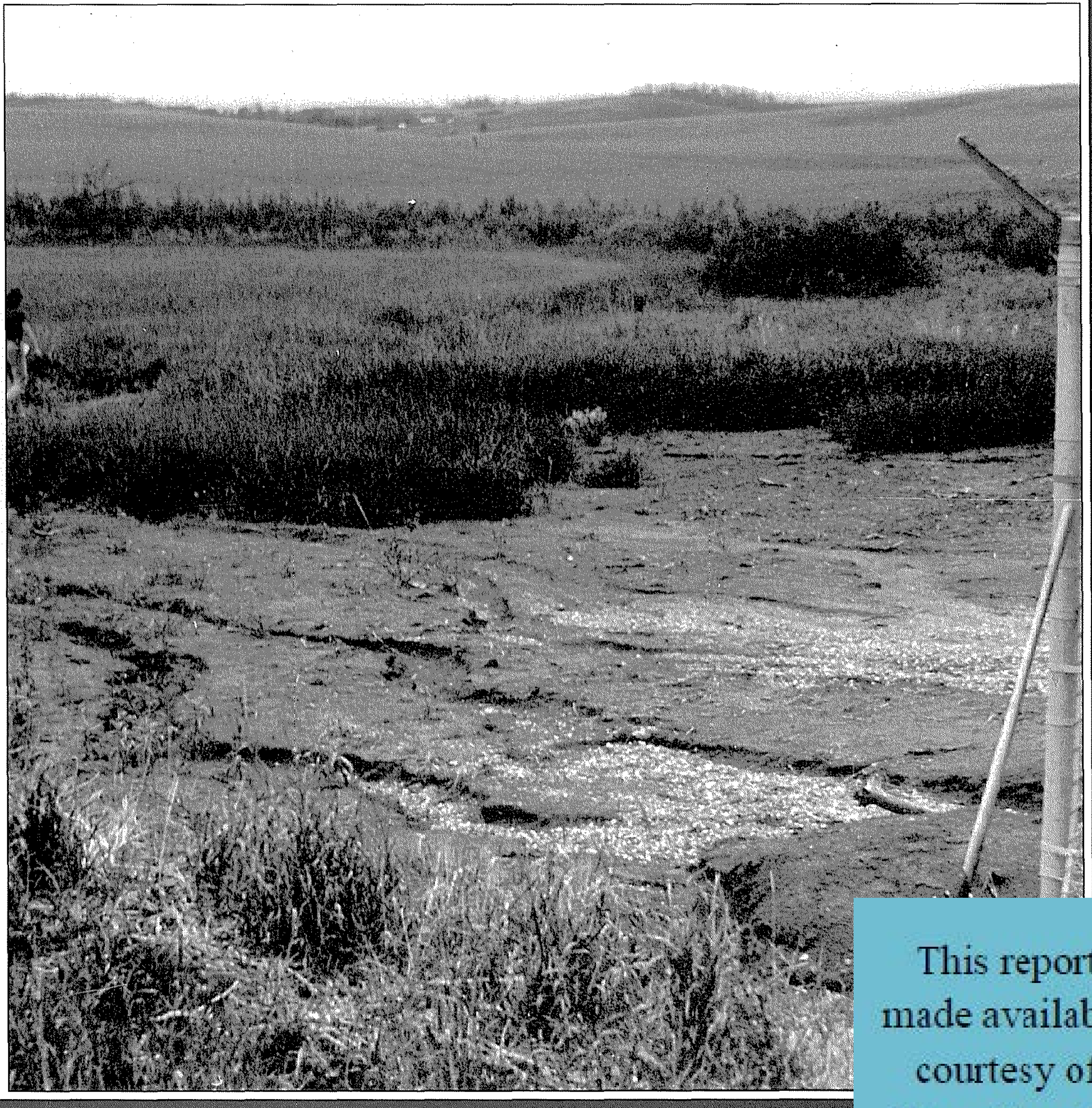
Dissipation of Bromacil in Humic Luvic Gleysols in Northwestern Alberta



NOVA Gas Transmission

DISSIPATION OF BROMACIL IN HUMIC LUVIC GLEYSOLS IN NORTHWESTERN ALBERTA

by
Sandra Landsburg, M.Sc., P.Ag.

and

Elizabeth Dwyer, M.Sc., P.Ag.

Environmental Research Monograph 1995-3
NOVA Gas Transmission Ltd.
Community Resources

December 1995

FOREWORD

NOVA Corporation (NOVA) is a major Canadian energy company involved in pipelining and the manufacturing and marketing of produced petrochemicals. NOVA Gas Transmission Ltd. (NGTL) of NOVA is concerned with natural gas system design, pipeline construction, research and facility operations through the province of Alberta. Since its incorporation in 1954, NGTL has installed more than 18 000 km of natural gas pipeline and continues to operate, maintain and expand this system.

NGTL Environmental Research Monographs are published verbatim from the final reports of professional environmental consultants or company staff. Only proprietary technical or budget-related information is withheld. Since NGTL decisions are not necessarily based on one opinion, recommendations found in the text should not be construed as commitments to action by the company.

NGTL welcomes public and scientific interest in its environmental activities. Please address any questions or comments to: Manager, Community Resources, NOVA Gas Transmission Ltd., P.O. Box 2535, Station "M", Calgary, Alberta, T2P 2N6.

This study was commissioned to evaluate the dissipation of bromacil in Humic Luvic Gleysols amended with cow manure in northwestern Alberta. This report was prepared by Sandra Landsburg, an NGTL department staff member and Elizabeth Dwyer, a private Consulting Agrologist. This report may be cited as:

Landsburg, S. and E. Dwyer. 1995. Dissipation of Bromacil in Humic Luvic Gleysols in Northwestern Alberta. NGTL Environmental Research Monographs 1995-3. NOVA Gas Transmission Ltd., Calgary, Alberta, 56 pp.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The dissipation of bromacil in Humic Luvic Gleysols amended with cow manure was evaluated at two sites in northwestern Alberta from 1984 to 1987. At each site, nine locations were sampled in 4 cm increments from 0 to 40 cm, and analyzed for bromacil, pH, electrical conductivity (EC), and organic carbon (OC). The addition of manure increased values for OC and pH within the surface 16 cm at Site 1 and 24 cm at Site 2. These increases reflected the inherent organic-alkaline nature of the manure itself. Largest increases for both variables occurred between 8 and 16 cm, indicating the predominant depth of cultivation and rooting. Cow manure increased EC values within the surface 4 cm at Site 1 and 12 cm at Site 2. Decreases occurred between 24 and 40 cm at each site, and were caused by leaching. Cow manure promoted microbial degradation of bromacil through increased levels of OC. Bromacil concentrations were lower at the depths where OC percentages were higher. Bromacil concentrations were also reduced throughout the entire 40 cm at Site 2 by leaching. Leaching was restricted at Site 2 by an intermittent high water table, where bromacil concentrations were decreased only within the surface 12 cm. Overall, results of the study show bromacil to be dissipated by two methods: microbial degradation and leaching.

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to all the people who supported the progress of this study. From NGTL, we thank Dr. A. Fedkenheuer for his advice and valuable suggestions, and C.L. Cloutier for the field work and data collection. We acknowledge D. Cassidy of Cassidy Exploration Ltd. for professional advice and cooperation. A special thanks goes to T. Entz from Lethbridge, Alberta for clarification of the statistical analyses required for this project. Also, thank you to the NGTL Airdrie Resource team for their efforts in typing, editing and assistance in the completion of this report.

1.0 INTRODUCTION

In Alberta, legislation indirectly affects vegetation management on aboveground facilities such as meter stations and compressor stations. The Electrical Protection Act defines hazardous areas as those areas surrounding buildings in which flammable gases or vapours may be present in sufficient quantities to produce explosive or ignitable mixtures. Precautions must be taken within the defined zones to prevent sparking, as this could cause an explosion. Vegetation growing on these sites creates a risk since control involves using electric or gasoline mowers, which can create sparks.

The oil and gas industry has responded to the legislation by keeping all aboveground facilities free of vegetation. This is commonly accomplished by application of non-selective, residual herbicides generally referred to as soil sterilants. The desirable attribute of persistence of sterilants may become a problem when a soil sterilant spreads to an adjacent farm field, thus eliminating or inhibiting crop growth. Information is scarce on the persistence, mobility, and associated soil reclamation of sterilants.

Bromacil is a commonly used soil sterilant that has caused revegetation and reclamation problems both on and off aboveground facilities. As a result, NOVA Gas Transmission (NGTL) initiated a study in 1985 to investigate the dissipation of bromacil in Humic Luvic Gleysols in northwestern Alberta. This report presents the results of the three-year study.

2.0 LITERATURE REVIEW

2.1 Soil Sterilants

A herbicide is "an agent (as a chemical) used to destroy or inhibit plant growth; specifically a selective weed killer that is not injurious to crop plants" (Guralnik 1986). There are a wide variety of herbicides on the market today, each of which has unique properties associated with its active ingredient. Some herbicides are used mainly as pre-emergence treatments while others are applied directly to the vegetation as contact or post-emergence herbicides. The majority of herbicides may be used as both pre- and post-emergence treatments. Herbicides are also classified according to selectivity. Selective herbicides control specific types of vegetation at recommended registered rates of application. Non-selective herbicides are employed for total vegetation control on land not being used for crop production. Some herbicides are considered both selective and non-selective, depending on their rate of application.

Non-selective, residual herbicides are commonly referred to as soil sterilants. They are used when long-term, total vegetation control is desired. At aboveground facilities in Alberta, they are used to control vegetation to prevent fire at a facility. Extreme caution must be taken in sterilant selection and use because of long-term effects.

The residual effect, or length of persistence, of a sterilant in the soil varies greatly with influences by several processes. These processes may be placed into two groups. The first group is degradation processes, including biological, chemical and photochemical decomposition. The second group is transfer processes, including volatilization into the atmosphere, adsorption by soil particles, surface runoff into ponds or lakes, leaching through soil, adsorption and exudation by plants, and retention in the vegetation (Sharma 1977). The persistence of a soil sterilant is also dependent upon chemical structure, physical properties, adsorptive properties, temperature and moisture, composition, and microbial content of the soil (Smith 1982). The physico-chemical properties of the sterilant are also important to persistence.

Great attention must be paid to where and when soil sterilants are applied because of the long-term repercussions. Most sterilants are relatively insoluble and become bound to soil particles, preventing them from readily leaching. However, heavy rainfall or high winds may cause physical movement of herbicide-contaminated soil particles (Clark 1986). In addition, if the sterilant is applied before or during a heavy rainfall, or during high winds, the sterilant will be easily washed or blown away before becoming bound to soil particles.

In 1982, the Pesticides Management Branch of Alberta Environment instituted a method for monitoring the types of sterilants used on forested regions within the province. Notices of Intent to apply sterilants prepared by the Branch were distributed to applicators and oil and gas leaseholders. A form was to be completed and submitted for approval before sterilant application. Preliminary results showed atrazine (Primatol), followed by bromacil (Hyvar X, Calmix, Krovar), diuron (Karmex) and tebuthiuron (Spike) to be the four most commonly used active ingredients in sterilants. It was considered reasonable to assume that the same sterilants would be used in similar proportions for vegetation control in the agricultural areas of Alberta.

2.2 Bromacil

2.2.1 General Description

Bromacil is a residual herbicide which is selective or non-selective depending on the application rate. It can be used alone or in combination with other herbicides. It is used at rates of up to 27 kg active ingredient/ha on non-cropland areas for non-selective control of a wide range of annual and perennial grasses and broadleaf weeds and certain woody species. It is used at rates of 2 to 7 kg active ingredient/ha for selective control of annual and perennial weeds in orange, grapefruit and lemon orchards, and for seedling weeds in pineapple (Beste et al. 1983). Bromacil can be applied by spraying or spreading dry on the soil surface, preferably just before or during a period of active weed growth. The basic physical and chemical properties of bromacil are outlined in Table 1. Of special note are the high solubility and stability of bromacil in water. Most soil sterilants are less soluble and less stable.

Bromacil may persist at phytotoxic levels for up to six months when applied at normal rates of 2 to 5 kg/ha (Gardiner 1975). According to Hassall (1982), bromacil applied at a rate of 1.7 kg/ha can be expected to persist at toxic levels for six months to a year. Phytotoxic levels have been reported by Angemar et al. (1984), as being ≤ 0.1 mg bromacil/kg soil for mineral soils and 0.4 mg/kg for peat soils. Phytotoxicity values in ED_{50} (the dose that reduces test plants fresh weight by 50%) were found to be 0.4, 0.08, 0.06, and < 0.01 mg/kg soil for an organic, clay loam, loess and a sandy loam soil, respectively (Angemar et al. 1984).

2.2.2 Behaviour in Plants

Bromacil can be applied at either the pre- or post-emergent stage of plant growth. It is most readily absorbed through the plant root system with lesser amounts entering through the foliage and stems. Gardiner et al. (1969) found orange plants maintained for four weeks in a sand nutrient solution containing 10 ppm ^{14}C-2-bromacil took up less than 5% of the applied active ingredient. Approximately 85% of the activity was found in the roots and 17% in the stem and leaves of the plant. Schreiber et al. (1975) found bromacil uptake by wheat roots increase with increased soil water. Once in the roots, bromacil is transferred from roots to shoot leaf chloroplast (Shriver and Bingham 1973).

Table 1: Physical and Chemical Properties of Bromacil.

Common Name[1]:	Bromacil (ASA, WSSA, BSI, ISO)	
Chemical Name[1]:	5-bromo-3-<u>sec</u>-butyl-6-methyluracil	
Molecular Formula[1]:	$C_9H_{13}BrN_20_2$	
Molecular Weight[1]:	261.1	
Product Names[1]:	Calmix Pellets	
	Hybor-D	
	Hyvar-X Weed Killer	
	Hyvar-XL Weed Killer	
	Krovar I Weed Killer	
	Krovar II Weed Killer	
Physical Form[1]:	Odourless, white crystalline solid	
Melting Point[1]:	158 - 159°C	
Specific Gravity[1]:	1.55 25/25°C	
Solubility (25°C)[1]	<u>solvent</u>	<u>g bromacil/100 g</u>
	acetone	16.7
	absolute ethanol	13.4
	acetonitrile	7.1
	xylene	3.2
	sodium hydroxide (3% aqueous)	8.8
	water	0.0815 (815 ppm)
Stability[2]	Temperature stable up to melting point (gradually sublimes below melting point). Stable in water aqueous bases and common organic solvents. Decomposes slowly in strong acids Subject to microbial decomposition under moist conditions in soil.	

[1] Adapted from Beste et al. (1983).

[2] Adapted from E.I. duPont de Nemours + Company, Inc. (1979).

Bromacil is a powerful and selective inhibitor of photosynthesis (Hilton et al. 1964; Hoffman et al. 1964; Hoffman 1971). Bromacil inhibits photosynthesis in vascular plants, algae and blue-green bacteria by blocking a step in the electron transport chain of photosystem II (Scott 1987).

2.2.3 Behaviour in Soil

The movement of bromacil in soil seems to be closely related to soil water. Increased amounts of water may increase the degree of downward movement (Reed and Holt 1982). Weber (1972) showed that bromacil moved laterally over the soil surface in surface waters and that it leached vertically into the soil profile. Gerstl and Yaron (1983b) studied the movement of bromacil in soils of various textures after application from a point source. After several cycles of wetting and drying, bromacil was distributed in a pattern similar to that of the soil water characteristics of each soil type. Concentrations were lower around the emitter and higher in the wetted soil volume, even in a heavy clay soil. Morrow and McMarty (1976) applied bromacil to a number of warm and cool season grasses on a silty clay loam soil with 2.5% organic matter. Bromacil applied at 6.7 kg/ha moved down to the 8 to 15 cm zone after 16 months and 710 mm of precipitation. This was further than other herbicides examined (simazine, diuron, atrazine and terbacil). Koren (1972) applied bromacil annually for seven years to a sandy loam and silty clay loam soil at rates between 1.6 and 2.4 kg/ha. Of the annual dosage applied, 54% was still present with highest concentrations between 10 and 20 cm. Over a three-year period, bromacil leached to 90 cm when applied to irrigation ditches (Reed and Holt 1982). Zandvoort et al. (1980) found bromacil to leach to 100 cm after two years, and calculations showed it probably reached the water table. Hebb and Wheeler (1978) found bromacil in groundwater three months after application. It was highest (1.25 ppm) one month later.

Bromacil is much less subject than many other herbicides to adsorption on soil colloids. Rhodes et al. (1970) found 1.5 ppm bromacil adsorbed on a silt loam in equilibrium with 1 ppm in soil solution at room temperature, compared with 2.6 ppm for monuron and 4.0 ppm for diuron. Corwin and Farmer (1984) found a positive correlation between bromacil adsorption and organic carbon content in fresh water sediments. Bromacil falls into group three of the mobility classification suggested by Helling and Turner (1968). The lower adsorption of bromacil may reflect the high solubility (815 ppm in water at 25°C) and leaching characteristics discussed earlier.

In Alberta, Scott (1987) found more bromacil to be adsorbed in a Chernozemic soil than in a Luvisolic soil. The high adsorption in the Chernozem was caused by higher clay and organic matter contents. Haque and Coshow (1971) and Angemar et al. (1984) also found increasing adsorption in soils as the organic matter content increased.

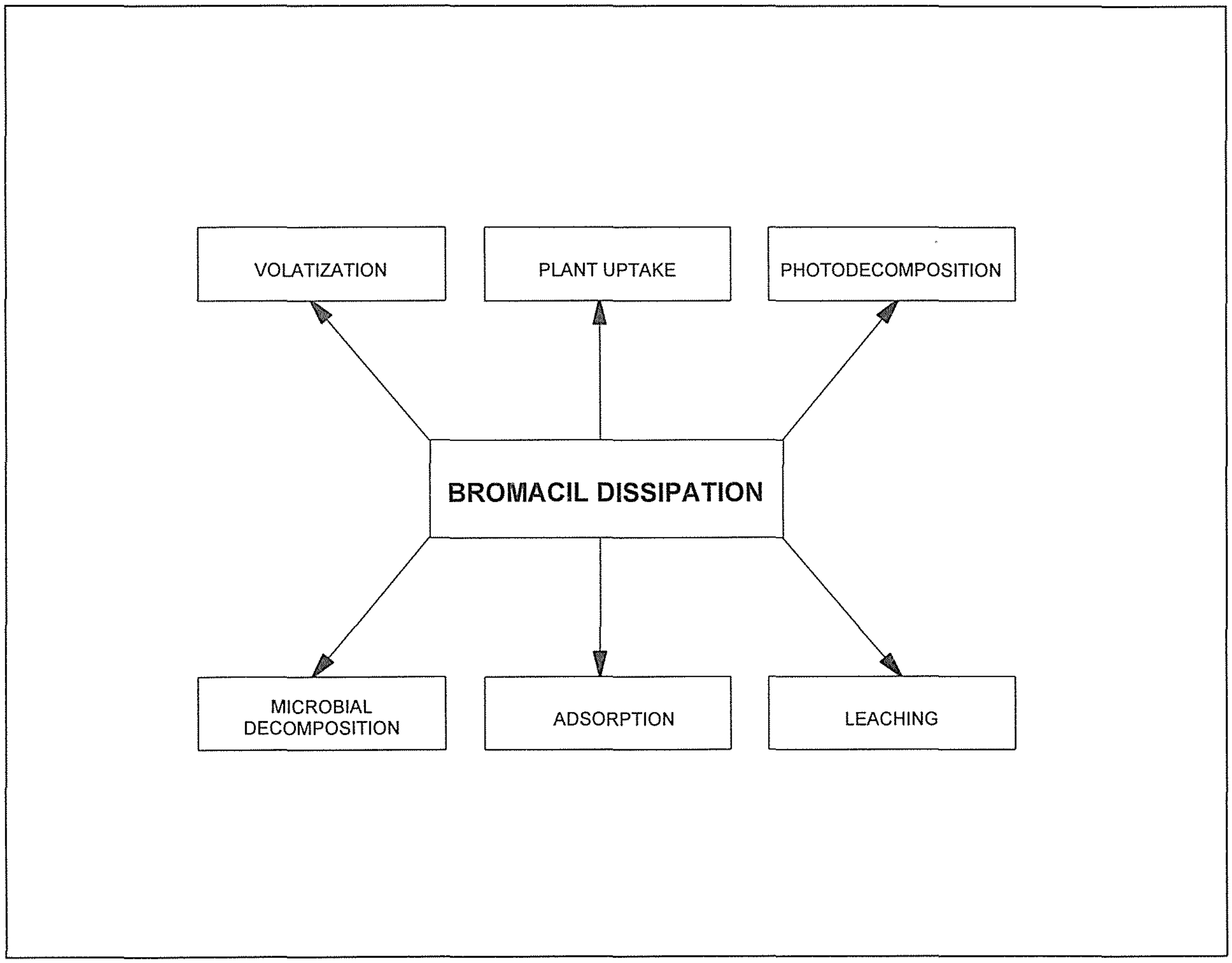
2.3 Dissipation Of Bromacil

There are several possible methods of bromacil dissipation: volatilization, photodecomposition, plant uptake, adsorption, microbial degradation and leaching (Fig. 1). Volatization and photodecomposition are thought to be of minor importance (Bingeman et al. 1962; Gardiner 1975). Plant uptake has not been discussed much in the literature, but is believed to be important. Adsorption, microbial degradation and leaching are the major methods of bromacil degradation reported in the literature.

