THE UNIVERSITY OF CALGARY

THE EFFECTS OF CULTIVATION ON SELECTED SOILS IN THE SPECIAL AREAS OF ALBERTA

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "The Effects of Cultivation on Selected Soils in the Special Areas of Alberta", submitted by Jan K. Clark in partial fulfillment of the requirements for the degree of Master of Science.

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ABSTRACT

The impact of man's cultivation practices upon soil is not fully understood. To increase that understanding this thesis investigates soils in the Special Areas of Alberta to determine what effects more than 50 years of cultivation has had on certain soil properties.

Thirty test sites were selected for study within a thirty two kilometre radius of Consort, Alberta (Special Area #4). Fifteen were located on uncultivated soil and fifteen were located on cultivated soil. A number of properties of the soils within the plots (including texture, water content, porosity, organic matter content and compaction) were analyzed and compared.

Trends observed in the results obtained from the field and laboratory analysis showed that cultivation had affected the soil properties investigated in the study. The cultivated soils investigated exhibited a decrease in pH, organic matter content, porosity, water content and water stable aggregates and an increase in bulk density, salinity and water storage potential. Study conclusions are intended to assist Alberta Municipal Affairs and the Special Areas Board in determining whether or not parcels of land within the Special Areas should be considered for public sale.

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DEDICATION

To Carey for his support and encouragement over the past three years.

To my mother for her unending faith in my capabilities.

To "the guys"...

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CHAPTER I

INTRODUCTION

1.1 Introduction

The impact cultivation has on the soil is of growing concern today. An understanding of the role of cultivation in soil degradation is being seen as essential to the long term well being of man's relationship to the soil. Scientists feel that once the effects are known, it will provide a basis upon which improved methods of cultivation can be developed which will reduce the impact and, in turn, preserve and protect the soil.

Tillage of some sort has been practiced for at least 10,000 years in various parts of the world, although our current cultivation practices are only about 250 years old (Simonson, 1968). The purpose of cultivation has remained the same throughout that time; to supply a suitable seedbed, control weeds and improve nutrient supply. Through that process, man has exerted an increasingly stronger influence on soil and its formation by disturbing the top soil, replacing the growth of natural vegetation with monoculture and artificially adding nutrients to the soil through the use of fertilizer. As a result of his activities, man has altered the productivity of the soil in both positive and negative ways.

Agricultural settlement in the prairie region of Western Canada began about 1885 (Anderson, 1975). In 1908 the region known today as the Special Areas of Alberta was opened to homesteading. Due to the need of the homesteaders for an immediate cash crop, and because the climate was suitable to grow it, wheat soon became the dominant crop in that area. However, low precipitation during the growing season and an abundant growth of weeds forced many farmers to introduce the practice of summerfallowing into their cropping system. The effect of that practice and the deterioration of the original structure and organic matter of the soil due to continuous cropping resulted in extensive soil erosion during the late 1920's and 1930's. During that time, a prolonged dry spell culminated in severe dust storms and soil degradation of disastrous proportions.

It appeared that the productivity of the agricultural land of the Special Areas had been destroyed completely. As a result of that disaster major programs of research and reclamation were undertaken by the federal, provincial and municipal governments. One such program was implemented through the enactment of the Special Areas Act by the Alberta Government in 1938. As a result, the Special Areas Board was set up and given a mandate to rehabilitate and control the use of approximately 2 million ha. of tax recovery land. Today, part of that area comprises the

Special Areas of Alberta.

In 1981, the Minister of Municipal Affairs and the Special Areas Board agreed to sell portions of the Special Areas back to the public. Farmers who currently lease land under cultivation and grazing lease may purchase from 3 to 10 quarter sections of land. People from outside the area have to lease land in the Special Areas for ten years before being allowed to buy. Lands within the Special Areas which the Board deems as "sensitive" will not be put up for sale and caveats preventing cultivation will be placed on lands which are prone to wind and water erosion. Those caveats will be transferred with the title of the land from one owner to the next, protecting that land in perpetuity (Alberta Environment, 1986).

The announcement of the sale of those lands was both criticized and endorsed throughout the Province of Alberta. At the Environmental Council of Alberta hearings, held in the fall of 1983 on maintaining and expanding the land base of the Special Areas, briefs were presented addressing both sides of the argument. The main concern respecting the land sale policy was the potential for increased wind erosion. However, general soil degradation was also an issue.

In determining which lands to sell, or whether a particular parcel of land should be sold, the Special Areas Board needs to consider whether that land could be used for crop production or if it should be kept for grazing purposes only. That decision should be based on how the soil of an area reacts to the effects of cultivation (i.e. whether it is prone to degradation or whether it can maintain a good physical condition). To assist the Board in making that decision, research into the effects of cultivation on selected soils in the Special Areas was conducted for this thesis.

1.2 Objective and Scope

The total effect that man has had on the development of a soil and its characteristics, as a result of cultivation, is not fully understood. This study attempts to provide further insight into man's impact upon soils. Specifically, the objective of the proposed study is to determine if cultivation practices are affecting selected properties of the soil at particular locations within the Special Areas of Alberta and if so, how those properties are being affected.

The scope of this research includes:

1. an investigation of the history of the land use in the Special Areas,

2. the identification of the soils within the test sites chosen for this study to the subgroup level,

3. the determination of the effects of cultivation on selected soil properties, as identified

through field and laboratory tests,

4. a descriptive and statistical analysis of the resulting data to determine the significance of the effects of cultivation on the soils investigated in this study, and

5. the formulation of recommendations to assist Alberta Municipal Affairs and the Special Areas Board in determining whether or not parcels of land in the Special Areas should be considered for public sale.

1.3 Organization of the Thesis

This thesis is divided into eight chapters. In the remainder of Chapter I, the settlement and land use history of the Special Areas of Alberta is presented. Chapter II describes the environmental setting of the study area, including the physiography, vegetation, climate, drainage, bedrock geology and surficial geology of the area. The type of soils found in the Special Areas, are described in Chapter III along with the factors which have influenced the formation of those soils. That chapter also discusses, the present land use of those soils.

Chapter IV examines a variety of literature dealing with the effects of cultivation on various soil properties and methods used to measure those effects. Chapter V provides details on the methods employed in this thesis for gathering and analyzing the information used in this investigation. The data gathered from the 15 individual test sites investigated during this study are presented in Chapter VI. Chapter VII furnishes a descriptive discussion and statistical analysis of the trends identified in the data. Conclusions and recommendations, based on the results of the study, are provided in Chapter VIII.

1.4 History of the Special Areas of Alberta

1.4.1 Initial Settlement, 1857 to 1911:

The history of the Special Areas of Alberta has been characterized by cycles of inmigration and abandonment since the first homesteaders arrived. This was due not only to the fluctuating economic situation in the area, caused by the rise and fall of wheat prices, but also to the extreme variation of the environmental conditions of the area. As a result, farming was a marginal occupation in this area at the best of times (Anderson, 1975).

In 1857, the Secretary of State for the Colonies commissioned Captain John Palliser to explore the area of land between the North Saskatchewan River and the United States Border, from the Red River west to the Rocky Mountains. In his report, Palliser described the area as a desert and stated that sustained agriculture would not be suited to it (Anderson, 1975).

The federal government chose to ignore Captain John Palliser's warning and proceeded to encourage settlers into the area. After a certain amount of debate and delay, the area which was to become known as the Special Areas of Alberta, was opened for homesteading in 1908-09. The reason for the government's move was two-fold: larger markets were needed for eastern Canadian goods and settlers were hungry for land. Once opened for homesteading, the area filled up rapidly and soon became over-populated, in respect to its carrying capacity (Burnet, 1951).

During that initial settlement period, the terms for homesteading in this area were the same as for the rest of the province; the first quarter section could be obtained for $10 and the second for $3 an acre. The final titles were transferred after three years of cultivation (Martin, 1977). The terms were very attractive, but the results were devastating. Prime pasture land, which previously had maintained economically viable ranching operations, disappeared under the plows of the recently arrived farmers.

Many of the newcomers had little or no farming experience, let alone experience in dry-land farming. Few had ever experienced severe drought conditions like those characteristic of this region. Mild warnings, such as the drought of 1910, tended to go unheeded as the flood of immigrants continued. Between 1906 and 1911, the population of the area increased from 187 to 11,039 (Martin, 1977).

