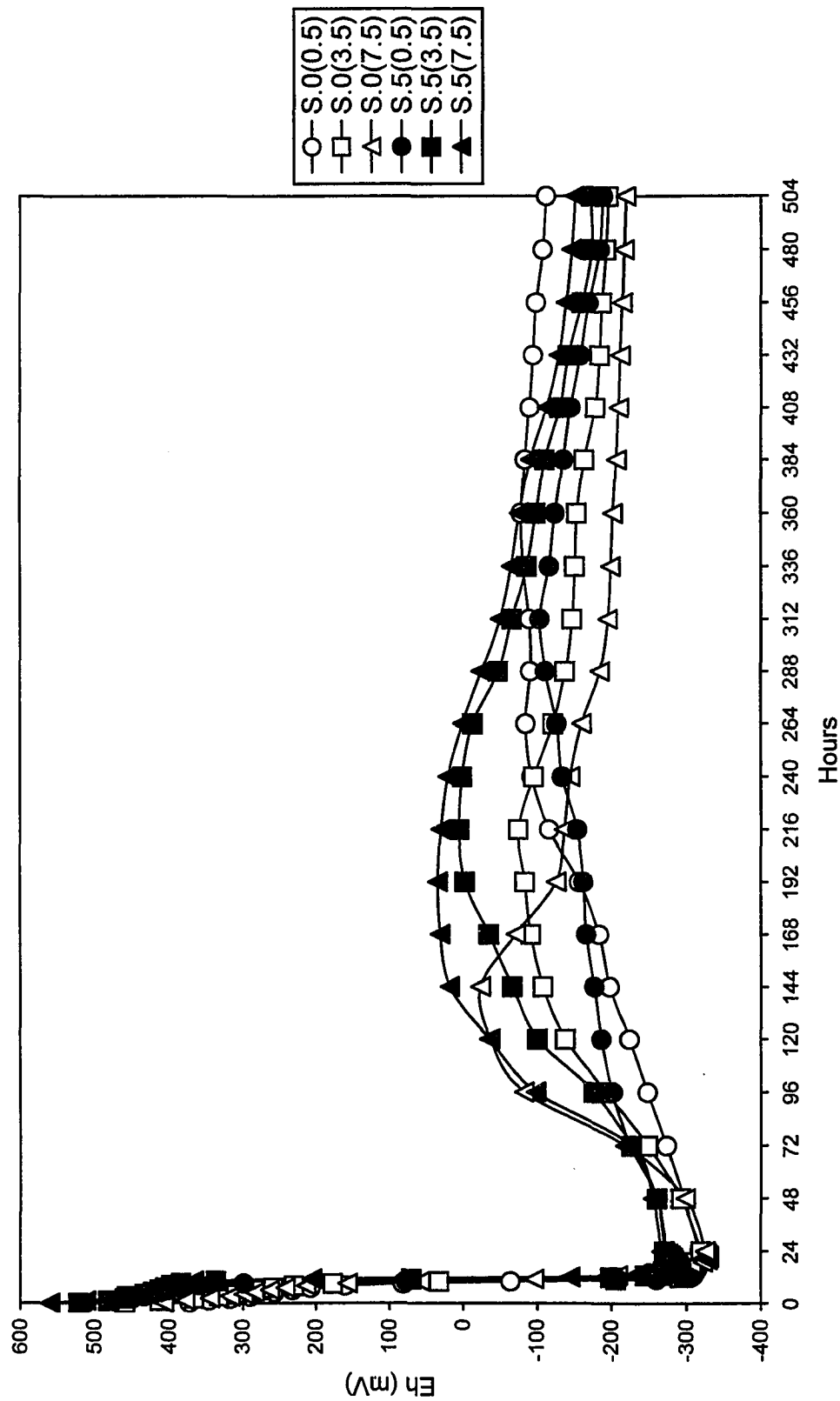


Fig. 4.3.2. Mean Eh of the natural pH and pH adjusted to 5 Sharkey soil at different depths sampled at 24-hour intervals.

of increasing Eh accelerated to -20 mV within 144 hours before decreasing again. The rate of decreasing Eh was higher than that of the S.0.(3.5) position. The Eh decreased from -20 to -200 mV between 144 and 312 hours and remained constant during the experiment.

The Eh for the soil adjusted to pH 5 Sharkey during the incubation period is presented in Figure 4.3.2. A bimodal distribution was observed. The Eh at the S.5.(0.5) position decreased from 510 to -270 mV within 24 hours and gradually increased to -100 mV within 312 hours. It decreased gradually to -190 mV after 21 days. The distribution of Eh at the S.5.(3.5) position within 72 hours was similar to that of the S.5.(0.5) position. The rate of increasing Eh was greater than that of the S.5.(0.5) position after 96 hours. The Eh increased to 10 mV within 216 hours and decreased gradually to -170 mV after 21 days. The rate of increasing Eh at the S.5.(7.5) position was greater than that of the S.5.(0.5) and S.5.(3.5) positions. After the minimum Eh (-270 mV) was attained within 24 hours, the Eh increased to 40 mV within 192 hours and decreased to -150 mV during the experiment. The maximum Eh value attained for the S.5.(0.5), S.5.(3.5), and S.5.(7.5) positions was -100, 10, and 40 mV, respectively.

4.3.3. Mn and Fe in Soil Solution

Moreland Soil

The distributions of Mn for the natural pH and pH adjusted to 5 Moreland soil are presented in Figure 4.4.1. The concentration of Mn ions in the interstitial water at the M.0(0.5) position was 0 mg/L after 24 hours. It increased

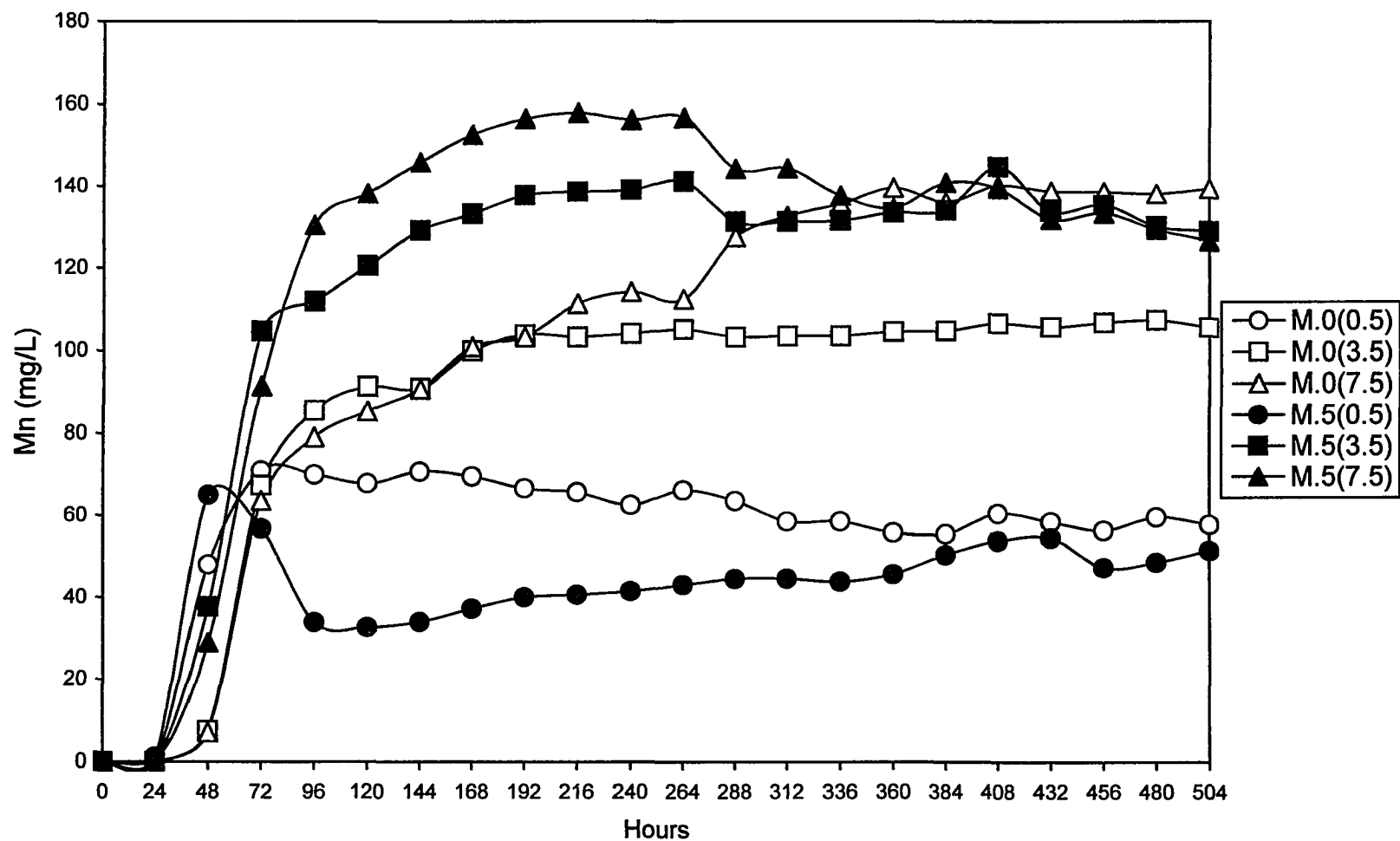


Fig. 4.4.1. Mn concentrations of the natural pH and pH adjusted to 5 Moreland soil at different depths sampled at 24-hour intervals.

to 48.1 mg/L within 48 hours and reached a maximum of 71.0 mg/L within 72 hours. The Mn started to decrease gradually to 57.9 mg/L for 21 days. Mn ions could not be detected within 24 hours at the M.0(3.5) position but increased to 7.55 mg/L within 24 hours. The rate of increase in Mn ions was accelerated to 67.4 mg/L within 72 hours and to 100 mg/L within 168 hours, and remaining constant during the experiment. The Mn at the M.0(7.5) position was similar to that of the M.0(3.5) position within 168 hours. However, the Mn continuously increased to 140 mg/L for the remainder of the experiment. The concentrations of Mn ions in the interstitial water were 57.9, 106, and 139 mg/L at the M.0(0.5), M.0(3.5), and M.0(7.5) positions during the experiment, respectively.

The concentration of Mn ions was 1.25 mg/L in the interstitial water within 24 hours and increased to 65.1 mg/L within 48 hours at the M.5(0.5) position (Fig. 4.4.1). It decreased to 34.2 mg/L within 96 hours and gradually increased to 51.6 mg/L after 21 days. No Mn ions were detected within 24 hours for the M.5(3.5) position but increased to 37.7 mg/L within 48 hours and continuously increased to 105 mg/L within 72 hours. The rate of increasing Mn ions slowed after 72 hours and the Mn stabilized at 130 mg/L during the experiment. The distribution of Mn ions at the M.5(7.5) position was similar to that of the M.5(3.5) position within 72 hours of incubation. The distribution of Mn showed a higher increasing rate between 24 and 96 hours. The Mn increased to 160 mg/L within 192 hours and decreased gradually to 130 mg/L after 21 days. There was no apparent difference in Mn between the M.5(3.5) and M.5(7.5) positions after 336 hours of incubation.

No Fe ions were detected in the interstitial water within 24 hours for any of the M.0 treatments (Fig. 4.4.2). The Fe from the M.0(0.5) position increased to 17.0 within 48 hours. The rate of increasing Fe was higher between 48 and 216 hours and Fe reached a value of 360 mg/L within 216 hours. It stabilized at 390 mg/L during the remainder of the experiment. The Fe did not appear in the interstitial water within 48 hours at the M.0(3.5) position but increased to 16.0 mg/L within 72 hours and gradually increased to approximately 45.0 mg/L after 21 days. The Fe at the M.0(7.5) position was similar to that of the M.0(3.5) position. The Fe at the M.0(3.5) and M.0(7.5) positions was not significantly different within 168 hours. The Fe increased to 26.3 mg/L within 96 hours and decreased gradually to 13.8 mg/L after 21 days.

The Fe in the interstitial water for the Moreland soil adjusted to pH 5 is presented in Fig. 4.4.2. Fe ions increased to 38.6 mg/L within 48 hours at the M.5(0.5) position. The rate of increasing Fe was greater between 24 and 72 hours. The Fe increased to 108 mg/L within 72 hours and continuously increased to 383 mg/L after 21 days. No Fe ions were observed within 48 hours at the M.5(3.5) position but increased to 57.5 mg/L within 72 hours and continuously increased to 200 mg/L during the experiment. The distribution of Fe ions at the M.5(7.5) position was similar to that of the M.5(3.5) position within 96 hours but decreased gradually from 75.9 mg/L after 96 hours to 25.8 mg/L over 21 days.

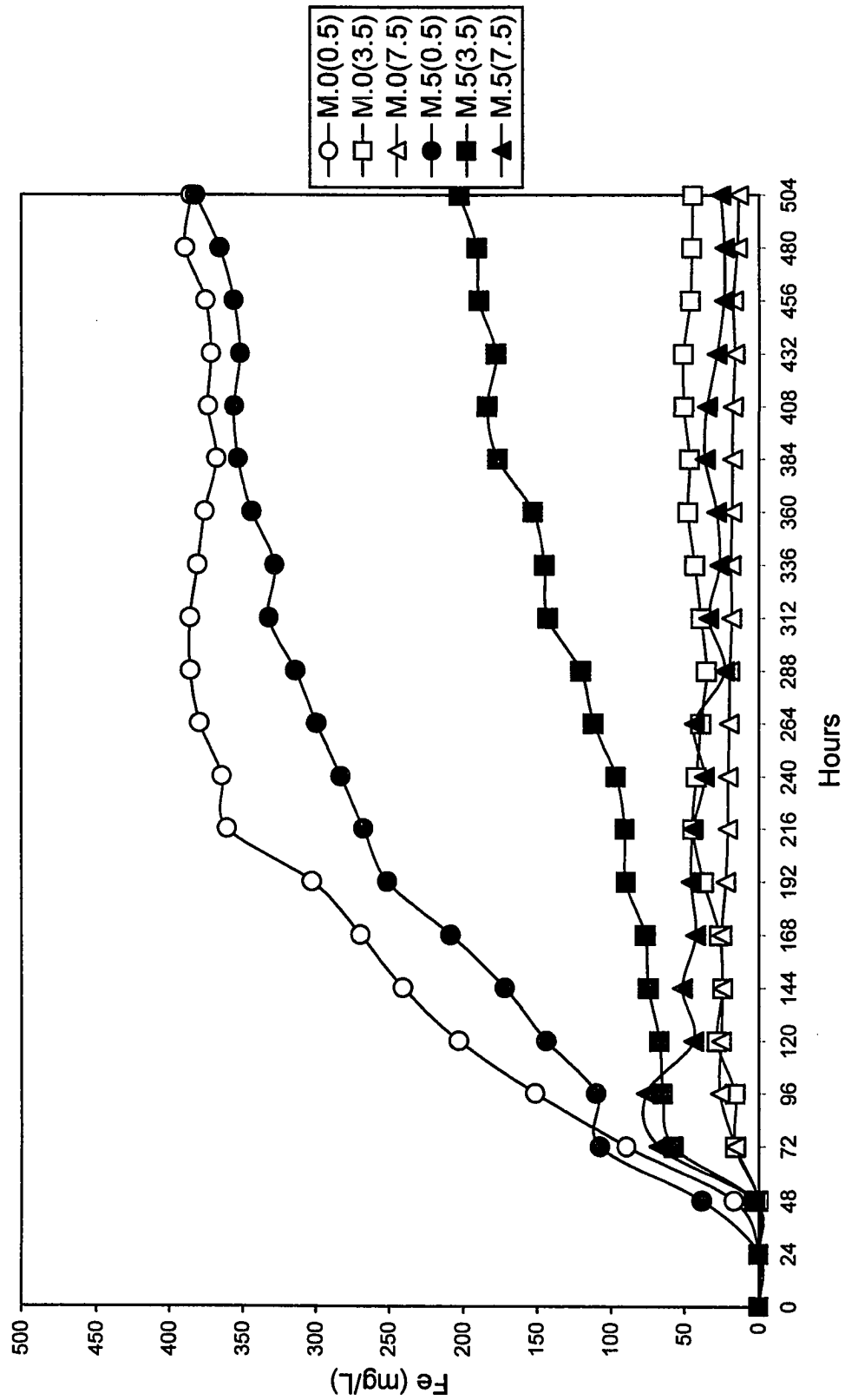


Fig. 4.4.2. Fe concentrations of the natural pH and pH adjusted to 5 Moreland soil at different depths sampled at 24-hour intervals.

