Effects of Sedge Peat Decomposition on Selected Soil Properties and Phytotoxicity of Soil Applied Herbicides.

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© Craig N. Maxwell

A thesis
presented to the University of Manitoba
in partial fulfillment of the
requirements for the degree of
Master of Science
in
Plant Science

ISBN Ø-315-34Ø73-8

EFFECTS OF SEDGE PEAT DECOMPOSITION ON SELECTED SOIL PROPERTIES AND PHYTOTOXICITY OF SOIL APPLIED HERBICIDES

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ABSTRACT

Maxwell,C.N.,M.Sc.,The University of Manitoba,March,1986. Title:Effects of sedge peat decomposition on selected soil properties and phytotoxicity of soil applied herbicides. Major Professor: Dr. M.K. Pritchard.

Field,greenhouse,laboratory and growth room experiments were conducted on sedge peat soils from the same location in eastern Manitoba that had been sequentially brought into cultivation in 1962,1975,1980 and 1981.Several soil properties were used to characterise peat decomposition status, and bioassays were used to measure the effects of peat decomposition on the activity of the soil applied herbicides; chlorpropham (isopropyl-m-chlorocarbanilate), linuron (3-(3,4-dichlorophenyl)-1-methoxy-1-methylurea), and pronamide (3,5-dichloro-(N-1,1 dimethyl-2-propynyl) benzamide).

Organic matter, determined at 400°C, decreased as decomposition advanced, as did organic carbon content measured with the Walkley Black technique. The fibre content by both unrubbed and rubbed evaluations proved to be good indicators of decomposition status. Bulk density, determined by two laboratory methods, increased with peat decomposition. The preferred technique for bulk density determination was the constant water potential method rather than the oven dried technique. Uniform compaction of the different soils was required as the bulk density was strongly dependent on compaction. Hygroscopic coefficient also showed merit as a tool for the measurement of peat decomposition.

Investigations with linuron in field and greenhouse experiments in 1981 indicated slightly increased control of crop and weed growth on the less decomposed peats compared to the 1962 breaking. The tendency was reversed for the chlorpropham treatments where lettuce growth was more inhibited due to increased herbicide activity on the most decomposed peat. Pronamide showed no trends for changed activity on differentially decomposed peats, but exhibited unexpectedly good weed control on organic soils. Growth room herbicide adsorption studies using phage dish bioassays did not confirm these observations. The range of sedge peat decomposition studied may have been too small to differentially affect herbicide adsorption as all peats were mesic. Herbicide inactivation by soil organic matter could not be associated with any of the soil properties due to the difficulties encountered in trying to quantify herbicide activity using bioassay techniques with peat soils.

ACKNOWLEDGEMENTS

I was very fortunate to have Dr. Merv Pritchard as an advisor for the bright atmosphere in which he directed my research and ready wit that sustained it. His patience, guidance when I was side-tracked by confounding problems,and encouragement contributed greatly to the completion of this project.

I would also like to thank my committee members, Dr. Ian Morrison and Dr. Barry Webster who helped me to circumvent the difficulties in the research stage by informed suggestions of alternate techniques.I am also thankful to Dr. George Marshall and Dr. Ghaus Choudhry who encouraged me greatly during the preparation of the manuscript and for their constructive and thought provoking queries of areas that needed clarification.

Special thanks go to Mary de Pauw who was wrenched away from social activities to the novel experiences of interpreting my manuscript and the nuances of feeding it to the computer. Working in the Plant Science Department was enhanced by the friendship and help extended by all of the students and staff particularly Lorne Adam and John Watson. To all the friends inveigled into the monotony of root measuring, I can only hope that the Pinawa parties compensated you.

Last, and by no means least, I would like to thank my family for their concern, interest and support during my sojourn in Winnipeg.

DEDICATION

HERRICK:-

Putrefaction is the end

Of all that Nature doth entend.

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INTRODUCTION

It is estimated that 0.6×10^6 ha of peat soils are potentially arable in Manitoba representing almost 20% of the 3.2×10^6 ha of marginally arable mineral soil reserves in the province. The major usage of the organic soil currently under cultivation is for forage,sod, and cereal production. The high cost of drainage and land clearance may be justified most readily by horticultural development of adapted crops, particularly vegetable and sod production.

Early and residual weed control, especially in shallow rooted crops, is critical but rendered difficult due to sorption of soil-applied herbicides by the organic matter component of the soil. The complex sorption and consequent inactivation of the herbicides by organic soils may be affected by decomposition of the soil, by pH, and by transition metals that affect the organic matrix.

Recommendations for certain herbicides indicate that they may be inactivated by high organic matter contents implying inactivity on peats. At higher than normal herbicide rates this may not be true, particularly on some forms of peat, due to origin or decomposition status.

In this study soils were obtained from the same general location but which had been under cultivation for different periods of time. Various

techniques were used to determine the physical and chemical properties of the peat in an attempt to correlate the peat decomposition to those properties.

Bioassays were used to determine the bio-availability of desorbed or non-sorbed linuron, chlorpropham, and pronamide on these organic soils and to correlate sorption with rapid diagnostic tests of soil decomposition.

Chapter II

LITERATURE REVIEW

2.1 INTRODUCTION

Soil-applied herbicide activity is often most closely correlated with organic matter content (Dutt and Harvey, 1980; Hayes, 1970; Bailey and White, 1970; Adams, 1973). Organic matter decreases the phytotoxicity of herbicides by the rapid sorption of molecules by physical and chemical bonding dependent on the nature of the pesticide (Choudhry, 1984; Sposito, 1984). Sorption is comprised of the physical surface Van der Waal's interactions and hydrogen bonds characterising adsorption and (in practice difficult to distinguish from) the longer term chemical bonding and incorporation into the organic matrix of absorption (Worobey, 1980; Khan, 1973; Wauchope and Meyers, 1985). The rapidly acting forces of adsorption and desorption affect the response of the pesticide to physical, chemical, and microbial decomposition, volatilisation, and leaching and most pertinently influence, either directly or indirectly, pesticide phytotoxicity (Bailey and White, 1970). The extent of herbicide adsorption is dependent upon the nature of both the pesticide and the adsorbent organic matter (Adams, 1973; Bailey and White, 1970).

2.2 NATURE OF THE HERBICIDE

The nature of the herbicide affects its water solubility, and may be ameliorated by formulation and adjuvants. In 1967, Lambert (also Briggs, 1981) suggested that solubility in water was a function of molecular volume, or parachor, and the ability to form hydrogen bonds with the solvent. Solubility, however, was found to be important to adsorption only at high concentrations, while at field and even experimental rates the nature of the adsorbent become more important in herbicide activity (Van Bladel and Moreale, 1977). Solubility may be reduced in quasicrystalline water when the water molecules are more ordered by adsorption (Low, 1962). The adsorption of water molecules is dependent upon the nature of the colloidal surface (Kay and Goit, 1977; Chen and Schnitzer, 1976b) and inversely related to temperature (Taylor, 1972). The influence of water and organic matter on herbicide adsorption are more comprehensively discussed in later sections of the review.

A characteristic of herbicides commonly associated with adsorption is the octanol:water partition coefficient (Briggs, 1981; Christ, 1978; Bastide, Cantier and Coste, 1981) which is also dependent on the hydrophobic:hydrophilic balance of the herbicide (Hance, 1967). The less ionised herbicides have higher solubility in the non-polar solvent. Hydrophobic adsorption is frequently cited for the molecular form of herbicides adsorbed to non-polar regions of the adsorbent (Grover, 1971; Kozak, Weber, and Sheets, 1983; Nearpass, 1976; Van Bladel and Moreale, 1977; Weber and Peter, 1982). Kozak, Weber, and Sheets (1983) ascribed the adsorption of molecular prometryn to hydrophobic adsorption. They attributed adsorption to low solubility in water, however the non-

ionisable metalochlor was not thus adsorbed as the solubility was 530 ppm. Hydrophobic adsorption results from repulsive dissolution by surface tension of the water, while metalochlor was adsorbed by lipophilic or positive attraction by non-polar surfaces. The lipophilic adsorption is due to Van der Waal's interactions of flickering dipole attraction (Kozak et al, 1983; Nearpass, 1976) and by π bonding of aromatic nuclei of the pesticide and adsorbent (Weber and Peter, 1982).

A partial charge may be induced in the molecular form of the molecule by a charged group on the adsorbent resulting in polarization enabling Van der Waal's interaction. A lone electron pair permits hydrogen bonding, frequently between an amide or carboxylic group on non-ionic pesticides such as substituted ureas (Khan and Mazurkewich, 1974; Stevenson, 1974), carbamates (Stevenson, 1974; Ward and Upchurch, 1965), and acetanilides (Weber and Peter, 1982).

Charged pesticides are most strongly adsorbed (Stevenson, 1974) particularly the bipyridilliums and the substituted triazines. Some authors found that pH affected adsorption of these ionic pesticides in both clays and organic matter (Hance, 1969; Van Bladel and Moreale, 1977; Nearpass, 1976; Kozak, Weber and Sheets, 1983) in the diprotonated form. Other authorities reported variation of adsorption with pH only on predominantly clay soils, with organic soils moderating the effect due to protonation of the pertinent functional groups on the soil also (Harris and Warren, 1964; Talbert and Fletchall, 1965). The difference is partially explained by the use of mineral soils by the former groups cited, except for Kozak,Weber and Sheets (1983) who were using different organic fractions with pH dependent adsorption to the humic fraction, and Nearpass (1976) using peat fractions.

Weber (1980) found pH dependent complexing of the following basic herbicides: fluridone, tebuthiuron, and buthidazole with organic matter. The bonding involved with the basic herbicides is often by charge transfer complexes, ligand exchange to transition metals, and or ion exchange on sulphide and carboxylic groups (Bailey and White, 1970; Choudhry, 1984; Hayes, 1970).

2.3 NATURE OF ORGANIC MATTER

Organic matter in the soil provides non-polar adsorption sites in the form of fats, waxes, and resins in the non-humic fraction for hydrophobic bonding (Morita, 1976). Additional fatty acids are produced by anaerobic decomposition of proteins with the release of ammonia (Gray and Williams, 1971). Kozak,Weber and Sheets (1983) included stable proteins as hydrophobic adsorption sites. Weber and Peter (1982) suggested π bonding for benzene ring of planar herbicides to aromatic nuclei in organic matter as another form of hydrophobic sorption. Aliphatic side chains on humified organic matter were also suggested as hydrophobic adsorption sites by Stevenson (1974). The non-polar bonds form without competition by water molecules (Choudhry, 1984).

The main forms of molecular herbicide bonding are by Van der Waal's interactions and hydrogen bonding. Van der Waal's forces are formed from very short range dipole-dipole interactions, but there is competition at the surface of the adsorbent with water (Choudhry,1984; Khan, 1973). Hydrogen bonds are formed by the covalent sharing of the lone pair electrons of the adsorbed herbicide or adsorption site with an interposed hydrogen atom, linked by electrostatic forces to the other moiety. The most common sites are carboxyl, amine, and carbonyl that

form weak to moderate hydrogen bonds, while more stable bonds are formed at phenyl hydroxy sites (Sposito, 1984).

The amount of herbicide, using atrazine and linuron in fresh water sediments, adsorption per gram of organic matter varies less than adsorption per gram of soil (Wauchope and Meyers, 1985). Some authorities found K_0 or Q (adsorptive capacity of organic matter in ug herbicide g^{-1} organic matter, at equilibrium solution concentration of 1 ug mL^{-1}) to be constant for a given herbicide (Grover, 1971 and 1975; Briggs, 1981; Lambert, Porter and Schifferstein, 1965; Wauchope and Meyers, 1985). Other authorities, however, found differences due to originating plant material (Gaillardon, Gaudry and Calvet, 1983; Talbert and Fletchall, 1965), different stages of decomposition (Morita, 1976), or a mixture of the two by location (Mappelbeck and Waywell, 1983; Doherty and Warren, 1969). Further speciific differences in adsorption are mentioned during the passive stage of plant uptake by Leopold, van Schaik, and Neal (1960), by Tames and Hance (1969) and by Morrison and Van den Born (1975). Increasing organic matter content may decrease the amount of herbicide adsorbed per gram of organic matter due to interactions within the organic matter reducing the number of available sites (Deli and Warren, 1971).

The different organic matter fractions may have varying adsorptive capacities with lignin being the most adsorptive (Weber and Peter, 1982; Gaillardon, Gaudry, and Calvet, 1983). Lignin is the most slowly degradable plant tissue, but interactions with humified materials mask the total adsorption from individual fractions (Gaillardon et al, 1983; Nearpass, 1976).

Several other characteristics of the organic matter and of organic soils may be associated with decomposition and adsorption, and those studied are discussed in the following sections.

2.3.1 Carbon Content

The organic carbon content of the soil is a major factor affecting adsorption (Choudhry, 1984; Dutt and Harvey, 1980). The carbon recovery, however, is method dependent (Allison, 1960), due to incomplete oxidation of organic matter at various temperatures, whether by wet or dry combustion. The conversion factors of carbon to organic matter range from 1.6 to 3.3 (Chapman and Pratt, 1978) and are thus a source of error. Recent legislation in the U.S.A. has banned the use of chromic acid used previously as a standard in wet combustion techniques. Altering the method affects the carbon containing moieties digested and also the degree of correlation with adsorption (Weber and Peter, 1982).

Adsorption may be measured as the milligrams of herbicide adsorbed per gram of soil, or per gram of organic matter (K_0 or Q), or per gram of organic carbon (K_0). In organic soils the latter two parameters provide the most meaningful measurements due to the slight effects of the mineral fraction of the soil (Sposito, 1984).

2.3.2 Fibre Content and Particle Size Analysis

Fibre content and particle size analysis are linked by a convention derived from sphagnum peat whereby all particles retained on a 100 mesh (0.15 mm) sieve are termed fibres (Levesque, Morita, Schnitner, and Mathur, 1980; Levesque and Dinel, 1977).

The effect of particle size on nutrient mineral adsorption has been examined by Puustjarvi (1976) and Williams (1983) who both found a decrease of particle size with decomposition and a concommitant increase in mineral content which they attributed to increased adsorptive surface area. Both authors also found more variable adsorption with large particles. Williams (1983) suggested that larger particles had more labile (reactive) functional groups that were prone to mineralisation resulting in variable adsorption.

The adsorbtive capacity (K) of peats for linuron were studied by Morita (1976). It was found that the more decomposed sedge peats had greater Freundlich K values than less decomposed sphagnum peats. The correlation coefficient of linuron adsorption to fibre content was r= -0.84, implying that linuron adsorption is affected by fibre content. The effect was negated 50 days after herbicide application due to irreversible binding to hydrophobic moieties such as fats, waxes, and resins (Morita, 1976), or by drying of the sample.

Bailey and White (1964 and 1970) found increased herbicide adsorption was linked to increased surface area with decreased particle size. Chen and Schnitzer (1976b) found that the surface area of fulvic acids were three percent greater than humic acids and exhibited higher water adsorption. The surface area of soils was artificially increased by dispersion in slurry experiments disrupting aggregate structure and increasing the adsorptive capacity (K) of soils (Green and Obien, 1969). The fibre content measured on a percentage volume basis by Kay and Goit (1977) reflected a decrease in water adsorption with increased decomposition. The effect occurred despite an increased surface area, and was

due to increased percentage of hydrophobic lignin content in the more decomposed sample, that may account for the discrepency of their results from those that follow.

2.3.3 Water Content

The water content of soils may be measured on a weight basis as the gravimetric water content (w):-

$$w = \frac{\text{weight of water in soil}}{\text{weight of oven dry soil}}$$

The volumetric water content (Θ) is determined on a volume basis:-

$$\Theta = \frac{\text{volume of solution}}{\text{volume of wet soil}}$$

The two are related by bulk density such that:-

$$\Theta = w \times \text{bulk density}$$

(Shaykewich, 1981; Boelter, 1968).

At low water potentials, in "dry" peat, the water is strongly bound to the organic matter as a gel (Barden and Berry, 1968; Volvarich, Korol, Lishtvan, Mamtesis and Churaev, 1975; Kay and Goit, 1977; Schnitzer and Desjardins, 1966). The authors attribute most of the strong adsorption to hydrogen bonding at carboxyllic groups, while Schnitzer and Desjardins (1966) included carbonyl groups. Most of the authors found that water adsorption increased with decomposition at low water potentials (increased numeric value, but negative potential) (Barden and Berry, 1968, Given and Dickenson, 1975; Schnitzer and Desjardins, 1966). The strong adsorption decreases the solubility of

ions and increases the energy of evaporation from 2.317 kJ per mol in free water to 3.583 kJ per mol when adsorbed as a gel to peat organic matter (Volvarich et al., 1975). The effect of adsorption is increased by the presence of multivalent ions such that 67-82% of water on a wet peat basis is affected to form a gel. Sodium and potassium return the water to a solution, but even so 38-56% of the water is weakly bound to the peat, while 9-13% is still strongly bound (Given and Dickinson, 1975). The net effect is that peat soils create their own water tables (Puustjarvi, 1978; Shaykewich, 1981), and soil solutions have lower solubility for ions (Low, 1962).

At higher water potentials most water is weakly bound in large pores the size of which decrease with decomposition, decreasing fibre content, increased compaction, or decreased particle size (Puustjarvi, 1978; Boelter, 1968; Walmsley and Lavkulich, 1975). Most authors reported the water content as gravimetric water content. The authors also found that large pores released water most easily, while small pores retained the water strongly. Thus, at saturation, less decomposed peats hold more water than more decomposed peats but this is more readily lost at high water potentials.

Gravimetric water percentages indicate that undecomposed peats contain more water than decomposed peats, but when the bulk density is also considered, undecomposed peats only have more volumetric water from 0 until -50 kPa. At lower water potentials (greater numeric value) the volumetric water percentage is greater for more decomposed peats (Boelter, 1968).

The more decomposed peats contain more available water on a volumetric basis than undecomposed peats, and fen peats more than woody peats which contain substantially more volumetric water than sphagnum moss on equipotential or moisture equivalence basis (Boelter, 1968).

Herbicide availability is affected by rainfall as shown by the increased phytotoxicity of pronamide (Carlson, Lignowski and Hopen, 1975) and linuron (Maier-Bode and Hartel, 1981) after rainfall, and dinitramine activity following surface or sub-surface irrigation (Okafor, Sagar, and Shorrocks, 1983) on mineral soils. In studies of herbicide activity in different soils Moyer (1979) found that the correlation of activity of dinitroaniline herbicides on wild oats was reduced from 0.94 with organic matter at constant moisture contents to 0.80 when the moisture content varied.

Green and Obien (1969) believed that the effect of moisture on herbicide activity was a dilution effect in the available water range evidenced only on soils of low adsorptive capacity. In 1972, Moyer, McKercher, and Hance showed that monuron and diuron were completely desorbed from peat if maintained at 99% relative humidity. Some irreversible sorption occurred if the humidity was lowered to 62%. Prometryn and linuron showed some irreversible sorption at both humidity levels, although greater absorption occurred at 66% relative humidity. In practice, only the surface layer of peat would dry below the 99% humidity level, but the experiment showed the need for rapid incorporation.

Further work on mesic peat by Hogue in 1976 showed that the moisture content during the application of linuron affected the susceptibility of tomato and mustard bioassays despite subsequent irrigation immediately following treatment. In root mat exposure experiments to wet and dry treated peat soils, the moist soils caused greater injury to the bioassay plants. The most dramatic effect was a 93.3% reduction in tomato growth with a soil moisture content of 200% compared with an 18.7% reduction in growth with the same mesic peat at 50% moisture content.

Removal of moisture effects on herbicide activity in bioassays is normally accomplished by using soils at field capacity (Webster, Shaykewich, Kanhai and Reimer, 1978). The need for removal of available moisture effects on bioassay growth were shown by Ward and Upchurch (1965) and Stickler, Knake and Hinesley (1969). At higher levels of available water the control plants grew more rapidly affecting the expression of the treatments. The free water in pore spaces has a water potential of 0 bars and thus saturated soils have the same water potential, and was used by Savage (1973) and Savage and Wauchope (1974) to prevent moisture from influencing the adsorptive capacity of soils. Excessive water and shaking of slurries prevents the establishment of accurate adsorption data due to aggregate disruption overestimating the adsorptive capacity of soils (Green and Obien, 1969; Liestra and Dekkers, 1976; Savage and Wauchope, 1974). Some of the error associated with the slurry method may be decreased by using soils with similarly sized particles (Williams, 1983).

2.3.4 Bulk Density

Bulk density for peats is expressed as the oven dry weight of either field moist or oven dry volume of the soil (Boelter, 1968). The volume of peat soils changes with dessication (Millette and Broughton, 1984). Boelter and Blake (1964) found muck soils to swell to the greatest extent, while herbaceous peats were intermediate and sphagnum mosses exhibited the least volume changes with moisture.

Cultivation increases the bulk density of peat by breaking down the fibres and thus reducing the pore volume (Jasmin et al., 1981). There is, however, no correlation of bulk density with fibre content (Levesque, Morita et al., 1980). Bulk density of wood peats from several Ontario locations increased linearly with respect to the 10 point Von Post decomposition scale. Increases in bulk density were 0.02 g cm^{-3} per humification stage, with a range of bulk densities from 0.07 to 0.23 g cm^{-3} (Silc and Stanek, 1977). The relationship was specific to woody peats and not applicable to other peat types (Vigier and Campbell, 1980). Puustjarvi and Robertson (1975) showed a similar relationship existed for sphagnum mosses also.

Peat bulk density varies with plant origin such that fen>forest>sphagnum peat (Walmsley and Lavkulich, 1975). Bulk density within ecotypic classifications is correlated positively with ash content, although the relationship is non-linear (Maclean et al., 1964).

Bulk density not only characterizes different stages of decomposition (The Canadian System of Soil Classification, 1978) but affects the volumetric water content of the soil (Boelter, 1964) and reflects the porosity also (Jasmin et al., 1981). In crop and bioassay situations

the soil applied herbicides are often cultivated or mixed into a fixed depth or volume of soil and the soil dilution (Sheets, 1958) will be by greater amounts of organic matter with increased bulk density.

2.3.5 Decomposition and Colorimetric Determinations

The physical characteristics of peat that change with decomposition, such as fibre content, result from chemical changes that are difficult to follow due to the complexity of the humic materials (Levesque, Morita, Schnitzer, and Mathur, 1980). The original constituent plant chemicals are transformed into hydrophilic, dark-coloured, chemically complex polyelectrolytes. The polyelectrolytes have molecular weights ranging from a few hundred to several thousand and exhibit the aromatic properties of substitution reactions (Schnitzer and Khan, 1972). The polymers are three dimensional which increases the difficulty of analysis, exemplified by the inability to characterize even simple three dimensional polymers like urea formaldehyde (Tan, 1982). The mesh-like structure may be important due to adsorption of pesticides within the matrix (Khan, 1973).

Most research has been done on the humic and fulvic acid extracted from mineral soils, and thus concentrated on well decomposed organic matter. Those decomposition products result primarily from the transformations associated with the lignin cycle of decomposition (Felbeck, 1971; Cherkinskiy, 1981; Schnitzer and Khan, 1972; Tan, 1982; Worobey, 1980). The functional groups studied were mainly carbonyl, carboxyl, alcoholic hydroxyl and phenolic hydroxyl moieties.

Early decomposition shows greater effects of plant type upon decomposition as angiosperm plants have differing quantities and types of lignic phenols than gymnosperm plants, and the phenolic contents increase with secondary thickening (Whitehead, Dibb and Hartley, 1981; Mason, 1955; Gray and Williams, 1971). Sphagnum mosses only contain the phenolic precursors of lignin (Volvarich, Korol, Lishtvan, Mamtesis, and Churaev, 1975).

The phenols in lignin, derived from the Shikimic Acid Pathway, are transformed by aerobic fungi of the ascomycetes and basidiomycetes via ligases and physical penetration by rhizomorph mycelia to carboxyllic acids of humic and fulvic acids (Broadbent, 1953; Volvarich, Korol, Lishtvan, Mamtesis, and Churaev, 1975; Gray and Williams, 1971; Martin and Haider, 1971). This type of degradation may only proceed after drainage and following initial degradation by sugar fungi and bacteria (Garrette, 1981) and develops in concert with mesofauna activity in secondary degradation (Broadbent, 1953; Gray and Williams, 1971; Babel, 1975; Garrette, 1981).

Primary degradation of peat involves the more reactive polysaccharides and reactive, or labile portion of organic matter (Cherkinskiy,1981; Garrette, 1981). The sugar-amino acid pathway predominates over the lignin pathway of decomposition, particularly in continental climates that pertain in Manitoba and especially during primary decomposition (Stevenson, 1982; Morita, 1983; Tyuremnov, 1976). Monosaccharide differences with decomposition and plant origin were shown by Lowe (1978), Morita (1983), Morita and Sowden (1981) and Morita, Levesque and Mills (1980).

Peat extracts derived from sodium pyrophosphate show increased absorbance of light at 550 nm due to the formation of chromogenic compounds with decomposition. The pH of the extract affects the colour derived by increased extraction efficiency at high pH (Ivarson, 1977; Whitehead, Dibb and Hartley, 1981) or by altered oxidation state of the chromogenic compounds (Morita, 1980).

Conjugated dienes were proposed as chromogenic compounds by Felbeck (1971) especially with nitrogenous substituent groups that also stabilize the diene structure. The dienes may be responsible for π bonding aromatic nuclei of herbicides (Weber and Peter, 1982) while the nitrogenous amines may facilitate hydrogen bonding to carboxyllic groups on the herbicide (Sposito, 1984; Ward and Upchurch, 1965). Sodium pyrophosphate extracts these hydrophobic chemicals as a gel suspension, extracting groups responsible for hydrophobic partitioning of herbicides from solution (Grover, 1966; Kozak, Weber, and Sheets, 1983; Stevenson, 1974; Van Bladel and Moreale, 1977; Hance, 1967).

Phenols and polyphenols form coloured compounds, particularly following demethoxylation by phenoloxidase enzymes from plant cytoplasm or microbial origin (Davies, 1971; Mason, 1955; Haider, Frederick and Flaig, 1965, Martin and Haider, 1971; Gray and Williams, 1971). Phenolic hydroxyls have been implicated in sorption by Sposito (1984), Hayes (1970) and Weber and Peter (1982). The removal of methoxy groups forms quinones, semiquinones, and iminoquinones that have been implicated as chromogens (Flaig, Beutelspacher and Rietze, 1975; Broadbent, 1953; Levesque, Morita, Schnitzer and Mathur, 1980). As free radicals, these groups are capable of forming polarization Van der Waal's interac-

tions with molecular herbicides (Adams, 1973; Bailey and White, 1964) or polymerise with herbicides (Choudhry, 1984). Phenolic amides formed by polycyclic substitution (Mason, 1955) are also coloured and react with carboxyllic groups on herbicides to form hydrogen bonds (Ward and Upchurch, 1965). Highly coloured polyphenolic glycosides are released from plant tissues (Davies, 1971) or may form from microbial decomposition (Mason, 1955).

Chelation of transition metals form coloured compounds also (Greenland, 1971; Davies, 1971),and ligand formation as chelates occurs with basic herbicides (Worobey, 1980; Choudhry, 1984; Bailey & White, 1970; Hayes, 1970; Adams, 1970).

Most of the colour, however, is due to the presence of hexoseamines formed by either direct chemical reaction or microbially mediated (Stevenson, 1982; Morita and Sowden, 1981). The chromogenic compounds can be linked to adsorption by hydrogen and π bonding as cited above, and should provide information on organic matter adsorption as affected by decomposition.

2.3.6 pH and Cation Exchange Capacity

It has been well documented that pH affects the cation exchange capacity (Kononova, 1966; Andre and Pijarowski, 1977; Sanders and Bloomfield, 1980), such that increased pH increases the cationic exchange capacity. McLaren, Williams, and Swift (1983) using humic acid, soil oxide, and montmorillonite in copper solution, found the reverse to be true, with decreasing copper adsorption on the humic acid above pH 5. The former viewpoint was theoretically backed by Russell

(19730 who wrote that the polymer is easier to acidify as increasing the pH results in polymer swelling, exposing more carboxyl groups that buffer the pH of the polymer and provided more sites for cationic exchange. Empirically, as peat decomposes, the pH increases (Kononova, 1966; Morita and Sowden, 1981; Walmsley and Lavkulich, 1975; MacLean, Jasmin and Halstead, 1967).

Schnitzer and Desjardins (1966) found that more decomposed soils had higher pH due to coordination complex formation with transition metals and ion exchange. The cation exchange capacity was restored by treatment with a hydroflouric acid and hydrochloric acid mixture. Decomposition was thus expected to increase the pH and the total:exchangeable cation ratio. Khan and Mazurkewich (1974) found that linuron did not form bonds to the organic matrix in humic acids via cation bridges, although adsorption was moderated by the saturating cation, as shown by Hance (1969).

The measured pH is also affected by handling of the samples prior to evaluation such that air or oven drying decreases the values by 0.6 pH units in 0.1M $CaCl_2$ $2H_20$ (Van Lierop and Mackenzie (1977). The electrolyte may also reduce the pH by 0.44 ($CaCl_2$) or 0.70 units (KCl) (Van Lierop, 1981).

The above differences were also detected by Stanek (1973) who found the greatest decrease in measured pH of 0.6 for 0.1M $CaCl_2$ $2H_20$ from that measured in 1:1 soil:water. Van Lierop and Mackenzie (1977) also found that suspended organic matter decreased the pH value (by 0.27 units) below that recorded in clear supernatant solutions. They also

found that the pH of the supernatant and sediment varied by up to 0.8 pH units. The seasonal time of sampling affected the pH registered, and the variation was greater in 0.01M $CaCl_2$ $2H_2O$ (0.80 units) than in 1M KCl (0.2 units) (Van Lierop and Mackenzie, 1977).