2.3.1 Plant Uptake

Dissipation by plant uptake has not been given much attention in the literature; however, Leistra and Frissel (1975) and Appleby (1985) suggest that plants may significantly reduce herbicide persistence in soil. The use of specific trap plants resistant to specific sterilants is a possible reclamation method (Sharma 1977). When herbicides are taken up by resistant plants, they are metabolized or stored, usually as glucoside and peptide conjugates (Burns 1975). While usually killing the herbaceous plant, uptake of bromacil removes herbicide from the soil solution. Once it is in the plant, it will be degraded along with the decaying plant (Scott 1987). In some plants, low concentrations of bromacil have been found to be non-lethal and even to inhibit leaf senescence (Hiranpradit and Foy 1973). Other plants, both vascular and non-vascular (i.e., algae), have been found to be tolerant of or resistant to bromacil. Trees and shrubs are often more tolerant to bromacil than grasses and can therefore remove more bromacil from the soil (Scott 1987). Certain weeds have also developed a resistance to the effects of bromacil.

Figure 1. Methods of Bromacil Dissipation.



Scott (1987) reported that plants should be effective in a herbicide rehabilitation program for removing bromacil from the soil; providing the necessary environmental and nutritional factors for soil microbial growth; and removing bromacil from below cultivation depths. He also stated that both laboratory and field studies were needed to determine the effectiveness of plants in a bromacil reclamation plan.

2.3.2 Adsorption

A number of authors have focused on the adsorption of bromacil, a process related to the ease of bromacil movement through soil. The degree of mobility of a compound is negatively correlated with the adsorptive forces in the soil. Adsorption constants for bromacil in both mineral and organic soils are low, indicating that bromacil is only weakly adsorbed in comparison to many other herbicides (Rhodes et al. 1970)

Bromacil is more mobile in soil than many other herbicides (Smith et al. 1975; Weber and Whitacre 1982; Madhun et al. 1986). Its relative mobility decreases as organic natter content increases and pH decreases. Adsorption of bromacil in soil has been found to be positively correlated with soil organic matter levels (Haque and Coshow 1971; Furmidge and Osgerby 1967; Gerstl and Yaron 1983a; Angemar et al. 1984; Madhun et al. 1986). Organic matter adsorbs herbicide molecules, rendering them unavailable to vegetation (Sharma 1977).

The organic material most effective in adsorbing bromacil seems to be powdered activated charcoal (Scott 1987), which has been used in spot treatments of herbicide spills (Shea 1985). In general, 20 kg of activated charcoal/kg active ingredient should be added to the soil (Industrial Vegetation Management Association of Alberta 1984). Scott (1987) reported that powdered activated charcoal added to soil at rates as low as 0.1 g/kg soil could double the adsorptive capacity of a Chernomzemic soil. The addition of activated charcoal to a bromacil-contaminated soil immediately increased seedling productivity by lowering the amount of biologically available bromacil. Bromacil was adsorbed by the activated charcoal, thereby inhibiting the phytotoxic effect of the sterilant (Scott 1987).

Probably the most readily available and commonly used soil amendment with high adsorptive properties is organic matter in the form of decayed plant or animal matter, manure, or sewage sludge (Shea 1985). Application rates of herbicides are largely determined by soil organic matter content because of the affinity of these materials for organic compounds. Adsorption on organic matter is greatest for non-ionizable hydrophopic sterilants and least for ionizable, highly water soluble chemicals, but all herbicides have some affinity for organic matter (Shea 1985). The addition of organic matter will increase biological degradation if it encourages the growth of the microorganisms able to degrade the sterilant. Doyle et al. (1978) found dairy manure to be more effective than sewage sludge in catalyzing complete herbicide degradation to carbon dioxide. Animal manure is a relatively available, inexpensive organic amendment, which may be added to soils containing herbicide residues. Manure is considerably cheaper than activated charcoal.

Findings by Angemar et al. (1984) suggested that bromacil adsorption increased as the pH decreased. This correlates with results reported by Rhodes et al. (1970), which showed decreased bromacil mobility as the pH decreased. Decreased bromacil phytotoxicity has also been reported in acidic soils (Weber and Best 1972).

Results reported for pH and organic matter indicate that decreasing pH and increasing organic matter with soil amendments, would promote bromacil adsorption in contaminated soils. Adsorption is only slightly correlated with clay content (Haque and Coshow 1971; Gerstl and Yaron 1983a).

2.3.3 Microbial Degradation

Microbial degradation is a mode of disappearance of bromacil from soils (Reid 1963; Torgenson and Mee 1967; Pionke and Chesters 1973). The breakdown process is slow (Leistra and Frissel 1975) and not well understood. Postulated routes of degradation include attack on the halogen-substituted portion (Gardiner 1975). Few microorganisms are capable of utilizing bromacil as a substrate. Two such organisms are the fungus Penecillium paraherquei abe (Torgenson 1969), and bacteria belonging to the Pseudomonas genus (Beste et al. 1983).

Microbial co-metabolism (microbial oxidation of a substance without using the derived energy to support microbial growth) has been suggested as a mechanism of degradation, particularly under saturated conditions (Wolf and Martin 1974). The importance of this process for the degradation of organic compounds in nature has also been reported by Horvath (1972).

The rate of microbial decomposition of bromacil in soil varies with temperature, moisture, texture, initial bromacil concentration and the addition of amendments. These same conditions also effect the half-life (time required for half of the original concentration of a reactant to disappear). Values reported range between 14 and 1494 days under various field and laboratory conditions (Gardiner et al. 1969; Leistra and Frissel 1975; Gerstl and Yaron 1983a). Under average field conditions, the half-life has been reported to be between 85 and 758 days (Gerstl and Yaron 1983a).

The effect of temperature on the half-life of bromacil differs with soil texture. Gerstl and Yaron (1983a) found that half-lives in a heavy clay soil were similar at 5°C and 25°C. In a loamy soil, they were two and one-half times longer at 5°C than at 25°C. Results by the same authors indicated that half-lives tended to decrease with increasing moisture content and decreasing initial concentration. They were also shorter for a heavy clay soil than for a loamy soil, especially at lower initial concentrations, temperature and moisture content.

Decomposition of bromacil increased when soil moistures were greater than field capacity (Wolf and Martin 1974). These authors reported faster degradation of bromacil in a sandy loam soil under flooded conditions than under aerobic conditions. The decomposition products differed in both cases. Under saturated conditions, virtually all bromacil was degraded to a metabolite which resided in the soil. Under aerobic conditions, approximately a quarter of the bromacil added was recovered as carbon dioxide while the remaining activity in the soil was in the form of the parent compound.

The effect of organic amendments on the decomposition of bromacil differs with the soil moisture content. Wolf and Martin (1974) reported that decomposition of bromacil was accelerated by about 10% under aerobic conditions when 0.5% (dry weight basis) corn stalks or lima bean straw was added to a sandy loam soil. This beneficial effect was not observed when lima bean straw was added to the same soil under saturated conditions.

Bromacil decomposition by microorganisms is influenced by soil fertility. If the soil is low in fertility, the growth of microorganisms and the degradation of herbicides is slower (Alberta

Agriculture 1986). Herbicides are more strongly adsorbed, and therefore less active in soils having a low pH (Sharma 1977). Fertilizers may be used to enhance soil acidification (McGill 1982) and therefore adsorption.

2.3.4 Leaching

The movement of bromacil through soil is closely related to movement of soil water. The flow of water through soil preferentially follows cracks and channels between soil aggregates. This can lead to short travel times, especially in clay soils after dry periods. White et al. (1986) reported that greater amounts of bromacil were leached from initially dry, undisturbed cores of a structured clay soil than from prewet cores. Continuous leaching resulted in greater herbicide removal than discontinuous leaching, presumably because some herbicide diffused from the conducting channels into soil aggregates during the quiescent period where there was less susceptibility to subsequent leaching. Weber and Whitacre (1982) also observed that the leaching of bromacil through a clay soil under unsaturated conditions was more pronounced than expected. This was attributed to the fact that under unsaturated conditions, water conductivity is greater in fine-textured soils than in coarse-texture soils. Yaron and Gerstl (1983a, b) found bromacil to be only slightly adsorbed by the soil, and evenly distributed in the root zone under irrigated conditions.

Leaching has been recognized to be an important process of bromacil dissipation in sandy soil (Rhodes et al. 1970; Hebb and Wheeler 1978; Zandvoort et al. 1980; Angemar et al. 1984; Singh et al. 1985; Madhun et al. 1986). Peaks of bromacil leaching were found to follow periods of high rainfall (Hebb and Wheeler 1978). However, despite high leaching rates, phytotoxic residues were still present in the surface soil after two years.

3.0 OBJECTIVES

Research to date indicates that the dissipation of bromacil is governed by a number of site-specific processes which are still not fully understood. Many studies have been conducted under controlled laboratory conditions to investigate a single process of bromacil dissipation. However, in a field situation, all processes act and interact simultaneously. This study was initiated to monitor the in situ dissipation of bromacil in Humic Luvic Gleysols in northwestern Alberta.

The objectives of this study were to monitor:

- the dissipation of bromacil over time and with depth in the soil profile,
- and the effects of manure on bromacil and specific soil parameters over time and with depth in the soil profile.

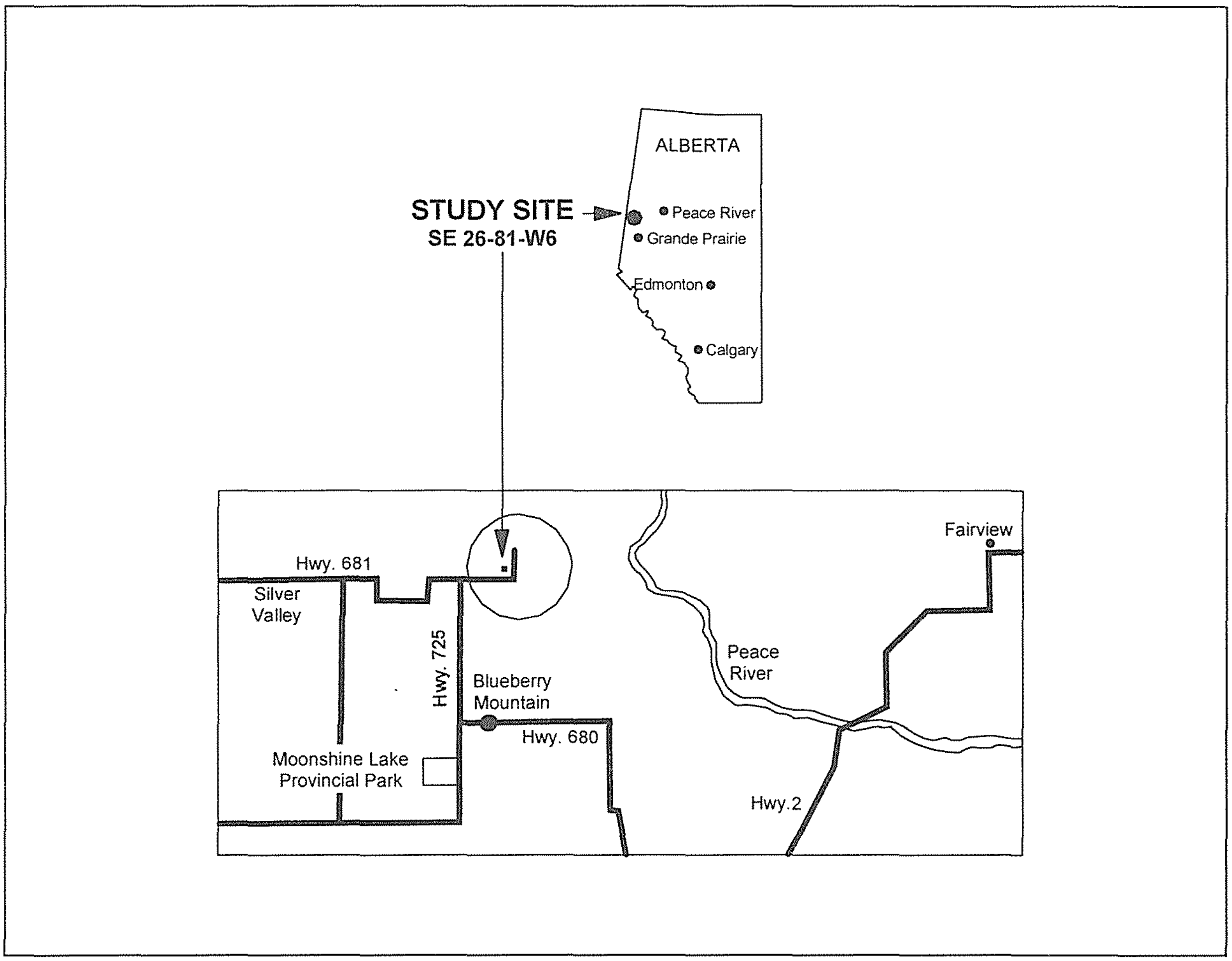
4.0 STUDY AREA

The research site is located in northwestern Alberta north of the Town of Blueberry Mountain (Fig. 2). The site is directly east of the Mulligan Creek Meter Station owned by NGTL. The legal location is the southeast quarter of section 26, township 81, range 8, west of the sixth meridian.

4.1 Climate

The climate of the area is characterized by relatively cold winters and moderately warm summers (Reeder and Odynsky 1965). The annual precipitation averages 450 mm, about 35% which falls during the summer months in short, intense rainfall events. The remaining 65% is distributed fairly evenly throughout the rest of the year. The mean frost-free period is 105 days (Reeder and Odynsky 1965).

Figure 2. Location of the Study Site.



4.2 Topography And Drainage

Elevation at the site and the surrounding area is approximately 640 m above mean sea level. The topography is nearly level, with a gentle eastward slope of less than 1% toward a slight depression containing two dugouts in the southeast corner of the quarter section.

The study site is situated in the north central part of a local drainage basin, which drains east-northeast toward the Peace River. The major creeks in this basin, from north to south, are: Fourth Creek, Mulligan Creek, Josephine Creek, Hamelin Creek and Blueberry Creek.

4.3 Vegetation

The area lies within the Boreal Forest Region. The native vegetation is a mixed forest in which aspen poplar is dominant. Other tree species are balsam poplar, white spruce, jack and lodgepole pine, white and grey birch, willow and alder (Reeder and Odynsky 1965). Shrubs include rose, gooseberry, raspberry, cranberry, chokecherry, saskatoon and hazelnut. Much of the native vegetation has been destroyed by repeated fires and land improvement practices. The study site is on a cultivated field with a grain and forage crop rotation. Grain farming is the dominant type of farming in the area (Reeder and Odynsky 1965).

4.4 Surficial And Bedrock Geology

The bedrock of the area is of Late Cretaceous age and is known as the Kaskapau formation. This formation is characterized by a dark gray silty marine shale with thin concretionary ironstone beds. It is interbedded with fine quartzose sandstone and thin beds of ferruginous oolithic mudstone (Alberta Geological Survey 1982).

Surficial deposits of glacio-lacustrine origin overlay this formation at the study site and constitute the parent material. These deposits contain varying amounts of clay, silt, and sand and are commonly varved at depth (Jones 1966).

4.5 Soils

The soils at the research site belong to the Josephine Soil Series and are classified as Humic Luvic Gleysols (Hu.LG). A typical profile consists of: a brown to grayish-brown Ap horizon approximately 16 cm deep; a Btg horizon approximately 26 cm deep; and a Cg horizon. These soils have the general properties specified for the Gleysolic Order (matrix colours of low chroma or distinct to prominent mottles of high chroma within 50 cm of the mineral surface) and the Luvic Gleysol great group (Btg horizon), but also have a mineral-organic surface horizon that meets the requirements of the Ap of Humic Gleysols. They are characterized by an acidic solum with saturated paste pH values of 5.0 to 5.5 in the Ap and 4.0 to 5.0 in the Btg and Cg horizons. Yellowish-brown mottles below the Ap horizon are indicative of imperfect to poor drainage. A clay texture is uniform throughout the profile. These soils have been rated as poor to fair in terms of a soil rating for agriculture (Reeder and Odynsky 1965).

5.0 METHODS

5.1 Preliminary Observations

On August 24, 1983, bromacil in the form of Hyvar XL was sprayed at an unknown rate on the Mulligan Creek Meter Station owned by NGTL. The following year crops failed to grow on portion of the adjacent farm field. The affected area was a strip parallel to Highway 681 extending approximately 500 m east from the meter station (Fig. 3). A preliminary investigation in July of 1984 indicated that soil from the affected area was contaminated with bromacil.

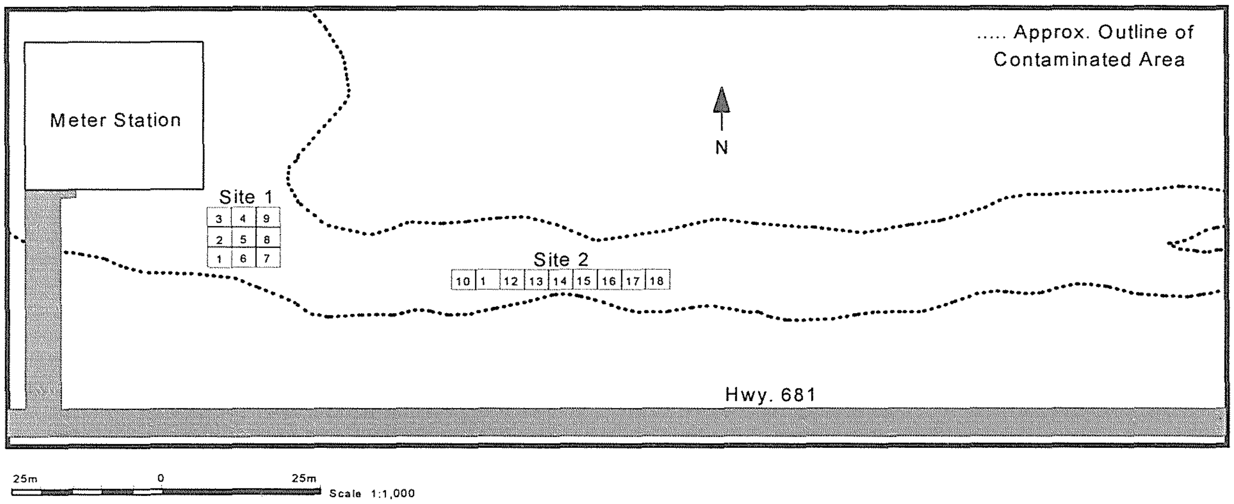
5.2 Experimental Design

In April of 1985, two sites were selected within the bromacil-contaminated area east of the meter station (Fig. 3). Each site was designed differently to fit within the contaminated area. Site 1 was 12 m long and 12 m wide, and Site 2 was 4 m wide and 36 m long. Each site was divided into 9, four-by-four-metre sampling plots or replicates. Site 1 consisted of blocks 1 to 9, and Site 2 of blocks 10 to 18.