Sharkey Soil

Figure 4.4.3 shows the Mn in the interstitial water for the Sharkey soil at different depths sampled at 24-hour intervals for three weeks. The Mn increased from 0 to 1.62 mg/L within 24 hours for the S.0(0.5) position. It increased to 25.7 mg/L within 72 hours and did not change for the remainder of the 21 days of incubation. No Mn ions were detected within 48 hours at the S.0(3.5) position but increased to 9.92 mg/L within 48 hours and stabilized at approximately 50.0 mg/L during the experiment. No Mn ions could be detected within 24 hours at the S.0(7.5) position. The rate of increase in Mn ions was greater between 24 and 120 hours. It increased to 50.0 mg/L within 120 hours and showed a gradual increase to 80.0 mg/L after 21 days.

The concentration of Mn for the pH 5 adjusted treatment was 2.24 mg/L before soil was incubated (Fig. 4.4.3). It increased to 24.9 mg/L within 48 hours at the S.5(0.5) position and started to decrease to 21.2 mg/L within 96 hours. It remained constant for the remaining 21 days. The Mn increased from 2.24 to 48.3 mg/L at the S.5(3.5) position within 120 hours. The rate of increasing Mn ions was slower after 120 hours and attained a value of 68.8 g/L during the experiment. The Mn at the S.5(7.5) position was similar to that of S.5(3.5) position. It increased to 63.0 mg/L within 120 hours. The increasing rate during this period of time was higher than that of S.5(3.5) position. It showed a gradual increasing trend after 120 hours and reached 85.6 mg/L at the end of 21 days of incubation.

250

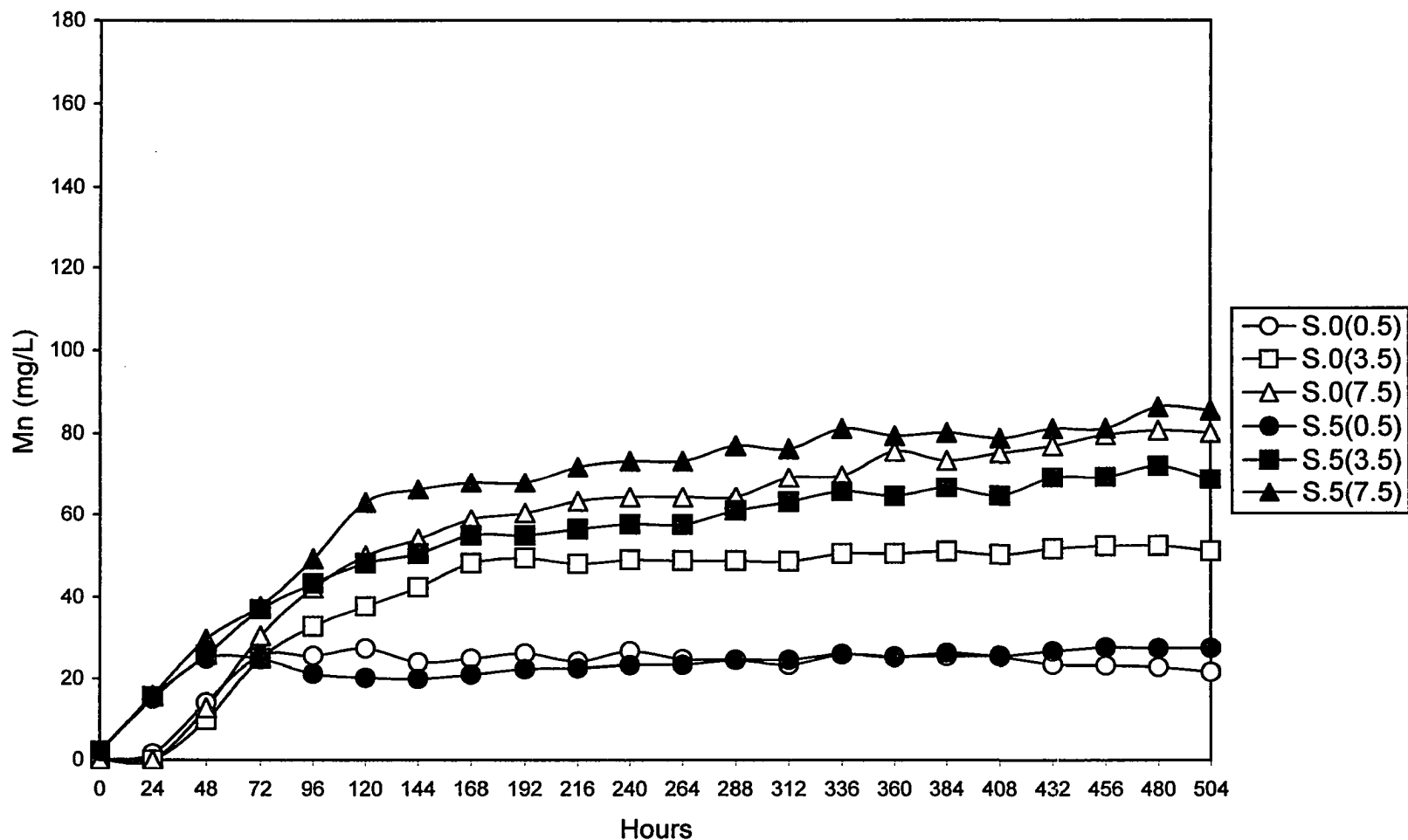


Fig. 4.4.3. Mn concentrations of the natural pH and pH adjusted to 5 Sharkey soil at different depths sampled at 24-hour intervals.

No Fe ions were detected within 48 hours at the S.5(0.5), S.5(3.5), and S.5(7.5) positions (Fig. 4.4.4). The Fe increased from 0 to 335 mg/L at the S.5(0.5) position within 192 hours. The rate of increasing Fe ions was greater during this period than during the rest of the incubation period. The Fe remained constant at 350 mg/L for 21 days. The Fe at the S.5(3.5) position was similar to that of the S.5(0.5) position during 120 hours but with a slower rate of increase. The Fe increased from 0 to 180 mg/L within 144 hours and gradually increased to 230 mg/L for the duration of the experiment. The temporal change in Fe ions for the S.5(7.5) position was similar to that of S.5(3.5) position but with a lower rate of increase within 144 hours. The Fe was 195 mg/L lower than that of S.5(3.5) position for the experiment.

The Fe increased from 0 to 1.57 mg/L at the S.5(0.5) position within 24 hours (Fig. 4.4.4). The rate of increasing Fe was higher between 48 and 96 hours. The Fe increased from 25.2 to 204 mg/L within this period. It increased gradually to 450 mg/L after 21 days. There was no apparent difference in the Fe within 264 hours at the S.5(3.5) and S.5(7.5) positions. The Fe increased from 0 to approximately 200 mg/L for both the S.5(3.5) and S.5(7.5) positions within 120 hours. Fe ions at the S.5(3.5) position showed a higher rate in increase after 288 hours than that of the S.5(7.5) positions. The Fe attained 340 mg/L at the S.5(3.5) position and 290 mg/L at the S.5(7.5) position during the experiment.

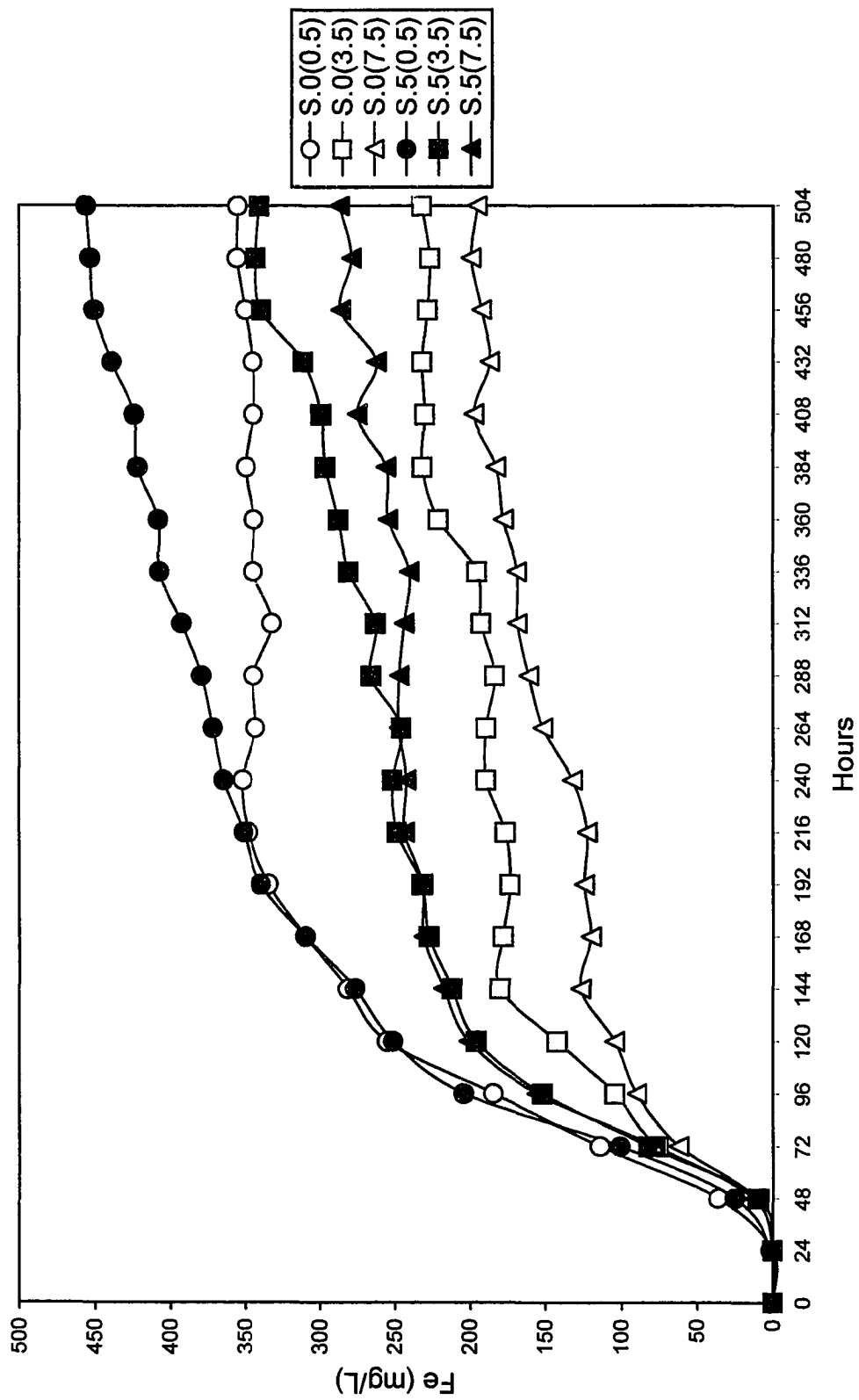


Fig. 4.4.4. Fe concentrations of the natural pH and pH adjusted to 5 Sharkey soil at different depths at 24-hour intervals.

4.3.4. Organic Carbon

Moreland Soil

The results of soluble organic carbon (SOC) in the interstitial water for the natural pH Moreland soil are shown in Figure 4.5.1. The SOC was 2.86 g/L at the M.0(0.5), M.0(3.5), and M.0(7.5) positions before the soils were incubated. It decreased to 1.85 g/L for the M.0(0.5) position within 96 hours and remained constant for 21 days. The distributions of SOC for the M.0(3.5) and M.0(7.5) positions were similar to that of M.0(0.5) position. The SOC decreased to 1.49 at the M.0(3.5) position and to 1.29 g/L at the M.0(7.5) position. It did not appreciably change for the remainder of the experiment.

The SOC decreased from 3.02 to 2.34 g/L for the M.5(0.5) position within 48 hours and stabilized at approximately 2.20 g/L within 192 hours (Fig. 4.5.1). The SOC decreased to 1.70 g/L within 240 hours and remained constant during the experiment. The rate of decreasing SOC was greater at the M.5(3.5) and M.5(7.5) positions within 72 hours than at the M.5(0.5) position. The SOC decreased from 3.02 to 1.41 g/L for the M.5(3.5) position within 72 hours. It remained constant during the experiment. The distributions of SOC for the M.5(3.5) and M.5(7.5) positions were similar. The SOC attained approximately 1.00 g/L at the M.5(7.5) position after 21 days.

Sharkey Soil

The distributions of SOC for the Sharkey soil showed the same trends as those of the Moreland soil (Fig. 4.5.2). The SOC decreased from 2.84 to 2.05 mg/L at the S.0(0.5) position within 48 hours and did not appreciably change

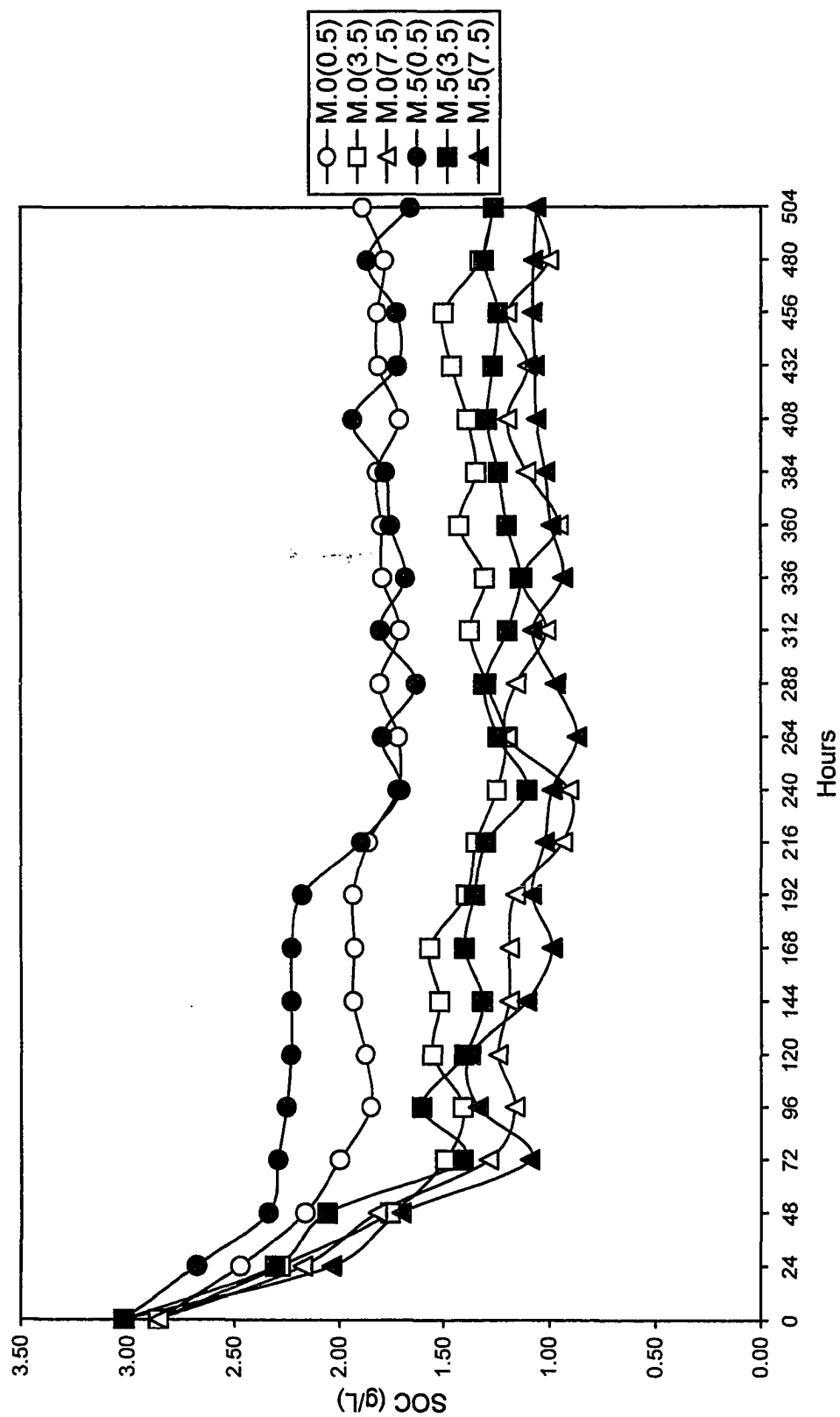


Fig. 4.5.1. SOC concentrations of the natural pH and pH adjusted to 5 Sharkey soil at different depths sampled at 24-hour intervals.