The variability may be additive or not, but reflects a problem of ascribing a pH value to the soil. Stanek (1973) stated that for practical purposes any of the recommended electrolytic solutions or water would provide the necessary information. Electrolytic solutions are used to decrease the variability between readings due to high salt levels in some soils that decrease the pH by compressing the double ion layer at the solution:soil interface (Van Lierop and Mackenzie, 1977). Schofield and Wormald Taylor (1955) found reduced salt effects by using 0.01M $CaCl_2$ entailed a pH decrease of 1.14 pH units, but reduced data variability by maintaining a complete Gouy's double layer without anion interference at the interface (as occurs in high chloride soils). Later workers neglected to subtract the constant correlation factor of 1.14 pH units from pH measurements in water as the objective was to compare soils and not to have absolute values. Absolute values may be found to be critical in adsorption studies with organic matter for Chen and Schnitzer (1976a) found major changes in humic and fulvic acid structure under a scanning electron microscope with pH, changing from open fibre bundles at low pH, to a spongelike mesh of finer fibres at pH 7 and homogenous sheets at pH 10 that will reduce the active surface area. Cations also greatly affected the fulvic acid structure at pH 5 with different effects due to different cations, all of which increased the thickness of the fibre bundles and thereby decreased the surface area. The effect of decreasing the surface area would be greatest on the

largest part of the polymer, namely the non-polar regions that bind to herbicides (Sposito, 1984).

2.4 ANALYTICAL TECHNIQUE FOR AVAILABLE HERBICIDE DETERMINATION

The interpretation of herbicide and residue data derived from instrumental methods to activity in field situations is difficult due to the determination being made for solvent extractable rather than plant available residues (Webster, Shaykewich, Kanhai and Reimer, 1978). The use of water as a solvent determines the readily soluble fraction and has been used in bioassay determinations also (Eshel and Warren, 1967; Stalder and Pestemer, 1980). The use of water as the solvent, however, leaves the weakly bound, plant available residues undetermined. Availability of the herbicide to plants is also affected by root exudates (Harris and Warren, 1964; Maier-Bode and Hartel, 1981) and by adsorption properties of roots mentioned earlier in this Literature Review. Plant maturity affects phytotoxicity of herbicides (Kohn, 1980; Maier-Bode and Hartel, 1980) and the climatic variables also influence growth rate and herbicide effects on plants (Hurle, 1977; Kohn, 1980; Eberle and Gerber, 1976). A petri dish bioassay developed in 1966 by Parker reduced the number of climatic variables affecting the assays, the duration of the assay, and plant variability due to environmental factors by using uniform seedling populations in sealed environments (Parker, 1966). The major variables affecting development of the bioassays were edaphic, and provided reproducable results essential to good bioassays (Nyffeler, Gerber, Hurle, Pestemer and Schmidt, 1982; Eshel and Warren, 1967).

The major benefit of whole plant bioassays is the ability to modify soil environments to observe changes in herbicide activity on plants to enhance our understanding of herbicidal activity in the field and the factors modifying that activity (Hogue, 1976; Rivera and Penner, 1978). Comparison of herbicide activity between different soils is often confounded by altered growth characteristics of even control assays due to edaphic factors. A commonly used transformation is to express the growth of treatment plants as a percentage of growth of control plants (Mapplebeck, 1980; Hogue, 1976; Nyffeler et al., 1982).

Bioassay accuracy is affected by the growth parameter measured (Marriage, 1975; Nyffeler et al., 1982). Root and stem elongation were used in the Parker (1966) method and recommended by Nyffeler et al., (1982). The Parker bioassay is most applicable to mitotic inhibitor herbicides rather than photosynthetic herbicides due to the long lag phase prior to activity with the latter herbicide category (Nyffeler et al., 1982; Eberle and Gerber, 1976).

Chapter III

MATERIALS AND METHODS

3.1 TEST SITE

Experiments were conducted on a farm with peat soils located at NW9-11-8E near Vivian, Manitoba; about 60 km east of Winnipeg. The soil had been drained and part of the farm brought into production in 1962 (Gusta, 1965).More land was drained in the fall of 1972 and 1978, the former being brought into production in the fall of 1975, and the latter in the fall of 1980 and 1981 (Figure 1). The soils are named throughout the experiments as the date of the year of breaking and cultivation (thus 1962 refers to the soil broken in the fall of 1962 for cultivation in 1963, and likewise for 1975, 1980, and 1981). The final soil type, 1981, is only referred to following sampling in 1982 and 1984. The initial 3 years of cultivation are believed to be the most critical period of decomposition of limed sphagnum bogs (Morita,1981), so the change of locations from 1981 to 1982 (Figure 2) was done so to utilise freshly broken soils for continuity. The 1975 and 1962 soils were assumed to remain more constant for soil characteristics.

A Manitoba Soil Survey (Michalyna, Gardiner, and Podolsky, 1975) classified the area as predominantly Okno series soil, with Fyala and Kircro series soils blending in at the margins as indicated in Figure 1.

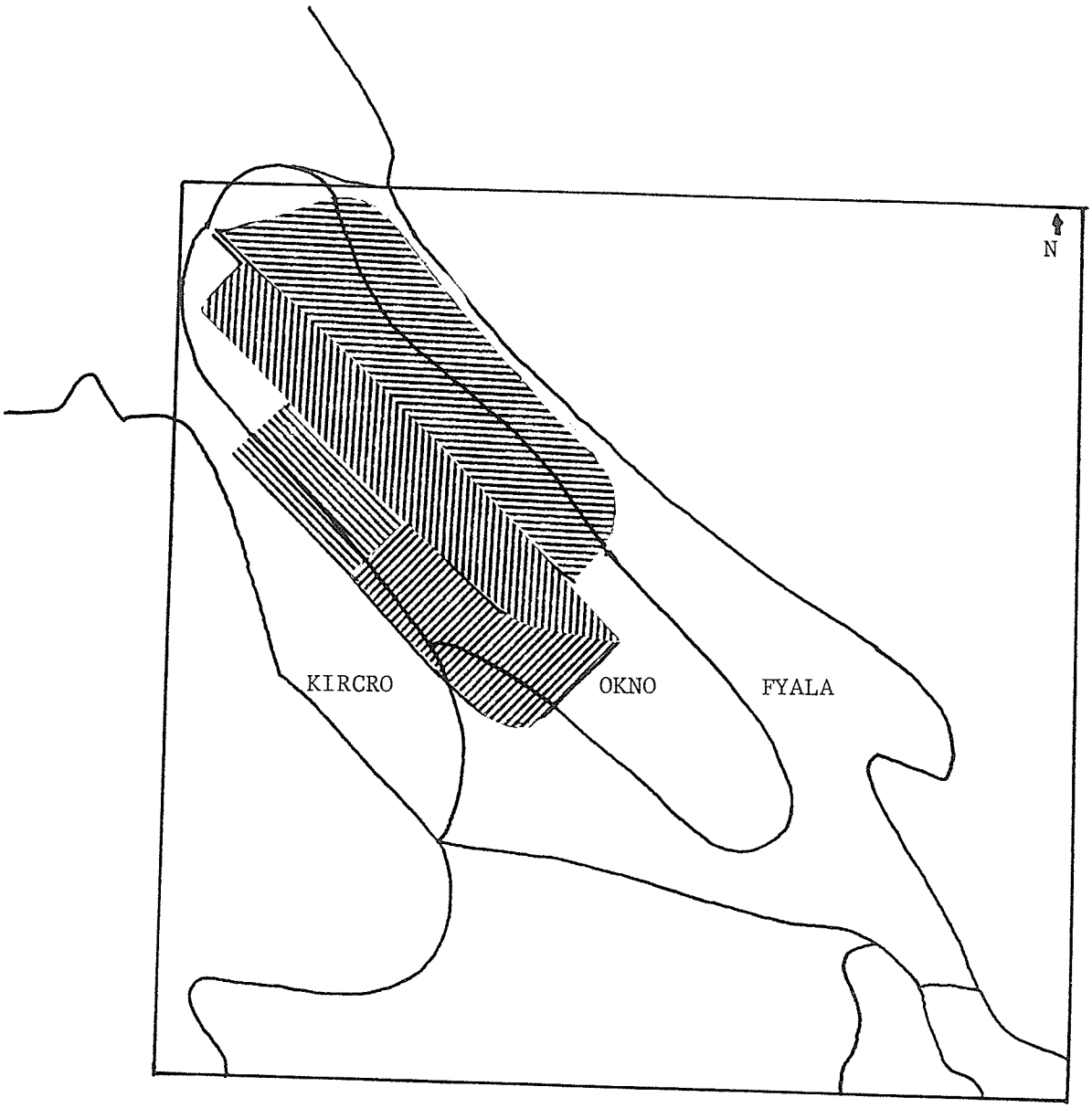


FIGURE 1. Map of soil series, farm location and dates of primary cultivation in Section 9-11-8E.

1962 breaking.

1975 breaking.

1980 breaking.

1981 breaking.

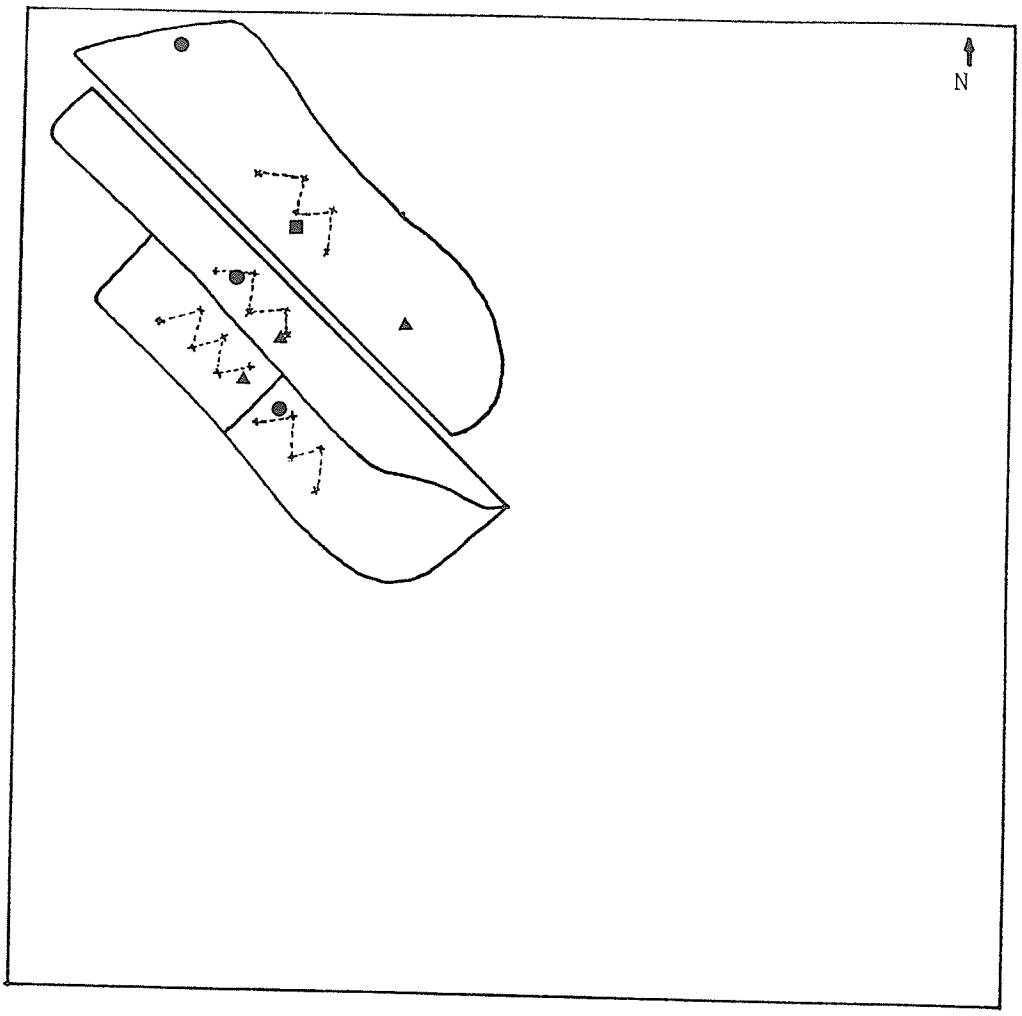


FIGURE 2. Map of experiment and sampling locations in Section 9-11-8E.

■ 1980 experimental site.
● 1981 experimental site.
▲ 1982 experimental site.
1984 sampling sites.

Soil characteristics for these soils are listed in Appendix A (Michalyna et al., 1975). A list of crop,weed and insect species mentioned in the thesis is presented in Appendix I,with common names used in the text of the thesis.

3.2 SOIL CHARACTERISATION

The locations for the experiments were in the Okno series soils (Figure 2). The soils used for characterisation were sampled on August 10, 1981 and November 6, 1982 from non-treated plots in the 1982 herbicide experiments. In 1984, further samples were taken on March 3 as shown in Figure 2 by the sampling method of Thomas and Wise (1982).

The samples were bulked and homogenised in a cement mixer and subjected to the following simple analyses for soil characterisation.

3.2.1 Organic Matter Content and Carbon Content

Organic matter content of the soil is frequently determined by weight loss on ignition by dry combustion (McKeague, 1978; A.O.A.C., 1975; Chapman and Pratt, 1978). The weight loss on ignition (LOI) is expressed as a percentage and is calculated by:-

$$LOI\% = \frac{\text{(weight of oven dry sample - weight of sample after ignition)}}{\text{(weight of oven dry sample)}} \times 100$$

(Atkinson, Giles, MacLean, and Wright, 1958).

The temperature used affects the amount of organic matter lost by combustion, with more burnt off at higher temperatures (Dormaar and Webster, 1964).

Oven dried samples (105°C for 24 h in a Labline convection oven) were tested for carbonates using 4N HCl, but there was no effervescence, thus no steps were required for carbonate removal (Allison, 1960).

One-g samples of each soil breaking were placed into crucibles and heated in a Gallenkamp muffle furnace at 400°C (Dormaar and Webster, 1964), 550°C (Chapman and Pratt, 1978; A.O.A.C., 1975), 580°C (normal temperature used in Plant Tissue Analysis Laboratory, Plant Science Department, University of Manitoba) or 700°C (Dormaar and Webster, 1964) for more complete combustion of organic matter. The ashes were allowed to cool in a dessicator, and were then weighed to the nearest milligram.

Since the use of carbon dioxide detectors and high temperatures (1650°C) have been recommended for organic matter determination (Tabatai and Bremner, 1970), this method was also used. The closest approximation attainable was a Carlo Erba Elemental Analyser Model 1102 at the Department of Fisheries and Oceans, Fresh Water Institute, Winnipeg, Manitoba R3T 2N6 which is an induction furnace which can attain a temperature of 950°C. The carbon content was measured using a carbon dioxide detector.

Wet combustion techniques were also used for organic matter determination. The Walkley Black technique and Allison's technique were used. The Walkley Black method, evolved in 1934 was carried out as outlined by Haluschak (1984) and Chapman and Pratt (1978). Samples of 0.1 g oven-dried peat were weighed into 125 mL erlenmeyer flasks. Twenty-mL potassium permanganate were added to each sample and swirled to disperse the soil in the solution (to obtain 1 N solution dissolve 49.04 g of oven

dried, 105°C, reagent grade $K_2Cr_2O_7$ in water and dilute to 1,000 mL). Sulphuric acid (40 mL,18N) was rapidly added to the suspension. The exothermic reaction produced a reaction temperature of 124°C (Allison, 1960) that oxidized about 75% of the organic matter (McKeague, 1978) and was carried out under a fume hood. It was assumed that only the organic carbon reacts with the potassium dichromate. The residual potassium dichromate was then diluted with 100 mL distilled water and reacted with 0.05 N ferrous ammonium sulphate heptahydrate (160 g $Fe(NH_4)_2(SO_4)_27H_2O$ reagent grade dissolved in 40 mL 18 N H_2SO_4), allowed to cool and diluted to 1,000 ml. One-mL of orthophenanthroline was used as an indicator that changes from purple/blue to green at the end point. The titration was done on an automatic titrator that ceased titration at 750 mV. A blank without soil was also run.

$$\% \text{ organic carbon} = \frac{B - V}{B} \times \frac{Vo \times No \times C}{\text{wt of sample}}$$

B was the volume of $Fe(NH_4)_2(SO_4)_2$ used for the blank titration
V was the volume of $Fe(NH_4)_2(SO_4)_2$ used for each soil type
Vo was the volume of $K_2Cr_2O_7$ added
No was the normality of the $K_2Cr_2O_7$ solution
C was the equivalent weight of carbon, and ascribed a value of 3 by Soil Science Department,University of Manitoba.

A factor of 75% has been attributed to the degree of total combustion by McKeague (1978) or 77% by Haluschak (1984). As both figures were approximations the data were not transformed.

More complete wet combustion was affected using a method devised by Allison (1960). A 0.05 g sample of triturated (oven dried and ground to <0.5mm) soil was weighed into a digestion flask (Kjeldahl flask fitted

with a side arm, tap, and reservoir to admit the digestion acid and air inlet tube [Figure 3]). One-g $K_2Cr_2O_7$ was placed into the flask with 3 mL H_2O. After fitting the digestion flask onto the reflux condenser, a CO_2-free air supply (passed through a soda lime tower with caroxite indicator near the top to show air stream to be CO_2 free) was passed through the system to remove CO_2 contamination in the system. A weighed Nesbitt bulb was attached (as shown in Figure 3) and 25 mL of digestion acid (600 mL 18 N H_2SO_4 into 400 mL of 85% H_3PO_4 (orthophosphoric acid), cooled and stored in a glass stoppered bottle) was added to the digestion flask reservoir. The tap, lubricated with digestion acid, was opened to introduce the acid then closed immediately to prevent escape of CO_2.The CO_2-free air flow was adjusted to 1 to 2 bubbles per sec. The flask was heated to bring contents to a boil at 210°C in 3-4 min and heating was continued for a total of 10 min. If white fumes were seen in the top half of the condenser these were of sulphur dioxide and heat was reduced.

The flask was removed from the heat source after 10 min and aerated with 6-8 bubbles per sec, for 10 min. The Nesbitt bulb was disconnected,brushed with a camel hair brush, and re-weighed to the nearest tenth of a milligram.

The gasses evolved were cleaned in a train of solutions to prevent contamination of the Caroxite in the Nesbitt bulb. Chloride was removed using a potassium iodide trap (50% KI using 100 g oven dried KI and 100 mL H_2O) and saturated silver sulphate solution (1 g $AgSO_4$: 125 mL H_2O). Water vapour was removed using 18 N H_2SO_4, calcium chloride, or magnesium chlorate (anhydrone) [$Mg(ClO_4)_2$].

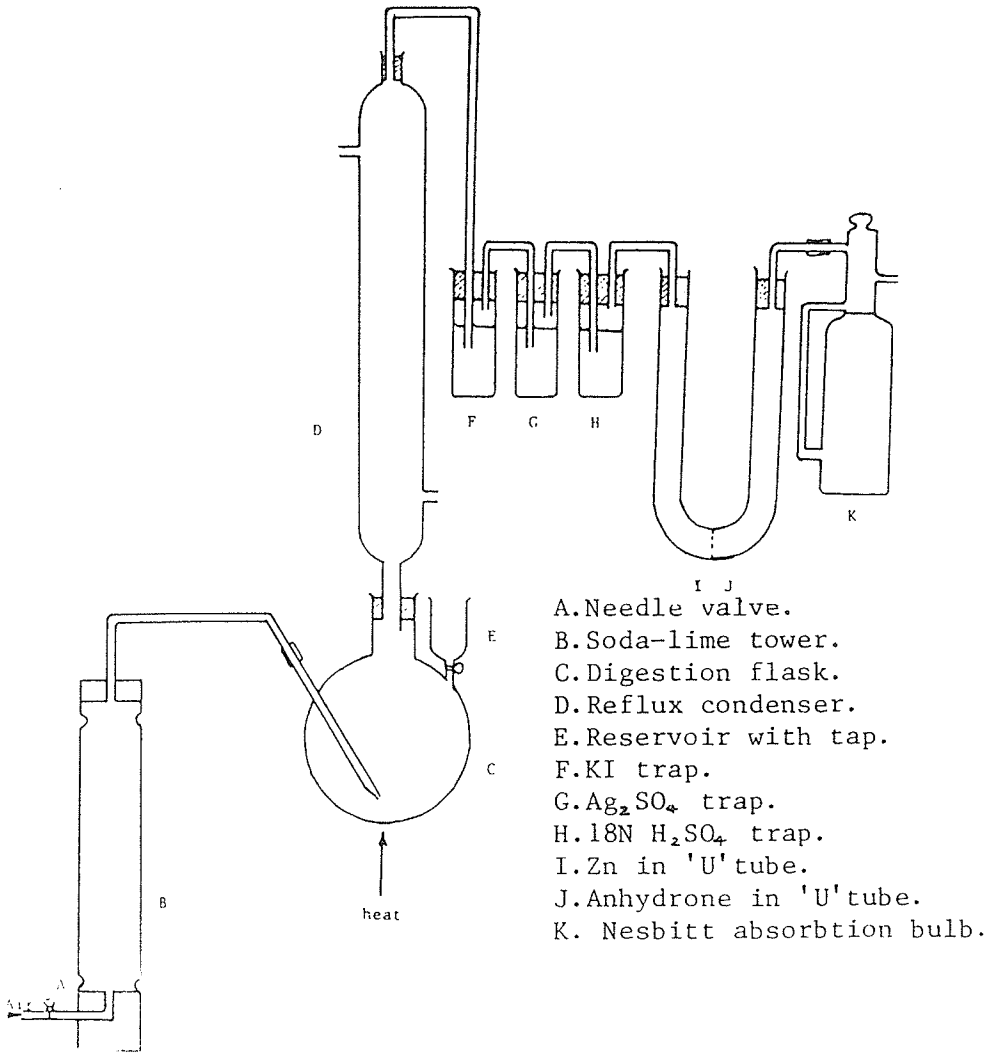


FIGURE 3.Apparatus for determination of carbon by Allison method.

Any excess fumes from the refluxing of acid were removed by 30 mesh granular zinc.

The increased weight of the Nesbitt bulb was due to CO_2, thus to derive carbon content the weight was multiplied by 0.2727. CO_2 losses from the system were minimised by using glass and gum rubber connections rather than tygon tubing (Sestak, Catsky and Jarvis, 1971). The experiment was repeated six times with the mean weight recorded.

3.2.2 Fibre Content

The most common method for determining the fibre content of organic soils recommended by McKeague (1976 and 1978), The Canadian System of Soil Classification (1978), and Haluschak (1984) was evolved by Lynn and McKenzie (1971). Six replicates of each breaking were analysed for unrubbed and 5 replicates for rubbed fibre content.

3.2.2.1 Unrubbed Fibre Content

About 45 cm^3 of moist peat were removed from a homogenized, representative sample, and lightly squeezed in a paper towel to remove excess moisture. A 5 cm^3 plastic syringe with half of the cylinder wall removed in a longitudinal direction, was packed with the moist peat. A spatula was used to expel excess air, but not water, to obtain a 5 cm^3 volume. The soil was transferred to a 100 mesh sieve and washed with water from a faucet delivering 400 mL in 5 sec. The sample was washed until water passing through the sieve appeared clear, with a white background. The sample was collected by backwashing and then placed on a

paper towel, again removing excess water. The volume was measured in a syringe as before and the result recorded as a percentage of the original volume.

3.2.2.2 Rubbed Fibre Content

The unrubbed fibre content sample was returned to the sieve and washed again, and rubbed between thumb and fingers. The rubbing and washing was continued until the fibres rolled, rather than smeared (slid) between fingers and thumb. The volume was measured and recorded as in unrubbed fibre percentage.

3.2.3 Particle Size Analysis

3.2.3.1 Wet Sieve Technique

Particle size analysis determines the fractions of unrubbed fibres of different sizes and smaller particles of more humified material by weight for a more complete view of different peat samples. The Association of Official Agricultural Chemists (A.O.A.C., 1975) recommends dry sieving. The method however caused mechanical damage increasing the smaller particle fractions. To alleviate this problem Dinel and Levesque (1976) evolved a wet sieving method. The method was also used by Jasmin, Hamilton, Millette, Hogue, Bernier, and Campbell (1981), Levesque, Morita, Schnitzer, and Mathur (1980), and by Williams (1983).

Particle size analysis was replicated five times on 12 g samples of homogenised field moist samples. The normal method entailed oscillating a nest of sieves using air bubbled through the submerged sieves. The

technique was modified by oscillating a nest of five sieves using a rotatory shaker (Laboratory rotator, Model G2 New Brunswick Scientific Company Inc. Brunswick, N. J.) to move a rubber policeman against the top 7.5 cm internal diameter sieve. The jarring action was reduced by using this method and resulted in uniform shaking at 150 r.p.m. for 15 min. The fractions assessed were collected on 1.5, 1.0, 0.5, 0.15, and 0.075 mm sieves and also from the body of the solution. The sieves were sealed together using Parafilm to prevent separation of the sieves and the escape of large particles into the wash water. Care was taken to prevent trapping air under the sieves that could prevent reproducible sieving.

3.2.3.2 Dry Sieving

The most obvious difference between soils from the sites was the amount of clods present. Using minimal shaking on a 1.2 cm sieve, the soil samples were evaluated for the field moist weight of soil retained on the sieve, and then expressed as the percentage of the total fresh weight. The result showed the percentage of each soil present as clods.

3.2.4 Sodium Pyrophosphate ($Na_4P_2O_7 10H_2O$) Index for Decomposition Index

Rubbed fibre contents yield a standard for classifying organic soils into taxonomic groups, namely fibric, mesic, and humic groups. Other soil properties also vary with decomposition and may be measured. One of the most common parameters measured was the soluble fraction. Several electrolytic dispersants were tested by Levesque and Dinel

(1977) who concluded that there were few differences between the salts used. The most frequent solution was of 1 g of sodium pyrophosphate dissolved in 4 mL of water (The Canadian System of Soil Classification, 1978; Farnham, Brown and Finney, 1970; Ivarson, 1977; Levesque, Dinel, and Marcoux, 1980).A 2.5 mL sample of air dried soil (or 1 gram) was mixed and allowed to equilibrate in the pyrophosphate solution for 24 h. The analysis was conducted by dipping 1 cm of a strip of filter paper into the slurry and comparing the colour of the filter paper to a standard colour chart (Munsell 7.5 or 10 YR charts are used to identify peats) or other standard solutions (Maclean, Halstead, Mack, and Jasmin, 1964). A more quantitative and less subjective method using pyrophosphate solubility had been developed in 1956 by Kaila. (The use of a spectrophotometer to measure absorbance of an extracted solution requires the use of more laboratory equipment, putting it beyond the scope of field testing of the Munsell chart method).

The Kaila method involved the use of 11.152 g of sodium pyrophosphate decahydrate ($Na_4P_2O_7 10H_2O$) dissolved in 1 L of distilled water to produce a 0.025 M solution. A 0.5 g sample of triturated air dried soil was shaken for 18 h in 50 mL of the sodium pyrophosphate solution. The filtrate was made to 250 mL volumetrically and the absorbance measured at 550 nm. (The presentation of the data are usually as cardinal numbers, following multiplication of the spectrophotometer readings by 100). This method has been used by Haluschak (1984), McKeague (1976), Levesque, Morita, Schnitzer, and Mathur (1980), Morita (1982), Morita, Levesque, and Mills (1980) and Schnitzer and Desjardins (1965 and 1966).

Fresh soil samples were taken in March 1984 and the pyrophosphate index measured. Both the pedalogical method of analysing sodium pyrophosphate extraction by comparison with a standard Munsell chart, and also the laboratory method of absorbance using the Kaila method were used to determine the taxonomic states of the peat soil. The Munsell chart method was also performed on the fibre and rubbed fibre fraction to observe the effect of these treatments on the pyrophosphate index.

Another turbidometric analysis method used was devised in 1922 in Sweden by Von Post. The method was a popular field test assessment relying on the amount and type of exudate extruded between the fingers and the quality and quantity of the residue in the palm after squeezing a peat sample in the hand. Translations appear in Stanek and Silc (1977), The Canadian System of Soil Classification, and many other technique manuals and papers. Three replications were carried out using saturated peat samples, large enough to fit into the palm of one hand and squeezed.

3.2.5 Bulk Density Determinations

3.2.5.1 Laboratory Method

Earlier work in the Plant Science Tissue Analysis Laboratory, University of Manitoba had been used to categorize commercial peat for greenhouse work. Oven-dried (16 h at 105°C) peat was sieved through number 10 mesh (1.5 mm opening) and packed to a uniform volume in a 20 mL beaker. Packing was achieved by tapping the beaker 5 times, and levelling the contents. The weight of the soil was obtained for 3 samples taken from each of the three peat areas. The method used

required several attempts to add the correct amount of peat to obtain the correct, settled and levelled, volume. The method was repeated 3 times for each soil type. The bulk density was then calculated according to oven dry wt/volume formula. The method was very similar to that used by MacLean, Halstead, Mack, and Jasmin (1964) who utilised a specialised piece of equipment to standardise their volume of air dried peat by removing excess soil with a sliding lid.

3.2.5.2 Laboratory Method at Constant Water Potential

The shallow depth of soil sampling prohibited the removal of cohesive cores. Samples were prepared in the laboratory to simulate field conditions. Two states of compaction were used.