5.3 Soil Amendments

In May of 1985, approximately 20 cm of well-decomposed cow manure was disced into Site 1 and Site 2. Anhydrous ammonia at a rate of 56 kg/ha and 112 kg/ha of the fertilizer 11-51-0 were also added to both sites. The cropping pattern consisted of a wheat-alfalfa rotation. In 1984, the contaminated area was in alfalfa, which was cut for hay in June and worked into the soil in the fall as a green manure. In 1985, the site was seeded to alfalfa with a cover crop of wheat, which was harvested in August. In 1986 the alfalfa was cut for hay in June and worked into the soil in the fall. The site was once again seeded to alfalfa with a cover crop of wheat in 1987. Each year the sites were fertilized with anhydrous ammonia at a rate of 70 kg/ha and 11-51-0 granular at 30 kg/ha.

Figure 3. Experimental Design of the Bromacil Plots.



5.4 Soil Sampling

In November 1984, 18 locations were sampled for background soils information: nine from an area surrounding and including Site one, and nine from an area surrounding Site two. Soil samples were collected in August 1985, 1986 and 1987 from each of the 18 sampling plots: nine from Site one and nine from Site two. At each sampling location, a pit was excavated. Soil samples were taken from the vertical face in 4 cm increments from the soil surface to a depth of 40 cm. Each sample was placed in a plastic bag and stored frozen until analyzed.

5.5 Laboratory Analyses

Inorganic analyses were performed by Norwest Labs in Edmonton, Alberta using techniques listed in McKeague (1978) as follows: pH (Sect. 3.14); electrical conductivity (Sect. 3.21); particle size analysis (Sect. 2.12); and total carbon (Sect. 3.611).

Total bromacil determinations were performed by Enviro-Test Laboratories in Edmonton, Alberta, using a shake/sonicate method developed for this project. This method involved putting 25 g of an air-dried and sieved soil sample into a culture tube. Ethyl acetate (50 mL) was added and the tube sealed with a teflon-lined screw cap. Sixteen tubes at a time were mounted on a wrist-action shaker and agitated on high for 30 minutes. Following this, the tubes were placed in an ultra-sonic bath for 10 minutes. The samples were then allowed to settle and the supernatant liquid removed. Filtration through glass wool was used to remove fine particles. The ethyl acetate extract was then analyzed using a Varian 3400 gas chromatograph with an electron capture detection (GC/ECD). Calibrated standards of bromacil at three levels were also analyzed for quantification purposes. The method detection limit was 0.01 ppm. High bromacil concentrations or complex samples were confirmed by a GC/mass selective detector, which scans for only those ions associated with the target compound, and is therefore very selective. Results for both soil inorganic and organic analyses are listed in Appendix A1.

5.6 Statistical Procedures

Site 1 and 2 were treated as two separate experiments as preliminary statistical evaluations showed the background soil samples from each site to be significantly different in terms of pH, electrical conductivity (EC), and organic carbon (OC) (Appendix A2 and A3).

Significant differences between means at each site were determined using confidence intervals according to the procedure outlined in Snedecor and Cochrane (1980) at the 95% confidence level ($p \leq 0.05$). This procedure was used to determine significant differences between each study year (1984, 1985, 1986, 1987) at each depth (4 cm increments from 0 to 40 cm) for each parameter monitored (bromacil, pH, EC, OC). The same procedure was also used to compare the background data from both sites. Results of the statistical procedures are listed in Appendix A4 through A11.

6.0 RESULTS

6.1 Site 1

6.1.1 Bromacil

Between 1985 and 1987, bromacil concentrations were highest within the surface 12 cm of the soil profile, and then decreased with increasing depth (Fig. 4). Within the surface 12 cm, bromacil concentrations significantly decreased between 1985 and 1987. Concentrations of bromacil in ppm for each year were: 0.62 and 0.31 (0 to 4 cm); 0.69 and 0.32 (4 to 8 cm); and 0.54 and 0.32 (8 to 12 cm) respectively. Below 12 cm, there were significant decreases from 1985 to 1986 and significant increases from 1986 to 1987. The decreases occurred at the 20 to 24 (0.19 and 0.06 ppm), 24 to 28 (0.12 and 0.04 ppm), 28 to 32 (0.11 and 0.02 ppm) and 36 to 40 cm (0.10 and 0.00 ppm) depths. Significant increases occurred between the 32 to 36 (0.01 and 0.04 ppm) and 36 to 40 cm (0.00 and 0.04 ppm) depths. The decreases and subsequent increases below 12 cm resulted in no significant differences in bromacil concentrations between 1985 and 1987.

6.1.2 Organic Carbon

Following the manure addition in 1985, OC contents significantly increased between the 4 to 12 cm depth (Fig. 5). Percentages increased from 2.5 to 4.8 (4 to 8 cm), and 2.5 to 3.5 (8 to 12 cm). Figure 5 illustrates decreases in OC in 1986 followed by increases in 1987. These changes were significant at the 12 to 16 cm depth in 1986 (2.5 to 1.8%) and the 8 to 12 cm (2.7 to 4.2%) and 12 to 16 cm (1.8 to 3.2%) depths in 1987. When the 1985 and 1987 percentages of OC were compared, the only significant difference was an increase at the 12 to 16 cm depth. Percentages increased from 2.5 to 3.2. Even though not significantly different, the remaining depths monitored tended to have higher percentages of OC in 1987 when compared to 1985.

When OC contents in 1987 were compared to background percentages in 1984, significant increases occurred between 4 and 16 cm. Percentages for each year, respectively, were 2.5 and 4.3 (4 to 8 cm), 2.5 and 4.2 (8 to 12 cm) and 2.3 and 3.2 (12 to 16 cm). Significant increases reported between 8 to 16 cm were larger than those between 1984 and 1985.

Figure 4. Concentration of Bromacil with Depth at Site 1 in 1985, 1986 and 1987.

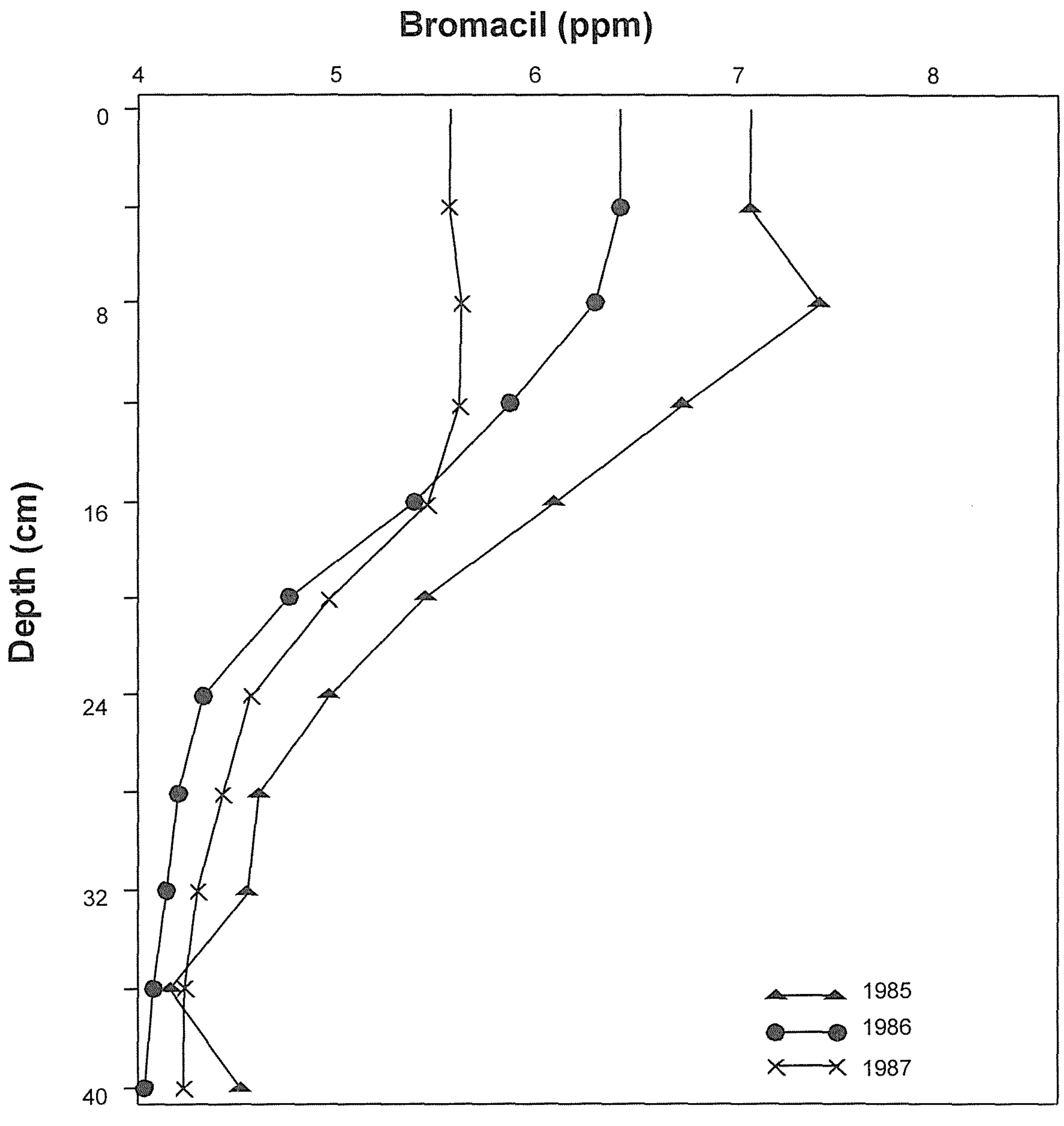
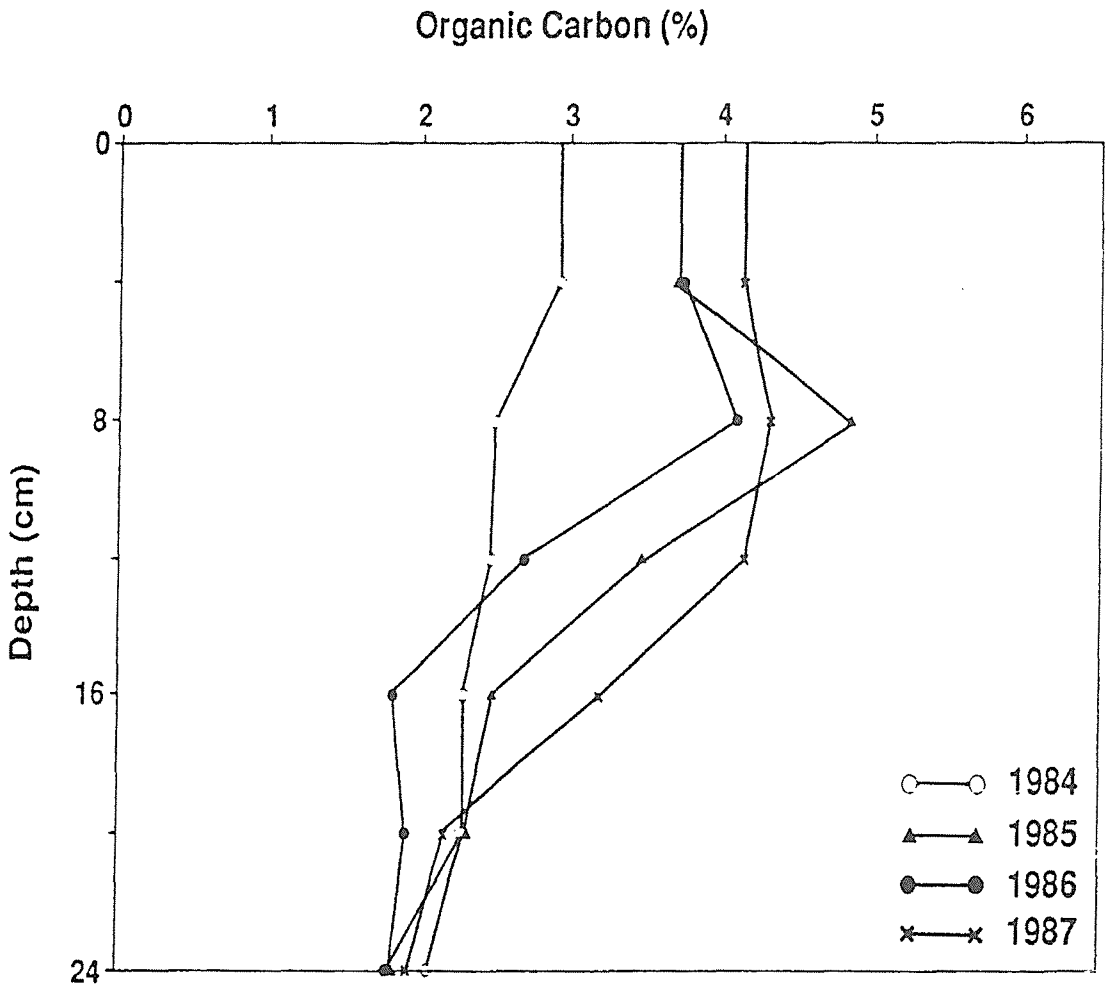


Figure 5. Percent organic carbon with depth at Site 1 before (1984) and after (1985 to 1987) manure application.



6.1.3 pH

pH was significantly increased after the manure application in 1985 within the surface 16 cm of the soil profile (Fig. 6). Values for each 4 cm depth for 1984 and 1985 were: 5.0 and 6.5; 5.1 and 6.6; 5.0 and 6.2; and 4.9 and 5.2, respectively. Changes in pH between 1985 and 1987 closely resembled those for OC: decreases in 1986 were followed by increases in 1987. In 1986, the pH decreased from 4.6 to 4.3 at the 36 to 40 cm depth. In 1987, the pH increased from 5.0 to 5.8 at the 12 to 16 cm depth. When comparing 1985 and 1987, the only significant difference was an increase at the 12 to 16 cm depth of 5.2 to 5.8.

Similar results were seen for pH as OC when comparing the background 1984 data to the 1987 data. Values for pH were significantly higher within the surface 16 cm of the soil profile. In 4 cm increments for 1984 and 1987 from 0 to 16 cm, pH values were: 5.0 and 6.1; 5.1 and 6.3; 5.0 and 6.4; and 4.9 and 5.8 respectively. For the 8 to 16 cm depths, significant differences were larger than those in 1984 and 1985.

6.1.4 Electrical Conductivity

The application of manure in 1985 significantly increased values for EC within the surface 12 cm, and significantly decreased values below 20 cm (Fig. 7). Between 1985 and 1986, EC decreased significantly within the surface 4 to 8 cm (4.2 to 2.7 mS/cm) and increased significantly within the 28 to 36 cm depths (0.5 to 0.7 mS/cm). There were no significant differences between 1986 and 1987. When the 1985 and 1987 data were compared, there was a significant decrease at the 4 to 8 cm depth, and significant increases from 24 to 40 cm. Values for EC in mS/cm for 1985 and 1987 were: 4.2 and 2.1 (4 to 8 cm); 0.6 and 1.0 (24 to 28 cm); 0.5 and 0.9 (28 to 32 cm); 0.5 and 0.8 (32 to 36 cm); and 0.5 and 0.8 (36 to 40 cm), respectively. Comparing the background 1984 and 1987 data, the EC was significantly increased at the 0 to 4 cm depth and significantly decreased between 24 and 40 cm. Values for EC in mS/cm for 1984 and 1987 were: 1.1 and 3.0 (0 to 4 cm); 1.5 and 1.0 (24 to 28 cm); 1.7 and 0.9 (28 to 32 cm); 1.8 and 0.8 (32 to 36 cm); and 1.9 and 0.8 (36 to 40 cm) respectively.

Figure 6. pH with Depth at Site 1 Before (1984) and After (1985 to 1987) Manure Applications.

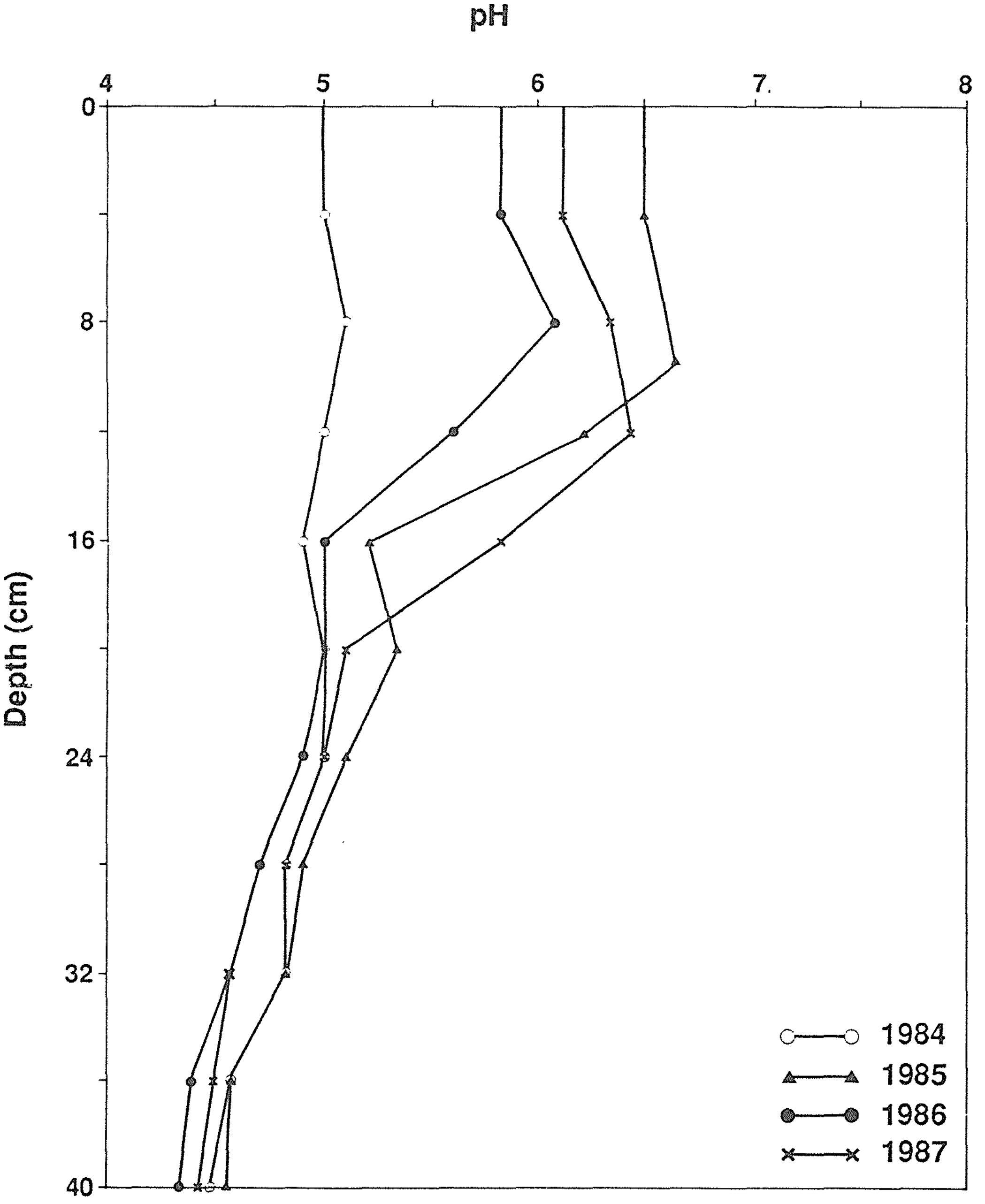
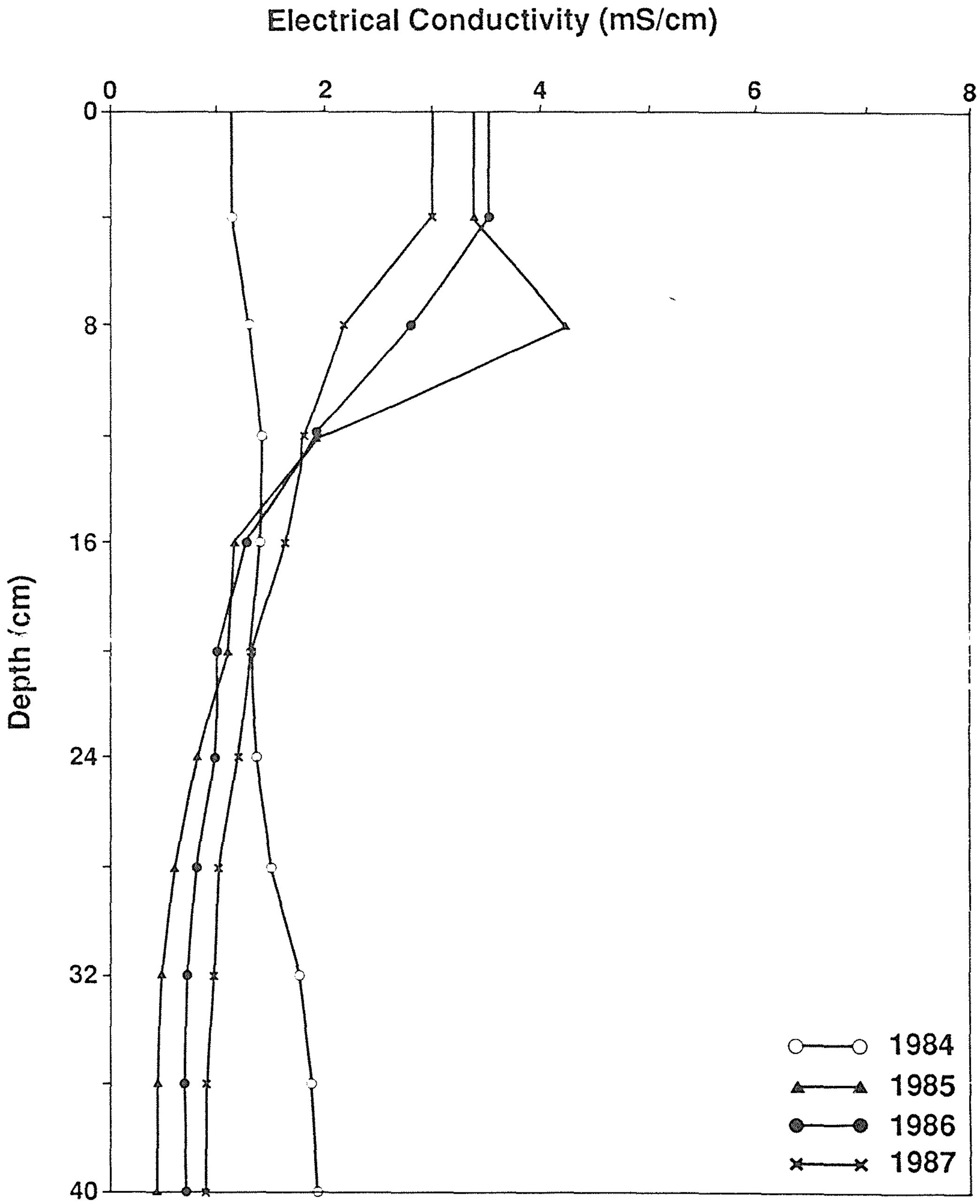