1.4.2 Early Farming, 1911 to 1929:

The largest levels of inmigration into the Special Areas occurred between 1911 and 1929. The favorable homesteading terms attracted new settlers to the area. The easily available credit, the relative ease with which the land could be cultivated (i.e. no trees to clear, few large rocks to move, etc.), the high quality of wheat that could be grown, as well as the good wheat prices resulting from the advent of World War I (during the bumper crops of 1915 and 1916, wheat prices increased from $.91 to $1.33 per bushel) assisted in drawing people to the area. As a result of all of those factors, the population doubled to 24,164 between 1911 and 1916. During this time, huge tracts of land were broken and planted to wheat (Burnet, 1951; Martin, 1977).

Drought conditions and lack of available land resulted in a decline in the rate of population growth within the Special Areas, but the total population of the area continued to increase after 1916. In 1921, the population of the region reached 29,689. Of that total, 88% lived on farms and only 3,658 lived in towns or villages. Due to the high wheat prices, those people who lived on farms had little interest in mixed farming. Wheat crops accounted for 75% of the farm income in 1925, with livestock accounting for only 25%. As a result of the decrease in livestock production, fodder crop production was minimal

(Martin, 1977).

The size of homesteads provided to immigrants during the settlement period was not conducive to livestock raising. In the Special Areas, 40 or more acres of grazing land were required for each animal; homesteads were typically 160 acres. Consequently, herds required larger tracts of land than usually was held by any one man or family. In addition, stock required a dependable water source and during times of drought this was not always available (Stewart and Porter, 1942).

During the early 1900's, there was virtually no economic diversification in this area because of the single minded pursuit of wheat. Small towns and villages which sprang up to cater to the new settlers were totally dependent on the success or failure of the wheat crops.

It is interesting to note that although wheat farming was the dominant economic enterprise, most of the land in this area has since then been surveyed and classified as marginal or submarginal for crop production. As was stated by Wyatt et al. (1938), "It would have been a kindness to these settlers if this survey had been made previous to settlement, as these settlers have abandoned their farms after wasting much money and many years of their lives in an attempt to build up farms on submarginal land."

With the increase in population, a demand developed for services such as roads, schools and hospitals.

Unfortunately, during that time municipal districts were small, and little consideration had been given to whether or not they had a sufficient tax base to provide for the cost of services demanded by the increasing population. As long as harvests and wheat prices remained good, problems of over expenditure and weak administration remained inconspicuous. Funds necessary for expansion of services were borrowed easily and services were expanded far beyond the means of the district to pay for such services (Martin, 1977).

The bumper crop of 1915 was the last good harvest until 1926. Unwise cultivation practices had exhausted much of the soil. In addition, the lack of rainfall during the next ten years became a major problem. Crops failed, and taxes were left unpaid; meanwhile the demand for agricultural and social assistance rose. That pattern continued until the good harvests of 1926 to 1928 brought temporary relief from the economic effects of the drought.

During the drought years the municipal districts still were expected to increase relief payments, provide seed and continue to maintain services. The effects of the lack of economic diversity were beginning to be felt. Revenues needed to maintain the services and provide the relief funds had to be generated almost exclusively from the farmers requesting the relief (Burnet, 1951).

The system could not continue to work. After 1915, farmers who were seriously in arrears in both mortgage payments and taxes began to leave the area. From 1921 to 1926, the population of the Special Areas had decreased by 23%. As the residents left, their debts were assumed by the municipal districts who seized the land in lieu of unpaid taxes under the authority of the Tax Recovery Act (Martin, 1977).

In 1926, the state of affairs in the Special Areas was dismal. Public liability amounted to $1,746,195, and private debt amounted to at least $2,750,000. Over-all indebtedness averaged $6 an acre, a figure considerably above the value of the land. Buyers were non-existent for the over-worked and weed infested land, which reduced its value even further (Martin, 1977).

A return to bumper crops between 1926-1928, caused renewed faith in the area and the population rose once again to 24,074. However, this economic and environmental reprieve was short lived.

1.4.3 The Depression, 1929 to 1938:

In 1929, crop yields plummeted along with the price and demand for wheat. In addition, one of the worst droughts ever experienced on the prairies began that year. These factors resulted in a complete collapse of the farming economy in this area. During the drought years that followed, the area became virtually empty of people; over three quarters of the cultivated land in the area was abandoned (Burnet, 1951; Gray, 1978).

It was not just the collapse of the economy and the drought that drove the people away; the re-occurring dust storms had their effect as well. Due to low rainfall, light soil, high winds and inadequate tillage practices, massive amounts of top soil were caught up by the wind and blown away. As more land was broken and the grass cover was removed, the fine, friable soil increasingly became vulnerable to wind erosion. As a result, dust storms occurred more and more frequently. The removal of the soil accentuated the deterioration of the land that had started as a result of the practice of continuous cropping. The outcome was the permanent loss of fertility of the land resulting in a decrease in it's productivity and yield (Roe, 1952).

By 1938, the combination of abandonment and loss of soil forced the Alberta Government to reclaim ownership of the majority of the land. To accomplish that, the government passed the Special Areas Act which authorized the government to administer and manage the reclamation and preservation of the area. Six special areas were formed and consolidated under one administration. A Special Areas Board was appointed to administer the Act and has acted as the local government authority for that area since 1938

(Edwards, circa 1978).

The aim of the Board was to return the region to the grass-based economy which existed prior to the settlement boom. To accomplish this the Board regained control of abandoned land through tax recovery proceedings. Soon 65% of the land was publicly owned and administered. The 37 original municipal districts were disassembled, and land exchanges were arranged to consolidate holdings into economically viable farming units. Free freight was provided to those people who wished to leave the area, and by 1941 the population had declined to just over 15,000. Soil surveys were conducted and used as a guide to resettlement. Regrassing and establishment of community pastures encouraged the return to a grass-based economy. Expansion of farm unit size was achieved through the issuance of cultivation or, more preferably, grazing leases, rather than through the sale of land. Within five years of the Board's creation, the major changes required to rehabilitate and stabilize the Special Areas had been accomplished successfully (Martin, 1977).

1.4.4 Recent History:

By the mid-1970's, under the administration of the Special Areas Board, public land ownership in the Special Areas grew 70%, the average farm size increased 400% to over 3,000 acres and the population declined to just over

11,000. Transition to a grass-based economy continued; the grazing area increased by 30% and the number of cattle in the area quadrupled. Regrassing continued at an even pace and community pastures constantly were filled to capacity (Martin, 1977).

The area now administered by the Special Areas Board has been reduced considerably from that included under the original Special Areas Act of 1938. This reduction in size has resulted, in part, from the establishment of the Suffield Army Experimental Range, north of Medicine Hat, and to some extent by the withdrawal of portions of the area by adjoining Counties and Municipal Districts. Wheat farming generally has given way to cattle ranching, especially in the western portion of the area. The soil has been stabilized over the area by seeding the land to Crested Wheat Grass, and a close watch is now kept to ensure that wind erosion does not occur from overgrazing or poor tillage practices (Edwards, circa 1978).

CHAPTER II

PHYSICAL ENVIRONMENT

2.1 Introduction

The Special Areas of Alberta covers 226 townships or over 2,104,440 ha. of undulating terrain in eastern Alberta (Marciak, 1984). Its boundaries touch the Red Deer River to the south, the Saskatchewan-Alberta border to the east, and extend to the north and west to within a few miles of Provost and Drumheller, respectively (see Fig. 2.1). The region is semi-arid, with little surficial water (i.e. lakes, rivers, streams, etc.). The average yearly rainfall is approximately 30 cm. and the area has a high evapotranspiration rate (Bowser, 1967). Natural vegetation is limited to hardy native sedges and grasses. The area is covered in Brown and Dark Brown soils which are susceptible to wind erosion. Most of the soil is unsuited to prolonged cultivation (Canada Land Inventory, 1965).