The first method was designed to simulate early season, pre-cultivation compaction. Thoroughly mixed 1 kg samples from each of the three locations were mixed with 5 L 40^{o}C water to obtain thorough wetting of even hydrophobic areas on the peat (Carlson, 1983).

The slurries were agitated every half hour for 3 h. The colloidal solution was then poured into PVC piping 10 cm internal diameter, 40 cm long fitted with a plastic 1 mm screen at the bottom and then allowed to drain for 3 days. The columns of soil thus formed were compact and were then cut to fit tared acrylic soil containers 6.28 cm internal diam., 3.3 cm high fitted with muslin screens on the bottom, for a total volume of 100 cm^{3}

The other compaction state was designed to simulate post cultivation bulk density. Fifty acrylic soil containers were filled to a 1 cm depth

with field moist peat from each location, then soaked with water from an atomizer and compacted with a one kg weight on top of a fitted wooden piston for uniform compaction throughout the sample. Successive layers were added and compacted to fill the acrylic cylinders.

Five replications of each soil type, at each compaction were transferred to sintered glass tension plates and equilibrated at a constant water potential (Boelter and Blake,1964).

The samples were subjected to -10 cm water potential to remove gravitational water (Boelter, 1964) that could cause problems due to leakage when weighing the samples (Bilderbeck, Fonteno, and Johnson, 1982).

Due to expansion, the cores were trimmed flush to the top of the soil containers with a razor blade when they had reached a constant weight. They were then allowed to equilibrate again to constant weight, checked on consecutive days.

The samples were then dried in moisture cans at 105^{0}C for 16 h to obtain the oven dry weights.

The bulk density was then calculated by:-

$$\text{Bulk density} = \frac{\text{oven dry weight of soil (g)}}{\text{volume of soil sample (cm}^3\text{)}}$$

3.2.5.3 Field Method

The surface 5 cm layer of peat was being sampled for residue analysis (section 3.3.3.) as adsorption was expected to prevent leaching of the

herbicides to a greater depth. The bulk density was therefore determined for the top 5 cm layer as well.

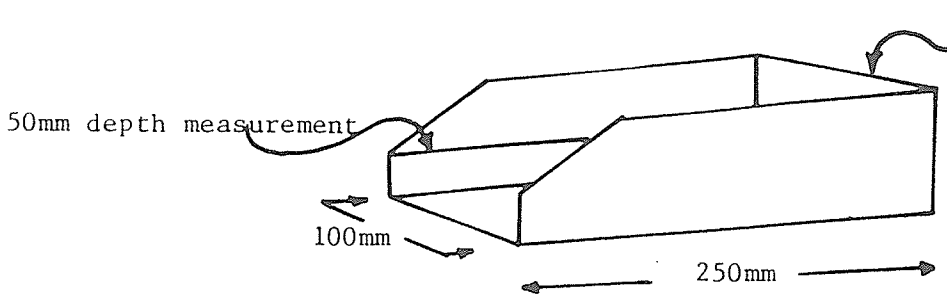
The area was rotovated to a depth of 15 cm on July 28th, 1982, then compacted with the tires of a garden tractor to obtain more even compaction than with a roller. The tires exerted a greater pressure than the heaviest available roller. The plots were packed twice in perpendicular directions. The field was then irrigated with 1.5 cm of water (to incorporate the pronamide) following the removal of the first samples for bulk density. The sampling dates were July 28,30, and 31, August 2, 3, 5, 9, 11, 21, and 23,September 13 and 15, October 31, and November 2.These sampling dates were alternated and non coincident on the 1975 and 1962 peats, with all dates being used for sampling the 1981 breaking.The sampling intervals were 3, 6, 12, 24, 50, and 100 days after herbicide application.

Soil samples for bulk density were taken by removing the upper 5 cm of soil. A metal scoop was used as shown in Figure 4, the scoop was made of thin gauge metal to cut into the soil easily. The peat, particularly when dry, was non-cohesive necessitating measuring the sample volume with water in a plastic bag as in Figure 4, with the depth determined by a straight edge across the top of the hole.

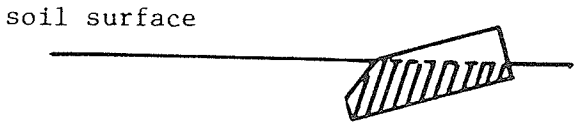
Three sub-samples were taken from each replicate from the 1982 herbicide trial control plots and combined to form a bulk density sample for that replication.

The samples were weighed, thoroughly mixed in a cement mixer, and a sub-sample removed and oven dried at $105^{0}C$ for 16 h. Bulk density was calculated by:-

a.

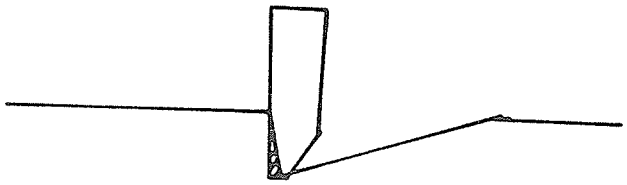


b.



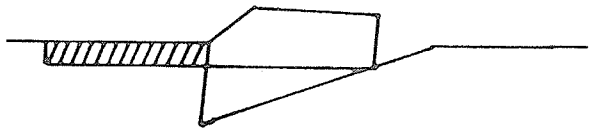
Push sampler into soil to depth greater than 5cm, remove peat, discard.

c.



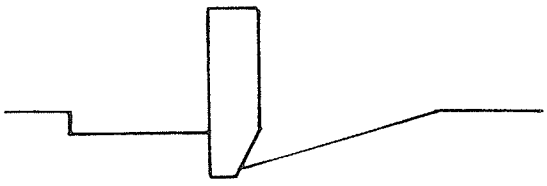
Trim hole to perpendicular, discard soil.

d.



Cut horizontal sample, 5cm deep transfer soil to labelled plastic bag.

e.



Measure volume of sample with water in plastic bag, with sampler closing open end of sample hole.

FIGURE 4. Sampling method for field bulk density determinations.

$$\text{Bulk density} = \frac{\text{Field moist, total weight of sample (g)} \times \dfrac{\text{[oven dry weight of sub-sample (g)]}}{\text{[Field moist weight of sub-sample (g)]}}}{\text{volume of sample (cm}^3\text{)}}$$

3.2.6 Water Content

3.2.6.1 Field Samples. Gravimetric Water Content

Soil samples from the plots were collected as described for the bulk density experiments. The samples were transported in plastic bags from the field to the laboratory to prevent evaporative water loss. Samples were comprised of three sub-samples from within replicates in the field and were homogenised in a cement mixer. Five replicated samples were then sub-sampled (20-50 g as received weight) into soil moisture cans that had been oven dried to prevent soil moisture errors (A.O.A.C., 1975). The sub-samples were then weighed and transferred to a Labline convection oven at 105°C for 24 h. The soils were dried uncovered, then allowed to cool in a dessicator with the lids on. The cooled oven-dried samples were then weighed.

Calculation

$$\text{Gravimetric moisture content (\%)} = \frac{\text{(g as received weight - g oven dry weight)}}{\text{g oven dry weight}} \times 100$$

(Haluschak, 1984; Atkinson, Giles, MacLean, and Wright, 1958).

The A.O.A.C. (1975) proposed a denominator as received weight to obtain a fraction less than unity. That calculation method would prohibit comparison of different peats having variable original water

contents and therefore moist weights. The preferred calculation yields data with gravimetric water contents of more than 100% (Haluschak, 1984).

Volumetric water contents were calculated for the 1982 samples by multiplying the gravimetric water contents by the bulk densities for each location (Boelter, 1968).

The bulk densities from both laboratory approximation methods and from the field data, on corresponding dates, were used to demonstrate the influence of bulk density on the volumetric water content.

The data were analysed by analysis of variance for a randomised block design, with least significant differences at 0.05 and 0.01 levels to segregate soil effects of decomposition on water content by date of sampling.

3.2.6.2 Hygroscopic Coefficient

Air dried soil has had most of the water initially present in the field sample removed, with only strongly adsorbed water being retained. The gravimetric water content of air dried soil was termed the hygroscopic coefficient. When a larger volume of soil was used the peripheral layers could insulate the core of the sample from dessication.

In field observations more water was retained at high moisture contents in clods of soil than in the finer general mass of the peat. The experiment on the hygroscopic coefficient sought to show whether the effect of increased moisture content in clods remained apparent at air

dryness. The plant structure in the clods was more defined than in the bulk of the peat,and therefore probably less decomposed.

The soil analysed was randomLy collected from the three locations on March 3, 1984 and each sample homogenised separately. Clods were selected that were small enough (1-2 cm) in one plane to permit thorough drying. The density of the clods was greater than the loose soil and could increase the insulating effect of the peripheral peat preventing internal drying. Loose soil was spread to a thickness of 4 cm and allowed to dry in a greenhouse for two weeks until no detectable colour differences, indicative of moisture differences, were observed in the slightly disturbed loose soil. Since relative humidity and temperature affect the moisture content of air dried soil there are daily and diurnal fluctuations of hygroscopic moisture content. To minimise variation the soils were rapidly packaged by location into plastic bags for loose and clodded soils. The samples were then stored for 3 days at a constant 30^{0}C to equilibrate.

Five sub-samples from each soil location for the loose soil, and 6 sub-samples of clods (due to greater expected variation) were then weighed in tared pre-heated soil moisture cans. Weights were taken of clods ranging from 2 to 7 g depending on clod size and of 5 g of loose soil, and were then dried uncovered in a Labline convection oven at 105^{0}C for 24 h. The gravimetric water contents were determined as before from the air dried and oven dried weights of soil.

The experiment was analysed as a completely randomised design, utilising the least significant differences at the 0.01 and 0.05 confidence levels to ascribe treatment differences.

3.2.7 Chemical Characteristics of Peat

The field was fall worked by the farmer in 1980 by discing to 15 cm. In the spring the field was worked as soon as trafficable on April 28, 1981, and fertilised as shown in Table 1, again by the farmer. Additional fertiliser was also broadcast using a Gandy field applicator at 50kg ha^{-1}. nitrogen. Copper at 17 kg ha^{-1}. was applied as $CuSO_4$ solution. Care was taken to prevent saturation of the solution. The additional fertilisers were applied on May 15, and were incorporated to 12 cm by rotovation on May 16 and packed.

Samples were taken on August 10,1981 from the plot not treated with herbicides, from the 0-15 cm depth, and were homogenised within soil type, and analysed for pH, conductivity, and nitrogen, potassium, calcium, magnesium, zinc, iron, manganese, and copper. In 1981 stored samples were analysed for cation exchange capacity.

In the spring of 1984 random samples were taken (Figure 2) adopting the sampling technique modified by sub-sampling the 0-2 cm surface crust and then the subsequent 5 cm. Analyses were pH with 1:4 soil:water (by weight) or 0.01 M $CaCl_2$, and electrical conductivity (m S cm^{-1}.) in 1984.

3.2.7.1 pH

A solution of 0.01 M $CaCl_2$ was prepared by dissolving 2.21 g $CaCl_2 2H_2O$ in 1.5 L distilled water. The pH of the solution was 5.8, and the conductivity 2.35 m S cm^{-1}, both of which were within the specifications listed by McKeague (1976).

TABLE 1

Fertiliser applied by broadcasting and incorporation to 15cm. on different peat breakings in 1981.

Year of breaking	Fertiliser applied (kg/ha)								
	N	P_2O_5	P	K_2O	K	Zn	Mn	Fe	Cu
1980	50	200	87	300	250	4	4	1	5
1975	40	125	55	20	16.6	4	4	1	2
1962	40	125	55	20	16.6	4	4	1	2

Peat slurries were prepared in 50 mL beakers with 10 g of fresh moist peat and 40 mL of either water or 0.01 M $CaCl_2$ (McKeague, 1976; Haluschak, 1984). The slurries were allowed to settle overnight, whilst covered. Prior to measuring the pH the sediment was again stirred into the supernatant and allowed to settle for 30 min. In 1981, the ratio of peat to water was 1:3 and the pH was measured using a Fisher Accumet model 310. In 1984 the pH of the supernatant solution was measured with a Copenhagen PHM82 standard pH meter, that was checked every fifth reading in standard solutions at pH 4 and pH 7 (Haluschak, 1984).

3.2.7.2 Electrical Conductivity

After measuring gravimetric water content as previously described, 50 g of the soil paste was made to the equivalent of 1:5 oven dry soil:water (McKeague, 1976). The paste was allowed to stand overnight and then placed in a Buchner funnel fitted with a Whatman #1 low ash filter paper. The filtrate collected under vacuum did not require the addition of sodium hexametaphosphate as no carbonates were present as determined by using 4N HCl. The electrical conductivity of the filtrate was measured using a model 32 Conductance meter, Scientific Division, Yellow Springs Instrument Co. Inc. The experiment was carried out at 25°C and thus did not require temperature correction (Chapman and Pratt, 1978).

In 1981 the conductivity was measured of a 1:3 fresh peat to water slurry on a Markson Science Inc. Electromark analyser.

3.2.7.3 Cation Exchange Capacity

The standard method for determining the cation exchange capacity for organic soils followed by Haluschak (1984), McKeague (1978) and the A.O.A.C.(1975) was developed by Thorpe (1973) for the A.O.A.C.

'Standard Solutions'

Sodium hydroxide (A.O.A.C., 1975).

The solution was CO_2 free to prevent the formation of sodium carbonate, so all burettes and storage vessels must be under air that has been passed through a soda-lime tower. CO_2-free air was passed through 5 L water for 12 h to remove carbon dioxide and 20 g of NaOH was added to the water. The final concentration was 0.1160 N NaOH as standardised with potassium pthalate ($KHC_8H_4O_4$) (A.O.A.C., 1975).

Potassium pthalate

After 4.5238 g of oven dried (120°C) potassium pthalate were dissolved in 300 mL distilled CO_2-free water, 20 mL $KHC_8H_4O_4$ was titrated with NaOH to end point with 3 drops phenolpthalein indicator to first colour at pH 8.6.

$$\text{Normality NaOH} = \text{g } KHC_8H_4O_4 \times 1000/\text{mL NaOH} \times 204.229$$

Barium acetate

A 0.5 N solution was prepared by dissolving 64 g $Ba(OAc)_2$ in distilled water, made up to 1 L.

Silver Nitrate Solution

A 1% silver nitrate solution was prepared by dissolving 1 g $AgNO_3$ in 100 mL distilled water.

Hydrochloric acid

0.5 N HCl was prepared by diluting 42 mL of concentrated 12 N (36.5 to 38%) HCl to 1 L with distilled water.

Cation Exchange Capacity Method.

Two g of triturated oven-dried peat from samples collected from the 1962, 1975, and 1980 sites were placed in 300 mL erlenmeyer flasks with 100 mL 0.5 N HCl, shaken on a rotary shaker overnight, and filtered through Whatman #1 filter paper. The samples were then washed with distilled water until no chloride ions were detected in the filtrate, as indicated by 3 mL 1% $AgNO_3$. The filtrate was discarded. The samples were then washed into clean 300 mL erlenmeyer flasks with 100 mL 0.5 N $Ba(OAc)_2$ after puncturing the bottom of the filter paper. The slurry was then shaken on a rotary shaker for 4 h, filtered, and washed with 300 mL H_2O. The filtrates were then sub-sampled into 4 beakers and titrated with 0.1160 N NaOH to first pink, using 5 drops of phenolpthalein indicator. Three repetitions were done for each soil type.The cation exchange capacity was calculated by:-

m Eq/100 g oven dried peat = (mL x normality NaOH x 100)/g sample

The sodium hydroxide was titrated against the acetic acid evolved by the adsorption of barium onto the cation exchange.

3.2.7.4 Exchangeable Cations

'Calcium, Magnesium and Potassium'

One g of air dried peat was placed into a 125 mL erlenmeyer flask and 25 mL of 1 N NH_4OAc added. The ammonium acetate was prepared by mixing 66.7 mL conc (15.0 N) NH_4OH with 57.5 mL glacial acetic acid (17.4 N). When a reaction of pH 7 was obtained, the sample was diluted to 1 L with distilled water. The pH remained at 7.

The slurries were shaken for 5 min, and filtered through a Whatman #40 filter paper, and the filtrate diluted to create dilution factors of 250, 2,500, and 25,000.

Absorbance was measured on a Perkin Elmer Spectrophotometer 403 using an oxygen acetylene flame with wavelengths of 211 mμ for Ca, 285 mμ for Mg, and 383 mμ for K (Isaac and Kerber, 1971), and the wavelength was adjusted fractionally for maximum absorbance.

'Iron,Manganese,Zinc,and Copper'

One g of peat was placed into a 125 mL erlenmeyer flask and 25 mL 0.1 N HCl added. The 0.1 N HCl was prepared by diluting 16.8mL concentrated 12 N (36.5-38%) HCl to 2 L with distilled water. The slurry was shaken for 30 min and filtered through a Whatman #40 filter paper. The filtrate was diluted to form a dilution factor of 125.

Absorbance was measured on the spectrophotometer at wavelengths of 248 mμ for Fe, 279 mμ for Mn, 214 mμ for Zn, and 325 mμ for Cu (Isaac and Kerber, 1971) with minor wavelength adjustments to obtain maximal absorbance.

3.2.7.5 Total Cations

A 1 g sample of air dried peat was ashed at 580°C for 16 h and moistened with distilled water. The ash was then dissolved in 5 mL 0.1 N HCl and diluted to 100 ml. The sample was then divided for analysis with iron being determined at a dilution of 1,000 Mn, Zn, and Cu at a dilution of 100. Ca, Mg, and K were diluted to 10,000 by taking 1 mL to 100 mL with 1 mL sodium ethylenediaminetetraacetic acid (EDTA) to remove phosphorus interference.

The Atomic Absorption Spectrophotometer was standardised using a standard solution of 2 ppm Fe, Mn, Cu,and Ca, 1 ppm K, 0.5 ppm Zn, and 0.4 ppm Mg. The methods were those used by the tissue analysis laboratory in the Plant Science Department at the University of Manitoba and were derived from Chapman and Pratt (1978) and the Perkin Elmer Analytical methods for atomic absorption spectrophotometry (1976).

3.2.7.6 Nitrate Nitrogen

Nitrates and nitrites are readily soluble in water, and the amount extracted was independent of the soil:water ratio. Ammonia, however, was adsorbed and must be desorbed by another ion. Samples for analysis were taken to a depth of 15 cm due to the mobility of nitrites and

nitrates in soil solution, and samples from each replication were homogenised in a cement mixer in March, 1982. The samples were evaluated after drying at 70°C to reduce the oxidation to nitrate of ammonia and nitrites (Piper, 1950).

The dried peat was sieved through a 2 mm sieve and 5 g weighed into a 125 mL erlenmeyer flask to which 50 mL of distilled water was added. After 10 min shaking on a rotary shaker, 0.2 g $Ca(OH)_2$ was added. After a further 5 min, 0.5 g $MgCO_3$ was added. After a further 15 min the mixture was filtered through a Whatman #1 filter, and 2 mL phenol disulphonic acid were added. (Phenol disulphonic acid exists as a mixture of disulphonic isomers, sulphonic isomers and perhaps even trisulphonic acid. The sulphonic groups are located at the ortho and para locations relative to the phenolic hydroxyl.The acid was prepared in an 800mL Kjeldhal flask with 450mL conc. H_2SO_4, 70mL phenol, and 225mL fuming H_2SO_4. The mixture was heated in a boiling water bath for 2h and stored in a dark brown bottle.) Twenty mL 0.3 N NH_4OH were added to 10 mL of the filtrate and made to 50 mL while another 10 mL were made to 50 mL analysed without NH_4OH to derive a correction factor due to soluble chromogenic compounds co-extracted from the peat. Absorbance was measured at 415 nm on a colorimeter. A further blank reading was obtained for the reaction mixture without peat. A standard curve was plotted using 20 mL NH_4OH to develop colour with $NaNO_3$ at 0.1, 0.2, 0.4, 0.6, 0.8, and 1 ppm nitrate. The concentration of nitrate in the soil was obtained by subtracting the absorbance due to the reagents and due to coextractives from the absorbance resulting from the reaction of NH_4OH with peat extracts. The concentration was then multiplied by 50 due to

dilution of 5 g of peat in 50 mL of water and the subsequent dilution of 10 mL of extract taken to 50 ml.

3.3 HERBICIDE ADSORPTION STUDY

3.3.1 Pre-screening, 1980

The field trial was conducted at Vivian, Manitoba on a field of peat soils that had been cultivated for different periods of time causing varying amounts of peat decomposition. The pre-screening trial to test for herbicide activity was conducted on the 1962 breaking (Figure 2). The experiment was designed as a randomised block, split plot with four replications. The plots were 12 m long and 1.5 m wide. Six meters were used for crop yields and were weeded while the other six meters were used for weed records.

The experimental area received a broadcast fertilizer application of 56 kg ha^{-1} N, 67 kg ha^{-1} P_2O_5, and 280 kg ha^{-1} K_2O on May 30, 1980 and the plots were then cultivated and packed.

Pre-plant incorporated herbicides were applied on June 2, 1980 and incorporated to 10 cm with a rotovator and the plot was packed with a roller. Bensulide (Prefar) was applied at 3, 6, and 12 kg ai ha^{-1}. Propham (Chem Hoe) was applied at 3, 6, and 12 kg ai ha^{-1}. Pronamide (Kerb) was applied at 1, 2, and 4 kg ai ha^{-1}. The herbicides were applied with a small plot sprayer in 233 L water ha^{-1} to a moist soil surface. The air temperature at the time of spraying was $18^{0}C$ in mostly sunny conditions.

The plot was seeded with a coated standard cultivar of lettuce (Ithaca) on June 4, 1980 with a single row Stanhay precision seeder. The plot was irrigated on June 6, 1980 to improve the uniformity of lettuce germination and emergence.

Pre-emergence herbicides were applied on June 7, 1980 also in 233 L water ha^{-1}. The temperature was 15°C, and the soil surface was very moist. Chlorpropham (CIPC) was applied at 3, 6, 9, and 12 kg ai ha^{-1}. Propachlor (Bexton) was applied at 2, 4, and 8 kg ha^{-1}.

The lettuce plants were thinned to 35 cm between plants at the 2 leaf stage on June 12 and sprayed weekly thereon with malathion to control leaf hoppers. Weed counts were made on July 8 from 4 - 1/4 m^2 quadrats per plot, and crop vigor visually assessed. Following early weed counts of small weeds, the plots were hand hoed regularly. The most abundant weeds were Oak-leafed Goosefoot, Maple-leaved Goosefoot, Biennial Wormwood, and Annual Bluegrass.

Yield data for lettuce was taken on August 16 and assessed for number of marketable heads per plot and marketable yield in kg $plot^{-1}$. Data were analysed by analysis of variance using Least Significant Difference (L.S.D.) at the 1% and 5% level of significance.

3.3.2 Field Trials, 1981

The experiments were designed as completely randomised block at the three locations on the organic soil site as shown in Figure 2, with four replications. Plots were 6 m long and 1.5 m wide. The plots were seeded with carrots, onions, and lettuce at 50 cm row spacing to widen

the scope of the experiment from the previous year when only lettuce was grown.

The experimental sites were fall worked by discing to a depth of 15 cm in 1980. In the spring, the field was worked as soon as trafficable on April 28, 1981 when micronutrients were applied at the rates shown in Table 1. Additional copper was applied to the 1975 and 1980 breakings at 17 kg ha^{-1} as copper sulphate solution on May 15 and incorporated to 12 cm by rotovation on May 16 and the plots were then packed.

On May 26, 1981 the plots were seeded with coated 'Hipak' carrot seed using a Stanhay 3-row belt seeder which delivered about 50 plants per meter. Coated seed of 'Ithaca' lettuce was planted at 1-1.5 cm depth with a Stanhay seeder, and were treated with Thimet at a rate of 11.2 kg ai ha^{-1} to control leaf hoppers for the first two weeks growth of the plants. Lettuce plants were thinned to 35 to 45 cm within rows 3 weeks after planting. 'Autumn Spice' cooking onions were seeded with a Planet Junior seeder at 2.5 cm depth, and treated at a rate of 11.2 kg ai ha^{-1}. Diazinon was placed at the same depth as the seed to control onion maggots and thrips. Malathion at 2.2 L ha^{-1}, or Thiodan at 2 L ha^{-1}, were sprayed twice weekly beginning in early July to control leafhoppers, the vector of aster yellows mycoplasma disease in lettuce and carrots.

On May 27, 1981 chlorpropham at 3, 6, and 12 kg ha^{-1}, linuron at 1, 2, and 4 kg ha^{-1}, and pronamide at 1, 2, and 4 kg ha^{-1} were applied as pre-emergence treatments in 233 L ha^{-1} water with a small plot sprayer. The plots were irrigated with 1.5 cm of water within 1 day of herbicide application to prevent losses due to volatilisation.

The three soil applied herbicides were selected on the basis of being commonly used in horticulture and being non-ionic, thereby reducing variation of adsorption due to pH effects. Linuron is commonly applied to horticultural crops including carrots, parsnips, celery, potatoes, and corn to control broadleaved and grassy weeds. Linuron inhibits the Hill reaction in photosynthesis, and has a half life of 2 to 5 months being decomposed primarily by microbial means. Chlorpropham and pronamide were selected from the prescreening trial in 1980. Horticultural use of chlorpropham is frequently in onions, garlic, carrots, Lima beans, and peas to control both broadleaved and grassy weeds. Compositae are tolerant and chlorpropham is used in lettuce in Ontario. Chlorpropham inhibits RNA and protein synthesis, respiration, photosynthesis, and translocation. Microbial decomposition reduces the half life of chlorpropham from 65 days at 15°C to 30 days at 30°C. Pronamide will control many broadleaved and grassy weeds in lettuce and sugarbeet and a wide range of other non-horticultural crops by inhibiting mitosis. The half life of pronamide is 2 to 9 months and it is subjected to chemical, microbial, and photochemical degradation (Yih and Swithenbank, 1970).

All three herbicides are primarily absorbed through the roots and transported acropetally (WSSA, 1983).The structures and chemical names are presented in Appendix J.Pronamide is subjected to volatilisation and is often incorporated by irrigation, however this practice may increase chlorpropham volatilisation due to competition of water at adsorption sites, (Kearney and Kaufman, 1976).

The emergence data were compiled from a complex rating system based on row filling, crop vigour, and crop uniformity. The most advanced and uniform rows received a rating of three. No emergence or burned-off seedlings merited a zero rating. The data are presented as means of four replications and were observed on June 19, 1981. The lettuce rows were thinned after rating.

Weed counts were taken by four randomLy located sub-sample $1/4m^2$ quadrats within each plot by destructive sampling on July 7. The plots were subsequently maintained weed-free to observe herbicide effects on yield without the uneven weed competition encountered in the experiments.

The crops were rated a second time on July 20, 1981 (55 days after seeding). The rating system was simplified into two components, crop uniformity and row filling, recorded separately. Optimal crop status merited a high percentage rating, while denuded plots rated zero for both evaluations. Lettuce head formation and aster yellows were also rated at that time.

Lettuce were harvested three times on the 1980 breaking on July 24, 31, and August 7, 1981. The final harvesting date was coincident on all three locations, with only one harvest being required for the other two sites. Only the marketable heads were harvested, and five were evaluated for tipburn, a physiological disorder of head lettuce.

The carrot crop was harvested by hand on August 28, 1981, and assessed for total and marketable yield. The same evaluations were made for onions on October 26, 1981.

3.3.3 Field Trials, 1982

The experiments were planned to avoid the aster yellows problems encountered in 1981. Growth room bioassays of soil samples taken from herbicide treated plots were to show the residual activity of chlorpropham, linuron, and pronamide. The experiments were designed in the field as completely randomized blocks with five replications on each soil breaking, namely the 1981, 1975, and 1962 breakings.

The experimental sites, Figure 2, were rotovated to a depth of 15 cm and packed twice with the tractor tires in perpendicular directions on July 28, 1982. The treatments were applied to plots 1.5 m x 6 m with 1 m interplot pathways. Linuron and pronamide were applied at 1, 2, and 4 kg ai ha^{-1} in 233 L ha^{-1}, and chlorpropham at 3, 6, and 12 kg ha^{-1} in the same volume. Irrigation on the same day of treatment supplied 12.5 mm of water to prevent volatilisation of the pronamide and chlorpropham, and to leach the herbicides into the peat soil. The 1962 breaking was treated with all three herbicides on July 28, 1982, and the 1981 breaking had linuron applied on the same day. The remaining treatments on the 1981 breaking and the 1975 breaking were treated and irrigated on July 30, 1982. The treatment dates were split due to the time requirement for sampling, preparation, and analysis of the bioassays.

Sampling was done with a metal scoop as depicted in Figure 4a-c. Samples were of the top 5 cm of soil as leaching was not expected to move the herbicides any deeper into the peat and so deeper sampling would dilute the herbicide concentration. Samples were comprised of three sub-samples per plot. Soil sampling was done on the first day of

application and 3, 6, 12, 24, 50, and 100 days after application for subsequent determination of herbicide activity. Analysis of the samples was for bulk density, moisture content and mainly for herbicide activity by the bioassay system described in section 3.3.5.

3.3.4 Greenhouse Screening, 1981

A greenhouse study was conducted to determine the effect of soil type, in particular organic matter and clay content, on herbicide activity and weed control. The soils selected included a sandy loam soil from Carman, a montmorillonite clay soil from the University of Manitoba experimental field at the Fort Garry campus, and three soil breakings, 1962, 1975 and 1980 from the sedge peat site at Vivian, Manitoba.

Common weed species were selected, Poa annua (L.) and Chenopodium album (L.) to represent typical peatland flora, while Setaria glauca (L.) Beauv. and Amaranthus retroflexus (L.) were representative of weeds from horticultural fields on mineral soils.