Figure 7. Electrical conductivity with depth at Site 1 before (1984) and after (1985 to 1987) manure application.



6.2 Site 2

6.2.1 Bromacil

Between 1985 and 1986, bromacil concentrations significantly decreased at all depths monitored (Fig. 8). In 4 cm increments from 0 to 40 cm for both 1985 and 1986, concentrations of bromacil in ppm were: 0.59 and 0.26; 0.55 and 0.27; 0.67 and 0.43; 0.75 and 0.37; 0.49 and 0.25; 0.41 and 0.13; 0.36 and 0.08; 0.20 and 0.06; 0.10 and 0.03; and 0.05 and 0.01. Bromacil concentrations also decreased in 1987, but the decreases occurred within the surface 16 cm only. Bromacil concentrations in ppm for 1986 and 1987 were: 0.26 and 0.14 (0 to 4 cm); 0.27 and 0.14 (4 to 8 cm); 0.43 and 0.19 (8 to 12 cm); and 0.37 and 0.19 (12 to 16 cm), respectively. Bromacil concentrations also decreased below 16 cm, but the decreases were not significant.

Over the three-year monitoring period, bromacil concentrations significantly decreased at all depths. Values in ppm at each sampling depth from 0 to 40 cm for 1985 and 1987 were: 0.59 and 0.14; 0.55 and 0.14; 0.67 and 0.19; 0.75 and 0.19; 0.49 and 0.17; 0.41 and 0.11; 0.36 and 0.05; 0.20 and 0.03; 0.10 and 0.02; and 0.05 and 0.01, respectively.

6.2.2 Organic Carbon

The addition of manure in 1985 significantly increased OC in the surface 12 cm. Percentages increased from 3.0 to 6.4 (0 to 4 cm); 3.0 to 6.4 (4 to 8 cm); and 3.1 to 4.8 (8 to 12 cm) between 1984 and 1985 (Fig. 9). During the same time period, OC also increased from 1.8 to 2.7% at the 20 to 24 cm depth.

Percentages of OC decreased in 1986 and increased in 1987. Significant decreases occurred at the 4 to 8 cm (6.4 to 4.7%) and 8 to 12 cm (4.8 to 2.8%) depths between 1985 and 1986. Significant increases occurred at the 4 to 8 cm (4.7 to 6.2%), 8 to 12 cm (2.8 to 6.1%), 12 to 16 cm (2.6 to 4.3%), and 16 to 20 cm (2.6 to 3.2%) depths between 1986 and 1987. These decreases and subsequent increases resulted in only one significant increase occurring when the 1985 data was compared to data from 1987. OC increased from 3.1 to 4.3% at the 12 to 16 cm depth.

Figure 8. Concentration of Bromacil with Depth at Site 2 in 1985, 1986 and 1987.

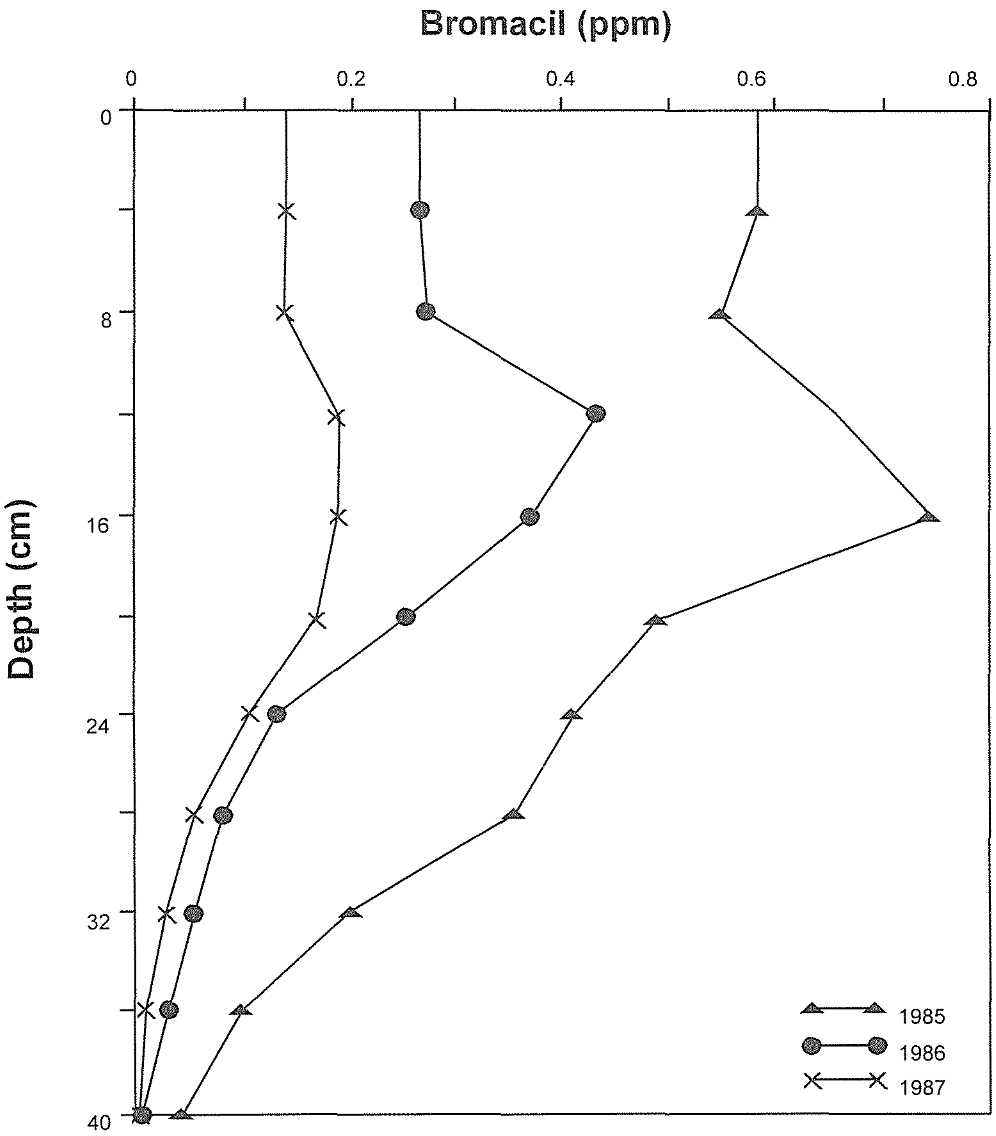
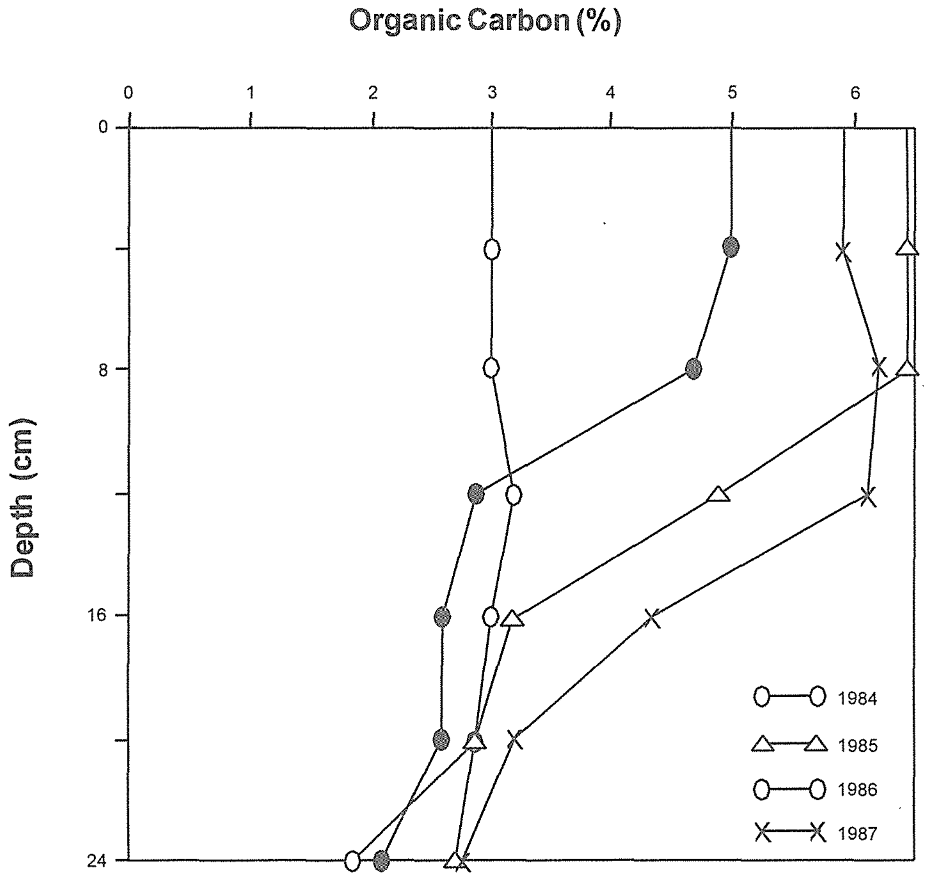


Figure 9. Percent Organic Carbon with depth at Site 2 before (1984) and after (1985 to 1987) manure application.



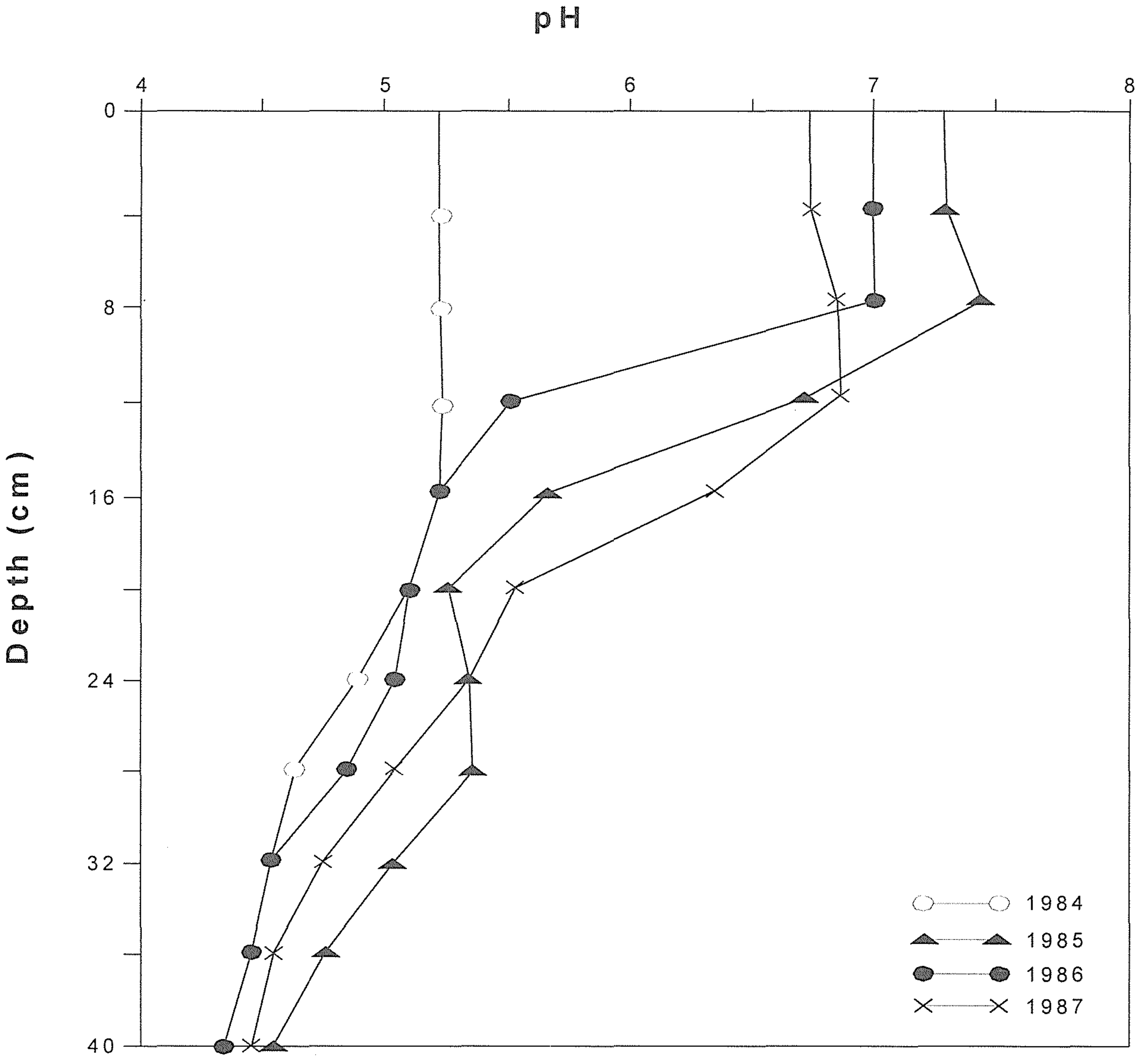
A comparison of the pre-manure background 1984 data to the 1987 data resulted in significant increases from the soil surface down to 24 cm except for the 16 to 20 cm depth increases in OC in 4 cm increments from 0 to 16 cm and 20 to 24 cm between 1984 and 1987 were: 3.0 to 5.9; 3.0 and 6.2; 3.1 and 6.1; 3.0 and 4.3; and 1.8 and 2.7. Similarly to Site 1, significant differences were larger at the 8 to 16 cm depth than in 1985.

6.2.3 pH

Following the manure addition in 1984, pH was significantly increased at all but the 16 to 20 and 32 to 36 cm depths of the soil profile in 1985 (Fig. 10). Increases at each 4 cm depth from 0 to 16, 20 to 32 and 36 to 40 cm for 1984 and 1985 were: 5.2 to 7.3; 5.2 to 7.4; 5.2 to 6.7; 5.2 to 5.6; 4.8 to 5.3; 4.6 to 5.3; 4.5 to 5.0; and 4.3 to 4.5. Values for pH significantly decreased at all depths except the 0 to 4 and 16 to 20 cm in 1986. Significant decreases were 7.4 to 7.0; 6.7 to 5.5; 5.6 to 5.2; 5.3 to 5.0; 5.3 to 4.8; 5.0 to 4.5; 4.7 to 4.4; and 4.5 to 4.3. In 1987, the reverse occurred with pH significantly increasing between 8 and 20 cm. Values at each depth increased from: 5.5 to 6.8; 5.2 to 6.3; and 5.1 to 5.5 between 1986 and 1987, respectively.

Comparisons of pH between 1985 and 1987 showed both increases and decreases. pH significantly increased between 12 and 20 cm and significantly decreased between 4 to 8 cm and 28 to 36 cm. When comparing background pre-manure data in 1984 and 1987, the pH was significantly increased from 0 to 28 cm. Values at each depth from 0 to 28 cm for 1984 and 1987, respectively, were: 5.2 and 6.7; 5.2 and 6.8; 5.2 and 6.8; 5.2 and 6.3; 5.1 and 5.5; 4.8 and 5.3; and 4.6 and 5.0. Compared to 1985, significant differences were increased between 12 to 16 cm, and decreased below 16 cm.

Figure 10. pH with depth at Site 2 before (1984) and after (1985 to 1987) manure application.



6.2.4 Electrical Conductivity

In 1985, values for EC were significantly increased in the surface 16 cm and decreased in the 20 to 40 cm depth following the manure addition (Fig. 11). No changes occurred at the 16 to 20 cm depth. Concentrations in mS/cm from 1984 and 1985 for all but the 16 to 20 cm depth from 0 to 40 cm were: 1.2 to 7.2; 1.3 to 6.4; 1.2 to 4.2; 1.5 to 2.8; 2.0 to 1.0; 2.3 to 0.7; 2.5 to 0.5; 2.5 to 0.5; and 2.6 to 0.5. In 1986, the reverse occurred with decreases from 0 to 16 cm and increases from 20 to 40 cm. Concentrations in mS/cm for 1985 and 1986 for all but the 16 to 20 cm depth from 0 to 40 cm were: 7.2 to 3.4; 6.4 to 3.5; 4.2 to 2.4; 2.8 to 1.9; 1.0 to 1.4; 0.7 to 1.3; 0.5 to 1.2; 0.5 to 1.1; and 0.5 to 1.0. In 1987, there were few changes with significant decreases from 0 to 8 cm (3.4 to 1.7 and 3.5 to 2.0 mS/cm, respectively) and significant increases from 28 to 40 cm (1.2 to 1.7; 1.1 to 1.5; and 1.0 to 1.4 mS/cm), respectively.