This chapter provides a description of the physical environment of the Special Areas of Alberta. The description covers the physiography and topography of the Special Areas, as well as the drainage system, climate, vegetation, bedrock geology and surficial geology of the area. The soils of the Special Areas are described in

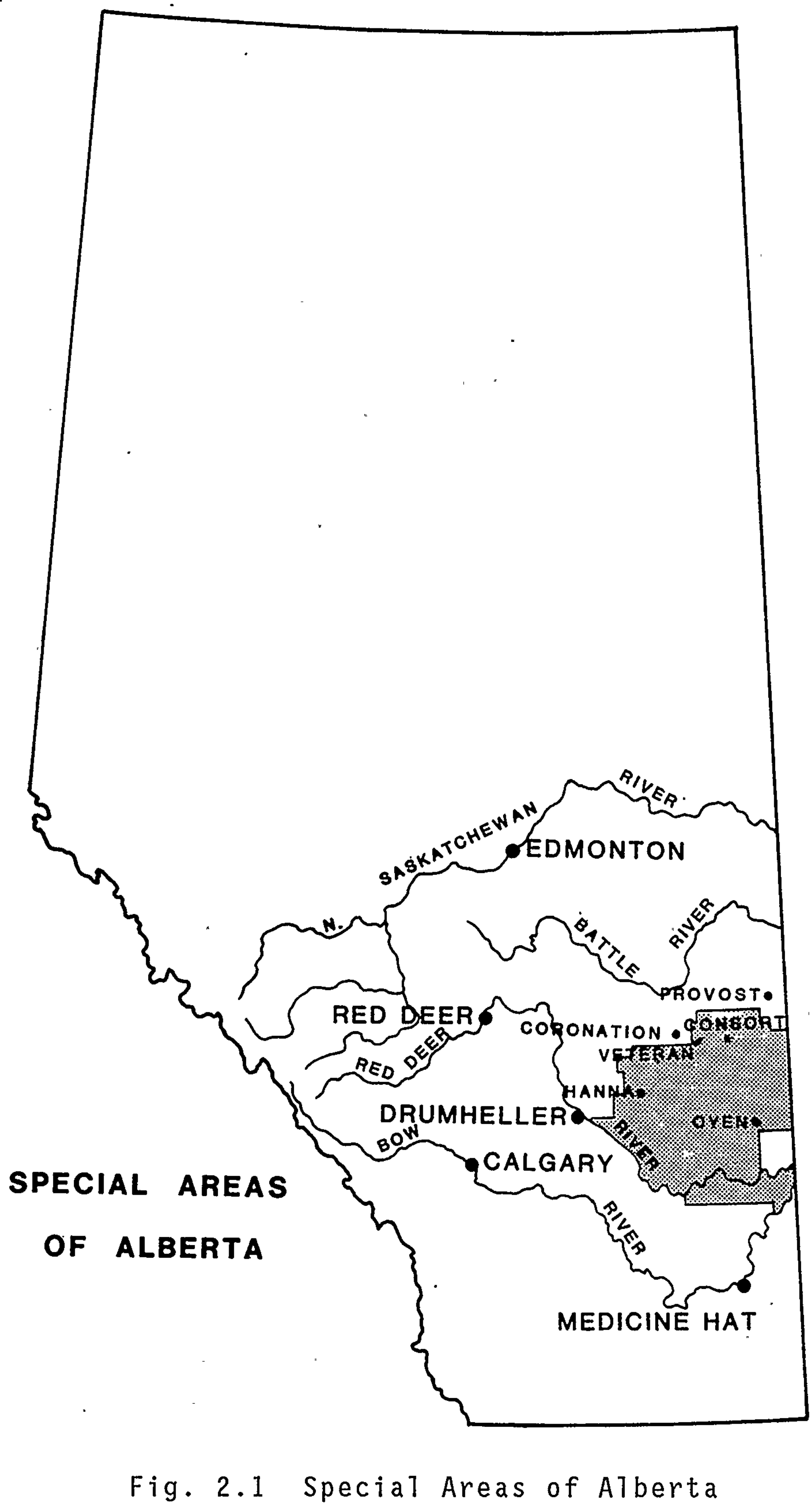


Fig. 2.1 Special Areas of Alberta

detail in Chapter III.

2.2 Physiography

The Special Areas are situated in the Great Plains physiographic region of Alberta. The region generally is characterised by flat topography in the western portions, and gently rolling to moderately rolling topography in the eastern portion. Extremely rough terrain (i.e. strongly rolling to rough broken) is concentrated in the north-east corner, the south central area and around Dowling Lake (see Fig. 2.2) (Kjearsgaard, 1976).

The more notable ranges of hills are the Neutral Hills in the north, the Hand Hills southwest of Hanna, and the Rainy Hills, found south of Iddlesleigh. The backbone of the Neutral Hills runs in an easterly direction from Twp. 37, Rge. 9, West of the 4th Meridian, into Saskatchewan. Nose Hill in Twp. 37, Rge. 9, West of the 4th Meridian, peaks at about 915 m., but there is a gradual slope or drop in elevation from the southwest to the east and northeast in the Special Areas. Elevations range from 884 m. near the town of Hanna, to 640 m. in the northeast section where Sounding Creek leaves the area (Wyatt et al., 1938).

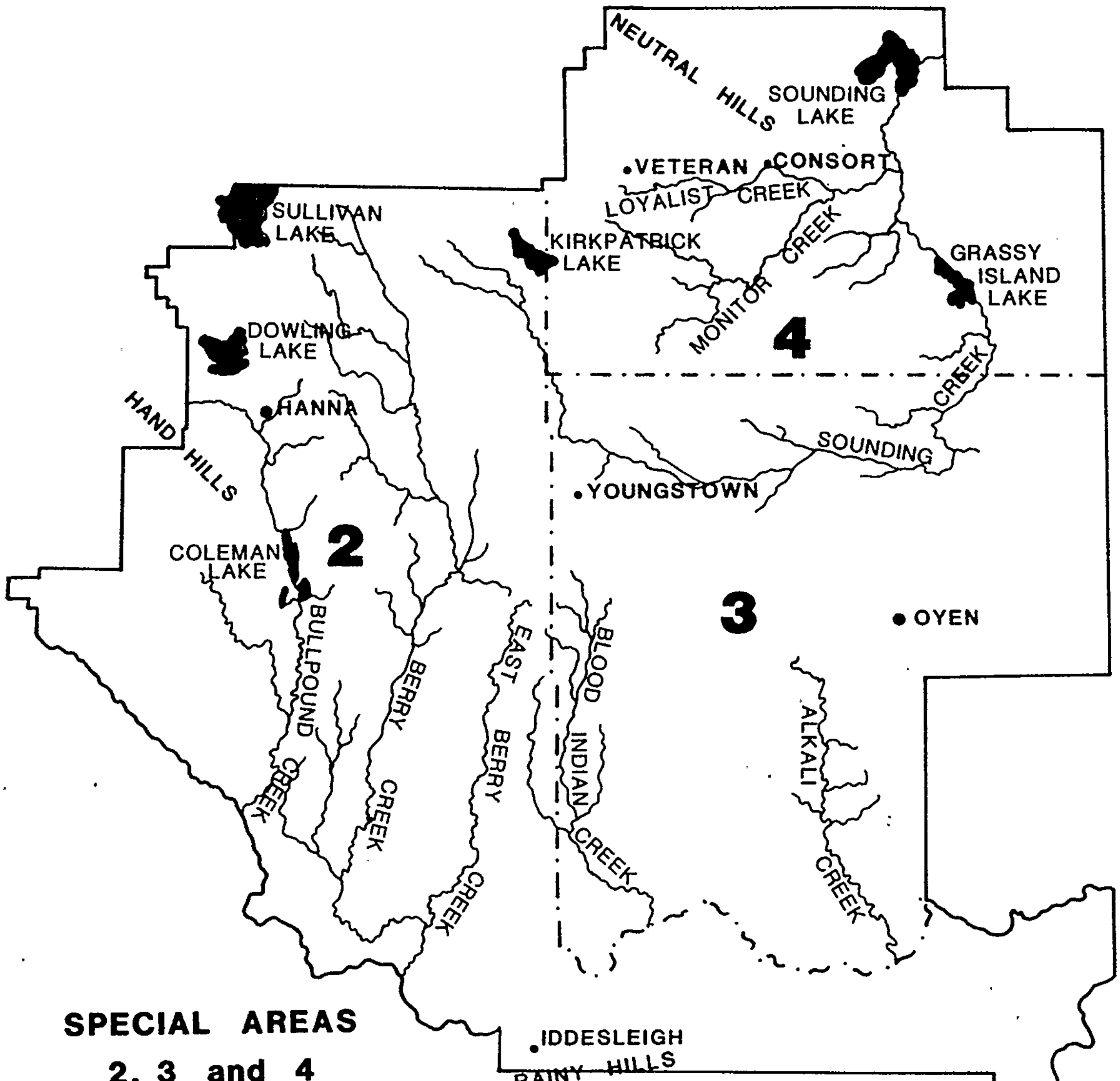


Fig. 2.2 Special Areas 2, 3 and 4

2.3 Drainage

The major drainage systems in the area are incised fairly deeply, i.e. Red Deer River, Sounding Creek and Monitor Creek, but the majority of the area is poorly drained. This is a direct result of the most recent glaciation which left an immature drainage system characterised by large areas of internal drainage, numerous sloughs and intermittent streams and lakes (Kunkle, 1962).

Slightly more than half of the area lies within the Red Deer River Drainage Basin and is drained by the Bullpound, Berry, Blood Indian and Alkali creeks. The northeastern portion lies in the North Saskatchewan River Basin and is drained by the Sounding and Monitor Creeks. The majority of the creeks in the area are seasonal tributaries which flow only during unusually wet years (Wyatt et al., 1938; Martin, 1977).