Plastic trays 54 cm x 26 cm x 6 cm, perforated with drainage holes were filled to a depth of 4 cm with each soil type in a non-replicated screening. The trays were planted on June 7, 1981 with rows of 50 seeds at 1 cm spacing at a depth of 1 cm with 5 cm between rows of each species.

Herbicides were applied on the same day in 100 L ha^{-1} water using a laboratory sprayer. Each tray was divided into an untreated area, a normal and twice normal rate for each herbicide. The control was obtained by covering that section for both passes of the sprayer, while

the normal rate was attained by covering that section only on the second pass of the sprayer. The normal rates applied were 3 kg ai ha^{-1} for chlorpropham, 1 kg ai ha^{-1} for both linuron and pronamide. The flats were watered to saturation immediately following spraying, and then daily for the duration of the experiment.

Ratings for plant emergence were taken, and susceptibility to herbicides were taken two weeks after herbicide application.

3.3.5 Phage Dish Bioassay

The objective of the research was to measure changes in herbicide activity due to sorption by organic matter, and to see if peat degradation affected the amount of herbicide sorbed. Short term bioassays were needed to avoid the confounding problem of herbicide degradation.

The main bioassay technique was evolved by Parker in 1965, and developed by Eshel and Warren (1967). The method has the benefit of rapidity for the evaluation of results and uniformity by removal of climatic factors on growth. Pregerminated seeds were placed on the field moist test soil or sand in phage dishes (100 x 100 x 15 mm, Lab-Tek Products). Root bioassays involved placing 10 seeds near the top of the dish in a line and canting the dish at 15 degrees to the vertical, facing downward so that the root grew along the inside surface of the lid.

Reduced variation in moisture conditions were obtained by adding 20 mL of herbicide solution to control soils to produce a standard curve. An equal volume of water brought the soils in treatment dishes to saturation also. The moisture content was brought to the 'glistening' stage

or beyond as the water potential was then 0 bars as free water was present. The similar moisture conditions were maintained by sealing the phage dishes with masking tape.

The root lengths were measured by removing the seedlings as the roots did not grow as straight as expected. The bioassay only required 72 h (at 30°C for 16 h and 20°C for 8 h per day) for most of the control roots to reach the bottom of the phage dishes.

In most of the bioassay work cucumber cultivar 'Marketer' was used as the bioassay plant; the germination procedure was similar for other species although the time for germination varied. A vacuum seed counter was used to obtain 100 seeds in each glass petri dish. The seeds were germinated on 2 layers of filter paper (Whatman #4 and black #551 Schleicher and Schuell 9 cm on top) with 6 mL distilled water for 27 hours at 30°C. About 3/4 of the seeds had uniform radicle protrusion of 1 mm at that time and were selected for the bioassay. Ten plants were used per dish to prevent changes in herbicide activity due to population effects (Winkle, Leavett and Burnside, 1981).

3.3.5.1 Bioassay Plant Screening

Many plants have been used to measure herbicide activity quantitatively. The main criteria for a good bioassay (Eberle and Gerber, 1976) are that the test plant response to the herbicide increases proportionately to dose, and that within the limits of sample variability and test conditions, the response is reproducible.

The plant species selected had previously been tested under different bioassay conditions so the use of seedlings in phage dishes was expected to alter the sensitivity of the plants.

Shoot growth was measured by placing the germinated seeds at the bottom of the phage dish on a rack inclined at 15^0 to the vertical facing a light source. Shoot assays were conducted for linuron, a photosystem II inhibitor.

Herbicides were added in 20 mL of solution to form concentrations of 1, 2, 4, 8, 16, 32, 64, and 128 ppm by weight of the phage dish contents.

3.3.5.2 Pathology Experiments

The bioassay plant screening indicated cucumber as the most suitable for chlorpropham and pronamide quantitation. The original cultivar 'Centurion' was experimental and could not be obtained for analysis of the 1982 field trial. A rapid germination test of several cultivars showed 'Wisconsin SMR18' to have the most uniform germination. The cultivar 'Wisconsin SMR18' was prone to soil borne pathogen infections that caused random plant death in less than 3 days, invalidating the bioassay by affecting the root length arbitrarily with respect to herbicide rate.

The following experiments were performed on soil samples collected from the 1962 breaking to see what could be done to mitigate the pathogenicity of the organisms.

Disease Identification. Diseased bioassay plants were surface sterilised with 50% bleach for 2 minutes, washed in distilled water and placed on potato dextrose agar. The mycelia grown were identified morphologically under a light microscope by the pathology section in the Plant Science Department, University of Manitoba.

Pathogenicity of the isolated lines were tested on peat sterilised at 120°C for 30 minutes in a steam autoclave and compared to the infections derived from non-sterilised samples. Cucumber roots were grown through agar strips containing the isolated mycelia.

Temperature and Cultivar Effects. A fungus may infect a susceptible host plant if the conditions are suitable to the fungus and inhibitory to the plant. If the conditions are altered to favour the plant rather than the pathogen, infection may be resisted or outgrown. Two temperature regimes were tested as the high disease incidence may have resulted from the 23°C 'day' temperature at 16°C 'night' temperature used that would not favour the growth of cucumber, a warm temperature crop. The experimental regime of a 16 hour 'day' temperature of 30°C and an 8 hour 'night' temperature of 20°C was tested against the normal temperature regime.

The disease isolation experiment had enabled the identification of Rhizoctonia spp, Fusarium spp, and Rhizopus spp. 'Wisconsin SMR18' is particularly susceptible to Rhizoctonia spp., so five other cultivars 'Spartan', 'National Pickling', 'Long Green', 'Straight 8', and 'Marketer' were also tested

for their susceptibility to the pathogen responsible for the disease. Analysis was for presence or absence of disease on a percentage basis. The experiment was carried out using two dishes per cultivar at each temperature regime. 30 mL of water was added to reduce the effect of moisture differences between dishes despite homogenising the soil.

Moisture Content. Disease is often manifested in very wet soils, particularly damping off diseases. The high moisture favours the development of the pathogen and may reduce the vitality of the plant by restricting oxygen availability.

The soil from the 1962 breaking was air dried for 24 hours in a greenhouse to reduce the moisture content, but not to air dryness. The sample was homogenised and then moistened with 0, 5, 10, 15, 20, 25, and 30 mL of distilled water. The cucumber cultivar 'Wisconsin SMR18' was used as it was the most susceptible cultivar.

The experiment was run using five dishes per treatment and was assessed as a presence or absence of disease after three days.

3.3.5.3 Herbicide and Soil Aqueous Slurry Experiment, 1983

The above experiments showed that although the non-isolated disease could be mitigated by manipulation of edaphic factors and by choice of cultivar, the infection still affected bioassays of fresh samples. The optimum bioassay conditions of 30°C and 20°C day/night temperature regime using the smallest amount of moisture possible to get even distribution of the herbicide through the dishes in the control treatments of 20 mL and using the most resistant cultivar 'Marketer' there

were still some dishes with five plants infected. It was hoped that the disease propagule resided on the soil matrix, not in suspension.

An aqueous:soil slurry technique was evaluated to assess the potential of the method for determining the extent of herbicide inactivation by peat soils. The method was used to circumvent the soil borne pathogen problem. Sterilisation with steam or irradiation would release free radicals from the organic matter, and their reactivity could affect sorption greatly. These techniques could not be used in the main experiment for that reason, but sterilisation removed the early seedling death problem and was used to try to identify the pathogen(s).

Chlorpropham was added to produce a final concentration of 0, 0.125, 0.25, 0.5, 1.0, or 2.0 ppm by weight, to a suspension of 100 g of field moist peat in 1400 mL of tap water. The supernatant solutions from slurries of the 1981 and 1962 breakings were evaluated for chlorpropham activity by the phage dish assay. A control curve of herbicide concentrations that had no soil interaction was also evaluated by the phage dish bioassay and was run simultaneously. The slurries of peat, herbicide, and water and the controls were shaken at 200 rpm for 16 hours in dark brown glass 2 L screw top jars. The jars were allowed to stand for an hour before sampling the supernatant solution with a syringe.

Phage dishes (100 x 100 x 15 mm, Lab Tek Products) were filled with 12-30 grade silica sand (Steel Bros. Canada). The sand was treated with 30 mL of supernatant to obtain uniform moisture content (Wiebe, 1981) and seeded with ten pre-germinated cucumber seeds.

A preliminary experiment examined the effect of temperature on herbicide susceptibility of cucumber cultivar 'Marketer' roots during growth of the bioassay. The temperature regimes studied were 30°C for 16 h and 20°C for 8 h compared to 23°C for 16 h and 18°C for 8 h. The lower temperature regime was used as it appeared to be more sensitive,and exhibited no problems due to disease infestation.

Analysis of the bioassays were done by measuring the root extension of 10 plants per dish after three days with a ruler. The mean root length in each dish was considered to be a sample, with five dishes per treatment. The experiment was run seven times to test reproducibility, and analysed as a split plot completely randomised design.

Chapter IV

RESULTS AND DISCUSSION

4.1 TEST SITE

All of the experiments were conducted on Okno series soils,with decomposition increasing with longer periods of cultivation. The most decomposed soil was thus found on the 1962 breaking, with more recent breakings being less oxidized having been exposed to less cultivation. The rate of decomposition was expected to vary on an annual basis,being slower on more decomposed soils. Soil characteristics were to be evaluated for utility in quantifying decomposition, with further experiments to observe the effects of decomposition on herbicide activity.

4.2 SOIL CHARACTERISATION

4.2.1 Organic Matter and Carbon Content

Increasing duration of cultivation of the peat soils showed a general, although inconsistent decrease in organic matter with increased time of cultivation (Table 2). There was little change in the organic matter content with decomposition at 580°C, however, at the other three combustion temperatures there was a major decrease evident in organic content during the first 5 years of cultivation. The combustion at 700°C caused higher apparent levels of organic matter which could be due to the loss of structural water or more complete combustion of the organic matter (Dormaar and Webster, 1964). The similarity in values

between the various combustion temperatures implies that temperature of combustion was not a critical factor when comparing the organic matter present between these soils, while maintaining a constant treatment temperature was important.

The data for combustion show that 400°C was the only temperature showing a consistent decline in readily volatilised lower molecular weight compounds and labile moieties with decomposition.The degradation may be accompanied by polymerisation to higher weight compounds. The samples were subsamples of the homogenised ball milled samples also subsampled and used in the induction furnace method (Table 3), that show different trends for carbon content. The 'low' temperature was cited by Dormaar and Webster (1964) as that which would only oxidize organic matter with no confounding effects of volatilisation of phosphorus and carbonate compounds.

The percentage of carbon from the soils sampled show similar values by the induction furnace method and the Allison wet combustion as found by Tabatai and Bremner (1970) (Table 3). The carbon content determined by the Allison method for the 1975 samples ranged from 39.8 to 52%, for the 4 replicates or sub-samples, having a mean value of 45%, and had the most variability between sub-samples. The 1962 samples had % carbon ranging from 38.10% to 44.98% in the Allison method, while those for the 1981 samples ranged from 40.68 to 46.86% (Appendix B). The data for the Allison method do not confirm the pattern exhibited by the dry combustion methods of decreased organic matter with longer duration of cultivation due to the high level of carbon in the 1975 samples. The induction furnace results also do not confirm a decrease in carbon content

TABLE 2

Organic matter content of peat taken from different breakings at Vivian in August 1981, as determined by dry combustion at four temperatures

Temperature (°C)	Number of repetitions comprising mean	Percentage organic matter (by weight)		
		Year of soil breaking		
		1962	1975	1980
400	2	82.5	83.8	86.8
560	3	87.1	86.3	90.7
580	6	82.8	82.3	80.4
700	4	89.4	88.7	92.7

TABLE 3

Percentage of peat as carbon from samples taken from different breakings at Vivian in 1981 and in 1982 as determined by various combustion techniques

Combustion technique	Percentage carbon (of oven dry weight)			
	year of soil breaking			
	1962	1975	1980	1981
LECO induction furnace	42.0	41.5	43.0	
Walkley Black digestion	21.9	25.2	33.2	
Allison digestion	42.1	45.3		44.1

with increased duration of cultivation. The only decrease in carbon content occurred during the first five years of cultivation by this method. The modified Walkley Black method was the first method tried to ascertain differences in carbon content, and showed a progression of decreasing carbon content with duration of cultivation. The very low values indicate that only readily digested carbon sources were combustable by the potassium dichromate:sulphuric acid mixture used. The difference was the basis for further work on adsorption studies, as it indicated a wide range in decomposition at the sites studied. The more recent peat breaking contained more readily oxidized organic matter, the amount of readily oxidized organic matter decreased with duration of cultivation. The ratio of readily oxidized to more stable organic matter by any of the other methods should provide an indication of decomposition; and may be capable of further development in relation to herbicide binding capacity of organic soils. Preferred methods are those measuring carbon dioxide evolved,or low temperature combustion,thereby precluding errors due to codistillation of other elements.

4.2.2 Fibre Content and Particle Size Analysis

The rubbed and unrubbed fibre content of the soils are presented in Table 4. The unrubbed fibre content show large differences between the soils. The differences for rubbed fibre contents are slightly greater between the soil broken in 1962 and 1975 than for the unrubbed soil fibre content method, but insignificantly different between the 1975 and 1981 soils. The peat soils are mesic when categorised by unrubbed fibre contents and have values between 33 and 67%(Levesque,Dinel,and

Marcoux,1980).All of the peats studied are therefore mesic.Stanek and Silc (1971),however confine the mesic category to 60-90% of the peat volume as unrubbed fibres. The latter categorises both the 1975 and the 1962 breakings as humic.

The rubbed fibre content is normally cited,and soils are categorised as mesic within the range of 10-40% (Levesque et al. 1980). By that definition the 1975 and 1981 breakings are fibric.Lucas (1982) used different rubbed fibre values,those within the 17-75% range categorised as mesic. Stanek and Silc (1971) assessed peats as mesic when the rubbed fibre contents were between 20 and 50%.All three breakings were mesic according to the latter authorities.

The fibre content measured by these methods, had a coefficient of variation of 22% for both rubbed and unrubbed fibre content method. This value was acceptably close to that obtained by Levesque and Dinel (1977) of 26%. The particle size analysis data (Table 5) had a coefficient of variation of 76%, and no significant differences between soils were evident. The major size fraction retained occurred on the 150 μm sieve, followed by the retention on the 75 μm sieve. This value (150 μm) defines whether or not the particles are classified as fibres. The coincidence of peak peat retention with the 150 μm sieve, that defines the particles classed as fibres, likely increases the variability of fibre contents. The mean percentage fibre contents by this method are 54.39% for the 1962, 53.39% for the 1975, and 55.03% for the 1981 soil breaking. These results show similar fibre contents with no change due to decomposition. The rubbed fibre values (Table 4) show a more uniform rate of annual decrease than for the unrubbed fibre content. The values from the particle size analysis as fibres were expected to lie

TABLE 4

Fibre and rubbed fibre content of different peat breakings at Vivian

Year of breaking	Fibre content (percentage of total weight)	
	Unrubbed fibre	Rubbed fibre
1981	65.3	49.0
1975	51.3	42.8
1962	38.7	28.8
c.v.	21.8	22.1
Tukey's test, α.01	3.02	11.91

between the rubbed and unrubbed values in Table 4 for each soil type (Sneddon, Farstad, and Lavkulich, 1971) due to partial mechanical rubbing by the sieves, and pertained in the 1981 breaking. The 1962 and 1975 values for fibres from the particle size analysis greater than 150 um were 54.39 and 53.39% respectively (from Table 5) and were even higher than the unrubbed fibre contents of 38.7 and 51.3% from Table 4. The difference may be due to measuring the percentage of fibres retained by volume (Table 4) and by oven dry weight (Table 5). The organic matter content as determined by loss on ignition at 580°C (Table 6) showed little difference in organic matter percentage between the soils within a given particle size. The particle size with statistically different (.05) organic matter content was for the 1981 soil retained on the 1.00 mm sieve. There was no reason for that difference other than very variable data for that treatment, three replications having values of 40% carbon content whilst the other three replications were close to 80%. The carbon content was expected to be lower for the finer particles, but was probably maintained at high levels by the low mineral content of the soils. The "fibres" for the 1962 soil, or particles greater than 150 μm were predominantly spheroidal aggregates most probably formed by wetting and drying of the peat (Puustjarvi and Robertson, 1980).

The disruption of the clods as shown in Table 7 indicates that cultivation rapidly decreases the number of clods greater than 1.2 cm diameter. The only statistically valid differences in clodiness occur between the most and least cultivated soils, but it is apparent that there are far fewer clods in the 1962 soil than in subsequent breakings.

Mechanical damage by cultivation, drying, and wetting cycles and oxidation are the most probable causes of clod disruption. The clods may increase herbicide activity due to lower adsorption of herbicide in the clod resulting from higher water content in the clods. Roots exploit the interior of the clods and may be exposed to the higher herbicide activity.

TABLE 5

Particle size analysis of different peat breakings

at Vivian, sampled in November, 1982

Year of breaking	Percentage recovery	Particle sizes (percentage of oven dry weight)					
		≥1.5mm	≥1.0mm	≥0.5mm	≥150μm	≥75μm	<75μm
1962	96.79	3.29	6.37	9.02	35.71	25.89	24.46
1975	93.46	6.25	1.86	11.60	33.68	29.73	16.88
1981	92.43	7.59	1.41	8.60	37.43	25.24	18.99

Tukey's test, $\omega_{.05}$ = 7.7
c.v. 76.32%

TABLE 6

Percentage organic matter of particles retained on sieves using dry combustion at 580°C for 24 hours for peat soils sampled at Vivian, 1982

Year of breaking	Organic matter (percentage of total oven dry weight)					
	≥1.5mm	≥1.0mm	≥0.5mm	≥150μm	≥75μm	<75μm
1962	86.24	78.47	83.93	85.12	85.16	77.73
1975	86.70	72.16	89.04	88.62	85.82	75.45
1981	87.47	59.90	86.36	86.13	83.75	79.41

Tukey's test, $\omega_{.05}$ = 18.52
c.v. 13.29

TABLE 7

Coarse dry sieve weights for fresh peat clod percentage for peat soils sampled at Vivian, November, 1982

Year of breaking	Percentage of clods greater than 1.2cm. (fresh, field moist weight)
1962	24.1
1975	41.9
1981	47.7

Tukey's test, w .05 = 19.84
c.v. 17.49

TABLE 8

Sodium pyrophosphate decomposition index of sequentially broken peat measured by comparison with the Munsell chart(10YR)

Soil breaking		*Value/chroma	**Sodium pyrophosphate index
1981	Fresh sample	8/3	5
	Fresh sample	8/3	5
	Fibre	8/3	5
	Rubbed fibre	8/2	6
1975	Fresh sample	8/3	5
	Fresh sample	8/3	5
	Fibre	8/2	6
	Rubbed fibre	8/1	7
1962	Fresh sample	8/4	4
	Fresh sample	8/4	4
	Fibre	8/2	6
	Rubbed fibre	8/2	6

*Value is the colour and forms the vertical axis of the Munsell colour chart,while the chroma defines the shades of each value and extend horizontallv from each value.In the 10YR chart the colour is brown,and modified by changes in the red and vellow components of the brown colour.

**The sodium pyrophosphate index is obtained by subtraction of the chroma from the value.

TABLE 9

Sodium pyrophosphate index of sequentially broken peat soils measured by the Kaila method

Soil breaking	Pyrophosphate index
1982	8.05
1981	7.68
1975	7.22
1962	22.92

4.2.3 Sodium Pyrophosphate Index of Decomposition.

The data in Table 8 show all of the soils become fibric in behaviour by washing or rubbing the fibres. Stanek and Silc (1977) stated that fibric peats have pyrophosphate indices of 7 to 5, mesic peats 5 to 4, and humic peats from 3 to -3. Thus all of the fresh samples may be classified as mesic peats, although 5 has an arbitrary value as fibric and mesic. The Kaila method data (Table 9) are divided into taxonomic groups at absorbances of 0 to 15 for fibric peats, 15 to 30 for mesic peats and greater than 30 for humic peats (Levesque, Dinel, and Marcoux, 1980; and Levesque, Morita, Schnitzer, and Mathur, 1980). Only the soil broken in 1962 was therefore mesic by this method, with all the other breakings being fibric. The results therefore do concur but only subsequent to clarification due to the laboratory method. Schnitzer and Desjardins (1965) gave a different scale of <40 as peats and >60 as mucks,rendering all the breakings as peat soils. The accuracy of the numerical data obtained by the Kaila method also enable trends within the taxonomic groups to be followed which may impact upon herbicide bioactivity. The chemical reason for altered absorbances have not been elucidated although several theories have been expounded in the literature review.

The differences between the fresh sample index and those subjected to washing or rubbing indicate that the more decomposed samples have more water soluble decomposition products adhering to the fibres (Table 8). The 1981 breaking had no change in pyrophosphate index subsequent to washing, only after rubbing when the index increased to 6. The 1975 index increased with both washing and rubbing to yield values of 6 and 7, respectively. Washing thus removed some of the pyrophosphate soluble

decomposition products implying greater water solubility of the 1975 than for the 1980 decomposition products. Rubbing liberated further quantities of chromogenic material. The most decomposed soil broken in 1962 had a marked increase in pyrophosphate index following tap washing but no futher change after rubbing the fibres. The implication again was that the decomposition products are water soluble. Whitby and Schnitzer (1978) stated that fulvic acids are water soluble while humic acids are not. Further work could involve tests of humic:fulvic acid ratios by E_4:E_6 cited by Levesque, Morita, Schnitzer, and Mathur (1980) who found no differences due to decomposition in the ratio during their study of Quebec and Ontario peat soils.

The Von Post scale was frequently cited as a measurement of humification (The Canadian System of Soil Classification 1978, and Stanek and Silc, 1977). Levesque, Morita, Schnitzer, and Mathur (1980) concurred with the use of the Von Post scale for undrained peats, but stated that due to the formation of stable aggregates following drying the method was no longer entirely applicable to agricultural peats. In the case of the peats being studied there was a lack of conformity with the Von Post scale particularly with regard to the yellow colour of the expressed solution. All three samples were found to have the same values of 5. (Moderately decomposed; plant structure clear but becoming indistinct - yields much turbid brown water, some peat escapes between fingers, residue mushy). All three samples were found to be in the H_5, or moderately decomposed group. None were categorised as fibric peats in the H_1 to H_4 classes (Stanek and Silc, 1977). The Von Post scale was a coarse measurement of the state of decomposition, applicable to a greater range

of peat types than encountered in the present study. The main use was for soil surveys where a great range of peat types are encountered.

4.2.4 Bulk Density

4.2.4.1 Oven-dried Method

The laboratory method using oven dried samples resulted in bulk density values within ±0.1 g for 20 mL of peat soil for the 3 soil breakings. Oven dried peat was used as the air-dried peat, in larger volumes, showed weight changes perhaps due to hygroscopic water uptake or loss with ambient conditions. It was felt that a standard condition provided by oven drying would alleviate a possible source of variation due to moisture. The samples were not ground as that would destroy the physical properties of the peat reducing bulk density differences, and yield artifically high values as found in the paper by MacLean et al. (1964).

The values for bulk density were 0.255 g cm^{-3} for the 1962 site, 0.150 g cm^{-3} for the 1975 site, and 0.126 g cm^{-3} for the 1980 site. These values place the 1962 site in the humic class by The Canadian System of Soil Classification (1978), the other two sites are mesic.

4.2.4.2 Constant Water Potential Method

The results for bulk density and volumetric water content shown in Table 10a may be primarily regarded as showing differences between soil types. The bulk densities averaged for the two compaction levels obtained by slurry are 0.189 g cm^{-3} for the 1962 breaking, 0.155 g cm^{-3}

for the 1975 breaking, and 0.120 g cm^{-3} for the 1981 peat, measured in November 1982.

The least significant difference values show that there are differences in bulk density due to cultivation. Compaction was a factor affecting bulk density in the 1975 breaking at the 1% level of significance. The 1962 breaking has different bulk densities due to compaction only at the 5% level of significance, whilst the 1981 samples were not affected at either level of significance by compaction.

4.2.4.3 Field Method

The field moist bulk densities in Figure 5(and Appendix C)show extreme variation between replications and samples. The reason may be that at the shallow sampling depth bulk density was influenced by the dry surface layer and variable depth that the dry zone had penetrated to. The original field compaction was made as uniform as possible, but variation could not be avoided (as in Hogue,1976), despite 3 sub-samples per replication. The overlapping data preclude useful analysis.

Between early August and mid-September the bulk density was greater than at each end of the sampling period (Figure 5). Light rainfall had occurred throughout the sampling period. Heavy rainfall (34 mm) occurred on September 29, 1982 but was not responsible for , the decrease in bulk density that had taken place on all three locations by September 15, 1982.

The most unexpected results were the low bulk densities for the 1975 site, lower than for the freshly broken 1981 site, 0.140 and 0.170 g cm^{-3}, respectively. The oldest 1962 site had an average bulk density of

TABLE 10a

The effect of compaction on bulk density and volumetric water contents of sedge peats at three stages of decomposition

Year of breaking	Compaction	Bulk density	Volumetric water content
1981	[1] Loose	0.117	74.04
	[2] Slurry	0.123	90.28
	[3] Mean	0.120	82.16
1975	Loose	0.147	89.25
	Slurry	0.163	89.76
	Mean	0.155	89.51
1962	Loose	0.182	75.21
	Slurry	0.195	88.98
	Mean	0.189	82.09

[1] Loose = moistened and compacted by 1kg weight
[2] Slurry = soil shaken in hot water, and allowed to drain
[3] Mean = average value for year of breaking

L.S.D. .05
Between breakings, 0.0125 (B.D.), 7.080 (V.W.C.)
Between compaction states, 0.0103 (B.D.), 5.780 (V.W.C.)
L.S.D. .01
Between breakings, 0.170 (B.D.), 9.594 (V.W.C.)
Between compaction states, 0.0139 (B.D.), 7.834 (V.W.C.)

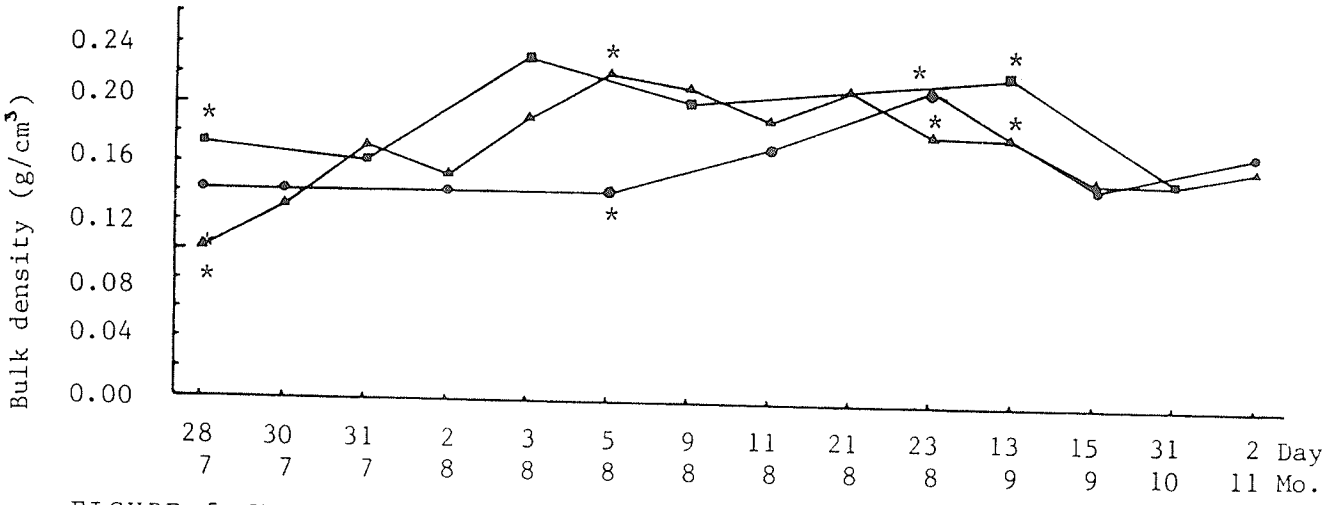


FIGURE 5. Changes in bulk density with time at three breakings of peat at Vivian, 1982.

▲ 1981 breaking.
● 1975 breaking.
■ 1962 breaking.
* Values on same date with bulk densities different at the .05 level (by L.S.D.)

0.190 g cm^{-3}, showing that it had not decomposed to the humic stage (The Canadian System of Soil Classification).

The summary of the data as presented in Table 10b shows that experimental variation was greatly reduced by using the constant water potential method. The coefficient of variation between years has been reduced and was indicative of a more reliable method for obtaining bulk density of peat. The data confirm the expected trend of increasing bulk density with decomposition.

The very high bulk density recorded with the oven dry laboratory approximation method for the 1962 breaking may be due to greater shrinkage of the most decomposed peat as suggested by Boelter and Blake (1964). The structure of the spheroidal aggregates enabled closer packing of the particles, than for the more fibrous peats, artificially inflating the bulk density derived by the oven dry laboratory method.

The high value derived for the 1981 breaking by field assessment may be due to the presence of more "clods", with higher bulk density than the general soil bulk, as indicated by the coarse sieve experiment.

The bulk density values utilised were thus those derived from the constant water potential experiment. The bulk density of the 1962 breaking was evaluated as 0.188 g cm^{-3}, 1975 as 0.155 g cm^{-3}, and 1981 as 0.120 g cm^{-3} at -10 cm water potential. The bulk density would affect the weight of organic matter available for adsorption,particularly following incorporation into the same soil volume.