A comparison of the post-manure monitoring years from 1985 to 1987 resulted in significant decreases from 0 to 16 cm, no change between 16 to 20 cm, and significant increases from 20 to 40 cm. Values for EC in mS/cm for all depths except 16 to 20 cm for 1984 and 1987 were: 7.2 and 1.7; 6.4 and 2.0; 4.2 and 2.0; 2.8 and 1.8; 1.0 and 1.6; 0.7 and 1.7; 0.5 and 1.7; 0.5 and 1.5; and 0.5 and 1.4. When pre-manure (1984) and post-manure (1987) data were compared, there was a significant increase from 4 to 12 cm and decrease from 24 to 40 cm. Concentrations in ppm for each depth from 4 to 40 cm for 1984 and 1987 were: 1.3 and 2.0; 1.2 and 2.0; 2.3 and 1.7; 2.5 and 1.7; 2.5 and 1.5; and 2.6 and 1.4. Compared to 1985 post-manure measurements, significant differences have decreased, both at the soil surface and lower in the profile.

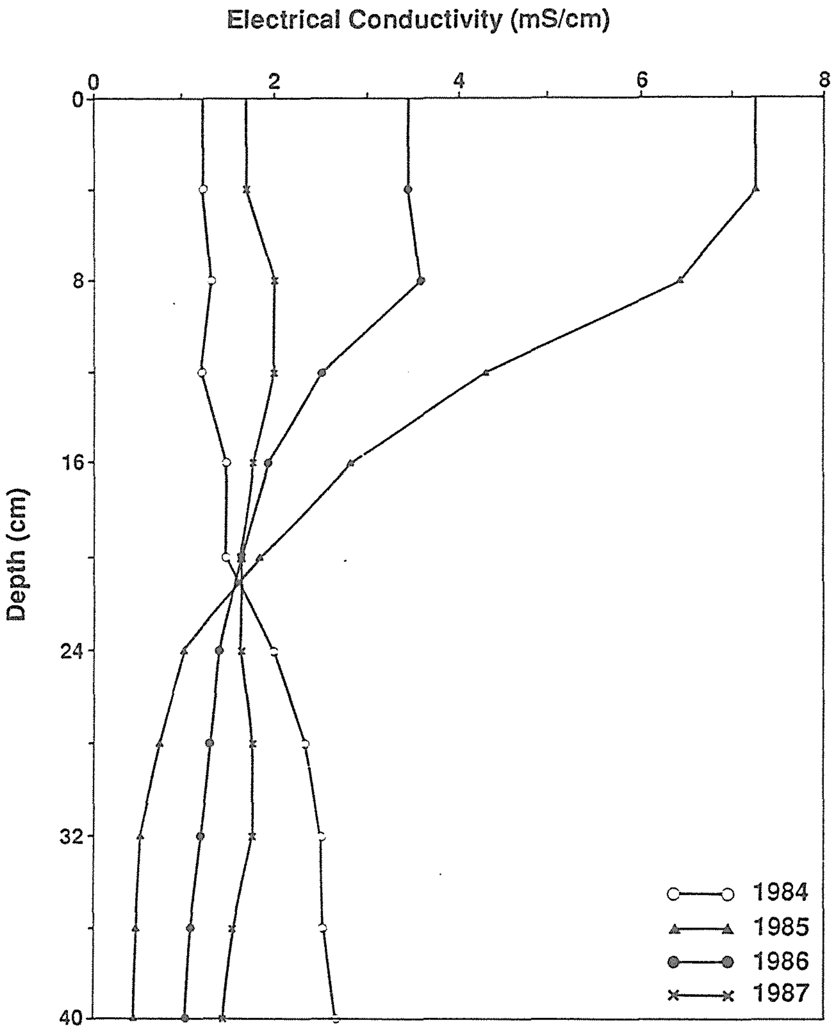
7.0 DISCUSSION

7.1 Organic Carbon

Percentages of OC at both Site 1 and 2 were influenced by the addition of cow manure. In 1985, approximately 20 cm of well-decomposed manure was disced into the soil. At both sites, OC was significantly increased within the surface 12 cm, reflecting the maximum depth of incorporation. Increases in OC through manure additions have been reported by others (Hoyt and Rice 1972; Mathers and Stewart 1980; Tunney 1980; Alberta Agriculture 1980).

The increases in OC relative to pre-manure percentages were greater at Site 2 than Site 1, suggesting uneven manure application. OC percentages were not affected by crop growth as all of the sampling plots were bare.

Figure 11. Electrical Conductivity with depth at Site 2 before (1984) and after (1985 to 1987) manure application



In 1986, OC percentages decreased between 4 to 16 cm at both sites. This decrease reflects the decomposition of the cow manure as the rate at which carbon is lost from the soil increases very rapidly as the organic content is raised (Brady 1974). It has been estimated that approximately fifty percent of the organic matter in livestock waste will be mineralized in the first year after application (Sluijsmans and Kolenbrander 1976). Once again, there was no crop growth on the sampling plots, resulting in no additions of OC to the soil system through vegetation.

In 1987, there was sporadic alfalfa, wheat and weed (Equisetum arvense L.) growth throughout both sites. Plant roots are an important source of OC (Brady 1974), and the increased percentages at depth at both sites reflect additions through rooting. OC increases occurred between 12 to 16 cm at Site 1, and 4 to 20 cm at Site 2.

Through both the addition of cow manure and roots, OC contents did increase at both sites over the three-year study. Increases were restricted to the surface 16 cm at Site 1 and 24 cm at Site 2, and both sites had the largest increase between 8 to 16 cm. This increase reflects the predominant depth of cultivation and rooting at both sites. Roots did not penetrate the soil as deeply at Site 1 as at Site 2. This may have been caused by the presence of an intermittent high water table at 24 cm in Site 1. Through capillary movement, the soils would have been saturated above 24 cm which would restrict rooting depths.

7.2 pH

Changes in pH over the length of the study period were similar to those observed for OC: increases followed organic matter additions through manure and plant roots, and decreases followed decomposition. The increase in pH after the manure addition in 1985 resulted from the manure itself which had a pH of 9.1. Increases occurred within the surface 16 cm at Site 1, reflecting the high water table and restricted leaching at Site 1. Values were increased throughout (0 to 16 cm) and below (16 to 40 cm) the zone of cultivation caused by leaching at Site 2. Significant increases were larger at Site 2 reflecting larger manure additions and effects caused by leaching.

Decreased pH values in 1986 resulted from microbial decomposition of the added OC. Upon decomposition, carbon dioxide (CO_2) is released. The effect of CO_2 is to decrease soil pH (Black 1965) through dissolution in water and the formation of carbonic acid (Bohn et al. 1979). Decreases may also have occurred through leaching of hydroxyl ions and subsequent release of hydronium ions from exchange sites on the organic matter. Increased pH values in 1987 are thought to have resulted from the re-establishment of the soil equilibrium following large hydronium ion additions through decomposition in 1986. There was also an increase in OC caused by the presence of roots, which may have affected the pH.

Through the addition of manure, pH values did increase at both sites over the three-year study. Increases were restricted to the surface 16 cm at Site 1 and surface 24 cm at Site 1. Both sites had the largest increase between 8 and 16 cm. These trends are similar to those reported for OC, reflecting a relationship between OC and pH.

7.3 Electrical Conductivity

Manure additions in 1985 increased values for EC at both sites. Applying manure at high rates has been shown to contribute to saline soil conditions through the addition of soluble salts (Mathers and Stewart 1974; Shortall and Liebhardt 1975; Wallingford et al. 1974, 1975). EC increased within the surface 16 cm at Site 1 and at all depths but two at Site 2.

Trends for soluble salt concentrations were also similar at both sites in 1986: concentrations decreased within the surface and increased at depth. Decreases were within the surface 8 cm at Site 1 and the surface 16 cm at Site 2. Increases were below 28 cm at Site 1 and 20 cm at Site 2. Therefore, at both sites, salts were leached from the soil surface to below 20 cm in 1986. This confirms the intermittent high water table at Site 1, as salts were below 24 cm. Livestock wastes contain organic matter, which may improve physical properties such as the structure and water-holding capacity of soils (Wallingford et al. 1975; Hoyt and Rice 1972; Tunney 1980). The application of feedlot manure has also been found to increase the hydraulic conductivity of soil (Mathers and Stewart 1980) therefore promoting leaching.

Both sites exhibited the same trends when comparing pre-manure (1984) and post-manure (1987) data. Salt concentrations increased within the soil surface and decreased at depth. They increased within the surface 4 cm at Site 1 and 12 cm at Site 2. Decreases were between 24 and 40 cm at both sites. These trends are thought to be caused by salt-enriched manure additions to the surface 12 cm of the soil and losses through leaching at depth. The trends at Site 1 suggest that even though a high or perched water table was present, leaching conditions to 40 cm depth were also present. Leaching is thought to have predominated over upward migration through capillary movement by the lack of increased salt concentrations between 4 and 24 cm.

7.4 Bromacil

Since the laboratory technique used in this project analyzed for total bromacil, the amount of bromacil adsorbed by organic matter was not determined. Only those dissipation methods resulting in complete removal of bromacil from the soil system will be discussed. Plant uptake, photo-decomposition and volatilization are assumed to be negligible in terms of the dissipation of bromacil at Site 1 and 2.

Between 1985 and 1987, bromacil concentrations decreased within the surface 12 cm at Site 1. Below 12 cm, concentrations decreased in 1986 and increased in 1987. These trends for bromacil coincide with those exhibited by the other parameters monitored.

The addition of solid manure adds organic matter to the soil which maintains better tilth, improves water intake, increases the release of CO_2, and increases the organic matter content of soil (Tisdale and Nelson 1975). As organic matter is added to soil, the number of soil microorganisms suddenly increases many-fold (Brady 1974). Therefore, manure additions to soil add nutrients and increase microbial activity required for microbial degradation of bromacil. It is well know that the major method of bromacil degradation in the soil is by microorganisms (Pancholy and Lynd 1969; Nemec and Tucker 1983; Scott 1987). The addition of manure to the surface 12 cm of the soil at Site 1 correlates well with the decrease in bromacil within the same depth over time.

The decrease and subsequent increase in bromacil below 12 cm can be attributed to leaching. Leaching of bromacil has been reported by many authors (Hebb and Wheeler 1978; Zandvoort et al. 1980; Reed and Holt 1982; Shipman 1983; Yaren and Gerstl 1983; and Angemar et al. 1984). In 1986, Site 1 had a leaching environment to depths below 40 cm as was illustrated by the EC data. As a result, bromacil leached from the surface 40 cm of the soil profile. In 1987, increases in OC and pH were restricted to the surface 16 cm and there were no changes in EC. These factors indicate that the water table was high, restricting leaching. Bromacil increases below 12 cm are thought to be from accumulation of that leached from the surface 12 cm. Restricted leaching kept it from moving out of the surface 40 cm.

At Site 2 between 1985 and 1987, bromacil concentrations decreased at all depths monitored. Microbial degradation and leaching were the two methods responsible: microbial degradation within the surface 24 cm where OC percentages were increased by the manure, and leaching below 24 cm. Field notes taken during plot sampling noted Site 2 as being dry with many vertical cracks. This soil condition would promote leaching as well as the aeration required for degradation. In 1987, bromacil decreases occurred throughout the entire soil profile, but were only significant within the surface 16 cm reflecting decreases caused by microbial degradation.

8.0 CONCLUSIONS

- The addition of cow manure increased organic carbon percentages within the surface 16 cm at Site 1 and the surface 24 cm at Site 2.
- OC promoted the microbial degradation of bromacil at Sites 1 and 2. Degradation occurred within the same depths as the increased organic carbon percentages.
- The addition of cow manure increased the pH within the surface 16 cm at Site 1 and surface 24 cm at Site 2 through the manure itself and microbial degradation products.
- The largest increases in pH and OC occurred between 8 and 16 cm. This interval reflects the predominant depth of rooting and cultivation.
- The addition of cow manure increased electrical conductivity values within the surface 4 cm at Site 1, and within the surface 12 cm at Site 2. Decreases occurred between 24 and 40 cm at both sites and resulted from leaching.

- Bromacil concentrations decreased within the surface 12 cm at Site 1 and throughout the entire soil profile at Site 2. Site 1 had restricted dissipation to 12 cm caused by the presence of a high water table which reduced leaching.

- The two methods of bromacil dissipation in Humic Luvic Gleysols in northwestern Alberta were microbial degradation and leaching.

9.0 LITERATURE CITED

Alberta Agriculture. 1986. Managing herbicide residues. Agdex 609-1. Edmonton, Alberta. 4 pp.

Alberta Agriculture. 1980. Land application of animal manure. Agdex 538-1. Edmonton, Alberta. 4 pp.

Alberta Geological Survey. 1982. Geological map of Alberta. Alberta Research Council. Natural Resources Division. Edmonton, Alberta.

Angemar, Y., M. Rebhun and M. Horowitz. 1984. Adsorption, phytotoxicity and leaching of bromacil in some Israeli soils. J. Environ. Qual. 13:321-326.

Appleby, A.P. 1985. Factors in examining fate of herbicides in soil with bioassays. Weed Sci. 33(2):2-6.

Beste, C.E., N.E. Humburg, H.M. Kempen, R.O. Radke, J.D. Riggleman, J.F. Stritzke, and G.R. Miller. 1983. Herbicide handbook of the Weed Science Society of America. Herbicide Handbook Committee. Weed Science Society of America. Champaign, Illinois. pp. 65-71.

Bingeman, C.W., R.W. Hill, R.W. Varner and T.A. Weidenfeller. 1962. Substituted uracils for industry weed control. Proc. N. Cent. Weed Contr. Conf. 19:42-43.

Black, C.A. ed. 1965. Methods of soil analysis part 2: chemical and microbiologial properties. Agronomy No. 9. American Society of Agronomy, Inc. Madison, Wisconsin. pp. 919-920.

Bohn, H.L., B.L. McNeal and G.A. O'Connor. 1979. Soil chemistry. John Wiley & Sons, Inc. U.S.A.

Brady, N.C. 1974. The nature and properties of soils. 8th ed. MacMillan Publishing Co., Inc. New York. 639 pp.

Burns, R.G. 1975. Factors affecting pesticide loss from soil. P. 103-141 in E.A. Paul and A.D. McLaren, eds. Soil Biochemistry. Marcel Dekker, New York.

Clark, T.L. 1986. Vegetation management of petroleum facility sites on agricultural land. Masters Thesis. Univ. of Calgary. Calgary, Alberta. 235 pp.

Corwin, D.L. and W.J. Farmer. 1984. Non-single valued adsorption desorption of bromacil and diquat by freshwater sediments. Environ. Sci. Technol. 18:507-514.

Doyle, R.C., D.D. Kaufman, and G.W. Brent. 1978. Effect of dairy manure and sewage sludge on 14C-pesticide degradation in soil. J. Agric. Food Chem. 26:987-989.

E.I. du Pont de Nemours & Company, Inc. 1979. Bromacil technical data sheet. Biochemicals Department. Wilmington, Delaware. 4 pp.

Furmidge, C.G.L. and J.M. Osgerby. 1967. Persistence of herbicides in soil. J. Sci. Fd. Agric. 18:269-273.

Gardiner, J.A. 1975. Substituted uracil herbicides. P. 293-314 in P.C. Kearney and D.D. Kaufman, eds. Herbicides: chemistry, degradation and mode of action. Marcel Dekker, Inc. New York.

Gardiner, J.A., R.C. Rhodes, J.B. Adams, Jr., and E.J. Soboczenski. 1969. Synthesis and studies with 2-C14-labeled bromacil and terbacil. J. Agr. Food Chem. 18:524-528.

Gerstl, Z. and B. Yaron. 1983a. Behavior of bromacil and napropamide in soils: I. adsorption and degradation. Soil Sci. Soc. Am. J. 47:474-478.

Gerstl, Z. and B. Yaron. 1983b. Behavior of bromacil and napropamide in soils: II. distribution after application from a point source. Soil Sci. Soc. Am. J. 47:478-483.

Guralnik, D., ed. 1986. Webster's new world dictionary of the American language, 2nd college ed. New World Dictionaries/Simon and Schuster. New York, New York. 1692 pp.

Haque, R. and W.R. Coshow. 1971. Adsorption of isocil and bromacil from aqueous solution onto some mineral surfaces. Environ. and Sci. Techn. 5(2):139-141.

Hassall, K.A. 1982. The chemistry of pesticides: their metabolism, mode of action and uses in crop protection. MacMillan Press Ltd., London. 372 pp.

Hebb, E.A. and W.B. Wheeler. 1978. Bromacil in lakeland soil groundwater. J. Environ. Qual. 7(4):598-601.

Helling, C.S. and B.C. Turner. 1968. Science. 162:562.

Hilton, J.L., T.J. Monaco, D.E. Moreland and W.A. Gentner. 1964. Mode of action of substituted uracil herbicides. Weeds. 12:129-131.

Hiranpradit, H. and C.L. Foy. 1973. Retardation of leaf senescence in maize by subtoxic levels of bromacil, fluometiuron and atrazine. Bot. Gaz. 134(l):26-31.

Hoffman, C.E. 1971. The mode of action of bromacil and related uracils. P. 65-85 in Proceedings: 2nd Int. Conf. on Pest. Chem.

Hoffman, C.E., J.W. McGahen and P.B. Sweetser. 1964. Effect of substituted uracil herbicides on photosynthesis. Nature. 202:577-578.

Horvath, R.S. 1972. Microbial co-metabolism and the degradation of organic compounds in nature. Bacteriological Reviews. 36(2):146-155.

Hoyt, P.B. and W.A. Rice. 1972. Effects of high rates of chemical fertilizer and barnyard manure on yield and moisture use of six successive barley crops grown on three Gray Luvisolic soils. Can. J. Soil Sci. 57:425-435.

Industrial Vegetation Management Association of Alberta. 1984. Field manual for rehabilitating soils affected by residual herbicides. Calgary, Alberta. 40 pp.

Jones, J.F. 1966. Surficial deposits of the Peace River District, Alberta. Alberta Research Council Bulletin 16. Edmonton, Alberta.

Koren, E. 1972. Leaching of trifluralin and oryzalin in soil with three surfactants. Weed Sci. 20(5):230-232.

Leistra, M. and M.J. Frissel. 1975. Computations on the material balance of pesticides in soil. P. 817-828 in F. Coulson and F. Corte eds. Environmental Quality and Safety. Vol. III Georg Thieme, Stuttgart.

Madhun, Y.A., V.H. Freed, J.L. Young and S.C. Fang. 1986. Sorption of bromacil, chlortoluron, and diuron by soils. Soil Sci. Soc. Am. J. 50:1467-1471.

Mathers, A.C. and B.A. Stewart. 1974. Corn silage yield and soil chemical properties as affected by cattle feedlot manure. J. Environ. Quality. 3:143-147.

Mathers, A.C. and B.A. Stewart. 1980. The effect of feedlot manure on soil physical and chemical properties. P. 159-162 in Proc. 4th Intern. Sym. on Livestock Wastes. Amarillo Civic Center. Amarillo, Texas.

McGill, W.B. 1982. Soil fertility and land productivity in Alberta. Environment Council of Alberta. ECA82-17/IB16. Edmonton, Alberta. pp. 47-65.

McKeague, J.A. 1978. Manual on soil sampling and methods of analysis. 2nd ed. Subcommittee on Methods of Analysis. Canadian Society of Soil Science. Ottawa, Ontario. 211 pp.

Morrow, L.A. and M.K. McMarty. 1976. Selectivity and soil persistence of certain herbicides used on perennial forage grasses. J. Environ. Qual. 5:462-465.

Nemec, S. and D. Tucker. 1983. Effects of herbicides on the endomycorrhizal fungi in Flordia citrus (Citrus spp.) soils. Weed Sci. 31:427-431.