Sullivan Lake and Sounding Lake are the major natural water reservoirs in the Special Areas. Both are in the north and are shallow (like most of the lakes in the study area). Like the creeks, these lakes are occasionally dry (in 1937 neither held any water) and therefore, are unreliable as major water reservoirs (Wyatt et al., 1938; Martin, 1977).

2.4 Climate

The Special Areas are influenced by the continental climatic regime which is characterised by cold winters and warm summers. The growing season is approximately 175 days long, starting about April 20 and terminating about October 12. Frost-free periods vary from 92 days in the northeast, to 100 days in the western and southern parts of the area. The variation between the length of the frost-free period and the growing period is because the frost-free period ends with one degree of frost. In many cases this slight amount of frost is not enough to harm many of the crops and they will continue to grow until a heavier frost kills them (Bowser, 1967). The July mean temperature is about 19°C, while the January mean temperature is about -14°C (Kjearsgaard, 1976).

The most serious climatic problem in the region is the lack of rainfall. The annual precipitation varies from a low of about 30 cm. in the southern portions, increasing to about 36 cm. in the northern parts. Approximately two thirds of the annual rainfall occurs during the growing season (Bowser, 1967). The Special Areas have the lowest annual precipitation in the province. Extreme variability in the amount of precipitation received in any one year accentuates the problems associated with low precipitation. Rainfall can vary as much as 40% from one year to the next (Martin, 1977).

Virtually none of the small amount of precipitation received by this area is retained. The long hours of sunshine, high summer temperatures, and drying winds leave the region with no moisture surplus. The evapotranspiration rate, which is the second highest in the province, exceeds the amount of precipitation received, resulting in a net loss of moisture during the average year. It is estimated that drought will occur 1 out of every 4 years in this area (Bowser, 1967).

The variations in the amount of rainfall throughout the area correspond generally to the distribution of the Dark Brown and Brown soil zones. The Dark Brown soils roughly represent those areas where the amount of precipitation has been the limiting factor to crop growth approximately 50% of the time. The Brown soils represent areas where the amount of rain usually has been a severe limiting factor to crop growth (Wyatt et al., 1938; Stewart and Porter, 1942; Kjearsgaard, 1976).

2.5 Vegetation

Most of the Special Areas are open prairie with a vegetative cover of grasses, herbs and a few low shrubs. Shrubs and trees are distributed sparsely and found primarily in the northern portions of the region. Only the hardiest forms of vegetation are native to this region.

(The following discussion of plant species commonly found in the Special Areas was compiled from information gathered during the 1985 field season and was verified by the following sources: Wyatt et al., 1938; Stewart and Porter, 1942; Campbell, Best and Budd, 1966; Wroe et al., 1972; Kjearsgaard, 1976; Cormack, 1977; Looman and Best, 1979; Looman, 1982; and personal communication with Mr. A. Spencer, Range Manager, Consort Region, Special Areas).

Perhaps the most frequently occurring plant species in the Special Areas is the club-moss (*Selaginella densa*). This plant plays an active role in preventing soil erosion by clinging to the ground, thus protecting the surface from the ravages of wind and water. This moss is particularly abundant in areas where pasture has been depleted. Wolf willow (*Elaeagnus commutata*) generally occurs in areas with coarse textured soils and adequate moisture supply. Virgin prairie areas (especially in the western portion of the region where Solonetzic soils occur) are characterized by buck brush (Syn. snow berry) (*Symphoricarpos occidentalis*). Prairie sage (*Artemisia gnaphalodes*), sagebrush (*Artemisia cana*) and prickly rose (*Rosa acicularis*) are found throughout the Special Areas. Salt sage (*Atriplex nuttallii*) usually is found in strongly solonized flats.

Native grasses and sedges cover the majority of the land surface in the Special Areas. Rapid growth of these plants results in maturity being reached by the beginning of August. During this usually dry month, the grasses dry and cure, retaining their nutritional value. This growth pattern makes the plants highly valuable for grazing. The long (45 cm. to 150 cm.) and fibrous root systems of the grasses and sedges help to improve the structure of the soil, as well as its moisture retention capability (Wroe, et.al., 1972).

The most commonly occurring grasses in the Areas are: spear grass (Stipa comata), june grass (Koeleria gracilis) canby blue grass (Poa canbyi), northern wheat grass (Agropyron dasystachyum), rough hair grass (Agrostis scabra), Kentucky blue grass (Poa pratensis), Mat Muhly (Muhlenbergia richardsonis) and western wheat grass (Agropyron smithii). Wild barley (Hordeum jubatum) and alkali grass (Distichlis stricta) are found in lower, more saline areas. In overgrazed areas, pasture sage (Artemisia frigida) and blue grama grass (Bouteloua gracilis) will form the largest part of the plant community. In sandy areas, sand grass (Calamovilfa longifolia) aids in stabilizing the soil.

There is a distinct change in the vegetative landscape towards the northern and western portions of the study area, within the Dark Brown Soil Zone. Aspen poplar stands (Populus tremuloides) become a common occurrence, particularly in areas of rougher topography. Near the edge of these poplar stands, timber oatgrass (Danthonia intermedia) is found. Most of the sloughs are surrounded by willows (*Salix sp.*) and aspen poplars. Areas in the north which have not been cultivated tend to have a denser ground cover than do similar areas farther south. The occurrence of rough fescue (*Festuca campestris*, Syn. *F. scabrella*) and Hookers oat grass (*Helictotrichon hookeri*) is the most notable change in the grass cover in the more northern parts of the region.

Weeds are a major problem in any dry-belt area in Alberta and the Special Areas are no exception. Moisture, which should go to nourishing crops, is taken up by weeds that are generally of no fodder value. Russian thistle (*Salsola kali* var. *tenuifolia*), lambsquarters (*Chenopodium album*) and Russian pigweed (*Axyris amaranthoides*) are common weeds in the Special Areas. These can become particularly troublesome in extremely dry years, in some cases, choking out entire grain crops. Tumbling mustard (*Sisymbrium altissimum*) and pepper grass (*Lepidium sp.*) can be found in areas of level solodized soils, with poverty weed (*Iva axillaris*) prevalent on gravelly soils.

2.6 Bedrock Geology

The bedrock geology of the Special Areas is quite well documented by Warren and Hume (1939 a and b), Kunkle (1962), Le Breton (1963), Irish (1966 and 1971) and Borneuf (1978). Most of the data on the bedrock geology has been derived from groundwater surveys, hydrogeology surveys and oil and gas exploration.

Three bedrock formations from the Upper Cretaceous underlie the study area. These are essentially flat lying deposits with an inclination, in most areas, of less than 1^{o} to the west (Kunkle, 1962). The Oldman formation occurs mainly in a narrow, curved belt starting in Sec. 15, Twp. 30, Rge. 4, West of the 4th Meridian, and extending downstream along the valley of Sounding Creek to the north border of the area. The strata consist of massive, crossbedded, medium to coarse grained, light grey-weathered sandstone; grey, clayey siltstone; grey-weathered, grey and green shale and ironstone concretions. The formation is non-marine in origin (Warren and Hume, 1939 a and b; Irish, 1966 and 1971; Borneuf, 1978).

About 80% of the study area is underlain by the Bearspaw formation which is of marine origin. This formation consists of dark-grey and brownish grey, rubblely and flaky shale; grey, argillaceous sandstone; ironstone concretionary bands and bentonite layers. The thickness of the formation underlying the study areas ranges from zero along Sounding Creek to 180-210 m. in the western part of the area (Warren and Hume, 1939 a and b; Irish, 1966 and 1971; Borneuf, 1978).

The Horseshoe Canyon formation (often referred to as the Edmonton formation) underlies slightly less than 20% of the area. The strata consists of mainly non-marine grey, light grey-weathering, argillaceous sandstone; grey and green silty shale; carbonaceous shale; ironstone concretionary beds; bentonite bands; coal seams and minor limestone beds. The thickness of the formation underlying the study area ranges from zero to about 75 m. (Warren and Hume, 1939 a and b; Irish, 1966 and 1977; Borneuf, 1978).

The bedrock topography of the area generally resembles that of the present day (Kunkle, 1962; Le Breton, 1963). The differences that exist are mainly due to deformation by ice and streams. Stream valleys that existed prior to glaciation now are buried partially or completely by glacial drift; however, some of the modern drainage courses occupy portions of the ancient bedrock channels, (Kunkle, 1962).

2.7 Surficial Geology

Very little research has been conducted on the surficial geology of the Special Areas, consequently the information in the following section was extrapolated from general statements about the surficial geology of south-central Alberta. What information does exist of the study area was used to substantiate the extrapolated information.