TABLE 10b

Bulk densities of peat soils as measured by various techniques

Method of sampling	Bulk density (g/cm^3)			Coefficient of variation
	Year of soil breaking			
	1962	1975	1981	
Field	.1899	.1596	.1698	16.86
Constant water potential	.1885	.1549	.1203	8.80

Vigier and Campbell (1980) used a gamma probe to determine the bulk density non-destructively. The technique used by Vigier et al. (1980) obviates sampling errors caused by sampling new locations in the plots with their inherent variation.

4.2.5 Water Content of Field Samples

4.2.5.1 Gravimetric Water Contents

Samples collected between July and November in 1962 were analyzed to obtain the gravimetric water content (Figure 6). The greatest water contents were found in the 1981 soil breaking. The results were different from the 1962 breaking at the 1% confidence level at all dates except October 31 when the 5% level of confidence pertained. The 1975 breaking had intermediate gravimetric water contents and were only comparable to the 1981 breaking due to alternating non-coincident sampling dates to the 1962 breaking. Differences were significant at the 5% confidence level between these 2 soils, on four of the seven sampling dates, showing less difference in gravimetric water content between the 1975 and 1981 breakings than for the 1962 and 1981 breakings. This was expected as cultivation speeds the decomposition of the soils and thereby affects the water holding capacity of the soils (Boelter,1968). The bulk densities of the peat enhances the differences between the gravimetric water contents of the different sites. The data show water content decreased until the middle of September,followed by a rapid increase in October and November values,due to rainfall at the end of September (34mm) and decreased evaporation.

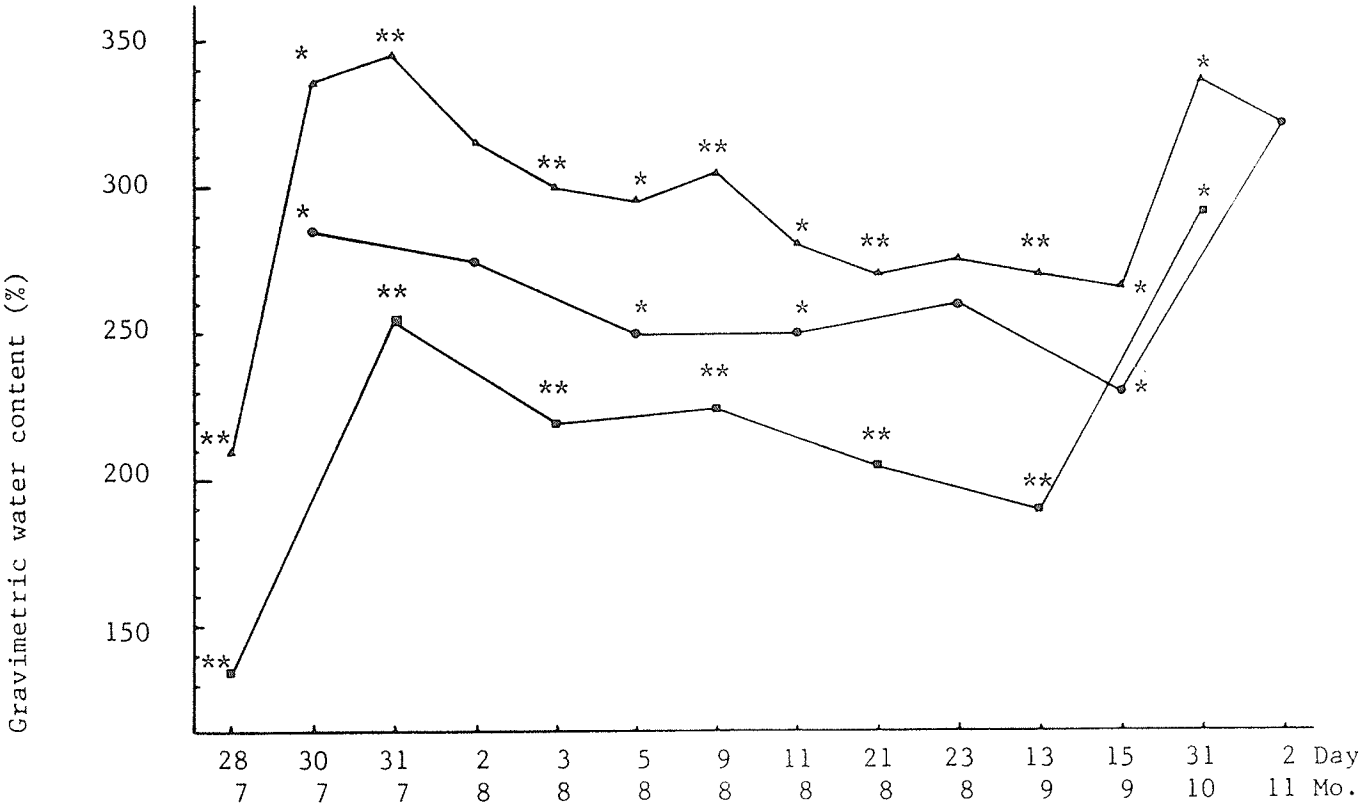


FIGURE 6. Changes in gravimetric water content with time at three locations.

▲ 1981 breaking.
● 1975 breaking.
■ 1962 breaking.
Water contents on same date different by:-
* .05(L.S.D.)
** .01(L.S.D.)

4.2.5.2 Volumetric Water Contents

The calculation of volumetric water content of the three peat types using the field bulk densities on each date produced Figure 7

Volumetric water content (θ) = gravimetric water content (W) x bulk density

The data for volumetric water contents were no longer separated into discrete lines of characteristic water contents. There are few significantly different water contents, and those present do not resolve definitive characteristics between soil types. The gradual decreases of water content until October 31 are masked by the increased variability of the data.

The volumetric water contents at each sampling date were also calculated using both the oven dry bulk density approximation (Figure 8.) and the constant water potential method (Figure 9). Both figures show a reversal of order of water content compared to the gravimetric water content for the three sites. This effect was expected (Boelter and Blake, 1964) and reflects the differences in bulk densities derived by each method. The 1962 breaking has the highest volumetric water content in both cases. The confidence level of 1% showed differences between the 1962 and 1981 breakings at all but the July 28 sampling dates in Figure 8. Only two dates revealed differences between the 1975 and 1981 breakings, on August 23 and November 2 at the 5% and 1% confidence level, respectively. Neither the August 23 or the November 2 data displayed statistically valid differences in the gravimetric presentation of the data, showing a further major change resulting from the transformation of gravimetric to volumetric water content. The differ-

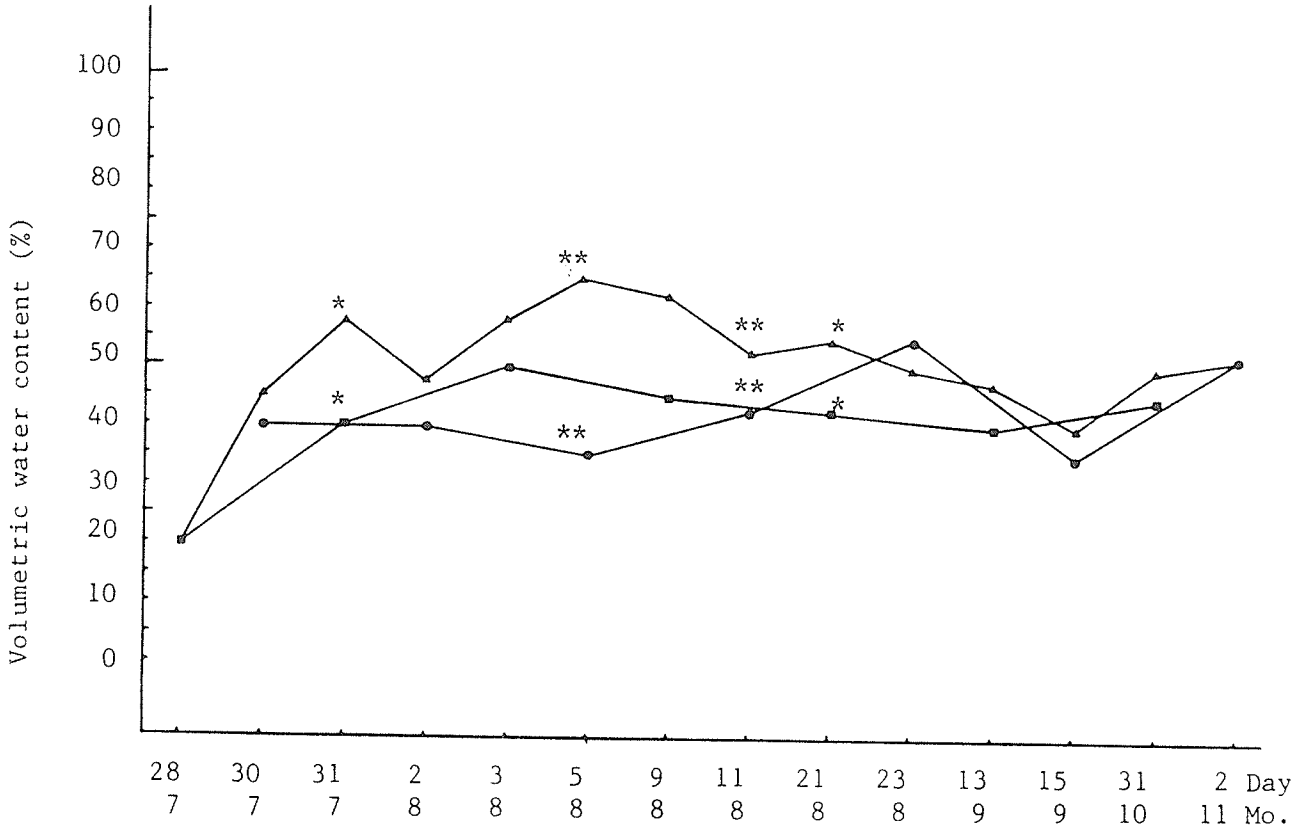


FIGURE 7. Changes in volumetric water content calculated using field bulk density measurements with time at three locations.

▲ 1981 breaking.
● 1975 breaking.
■ 1962 breaking.
Water contents on same date different by:-
* .05 (L.S.D.)
** .01 (L.S.D.)

ences between bulk densities by each method for each soil type affect the separation of soil type curves. In Figure 9, derived from the constant water potential method of determining bulk density the volumetric water contents are not as widely segregated as in Figure 8. The effect of bulk density on volumetric water content shows the importance of obtaining reliable bulk density data. The preferred method of constant water potential to obtain bulk densities reveals that there are only statistically different water contents between peat types on seven dates, or only half of them.

Volumetric water contents do not appear to vary widely between the three locations studied during drying phases. Differences do occur following precipitation, as shown on Figures 8 and 9. The coefficients of variation were similar for data recorded in Figures 7, 8, and 9, with cumulative C.V. of 124.51, 116.49, and 121.47, respectively. Clearly the most variable data were those recorded using the field bulk density measurements.

The data show that if water content was a significant factor affecting herbicide toxicity major differences in activity will be apparent between soils following precipitation or irrigation. Volumetric water content provides a measurement of the volume of water in a given volume of soil,permitting the direct comparison of soils with varying bulk densities as in peat soils.

4.2.5.3 Hygroscopic Coefficient

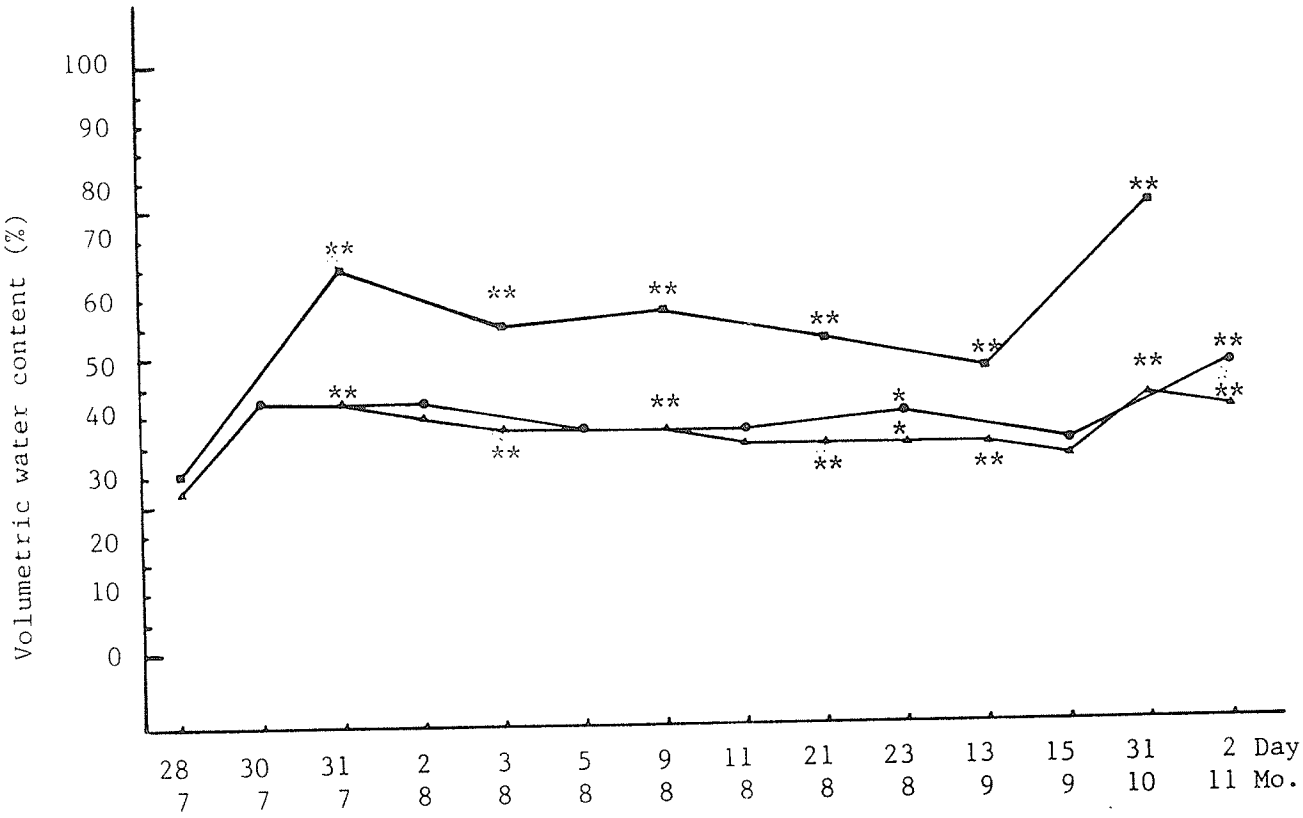


FIGURE 8. Changes in volumetric water content calculated using oven dry bulk density measurements with time at three locations.

▲ 1981 breaking.
● 1975 breaking.
■ 1962 breaking.
Water contents on same date different by:-
* .05 (L.S.D.)
** .01 (L.S.D.)

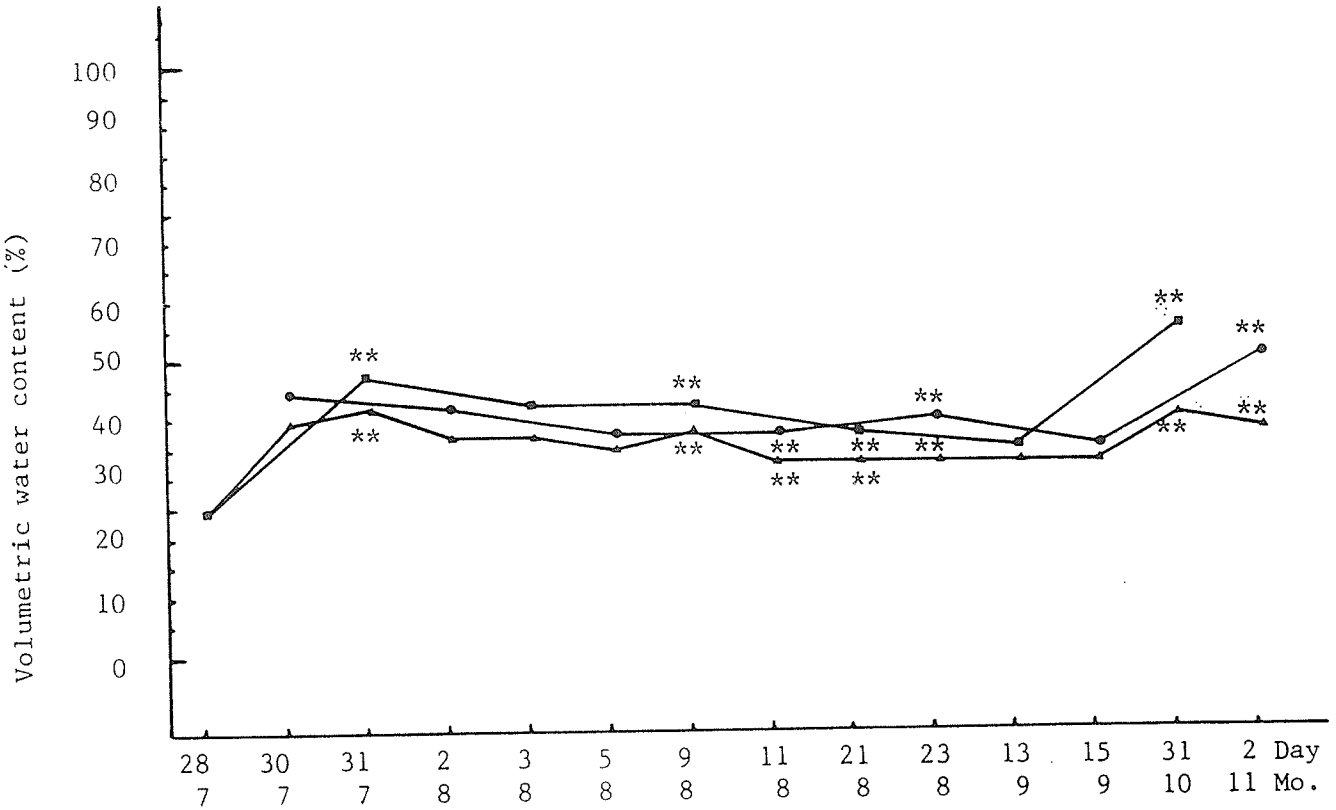


FIGURE 9. Changes in volumetric water content calculated using constant water potential bulk density measurements with time at three locations.

▲ 1981 breaking.
● 1975 breaking.
■ 1962 breaking.
Water contents on same date different by:-
* .05 (L.S.D.)
** .01 (L.S.D.)

The hygroscopic coefficients for the three peat soil breakings as soil clods and loose soil are presented in Table 11. The effect of soil type on hygroscopic coefficients shows that an increase in time of cultivation has increased the air dry gravimetric moisture content for both types of compaction. Compaction also has a major effect on the hygroscopic coefficients, being higher in the clods than in the loose soil.

The increase in the hygroscopic coefficients between periods of cultivation are due to increased decomposition resulting in stronger water adsorption. The increased adsorption may result from increased surface area, or the presence of more polar groups to adsorb to. The moisture content was still high as shown by the gravimetric water content being 2 to 3 times the weight of oven dry soil. Chen and Schnitzer (1976b) suggested that water may cluster around adsorption sites, due to the polarity of water, yielding higher water contents than attributable to a monolayer of water at those sites. The surface area of humic and fulvic acids measured with water was 80 times that measured with helium or nitrogen due to clustering (Chen and Schnitzer, 1976b).

The higher water content in the clods may be due to insulation of the clod core from atmospheric relative humidity by peripheral peat. The variability of the data for clods, as indicated by the coefficients of variation, was greater than for the loose soil in the two earlier breakings, but not so for the 1981 breaking. The indication was that more water was trapped in the older clods than in the more fibrous recently cultivated soil that may have more open pores. Another reason for the increased moisture content in the clods may be that there was less

TABLE 11

Hygroscopic coefficient of air dried peat at three stages of decomposition and two states of compaction sampled on March 3,1984.

Year of breaking	Compaction	Hygroscopic coefficient (gravimetric water content)			
		Mean percentage	L.S.D. grouping		Coefficient of variation
			Breaking	Compaction	
1981	Clod	233.05	a	a	2.70
	Loose	207.48		b	6.42
1975	Clod	275.22	b	a	11.60
	Loose	233.65		b	9.69
1962	Clod	308.57	c	a	6.74
	Loose	272.68		b	2.49

L.S.D. .01 between breakings=17.17

L.S.D. .01 between states of compaction within breakings=19.00

cation exchange and chelation of the carboxylic groups that are the primary adsorption sites (Schnitzer and Desjardins, 1966; Jasmin et al., 1981). The clods, by having a higher water content at field water potentials, will have less influx of cation bearing soil solution than in the general body of peat soil. The higher moisture content was indicated by squeezing handfulls of loose and clodded soils. Often only the latter yielded free water under pressure.

The experiment clearly demonstrates a difference between water adsorption with duration of cultivation and, within locations, of texture. If the foci for water adsorption are the same as those for herbicide adsorption similar trends should ensue, with increased adsorption of herbicide in peat soils with longer periods of cultivation and compaction.

4.2.5.4 Hygroscopic Coefficient,Methodology for Standardisation.

Hygroscopic coefficient varies with temperature and relative humidity. Brady (1974) stated that the water potential at which hygroscopic coefficient should be measured was -3100 kPa (-31 bar). Taylor (1972) measured the hygroscopic water content at a water potential of -2780 kPa (-27.8 bar), controlling relative humidity at 98%. Taylor (1972) performed experiments at room temperature to determine the hygroscopic coefficients for several mineral soils. Further work at a constant temperature of 25°C using a saturated solution of potassium dichromate would yield a relative humidity of 98% with a standardised water potential of -2790 kPa (-27.9 bar) (Collis-George and Melville, 1975). The temperature must be kept constant to maintain these condi-

tions in a dessicator containing moisture cans filled with peat for 4 to 6 weeks for the water content to equilibrate. The gravimetric moisture content should be repeated for both wetting and drying cycles as the hygroscopic coefficient will be greater for the drying cycle due to hysteresis effects (Shaykewich, 1981). The conditions pertaining for hygroscopic coefficient determinations should be standardised to permit repetition of experiments.

4.2.6 Chemical Characteristics of Peat.

4.2.6.1 pH

The pH values determined in 1981 for all soil locations were all in the region of pH 6 with minor differences up to 0.3 pH units for the most recent soil breaking (Table 12). The pH value for the 1962 breaking sampled in the spring of 1984 showed a considerable increase in pH over both the data obtained in 1981 for both the 0.01 M $CaCl_2$ and water methods of determination (Table 12) for both the surface crust (high salt) and for the lower 2-7 cm samples.A pH of 7.5 could affect the availability of herbicides and cations due to changes in polymer structure (Chen and Schnitzer,1976a). The availability of P, Fe, Zn, Mn, Cu, and Co decrease from pH 5.5 to 7.5 (Brady, 1974) or P, Mn, B, Cu, Zn (Lucas, 1982) with Mo availability low below pH 5.5.

There are no characteristic decreases of pH using 0.01 M $CaCl_2$ as predicted, nor was the variability of pH reduced using 0.01 M $CaCl_2$ (Appendix D). The surface peat 'crust' had high salt content due to evaporation, the samples were taken prior to cultivation that would mix the crust before seeding. The high salt concentration was expected to

TABLE 12.

Electrical conductivity, pH, and cation exchange capacity of organic soils at Vivian, Manitoba as determined in 1981 and 1984.

Location and depth (year of analysis)	Electrical conductivity (mhos cm^{-1})	pH determinations		Cation exchange capacity BaAc (mEq/100g)
		$CaCl_2$	water	
1962 2-7cm (1984)	1.16	7.3	7.6	-
1975 2-7cm (1984)	1.34	5.8	6.0	-
1980 2-7cm (1984)	1.10	5.7	5.9	-
1981 2-7cm (1984)	0.45	5.8	6.1	-
1962 0-2cm (1984)	5.54	7.6	7.7	-
1975 0.2cm (1984)	5.04	6.3	5.0	-
1980 0-2cm (1984)	5.21	6.0	5.9	-
1981 0-2cm (1984)	3.64	6.2	6.0	-
1962 0-15cm(1981)	3.9-4.0	-	5.9	334.1
1975 0-15cm(1981)	3.7-3.9	-	6.0	333.4
1980 0-15cm(1981)	3.4-3.5	-	5.7-5.9	354.6

TABLE 13

Soil test results from Manitoba Soils Testing Laboratory and experimental analysis in 1981 for organic soils at Vivian,Manitoba.

Location	N	K	Ca	Mg	Zn	Fe	Mn	Cu
	ppm							
1962 *	390	420+	12600	4160	6.5	130	34	6.5
1975 *	558	420+	15200	4290	35.8	95	73	4.5
1980 *	132	420+	10100	3830	70.0	83	40	6.3
1962 **	34.75	600	5400	3800	39.0	44	75	6.3
1975 **	47.05	600	5100	3000	48.0	30	85	3.8
1980 **	24.60	900	5300	3300	56.0	18	39	6.3
1962 ***	27500	500	20600	4800	40.0	620	168	60.0
1975 ***	29600	700	20500	3900	45.0	1550	180	19.0
1980 ***	29200	900	21300	3900	54.0	1710	85	35.0

* Provincial Soil Testing Laboratory.
** Exchangeable cation,N by phenol disulphonic acid method.
***Total cation,N by Carlo Erba combustion technique.

show the benefit of using 0.01 M $CaCl_2$, but this was not apparent in the data. The similarity of the results imply no benefits of one method over the other,thus for simplicity the determination using water may be better with a 1:4 soil:water ratio by weight as used by McKeague (1976) and Haluschak (1984). The pH effect on adsorptivity may affect non-ionic as well as ionic adsorbates and may be an important factor in herbicide activity. The organic matrix is altered by pH changes,as shown by Chen and Schnitzer (1976a) at pH 7.Decomposition was expected to increase pH as reported by Walmsley and Lavkulich (1972), Griffith and Schnitzer (1977), and Morita and Sowden (1981) due to substitution of protons by cations.

4.2.6.2 Electrical Conductivity

The electrical conductivity of the soils measured in 1981 show an increase due to cultivation (Table 12). The peat:water ratio of 1:3 in 1981 caused higher conductivities than in the comparable sub-surface samples measured in peat:water ratio of 1:5 in 1984. The 1984 data showed a less defined trend towards increased conductivity with duration of cultivation at both sampling depths, although the most recently broken site was clearly lower. The other sites show similar values without consistent trends due to cultivation. The conductivities are high and in normal soils would be expected to affect plant growth (McKeague, 1978) particularly of sensitive crops (Reisenauer, Quick, Voss, and Brown, 1978). Peat soils, however, tend to have higher water contents than mineral soils and therefore crops may tolerate higher salt contents due to the dilution effect of the soil water (Lucas, 1982). In

the 1962 breaking where clay subsoil had been tilled into the soil some salinity effects were found on lettuce, a sensitive crop.

4.2.7 Cation Exchange Capacity (C.E.C.)

The cation exchange capacity measured with barium acetate was recommended for organic soils, and results in higher values than determined with ammonium acetate (MacLean, Halstead, Mack, and Jasmin, 1963). The data (Table 12.) are much higher than figures in the literature due to the use of oven rather than air dried peat and unexpectedly show higher values for the freshly broken soil than for the 1962 and 1975 breakings. Cation exchange was thought to be due to oxygen containing functional groups and was expected to increase with oxidation due to cultivation. The cation exchange capacity was to be used in conjunction with pH to indicate COOH, ROH, ArOH abundance,being the major contributing groups to C.E.C.. The implication of decreased cation exchange capacity with decomposition is contrary to other authorities and contraindicated by the sodium pyrophosphate data which is an indicator of the moieties responsible for C.E.C.

4.2.7.1 Exchangeable and Total Cations

The data for exchangeable and total cations collected in 1981 are presented in Table 13.

The nitrate content of the soils by the Manitoba Provincial Soils Testing Laboratory and the phenoldisulphonic acid method were highest in the 1975 breaking. The 1980 breaking was lowest, showing a nitrate

depression due to rapid decomposition of organic matter causing immobilisation of nitrogen.

The total nitrogen was expected to increase with decomposition and annual fertilisation with nitrogen. The carbon:nitrogen ratios for the breaking in 1962, 1975, and 1980 were 14.7:1, 13.9:1, and 15.3:1 by the Carlo Erba induction furnace method. Decomposition was expected to decrease the C:N ratio as nitrogen content remains constant while the carbon content is expected to fall. There is no defined trend in the data.

The total and exchangeable cations present in the peat breakings are shown in Table 13.No major changes were apparent due to decomposition,although the available iron increases with decomposition while the total decreased.When compared to other Manitoba peats (Appendix E) it may be seen that the potassium and magnesium contents are high,calcium and iron similar, while zinc and manganese were lower.

The objective of studying cation contents was to test whether the total cation content:exchangeable would increase concommitantly with pH,and with decomposition as predicted from Schnitzer and Desjardins (1966), and Jasmin, Hamilton, Millette, Hogue, Bernier, and Campbell (1981). Changes in herbicide adsorption could occur due to decreased availability of protons for hydrogen bonding due to competitive adsorption by cations,or even absorption due to chelation. (Volvarich,Korol,Lishtvan,Mamtesis, and Churaev,1975).The exchangeable protons have been implicated as the probable sites for urea and aniline adsorption (Choudhry,1984) by hydrogen bonding. Linuron does not adsorb to organic matter via coordination bonding to cations on humic acid

according to the infra-red spectroscopy of Khan and Mazurkewich(1974).Cation adsorption thereby precluded linuron binding to carboxyl sites. The data showed great variability even for total cation content,so either the sampling technique or the analysis need to be improved for peats as suggested by Puustjarvi (1978).