Pancholy, S.K. and J.Q. Lynd. 1969. Bromacil interactions in plant bioassay, fungi cultures and nitrification. Weed Sci. 17(4):460-463.

Pionke, H.B. and G. Chesters. 1973. Pesticide-sediment-water interactions. J. Environ. Quality. 2(l):29-45.

Reed and Holt. 1982. Leaching of selected total vegetation control herbicides. Proc. Northeast Weed Sci. Soc. 36:39-43.

Reeder, S.W. and W. Odynsky. 1965. Soil survey of the Cherry Point and Hines Creek area. Research Council of Alberta Report No. 85. Research Council of Alberta. Edmonton, Alberta. 102 pp.

Reid, J.T. 1963. Science for the farmer. X(4):14.

Rhodes, R.C., I.J. Belasco and H.L. Pease. 1970. Determination of the mobility and adsorption of agrichemicals on soils. J. Agr. Food Chem. 18:524-528.

Schreiber, J.D., V.V. Volk and L. Boersma. 1975. Soil water potential and bromacil uptake by wheat. Weed Science. 23:127-130.

Scott, K.W. 1987. Laboratory and greenhouse studies for the rehabilitation of bromacil contaminated soils. Annual report 1986/87. Prepared for NOVA Corporation of Alberta. Calgary, Alberta. 40 pp.

Sharma, P. 1977. Activity and persistence of herbicides in the soil. Agriculture Bulletin No. 35. Univ. of Alberta. Edmonton, Alberta. pp. 31-34.

Shea, P.J. 1985. Detoxification of herbicide residues in soil. Weed Sci. 23(2):33-41.

Shipman, R.D. 1983. Movement and persistence of bromacil in non-cultivated soils. Proc. Northeast Weed Sci. Soc. 37:110-111.

Shortall, J.G. and W.C. Liebhardt. 1975. Yield and growth of corn as affected by poultry manure. J. Environ. Quality. 4:186-191.

Shriver, J.W. and S.W. Bingham. 1973. Physiological effects of bromacil on Kentucky bluegrass and orchardgrass. Crop Science. 13:45-49.

Singh, M., W.S. Castle and N.R. Achhireddy. 1985. Movement of bromacil and norflurazon in a sandy soil in Florida, U.S.A. Bull. Environ. Contam. Toxicol. 35:279-284.

Sluijsmans, C.M.J. and G.J. Kolenbrander. 1976. The nitrogen efficiency of manure in short and long term. Stikstof. 7(83/84):349-354.

Smith, A.E. 1982. Herbicides and the soil environment in Canada. Can. J. Soil Sci. 62:433-460.

Smith, A.E., R. Grover, G.S. Emmond and H.C. Korven. 1975. Persistence and movement of atrazine, bromacil, monuron and simazine in intermittently filled irrigation ditches. Can. J. Plant Sci. 55:809-816.

Snedecor and Cochrane. 1980. Statistical Methods. 7th ed. Am. Soc. QC. Milwaukee, Wi. pp. 96-99.

Tisdale, S.L. and W.L. Nelson. 1975. Soil fertility and fertilizers. MacMillan Publishing Co., Inc. New York. pp. 575-579.

Torgenson, D.C. 1969. Microbial degradation of pesticides in soil. P. 58-59 in J.E. Gunckel, ed. Current Topics in Plant Science. Academic Press. New York.

Torgenson, D.C. and H. Mee. 1967. Microbial degradation of bromacil. Proc. Northwest Weed Contr. Conf. 21:584.

Tunney, H. 1980. An overview of the fertilizer value of livestock waste. P. 181-184 in Proc. 4th Intern. Sym. on Livestock Wastes. Amarillo Civic Center. Amarillo, Texas.

Wallingford, G.W., L.S. Murphy, W.L. Powers and H.L. Manges. 1975. Disposal of beef feedlot manure: effects of residual and yearly applications on corn and soil chemical properties. J. Environ. Quality. 4:526-531.

Wallingford, G.W., L.S. Murphy, W.L. Powers and H.L. Manges. 1974. Effect of beef feedlot lagoon water on soil chemical properties and growth and composition of corn forage. J. Environ. Quality. 3:74-78.

Wallingford, G.W., L.S. Murphy, W.L. Powers and H.L. Manges. 1977. Salt accumulation in soil as a factor for determining application rates of beef feedlot manure and lagoon water. In Proc. 1976 Cornell Agricultural Waste Management Conference. Ann Arbor Science Publishers. Ann Arbor, Michigan.

Weber, J.B. 1972. Interaction of organic pesticides with particulate matter in aquatic and soil systems. P. 55-120 in R.F. Gould (ed.). Fate of Organic Pesticides in the Aquatic Environment. Advan. Chem. Ser. III:55-120. Amer. Chem. Soc. Washington, D.C.

Weber, J.B. and J.A. Best. 1972. Activity and movement of thirteen soil applied herbicides as influenced by soil reaction. P. 403-413 in Proc. of 25th Annual Meeting, Southern Weed Society. Dallas, Texas.

Weber, J.B. and D.M. Whitacre. 1982. Mobility of herbicides in soil columns under saturated and unsaturated flow conditions. Weed. Sci. 30:579-584.

White, R.E., J.S. Dyson, Z. Gerstl and B. Yaron. 1986. Leaching of herbicides through undisturbed cores of a structured clay soil. Soil Sci. Soc. Am. J. 50:277-283.

Wolf, D.C. and J.P. Martin. 1974. Microbial degradation of 2-carbon 14-bromacil and terbacil. Soil Sci. Soc. Amer. Proc. 38:921-925.

Yaron, B. and Z. Gerstl. 1983. Herbicide residues in soils following point source application. P. 207-212 in Proc. Int. Congr. Pestic. Chem. Vol. 4. 49WEAZ.

Zandvoort, R., G.W. Van den Born, J.M. Braber and J.H. Smelt. 1980. Leaching of the herbicide bromacil after application on railroads in the Netherlands. Water, Air and Soil Poll. 13:363-372.

10.0 APPENDICES

Table A1. Results of the Analyses Performed on the 18 Plot Samples from 1985 to 1987.

Site	Sample	Depth (cm)	OC(%) 85	OC(%) 86	OC(%) 87	Bromacil (ppm) 85	Bromacil (ppm) 86	Bromacil (ppm) 87	pH 85	pH 86	pH 87	EC (mS/cm) 85	EC (mS/cm) 86	EC (mS/cm) 87	SAT. (%) 85	SAT. (%) 86	SAT. (%) 87	Sand (%)	Silt (%)	Clay (%)
1	1	0-4	1.9	2.2	2.2	0.32	0.40	0.19	4.9	4.8	5.1	1.9	1.9	2.0	56	57	63			
	2	0-4	3.0	2.2	2.3	0.74	0.66	0.60	6.6	4.8	4.9	1.7	2.4	2.5	67	57	61	15	36	49
	3	0-4	3.7	4.5	3.5	0.94	0.58	0.31	7.2	6.6	6.4	3.1	3.8	3.7	62	62	65	18	38	44
	4	0-4	4.2	3.5	4.4	0.71	0.65	0.45	7.1	6.2	6.4	4.4	3.4	4.2	62	62	66	17	36	47
	5	0-4	3.6	4.2	4.8	0.54	0.19	0.24	6.3	6.1	6.6	2.8	3.9	2.8	57	64	66			
	6	0-4	2.3	2.3	2.9	0.63	1.06	0.39	5.1	5.0	5.2	2.3	3.1	2.1	58	56	62			
	7	0-4	4.0	5.0	4.1	0.43	0.25	0.18	6.5	4.3	6.0	2.4	4.0	1.6	62	64	66			
	8	0-4	6.3	5.0	5.9	0.51	0.47	0.15	7.2	7.3	7.0	6.3	4.9	2.8	69	67	67			
	9	0-4	4.7	4.6	6.6	0.73	0.18	0.26	7.5	6.7	6.9	5.1	4.0	5.2	70	63	68	20	38	42
2	10	0-4	5.2	3.5	6.7	0.68	0.48	0.25	7.0	6.2	7.1	6.7	3.6	1.6	64	57	64	22	36	43
	11	0-4	6.4	3.1	8.4	0.58	0.26	0.10	7.3	6.2	7.5	7.2	3.8	1.7	90	55	69			
	12	0-4	9.9	5.6	5.1	0.16	0.20	0.14	8.2	7.7	6.8	10.4	4.1	1.7	74	62	60			
	13	0-4	6.4	5.4	4.5	0.35	0.11	0.60	7.2	7.2	6.1	8.9	3.1	1.2	64	61	63			
	14	0-4	4.9	5.0	4.4	1.40	0.28	0.15	6.7	7.1	5.8	6.2	4.2	1.1	66	63	60	20	42	38
	15	0-4	7.0	5.0	5.0	0.21	0.30	0.16	7.5	6.4	6.1	5.6	2.4	1.1	67	63	67			
	16	0-4	7.0	5.3	7.7	0.67	0.34	0.11	7.6	7.8	7.4	7.9	3.0	1.9	65	60	68			
	17	0-4	5.7	8.0	7.0	0.52	0.25	0.16	7.2	8.0	7.7	6.6	4.5	2.3	64	63	66	30	31	39
	18	0-4	4.9	4.1	3.9	0.73	0.14	0.13	6.9	6.1	5.8	5.8	1.7	2.6	62	60	63	20	38	42
1	1	4-8	2.0	2.1	2.1	0.32	0.46	0.11	5.0	4.7	5.0	0.6	2.3	1.0	59	57	64			
	2	4-8	2.4	2.1	2.2	1.20	0.58	0.49	5.8	4.9	4.9	1.3	2.1	1.4	60	59	65	15	38	47
	3	4-8	7.1	9.6	4.0	0.80	0.46	0.52	7.5	7.6	7.4	4.5	3.1	2.4	73	72	64	32	36	32
	4	4-8	4.8	4.1	4.5	0.69	0.68	0.39	6.6	7.4	6.7	4.8	3.8	3.0	76	74	68	30	36	34
	5	4-8	4.9	3.0	4.9	0.74	0.51	0.44	6.6	5.7	6.5	2.4	2.5	2.8	61	63	64			
	6	4-8	2.6	3.8	2.2	0.74	0.47	0.28	5.2	6.2	4.7	1.6	1.2	1.5	60	59	59			
	7	4-8	6.7	5.0	5.7	0.25	0.31	0.09	7.5	6.6	6.6	6.1	3.6	1.5	72	64	68			
	8	4-8	6.9	2.7	5.3	1.08	0.35	0.28	7.4	5.2	7.2	5.8	2.5	2.2	70	60	64			
	9	4-8	6.1	4.3	7.7	0.37	0.31	0.32	7.8	6.5	7.4	10.7	3.1	3.4	100	63	68	16	38	46
2	10	4-8	6.4	4.8	6.9	0.55	0.21	0.22	7.4	7.0	7.1	6.4	4.2	2.2	81	60	71	28	34	38
	11	4-8	7.4	6.0	7.8	0.37	0.31	0.11	7.4	6.9	7.6	6.6	4.9	2.1	71	62	68			
	12	4-8	7.4	5.7	5.5	0.56	0.28	0.21	7.8	7.5	7.0	8.2	5.1	2.0	68	62	63			
	13	4-8	6.7	2.9	5.4	0.69	0.40	0.09	7.4	6.1	6.6	6.7	2.9	1.2	71	55	62			
	14	4-8	5.9	4.7	4.9	0.83	0.24	0.12	7.2	6.7	5.8	4.2	3.1	1.1	65	63	63	18	38	44
	15	4-8	6.2	4.9	5.2	0.35	0.41	0.15	7.4	6.5	6.0	6.1	1.9	1.2	69	63	63			
	16	4-8	6.8	5.6	8.0	0.68	0.16	0.14	7.5	7.9	7.2	9.1	2.7	3.0	68	64	66			
	17	4-8	6.4	4.1	7.2	0.55	0.04	0.08	7.4	7.6	7.4	6.4	3.4	2.7	101	61	67	20	33	47
	18	4-8	4.5	3.8	4.6	0.39	0.41	0.12	7.3	6.5	6.3	3.8	3.0	2.1	66	62	63	20	35	45

Table A1 (Continued):

Site	Sample	Depth (cm)	OC(%)			Bromacil (ppm)			pH			EC (mS/cm)			SAT. (%)			Sand (%)	Silt (%)	Clay (%)
			85	86	87	85	86	87	85	86	87	85	86	87	85	86	87			
1	1	8-12	2.2	2.0	2.4	0.57	0.43	0.08	5.2	4.7	5.1	0.5	1.7	0.8	55	59	60			
	2	8-12	1.9	1.7	2.3	0.56	0.32	0.25	5.2	4.9	5.0	0.6	0.9	1.2	58	57	65	15	38	47
	3	8-12	3.4	3.2	4.1	0.80	0.48	0.59	6.5	6.7	7.1	2.7	2.2	2.1	65	60	67	18	35	47
	4	8-12	3.1	2.4	6.4	0.83	0.58	0.48	6.1	5.5	7.8	2.3	2.3	2.5	64	61	68	15	37	48
	5	8-12	4.1	4.3	4.4	0.62	0.70	0.36	6.5	6.8	6.9	1.8	3.6	1.9	61	65	68			
	6	8-12	2.2	4.4	1.9	0.35	0.27	0.27	5.1	6.8	4.5	0.6	1.1	1.2	61	63	62			
	7	8-12	6.1	2.5	6.0	0.13	0.06	0.14	7.6	5.2	7.0	3.4	2.1	1.9	72	65	66			
	8	8-12	4.6	2.0	5.1	0.44	0.19	0.22	7.0	4.7	7.0	3.3	1.6	1.9	68	63	67			
	9	8-12	3.5	2.2	5.5	0.54	0.31	0.47	6.2	5.0	7.2	1.9	2.0	2.6	78	61	65	12	34	54
2	10	8-12	3.2	2.7	3.6	0.78	0.53	0.35	6.1	5.3	5.7	4.4	2.2	1.8	64	58	62	20	35	45
	11	8-12	3.1	3.3	9.7	0.51	0.38	0.15	5.4	5.8	8.0	4.0	2.8	2.8	56	56	77			
	12	8-12	5.3	2.3	6.3	0.64	0.64	0.19	7.2	5.2	7.2	6.1	3.2	2.1	67	56	67			
	13	8-12	4.8	2.3	5.2	0.67	0.49	0.09	6.7	5.0	6.5	4.2	2.3	1.1	88	57	62			
	14	8-12	4.9	3.1	4.8	0.84	0.07	0.06	6.3	5.5	5.7	2.5	2.3	0.7	63	60	65	17	37	46
	15	8-12	5.4	3.7	5.0	0.58	0.37	0.33	6.8	6.3	6.2	3.9	2.0	1.1	67	61	65			
	16	8-12	4.8	2.6	9.6	0.67	0.15	0.13	6.7	5.4	7.5	4.2	2.3	3.2	77	60	74			
	17	8-12	4.3	2.5	5.7	0.78	0.64	0.22	6.8	5.3	7.8	4.4	2.6	3.2	65	59	67	16	31	53
	18	8-12	7.6	2.8	4.6	0.59	0.58	0.18	8.0	5.3	6.7	4.3	1.8	2.0	73	57	62	16	38	46
1	1	12-16	2.5	1.5	2.6	0.02	0.17	0.07	5.4	4.8	5.3	0.5	0.7	0.8	56	59	58			
	2	12-16	1.9	1.3	2.2	0.38	0.10	0.23	5.3	4.7	5.1	0.5	0.7	1.0	57	55	64	13	41	46
	3	12-16	1.9	1.7	2.3	0.58	0.38	0.45	5.0	5.4	5.9	1.4	1.6	1.9	65	62	63	16	35	49
	4	12-16	1.9	2.2	5.8	1.10	0.38	0.47	4.9	5.1	7.3	1.3	1.5	2.1	60	61	71	16	36	48
	5	12-16	2.7	2.3	4.7	0.48	1.01	0.29	5.2	5.1	6.5	1.5	2.2	1.8	58	63	67			
	6	12-16	2.1	1.5	1.8	0.23	0.06	0.22	5.1	5.1	4.6	0.5	0.9	1.1	64	59	62			
	7	12-16	2.1	2.1	2.2	0.07	0.03	0.11	5.3	4.9	5.2	1.8	1.7	1.8	66	61	58			
	8	12-16	2.7	1.8	4.2	0.41	0.08	0.17	5.5	4.7	6.4	1.7	1.1	1.9	59	69	63			
	9	12-16	4.3	1.9	2.8	0.41	0.33	0.56	5.2	4.8	6.1	1.2	1.4	2.2	67	65	64	13	35	52
2	10	12-16	2.6	2.3	3.3	0.91	0.56	0.35	5.3	5.0	5.3	3.3	1.9	1.7	61	58	63	18	33	49
	11	12-16	2.4	3.1	3.7	0.31	0.32	0.18	5.1	5.5	6.5	2.5	2.2	2.0	58	56	60			
	12	12-16	4.6	1.9	5.4	0.65	0.52	0.24	6.7	4.8	7.2	4.4	2.5	2.1	66	58	67			
	13	12-16	3.9	1.7	5.2	0.41	0.30	0.07	6.0	4.8	7.0	3.1	1.9	1.2	62	56	63			
	14	12-16	3.7	3.2	3.8	0.87	0.05	0.04	5.2	5.6	5.5	1.7	1.8	0.7	61	62	62	18	40	42
	15	12-16	2.8	3.3	4.8	0.72	0.40	0.26	5.5	5.4	6.0	2.5	1.5	1.3	62	59	66			
	16	12-16	2.4	2.6	4.2	1.70	0.11	0.22	5.4	5.1	6.2	3.7	2.2	2.7	62	59	62			
	17	12-16	2.8	2.2	5.2	0.69	0.57	0.23	5.1	5.0	7.1	2.2	2.1	2.6	65	62	65	14	36	50
	18	12-16	2.7	2.8	3.4	0.47	0.51	0.10	6.2	5.3	5.7	2.3	1.3	1.8	63	59	60	16	38	46

Table A1 (Continued):