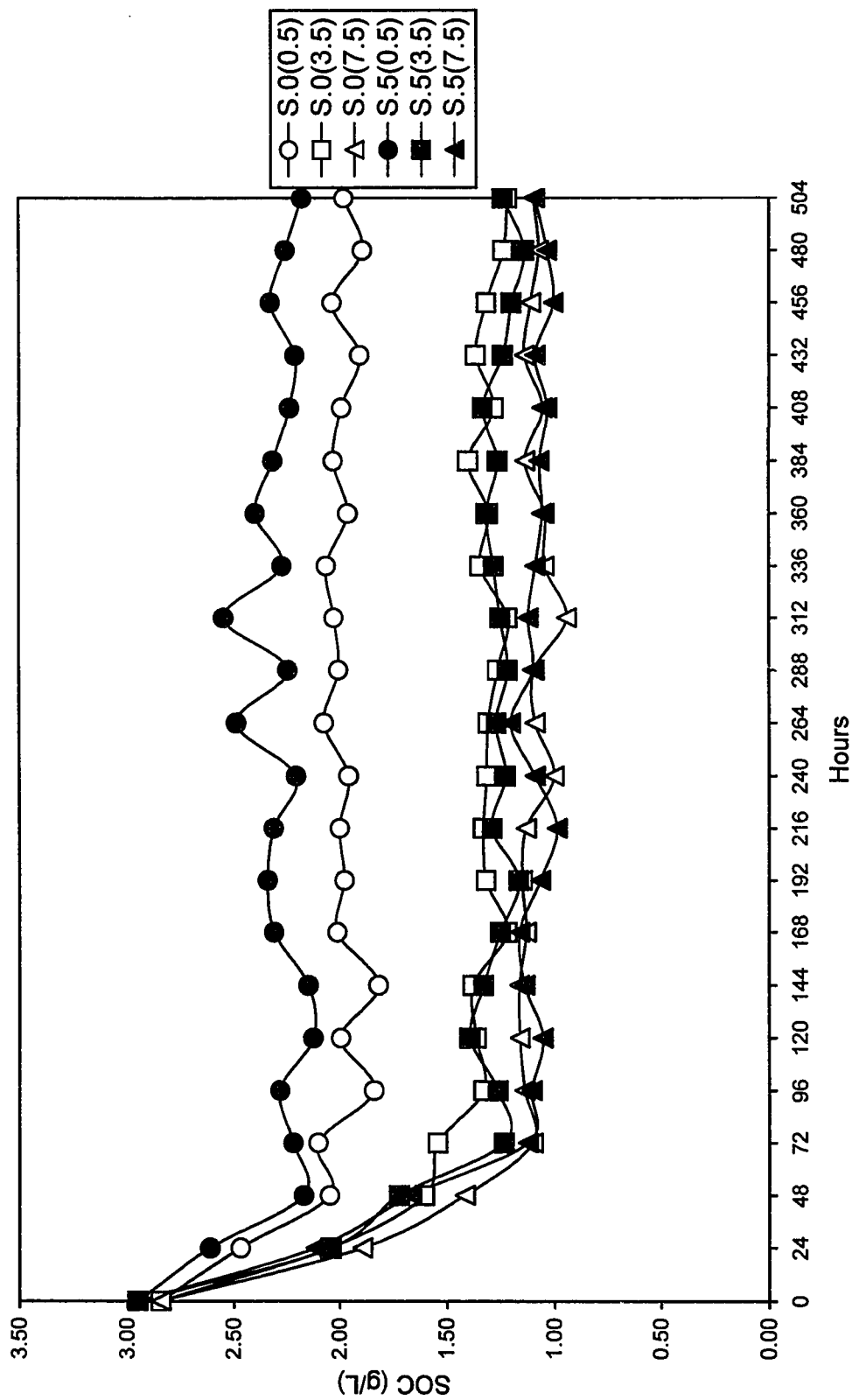


Fig. 4.5.2. SOC concentrations of the natural pH and pH adjusted to 5 Sharkey soil at different depths sampled at 24-hour intervals.

for the remainder of the 21 days of incubation. The SOC at the S.0(3.5), and S.0(7.5) positions was similar to that of S.0(0.5) position but with a greater rate of decrease within 72 hours. The concentration of SOC was 1.22 and 1.10 mg/L at the S.0(3.5) and S.0(7.5) positions after 21 days, respectively. The difference in SOC was not apparent at the S.0(3.5) and S.0(7.5) positions during the experiment.

The distributions of SOC for the soil adjusted to pH 5 were similar to those of the natural pH soil. The SOC decreased from 2.95 to 2.17 g/L at the S.5(0.5) position within 48 hours and remained constant for 21 days. The rate of decrease was greater at the S.0(3.5) and S.0(7.5) positions within 48 hours. The SOC decreased from 2.95 to 1.24 mg/L at the S.0(3.5) position and to 1.13 mg/L for S.0(7.5) position within 72 hours, respectively. The SOC did not apparently change during the experiment.

4.3.5. X-Ray Diffraction

The X-ray diffraction (XRD) pattern for the Sharkey soil did not show any Fe oxide mineral peaks. This confirmed that amorphous Fe was the major Fe form in the Sharkey soil. The XRD patterns for the Moreland soil are presented in Figure 4.6.1. The untreated soil, and the M.0(0.5) and M.0(7.5) samples after 3 weeks of incubation were scanned from 32° to 42° 2θ . The XRD diagram of untreated soil contained diagnostic peaks for both goethite and hematite at 26.9 and 25.1 nm. The hematite peak at 22.0 nm was too weak to be positively identified as hematite. There were no 26.9 and 25.1 nm peaks for the M.0(0.5) samples but still existed in the M.0(7.5) soil. The 26.9 and 25.1 nm were

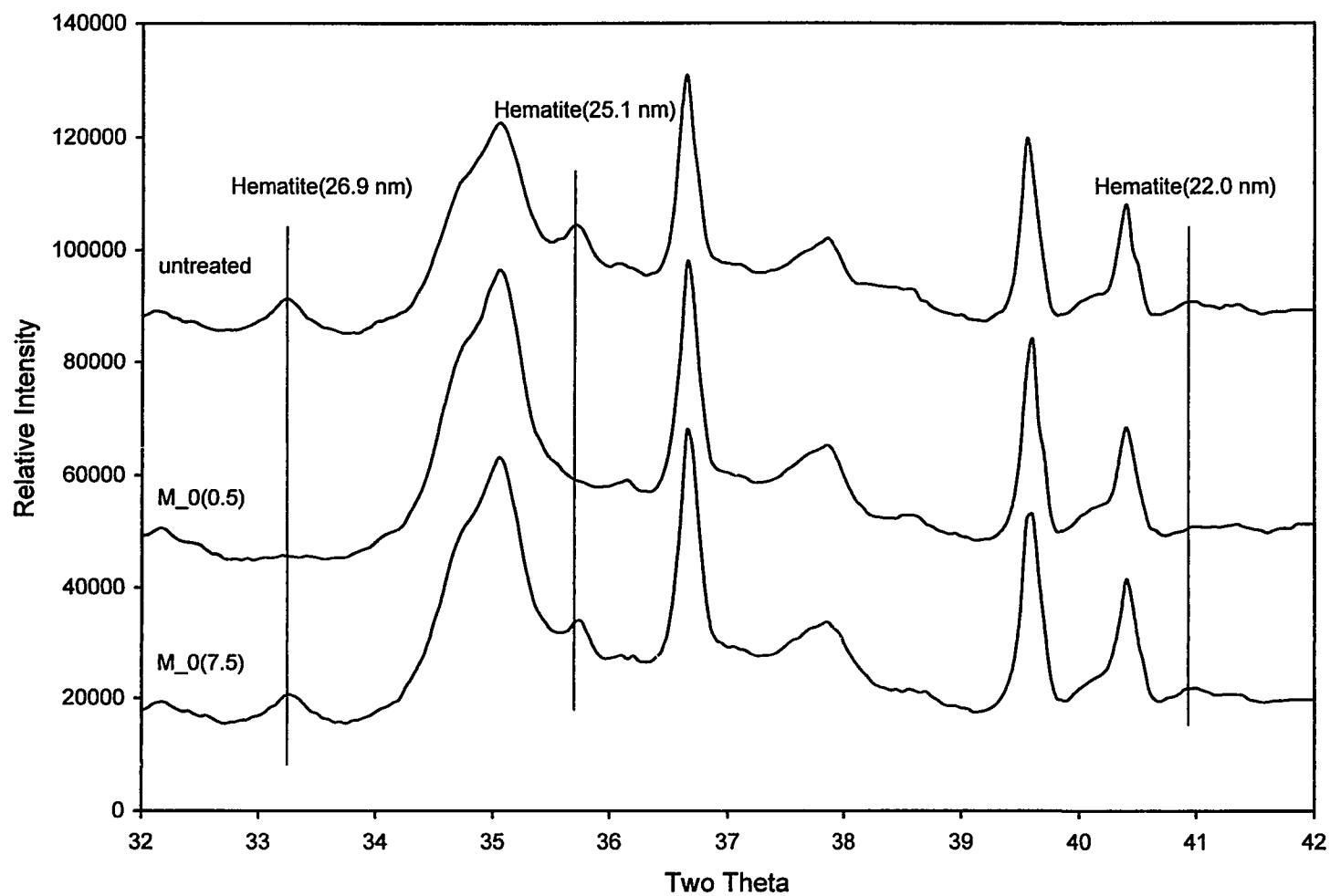


Fig. 4.6.1. X-ray diffraction patterns for the Moreland soil before and after 3 weeks of incubation.

common peaks for hematite and goethite, making it impossible to distinguish the two minerals in Figure 4.6.1.

The peak at 41.8 nm for hematite showed a noisy diffraction and could not be identified. Figure 4.6.2 presents the XRD patterns run from 20.5° to 22.5° 2θ for the original Moreland soil with different treatments. All treatments showed a quartz peak at 42.6 nm. The patterns of untreated soil and soil with DCB treatment did not exhibit a goethite peak at 41.8 nm. The soil with an internal goethite sample at a ratio of 9 to 1 by weight showed a clear goethite peak at 41.8 nm, indicating indirectly that the 26.9 and 25.1 nm peaks for the Moreland soil were hematite (Fig. 4.6.1).

4.3.6. Summary

A decrease in pH was observed at 0.5 and 7.5 cm positions within 48 hours for both the natural pH Moreland and Sharkey soils (Fig. 4.7). This is due to the accumulation of organic acids produced by fermentation. The pH at M.0(0.5) and S.0(0.5) positions did not change after the pH attained the minimum values due to the higher SOC (Fig. 4.8). The pH at the M.0(7.5) and S.0(7.5) positions tended to approach pH 7.0 during the experiment due to limited SOC and the anaerobiosis. The rate of decreasing pH for the S.0(7.5) position was greater than that of the M.0(7.5) position within 48 hours. The difference was ascribed to more reducible Mn in the Moreland soil (Fig. 4.9.1). The rate of increasing pH for the S.0(7.5) position was greater than that of the M.0(7.5) position after a minimum pH was attained. This was because of greater quantity of reducible Fe in the Sharkey soil controlled the pH (Fig. 4.9.2).

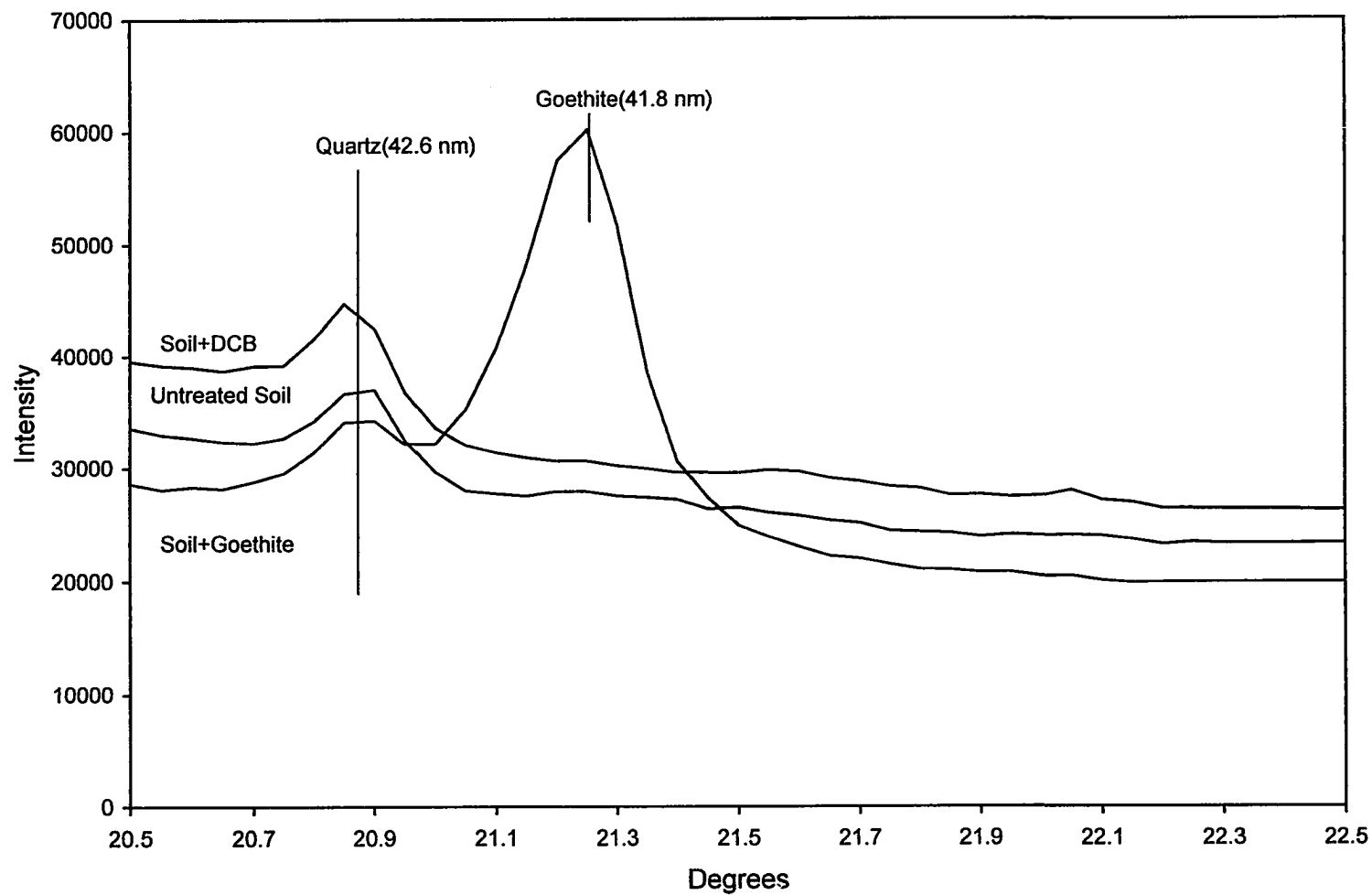


Fig. 4.6.2. X-ray diffraction patterns for the Moreland soil with different treatments.