4.3 HERBICIDE ADSORPTION STUDIES

4.3.1 Herbicide Pre-screening, 1980

The data presented in Table 14 show that in field trials conducted in 1980, bensulide did not control any of the predominating weed species, nor were there any marketable heads of Ithaca lettuce. Propham gave some control of annual bluegrass at higher rates, but this did not result in any yield increase in the marketable heads of lettuce. Pronamide gave good control of annual bluegrass, particularly at higher rates. The lettuce yield was increased especially at the higher rates of pronamide, despite decreased crop vigour earlier in the season at the highest rate. Chlorpropham caused some control of broadleaved weeds especially at the highest rate of 12 kg ai ha^{-1} rate,however vigour was also reduced. Annual bluegrass was also partially controlled at higher rates. The marketable yield of lettuce was increased at all rates of chlorpropham, despite the decreased crop vigour at the highest rate. Propachlor showed very good activity on all weeds, but also reduced crop vigour and yield, and thus indicated promise only as a directed spray. Chlorpropham and pronamide were selected for further research due to the selectivity and activity shown in this preliminary experiment.

TABLE 14.
Pre-plant incorporated and pre-emergence weed control in seeded head lettuce on peat soil, 1980.

Treatment		Number of weeds per M^2, July 8.						
Herbicide	Rate (Kg ai/ha)	Oak-leaved goosefoot	Maple-leaved goosefoot	Biennial wormwood	Annual bluegrass	Crop vigour*	No. marketable heads per plot	Marketable yield (Kg/plot) Aug, 16
Check	-	41	33	26	200	8.8	18.5	26.3
Bensulide	3 PPI	57	47	27	269	8.0	-	-
Bensulide	6 PPI	58	64	31	358	8.0	-	-
Bensulide	12 PPI	50	55	34	247	8.0	-	-
Propham	3 PPI	66	71	27	155	8.8	21.5	29.4
Propham	6 PPI	50	70	22	75	8.5	20.5	28.8
Propham	12 PPI	46	53	36	68	8.8	21.0	28.7
Pronamide	1 PPI	35	64	28	80	8.0	21.5	30.9
Pronamide	2 PPI	42	51	29	17	8.3	22.8	34.5
Pronamide	4 PPI	38	43	25	6	7.0	26.3	38.1
Chlorpropham	3 PRE	65	55	24	127	7.5	20.8	26.8
Chlorpropham	6 PRE	29	67	31	99	7.3	19.8	27.9
Chlorpropham	12 PRE	26	48	21	101	6.8	26.3	36.4
Propachlor	2 PRE	15	24	7	177	3.0	24.5	22.1
Propachlor	4 PRE	3	5	1	86	1.3	8.0	8.0
Propachlor	8 PRE	1	0	0	16	0	0	0
L.S.D. 5%		27	28	15	99		7.1	9.4
L.S.D. 1%		36	37	20	132		9.5	12.6

* 9 = no crop damage, 1 = severe crop damage

4.3.2 Field Trials, 1981

4.3.2.1 Weed Control

The most pertinent data relative to herbicide activity in peat soils having undergone various periods of decomposition were expected to be the weed control data. Regrettably, direct comparison of data were precluded by different weed spectra in the various breakings. The 1980 breaking was populated by perennial weeds, Sow and Canada thistle, and willow trees, which were little controlled by the herbicides. The data for the 1980 breaking is not presented. Tables 15a and 15b show the weed spectra of the 1962 and 1975 breakings respectively. Good control was derived by all herbicides on the 1962 breaking for Annual bluegrass, Prairie buttercup, and Shepherd's purse. The control of Shepherd's purse was best attained by chlorpropham. The 1975 breaking data (Table 15b) show less complete control of Annual blugrass. Spearmint was also well controlled on the 1975 breaking. Statistical analysis revealed no differences in treatments between soil types, although doubtless the disparity between the original population densities could have obscured any differences.

4.3.2.2 Crop Emergence

The crop emergence ratings determined on June 19, 1981 are shown as bar charts in Figures 10a-c. Figure 10a shows that in the control plots carrot emergence was variable with poor overall emergence on the 1975 breaking. Poor emergence is often a problem in small seeded crops, but

TABLE 15a.

Pre-emergence weed control in field experiment

1981 trial;1962 breaking

Treatment		Number of weeds per M^2, July 7			
Herbicide	Rate (Kg ai/ha)	Annual bluegrass	Prairie buttercup	Oak-leaved goosefoot	Shepherd's purse
Check	-	17	58	9	273
Chlorpropham	3 PRE	7	0	7	17
Chlorpropham	6 PRE	2	1	4	10
Chlorpropham	12 PRE	3	1	1	2
Linuron	1 PRE	8	43	9	185
Linuron	2 PRE	3	11	4	52
Linuron	4 PRE	0	5	2	47
Pronamide	1 PRE	9	22	5	214
Pronamide	2 PRE	6	16	9	231
Pronamide	4 PRE	0	4	3	55
L.S.D. 5%		NS	18.4	6.23	102.9
L.S.D. 1%		NS	24.8	NS	138.6
C.V.		176	80	83	66

TABLE 15b.

Pre-emergence weed control in field experiment

1981 trial;1975 breaking.

Treatment		Number of weeds per M^2, July 7	
Herbicide	Rate (Kg ai/ha)	Annual bluegrass	Spearmint
Check	-	12	10
Chlorpropham	3 PRE	5	2
Chlorpropham	6 PRE	3	0
Chlorpropham	12 PRE	1	0
Linuron	1 PRE	16	8
Linuron	2 PRE	8	2
Linuron	4 PRE	3	3
Pronamide	1 PRE	6	2
Pronamide	2 PRE	4	4
Pronamide	4 PRE	3	2
L.S.D. 5%		2.0	6.2
L.S.D. 1%		NS	NS
C.V.		91	130

unexpected in a soil as light as peat. No trends are discernable for decreased emergence with any of the herbicides . Both linuron and chlorpropham are registered for use on carrots, and it would appear that there is little effect of pronamide on the carrot cultivar 'Hipak' also.

Onion had poor emergence on the 1962 breaking (Figure 10b) as indicated by the control, and obscured chlorpropham treatment effects. The higher rates of chlorpropham decreased emergence similarly on recently broken soil types despite being registered for use on onions. Linuron decreased the emergence of onion proportionately with dose on the earlier breakings,however,emergence was also due to a soil effect rather than herbicidal activity. The higher rates of linuron on the 1980 breaking caused the greatest decrease in emergence. The decrease implies less binding on the more recently broken peat. Pronamide did not affect onion emergence.

Lettuce emergence (Figure 10c) was good, and unaffected, in the control and pronamide treatments respectively. Chlorpropham inhibited emergence of lettuce on the 1962 breaking markedly at all rates, and proportionately with dose on the 1975 breaking. Chlorpropham adsorption would appear to decrease with peat decomposition. Lettuce was susceptible to linuron, particularly at higher rates, with no discernable trend for soil herbicide interactions.

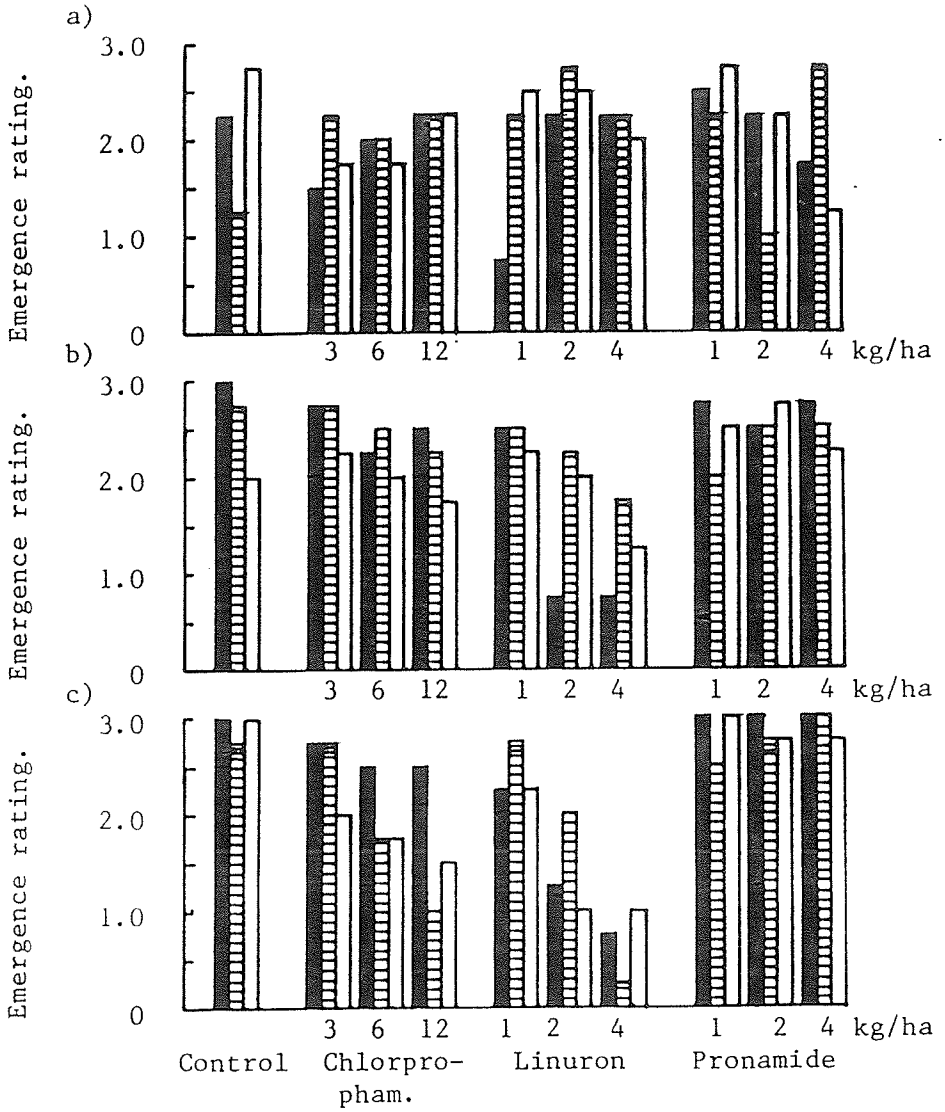


FIGURE 10 a-c. Emergence on June 19,1981 of three crops at Vivian, Manitoba on three breakings of peat.

a)....carrot.
b)....onion.
c)....lettuce.

1980 breaking.
1975 breaking.
1962 breaking.

4.3.2.3 Crop Development

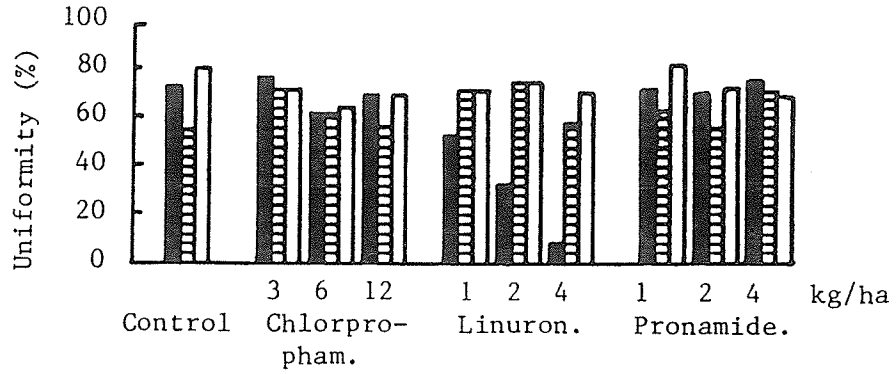
The July 20, 1981 crop evaluations provided a view of long term, time integrated crop tolerance (Kohn, 1980) following herbicide decomposition. Some recovery was evident following early herbicide injury that had shown the impact of chronic herbicide phytotoxicity on susceptible crops. The percentage rating scale pertained over a wider range of plant sizes and deformity than the earlier crop rating. The row filling percentage was easier to judge as a separate entity. Uniformity and vigour combined as percentage uniformity necessarily became more amgibuous particularly in the middle of the scale (Little, 1985).

Carrot

Carrot uniformity and row filling (Figures 11a and 11b) vary less in the control treatment than was shown at emergence (Figure 10a). Late emergence in the subsequent 31 days has compensated for early variability. Only linuron caused a rate dependent decrease in both percentage uniformity and row filling for carrots on the 1980 breaking, with little effect of any other treatments. The tolerance of carrot to linuron has been exceeded at twice and four times the normal rate only on the most recent breaking. Stronger sorption to the more decomposed soils could have lowered the toxicity on the other breakings.

Lettuce

The evaluation of the lettuce crop on July 20 included head formation as a separate assessment (Figure 11c). The total number of heads possible would have been 70 for each treatment. Head formation for the



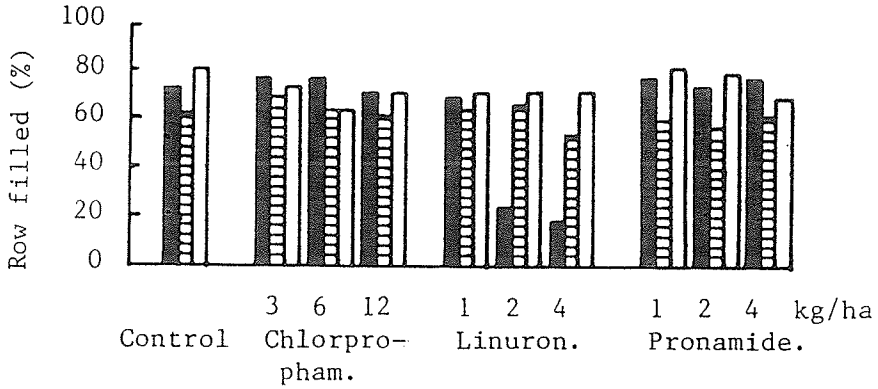


FIGURE 11a-b. Crop evaluation on July 20,1981 at Vivian on three peat breakings for carrot.

■ 1980 breaking.
▤ 1975 breaking.
□ 1962 breaking.

control treatment was 58 in the best locations, and only 40 on the 1975 location. The discrepancy may have been due to poor seedbed preparation.

Chlorpropham activity was greater on the more decomposed peats with proportional decreases in head formation with increased rates of herbicide. The decreased head formation appears to have been more influenced by percentage of row filling rather than uniformity (Figures 11e and 11d). Linuron was the most phytotoxic herbicide to lettuce, where dose proportional reductions in head formation, uniformity and row filling occurred. The 1962 breaking was least affected in both uniformity and head formation showing lower phytotoxicity probably due to sorption of linuron. Pronamide showed little toxicity to lettuce at any of the applied rates with all assessments being similar to the controls on all soils. The control and pronamide treatment row filling decreased due to an infestation of cutworms on the 1962 breaking in early July. Aster yellows incidence was high at 20% infection (Appendix F) despite attempts to control the leaf hopper, vector of the mycoplasma. Control of the insect was confounded by the presence of Chenopodium sp. The weed was prevalent particularly on the 1962 breaking, and acted as an alternative host outside the controlled area. Reinfestation of both lettuce and carrot crops was thus facilitated, thereby reducing their yields due to aster yellows.

Onions

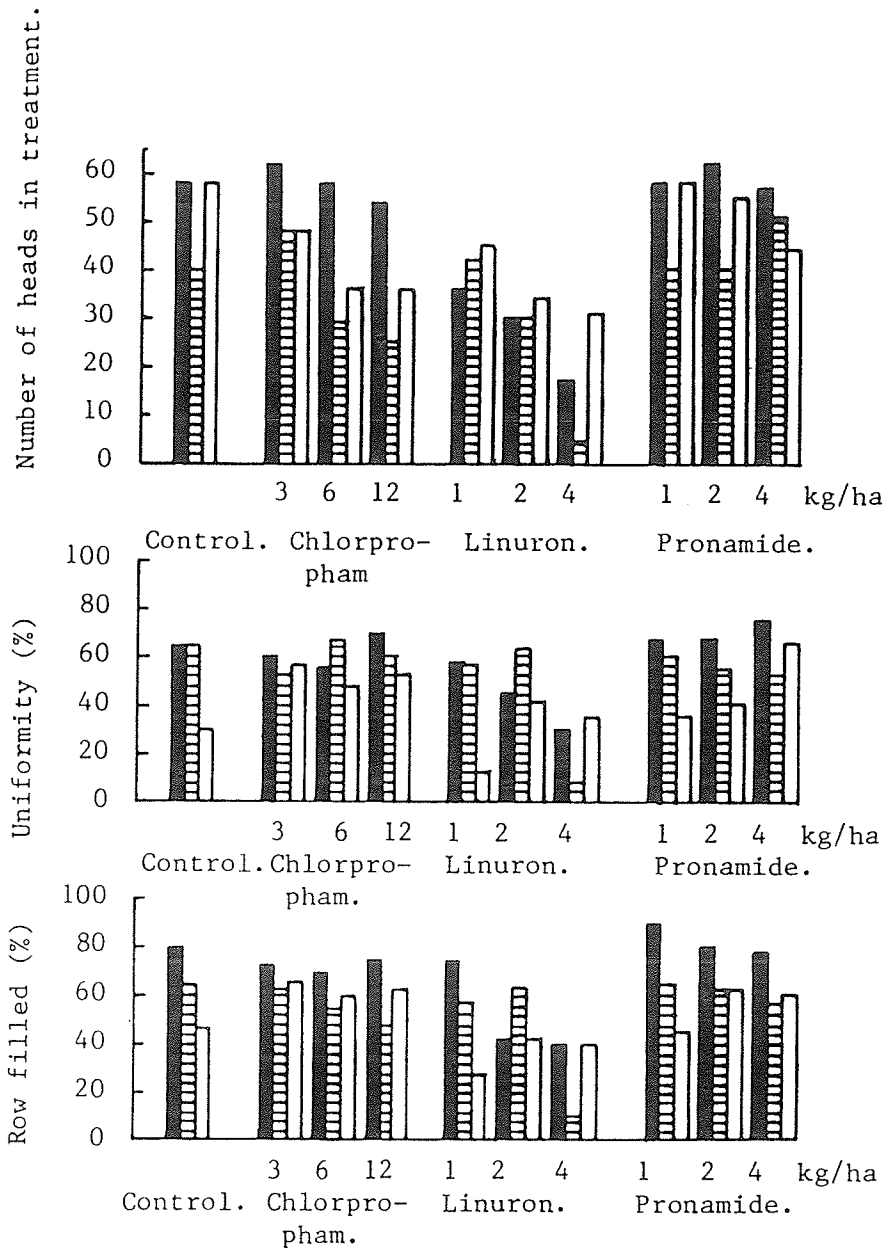


FIGURE 11c-e. Crop evaluation on July 20,1981 at Vivian on three peat breakings for lettuce.

- 1980 breaking.
- 1975 breaking.
- 1962 breaking.

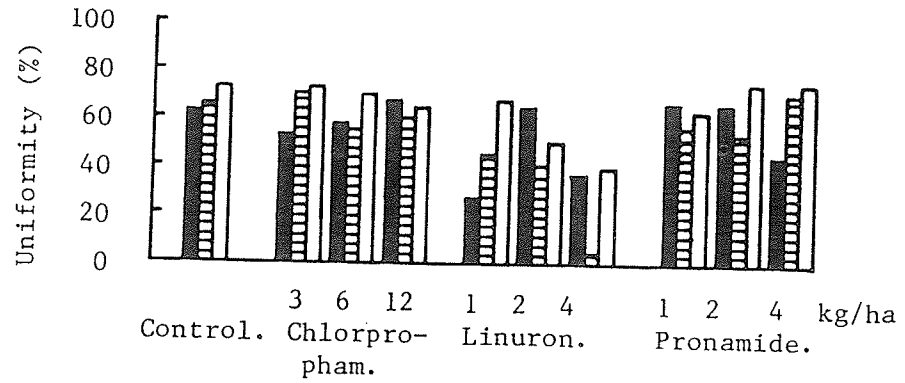
The uniformity on onions (Figure 11f) showed no differences due to location in the control, chlorpropham, or pronamide treatments. Linuron decreased onion uniformity particularly on the 1975 breaking. Row filling was poor on the 1975 breaking where linuron was most active, and showed some phytotoxicity of linuron on the 1962 breaking also. There were few effects on onion row filling with any of the other treatments. The major effect appears to have been emergence on the 1975 soil (Figure 10b).

4.3.2.4 Yield

Lettuce Yield.

A major difference in harvest dates for lettuce occurred for the three locations with three harvests on the 1980 breaking (Appendix G) and only one on the earlier breakings. The data for total lettuce harvested at each location by August 7,1981 are shown in Table 16. Most of the data show that variability of the data were greater than treatment effects, thus comments are confined to statistically non valid trends.

Frequently the yield in control plots were lower than in treated plots probably due to weeding damage. Lettuce production was greatest on the 1980 breaking succeeded by the 1975 location for the number of heads harvested.



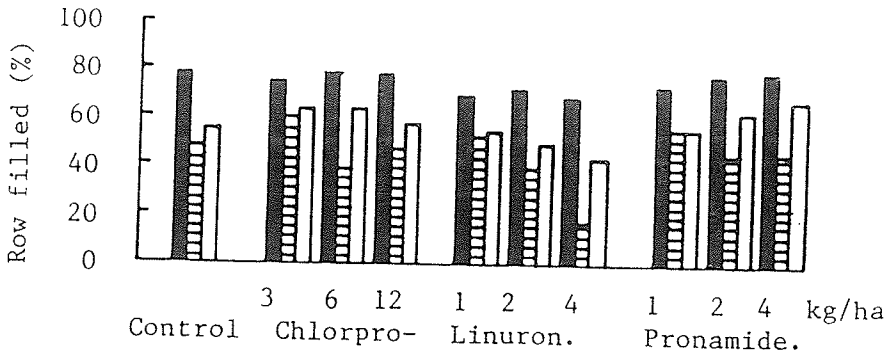


FIGURE 11f-g. Crop evaluation on July 20,1981 at Vivian on three peat breakings for onion.

■ 1980 breaking.
▤ 1975 breaking.
□ 1962 breaking.

TABLE 16

Total lettuce harvest 72 days after seeding on three locations at Vivian, 1981.

Treatment		Number of heads per treatment			Weight per head (kg)			Total weight (kg) per treatment		
		Year of breaking			Year of breaking			Year of breaking		
Herbicide	Rate (Kg ai/ha)	1980	1975	1962	1980	1975	1962	1980	1975	1962
Check	-	28	12	9	0.68	1.07	0.72	19.1	12.8	6.5
Chlorpropham	3 PRE	36	19	14	0.73	1.07	1.06	26.1	20.3	14.8
Chlorpropham	6 PRE	30	17	9	0.68	1.05	1.02	20.4	17.9	9.2
Chlorpropham	12 PRE	29	7	7	0.64	1.16	1.04	18.6	8.1	7.3
Linuron	1 PRE	14	11	5	0.92	1.03	0.88	12.9	11.3	4.4
Linuron	2 PRE	13	13	9	0.73	1.14	1.03	9.5	14.8	9.3
Linuron	4 PRE	7	1	8	0.80	1.80	1.11	5.6	1.8	8.9
Pronamide	1 PRE	24	15	8	0.72	1.11	1.10	17.3	16.7	8.8
Pronamide	2 PRE	25	10	8	0.65	1.08	1.10	16.2	10.8	8.8
Pronamide	4 PRE	16	13	6	0.70	1.00	1.30	11.2	13.0	7.8
L.S.D. 5%		13.92	NS	NS	NS	0.32	NS	10.63	9.6	NS
C.V.		43	61	97	35	39	70	46	66	108

Chlorpropham caused a yield increase at all three locations above that of the control at the 3 kg ai ha^{-1} rate. The increased yield was sustained at the 6 kg rate on only the 1975 breaking. There was no decrease in yield on the 1980 location for lettuce as total yield or number of heads even at the 12 kg ha^{-1}rate of chlorpropham. The increase may be due to decreased weed vigour causing less damage to the lettuce roots during weeding. Linuron at the 4 kg ha^{-1} rate reduced the yields on all sites, with an anomalously large yield on one plot for the 1962 breaking providing six heads of a total treatment harvest of eight heads.

The data for head weight clearly show that the 1980 breaking produced smaller heads, but even so they were large enough to be marketable. Tipburn caused quality losses in the harvests after July 25, 1981 and reduced head weight (Appendix H). Total yield data conforms to the head number effects.

Carrot Yield

The data in Table 17 show that variability, probably due to heavy aster yellows infestation (Appendix F), resulted in the elucidation of non-significant trends. The total yield from the 1962 breaking is more than double that of the other locations showing that carrot production is better on the more decomposed soil. The quality of the roots was also higher on the 1962 breaking as shown both by the marketable yield and percentage of the total yield deemed marketable. There is some indication of phytotoxicity for linuron and pronamide at the 4 kg ai ha^{-1} rate on both the 1962 and 1980 breakings. Marketability involved

the removal of roots that were infected with aster yellows or that were excessively disfigured. The accepted roots had a 'hairy' appearance due to the retention of secondary absorbing roots that are broken off during harvest in heavier mineral soils. Many of the larger carrots on the 1962 location had a kinked tip resulting from growth into the ploughshare layer.

Onion Yield

The total and marketable yields of onions harvested on October 26, 1981, 152 days after seeding are presented in Table 18. The total and marketable yields show that the 1962 peat reduced herbicide damage and also yielded the greatest onion harvest. The poorest harvest on the 1975 breaking may be traced to poor row filling (Figure 11g). The only herbicide showing activity was linuron in the total harvest and was more marked in the marketable harvest data. Linuron affected the percentage of marketable onions on all soils at the 4 kg ai ha^{-1} rate, and only the 1980 breaking at the 2 kg ai ha^{-1} rate.

The onion crop did not mature to a point where 50% of the tops were down as required under cooler climatic conditions (Ware and McCollum, 1980) and retained thick necks that would preclude good storage by increasing susceptibility to Botrytis sp., a grey mould known as neck rot.

TABLE 17.

Total and marketable yield of carrots at

3 locations at Vivian on August 28,1981.

Treatment		Yield components and locations								
Herbicide	Rate (kg ai/ha)	Total yield(kg/plot)			Marketable yield(kg/plot)			Marketable yield(% of total)		
		1980	1975	1962	1980	1975	1962	1980	1975	1962
Check	-	8.10	3.55	13.73	5.65	1.60	10.88	62	37	79
Chlorpropham	3 PRE	5.90	6.83	12.98	4.53	4.05	10.23	74	57	79
Chlorpropham	6 PRE	5.43	6.23	8.95	3.13	3.88	6.33	56	61	70
Chlorpropham	12 PRE	5.05	4.53	11.75	3.25	2.33	8.68	65	52	74
Linuron	1 PRE	2.10	7.13	12.28	1.45	4.28	9.00	49	58	74
Linuron	2 PRE	6.30	7.25	12.15	4.33	4.03	9.18	70	57	75
Linuron	4 PRE	4.20	4.18	10.00	3.20	2.45	7.25	69	61	71
Pronamide	1 PRE	6.85	5.53	15.30	4.88	3.20	12.08	72	57	79
Pronamide	2 PRE	6.65	3.73	12.55	4.95	1.85	9.48	77	48	73
Pronamide	4 PRE	5.00	6.63	9.30	2.98	3.95	7.08	59	61	75
Mean yield(location)		5.56	5.62	11.90	3.84	3.16	9.02	65	55	75
L.S.D. 5%		3.66	NS	NS	2.96	NS	NS	NS	NS	NS
C.V.		54	42	33	62	51	36	27	22	9

TABLE 18.

Total and marketable yield of onions at

3 locations at Vivian on October 26,1981.

Treatment		Yield components and locations								
Herbicide	Rate (kg ai/ha)	Total yield(kg/plot)			Marketable yield(kg/plot)			Marketable yield(% of total)		
		1980	1975	1962	1980	1975	1962	1980	1975	1962
Check	-	8.20	5.73	9.05	8.13	3.38	8.25	95	52	90
Chlorpropham	3 PRE	10.65	7.88	10.35	10.20	6.08	9.98	96	79	97
Chlorpropham	6 PRE	9.18	4.38	11.83	8.68	3.40	10.80	95	70	91
Chlorpropham	12 PRE	7.93	5.90	9.58	7.35	4.20	8.75	91	71	91
Linuron	1 PRE	7.35	3.50	9.98	6.98	2.94	9.00	94	84	90
Linuron	2 PRE	3.28	3.15	7.63	3.03	2.60	7.05	69	88	93
Linuron	4 PRE	1.70	0.50	4.75	1.40	0.28	4.45	35	27	82
Pronamide	1 PRE	9.58	4.83	6.65	9.08	3.25	6.23	95	67	94
Pronamide	2 PRE	8.60	5.05	11.15	7.88	3.05	10.10	94	54	90
Pronamide	4 PRE	9.98	6.30	12.68	9.43	4.73	12.08	93	75	95
Mean yield(location)		7.65	4.72	9.37	7.22	3.40	8.67	88	67	91
L.S.D. 5%		3.84	2.50	NS	3.48	NS	NS	24	NS	NS
C.V.		50	37	36	50	51	38	30	34	10

4.3.2.5 Summary

In summary, the yields of all three crops in 1981 were poor with only the carrots grown on the 1962 breaking being commercially viable. The lettuce yield was lowered by aster yellows and hot weather during harvesting, increasing the incidence of tipburn. Aster yellows also affected the marketability of the carrot crop. The onion crop did not mature to marketability.