Site	Sample	Depth (cm)	OC(%)			Bromacil (ppm)			pH			EC (mS/cm)			SAT. (%)			Sand (%)	Silt (%)	Clay (%)
			85	86	87	85	86	87	85	86	87	85	86	87	85	86	87			
1	1	16-20	2.3	2.0	2.8	0.00	0.05	0.10	5.3	4.9	5.5	0.6	0.7	0.6	54	59	57			
	2	16-20	2.1	1.1	2.1	0.18	0.07	0.18	5.2	4.5	5.1	0.5	0.6	0.8	57	62	69	13	31	56
	3	16-20	1.6	1.6	2.1	0.28	0.21	0.29	5.1	5.1	5.4	0.8	1.4	1.4	66	62	62	16	33	51
	4	16-20	1.8	2.3	2.6	0.71	0.12	0.22	4.9	5.1	5.5	0.9	1.2	1.7	60	62	62	14	37	49
	5	16-20	2.4	2.6	2.8	0.29	0.62	0.19	5.2	5.3	5.2	1.0	1.3	1.6	59	69	65			
	6	16-20	2.6	1.1	1.7	0.12	0.01	0.07	5.2	4.7	4.7	0.5	0.9	1.1	62	54	60			
	7	16-20	1.8	2.1	1.9	0.08	0.01	0.08	5.1	5.0	4.8	1.1	1.3	1.8	63	61	59			
	8	16-20	2.3	1.9	1.8	0.07	0.02	0.03	5.3	4.9	5.0	0.8	0.9	1.4	59	62	61			
	9	16-20	3.9	2.1	1.9	0.86	0.24	0.52	6.2	5.2	5.0	3.5	1.1	1.5	59	67	63	16	35	49
2	10	16-20	3.0	2.4	2.6	0.81	0.46	0.26	5.3	5.0	5.1	2.1	1.5	1.6	61	59	61	22	28	50
	11	16-20	1.8	3.2	3.4	0.24	0.22	0.39	5.0	5.5	5.6	1.4	1.8	1.9	61	59	61			
	12	16-20	3.2	1.8	3.2	0.72	0.30	0.31	5.7	4.7	5.8	2.9	2.0	1.7	58	62	60			
	13	16-20	3.1	1.6	3.8	0.16	0.13	0.02	5.2	5.0	5.8	2.0	1.6	1.0	59	57	61			
	14	16-20	3.4	3.1	2.5	0.58	0.05	0.02	5.3	5.3	5.4	1.1	1.8	1.1	64	59	60	18	36	46
	15	16-20	2.8	3.4	3.7	0.71	0.27	0.21	5.1	5.4	5.2	1.6	1.0	1.1	63	61	65			
	16	16-20	2.3	2.7	3.3	0.99	0.06	0.00	4.9	5.1	5.4	2.2	1.9	2.7	61	63	61			
	17	16-20	2.8	2.4	3.0	0.03	0.40	0.24	5.3	4.8	5.7	1.3	1.6	2.0	61	63	61	14	35	51
	18	16-20	2.6	2.7	3.0	0.17	0.36	0.07	5.2	5.3	5.3	1.3	1.2	1.8	58	62	61	16	39	45
1	1	20-24	0.9	1.6	1.5	0.01	0.02	0.04	4.7	4.7	5.0	0.6	0.7	0.7	50	60	66			
	2	20-24	1.6	1.2	1.9	0.16	0.06	0.12	4.8	4.5	5.1	0.4	0.6	0.8	66	60	66	11	33	56
	3	20-24	1.9	1.8	1.9	0.07	0.09	0.14	5.3	5.2	5.3	0.7	1.2	1.3	63	62	66	16	36	48
	4	20-24	1.9	1.6	2.3	0.28	0.03	0.14	5.1	4.7	5.2	0.7	0.9	1.1	55	71	63	11	34	55
	5	20-24	1.4	2.5	2.1	0.09	0.24	0.08	5.1	5.2	5.0	0.7	1.0	1.5	51	62	64			
	6	20-24	1.8	0.9	2.1	0.12	0.01	0.05	5.0	4.6	4.7	0.5	0.8	1.0	62	59	59			
	7	20-24	2.4	1.8	1.8	0.04	0.01	0.05	5.4	4.9	4.8	0.8	1.2	1.7	58	56	54			
	8	20-24	1.8	1.9	1.9	0.02	0.02	0.02	4.9	4.8	4.7	0.6	0.7	1.3	66	69	62			
	9	20-24	2.1	2.5	1.9	0.88	0.10	0.38	5.2	5.3	4.9	1.9	0.9	1.1	68	65	62	14	38	48
2	10	20-24	3.2	3.0	2.3	0.60	0.18	0.16	5.4	5.2	5.0	1.3	1.3	1.6	59	54	62	18	41	41
	11	20-24	1.7	2.9	2.8	0.15	0.10	0.32	5.1	5.2	5.6	0.8	1.5	1.9	59	59	63			
	12	20-24	2.8	1.2	3.5	0.69	0.10	0.20	5.3	4.6	5.6	1.6	1.4	1.8	57	61	61			
	13	20-24	2.9	2.5	3.3	0.06	0.17	0.00	5.2	5.1	5.7	1.3	1.3	0.9	58	60	61			
	14	20-24	3.0	1.1	1.7	0.29	0.03	0.01	5.5	4.6	5.2	0.7	2.0	1.2	61	58	61	22	26	52
	15	20-24	3.0	2.5	3.4	0.53	0.11	0.03	5.3	5.2	5.2	0.8	1.0	1.1	63	65	63			
	16	20-24	2.5	1.9	3.0	0.89	0.04	0.05	5.0	4.8	5.2	1.3	2.0	2.3	62	63	62			
	17	20-24	2.6	1.5	2.5	0.14	0.17	0.17	5.4	4.6	5.4	0.7	1.5	2.0	60	68	63	16	29	55
	18	20-24	2.6	2.5	1.7	0.30	0.25	0.04	5.4	5.3	5.1	0.7	1.1	1.7	58	55	59	18	34	48

Table A1 (Continued):

Site	Sample	Depth (cm)	OC(%)			Bromacil (ppm)			pH			EC (mS/cm)			SAT. (%)			Sand (%)	Silt (%)	Clay (%)
			85	86	87	85	86	87	85	86	87	85	86	87	85	86	87			
1	1	24-28				0.00	0.00	0.02	4.5	4.4	4.6	0.7	0.6	0.6	56	63	64			
	2	24-28				0.05	0.06	0.16	4.6	4.7	5.1	0.4	0.7	0.7	73	60	60	19	33	48
	3	24-28				0.02	0.06	0.22	5.3	5.3	5.0	0.6	1.0	1.0	62	61	63	17	36	47
	4	24-28				0.26	0.02	0.08	5.2	4.5	5.1	0.5	0.7	1.0	56	81	59	12	25	63
	5	24-28				0.03	0.16	0.03	4.7	5.1	4.7	0.6	0.8	1.5	54	57	58			
	6	24-28				0.05	0.00	0.08	5.0	4.4	4.7	0.5	0.8	0.8	60	64	61			
	7	24-28				0.03	0.00	0.03	5.3	4.7	4.9	0.6	1.1	1.6	56	48	55			
	8	24.28				0.02	0.00	0.01	4.5	4.4	4.3	0.5	0.6	1.1	72	69	60			
	9	24-28				0.61	0.03	0.10	4.8	4.7	4.7	1.1	0.7	0.9	68	65	66	14	32	54
2	10	24-28				0.71	0.09	0.15	5.5	5.2	4.7	0.8	0.9	1.5	59	55	63	25	31	44
	11	24-28				0.15	0.07	0.15	4.8	5.1	5.4	0.7	1.4	2.1	57	58	62			
	12	24-28				0.60	0.08	0.09	5.5	4.6	5.4	0.8	1.2	2.0	57	60	61			
	13	24-28				0.04	0.05	0.00	5.2	4.4	5.0	0.8	1.1	1.0	61	62	64			
	14	24-28				0.24	0.02	0.00	5.3	4.5	4.7	0.5	1.5	1.4	58	71	57	22	25	53
	15	24-28				0.25	0.09	0.02	5.2	4.9	4.9	0.5	1.1	1.4	60	63	58			
	16	24-28				0.72	0.02	0.02	5.2	4.4	5.1	0.8	2.1	2.1	58	55	58			
	17	24-28				0.02	0.12	0.03	5.3	4.8	5.2	0.5	1.1	2.0	57	64	64	17	31	52
	18	24-28				0.47	0.15	0.01	5.4	4.9	4.9	0.5	1.1	1.8	59	56	60	18	34	48
1	1	28-32				0.00	0.00	0.01	4.4	4.3	4.5	0.7	0.6	0.6	60	66	66			
	2	28-32				0.02	0.03	0.14	4.5	4.6	4.7	0.4	0.8	0.6	67	56	68	26	28	46
	3	28-32				0.02	0.02	0.19	5.1	4.8	5.1	0.5	0.9	0.9	62	56	60	18	34	48
	4	28-32				0.20	0.00	0.03	5.1	4.4	4.5	0.5	0.7	0.9	58	79	62	12	25	63
	5	28-32				0.40	0.12	0.01	4.6	5.1	4.3	0.5	0.7	1.2	59	59	61			
	6	28-32				0.05	0.00	0.03	4.9	4.3	4.2	0.4	0.8	0.8	64	65	63			
	7	28-32				0.02	0.00	0.02	4.9	4.7	5.0	0.5	1.1	1.7	48	39	59			
	8	28-32				0.00	0.00	0.01	4.4	4.4	4.2	0.5	0.5	1.0	72	82	60			
	9	28-32				0.61	0.01	0.12	4.9	4.4	4.6	0.7	0.6	0.7	65	66	70	13	32	55
2	10	28-32				0.36	0.07	0.09	5.1	5.0	4.5	0.7	0.8	1.3	64	55	62	20	33	47
	11	28-32				0.04	0.05	0.05	4.6	4.8	4.9	0.6	1.1	1.8	65	60	64			
	12	28-32				0.40	0.16	0.03	5.7	4.6	4.8	0.4	1.7	2.0	55	59	61			
	13	28-32				0.02	0.03	0.00	5.0	4.4	4.7	0.6	1.1	1.1	58	60	60			
	14	28-32				0.18	0.02	0.00	4.9	4.4	4.5	0.5	1.3	1.2	56	54	62	20	30	50
	15	28-32				0.13	0.05	0.02	4.8	4.6	4.6	0.5	1.0	1.3	59	64	57			
	16	28-32				0.49	0.01	0.08	5.0	4.2	4.8	0.6	1.9	2.4	60	53	71			
	17	28-32				0.02	0.07	0.08	4.8	4.4	4.8	0.5	1.0	1.8	64	60	69	21	25	54
	18	28-32				0.16	0.09	0.01	4.9	4.4	48	0.5	1.1	2.0	66	49	58	28	25	47

Table A1 (Continued):

Site	Sample	Depth (cm)	OC(%)			Bromacil (ppm)			pH			EC (mS/cm)			SAT. (%)			Sand (%)	Silt (%)	Clay (%)
			85	86	87	85	86	87	85	86	87	85	86	87	85	86	87			
1	1	32-36				0.00	0.00	0.01	4.4	4.2	4.2	0.7	0.7	0.6	60	65	67			
	2	32-36				0.02	0.01	0.11	4.5	4.3	4.5	0.5	0.8	0.5	66	40	67	56	15	29
	3	32-36				0.00	0.02	0.14	4.8	4.5	5.1	0.5	0.8	0.8	61	59	58	24	29	47
	4	32-36				0.09	0.00	0.04	4.8	4.3	4.3	0.5	0.7	0.8	57	73	67	12	25	63
	5	32-36				0.01	0.07	0.00	4.4	4.9	4.2	0.6	0.6	0.9	74	59	80			
	6	32-36				0.02	0.00	0.03	4.6	4.2	4.2	0.4	0.9	0.8	65	65	68			
	7	32-36				0.02	0.00	0.03	4.7	4.6	4.9	0.5	1.2	1.6	62	42	63			
	8	32-36				0.01	0.00	0.00	4.4	4.3	4.2	0.5	0.5	0.9	77	78	58			
	9	32-36				0.14	0.00	0.03	5.0	4.3	4.6	0.6	0.6	0.6	64	69	71	14	30	56
2	10	32-36				0.15	0.07	0.04	4.7	4.5	4.4	0.5	0.6	1.2	65	58	64	14	35	51
	11	32-36				0.03	0.04	0.03	4.5	4.6	4.5	0.5	0.9	1.6	65	59	64			
	12	32-36				0.27	0.04	0.01	5.4	4.4	4.6	0.5	1.0	1.9	56	62	58			
	13	32-36				0.03	0.01	0.00	4.5	4.6	4.6	0.5	1.0	1.2	62	57	59			
	14	32-36				0.03	0.02	0.01	4.5	4.4	4.4	0.4	1.4	1.1	50	57	64	19	29	52
	15	32-36				0.04	0.03	0.01	4.5	4.4	4.4	0.5	0.9	1.3	58	57	57			
	16	32-36				0.26	0.00	0.01	4.7	4.2	4.5	0.5	1.9	2.0	65	53	66			
	17	32-36				0.01	0.04	0.03	4.5	4.3	4.6	0.5	0.9	1.7	60	53	68	24	26	50
	18	32-36				0.08	0.04	0.03	4.6	4.4	4.6	0.5	0.9	1.8	59	54	57	30	23	47
1	1	36-40				0.00	0.00	0.01	4.3	4.2	4.3	0.7	0.7	0.6	58	68	75			
	2	36-40				0.07	0.01	0.09	4.5	4.3	4.4	0.4	0.8	0.5	58	47	67	52	15	33
	3	36-40				0.01	0.00	0.14	4.5	4.5	4.6	0.4	0.8	0.7	57	41	59	56	17	27
	4	36-40				0.69	0.00	0.03	4.7	4.3	4.3	0.5	0.7	0.7	54	66	78	12	27	61
	5	36-40				0.00	0.03	0.01	4.5	4.6	4.1	0.6	0.6	0.8	74	52	76			
	6	36-40				0.01	0.00	0.01	4.6	4.2	4.1	0.4	0.9	0.8	72	70	66			
	7	36-40				0.01	0.00	0.01	4.6	4.4	4.6	0.4	1.0	1.7	76`	50	50			
	8	36-40				0.00	0.00	0.00	4.4	4.3	4.4	0.6	0.5	0.8	79	75	73			
	9	36.40				0.14	0.00	0.02	4.9	4.2	4.6	0.6	0.6	0.6	65	66	66	12	33	55
2	10	36-40				0.07	0.03	0.03	4.6	4.3	4.3	0.5	0.6	1.1	66	61	69	14	30	56
	11	36-40				0.03	0.01	0.02	4.5	4.4	4.5	0.5	0.8	1.5	65	58	62			
	12	36-40				0.07	0.01	0.02	4.7	4.3	4.4	0.4	0.9	1.6	59	62	64			
	13	36-40				0.02	0.01	0.00	4.4	4.6	4.4	0.6	1.0	1.2	58	52	53			
	14	36-40				0.07	0.02	0.01	4.4	4.3	4.3	0.4	1.4	1.0	50	53	65	24	25	51
	15	36-40				0.04	0.01	0.00	4.5	4.4	4.3	0.4	0.7	1.2	60	57	54			
	16	36-40				0.08	0.00	0.00	4.4	4.2	4.3	0.5	1.6	1.9	57	52	69			
	17	36-40				0.02	0.02	0.02	4.5	4.3	4.4	0.4	1.0	1.6	57	38	59	27	26	47
	18	36-40				0.03	0.02	0.01	4.5	4.3	4.5	0.5	1.0	1.7	56	51	52	28	32	49

Table A2. Comparison of 1984 Background Data from Site 1 and Site 2.

PARAMETER	DEPTH (cm)	SITE 1		SITE 2		CONFIDENCE INTERVAL
		x[1]	SE[3]	x[2]	SE[3]	
OC (%)	0 - 4	2.9	0.3	3.0	0.3	0.1 ± 1.1
	4 - 8	2.5	0.2	3.0	0.2	0.5 ± 0.5
	8 - 12	2.5	0.2	3.1	0.2	0.6 ± 0.5*
	12 - 16	2.3	0.2	3.0	0.3	0.7 ± 0.7
	16 - 20	2.3	0.3	2.8	0.4	0.5 ± 0.9
	20 - 24	2.1	0.3	1.8	0.2	0.3 ± 0.9
pH	0 - 4	5.0	0.1	5.2	0.1	0.2 ± 0.3
	4 - 8	5.1	0.1	5.2	0.1	0.1 ± 0.3
	8 - 12	5.0	0.1	5.2	0.1	0.2 ± 0.3
	12 - 16	4.9	0.1	5.2	0.1	0.3 ± 0.3
	16 - 20	5.0	0.1	5.1	0.1	0.1 ± 0.3
	20 - 24	5.0	0.1	4.8	0.1	0.2 ± 0.4
	24 - 28	4.8	0.1	4.6	0.1	0.2 ± 0.3
	28 - 32	4.8	0.2	4.6	0.1	0.3 ± 0.2*
	32 - 36	4.6	0.1	4.4	0.1	0.2 ± 0.3
	36 - 40	4.5	0.1	4.3	0.1	0.2 ± 0.2
EC (m5/cm)	0 - 4	1.1	0.1	1.2	0.2	0.1 ± 0.2
	4 - 8	1.3	0.2	1.3	0.1	0.0 ± 0.6
	8 - 12	1.4	0.2	1.2	0.1	0.2 ± 0.5
	12 - 16	1.4	0.2	1.5	0.2	0.1 ± 0.7
	16 - 20	1.3	0.2	1.5	0.1	0.2 ± 0.5
	20 - 24	1.4	0.1	2.0	0.4	0.6 ± 0.5*
	24 - 28	1.5	0.1	2.3	0.3	0.8 ± 0.5*
	28 - 32	1.7	0.3	2.5	0.3	0.8 ± 0.8
	32 - 36	1.8	0.2	2.5	0.3	0.7 ± 0.8
	36 - 40	1.9	0.3	2.6	0.1	0.7 ± 0.2*

1 - Mean of 9 samples for OC and 8 samples for pH and EC
2 - Mean of 6 samples for OC and 7 samples for pH and EC
3 - Standard error
* - Significantly different at $p \le 0.05$; confidence intervals that do not include 0

Table A3. Comparison of 1985 Data from Site 1 (S1) and Site 2 (S2).

PARAMETER	STAT.	DEPTH (cm)																			
		0 - 4		4 - 8		8 - 12		12 - 16		16 - 20		20 - 24		24 - 28		28 - 32		32 - 36		36 - 40	
		S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
Bromacil (ppm)	$\bar{x}$[1]	0.62	0.59	0.69	0.55	0.54	0.67	0.41	0.75	0.29	0.49	0.19	0.41	0.12	0.36	0.11	0.20	0.03	0.10	0.10	0.05
	SE[2]	0.06	0.12	0.11	0.05	0.07	0.04	0.11	0.14	0.10	0.11	0.09	0.09	0.07	0.09	0.07	0.06	0.02	0.03	0.07	0.01
	CI[3]	0.03	± 0.13	0.14	± 0.13*	0.13	± 0.09*	0.34	± 0.37	0.20	± 0.32	0.22	± 0.28	0.24	± 0.24	0.09	± 0.19	0.07	± 0.04*	0.05	± 0.09
OC (%)	$\bar{x}$	3.7	6.4	4.8	6.4	3.5	4.8	2.5	3.1	2.3	2.8	1.8	2.7								
	SE	0.4	0.5	0.7	0.3	0.4	0.4	0.3	0.3	0.2	0.2	0.1	0.1								
	CI	2.7	± 1.4*	1.6	± 0.7*	1.3	± 1.3	0.6	± 0.8	0.5	± 0.6	0.9	± 0.4*								
pH	$\bar{x}$	6.5	7.3	6.6	7.4	6.2	6.7	5.2	5.6	5.3	5.2	5.1	5.3	4.9	5.3	4.8	5.0	4.6	4.7	4.6	4.5
	SE	0.3	0.1	0.4	0.1	0.3	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0
	CI	0.8	± 0.4*	0.8	± 0.5*	0.5	± 0.8	0.4	± 0.2*	0.1	± 0.3	0.2	± 0.2	0.4	± 0.3*	0.2	± 0.3	0.1	± 0.3	0.1	± 0.1
EC (mS/cm)	$\bar{x}$	3.3	7.2	4.2	6.4	1.9	4.2	1.2	2.8	1.1	1.8	0.8	1.0	0.6	0.7	0.5	0.5	0.5	0.5	0.5	0.5
	SE	0.5	0.5	1.1	0.6	0.4	0.3	0.2	0.3	0.3	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	CI	3.9	± 1.6*	2.2	± 1.3*	2.3	± 1.0*	1.6	± 0.7*	0.7	± 0.3	0.2	± 0.4	0.1	± 0.2	0.0	± 0.1	0.0	± 0.0	0.0	± 0.0
Clay (%)	$\bar{x}$	46	41	40	44	49	48	49	47	51	48	52	49	53	49	53	50	49	50	44	51
	SE	1.6	1.2	3.9	1.9	1.7	1.8	1.2	1.8	1.7	1.5	2.2	3.0	3.7	2.1	3.9	1.7	7.4	1.1	8.3	1.9
	CI	5	± 5	4	± 11	1	± 6	2	± 5	3	± 5	3	± 9	4	± 10	3	± 10	1	± 17	7	± 18

[1] Mean of 9 samples

[2] Standard error

[3] Confidence interval

* Significantly different at $p \leq 0.05$; confidence intervals that do not include 0

Table A4. Comparison of 1985, 1986 and 1987 Bromacil Data from Site 1 (S1).