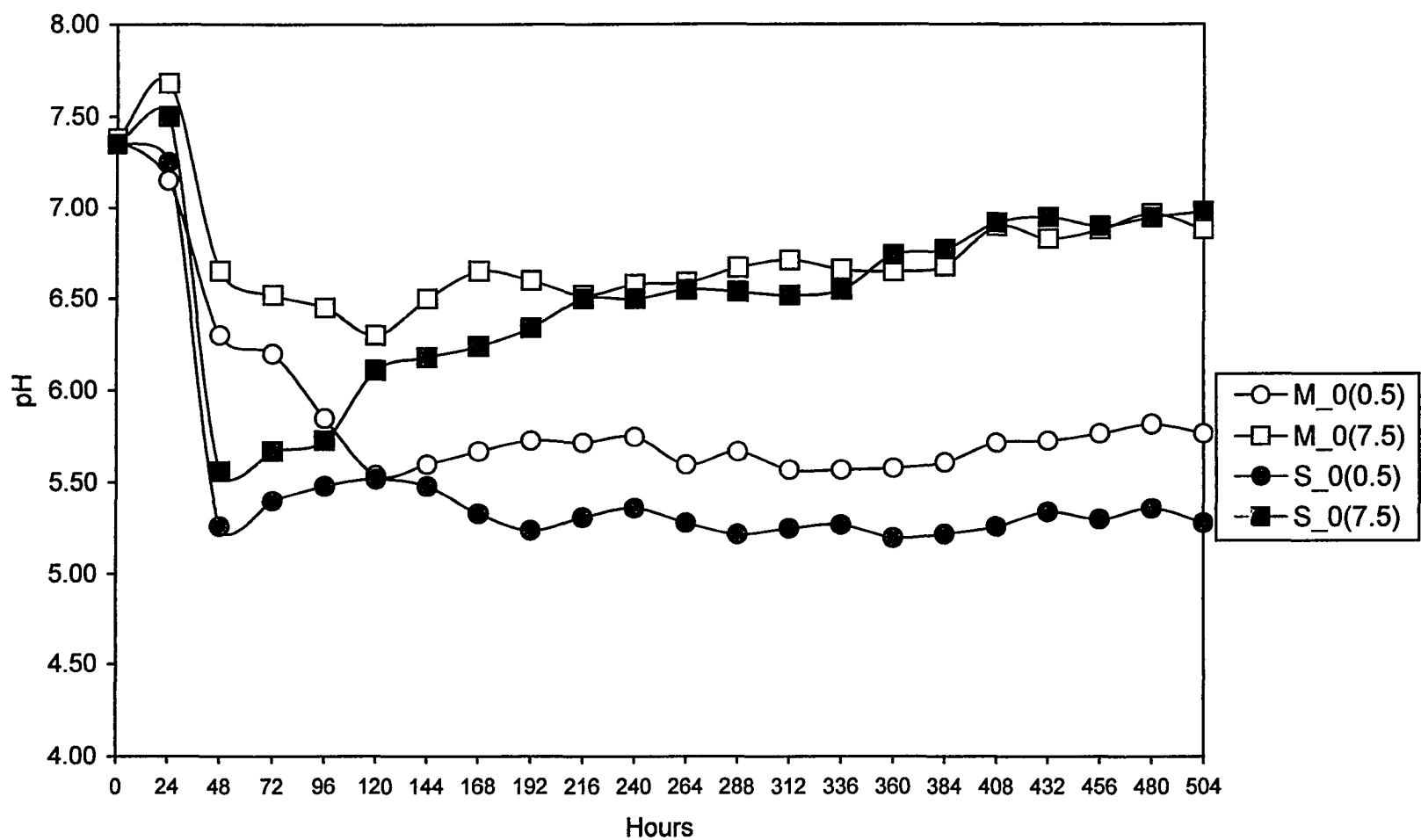


Fig. 4.7. The changes of pH for the natural pH Moreland and Sharkey soils at 0.5 and 7.5 cm positions.

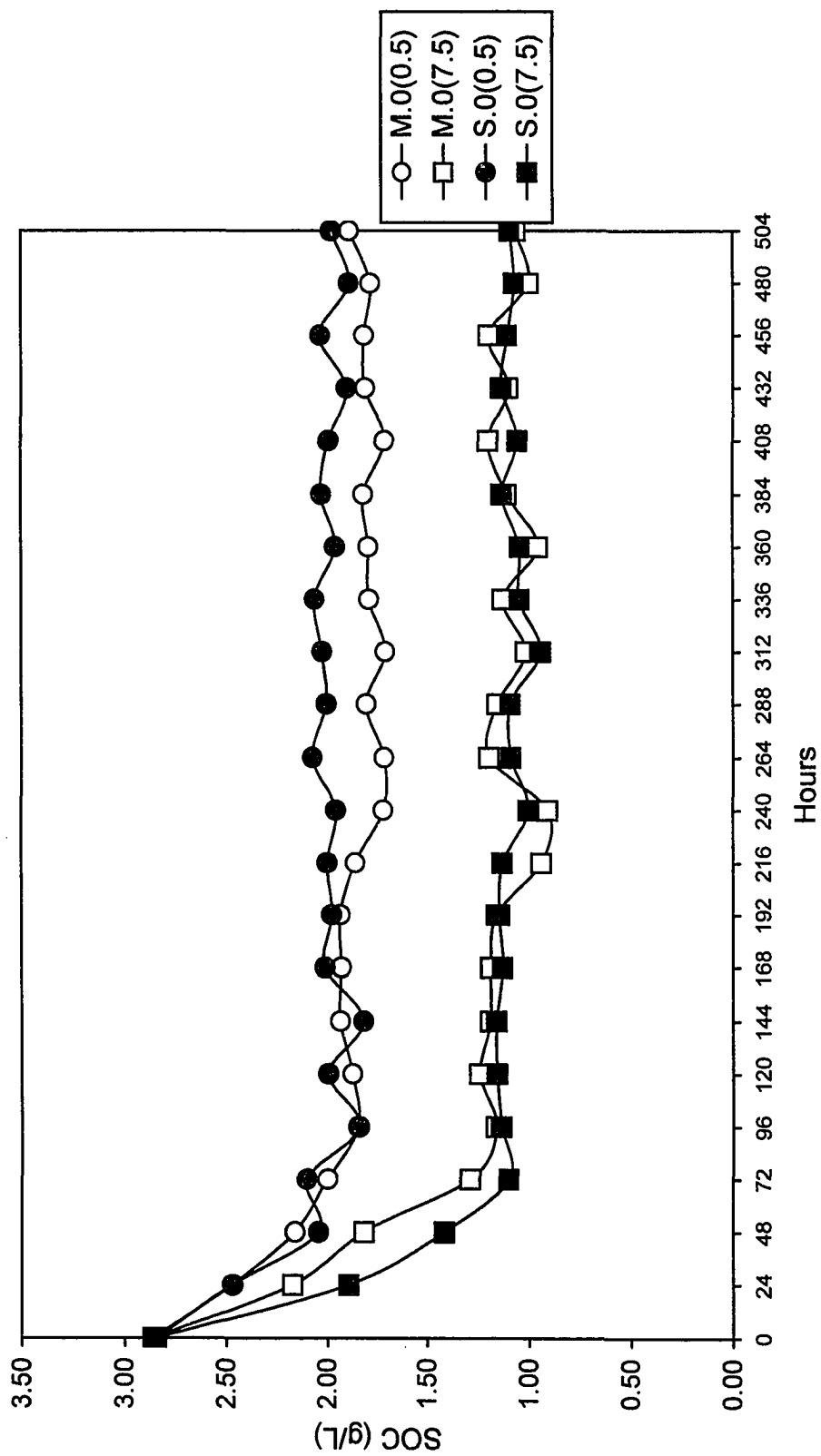


Fig. 4.8. SOC concentrations of the natural pH Moreland and Sharkey soils at 0.5 and 7.5 cm positions.

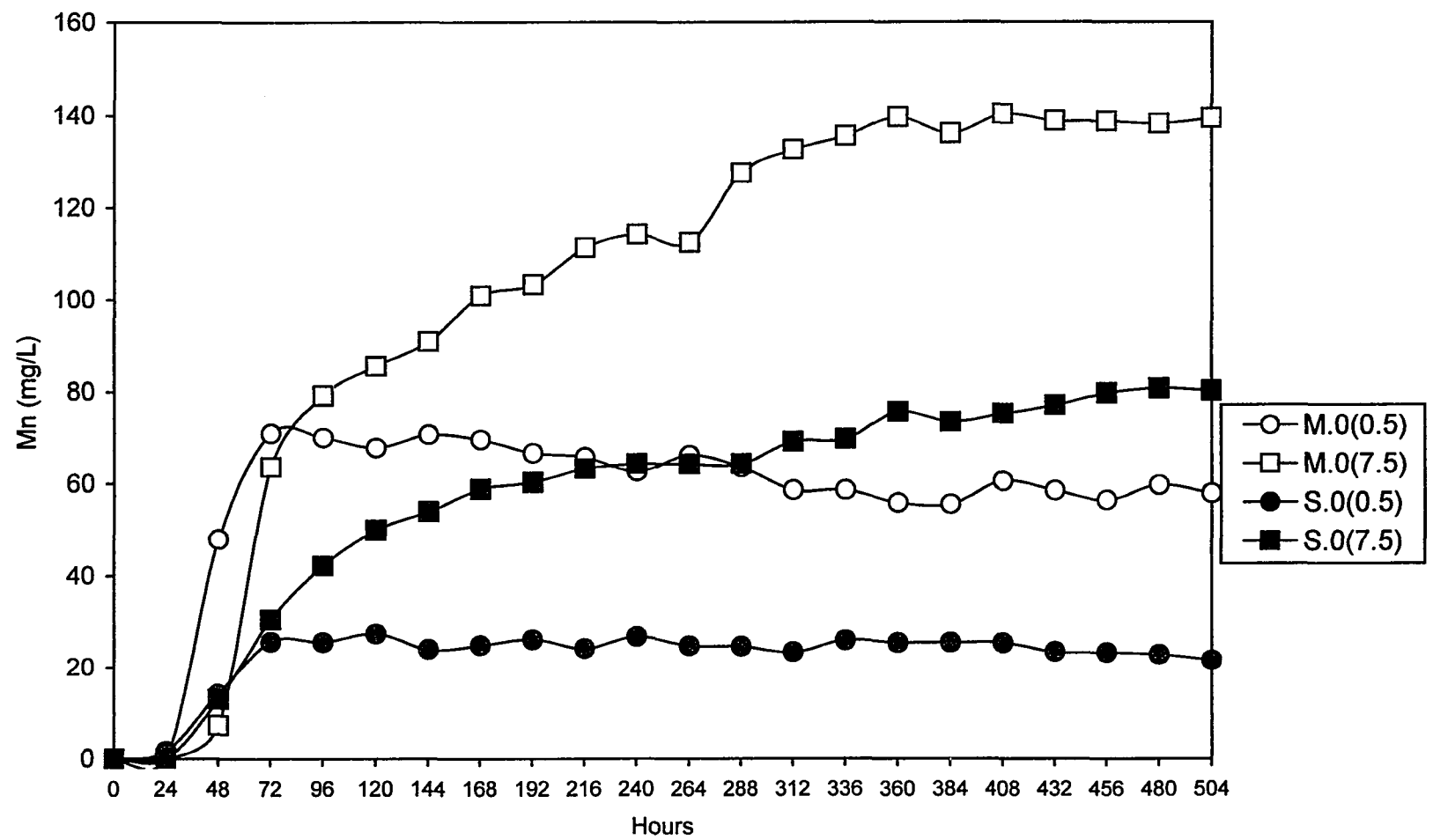


Fig. 4.9.1. Mn concentrations of the natural pH Moreland and Sharkey soils at 0.5 and 7.5 cm positions.

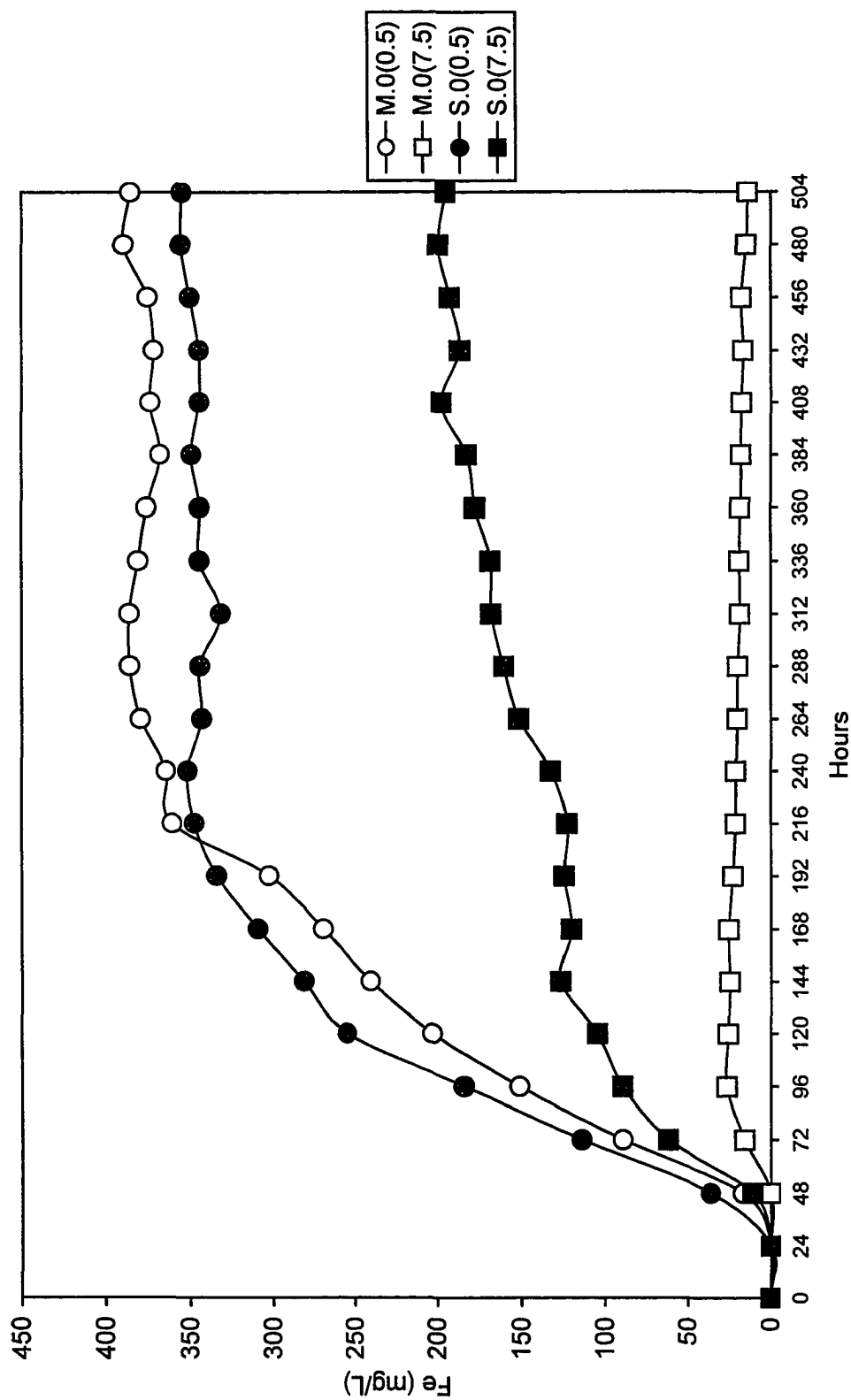


Fig. 4.9.2. Fe concentrations of the natural pH Moreland and Sharkey soils at 0.5 and 7.5 cm positions.