The data did not clarify the adsorptive properties of peat as affected by decomposition for chlorpropham, linuron, or pronamide. Linuron adsorption increased with decomposition marginally in most cases although not at all stages of development for all crops. Chlorpropham adsorption decreased with increased cultivation for lettuce at both times crop evaluations were made and at harvest indicating a different binding mechanism. Pronamide had little effect on crop yields even at the highest rate, and thus no measurable differential soil interaction.

Disease problems and lack of maturity may have concealed the activity of the herbicides so a bare plot technique using growth room bioassays to analyse herbicide activity was adopted the following year.

4.3.3 Field Trials, 1982

The linuron bioassays did not work due to non-proportional growth inhibition with herbicide rate, or increased growth at some rates of herbicide above the growth of the control (Table 19).

The best bioassay plant screened for chlorpropham and pronamide was cucumber (Table 19). The optimal conditions to control the diseases in the dishes could not be obtained for moisture content, as drying could affect decomposition, volatilisation, and adsorption of the herbicide. The minimum amount of herbicide solution applied to form a standard concentration curve to get even distribution in the field moist peat was 20 mL. 20 mL of water was added to each of the treatment dishes to obtain a 0 kPa water potential conditions in each dish. The 16 hour 30°C day and 8 hour 20°C night temperature regime mediated pathogen growth in separate experiments. The cucumber cultivar 'Marketer' was found to be least susceptible to infection. Despite these precautions, up to seven plants per dish were infected at various stages of growth of the bioassay preventing the accumulation of data relevant to herbicide activity.

TABLE 19.

Bioassay plant screening for phage dish experiments on organic soils, 1982.

Herbicide	Assay plant	Cultivar used	Plant part	Authority (where applicable, some bioassays not used before)	Range of sensitivity (ppm) Max.	Min.	ED_{50}	Rejection category**
Chlorpropham								
	Barley	Argyle	root		10-60	0	-	* NP
	Cucumber	Centurion	root	Hurt, Meade & Santelman, 1968 Eshel & Warren, 1967	16	0	8-10	None
	Mustard	Domo	root		-	-	-	*
	Oat	Terra	root		1	0	-	N
	Ryegrass	Lemtal	root	Upchurch & Mason, 1962	15-60	0	-	NP
Linuron								
	Barley	Argyle	shoot	Olech, 1968	1	0	-	* NP N
	Oat	Terra	shoot	Dubey & Freeman, 1966. Bayer, 1966	-	-	-	NP
	Onion	Matador	shoot	Mappelbeck & Waywell, 1983	-	-	-	NP
	Radish	Cherry belle	shoot	Buschmann, Grumbach & Bach, 1980	-	-	-	* NP
	Ryegrass	Lemtal	shoot	Dubey & Freeman, 1964	-	-	-	* NP
	Wheat	Neepawa	shoot		-	-	-	*
Pronamide								
	Barley	Argyle	root		2	0	0.5	NP
	Cucumber	Centurion	root		4	0	1.5-2	None
	Oat	Terra	root	Dutt & Harvey, 1980. Bastide, Cantier & Coste, 1981	2	0	0.5	NP

**Rejection category

N=range of herbicide concentration from minimum to maximum growth response too narrow for useful assay

NP=Non proportional growth response to herbicide rate

*=several treatments with greater growth than control

4.3.4 Greenhouse Screening, 1981

The objective of the experiment was to show how herbicide phytotoxicity was reduced by soil type, and often with an interaction of soil, herbicide type, and plant species.

4.3.4.1 Emergence Rating

The emergence rating data are presented in Table 20 and show that yellow foxtail and lamb's-quarters had poor emergence on the 1980 breakings. The 1975 breaking, however, only had good emergence for carrot. The 1962 breaking had good emergence for all of the bioassay plants. The clay soil from the University of Manitoba experimental field permitted poor emergence throughout the range of bioassay plants. The sandy soil from Carman, Manitoba showed good emergence except for annual bluegrass, red root pigweed, and lamb's-quarters.

The phytotoxicity of the herbicides shown in Tables 21a-c was confounded by the erratic emergence, but indicated that herbicidal activity was affected by soil type.

4.3.4.2 Chlorpropham Activity

The chlorpropham data in Table 21a show that the three crop plants exhibited tolerance to the herbicide, although erratic emergence decreased growth in the Carman sandy soil in the unsprayed and 3 kg ai ha^{-1} rate treatments in carrots. Annual-bluegrass, yellow foxtail, and red root pigweed were poorly controlled in the organic soils, while the

TABLE 20.

Emergence rating for greenhouse screening of 7 bioassay plants on 5 soil types.

Soil type	Bioassay plants: Onion	Carrot	Lettuce	Annual bluegrass	Yellow foxtail	Red root pigweed	Lamb's quarters
1980 breaking	8	8	7	8	5	7	3
1975 breaking	5	8	5	5	5	3	4
1962 breaking	7	9	9	9	8	9	9
Clay soil	5	5	5	2	3	2	2
Sand soil	9	7	7	4	9	5	3

Rating scale:- Maximum emergence,45+ seeds = 9
Minimum emergence,5 or less = 1

mineral soils showed good control likely due to stronger sorption in the organic soils. Lamb's-quarters showed good control was possible on the sandy loam soil and the 1975 breaking, while control was poor on the other two breakings. Poor emergence on the clay soil confounded the data for red root pigweed and lamb's-quarters.

4.3.4.3 Linuron Activity

Carrot was tolerant in all soil types to both rates of linuron, as shown in Table 21b. Clay soils allowed the greatest activity on all the other bioassay plants. Red root pigweed, lettuce, and lamb's-quarters showed great sensitivity on all soil types at both rates of application, although moderated for lettuce on the 1962 breaking at the 1 kg ai ha^{-1} rate. Poor control was obtained for yellow foxtail on the organic and sandy soil, with poor control of annual bluegrass on the latter. The low phytotoxicity in sand may have resulted from leaching. Growth inhibition proportional to rate of application occurred for onion and annual bluegrass in the organic soils, and for onion in the sandy soil. Quantitative bioassays require proportional inhibition of growth, indicating that onion and annual bluegrass could be suitable bioassay plants.

4.3.4.4 Pronamide Activity

All of the crops were tolerant to pronamide on all soil types, as shown in Table 21c, although carrot was susceptible at the high rate on the mineral soils. The grassy weeds were well controlled on all soils at both rates of application, as were the broadleaved weeds on mineral

soils. Red root pigweed was proportionally controlled with rate on the organic soils while the data for lamb's-quarters were eratic.

4.3.4.5 Summary

Organic soils decreased the activity of chlorpropham and linuron and to a lesser extent of pronamide on susceptible plant species. Possibly leaching of linuron below the rooting zone for some plants reduced phytotoxicity unexpectedly in the sandy soil. The data were confounded by uneven germination particularly of field collected weed seeds negating their use as bioassays (Anderson, 1968). Onion appeared to have merit as a linuron bioassay plant.

TABLE 21a.

Growth suppression ratings after 14 days, of 7 bioassay plants in a greenhouse study on 5 soil types for 3 herbicides;

a. Chlorpropham.

	Bioassay plants						
	Onion	Carrot	Lettuce	Annual bluegrass	Yellow foxtail	Red root pigweed	Lamb's quarters
1980 breaking							
control	9	9	9	9	9	9	9
3 kg/ha	9	9	9	7	9	7	7
6 kg/ha	9	9	9	5	5	7	9
1975 breaking							
control	9	8	7	3	9	5	9
3 kg/ha	9	9	9	1	9	3	5
6 kg/ha	9	9	8	5	9	3	3
1962 breaking							
control	9	8	9	9	1	9	8
3 kg/ha	9	9	9	1	1	5	9
6 kg/ha	9	9	9	7	9	7	9
Clay soil							
control	9	8	6	5	7	2	2
3 kg/ha	9	9	9	1	9	3	2
6 kg/ha	9	9	9	1	5	2	1
Sand soil							
control	9	7	9	5	9	9	9
3 kg/ha	9	3	9	3	7	7	3
6 kg/ha	9	8	9	2	3	2	1

Rating scale:- Maximum growth, healthy plants = 9
Minimum growth, necrotic plants = 1

TABLE 21b.

Growth suppression ratings after 14 days, of 7 bioassay plants in a greenhouse study on 5 soil types for 3 herbicides;

b. Linuron.

	Bioassay plants						
	Onion	Carrot	Lettuce	Annual bluegrass	Yellow foxtail	Red root pigweed	Lamb's quarters
1980 breaking							
control	9	9	9	9	9	9	9
1 kg/ha	5	5	1	3	9	1	1
2 kg/ha	1	9	1	2	8	1	1
1975 breaking							
control	9	9	9	9	9	3	3
1 kg/ha	5	9	1	5	7	1	1
2 kg/ha	1	9	1	5	1	1	1
1962 breaking							
control	9	9	9	9	9	9	9
1 kg/ha	7	9	5	5	5	1	1
2 kg/ha	1	9	3	3	5	1	1
Clay soil							
control	9	9	9	9	9	3	3
1 kg/ha	1	9	1	2	1	1	1
2 kg/ha	1	9	1	2	1	1	1
Sand soil							
control	9	9	3	9	9	9	1
1 kg/ha	5	9	1	9	9	1	1
2 kg/ha	2	9	1	9	7	1	1

Rating scale:- Maximum growth, healthy plants = 9
Minimum growth, necrotic plants = 1

TABLE 21c.

Growth suppression ratings after 14 days, of 7 bioassay plants in a greenhouse study on 5 soil types for 3 herbicides;

c. Pronamide.

	Bioassay plants						
	Onion	Carrot	Lettuce	Annual bluegrass	Yellow foxtail	Red root pigweed	Lamb's quarters
1980 breaking							
control	7	9	9	9	1	9	9
1 kg/ha	9	9	9	1	1	6	3
2 kg/ha	8	9	9	1	1	3	1
1975 breaking							
control	9	9	9	9	9	9	9
1 kg/ha	9	8	9	1	3	5	2
2 kg/ha	9	9	9	1	1	2	2
1962 breaking							
control	9	9	9	5	9	9	9
1 kg/ha	8	8	9	1	2	2	9
2 kg/ha	7	9	9	1	4	5	2
Clay soil							
control	9	9	7	1	9	3	1
1 kg/ha	9	9	9	1	2	1	1
2 kg/ha	9	6	9	1	1	1	1
Sand soil							
control	9	9	3	3	9	3	5
1 kg/ha	9	9	9	1	2	2	2
2 kg/ha	9	5	9	1	1	1	1

Rating scale:- Maximum growth, healthy plants = 9
Minimum growth, necrotic plants = 1

4.3.5 Phage Dish Bioassay, 1982-1984

4.3.5.1 Bioassay Plant Screening, 1982

The plants screened by the phage dish bioassay are listed in Table 19. The plants were screened to quantify bioactive rates of chlorpropham, linuron, and pronamide. Only the plants with proportional growth inhibition to herbicide rate were selected for further research. The categories used to reject the bioassay plants screened were:-

a) if some rates of the herbicide increased the growth of the treated plants over the growth of the control plants (Wiedman and Appleby, 1972).

b) non-proportional growth response to herbicide rate or very variable data.

c) very narrow range of herbicide rates causing complete range of growth inhibition, or growth inhibition response outside range of likely field rates.

The observations in Table 19 show that the only suitable bioassay plant was cucumber, and that only chlorpropham and pronamide could be assayed using the Parker (1966) bioassay.

Cucumber cultivar 'Centurion' had a wide range of root growth suppression that increased from 100% of growth of the control to 10% of the control at 30 ppm for chlorpropham in the organic soil (Figure 12). The sensitive part of the bioassay however occurs where rapid changes in growth inhibition occur for small changes in herbicide concentration. The steeply sloped part of the graph in Figure 12 reflects the sensitive

range of the bioassay, with a major change of sensitivity occurring after 16 ppm chlorpropham. The bioassay should therefore be useful up to 16 ppm, a concentration well above expected field rates.

The inhibition of cucumber root growth by pronamide in peat soils decreased growth by 80% of the control plants by 16 ppm. The change in sensitivity of the assay was less abrupt (Figure 13) and occurred at 4 ppm pronamide. The decreased sensitivity of the bioassay occurs at the maximum rate used in the 1982 field experiment.

The cucumber root bioassay for both herbicides in the standard concentration curve, where sand was used as a medium with different concentrations added, showed much greater herbicide activity. Growth inhibition was greater than that obtained at even the highest rates on peat. The chlorpropham activity in the standard concentration curve showed maximal growth inhibition by 4 ppm, with 90% inhibition of growth of the control due to 1 ppm chlorpropham.

Pronamide caused 90% growth inhibition by 0.25 ppm in the standard concentration curve, which was greater than the growth inhibition pertaining at 16 ppm on the peat soil.

4.3.5.2 Pathology Experiments

The very high incidence of disease in the bioassay phage dishes in 1982 necessitated experiments to identify the pathogen and to control or at least to mitigate the infection.

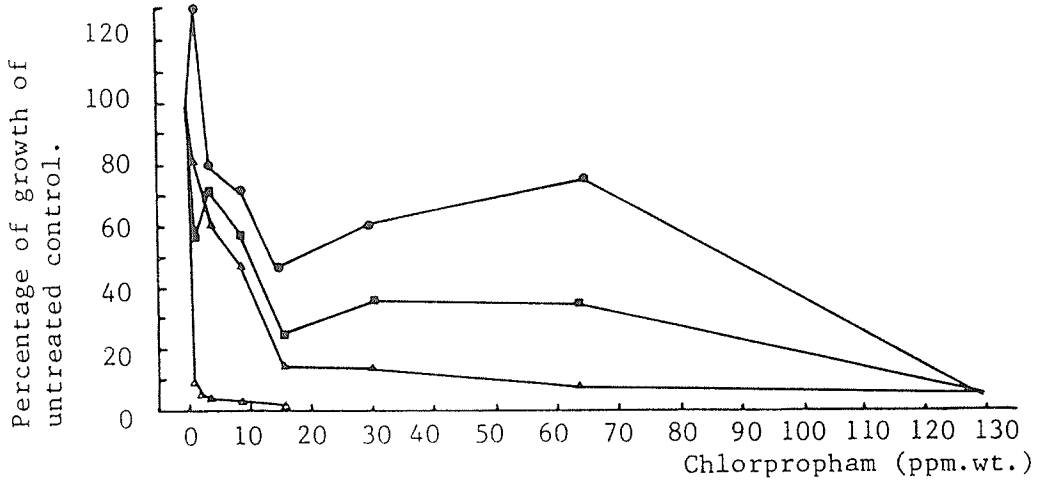


FIGURE 12. Bioassay screening experiment, 1981:- Cucumber cv.'Centurion' with chlorpropham in phage dish bioassay.

▲ 1980 breaking.
● 1975 breaking.
■ 1962 breaking.
△ Herbicide solution concentration applied to sand, with no loss of activity due to adsorption.

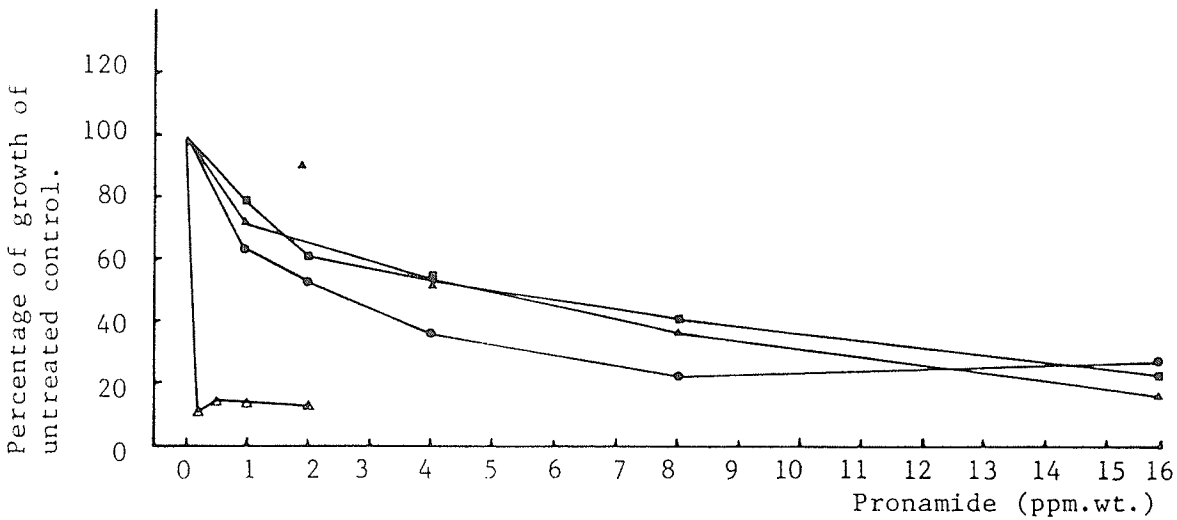


FIGURE 13.Bioassay screening experiment 1981:-
Cucumber cv.'Centurion' with pronamide
in phage dish bioassay.

▲ 1980 breaking.
● 1975 breaking.
■ 1962 breaking.
△ Herbicide solution concentration applied to sand,with no loss of activity due to adsorption.

Disease identification. The diseased seedlings were surface sterilised with 50% bleach for 2 min to remove non-pathogenic surface fungi and plated onto potato dextrose agar. Earlier isolations were identified as Rhizoctonia sp., however, the isolate failed to infect fresh seedlings in a sterilised peat medium. Subsequent isolations were identified as two strains of Fusarium spp. and Rhizopus spp. The only fungus pathogenic to cucumber bioassay was one strain of Fusarium, but it did not illicit the same symptoms. The pathogen responsible for the disease may require a more complex agar to permit isolation.

Temperature and cultivar evaluation. Two temperature regimes were compared for disease susceptibility of the six cucumber cultivars listed in Table 22. Most of the cucumber cultivars had lower incidence of infection with the higher temperature regime that favoured the growth of cucumber. The most resistant cucumber cultivar was 'Marketer', having only 10% infected regardless of temperature regime.

Moisture content. Samples of 1962 breaking peat were dried in a greenhouse, but not to air dryness. Distilled water was added as shown in Table 23 to produce different soil moisture contents. There is a much higher incidence of disease in cucumber cultivar 'Wisconsin SMR 18' at the higher moisture contents. The standard herbicide concentration curve used to determine the unknown field rates required the addition of at least 20 mL of solution to enable uniform surface application and penetration through the field moist samples and to raise the water content to 'glistening' or 0 kPa water potential. To standardise experimental conditions, 20 mL of tap water were added to each of the treat-

TABLE 22.

Percentage of diseased cucumber bioassay plants in temperature and cultivar study.

Cucumber cultivar	Temperature regime(16hr'day/8hr'night')	
	30°C/20°C	23°C/16°C
Wisconsin SMR 18	65	85
Spartan	55	75
National Pickling	50	85
Long Green	35	50
Straight 8	50	75
Marketer	10	10

ment samples collected from the field. Even the addition of 10 mL of water resulted in more than 50% of the roots being infected by the disease, which rendered the root growth assessment for herbicide phytotoxicity inaccurate. The lower moisture contents did lower disease incidence, but the requisite air drying of field samples would alter the herbicide phytotoxicity by possible volatilisation losses and changes in the adsorption due to solution phase concentration changes.

Summary. Although these experiments did show mitigation of disease, particularly by changing cultivar and temperature, the field samples did not. Moisture content could not be modified, and further experiments with Captan, Thiram, and PNCB did not affect disease incidence. Fresh peat from Vivian in 1981 was therefore a poor medium for the phage dish bioassay. It was not conclusively proven whether the seedling mortality was due to a pathogenic organism, peat decomposition toxins, or physiological due to low oxygen supply. Pathogens were suspected as steam sterilisation resolved the mortality problem while aeration had no effect. Steam treatment, however, could hydrolytically decompose the different breakings at different rates, and also herbicide in field treated samples.

4.3.5.3 Chlorpropham and Peat Slurry Experiments, 1983

The slurry method involved shaking 100 g of 1981 and 1982 breakings peat on a field moist basis in 1400 mL of water and chlorpropham at different rates. The supernatant solution was tested for bioactivity in the phage dish assay using sand as a support matrix. Standard herbicide

TABLE 23.

The effect of increased moisture content of peat on the percentage of disease incidence in cucumber cv.'Wisconsin SMR 18'bioassay grown on the 1962 peat breaking at Vivian,collected in August,1981.

Volume of distilled water added per dish	Percentage of plants infected
0	16 a *
5	32 b
10	54 d
15	48 c
20	58 de
25	62 e
30	76 f

*Numbers followed by the same letter are not significantly different at the 5% confidence level when grouped by the Duncan's Multiple Range Test.

concentrations at the same rates in 1500mL of water were analysed simultaneously. Initial experiments were conducted to determine the optimal temperature regime, with five subsequent repetitions to determine the reproducibility of the bioassay.

The slurry method was used to circumvent the soil borne pathogens present in the peat. Each experiment consisted of five dishes containing ten plants for each treatment. The initial two repetitions of the experiment were done using only peat slurry supernatant and were incubated at the different temperature regimes of 30°C day, 20°C night temperature and 23°C day, 18°C night temperature. The lower regime appeared to be more sensitive as significant differences between the adsorptive capacity for each breaking were indicated even at the low concentration.There were no disease symptoms evident to preclude the use of that regime. The higher temperature regime exhibited differences in root growth, as a percentage of growth of control root length where no herbicide was applied, only at the two highest concentrations of 1 and 2 ppm.

The third repetition of the experiment had lower growth of the no herbicide treatment for the 1981 and 1962 breakings than for the treatments up to 0.5 ppm. These results were anachronous to the other repetitions of the experiment and resulted from preparing the control treatments last. The growth of the seedlings were impaired by leaving the lids off of the germination dishes and allowing the upper portion of the seeds to dry. The uniformity was also decreased by subconscious selection of more vigorous seedlings earlier in the preparation. Later experiments were prepared by replication, not treatment, to avoid that

problem. Dishes of germinated seeds contained 75 nearly uniformly protruding radicals (Figure 14) and were used in rotation, filling one dish each time to prevent excessive drying. Excess seeds were germinated to reduce the problem of selecting the most developed seedlings first and using those with smaller radical protrusion last.

The final four repetitions of the experiment were analysed individually and subjected to a test of homogeneity devised by Bartlett (LeClerg, 1962). The root lengths were found to yield more homogeneous results than the data transformed as the percentage growth of the control root length.

The data in Figure 15 show that only the 2 ppm chlorpropham caused any difference in the cucumber root elongation at the 5% confidence interval as measured by the least significant difference when comparing the two peat breakings. The difference between chlorpropham bioactivity to cucumber cultivar 'Marketer' did not vary much over the range of the treatments between the two peats. The margin of error decreased at the higher rates as shown by the least significant difference bars at each herbicide rate.

The data in Figure 15 clearly show deactivation by sorption to peat compared to the standard herbicide concentration curve of herbicide in solution put onto sand. The growth reduction for the seedlings treated with the herbicide solutions levels off at the 0.5 ppm rate, and continues to decline marginally thereon, indicating a limit of the

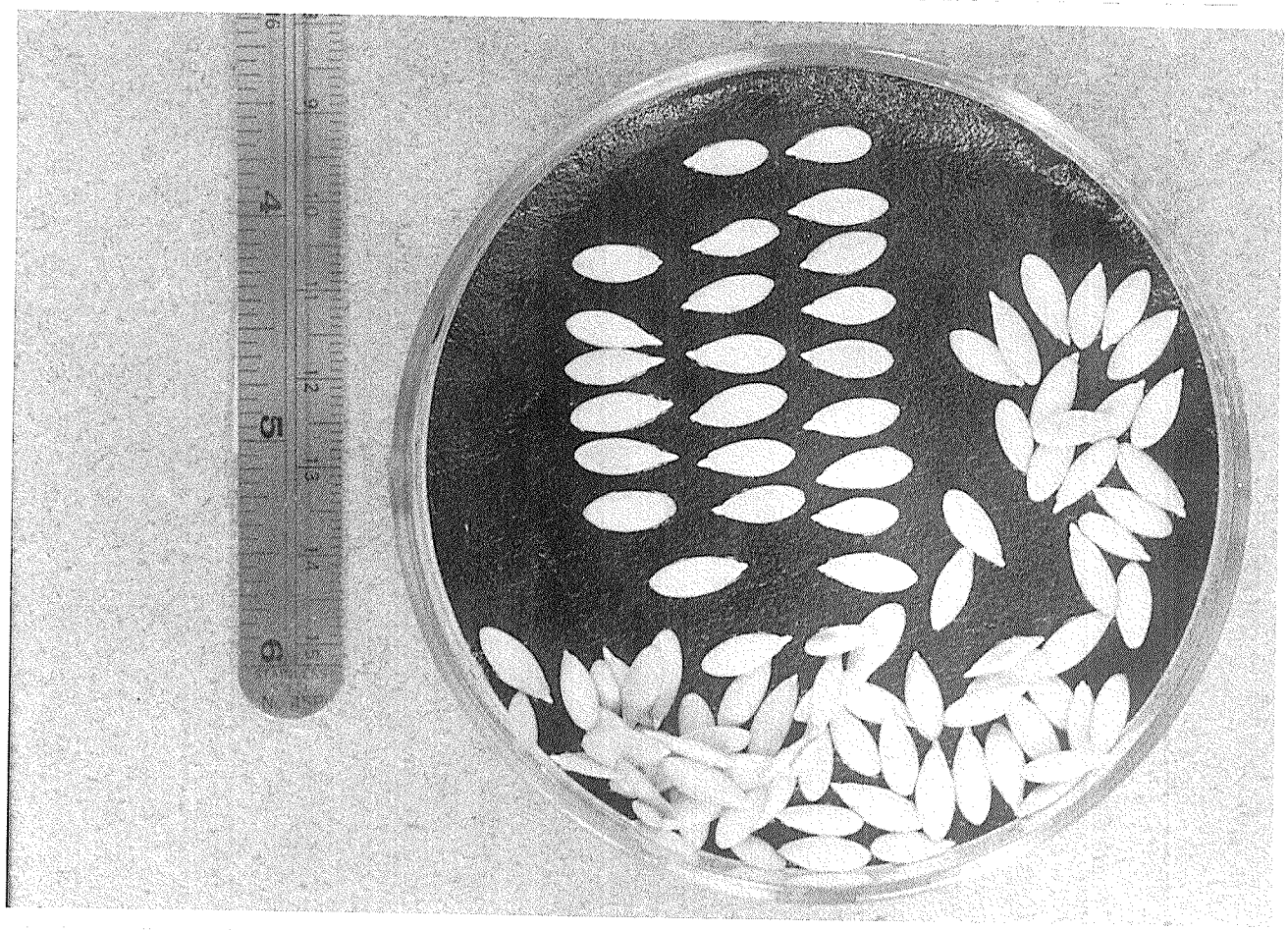


FIGURE 14. Pregerminated cucumber seeds showing uniformity and length of radical protrusion for use in the phage dish bioassays.

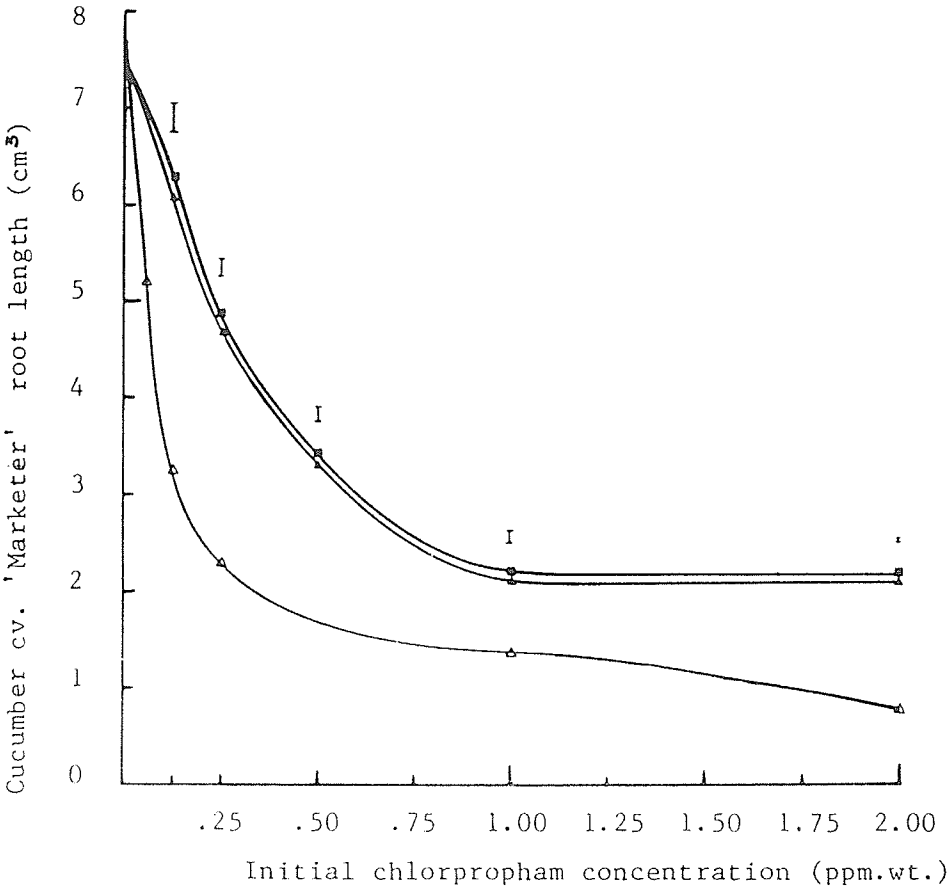


FIGURE 15. Comparison of chlorpropham activity on two peat breakings and herbicide solution applied to sand that would not affect the activity by adsorption.

▲ 1981 breaking.
■ 1962 breaking.
△ Herbicide solution on sand.

bioassay to below 0.5 ppm for characteristic growth reduction (Figure 16).