Flint (1971) stated that the glacial deposits of central Alberta represent the repeated fluctuation of the ice fronts of both the Laurentide and the Cordilleran ice sheets. As a result, many of the stream-line features which could identify the direction of the ice flow have been destroyed by various glacial advances. However, he felt that during deglaciation the ice sheet would have had a natural tendency to retreat in an east by northeasterly direction, due to the lower elevation in that direction. The movement in that direction may have been enhanced at the time by the subsidence of the land at the glacier center (i.e. Hudson Bay area). Flint continued by commenting on the nearly continuous mantle of glacial drift in this area and noting its high clay content.

Gravenor and Bayrock (1961) and Stalker (1960), agreed with Flint on the direction of glacier retreat due to the configuration of the Viking moraine. In addition, they stated that the position and orientation of glacial lakes and outlet channels in central Alberta indicate that the glacier retreated to the northeast damming easterly drainage at the front of the ice. They further suggested that the glacial features evident in central Alberta (i.e. flat to gently rolling morainal features, e.g. ground moraine, hummocky moraine, washboard moraine, till ridges, etc.) are the result of large scale down-wasting, leading to stagnation, followed by local rejuvenation of small lobes or fingers of ice.

In 1955, Gravenor and Bayrock mapped the surficial geology of the Coronation area. They found evidence of only one thin till. This till consisted of debris from the underlying Bearspaw shales and Edmonton sandstones. It also contained large amounts of bentonite obtained from these formations. This till was very plastic and slippery when wet, which led Gravenor and Bayrock to suggest that the cause of the thinness of the tills in the area may have been due to the high clay content of the bedrock. The pre-existing till would have been removed from the area by the last glaciation, but upon retreating the basal ice of the glacier may have become packed with bentonite, lowering the friction between the ice and the bedrock. Therefore, the ice could have slid along the bedrock without picking up much material.

Gravenor (1956a) also mapped the surficial geology of the Castor area. He found the surficial geology of that area difficult to interpret, not because it was complicated, but because there is a lack of surficial deposits. The south part of the area is virtually till free, and the north part is a flat featureless till plain, named the Torlea Flats. Since this area also overlies the Bearspaw formation, with its high clay content, Gravenor suggested that the till was removed by a similar process as the one Gravenor and Bayrock (1955) described for the Coronation area, (i.e. the ice sliding over the bedrock).

In 1956(b), Gravenor published a volume of airphotos of the Plains Region of Alberta, upon which glacial features had been identified. The majority of the features identified on these airphotos were ablation features or ice contact features. Many of these airphotos were of land within the Special Areas or surrounding it. Almost without exception, the information presented on the airphotos suggested that the surficial geology of these areas resulted from the retreat or stagnation of ice.

In the Reconnaissance Soil Survey of the study area, Kjearsgaard (1976) constructed a table of the extent of various surficial deposits in part of the Special Areas, (see Table 2.1). This information together with the above discussion was used to interpolate the surficial geology of the Special Areas.

Till deposits predominate in the study area, with lacustrine, fluvial and aeolian deposits having a much lower acreage. Locations covered in soft rock are second to till in areal extent and are comprised of weakly consolidated sedimentary Cretaceous materials. These usually are capped by a layer of till which varies in thickness. The till contains portions of the unmodified soft rock, giving it properties similar to the underlying material. As a result, it is difficult to distinguish the two materials in many cases. The unmodified Cretaceous materials strongly influence the characteristics of the water and soil in the study area, and, therefore, the

TABLE 2.1

EXTENT OF THE SURFICIAL DEPOSITS IN THE HANNA-OYEN AREA

Material	% of Total Area
Till	51
Soft rock	17
Fluvial	8
Fluvial-Aeolian	7
Lacustrine	4
Fluvial gravels	2
Aeolian	1
Unclassified	10

identification of the boundaries of this material is important from an interpretative point of view (Kjearsgaard, 1976).

From the above information on the surficial deposits of the study area and the previous information on its physiography and topography, it is suggested that the western portion of the area is covered mostly by ground moraine and the eastern portion generally is covered by hummocky moraine. This suggestion is based on the observation that the western half of the area is relatively flat and has a thin layer of till covering the weathered bedrock. Both ground moraine and the weathered rock would tend to produce a relatively flat landscape. On the other hand, the till cover in the eastern half of the area varies in thickness (although it is generally much thicker than the till in the western section) which results in an undulating to rolling topography. Hummocky moraine is characterised by variable thickness, due to its mode of deposition and produces features of greater vertical relief than ground moraine does. The presence of hummocky moraine would explain the type of topography found in the eastern portion of the Special Areas.

Based on the above assumptions of the till cover in the Special Areas and the information available on the surficial deposits in central Alberta, it would appear that the ice retreated from the area in the same manner as has been suggested for the rest of central Alberta. Gravenor and Bayrock (1961), Stalker (1960) and Flint (1971) all concluded that stagnation and down-wasting in an east by northeasterly direction was the most likely mode and direction by which the ice sheet would have retreated from central Alberta. It is unlikely that the ice from the Special Areas retreated in a different manner and from all the evidence reviewed, it did not.

2.8 Summary

The Special Areas of Alberta are part of the Great Plains physiographic region of North America. The physiography of the study area, which is generally flat in the western portion and gently to moderately rolling in the eastern portion, is accompanied by a gradual decrease in elevation to the east and northeast. The major drainage systems in the study area are the Red Deer River, Sounding Creek and Monitor Creek. The majority of the area has poorly integrated surface drainage with over half of the area lying in the Red Deer River drainage basin and the north east portion lying in the North Saskatchewan River drainage basin.

The most serious climatic problem in the Special Areas is the lack of rainfall. This area experiences the lowest annual rainfall as well as the second highest evapotranspiration rate in the Province of Alberta; in an average year the area experiences a net loss in moisture. Grasses and herbs cover the majority of the study area, with low shrubs and trees distributed sparsely in the northern portion of the area.

The Bearspaw formation, which is of marine origin, underlies approximately 80% of the area, with the Oldman formation and the Horseshoe Canyon (Edmonton) formation underlying much smaller portions. Till covers slightly more than half of the study area, while Cretaceous soft rock covers less than 20%. The remaining surface area is covered by aeolian, fluvial or lacustrine deposits.

The environmental factors described in this chapter have all influenced the soils that have formed in the Special Areas since the last glaciation. These soils, and the effects of the environmental factors on their formation, are discussed in the following chapter.

CHAPTER III

SOILS OF THE SPECIAL AREAS

3.1 Introduction

Prior to the Dominion Economics Division Soil Study (1940), no comprehensive soil survey of the Special Areas had been made. However, partial surveys had been conducted for most of the area by 1938. In these surveys the Special Areas were placed in the Brown Soil zone. The soils of the western and northern sections of the area were classified in the Dark Brown soil zone because they contained a higher percentage of organic matter than the light brown soils which cover the majority of the area (Wyatt and Newton, 1927; Wyatt et al., 1937; Wyatt, et al., 1938).

One of the major features of the Special Areas that has frustrated both farmers working the land and scientists trying to reclaim it, has been the highly variable nature of the distribution of the soils, as well as their associated characteristics. The fertility of the soils in the Special Areas varies greatly from place to place. Farmers in the area stress that the best lands are likely to lie immediately alongside the worst; one quarter having productive soil and the adjacent quarter being barren (Burnet, 1951).

This chapter provides an insight into the nature of the soils of the Special Areas. Included is a discussion of the soils of the Special Areas as they are classified according to the Canadian System of Soil Classification and a description of the roles the various soil forming factors had in the development of those soils.

3.2 Soil Classification

The diagnostic characteristics of all horizons or layers recognizable in the soil profile are the basis upon which a soil is classified. Recognition of secondary or subordinate features within the major horizons help to further define and classify a soil. The soil profile consists of a vertical cross section made up of a succession of horizons extending from the surface of the soil down into the underlying geological material or parent material. These horizons reflect the formation of soil from the original parent material by processes involving physical and chemical weathering and biological activities. These processes result in the breakdown and alteration of the parent material, the differential transference of various constituents which make up the altered material and the production of soil structure (Brady, 1984).

In a soil survey conducted in 1976 on a large portion of the Special Areas, Kjearsgaard used the profile characteristics of the soils in the area to classify them into four soil orders: Chernozemic, Solonetzic, Regosolic and Gleysolic. Of these orders, the Chernozemic and Solonetzic orders predominate (see Table 3.1).