Less time was needed for the Eh to increase at the M.0(7.5) and S.0(7.5) positions than at the M.0(0.5) and S.0(0.5) positions after the minimum Eh was reached (Fig. 4.10). This was due to greater SOC within the 0.5 cm position, resulting in reducing the rate of increasing Eh (Fig. 4.8). Less time was required for the Eh to increase for the Sharkey soil than those for the Moreland soil. This was due to more reducible Fe (Fe_0) in the Sharkey soil (Fig. 4.11). A broader bimodal Eh distribution was observed for the pH 5 Moreland and Sharkey treatments. The pH 5 treatment increased the solubility of reducible inorganic compounds (Fig. 4.3.1 and 4.3.2).

Manganese was detected before Fe from the interstitial water (Fig. 4.12) because Mn has a lower standard redox potential and higher solubility than Fe. The appearance of Fe in the interstitial water within 72 hour at the M.0(7.5) position and the Mn continuously increased after 72-hour of incubation, indicating that the reduction of Mn and Fe occurred simultaneously. X-ray diffraction pattern showed that the reduction of hematite was not homogeneous within the profile (Fig. 4.6.1). The reduction of hematite was more pronounced within the 0.5 cm position where there was higher SOC. There was no relationship among Eh, pH, and Fe in the interstitial water (Fig. 4.13), presumably due to the formation of Fe-humus complexes, mixed redox potential, and non-equilibrium soil status.

4.4. Discussion and Conclusions

Some investigations showed that an oxidant with a lower standard redox potential was not reduced until all of other oxidants with higher standard redox

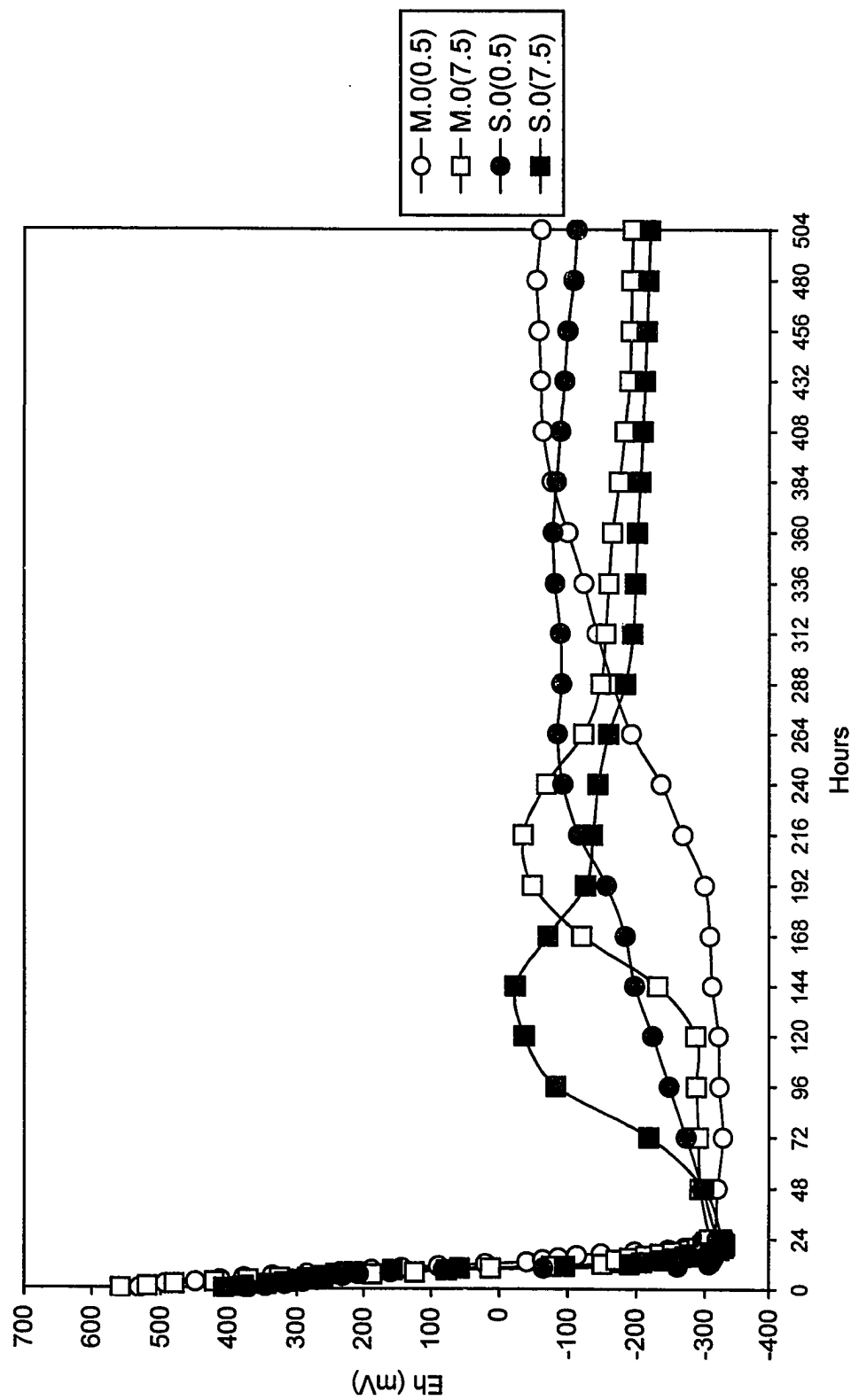


Fig. 4.10. The changes of Eh for the natural pH Moreland and Sharkey soils at 0.5 and 7.5 cm positions.

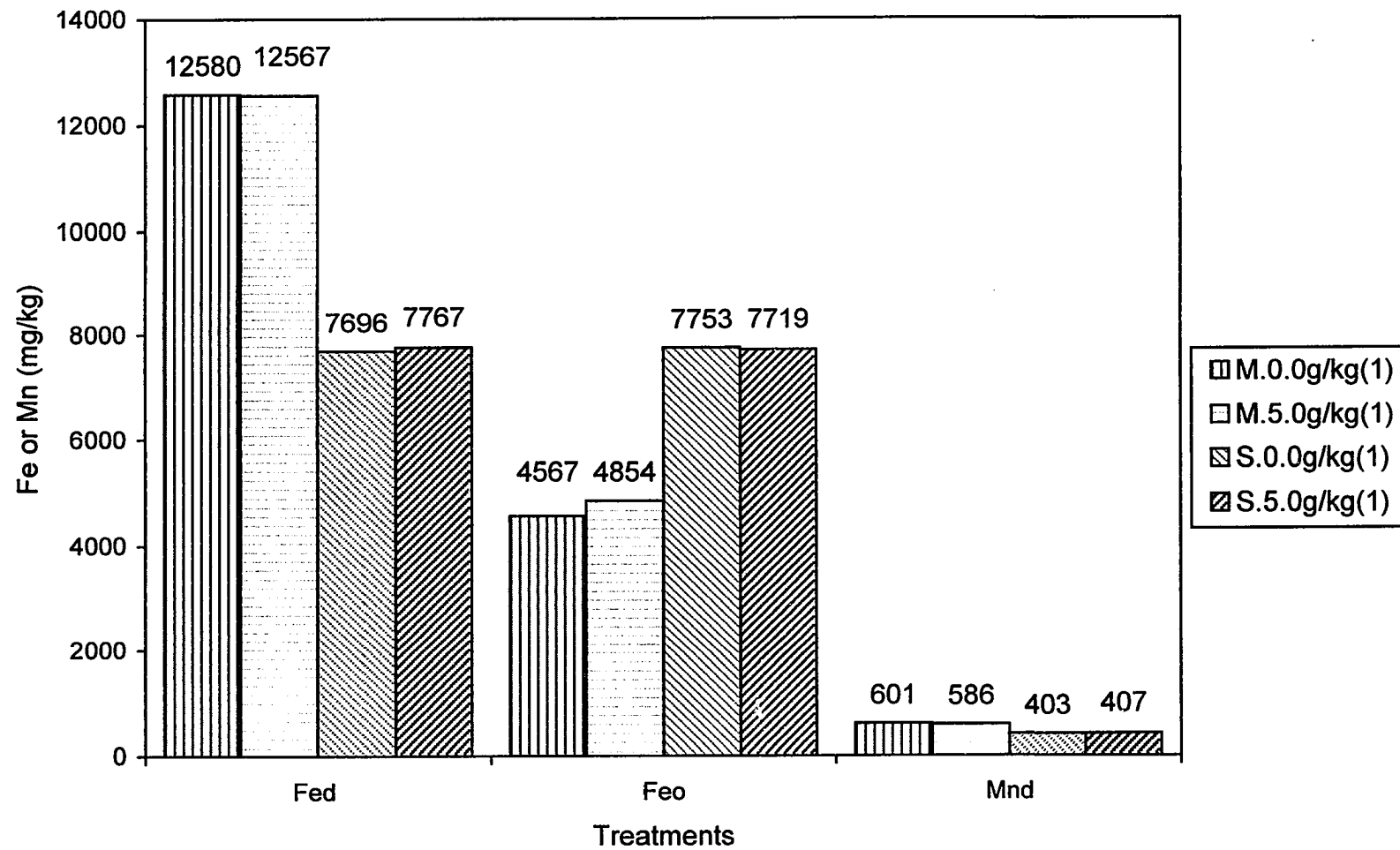


Fig. 4.11. Mn and Fe extracted by DCB and acid-oxalate for the natural pH Moreland and Sharkey soil with 5g/kg sucrose.

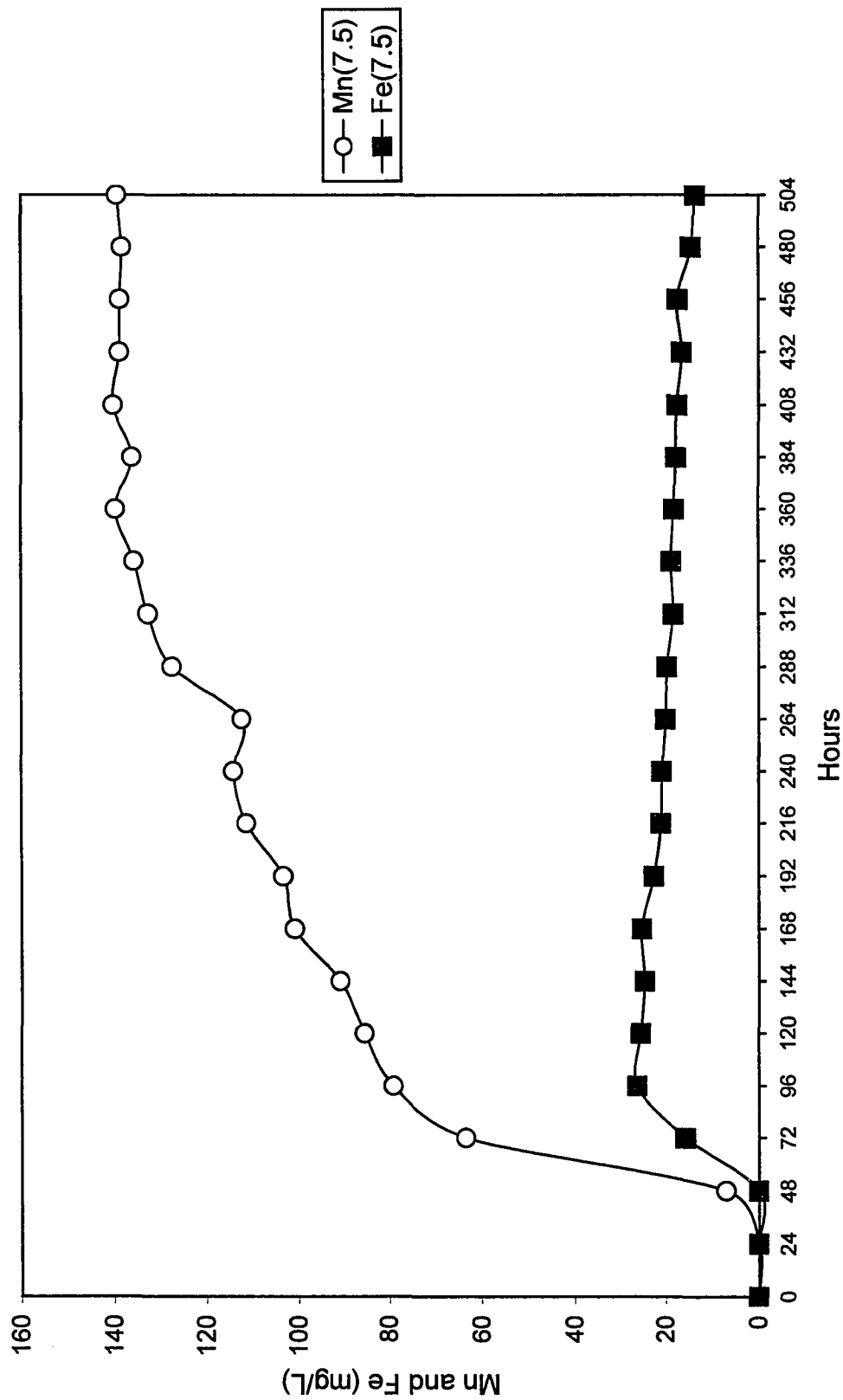


Fig. 4.12. Mn and Fe concentrations for the natural pH Moreland at 0.5 and 7.5 cm positions.