The herbicide-peat interaction delays the point of levelling off to 1 ppmw of the herbicide concentration, at a much lower chlorpropham concentration than in the earlier study,at 4ppm.(Figure 13). The growth reduction corresponds to the 0.25 ppm rate of the herbicide, and does not decrease below that level. The reason for the lower response by cucumber cultivar 'Marketer' to chlorpropham is not fully understood, but both peat breakings responded similarly. Variability within treatments prevented calculation of meaningful adsorption coefficients.

The conclusion is that there is little difference in the adsorptive capacity for chlorpropham with increased decomposition of peat as measured by the slurry method utilising bioassay plant response.

The amount of organic matter present in the peat samples varied, as the gravimetric water content in the 100 g of peat was not constant. The 1981 breaking had a range of gravimetric water contents from 498 to 527%, translating to a mean oven dry weight of 16.1 g. The gravimetric water content of the 1962 peat sample ranged from 434 to 465%, resulting in a mean oven dry weight of 19.0 g.

The adsorptive mass of the average 1962 peat sample was thus 18% greater than for the average 1981 sample. The organic matter and organic carbon contents of the samples are shown in Table 24. The slightly higher adsorption by the 1962 breaking shown by Figure 15 could be due to similar specific herbicide adsorption on both types of peat

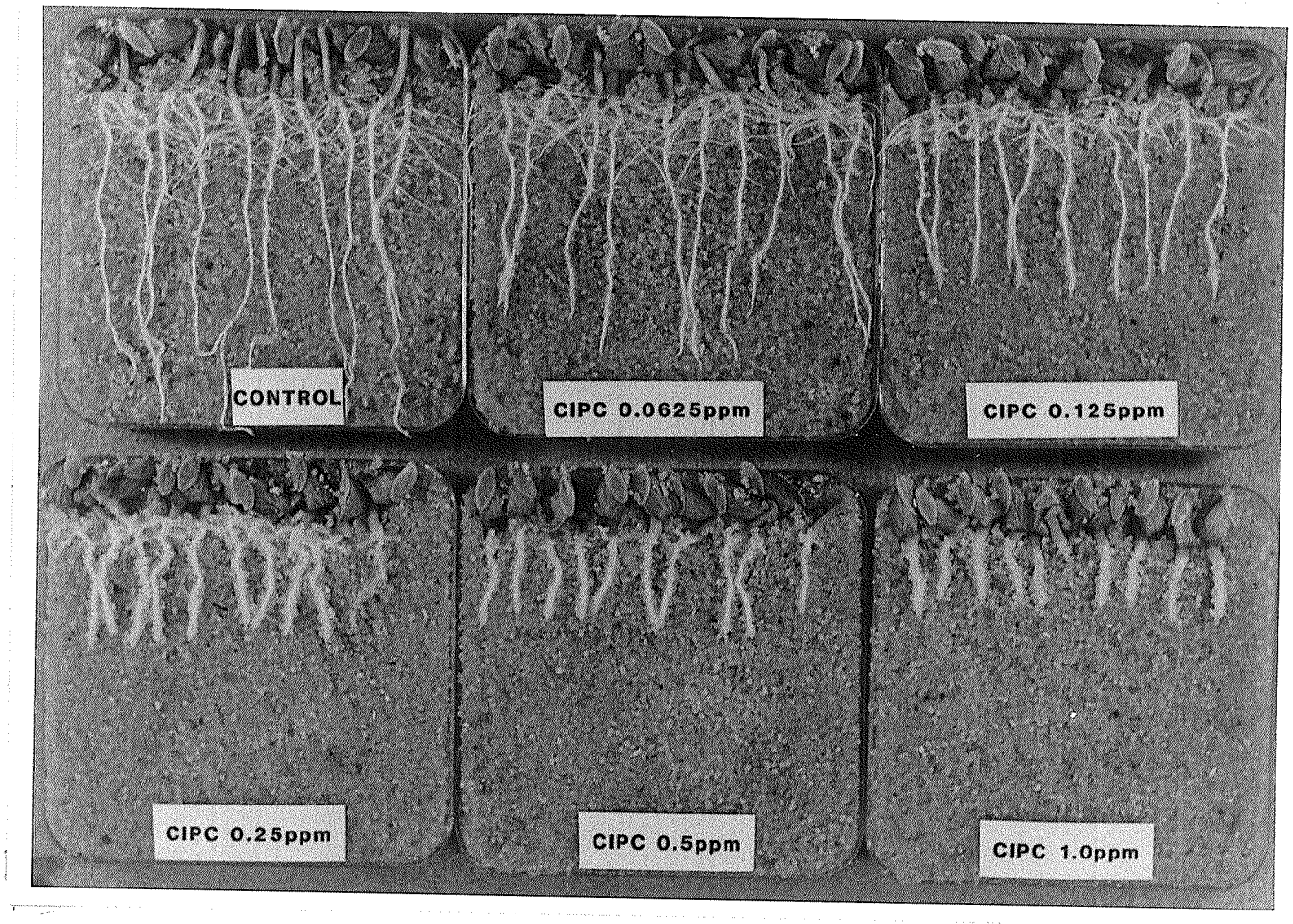


FIGURE 16. Phage dish bioassay using a range of chlorpropham concentrations from 0.0625 to 1.00 ppm. and water as control shown by cucumber cv.'Marketer' root growth after 72 hours.

(1962 and 1981 breakings) as there is marginally more organic matter and organic carbon in the 1962 samples. The only exception is for the Walkley Black method, whereby less organic carbon is present in the 1962 sample.

The choice of technique for organic matter or carbon content could thus determine whether the view projected by Doherty and Warren (1969), Nearpass (1976), and Morita (1976) of increased nonionic herbicide adsorption with organic matter decomposition was supported. The view of Briggs (1981), Wauchope and Meyers (1985), and Grover (1975) that organic matter has the same adsorptive properties regardless of decomposition state could also be supported by selection of any technique but the Walkley Black procedure.

The relevance of the method of organic matter content determination affecting the correlation of adsorptive capacity to organic matter content has been previously discussed by Weber and Peter, 1982.

TABLE 24.

Weight of organic matter and organic carbon available for adsorption,as determined by different methods,for the 1962 and 1980 peat breakings used in the slurry bioassay experiment in 1983.

Method of determination	1962 breaking(g)	1980 breaking(g)
Organic matter determinations		
Dry combustion 400° C	15.68	13.97
Dry combustion 560° C	16.55	14.60
Dry combustion 580° C	15 73	12.94
Dry combustion 700° C	16.99	14.92
Organic carbon determinations		
Walkley Black method	4.16	5.35
Induction furnace 960°C	9.42	6.92
Allison method	8.00	7.10

Chapter V

GENERAL DISCUSSION

The experiments were performed on the Okno series soils,that were brought into production at different times, which permitted the evaluation of techniques to characterise sedge peat decomposition. Several of the properties showed no trends between freshly cultivated peats,those cultivated for 6 or 7 years, and the most decomposed that had been cultivated for 19 or 20 years.The soil properties that did not characterise decomposition were particle size analysis,sodium pyrophosphate index,field volumetric water contents,pH,mineral content, and carbon to nitrogen ratio despite their previous use in the literature for the characterisation of peats.

Organic matter content was determined at several combustion temperatures, the lowest being 400°C.The 400°C temperature showed decreasing organic matter content with increased duration of cultivation, and was the only temperature to reflect oxidative decomposition of the peat.Cherkinskiy et al. (1975) stated that early decomposition of organic matter was of the labile, or chemically reactive moieties, which would also be the first to volatilise with heating.Lower temperatures may prove to be more sensitive still at quantifying early stages of peat decomposition. The lower temperature wet digestion method, the Walkley Black technique, was also more sensitive to changes in the peat than the Allison method. The implication again is that the changes in the labile

groups should be quantified rather than the total organic carbon content.

A characteristic long associated with organic soils is the fibre content, which also showed characteristic changes with decomposition. The unrubbed fibre content showed that decomposition was more rapid on an annual basis immediately after breaking the soil than when the soil had been worked for several years. Most of the properties measured also reflected that trend, however, the rubbed fibre content, coarse clod analysis, and oven dry bulk density indicated a uniform annual rate of decomposition. These three properties are representative of the fibre content that is comprised of lignin and the slow decomposition associated with the lignin decomposition pathway. Lignin has a very complex structure and is decomposed by fungi with adapted rhizomorphs and ligase enzymes that can cleave the lignin molecule (Garrette, 1981) that have stable populations during decomposition. The changed rates of decomposition reflect the degradation by sugar fungi and bacteria, the populations of which are more responsive to draining the environment, and digest the more readily metabolised moieties.

Lignin and fibre breakdown is also achieved by the physical working of the soil disrupting the fibre integrity (Puustjarvi and Robertson,1975). The oven dried particles retained on the 1.5mm sieve for the 1962 breaking in the particle size analysis experiment were visually spherical. The qualitative change in that experiment was not reflected in the quantitative data obtained in that experiment, however, the change did affect the oven dry bulk density results. The oven dry bulk density showed a greatly increased value of 0.255 gcm^{-3} when

compared to the constant water potential value of 0.189 gcm^{-3} for the 1962 breaking.Both techniques gave similar values of 0.150 gcm^{-3} and 0.120 gcm^{-3} for the bulk densities of the 1975 and the 1980 breakings, respectively. The discrepency between the two techniques is probably due to the close packing of the spherical aggregates of the 1962 breaking that does not occur for the fibrous peats when the beaker was tapped to obtain a uniform volume of 20mL in the oven dry bulk density method.Drying of more decomposed peats also causes larger changes in volume (Boelter and Blake, 1964) that would enhance the close packing effect on bulk density.

The constant water potential method for bulk density determinations showed the normal trend of slowed decomposition with time due to the influence of adhering decomposition products on the fibres and water bound to the matrix.Uniform compaction by either the slurry method or the weight compaction of wet loose peat showed the same effects of increased bulk density with more decomposed soils.The bulk densities were also affected by the compaction state, having higher bulk densities for the slurry method. Compaction also affected the hygroscopic coefficient of loose soil and clods, being higher in the latter, and both states reflected an increase in water content with decomposition.The rate of change of the coefficient was greater on an annual basis in recently broken peats.

The decomposition status of sedge peats may thus be categorised by organic matter at 400°C., organic carbon by the Walkley Black method,fibre contents,bulk density (particularly by the constant water potential method), and by the hygroscopic coefficient.

The decomposition status may affect the adsorptive properties of soil applied herbicides, although the experiments performed were inconclusive.The 1981 field work and greenhouse studies indicated higher activity of linuron on the least decomposed peats, particularly on onion development and yield, carrot development and lettuce yield in the field studies.The greenhouse study showed lower activity on the 1962 breaking for lettuce, onion, and annual bluegrass. Chlorpropham showed the opposite trend, towards decreased adsorption with a lower growth of indicator plants on the most decomposed peat. Plants that showed more inhibition of growth on the 1962 breaking were early stages of lettuce development in the field. The lettuce yield also showed a decrease with the high rate of chlorpropham on the 1962 breaking. Pronamide showed greater activity than expected from Yih, Swithenbank,and McRae (1970) who reported strong adsorption and inactivation by organic matter. There were no trends of peat decomposition affecting pronamide adsorption.

Subsequent growth room bioassays to confirm and quantify these trends were confounded by soil borne pathogens in the phage dishes containing peat soils. The use of the slurry technique for the determination of soil decomposition effects on chlorpropham activity solved the pathogen problem. The modified soil structure (Green and Obien, 1969) and competition by water at adsorption loci (Kearney and Kaufman, 1976) may have obscured any differences in chlorpropham adsorption existing between the peats. The range of decomposition extended to 20 years of cultivation, and may have been too small to differentially affect herbicide adsorption. Future work on differential herbicide adsorption due to peat

decomposition should utilise a wider range of peat soil stages of decomposition from areas free of pathogens, or using a pathgen resistant assay plant.The phage dish bioassay may be modified by using sand and peat as mixtures or layers to reduce disease incidence,water availability differences and soil structure modification. Further tests could also be done with pot bioassays of various types as described by Hogue in 1976. The development of suitable bioassays may enable the correlation of herbicide activity with soil properties measuring decomposition. Properties could then be isolated that would indicate the need for the modification of herbicide rates to get optimal weed control with minimal crop damage, or whether changes in activity really occur with decomposition.

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APPENDIX A.

Soil characteristics for Fyala,Kircro and Okno

series soils(Michalyna,Gardiner,and Podolsky,1975)

Series	Pyrophosphate	Ash	Bulk density	pH	Total N	Total C	Exchangeable cations					Soil capability classification for agriculture *
							CEC	Ca	Mg	K	Na	
	%	%	gcm^{-3}		%		(mEq/100g)					
Fyala	-	-	-	7.3	2.2	41.2	39.9	20.8	24.4	0.7	0.3	5W2
Kircro	20.5	15.0	0.16	6.7	2.4	56.7	156.3	116.7	26.3	0.8	0.6	03W
Okno	5.8	8.1	0.12	3.9	1.6	58.0	151.7	83.1	33.3	1.4	0.4	04WL

*04WL Severe limitations as formed from forest peat,strongly acid to neutral,variable decomposition causing variable drainage that decreases with decomposition.Problems due to slope increasing water inflow.Wood fragments cause uneven seedbed.Substratum sandy clay loam.

5W2 Capable of producing only perennial forage due to poor drainage,continuous high water table,poor runoff and slow permeability.Respond well to nitrogen and phosphorus.Further limitations are shallow peat depth and requirement for clearing bush.(Mineral classification.)Substratum calcareous lacustrine clay.

03W Minor degree of developmentdifficulty rating due to lower water table to 45-90cm.Uniform with respect to degree of decomposition and nature of plant residues.Water movement similar to medium textured mineral soils.Derived from fen peat.Medium acid to neutral soils.Substratum calcareous,coarse,lacustrine sand.

APPENDIX B.

Percentage carbon of peat from different locations at Vivian Manitoba as determined by the Allison wet combustion procedure, sampled in 1982.

Soil type		
1962	1975	1981
44.62	45.07	40.85
42.64	44.65	44.55
43.50	44.97	44.95
38.10	45.03	40.68
38.88	52.00	46.86
44.98	39.81	46.55

APPENDIX C

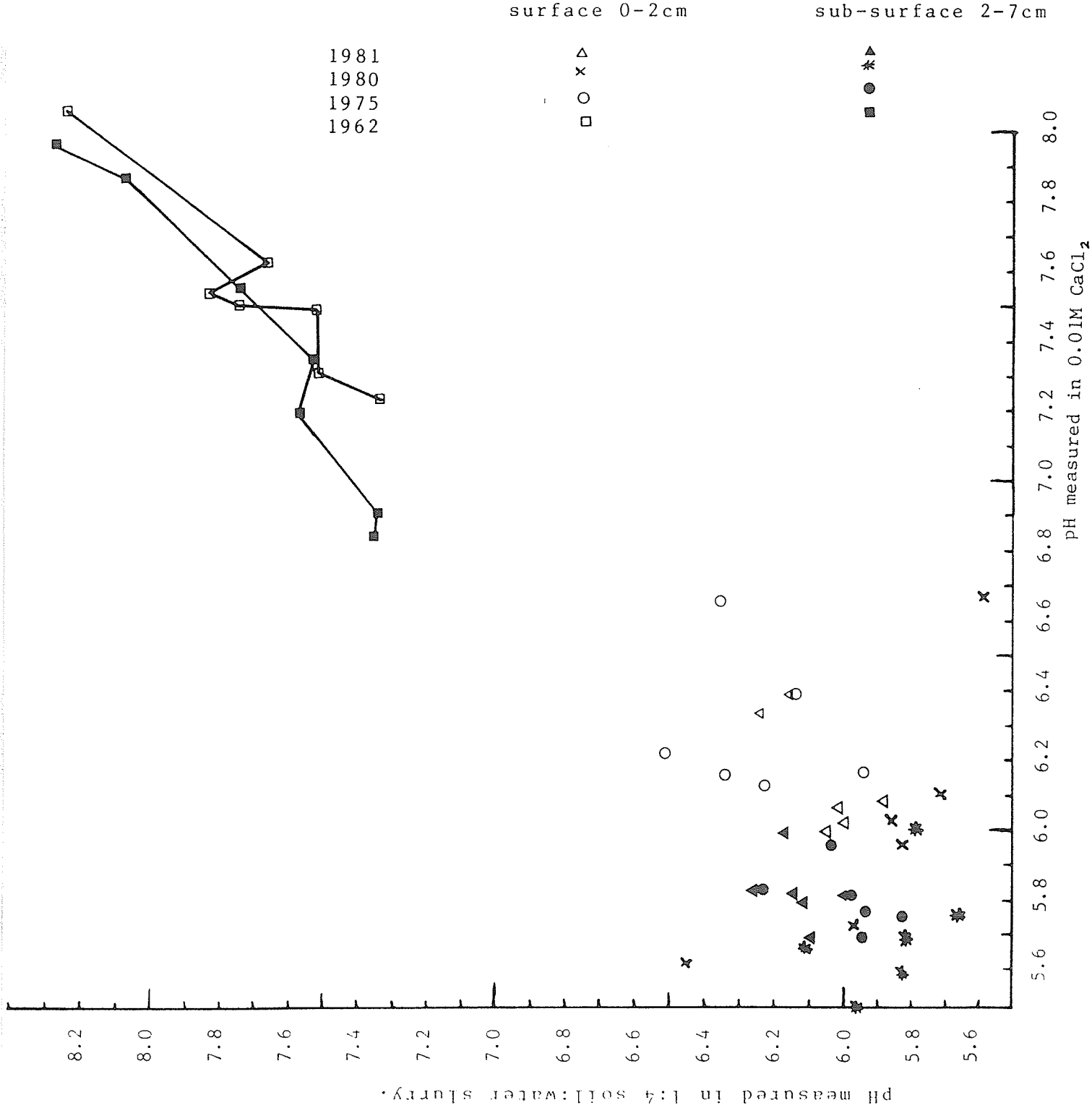
Field bulk density values obtained at various dates for three stages of sedge peat decomposition at Vivian,Manitoba in 1982.

Soil type

	1962			1975			1981		
Date sampled	Mean	Max.	Min.	Mean	Max.	Min	Mean	Max.	Min.
28/7	.160	.195	.127				.102	.108	.065
30/7				.153	.183	.131	.132	.146	.118
31/7	.157	.177	.135				.168	.233	.119
2/8				.144	.177	.128	.148	.170	.123
3/8	.229	.273	.191				.192	.205	.182
5/8				.143	.160	.129	.218	.259	.185
9/8	.203	.222	.189				.206	.258	.160
11/8				.173	.196	.162	.187	.199	.175
21/8	.211	.234	.201				.206	.219	.156
23/8				.213	.226	.198	.183	.194	.156
13/9	.215	.243	.201				.176	.198	.133
15/9				.157	.180	.122	.148	.179	.118
31/10	.154	.173	.142				.148	.179	.112
2/11				.166	.192	.131	.162	.182	.145
Overall mean	.190			.140			.170		

APPENDIX D.

pH of peat soil measured in 1:4 peat:water, or 0.01m $CaCl_2$ showing effects of salinity in surface crust on three peat breakings from Vivian, Manitoba, in 1984.



APPENDIX E

Electrical conductivity,pH and exchangeable cation contents (ppm) of peat soils analysed at the University of Manitoba,Plant Science Tissue Analysis Laboratory,1975/1976.

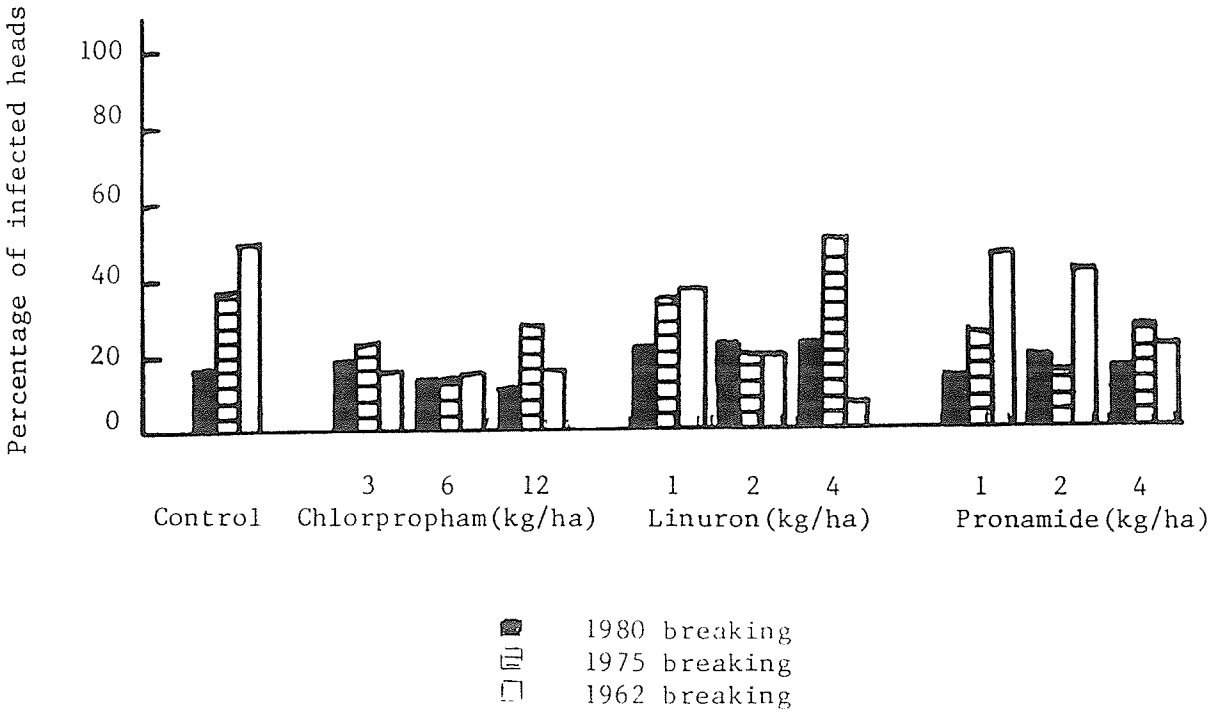
Soil location	pH	Conductivity 4:1(water)	NO_3	P	K	Ca	Mg	Mn	Zn	Fe	Cu
Vivian,1962(in text)-		-	-	-	600	5400	3800	75	39	40	6.3
Vivian,1975(in text)-		-	-	-	600	5100	3000	85	48	30	3.8
Vivian,1980(in text)-		-	-	-	900	5300	3300	39	56	18	6.3
Vivian,1962(Soils)	6.0	2.3	390	258	420	12600	4160	34	21	130	6.5
Vivian,1975(Soils)	6.2	3.1	558	120	420	15200	4290	73	20	95	35.8
Vivian,1980(Soils)	6.0	1.4	132	135	420	10100	3830	40	11	83	70.0
Commercial 1	6.4	0.77	111	78	5080	16950	1675	478	330	169	-
Commercial 2	6.5	0.56	93	66	4500	17450	1650	395	291	115	-
Commercial 3	6.4	0.15	49	73	500	1000	563	72	44	64	-
Jenpeg	7.8	0.21	62	8	105	14725	2075	265	108	21	-
Snow Lake	5.9	0.28	138	18	153	12500	2175	231	83	19	-
Watermelon	6.2	0.34	30	27	63	15750	5880	113	13	6	-
Churchill	5.6	2.00	4860	185	16870	10700	2000	143	309	198	-
South Indian Lake	6.3	0.20	400	178	573	12900	1300	314	180	51	-
Brochet	4.8	0.19	65	87	209	2380	340	142	76	20	-
Nelson House	5.5	0.39	144	85	481	6890	890	110	230	42	-
Cross Lake	5.5	0.24	80	60	409	6700	760	112	450	45	-
Erickson 1	6.6	0.21	178	46	310	5340	1040	120	78	8	-
Thompson	5.6	0.10	190	32	130	6075	725	41	13	961	-
Lynn Lake	5.6	0.18	183	126	148	5500	658	24	13	116	-
New Brunswick 1	4.1	0.12	226	22	165	1750	1250	26	10	110	-
New Brunswick 2	4.3	0.18	130	23	200	8000	1200	45	30	223	-
Elma	4.1	0.19	150	27	875	2400	875	208	21	78	-
Beausejour	3.8	0.33	145	19	218	2575	600	31	10	20	-
Erickson 2	4.5	0.16	62	34	73	2600	680	68	26	395	-

(in text).....analysis as in text,(Soils).....Soils department,University of Manitoba testing laboratory of same samples.
Commercial 1+2...were fertilised for use in greenhouse and growth cabinet respectively
-.....no analysis done,or variable as reported in Tables 12 and 13.

APPENDIX F.

Incidence of aster yellows in lettuce in 1981,

on three breakings of peat at Vivian,Manitoba.



APPENDIX G.

Lettuce harvests on 1980 breaking at Vivian,1981

Treatment		Lettuce yield per treatment(ie 5 plot total)								
		Early harvest,July 24			Maximum harvest,July 31			Late harvest,August 7		
Herbicide	Rate (Kg ai/ha)	Number of heads	Weight per head Kg	Total weight Kg	Number of heads	Weight per head Kg	Total weight Kg	Number of heads	Weight per head Kg	Total weight Kg
Check	-	2	0.75	1.5	21	0.74	15.6	5	0.40	2.0
Chlorpropham	3 PRE	1	0.70	0.7	19	0.78	14.9	16	0.66	10.5
Chlorpropham	6 PRE	4	0.73	2.9	16	0.69	11.0	10	0.65	6.5
Chlorpropham	12 PRE	3	0.53	1.6	17	0.75	12.7	9	0.48	4.3
Linuron	1 PRE	1	1.10	1.1	10	0.94	9.4	3	0.80	2.4
Linuron	2 PRE	1	0.80	0.8	7	0.77	5.4	5	0.66	3.3
Linuron	4 PRE	2	0.75	1.5	3	0.87	2.6	2	0.75	1.5
Pronamide	1 PRE	4	0.55	2.2	15	0.79	11.8	5	0.66	3.3
Pronamide	2 PRE	5	0.64	3.2	14	0.64	9.0	6	0.67	4.0
Pronamide	4 PRE	4	0.48	1.9	8	0.83	6.6	4	0.68	2.7

APPENDIX H.

Percentage of lettuce harvested with symptoms of tipburn in 1981 by location and harvest date.

Treatment		location and date of harvest*			
Herbicide	Rate (Kg ai/ha)	1980 breaking July 31	1980 breaking Aug 7	1975 breaking Aug 7	1962 breaking Aug 7
Check		47.5	100.0	77.5	66.7
Chlorpropham	3 PRE	35.0	100.0	67.5	100.0
Chlorpropham	6 PRE	33.7	82.5	70.0	100.0
Chlorpropham	12 PRE	40.0	100.0	62.5	83.3
Linuron	1 PRE	38.3	100.0	58.3	100.0
Linuron	2 PRE	12.5	100.0	58.0	80.0
Linuron	4 PRE	60.0	50.0	0	66.7
Pronamide	1 PRE	60.0	100.0	70.0	100.0
Pronamide	2 PRE	41.3	100.0	60.0	72.0
Pronamide	4 PRE	58.3	100.0	68.0	88.7

*July 24 harvest had no tipburn.

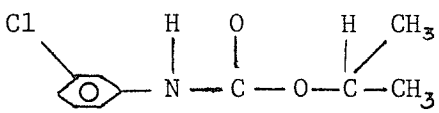
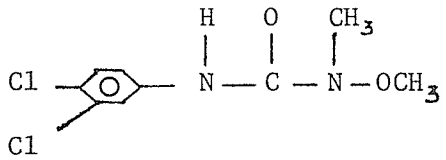
APPENDIX I.

List of common and scientific names mentioned in this thesis.

Common name		Scientific name	
Crop plants:-	Barley	Hordeum vulgare	L.
	Carrot	Daucus carota	L.
	Cucumber	Cucumis sativa	L.
	Lettuce	Lactuca sativa	L.
	Mustard	Sinapis alba	L.
	Oat	Avena sativa	L.
	Onion	Allium cepa	L.
	Radish	Raphanus sativus	L.
	Ryegrass	Lolium italicum	R.Br.
	Sugar beet	Beta vulgaris	L.
	Wheat	Triticum aestivum	L.
Weed plants:-	Annual bluegrass	Poa annua	L.
	Bog willow	Salix pedicellaris	Pursh.
	Canadian thistle	Cirsium arvense	(L)Scop.
	Lamb's quarters	Chenopodium album	L.
	Maple leaved goosefoot	Chenopodium hybridum var gigantospermum	L. (Aellen)Rouleau.
	Oak leaved goosefoot	Chenopodium glaucum	L.
	Perennial sow thistle	Sonchus arvensis	L.
	Prairie buttercup	Ranunculus rhomboideus	Goldie.
	Red root pigweed	Amarathus retroflexus	L.
	Shepherd's purse	Capsella bursa pastoris	(L)Medic.
	Spearmint	Mentha spicata	L.
	Yellow foxtail	Setaria glauca	(L)Beauv.
Insects:-	Aster leafhopper	Macrosteles fascifrons	Stal.
	Onion maggot fly	Hylemya antiqua	Meigen.
	Onion thrip	Thrips tabaci	Lind.

APPENDIX J.

Chemical designation and structures of herbicides cited in text.

Trade Name	Chemical designation	Structure
Chlorpropham	Isopropyl m-chlorocarbanilate	
Linuron	3-(3,4-dichlorophenyl)-1-methoxyl-1-methylurea	
Pronamide	3,5 dichloro (N-1,1 dimethyl-2 propynyl) benzamide