		Depth (cm)									
Year	**Stat.**	**0 - 4**	**4 - 8**	**8 - 12**	**12 - 16**	**16 - 20**	**20 - 24**	**24 - 28**	**28 - 32**	**32 - 36**	**36 - 40**
1985	$\bar{X}$[1] SE[2]	0.62[4] 0.06	0.69 0.11	0.54 0.07	0.41 0.11	0.29 0.10	0.19 0.09	0.12 0.07	0.11 0.07	0.03 0.02	0.10 0.07
1986	$\bar{X}$ SE	0.49 0.09	0.46 0.04	0.37 0.07	0.28 0.10	0.15 0.07	0.06 0.02	0.04 0.02	0.02 0.01	0.01 0.01	0.00 0.00
1985 x 1986	CI[3]	0.13 ± 0.24	0.23 ± 0.13*	0.17 ± 0.21	0.13 ± 0.31	0.14 ± 0.25	0.13 ± 0.09*	0.08 ± 0.07*	0.09 ± 0.07*	0.02 ± 0.02	0.10 ± 0.09*
1987	$\bar{X}$ SE	0.31 0.05	0.32 0.05	0.32 0.06	0.29 0.06	0.19 0.05	0.11 0.04	0.08 0.02	0.06 0.02	0.04 0.02	0.04 0.02
1986 x 1987	CI	0.18 ± 0.11*	0.14 ± 0.14	0.05 ± 0.18	0.01 ± 0.13	0.04 ± 0.17	0.05 ± 0.09	0.04 ± 0.06	0.04 ± 0.06	0.03 ± 0.02*	0.03 ± 0.02*
1985 x 1987	CI	0.31 ± 0.17*	0.37 ± 0.13*	0.22 ± 0.19*	0.12 ± 0.13	0.10 ± 0.11	0.08 ± 0.11	0.04 ± 0.07	0.05 ± 0.07	0.01 ± 0.05	0.06 ± 0.09

1 - Mean of 9 samples
2 - Standard error
3 - Confidence interval
4 - Units are ppm
* Significantly different at $p \leq 0.05$; confidence intervals that do not include 0

Table A5. Comparison of 1984, 1985, 1986 and 1987 Organic Carbon Data from Site 1.

		Depth (cm)					
Year	**Stat.**	**0 - 4**	**4 - 8**	**8 - 12**	**12 - 16**	**16 - 20**	**20 - 24**
1985	$\bar{x}^1$ SE^2	3.7^4 0.4	4.8 0.7	3.5 0.4	2.5 0.3	2.3 0.2	1.8 0.1
1986	$\bar{x}$ SE	3.7 0.4	4.1 0.8	2.7 0.3	1.8 0.1	1.9 0.2	1.8 0.2
1985 x 1986	CI^3	0.0 ± 1.3	0.7 ± 2.2	0.8 ± 1.2	0.7 ± 0.2*	0.4 ± 0.6	0.0 ± 0.5
1987	$\bar{x}$ SE	4.1 0.5	4.3 0.6	4.2 0.6	3.2 0.5	2.2 0.1	1.9 0.1
1986 x 1987	CI	0.4 ± 1.4	0.2 ± 2.1	1.5 ± 1.4*	1.4 ± 0.5*	0.3 ± 0.5	0.2 ± 0.2
1985 x 1987	CI	0.4 ± 1.4	0.5 ± 2.0	0.7 ± 1.5	0.7 ± 0.4*	0.1 ± 0.6	0.1 ± 0.2
1984	$\bar{x}$ SE	2.9 0.3	2.5 0.2	2.5 0.3	2.3 0.2	2.3 0.3	2.1 0.3
1984 x 1985	CI	0.8 ± 1.2	2.3 ± 0.7*	1.0 ± 0.4*	0.2 ± 0.7	0.0 ± 0.7	0.3 ± 0.4
1984 x 1987	CI	1.2 ± 1.3	1.8 ± 0.7*	1.7 ± 0.7*	0.9 ± 0.4*	0.1 ± 0.6	0.2 ± 0.2

1 - Mean of 9 samples
2 - Standard error
3 - Confidence interval
4 - Units are ppm
* Significantly different at $p \leq 0.05$; confidence intervals that do not include 0

Table A6. Comparison of 1984, 1985, 1986 and 1987 pH Data from Site 1.

		Depth (cm)									
Year	Stat.	0 - 4	4 - 8	8 - 12	12 - 16	16 - 20	20 - 24	24 - 28	28 - 32	32 - 36	36 - 40
1985	$\bar{x}$[1] SE[2]	6.5 0.3	6.6 0.4	6.2 0.3	5.2 0.1	5.3 0.1	5.1 0.1	4.0 0.1	4.8 0.1	4.6 0.1	4.6 0.1
1986	$\bar{x}$ SE	5.8 0.4	6.1 0.3	5.6 0.3	5.0 0.1	5.0 0.1	4.9 0.1	4.7 0.1	4.6 0.1	4.4 0.1	4.3 0.0
1985 x 1986	CI[3]	0.7 ± 1.0	0.5 ± 1.0	0.6 ± 0.9	0.2 ± 0.2	0.3 ± 0.3	0.2 ± 0.3	0.2 ± 0.3	0.2 ±0.3	0.2 ± 0.2	0.3 ± 0.2*
1987	$\bar{x}$ SE	6.1 0.3	6.3 0.4	6.4 0.4	5.8 0.3	5.1 0.1	5.0 0.1	4.8 0.1	4.6 0.1	4.5 0.1	4.4 0.1
1986 x 1987	CI	0.3 ± 0.9	0.2 ± 1.1	0.8 ± 1.1	0.8 ± 0.2*	0.1 ±0.3	0.1 ± 0.3	0.1 ± 0.3	0.0 ± 0.3	0.1 ± 0.3	0.1 ± 0.2
1985 x 1987	CI	0.4 ± 0.9	0.3 ± 1.1	0.2 ± 1.0	0.6 ± 0.2*	0.2 ± 0.3	0.1 ± 0.2	0.1 ± 0.3	0.2 ± 0.3	0.1 ± 0.3	0.2 ± 0.2
1984	$\bar{x}$ SE	5.0 0.1	5.1 0.1	5.0 0.1	4.9 0.1	5.0 0.1	5.0 0.1	4.3 0.1	4.8 0.2	4.6 0.1	4.5 0.1
1984 x 1985	CI	1.5 ± 0.5*	1.5 ± 0.5*	1.2 ± 0.2*	0.3 ± 0.2*	0.3 ± 0.3	0.1 ± 0.3	0.1 ± 0.3	0.0 ± 0.4	0.0 ± 0.2	0.1 ± 0.2
1985 x 1987	CI	1.1 ± 0.2*	1.2 ± 0.5*	1.4 ± 0.5*	0.9 ± 0.2*	0.1 ± 0.3	0.0 ± 0.3	0.0 ± 0.3	0.2 ± 0.4	0.1 ± 0.3	0.1 ± 0.2

1 - Mean of 9 samples
2 - Standard error
3 - Confidence interval
* - Significantly different at $p \leq 0.05$; confidence intervals that do not include 0

Table A7. Comparison of 1984, 1985, 1986 and 1987 Electrical Conductivity Data from Site 1.

		Depth (cm)									
Year	**Stat.**	**0 - 4**	**4 - 8**	**8 - 12**	**12 - 16**	**16 - 20**	**20 - 24**	**24 - 28**	**28 - 32**	**32 - 36**	**36 - 40**
1985	$\bar{x}$[1] SE[2]	3.3[4] 0.5	4.2 1.14	1.9 0.4	1.2 0.2	1.1 0.3	0.8 0.1	0.5 0.0	0.5 0.0	0.5 0.0	0.5 0.0
1986	$\bar{x}$ SE	3.5 0.3	2.7 0.3	1.9 0.3	1.3 0.2	1.0 0.1	0.9 0.1	0.8 0.1	0.7 0.1	0.7 0.1	0.7 0.1
1985 x 1986	CI[3]	0.2 ± 1.3	1.5 ± 1.1*	0.0 ± 1.0	0.1 ± 0.5	0.1 ± 0.4	0.1 ± 0.2	0.2 ± 0.2	0.2 ±0.1*	0.2 ± 0.1*	0.2 ± 0.2*
1987	$\bar{x}$ SE	3.0 0.4	2.1 0.3	1.8 0.2	1.6 0.2	1.3 0.1	1.2 0.1	1.0 0.1	0.9 0.1	0.8 0.1	0.8 0.1
1986 x 1987	CI	0.5 ± 1.1	0.6 ± 0.8	0.1 ±0.7	0.3 ± 0.5	0.3 ±0.3	0.3 ± 0.3	0.2 ± 0.2	0.2 ± 0.2	0.1 ±0.3	0.1 ± 0.2
1985 x 1987	CI	0.3 ± 1.4	2.1 ± 1.1*	0.1 ± 0.4	0.4 ± 0.5	0.2 ± 0.4	0.4 ± 0.4	0.4 ± 0.3*	0.4 ± 0.2*	0.3 ±0.2*	0.3 ± 0.2*
1984	$\bar{x}$ SE	1.1 0.1	1.3 0.2	1.4 0.2	1.4 0.2	1.3 0.2	1.4 0.1	1.5 0.1	1.7 0.3	1.8 0.2	1.9 0.3
1984 x 1985	CI	2.2 ± 0.7*	2.9 ± 1.1*	0.5 ± 0.4*	0.2 ± 0.6	0.2 ± 0.4	0.6 ± 0.4*	0.9 ± 0.3*	1.2 ± 0.2*	1.3 ±0.2*	1.4 ± 0.2*
1985 x 1987	CI	1.9 ± 0.5*	0.8 ± 0.8*	0.4 ± 0.6*	0.2 ± 0.6	0.0 ± 0.4	0.2 ± 0.4	0.5 ± 0.3*	0.8 ± 0.2*	0.1 ±0.4*	1.1 ± 0.2*

1 - Mean of 9 samples
2 - Standard error
3 - Confidence interval
4 - Units are mS/cm
* - Significantly different at $p \leq 0.05$; confidence intervals that do not include 0

Table A8. Comparison of 1985, 1986 and 1987 Bromacil Data from Site 2.

		Depth (cm)									
Year	**Stat.**	**0 - 4**	**4 - 8**	**8 - 12**	**12 - 16**	**16 - 20**	**20 - 24**	**24 - 28**	**28 - 32**	**32 - 36**	**36 - 40**
1985	$\bar{X}^1$ SE^2	0.59^4 0.12	0.55 0.05	0.67 0.04	0.75 0.14	0.49 0.11	0.41 0.09	0.36 0.09	0.20 0.06	0.10 0.03	0.05 0.01
1986	$\bar{x}$ SE	0.26 0.04	0.27 0.04	0.43 0.07	0.37 0.06	0.25 0.05	0.13 0.02	0.08 0.01	0.06 0.02	0.03 0.01	0.01 0.00
1985 x 1986	CI^3	0.33 ± 0.13*	0.28 ± 0.15*	0.24 ± 0.09*	0.38 ±0.15*	0.24 ± 0.13*	0.28 ± 0.11*	0.28 ± 0.09*	0.14 ±0.07*	0.07 ± 0.05*	0.03 ± 0.01*
1987	$\bar{x}$ SE	0.14 0.02	0.14 0.02	0.19 0.03	0.19 0.03	0.17 0.05	0.11 0.04	0.05 0.02	0.03 0.01	0.02 0.00	0.01 0.00
1986 x 1987	CI	0.12 ± 0.04*	0.13 ± 0.04*	0.24 ±0.9*	0.18 ± 0.7*	0.08 ±0.15	0.2 ± 0.9	0.3 ± 0.5	0.03 ± 0.04	0.01 ±0.2	0.00 ± 0.01
1985 x 1987	CI	0.45 ± 0.14*	0.41 ± 0.07*	0.48 ± 0.10*	0.56 ± 0.16*	0.32 ± 0.13*	0.30 ± 0.11*	0.31 ± 0.9*	0.17 ± 0.07*	0.08 ±0.05*	0.04 ± 0.01*

1 - Mean of 9 samples
2 - Standard error
3 - Confidence interval
4 - Units are ppm
* - Significantly different at $p \leq 0.05$; confidence intervals that do not include 0

Table A9. Comparison of 1984, 1985, 1986 and 1987 Organic Carbon Data from Site 2.

		Depth (cm)					
Year	**Stat.**	**0 - 4**	**4 - 8**	**8 - 12**	**12 - 16**	**16 - 20**	**20 - 24**
1985	$\bar{x}$[1] SE[2]	6.4[4] 0.5	6.4 0.3	4.8 0.4	3.1 0.3	2.8 0.2	2.7 0.1
1986	$\bar{x}$ SE	5.0 0.5	4.7 0.3	2.8 0.2	2.6 0.2	2.6 0.2	2.1 0.2
1985 x 1986	CI[3]	1.4 ± 1.5	1.7 ± 0.9*	2.0 ± 0.4*	0.5 ± 0.7	0.2 ± 0.6	0.6 ± 0.6
1987	$\bar{x}$ SE	5.9 0.5	6.2 0.4	6.1 0.7	4.3 0.3	3.2 0.1	2.7 0.2
1986 x 1987	CI	0.9 ± 1.5	1.5 ± 1.2*	3.3 ± 0.3*	1.7 ± 0.7*	0.6 ± 0.5*	0.6 ± 0.7
1985 x 1987	CI	0.5 ± 1.6	0.2 ± 1.1	1.3 ± 1.8	1.2 ± 0.8*	0.4 ± 0.5	0.0 ± 0.6
1984	$\bar{x}$ SE	3.0 0.3	3.0 0.2	3.1 0.2	3.0 0.3	2.8 0.4	1.8 0.2
1984 x 1985	CI	3.4 ± 1.5*	3.4 ± 0.9*	1.7 ± 0.5*	0.1 ± 0.8	0.0 ± 0.8	0.9 ± 0.6*
1984 x 1987	CI	2.9 ± 0.7*	3.2 ± 0.7*	3.0 ± 0.9*	1.3 ± 0.9*	0.4 ± 0.5	0.9 ± 0.7*

1 - Mean of 9 samples
2 - Standard error
3 - Confidence interval
4 - Units are %
* - Significantly different at $p \leq 0.05$; confidence intervals that do not include 0

Table A10. Comparison of 1984, 1985, 1986 and 1987 pH Data from Site 2.

		Depth (cm)									
Year	**Stat.**	**0 - 4**	**4 - 8**	**8 - 12**	**12 - 16**	**16 - 20**	**20 - 24**	**24 - 28**	**28 - 32**	**32 - 36**	**36 - 40**
1985	$\bar{x}$[1] SE[2]	7.3 0.1	7.4 0.1	6.7 0.2	5.6 0.2	5.2 0.1	5.3 0.1	5.3 0.1	4.8 0.1	4.7 0.1	4.5 0.0
1986	$\bar{x}$ SE	7.0 0.3	7.0 0.2	5.5 0.1	5.2 0.1	5.1 0.1	5.0 0.1	4.8 0.1	4.5 0.1	4.4 0.0	4.3 0.0
1985 x 1986	CI[3]	0.73± 0.6	0.4 ± 0.2*	1.2 ± 0.2*	0.4 ± 0.2*	0.1 ± 0.3	0.3 ± 0.2*	0.5 ± 0.3*	0.5 ±0.3*	0.3 ± 0.2*	0.2 ± 0.1*
1987	$\bar{x}$ SE	6.7 0.3	6.8 0.2	6.8 0.3	6.3 0.2	5.5 0.1	5.3 0.1	5.0 0.1	4.7 0.0	4.5 0.0	4.4 0.1
1986 x 1987	CI	0.3 ± 0.8	0.2 ± 0.6	1.3 ±0.2*	1.1 ± 0.2*	0.4±0.3*	0.3± 0.3	0.2± 0.3	0.2 ± 0.2	0.1 ±0.1	0.1 ± 0.1
1985 x 1987	CI	0.6 ± 0.6	0.6 ± 0.2*	0.1± 0.8	0.7 ± 0.6*	0.3 ± 0.2*	0.0 ± 0.2	0.3 ± 0.3	0.3 ± 0.2*	0.2 ±0.1*	0.1 ± 0.1
1984	$\bar{x}$ SE	5.2 0.1	5.2 0.1	5.2 0.1	5.2 0.1	5.1 0.1	4.8 0.1	4.6 0.1	4.5 0.1	4.4 0.1	4.3 0.1
1984 x 1985	CI	2.1 ± 0.4*	2.2 ± 0.2*	1.5 ± 0.2*	0.4 ± 0.2*	0.1 ± 0.3	0.5 ± 0.2*	0.7 ± 0.2*	0.5 ± 0.2*	0.3 ±0.3	0.2 ± 0.1*
1985 x 1987	CI	1.5± 0.2*	1.6 ± 0.2*	1.6 ± 0.4*	1.1 ± 0.2*	0.4 ± 0.3*	0.5 ± 0.3*	0.4 ± 0.3*	0.2 ± 0.2	0.1 ±0.1	0.1 ± 0.1

1 - Mean of 9 samples
2 - Standard error
3 - Confidence interval
*- Significantly different at $p \leq 0.05$; confidence intervals that do not include 0

Table A11. Comparison of 1984, 1985, 1986 and 1987 Electrical Conductivity Data from Site 2.

		Depth (cm)									
Year	Stat.	0 - 4	4 - 8	8 - 12	12 - 16	16 - 20	20 - 24	24 - 28	28 - 32	32 - 36	36 - 40
1985	$\bar{x}$[1] SE[2]	7.2[4] 0.5	6.4 0.6	4.2 0.3	2.8 0.3	1.8 0.2	1.0 0.1	0.7 0.0	0.5 0.0	0.5 0.0	0.5 0.0
1986	$\bar{x}$ SE	3.4 0.3	3.5 0.4	2.4 0.1	1.9 0.1	1.6 0.1	1.4 0.1	1.3 0.1	1.2 0.1	1.1 0.1	1.0 0.1
1985 x 1986	CI[3]	3.8 ± 1.3*	2.9 ± 1.4*	1.8 ± 0.4*	0.9 ± 0.2*	0.12± 0.5	0.4 ± 0.3*	0.56± 0.2*	0.56±0.2*	0.36± 0.2*	0.25± 0.2*
1987	$\bar{x}$ SE	1.7 0.2	2.0 0.2	2.0 0.3	1.8 0.2	1.6 0.2	1.6 0.2	1.7 0.1	1.7 0.1	1.5 0.1	1.4 0.1
1986 x 1987	CI	1.7 ± 0.7*	1.5 ± 0.9*	0.4 ± 0.4	0.1 ± 0.5	0.0±0.4	0.2 ± 0.4	0.4± 0.4	0.5 ± 0.4*	0.6 ± 0.4*	0.4 ± 0.3*
1985 x 1987	CI	5.5 ± 0.7*	4.4 ± 0.7*	2.2 ± 0.9*	1.0 ± 0.8*	0.2 ± 0.6	0.6 ± 0.4*	1.0 ± 0.2*	1.2 ± 0.2*	1.0 ± 0.2*	0.9 ± 0.1*
1984	$\bar{x}$ SE	1.2 0.2	1.3 0.1	1.2 0.1	1.5 0.2	1.5 0.1	2.0 0.4	2.3 0.2	2.5 0.3	2.5 0.3	2.6 0.1
1984 x 1985	CI	6.0 ± 0.7*	5.1 ± 0.7*	3.0 ± 0.4*	1.3 ± 0.8*	0.3 ± 0.5	1.0 ± 0.5*	1.6 ± 0.5*	2.0 ± 0.5*	2.0 ± 0.5*	2.1 ± 0.2*
1985 x 1987	CI	0.5± 0.6	0.7 ± 0.6*	0.8 ± 0.4*	0.3 ± 0.7	0.1 ± 0.5	0.4 ± 0.5	0.6 ± 0.5*	0.8 ± 0.5*	1.0 ± 0.5*	1.2 ± 0.3*

1 - Mean of 9 samples
2 - Standard error
3 - Confidence interval
4 - Units are mS/cm
* - Significantly different at $p \le 0.05$; confidence intervals that do not include 0