TABLE 3.1

PERCENT DISTRIBUTION OF SOIL ORDERS IN THE HANNA-OYEN AREA

Order	% of Total Area
Chernozemic	42
Solonetzic	51
Gleysolic	4
Regosolic	3

In the following portion of this chapter, the characteristics of the soil orders and great groups in which the soils of the Special Areas are classified will be discussed briefly. Emphasis has been placed on the specific situations in which the soils of the Special Areas are found.

3.2.1 Chernozemic Order:

The Chernozemic soils found in the Special Areas consist of well to imperfectly drained mineral soils developed under grassland vegetation. The characteristics of their profiles (e.g. the humus-rich A horizon) are considered to be developed and maintained by the accumulation and decomposition of a cyclic growth of xerophytic to mesophytic grasses and forbs (Agriculture Canada, 1977).

Chernozemic soils are subdivided into either the Brown or Dark Brown great groups. The Brown Chernozemic soils are characterized by A horizons with grayish brown to light brownish gray dry colors and are generally low in organic matter content. They develop mainly on glacial till, lacustrine or fluvial deposits and occur in areas which have severe moisture deficits during the growing season. The soils are associated with areas of level to rolling topography and tend to be weakly to moderately calcareous. Brown Chernozemic soils are predominantly loamy in nature, although clayey and sandy textures do occur depending on the composition of the parent material from which they develop (Anderson, 1975; Kjearsgaard, 1976; Agriculture Canada, 1977).

The Dark Brown Chernozemic soils in the Special Areas have A horizons with dark grayish brown to dark brown dry colours. The organic matter content and thickness of horizons are generally greater than those of the Brown Chernozemic soils. These soils are found in areas characterized by moderately severe moisture deficits during the growing season and occur on similar deposits and topography as the Brown Chernozems. They are weakly to moderately calcareous and are dominantly loamy in texture, although soils with clayey and sandy textures do exist (Anderson, 1975; Kjearsgaard, 1976; Canadian Soil Survey Committee, 1978).

3.2.2 Solonetzic Order:

The word Solonetz is Russian in origin and was originally used to indicate soils that were saline or alkaline. In Canada, this word is used to describe mineral soils that are moderately well to imperfectly drained and which have developed from saline parent materials. The horizons of these soils have distinct physical and chemical characteristics which have resulted from a combination of processes, including salinization, desalinization and leaching (Richards, 1954; Toogood and Cairns, 1973).

The Solonetzic soils found in the Special Areas of Alberta generally develop in areas of similar vegetation and topography as the Chernozemic soils. For that reason, their A horizons often assume Chernozemic-like characteristics. Their B horizons are characterized by a hard, columnar structure which Chernozemic soils lack, and the C horizons of the Solonetzic soils are much more saline. Although they have developed from a variety of parent materials, Solonetzic soils occur most frequently on till and weathered soft rock material (which originates from the underlying bedrock). All three great groups of the Solonetzic order have been identified in the Special Areas (Toogood and Cairns, 1973; Kjearsgaard, 1976).

3.2.3 Gleysolic Order:

The Gleysolic soils in the Special Areas are poorly drained, moderately calcareous mineral soils. Their profiles are affected continuously or periodically by water saturated and reduced conditions. The result of those conditions can be seen in the occurrence of gleyed horizons characterized by dull gray, greenish and blue-gray colors. These soils develop on nearly level or undulating topography, associated with water bodies and stream valleys. They support hydrophytic type grasses and shrubs and are usually loamy to clayey in texture. Only the Gleysol great group has been identified in the Special Areas and many of these soils belong to the saline subgroups (Kjearsgaard, 1976; Canadian Soil Survey Committee, 1978).

3.2.4 Regosolic Order:

The Regosolic soils of the Special Areas are well to imperfectly drained soils, characterized by either weak horizon development or none at all. They occur mainly in sand dune areas, or on recent deposits along drainage channels (Kjearsgaard, 1976; Canadian Soil Survey, 1978).

3.3 Soil Formation

The soils which have developed in the Special Areas are the result of the combined effect of many processes which have proceeded at different rates and in different ways. As a result, the degree and variability of these processes, and their interaction, are reflected in the numerous types of soils found in the Special Areas. Those processes, which are responsible for the kind, rate and extent of soil development, can be grouped into five factors: climate, vegetation, parent material, topography and time (Foth, 1978; Jenny, 1980; Brady, 1984). To understand why there is such a large variation in the soils of the Special Areas, why they vary in their productivity and how they may be properly used, we need to know how these five factors influenced the development of those soils.

The presence of horizons in all soils suggests that certain processes are common to the development of all soils. As a result, even though there is a large variety of soils, each one is not a product of a distinctively different set of processes (Knox, 1965). Horizon differentiation results from processes that add, take away, transform or translocate material. For example, vegetation and animals add material to the organic fraction of the soil, carbon in organic matter is lost from the soil as carbon dioxide due to microbial decomposition, nitrogen is transformed from organic to inorganic forms, and clay particles are subject to translocation from place to place within the soil profile.

The following section of this chapter discusses the effects of the five factors on the development of the soil in the Special Areas.

3.3.1 Formation of the Soils in the Special Areas:

At a Symposium on the soils of Canada, in 1960, V.K. Prest, stated that, "The Wisconsin Glaciation has given Canada its soils..." (Legget, 1961:17). If this statement is true, then the distribution of the soils in the study area should closely mirror that of the surficial deposits. In addition, the soil's composition and some of its characteristics should reflect the underlying deposits as well, since much of the material composing the glacial tills was derived from the underlying Paleozoic and Mesozoic limestones and shales. These formations are highly saline and rich in clay, especially bentonite, which tends to swell upon wetting and shrink when it dries (Prest, 1961).

The soils of the Special Areas are relatively young geologically, having developed since the last glaciation some 10,000 to 13,000 years ago. As the glaciers melted, glacial till was left behind and subsequently was resorted by wind and water to produce the parent material from which the soils in this area were derived. The characteristics evident in these soils suggest that they are still in the early stages of their development. The texture of the soils is influenced highly by the nature of the parent material from which they have developed; a variation in the texture of underlying parent material usually results in a corresponding change in the associated soil (Kjearsgaard, 1976).

The soils in this area generally lack thick, complex horizon development. The high clay content of these soils is most likely due to the large amount of clay present in the parent material rather than to the process of prolonged weathering, since the dry, cool climate of this region is not conducive to chemical weathering. The abundance of primary minerals present in the soil and the maintenance of the organic matter content of the soil by the annual addition and decomposition of vegetal matter, also suggests that these soils are still fairly young.

One finds a fair amount of difference in the distribution of the bedrock deposits in the study area and the distribution of the soil orders. The Bearspaw Formation, which is of marine origin and highly saline, covers approximately 80% of the study area and underlies a large portion of both the Solonetzic and Chernozemic soils.

Therefore, it is evident that although this formation provides the parent material for both soil types, factors other than the presence of saline bedrock must influence the distribution of the Chernozemic and Solonetzic soils. Only a fair correlation exists when comparing the distribution of the surficial deposits to the soil orders. The Solonetzic soils are underlain by both the weathered soft rock (highly saline) and the till (less saline).

If only the areal distribution of the surficial deposits is considered, it would appear that the underlying bedrock and surficial deposits do not control the distribution of the soil orders, but instead, only provide the parent material for soil development. However, if one looks at the topography of an area and the thickness of the surficial deposits, a much stronger similarity in distribution is apparent. In the areas where the topography is undulating to moderately rolling and the till deposits are thick, the soils are generally Chernozemic; whereas, in the areas where the topography is relatively level and the till deposits are thin or absent, weathered soft rock is close to the surface and soils tend to be Solonetzic. This suggests that the thickness of the till somehow affects the influence of the highly saline soft rock. This hypothesis was supported in a paper recently presented at the 22nd Annual Alberta Soil Science Workshop (R. Wells and G. Lickacz, 1986).

There are at least two ways in which the thick till could be filtering the potential effects of the saline soft rock; both are related to the movement and distribution of the groundwater in the area. The first is that the till may allow water to filter through it more easily than the weathered soft rock does because the till has undergone weathering and leaching for an extensive period of time and may have lost a great deal of its clay content. In addition, the prolonged weathering and leaching of the till also may have removed much of the salt present in the original material from which it was formed. Conversely, these constituents (i.e. clay and salt) are being renewed constantly in the soft rock material due to its continual formation from the weathering and break down of the bedrock below it. Therefore, as a result of its lower clay content, the till would not hold as much water nor inhibit its movement as much as the soft rock would. In addition, water held in the till would be less saline than that held in the soft rock.