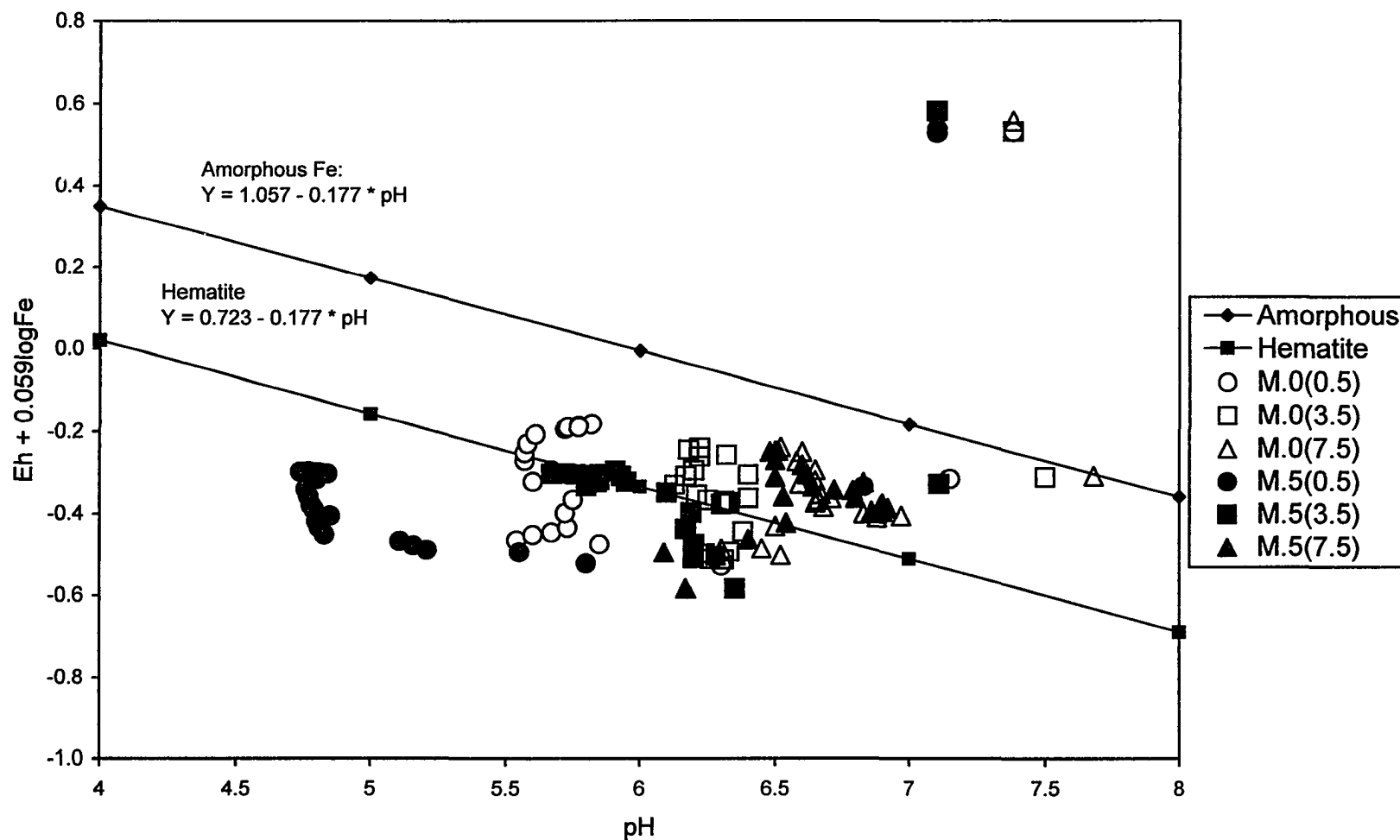


Figure 4.13. The relationship between Eh, pH, and Fe activity of Moreland soils for the amorphous Fe oxides and hematite systems.

potentials were completely reduced. Many reports concurred regarding the stepwise reduction of oxidants in the following order: oxygen, nitrate, manganic manganese, ferric iron, sulfate, carbon dioxide, and hydrogen (Turner and Patrick, 1968; Patrick and Delaune, 1972; Ponnampersuma, 1972; Van Breemen and Brinkman, 1978; Patrick, 1980).

A decrease in pH was observed for both the Moreland and Sharkey soils (Fig. 4.2.1 and 4.2.2). The Mn and Fe reducing microbes that gained less energy per electron transfer could not compete with fermentors such as *Bacillus* and *Clostridia* for oxidizable sucrose (Lovley, 1992). The production and accumulation of organic acids decreased the pH within 48 hours. Fermentation reactions decreased with decreased fermentable sucrose. The Mn and Fe reducing microbes began to use fermentation acids as energy sources and inorganic oxidants as electron acceptors. As the reduction of inorganic oxidant consumed protons, the pH increased. The pH at the M.0(0.5), M.5(0.5), S.0(0.5), and S.5(0.5) positions did not increase after incubation due to the continuous supply of fermentable sucrose from the solution above. The pH at the M.0(7.5), M.5(7.5), S.0(7.5), and S.5(7.5) positions showed an increasing trend and approached pH 7.0 during the experiment, indicating that fewer protons were produced by fermentation than were consumed by anaerobic respiration. The results also suggested that organic acids produced above the soil surface were partially absorbed by the soil and partially consumed before they diffused to the 7.5 cm depth. The rate of decreasing pH for the Sharkey soil was greater than that of the Moreland soil within 48 hours.

The difference was ascribed to more reducible Mn in the Moreland soil (Fig. 4.3.1 and 4.3.3). The rate of increasing pH for the Sharkey soil at the S.0(7.5) and S.5(7.5) positions was greater than that of the Moreland soil after a minimum pH was attained. This was due to the reduction of Fe controlling the pH (Fig. 4.3.2 and 4.3.3), implying that amorphous Fe was more reducible than was crystalline Fe.

A decrease in Eh for the Moreland and Sharkey soils within 24 hours (Fig. 4.3.1 and 4.3.2) was due to the surplus of electrons produced by fermentation, since neither Mn nor Fe was detected except for the S.5 treatment (Fig. 4.4.1, 4.4.2, 4.4.3, and 4.4.4). The distribution of the Eh for the Moreland soil was similar to that of the different sucrose treatments presented in Chapter 3. The SOC was greater at the M.0(0.5) and M.5(0.5) positions than at the M.0(7.5) and M.5(7.5) positions (Fig. 4.5.1). Less time was needed for Eh to increase at the M.0(7.5) and M.5(7.5) positions after the minimum Eh was reached. The SOC remained constant at different positions for the Moreland soil after 72 hours of incubation, indicating a constant supply of electrons. The bimodal distribution of the Eh was due to the aggregate stability and competition between fermentative and Fe- and Mn-reducing bacteria. The explanation for the bimodal distribution was given in Chapter 2. Amorphous Fe was the major form in the Sharkey soil. Less time was needed to increase the Eh for the Sharkey soil than for the Moreland soil, suggesting that anaerobic microbes needed less energy to reduce amorphous Fe. The propagation rate of Fe- and Mn- reducing bacteria was greater for the Sharkey soil than for the Moreland

soil. The maximum Eh was greater and the bimodal distribution was broader at the S.5(3.5) and S.5(7.5) positions than at the S.0(3.5) and S.0(7.5) positions. This indicated that larger quantity of Fe was reduced at the S.5(3.5) and S.5(7.5) positions (Fig. 4.4.4), resulting in a greater Eh and broader bimodal distribution even though the increased Fe concentration decreased the Eh.

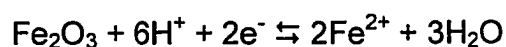
The Mn was greater than the Fe within 48 hours at the M.0(0.5), M.0(3.5), M.5(0.5), and M.5(3.5) positions, indicating that Mn was preferentially reduced. However, the appearance of Fe in the interstitial water within 72 hour at the M.0(7.5) position and the Mn continuously increased after 72-hour of incubation. The coexistence of Mn and Fe in the interstitial water implied that the Mn and Fe were reduced simultaneously. This result contradicted the sequential reduction theory. Patrick and Jugsujinda (1992) found an overlap between Mn and nitrate reduction and noted that the overlap occurred because the Eh was low enough to support Mn reduction before all the nitrate was reduced. However, the paradox was explained as an effect of the microsites surrounding the microbes (Munch et al., 1978). Mn was probably reduced in preference to Fe because of their thermodynamic conservation. However, as soon as Mn surrounding the microbes was exhausted, nearby Fe was reduced. Based upon the results of XRD (Fig. 4.6.1), the hematite disappeared at the M.0(0.5) position, but still existed at the M.0(7.5) position after 21 days of incubation. This strongly showed that the microbes preferred to use nearby oxidants as electron acceptors and supported the microsite concept of Munch et al. (1978).

The distribution of the Mn in each incubation box was larger at the 7.5 cm position than at the 0.5 cm position. The reverse was true for the distribution of Fe. The distribution of Mn conflicted with the expected greater SOC and lower Eh at the 0.5 cm position. This was attributed to the diffusion of Mn into the soil profile because Mn was either not complexed or only weakly complexed with SOC (McBride, 1978; Camerlynck and Kienkens, 1982). After the Mn saturated the cation capacity of clays, it diffused upward into the above solution following a concentration gradient. The pH adjusted to 5 treatment had more diffusion of Mn because the concentration was increased, which increased the gradient within the soil profile. The decrease of Mn at the M.5(0.5) position after 48 hours of incubation was part of the evidence.

The Fe ions have a higher coordination potential with SOC bridging to clay particles via chelation with SOC. Thus, the mobility of reduced Fe was limited to the area where it was formed. The concentrations and rate of increasing Fe were greater for the Sharkey soil than for the Moreland soil. This was more evident at the 3.5 and 7.5 cm positions, indicating that amorphous Fe was preferentially reduced. However, higher Mn concentrations could also consume energy sources and diminish the reduction of Fe within the Moreland soil.

The reduction of Fe for the Moreland soil was the result of changes in redox equilibria whose processes can be represented by the following reactions and equations:

1. Fe_2O_3 — Fe^{2+} system (hematite)



$$\text{Eh} = 0.728 - 0.059 \log(\text{Fe}^{2+}) - 0.177 \text{ pH}$$

2. $\text{Fe}(\text{OH})_3$ — Fe^{2+} system (amorphous)



$$\text{Eh} = 1.057 - 0.059 \log(\text{Fe}^{2+}) - 0.177 \text{ pH}$$

By applying the Nernst equation, the relationship between the equation $\text{Eh} + 0.059 \log(\text{Fe}^{2+})$ and pH were plotted (Fig. 4.13) using standard redox potential data for hematite and amorphous Fe (Ponnamperuma et al., 1967; Langmuir and Whittemore, 1971). At first view, three different data sets indicated that Fe^{2+} in the interstitial water was controlled by different species of Fe. Data above the amorphous theoretical line indicated under-saturation of the interstitial water with respect to Fe^{2+} . This means that amorphous Fe controlled the equilibria between ferric and ferrous Fe in the interstitial water. Those 6 data points above the amorphous line were obtained at the beginning of incubation. Another data set between the amorphous and hematite theoretical lines indicated that hematite controlled the solubility of Fe in the interstitial water. The final data set was below the hematite theoretical line. This indicated that the Fe^{2+} in the interstitial water was over-saturated due to the formation of Fe-humus complexes. However, the Eh showed a bimodal distribution and the pH remained constant after 144 hours, whereas the Fe increased during the experiment (Fig. 4.2.1, 4.3.1, and 4.4.2). The data points obtained at the same position converged at a local area with respect to pH.

The conclusion is that there was no relationship among the Eh, pH, and Fe. This means that the results do not fit the Nernst theoretical equation. The Nernst equation is only confirmed for a pure chemical system. For natural systems, SOC continuously provides electron sources for Mn and Fe to reduce and soils do not reach oxidation-reduction equilibrium (Bohn, 1971). Thus, the Nernst equation may not apply to real soil situations.

CHAPTER 5.

SUMMARY AND CONCLUSIONS

Moreland clay (very fine, smectitic, thermic, Oxyaquic Hapluderts) derived from Red River alluvium does not exhibit redoximorphic features, though it is saturated for more than two months during the growing season. Sharkey clay (very-fine, smectitic, thermic Chromic Epiaquerts) derived from the Mississippi River exhibits redoximorphic features. Energy sources and pH were used to investigate their effects on Eh, pH, soil color, and iron oxide transformation for these two Vertisols in Louisiana.

The conclusions drawn from this study are as follows:

1. The Moreland soil does not exhibit redoximorphic features because it does not provide sufficient carbon source to anaerobic microbes. Hematite, which is not easily reduced by microbes, is the major Fe form in the Moreland soil. Red color is throughout the Moreland profile. The Sharkey soil exhibits redoximorphic features because of greater concentrations of OC and amorphous Fe, together with lower concentrations of Mn, which resulted in low chroma in the soil matrix.
2. Soil pH as low as 5 had less effect on Eh than did OC. The different pH treatments for the Moreland soil with no sucrose treatment did not show redoximorphic features during the experiment. With a 10 g/kg sucrose treatment, low chroma (≤ 2) redoximorphic features extended into the Moreland soil surface. Soil pH did not approach 7.0 for the Moreland and Sharkey soils with or without sucrose treatment during 21 days of submergence. In addition

to anaerobic respiration, fermentation was a major process controlling the pH of soils with high SOC.

3. Concentrations of OC and types and concentrations of inorganic compounds controlled the change in soil pH and Eh. The Sharkey soil treated with sucrose had a lower pH than did the Moreland soil due to less Mn. The bimodal distribution of Eh correlated with the concentrations of added sucrose for both the Moreland and Sharkey soils.

4. Sodium pyrophosphate, acid-oxalate, and DCB can be used to estimate the transformation of crystalline Fe and amorphous organic and inorganic Fe. The reduced Fe from amorphous and crystalline Fe transformed into Fe-humus complexes during the flooding period and Fe-humus complexes transformed into amorphous inorganic Fe after drying.

5. Three different methods used to measure the concentrations of OC failed to estimate the change in Eh. Based upon the formation of redoximorphic features, the addition of 2.5 g/kg sucrose to the natural pH Moreland soil (pH 7.4) and 1 g/kg sucrose to the pH adjusted to 5 Moreland soil can be regarded as the threshold concentration of SOC required for the formation of redoximorphic features. However, the formation of redoximorphic features did not really reflect the concentrations of Fe ions in the soil solution. The natural pH Sharkey soil (pH 6.4) with no sucrose treatment formed redoximorphic features, but negligible Fe ions appeared in the soil solution.

6. The Eh, pH, and concentrations of Fe ions within the interstitial water failed to satisfy the Nernst equation. This was probably due to the soils' non-

equilibrium status and the formation of Fe-humus complexes during the experiment.

7. According to the results for Fe and Mn in the interstitial water, anaerobic microbes preferentially reduced Mn. However, based upon the results of the XRD, there was no hematite within the upper 0.5 cm but hematite still existed within 7.5 cm of the Moreland soil after 3 weeks of incubation. This result showed that anaerobic microbes used nearby inorganic compounds as electron acceptors and did not follow the reduction sequence theory.

8. Based upon the data of Eh, pH, and concentrations of Fe in the interstitial water, the result did not fit Nernst equation because it involved biological reactions.

The results of this study reaffirmed the importance of energy sources for the formation of redoximorphic features in flooded soils. In addition to anaerobic respiration, fermentation should be considered as a factor controlling the change in soil pH.

REFERENCES

- Alexander, M. 1977. Soil microbiology. John Wiley and Sons. 2nd ed. New York, NY.
- Arshad, M. A., R. J. St. Arnaud, and P. M. Huang. 1972. Dissolution of trioctahedral layer silicates by ammonium oxalate, sodium dithionite-citrate-bicarbonate, and potassium pyrophosphate. *Can. J. Soil Sci.* 52:19-26.
- Bao, X. M. 1985. Iron and manganese. p. 69-91. In T. R. Yu (ed.) *Physical Chemistry of Paddy Soils*. Science Press, Beijing, China.
- Barlett, R. J. and B. R. James. 1993. Redox chemistry of soils. *Adv. Agr.* 50: 151-208.
- Barlett, R. J. and B. R. James. 1995. System for categorizing soil redox status by chemical field testing. *Geoderma*. 68:211-218.
- Barner, S. J. 1983. Introduction to microbiology. In H. C. Vogel (ed.) *Fermentation and biochemical engineering handbook: principle, process design, and equipment*. Noyes Publication, Park Ridge, NJ.
- Barnum, D. W. 1982. Potential-pH diagrams. *J. Chem. Educ.* 59: 809-812.
- Bascomb, C. L. 1968. Distribution of pyrophosphate-extractable iron and organic carbon in soils of various groups. *J. Soil Sci.* 19:251-268.
- Berner, B. A. 1981. A new geochemical classification of sedimentary environments. *J. Sed. Petrology*. 51:359-365.
- Bigham, J. M., S. E. Heckendorn, W. F. Jaynes, and N. E. Smeck. 1991. Stability of iron oxides in two soils with contrasting colors. *Soil Sci. Soc. Am. J.* 55:1485-1492.
- Blodgett, R. H., J. P. Crabaugh, and E. F. McBride. 1993. The color of red beds a geologic perspective. p. 127-159. In J. M. Bigham and E. J. Ciolkosz (eds.) *Soil Color*. Soil Soc. Am. Special Publication NO. 31, Madison, WI.
- Bloomfield, C. 1950. Some observations on gleying. *J. Soil Sci.* 1: 205-211.
- Bloomfield, C. 1951. Experiments on mechanisms on gley formation. *J. Soil Sci.* 2: 196-211.
- Blume, H. P. and U. Schwertmann. 1969. Genetic evaluation of the profile distribution of aluminum, iron, and manganese oxides. *Soil Sci. Soc. Am. Proc.* 33:438-444.