Secondly, the surface water and ground water would tend to be more saline in the western portion of the Special Areas than in the eastern portion. The difference in the salinity of the water in these two areas can be attributed to the proximity of the saline soft rock to the ground surface, which is controlled by the thickness of the overlying till deposits. In the western portion of the area, the till cover is thin or non-existent, allowing the saline material to be close to the surface and, therefore, close to the water regime of the area. As a result of this close proximity, the salt contained in the saline soft rock material is dissolved and held in suspension by the surface and ground water, increasing the salinity of the water. In turn, the soils which are influenced by the water regime in the western portion of the Special Areas would be affected by the large amount of salt suspended in the water.

Due to the dry climate of the Special Areas, which results in a lack of available moisture in the area, water generally is distributed by capillary action upwards, rather than by percolation downwards (Van Schaik and Stevenson, 1967). In areas where the saline parent material is close to the surface, dissolved salt travels upward with the water and is brought to the surface of the soil. As the water evaporates, the salt is left behind and forms alkali patches. When rain does occur, this salt is then translocated to the B horizon in the form of sodium saturated clays and becomes the "building blocks" for the formation of the hard, prismatic Bnt horizon of the Solonetzic soils (Sommerfelt and Chang, 1980).

In areas where the saline parent material is not close to the surface, the upward moving water filters through the less saline till. Salt, which is present in the water in these areas, will probably filter out of the water as it rises through the till. As a result, once the water reaches the surface and evaporates, less salt will be left to form alkali patches. Subsequently, when rain occurs there will be less sodium to transfer into the B horizon and, depending on the amount of clay present, a Bm or Bt horizon should develop (Sommerfelt and Chang, 1980).

The area covered by Solonetzic soils is somewhat larger than either the distribution or thickness of the surficial deposits would suggest it should be. To explain this, one must consider the movement of the ground water as an additional factor. Saline water is more dense than non-saline water and as a result, the denser salt water tends to migrate towards areas which are less dense (i.e. that of the non-saline ground water). The migration of the salt water into an uncontaminated area results in the salinization of the soils in that area, which eventually will lead to the formation of Solonetzic soils. Thus, the area covered in Solonetzic soils will expand with the migration of the saline ground water (Richards, 1954; Van Schaik and Stevenson, 1967; Sommerfelt and Chang, 1980).

The high variability of both the soils in this area and their capability can be related to the composition and distribution of the surficial deposits, as well as to the difference in thickness of those deposits. In the western portion of the area, the topography is flat due to the presence of ground moraine which varies little in relief.

The till cover is very thin in this area, and, consequently, the underlying saline parent material, close to the surface, greatly influences the development of the soil. Solonetzic soils are found more often in this area than in the eastern portion of the region.

In the eastern portion of the area, the topography is rolling to undulating, reflecting the presence of hummocky moraine deposits. Due to its mode of deposition, the till deposits associated with hummocky moraine are highly variable in their thickness. As a result, the till deposits are very thin in some areas, allowing the saline parent material to lie close to the surface, thereby exerting a strong influence on the developing soils. In other areas, the till deposits are thick causing the saline material to be further away from the surface, and therefore exerting little influence on the soils. This would explain why very poor soils with a high salt content are interspersed with, and adjacent to, more fertile soils with a lower salt content.

Although the topography of the area and the composition of the bedrock and surficial deposits have influenced the soil formation in this area, they are not the only factors from which the soils have evolved. The dry climate of the Special Areas, with its lack of rainfall, also has had a great influence on the soils of this area in three ways: a high nutrient level has been maintained in the soils due to the lack of weathering and leaching; the salt content of the soil is high due to the movement of groundwater by capillary action (as discussed above); and plant growth has been limited severely due to a lack of available water which has resulted in a relatively low organic matter content.

In the northern part of the Special Areas, around Coronation, the amount of rainfall received is greater than in the southern portions. The soils in the northern part have been formed from the same surficial material as have the soils to the south. However, the capability of the soils near Coronation is much higher. Although the soils are not as fertile as those farther south (due to the increase in leaching as a result of the increased rainfall), crop growth is not limited as much by the lack of water. In addition, the soils of this portion are generally Chernozemic, with much smaller inclusions of Solonetzic soil interspersed throughout. This is due mostly to the decrease in water dispersal by capillary action and an increase in percolation. Percolation generally inhibits movement of salt to the surface of the soil by leaching it downward. Consequently, one major difference between the soils and their distribution near Coronation and those further south would appear to be the climate and the resulting increase in available water.

Finally, the vegetation of this area has had a major effect on the development of the Chernozemic, Solonetzic and Chernozemic-like Regosols which characteristically form under grassland vegetation. The plant residues of the grassland vegetation have influenced the colour of the soils and also the type and amount of nutrients available in those soils. In addition, the growth cycle of the grasses and forbs in this area maintains the organic matter content of these soils year by year. The more lush vegetation found in the northern portions of the Special Areas (due to the increase in precipitation) results in a change from Brown soils to Dark Brown soils.

3.4 Summary

The soils of the Special Areas have been classified into four soil orders: Chernozemic, Solonetzic, Gleysolic and Regosolic. Of those four orders, Chernozemic and Solonetzic soils predominate. The soils of this region have formed as a result of the combined effects of five soil factors which are responsible for the kind, rate and extent of soil development: climate, time, topography, parent material and vegetation. Although the soils in the area are relatively young geologically, the effects of climate, topography and vegetation on soil formation can be seen in addition to the strong influence of the parent material.

The following chapter reviews literature on the effects of cultivation on soils, in general. That information forms the basis upon which the effects of cultivation on the soils in the Special Areas found in this study are analyzed and interpreted.

CHAPTER IV

LITERATURE REVIEW

4.1 Introduction

Tillage practices have changed throughout the years as man's knowledge and understanding of soil and technology has evolved. However, the basic reasons for cultivation have remained relatively the same, to provide a suitable seedbed, to control weeds and to improve nutrient supply (Alberta Agriculture, 1981; McGill, 1982).

All tillage practices change the structure of the soil (Foth, 1978). The traditional and still widely practiced process of tillage is based on a series of primary cultivations (aimed at breaking the soil mass into a loose system of clods of mixed sizes) followed by secondary cultivations (aimed at further pulverization, repacking and smoothing the soil surface) (Alberta Agriculture, 1981; McGill, 1982). The most immediate result of this practice is a disruption in structure and stability through the shearing and breaking of the soil aggregates and the burying of the plant residues (McGill, 1982). Cultivation of a field may have the immediate effect of loosening the soil, and increasing soil aeration and infiltration of water. The long term effects of cultivation, resulting from crushing of soil aggregates, may be a less well-aggregated and more compact soil (Foth, 1978).

Several studies have shown that the disruptive effect of tillage increases as the number of operations, and the speed and distance of the soil movement, increases (Bolton and Aylesworth, 1959; Dew, 1968; Low, 1972; Davies et al., 1973; Skidmore et al., 1975; Soane and Pidgeon, 1975; Millette et al., 1980; Coote and Ramsey, 1983; and Lindstrom and Onstad, 1984). It generally has been found that soils associated with cropping systems requiring infrequent tillage exhibit less deterioration than those under continuous cropping systems.

The effect of cultivation on soil is a worldwide concern. Although we recognize that man has altered the soils he has cultivated, the result of that alteration is not well understood. In the past, soil always has been viewed as a medium for the production of goods, not as an entity in itself. Any conservation methods which were practiced were employed only to ensure the productivity of the soil, not its integrity. Therefore, man's desire to increase soil productivity has not resulted necessarily in a positive impact upon the soil. The methods which have been used to improve productivity have not always improved the quality of the soil, but certainly have altered it.

Only recently, scientists have begun to view soil as an integral part of our ecosystem as opposed to an isolated system (Pawluk, 1971). Viewed from this perspective, they have begun to realize the complexity of the soil system and the role it plays in the well-being of our world. As a result, an appreciation for the importance and significance of an understanding of the effects (both long and short term) of soil disturbance has developed in recent years.

4.2 History of Cultivation

Archaeological evidence has shown that man has been practicing crop husbandry for at least 10,000 years and therefore it is reasonable to assume that tillage of some sort has been practiced since that time (Simonson, 1968). However, our current cultivation practices are only 250 years old. In 1733, Jethro Tull introduced the horse-drawn cultivator, which increased crop yields substantially. His explanation for this increase was that tillage improved soil productivity by breaking down the individual soil particles into smaller fractions which then were taken in directly by the plant and used for food. Thus, Tull believed one obviously would increase the "pasture" of the plant by increasing the total surface of soil particles exposed to the roots (Simonson, 1968).