- Blume, H. P. and E. Schlichting, 1985. Morphology of wetland soils. p. 161-176. In *Wetland soils: Characterization, classification, and utilization*. Proc. of a workshop held March 26 to April 5, 1984. Int. Rice Res. Inst., Los Banos, Philippine.
- Bohn, H. L. 1968. Electromotive force of inert electrodes in soil suspension. *Soil Sci. Soc. Amer. Proc.* 32:211-215.
- Bohn, H. L. 1969. The E.M.F. of platinum electrodes in dilute soil solution and its reaction to soil pH. *Soil Sci. Soc. Am. Proc.* 33:639-640.
- Bohn, H. L. 1971. Redox potentials. *Soil Sci.* 112:39-45.
- Bohn, H. L., B. L. McNeal, and G. A. O'Conner. 1985. *Soil Chemistry* (2nd ed). John Wiley and Sons, NY.
- Bouma, J. 1983. Hydrology and soil genesis of soils with aquic moisture regimes. p. 253-281. In L. P. Wilding, N. E. Smeck, and G. F. Hall (eds.) *Pedogenesis and Soil Taxonomy I. Concepts and interactions*. Elsevier. Publishing Co. Amsterdam, The Netherlands.
- Bowman, R. A. and D. D. Focht. 1974. The influence of glucose and nitrate concentrations upon denitrification rate in sandy soils. *Soil Biol. Biochem.* 6:297-301.
- Brinkman, R. 1970. Ferrollysis, a hydromorphic soil forming process. *Geoderma.* 3:199-206.
- Brown, L. 1970. Soils of the southern Mississippi River alluvium. Southern Coop Series Bull. 178. Ark. Exp. Station, Univ. Arkansas, Fayetteville, AR.
- Bryant, R. B. and J. Macedo. 1990. Differential chemoreductive dissolution of iron oxides in a Brailian Oxisol. *Soil Sci. Soc. Am. J.* 54:819-821.
- Buol, S. W. and M. N. Camargo. 1992. Wet Oxisols. p. 41-49. In J. M. Kimble (ed.) *Proceeding of the Eighth International Soil Correlation Meeting (VIII ISCOM) : Characterization, Classification, and Utilization of Wet Soils*. USDA, SCS, National Soil Survey Center, Lincoln, NE.
- Callebaut, F., D. Gabriels, W. Minjauw, and M. De Boot. 1982. Redox potential, oxygen diffusion rate, and soil gas composition in relation to water table level in two soils. *Soil Sci.* 134: 149-156.
- Camerlynck, R. and L. Kiekens. 1982. Speciation of heavy metals in soils based on charge separation. *Plant Soil.* 68:331-339.

- Childs, C. W. 1981. Field tests for ferrous iron and ferric-organic complexes (on exchange sites or in water-soluble forms) in soils. *Aust. J. Soil Res.* 19:175-180.
- Clothier, B. E., J. A. Pollock, and D. R. Scotter. 1978. Mottling in soil profile containing a coarse-texture horizon. *Soil Sci. Soc. Am. J.* 42:761-763.
- Cogger, C. G., and P. E. Kennedy. 1992. Seasonally saturated soils in the Puget Lowland I. Saturation, reduction, and color patterns. *Soil Sci.* 153:421-433.
- Cogger, C. G., P. E. Kennedy, and D. Carlson. 1992. Seasonally saturated soils in the Puget Lowland II. Measuring and interpretation redox potentials. *Soil Sci.* 154:50-58.
- Collins, J. F. and S. W. Boul. 1970a. Effects of fluctuation in the Eh-pH environment on iron and/or manganese equilibria. *Soil Sci.* 110:111-118.
- Collins, J. F. and S. W. Boul. 1970b. Patterns of iron and manganese precipitation under specific Eh-pH conditions. *Soil Sci.* 110:157-162.
- Comerma, J. A. 1985. Hydromorphic Vertisols. p.407-420. In *Wetland Soils: Characterization, classification, and utilization. Proceedings of international workshop.* International Rice Research Institute. Los Banos, Philippines.
- Connell, W. E and W. H. Patrick, Jr. 1968. Sulfate reduction in soil: Effects of redox potential and pH. *Science.* 159:86-87.
- Couto, W., C. Sanzanowicz, and A. de O. Barcelos. 1985. Factors affecting oxidation-reduction processes in an Oxisol with a seasonal water table. *Soil Sci. Soc. Am. J.* 49:1245-1248.
- Daniels, R. B., G. H. Simonson, and R. L. Handy. 1961. Ferrous iron content and color of sediments. *Soil Sci.* 91:378-382.
- Daniels, R. B., E. E. Gamble, and L. A. Nelson. 1971. Relation between soil morphology and water-table levels on a dissected North Carolina coastal plain surface. *Soil Sci. Soc. Amer. Proc.* 35:781-784.
- Daniels, R. B., E. E. Gamble, and S. W. Buol. 1973. Oxygen content in the ground water of some North Carolina Aquults and Udufts. p. 153-166. In R. Bruce (ed.), *Field Soil Water Regime*, *Soil Sci. Soc. Am.* 1973 Special Pub. 5.

- Daniels, R. B. and S. W. Buol. 1992. Water table dynamics and significance to soil genesis. p. 66-74. In. J. M. Kimble (ed.) Proceeding of the Eighth International Soil Correlation Meeting (VIII ISCOM) : Characterization, Classification, and Utilization of Wet Soils. USDA, SCS, National Soil Survey Center, Lincoln, NE.
- Dobos, R. R., E. J. Ciolkosz, and W. J. Waltman. 1990. The effect of organic carbon, temperature, and redox conditions on soil color. *Soil Sci.* 150: 506-512.
- Dudal, R. 1992. Introductory address: wet soils. p. 1-4. In. J. M. Kimble (ed.) Proceeding of the Eighth International Soil Correlation Meeting (VIII ISCOM) : Characterization, Classification, and Utilization of Wet Soils. USDA, SCS, National Soil Survey Center, Lincoln, NE.
- Evans, C. V. and D. P. Franzmeier. 1986. Saturation, aeration, and color patterns in a toposequence of soils in north-central Indiana. *Soil Soc. Sci. Am. J.* 50: 975-980.
- Fanning, D. S., R. L. Hall, and J. E. Foss. 1973. Soil morphology, water tables and iron relationships in soils of the Sassafras drainage catena. p. 71-79. In E. Schlichting and U. Schwertmann (eds.) *Pseudogley and gley*. Trans. Comm. V and VI Int. Soil Sci. Soc., Verlag Chemie, Weinheim, West Germany.
- Fanning, D. S., M. C. Rabenhorst, and M. L. Thompson. 1992. Micro-macromorphology of wet soils in relation to classification. p. 106-112. In. J. M. Kimble (ed.) Proceeding of the Eighth International Soil Correlation Meeting (VIII ISCOM) : Characterization, Classification, and Utilization of Wet Soils. USDA, SCS, National Soil Survey Center, Lincoln, NE.
- Faulkner, S. P., W. H. Patrick, Jr., and R. P. Gambrell. 1989. Field techniques for measuring wetland soil parameters. *Soil Sci. Soc. Am. J.* 53:883-890.
- Faulkner, S. P. and W. H. Patrick, Jr. 1992. Redox processes and diagnosis wetland soil indicators in bottomland hardwood forests. *Soil Sci. Soc. Am. J.* 56:856-865.
- Federal Register. 1994. Changes in Hydric Soils of the United States. Washington, DC.
- Franzluebbers, A. L., R. L. Haney, C. W. Honeycutt, H. H. Schomberg, and F. M. Hons. 2000. Flush of carbon dioxide following rewetting of dried soil relates to active organic pools. *Soil Sci. Soc. Am. J.* 64:613-623.

- Franzmeir, D. P., J. E. Yahner, G. C. Steinhardt, and H. R. Sinclair, Jr. 1983. Color patterns and water table levels in some Indiana soils. *Soil Sci. Soc. Am. J.* 47: 1196-1201.
- Gambrell, R. P. and W. H. Patrick, Jr. 1978. Chemical and microbiological properties of anaerobic soils and sediments. p. 375-423. In *Plant life in anaerobic environments*. Ann Arbor Sci. Publishers. Ann Arbor, MI.
- Garrels, R. M. and C. L. Christ. 1965. *Solutions, Minerals, and Equilibria*. Harper, New York, NY.
- Gilliam, J. W. and R. P. Gambrell. 1978. Temperature and pH as limiting factors in loss of nitrate from saturated Atlantic Coastal Plain soils. *J. Environ. Qual.* 7: 526-532.
- Gilliam, J. W., R. W. Skaggs, and S. B. Weed. 1979. Drainage control to diminish nitrate loss from agricultural fields. *J. Environ. Qual.*, 8:137-142.
- Gotoh, S. and W. H. Patrick, Jr. 1974. Transformation of iron in a waterlogged soil as affected by redox potential and pH. *Soil Sci. Soc. Am. Proc.* 38:66-71.
- Griffin, R. W., L. P. Wilding, and L. R. Dress. 1992. Relating morphology properties to wetness conditions in the gulf coast prairie of Texas. p. 126-134. In: J. M. Kimble (ed.) *Proceeding of the Eighth International Soil Correlation Meeting (VIII ISCOM) : Characterization, Classification, and Utilization of Wet Soils*. USDA, SCS, National Soil Survey Center, Lincoln, NE.
- Harmsen, K. and N. van Breemen. 1975. Translocation of iron in acid sulfate. II. Production and diffusion of dissolved ferrous iron. *Soil Sci. Soc. Am. Proc.* 39:1148-1153.
- Hayashi, H. and M. Yamada. 1990. Kinetics of dissolution of noncrystalline oxides and crystalline clay minerals in a basic Tiron solution. *Clays Clay Miner.* 38:308-314.
- Howeler, R. H. and Bouldin, D. R. 1971. The diffusion and consumption of oxygen in submerged soils. *Soil Sci. Soc. Am. Proc.* 35: 202-208.
- Hudnall, W. H., A. A. Szogi, B. A. Touchet, J. P. Edwards, and W. C. Lynn. 1990. *Guidebook for Louisiana. Eighth International Soil Correlation Meeting: Classification and Management of Wet Soils*. USDA-Soil Conservation Service-National Soil Survey Center. Lincoln, NE.

- Hudnall, W. H. and L. P. Wilding. 1992. Monitoring soil wetness conditions in Louisiana and Texas. p. 135-151. In: J. M. Kimble (ed.) Proceeding of the Eighth International Soil Correlation Meeting (VIII ISCOM) : Characterization, Classification, and Utilization of Wet Soils. USDA, SCS, National Soil Survey Center, Lincoln, NE.
- Hudnall, W. H. and W. B. Petterson. 1997. Sharkey Field Tour. Louisiana, Mississippi, and Arkansas. Agronomy Department, Louisiana Agriculture Experiment Station, Baton Rouge, LA.
- Hurt, G. W. and W. E. Puckett. 1992. Proposed hydric soil criteria and their field identification. p. 148-151. In: J. M. Kimble (ed.) Proceeding of the Eighth International Soil Correlation Meeting (VIII ISCOM) : Characterization, Classification, and Utilization of Wet Soils. USDA, SCS, National Soil Survey Center, Lincoln, NE.
- Jacob, J. S., r. W. Griffin, W. L. Miller, and L. P. Wilding. 1997. Aquert and aquertic soils: a querulous proposition. p. 61-77. In M. J. Vepraskas and S. W. Sprecher (eds.) Aquic Conditions and Hydric Soils: The problem Soils. Soil Science Society of America, Madison, WI, USA. Special Publication Number 50.
- Jarvis, S. C. 1984. The forms of occurrence of manganese in some acidic soils. J. Soil Sci. 35:421-429.
- Jeffery, J. W. O. 1961. Measuring the state of reduction of a waterlogged soil. J. Soil Sci. 12: 317-325.
- Kellerman, V. V. and I. G. Tusurupa. 1965. Sources of available iron in the soil. Soviet Soil Sci. 1176-1183.
- Kodama, H. and C. Wang. 1989. Distribution and characterization of noncrystalline inorganic components in Spodosols and Spodosol-like soils. Soil Sci. Soc. Am. J. 53:526-534.
- Langmuir, D. and D. O. Whittemore. 1971. Variations in the stability of precipitated ferric oxyhydroxides. In J. D. Hem (ed.) Nonequilibrium systems in natural water chemistry. Advan. Chem. 106:209-234. Amer. Chem. Soc.
- Light, T. S. 1972. Standard solution for redox potential measurements. Anal. Chem. 44:1038-1039.
- Lindbo, D. L. 1997. Entisols-fluvents and fluvaquents: problems recognizing aquic and hydric conditions in young, flood plain soils. p. 133-151. In M. J. Vepraskas and S. W. Sprecher (eds.) Aquic conditions and hydric soils:

The problem soils. Soil Science Society of America, Madison, WI, USA.
Special Publication Number 50.

- Lindsay, W. L. 1972. Chemical equilibria in soils. John Wiley and Sons, New York, NY.
- Liu, C. W. and T. N. Narasimhan. 1989. Redox-controlled multiple-species reactive chemical transport. 1. Model development. Water Resour. Res. 25: 869-882.
- Lockwood, L. B. 1979. Production of organic acids by fermentation. In Microbial Technology. Peppler and Perlman (ed.) 2nd. Academic Press. New York, NY.
- Loveland, P. J. and P. Digby. 1984. The extraction of Fe and Al by 0.1 M pyrophosphate solutions: a comparison of some techniques. J. Soil Sc. 35:243-250.
- Lovley, D. R. 1992. Microbial oxidation of organic matter coupled to the reduction of Fe(III) and Mn(IV) oxides. p. 101-114. In: Biomineralization process, Iron, Manganese. H. C. W. Skinner and R. W. Fitzpatrick (eds.). Catena supplement 21. Cremlingen-Destedt, Germany.
- Lowrance, R. and D. Smittle. 1988. Nitrogen cycling in a multiple vegetable production system. J. Environ. Qual. 17: 158-162.
- Lu, Y., R. Wassmann, H. U. Neue, and C. Huang. 2000. Dynamic of dissolved organic carbon and methane emissions in a flooded rice soil. Soil Sci. Soc. Am. J. 64: 2011-2017.
- Macedo, J. and R. B. Bryant. 1987. Morphology, mineralogy, and genesis of a hydrosequence of Oxisol in Brazil. Soil Sci. Soc. Am. J. 51: 690-698.
- Macedo, J. and R. B. Bryant. 1989. Preferential microbial reduction of hematite over goethite in a Brazilian Oxisol. Soil Sci. Soc. Am. J. 53: 1114-1118.
- Mausbach, M. J. 1992. Soil survey interpretations for wet soils. p. 172-178. In. J. M. Kimble (ed.) Proceedings of the VIII International Soil Correlation Meeting, Classification, and Management of Wet Soils. USDA, Soil Conservation Service-National Soil Survey Center. Lincoln, NE.
- Mausbach, M. J. and J. L. Richardson. 1994. Biogeochemical processes in hydric soil formation. Wetland Biogeochem. 1:68-127.
- McBride, M. B. 1978. Transition metal bonding in humid acid: An ERS study. Soil Sci. 126: 200-209.

- McKeague J. A. and J. H. Day. 1966. Dithionite- and oxalate-extractable Fe and Al as aids in differentiating various classes of soils. *Can. J. Soil Sci.* 46:13-22.
- McKeague, J. A. 1967. An evaluation of 0.1 M pyrophosphate and pyrophosphate dithionite in comparison with oxalate as extractants of the accumulation products in podzols and some other soils. *Can. J. Soil Sci.* 47:95-99.
- McKeague, J. A. and P. A. Schuppli. 1982. Changes in concentration of iron and aluminum in pyrophosphate extracts of soils and composition of sediment resulting from ultracentrifugation in relation to spodic horizon criteria. *Soil Sci.* 134:265-270.
- Meek, B. D. and L. B. Grass. 1975. Redox potential in irrigated desert soil as an indicator of aeration status. *Soil Sci. Soc. Am. Proc.* 39:870-875.
- Mehra, O. P. and M. L. Jackson. 1960. Iron oxide removal from soils and clays by a dithionite-citrate system buffered with sodium bicarbonate. *Clays Clay Min.* 7:317-327.
- Miller, B. J. 1983. Ultisols. p. 283-323. In L. P. Wilding et al. (ed.) *Pedogenesis and soil taxonomy. II. The soil orders.* Elsevier Science Publishing Co., New York, NY.
- Mitsuchi, M. 1992. Anthropically induced wet soils. p. 179-184. In J. M. Kimble (ed.) *Proceeding of the Eighth International Soil Correlation Meeting (VIII ISCOM) : Characterization, Classification, and Utilization of Wet Soils.* USDA, SCS, National Soil Survey Center, Lincoln, NE.
- Mokma, D. L. and S. W. Sprecher. 1994. Water table depths and color patterns in soils developed from red parent materials in Michigan, USA. *Catena.* 22: 287-298.
- Mortland, M. M. 1986. Mechanisms of adsorption of nonhumic organic species by clays. p. 59-76. In P. M. Huang and M. Schnitzer (eds.) *Interactions of Soil Minerals with /natural Organics and Microbes.* Soil Science Society of America, Madison, WI, USA. Special Publication Number 17.
- Munch, J. C., Th. Hillebrand, and J. C. J. Ottow. 1978. Transformation in the Feo/Fed-ratio of pedogenic iron oxides affected by iron-reducing bacteria. *Can. J. Soil Sci.* 58:475-486.
- Munch, J. C. and J. C. J. Ottow. 1980. Preferential reduction of amorphous to crystalline iron oxides by bacterial activity. *Soil Sci.* 129:15-21.

- Norvell, W. A. 1988. Inorganic reactions of manganese in soils. p. 37-58. In Graham, R. D., Hannam, R. J., and Uren, N. C. (eds.) *Manganese in Soils and Plants*. Kluwer Academic, Glen Osmond, South Austria.
- Obenhuber, D. C. and R. Lowrance. 1991. Reduction of nitrate in aquifer microcosms by carbon additions. *J. Environ. Qual.* 20:255-258.
- Okazaki, M. and H. Wada. 1976. Some aspects of pedogenic processes in paddy soils. *Pedologist (Japan)*. 20: 139-150.
- Olomu, M. O., G. J. Racz, and C. M. Cho. 1973. Effect on flooding on the Eh, pH, and concentrations of Fe and Mn in several Manitoba soils. *Soil Sci. Soc. Am. Proc.* 37:220-224.
- Ottow, J. C. G. 1970. Bacteria mechanism of gley formation. *Nature*, 225:103.
- Ottow, J. C. G. and H. Glathe. 1971. Isolation and identification of iron reducing bacteria from gley soils. *Soil Biol. Biochem.* 3:43-55.
- Patrick, W. H., Jr. 1980. The role of inorganic redox systems in controlling reduction in paddy soils. p. 107-117. In *Symposium on paddy soils*. Proc. Institute of Soils Science, Academic Sinica. Nanjing, China.
- Patrick, W. H., Jr. and I. C. Mahapatra. 1968. Transformation and availability to rice of nitrogen and phosphorous in waterlogged soils. *Adv. Agron.* 20:323-358.
- Patrick, W. H., Jr. and D. S. Mikkelsen. 1971. Plant nutrient behavior in flooded soils. p. 187-215. In R. A. Olsen (ed.) *Fertilizer technology and use*. 2nd ed. SSSA, Madison, WI.
- Patrick, W. H., Jr. and R. D. Delaune. 1972. Characterization of the oxidized and reduced zones in flooded soil. *Soil Sci. Soc. Am. Proc.* 36:573-576.
- Patrick, W. H. Jr and A. Jugsujinda. 1992. Sequential reduction and oxidation of inorganic nitrogen, manganese, and iron in flooded soil. *Soil Sci. Soc. Am. J.* 56:1071-1073.
- Pawluk, S. 1972. Measurement of crystalline and amorphous iron removal in soils. *Can J. Soil Sci.* 52:119-123.
- Petty, D. E. and R. E. Switzer. 1996. Sharkey soils in Mississippi. Miss. Agricultural and Forestry Experiment Station Bulletin 1057, Mississippi State University, Starkville, MS.

- Pickering, E. W. P. L. M. Veneman. 1984. Moisture regimes and morphological characteristics in a hydrosquence in central Massachusetts. *Soil Sci. Soc. Am. J.* 48: 113-118.
- Ping, C. L., J. P. Moore, and M. H. Clark. 1992. Wetland properties of permafrost soils in Alaska. pp. 198-205. In J. M. Kimble (ed.) *Proceeding of the Eighth International Soil Correlation Meeting (VIII ISCOM): Characterization, Classification, and Utilization of Wet Soils*. USDA, SCS, National Soil Survey Center, Lincoln, NE.
- Ponnamperuma, F. N. 1972. The Chemistry of submerged soils. *Adv. Agron.* 24:29-96.
- Ponnamperuma, F. N. and R. U. Castro. 1964. Redox systems in submerged soils. *Trans. Intern. Congr. Soil Sci.* 7th Congr. Bucharest, Hungary.
- Ponnamperuma, F. N., W. L. Yuan, and M. T. Y. Nhung. 1965. Manganese dioxide as a remedy for a physiological disease of rice associated with reduction of the soil. *Nature*. 207: 1103-1104.
- Ponnamperuma, F. N., E. Martinez, and T. Loy. 1966. Influence of redox potential and partial pressure of carbon dioxide on pH values and the suspension effect of flooded soils. *Soil Sci.* 101: 421-431.
- Ponnamperuma, F. N., E. M. Tianco, and T. A. Lot. 1967. Redox equilibria in flooded soils. I. The iron oxide systems. *Soil Sci.* 103:374-382.
- Ransom, M. D. and N. E. Smeck. 1986. Water table characteristics and water chemistry of seasonally wet soils of southwestern Ohio. *Soil Sci. Soc. Am. J.* 50:1281-1290.
- Scheffer, F., E. Welte, and F. Ludwig. 1958. Zur Frage der Eisenoxidhydrate im Boden. *Erde* 19: 51-64.
- Scheinost, A. C. and U. Schwertmann. 1999. Color identification of iron oxides and hydroxysulfates: use and limitations. *Soil Sci. Soc. Am. J.* 63: 1463-1471.
- Schnitzer, M. 1986. Binding of humic substances by soil mineral colloids. p. 77-101. In P. M. Huang and M. Schnitzer (eds.) *Interactions of Soil Minerals with /natural Organics and Microbes*. Soil Science Society of America, Madison, WI, USA. Special Publication Number 17.
- Schwertmann, U. 1993. Relations between iron oxides, soil color, and soil formation. In J. M. Bigham and E. J. Ciolkosz (eds.) *Soil color*. Soil

Science Society of America, Madison, WI, USA. Special Publication Number 31.

Schwertmann, U., R. W. Fitzpatrick and J. Le Roux. 1977. Al substitution and differential disorder in soil hematites. *Clays Clay Miner.* 25:373-374.

Schwertmann, U. and R. M. Taylor. 1977. Iron oxides. p. 145-179. In J. B. Dixon and S. B. Weed (eds.) *Mineral in Soil Environments*. Soil Sci. Soc. Am., Madison, WI.

Schwertmann, U., E. Murad, and D. J. Schulze. 1982. Is there Holocene reddening (hematite formation) in soils of axeric temperature areas? *Geoderma*. 27:209-223.

Schwertmann, U., H. Kodama, and W. R. Fischer. 1986. Mutual interactions between organics and iron oxides. p. 223-250. In P. M. Huang and M. Schnitzer (eds.) *Interactions of Soil Minerals with /natural Organics and Microbes*. Soil Science Society of America, Madison, WI, USA. Special Publication Number 17.

Scott, A. D. and D. D. Evans. 1955. Dissolved oxygen in saturated soil. *Soil Sci. Soc. Am. Proc.* 19: 7-12.

Simonson, G. H. and L. Boersma. 1972. Soil morphology and water table relations: II. Correlation between annual water table fluctuations and profile features. *Soil Sci. Soc. Am. Proc.* 36:649-653.

Smid, A. E. and E. G. Beauchamp. 1976. Effects of temperature and organic matter on denitrification in soil. *Can. J. Soil Sci.* 56: 385-391.

Smith, G. D. 1983. Historical development of soil taxonomy – background. In L. P. Wilding et al (eds.). *Pedogenesis and soil taxonomy. I. Concepts and interactions*. Elsevier Science Publ. Amsterdam, The Netherlands.

Soil Survey Staff. 1975. *Soil Taxonomy*. Agric. Handbook No. 436, USDA. U.S. Government Printing Office, Washinton, DC.

Soil Survey Staff. 1998. *Keys to Soil Taxonomy*. 8th ed. USDA-SCS Publ. U.S. Government Printing Office, Washington, DC.

Sposito, G. 1989. *The chemistry of soils*. Oxford University Press Inc., New York, NY.

Stanford, G., R. A. Vander Pol, and S. Dzienia. 1975. Denitrification rates in relation to total and extractable soil carbon. *Soil Sci. Soc. Am. Proc.* 39:284-289.

- Stevenson, F. J. and A. Fitch. 1986. Chemistry of complexation of metal ions with soil solution organics. p. 29-58. In P. M. Huang and M. Schnitzer (eds.) *Interactions of Soil Minerals with /natural Organics and Microbes*. Soil Science Society of America, Madison, WI, USA. Special Publication Number 17.
- Stone, A. L. 1997. Reactions of extracellular organic ligands with dissolved metal ions and mineral surfaces. p. 309-344. In Banfield, J. F. and K. H. Nealson (eds). *Geomicrobiology: interactions between microbes and minerals*. Miner. Soc. Amer. Washington, D.C. *Reviews in Mineralogy*, volume 35.
- Szogi, A. A. and W. H. Hudnall. 1991. Soil redox capacity factors: A study on hydric soils of Louisiana. Agron. Dept. Memo. Baton Rouge, LA.
- Turner, F. T. and W. H. Patrick, Jr. 1968. Chemical changes in waterlogged soils as a result of oxygen depletion. p. 53-56. In J. W. Holmes (ed.) *Int. Congr. Soil Sci. 9th, Adelaide*. Vol. 4. Elsevier, New York, NY.
- Torrent, J., U. Schwertmann, H. Fechter, and F. Alferez. 1983. Quantitative relationships between soil color and hematite content. *Soil Sci.* 136:354-358.
- U.S. Department of Agriculture, Natural Resources Conservation Service. 1998. *Field Indicators of Hydric soils in the United States*. G. W. Hurt, P. M. Whited, and R. F. Pringle (eds.) USDA, NRCS, Fort Worth, TX.
- van Breemen, N. 1975. Acidification and deacidification of coastal plain soils as a result of periodic flooding. *Soil Sci. Soc Am. Proc.* 39:1153-1157.
- Veneman, P. L. M., M. J. Vepraskas, and J. Bouma. 1976. The physical significance of soil mottling in a Wisconsin toposequence. *Geoderma*. 15:103-118.
- Vepraskas, M. J. 1992. Redoximorphic features for identifying aquatic conditions. N.C. Agri. Research Services, Technical Bulletin 301, North Carolina State University, Raleigh, NC.
- Vepraskas, M. J., F. G. Baker, and J. Bouma. 1974. Soil mottling and drainage in a Mollic Hapludalf as related to suitability for septic tank construction. *Soil Sci. Soc. Am. J.* 38:497-501.
- Vepraskas, M. J. and J. Bouma. 1976. Model experiments on mottle formation simulating field conditions. *Geoderma*. 15:217-230.

- Vepraskas, M. J. and L. P. Wilding. 1983a. Albic neoskeltons in argillic horizons as indices of seasonal saturation and iron reduction. *Soil Sci. Soc. Am. J.* 47:1202-1208.
- Vepraskas, M. J. and L. P. Wilding. 1983b. Aquic moisture regimes in soils with and without low chroma colors. *Soil Sci. Soc. Am. J.* 47:280-285.
- Vepraskas, M. J. and L. P. Wilding. 1983c. Deeply weathered soils in the Texas Coastal Plain. *Soil Sci. Soc. Am. J.* 47:293-300.
- Wada, K. 1989. Allophane and imogolite. p. 603-638. In J. B. Dixon and S. B. Weed (eds.) *Mineral in Soil Environment*. Soil Sci. Soc. Am., Madison, WI.
- Wahid, P. A. and M. V. Kamalam. 1993. Reductive dissolution of crystalline and amorphous Fe (III) oxides by microorganisms in submerged soil. *Biology and Fertility of Soils*. 15:144-148.
- White, A. F., M. L. Peterson, and R. D. Solbau. 1990. Measurement and interpretation of dissolved oxygen in ground water. *Ground Water*. 28:584-590.
- Yu, T. R. 1991. Physico-chemical properties of acid soils of the tropics in relation to rice growth. p. 33-42. In: P. Deturck and F. N. Ponnampereuma (eds.) *Rice production on acid soils of the tropics*. Unigraphics Ltd., Colombo, Sri Lanka.
- Zobeck, T. M. and A. Ritchie, Jr. 1984. Analysis of long-term water table depth records from a hydrosequence of soils in central Ohio. *Soil Sci. Soc. Am. J.* 48:119-125.

VITA

Jang-Hung Huang was born on Oct. 23, 1961, in Changhua County, Taiwan. He graduated from the Department of Soil Science, National Chunghsing University in 1985. He obtained his master's degree from the Department of Agricultural Chemistry, National Taiwan University in 1990.

He began his professional career in 1990 as a research assistant in Taiwan University. In 1991, he served as a teaching assistant in National Chunghsing University. He was promoted to instructor in 1996.

In 1998, he attended Louisiana State University in August for his advanced study in soil science. He is presently a candidate for the degree of Doctor of Philosophy in agronomy.

DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: Jang-Hung Huang

Major Field: Agronomy

Title of Dissertation: Effects of Energy Source and Soil Reaction on Redox, Soil Color, and Sesquioxide Transformation for the Moreland and Sharkey Soils

Approved:

Wayne H. Hudnell
Major Professor and Chairman
John M. Parker
Dean of the Graduate School

EXAMINING COMMITTEE:

Robert P. Dambrell
John F. Taylor
W. J. G. Latta
Ray E. Furr
Wm. H. Patrick

Date of Examination:

June 29, 2001