Subsequent to Tull's work, two schools of thought developed in Europe regarding the benefits of cultivation; one based in Germany and the other in England. The German school regarded tillage as a process to control or obtain a desirable state of soil "tilth"; that is, optimum soil structure for optimum plant growth. The idea that tillage could increase nutrient supply and control weeds was considered to be a secondary effect. The English school regarded tillage as a mechanism for weed control that could account for all the yield differences to be found (Kuipers, 1963 and 1970).

By the late 1800's and early 1900's, scientists and practitioners alike were convinced that tillage was essential, both to produce a seedbed and to destroy weeds. Consequently, there was little incentive for an objective examination of the purpose that cultivation was serving. Not until the European methods of cultivation (plowing and harrowing) were introduced to the more extreme climates of the North American prairies did scientists begin to re-examine tillage principles (Russell, 1978).

Before tillage was introduced to the Canadian prairies, the soils were more or less in a steady state with their environment (Biederbeck et al., 1981). The introduction of arable agriculture disrupted this steady state by hastening the decomposition of soil organic matter and exposing the soil to wind and water erosion. In the early 1900's, large portions of the Canadian prairies and parkland were broken by plow for crop production. Weed control was accomplished by tillage since no herbicides were available. From the early 1900's to the dust bowl years of the 1930's, maximum tillage was practiced. Plowing and harrowing were used to firm up the seedbed and form a dust mulch to conserve moisture (Cameron et al., 1981).

During the 1930's, drastic changes occurred in tillage practices on the prairies in an effort to preserve and protect the soil from the devastating effects of drought and wind erosion. These changes involved improved conservation tillage practices, control of weeds by herbicides, increased use of fertilizers, increased use of summerfallowing, the use of the combine for harvesting (thus allowing more organic residue to be returned to the soil), and the use of larger machinery and tractors, permitting more timely field operations for seed bed preparation and harvesting (Cameron et al., 1981).

A change in attitude developed along with the change in tillage practices. Scientists no longer believed that the old European tillage practices could be applied directly in Western Canada and they began to challenge the old ideas. Intensive research and brainstorming resulted in the development of numerous new concepts and inventions. Many of the new methods were discovered by trial and error; others were discovered out of desperation (Horner, 1959; Johnston, 1977).

Modern soil scientists have continued this trend of questioning and researching the effects of cultivation on the soil in hope of developing tillage techniques which will produce the best possible environment for productive plant growth, while causing the least amount of degradation to the soil. Studies of the effects of tillage on the soil help to determine the problems being faced by today's farmers and assist scientists to determine the direction of their research.

4.3 Approach

Several studies, papers and books, dating from 1925 to 1984, were reviewed as background for this thesis research. The results and conclusions obtained from this information varied depending on the type of soil studied, the length of the study, environmental conditions of the study area, the duration and intensity of the cultivation, the methods used in the study and the purpose for which the study was being conducted. However, a number of conclusions were common to many of the documents which were reviewed; these conclusions are noted and discussed in the following sections of this chapter.

Most of the studies reviewed compared the effects of cultivated soils to those of adjacent virgin or uncultivated soils. The assumption on which comparisons were made was that the virgin soils represented or approximated the conditions of cultivated soil prior to tillage. If this premise is accepted, then the comparisons and results obtained from the research can be considered to be valid representations of the alterations the soil has undergone (Doughty et al., 1954). That was the basis upon which the results of the present study were compared and analyzed.

4.4 Soil Properties

Throughout the information reviewed for this research, a number of soil properties were identified as key factors in soil analysis and in the identification of changes within a soil which have resulted from cultivation. Those factors include organic matter content, bulk density, porosity, aeration, water content, water availability, particle size distribution, pH and salinity, soil aggregation and soil compaction. The following discussion of the literature reviewed for this thesis focuses primarily on these properties and information considered relevant to the research.

4.4.1 Organic Matter Content:

The organic fraction of soil carbon includes mainly plant remains, animal remains and microorganisms in all stages of decomposition. The major components of inorganic carbon are calcite and dolomite. Soluble forms of carbonate carbon occur in highly alkali soils of arid regions, but the amount of carbon in this form is generally small in comparison to the insoluble carbon which is present (Mortensen, 1965:1401-1408).

Many studies have shown that cultivation has a highly disruptive effect on a soil's ability to maintain its organic matter content. Rovira and Greacen (1957) and Ketcheson (1980) attributed the loss of organic matter to the extent of disruption experienced by a soil due to tillage. They believed the greater the disruption of the soil, the greater the exposure of organic matter (previously inaccessible to microbial attack) and its subsequent oxidation. Ridley and Hedlin (1968) suggested that loss of organic matter was due to a number of conditions including: more favorable environment for organisms to decompose organic matter, less plant residue returned to the soil because the land was not covered continuously with vegetation, greater oxidation of the organic matter due to exposure by cultivation, and erosion.

Dormaar (1979) reported a decrease in organic carbon of 42%, 40% and 60% on Chernozemic soils after 16, 20, and 65 years of cultivation, respectively. Cultivation on soils in eastern Quebec caused carbon losses of 30% to 35% of that originally present in virgin soils (Martel and McKenzie, 1980). Voroney et al. (1981) reported a loss of 58% to 64% of the organic matter when comparing a cultivated area to a native grassland soil. The rate of loss was shown to be most rapid during the first 5 to 10 years after breaking.

Campbell and Biederbeck (1981) estimated that a period of 70 to 80 years of cereal cropping resulted in about a 40% to 60% decrease in organic matter content in the top 15 cm. of the soil in southwestern Saskatchewan. Martel and Paul (1974) also reported 40% to 50% losses of organic matter in Saskatchewan soils. In addition, various studies have noted losses of organic matter in the 15-20 cm. layer of a variety of soils (Caldwell et al., 1939; Campbell et al. 1976; McGill et al., 1981).

Alderfer and Merkle (1941), Page and Willard (1946), Bolton and Webber (1952) and Campbell and Biederbeck (1981) all suggested that loss of organic matter is influenced by soil texture. They reported that medium textured soils generally had the highest organic matter content. Losses of organic matter were highest in coarse textured soils because these soils were aerated better, thus causing the organic matter to decompose more readily and erode more easily.

Alderfer and Merkle (1941) reported on the structural stability of native forest soils in Pennsylvania stating that the soil structure deteriorated rapidly when no fibrous-rooted, structure-maintaining crop was included in the rotation. They found that frequent additions of organic matter showed an ability to retain comparable physical conditions to native soil.

Page and Willard (1946) noted that the reduction of roots and organic matter being returned to the soil due to tillage practices was resulting in a reduction of soil organic matter and subsequently a loss of soil structure in Ohio. As the soil structure deteriorated, natural openings in the soil (i.e. pores, cracks, root and earthworm casts) were being filled by fine soil particles. As a result infiltration and drainage problems were occurring. Where liberal amounts of organic matter was returned to the soil, the structure was not affected as adversely.

Dormaar (1983:57-58) provides a cautionary note when calculating organic matter loss due to cultivation, when he states that "Breaking and cultivating prairie soils is considered to be exploitative and allegedly leads to large losses of organic matter . . . Indeed, cultivation increases mineralization of the organic matter per se and makes inaccessible organic matter available to microbial attack. However, cultivation not only compacts the soil it also dilutes the organic matter by mixing the Ah horizon with parts of the Bm horizon".

4.4.2 Bulk Density:

Bulk density expresses the ratio of the mass of dried soil to its total volume (solids and pores together) (Hillel, 1982). It is not an invariant quantity for a given soil but is affected by the structure of the soil (i.e. its looseness or degree of compaction, as well as its swelling and shrinking characteristics, which in turn are dependent upon clay content and wetness). For this reason it is often used as a measure of soil structure (Saini, 1966; Greenland, 1981). Archer and Smith (1972) noted that changes in bulk density affect available water and air capacity, drainage rate, trafficability and penetration by roots.

Cultivated soil usually is denser than native grassland soil (Aina, 1979). Voroney et al. (1981) compared the bulk density of a native grassland to that of a soil cropped in a 2 and 3 year grain-summerfallow rotation since 1910. They reported that the bulk density of the cultivated soil was 16% higher than that of native grassland soil.

Several studies were reviewed which dealt with the effect of tillage on bulk density (Williams and Cook, 1961; Saini, 1966; Ferguson, 1967; Dew, 1968; Archer and Smith, 1972; Black, 1973; Dormaar et al., 1978; Aina, 1979; Black and Siddoway, 1979; Greenland, 1981; Voroney et al., 1981; Hillel, 1982; Mbagwu et al., 1983; Coote and Ramsey, 1983). All of the above studies cited an increase in bulk density due to cultivation. The bulk density of a soil continues to increase with each tillage pass over a field. However, the upper levels of a cultivated soil generally have a comparatively lower bulk density than the lower levels

(Dew, 1968). The addition of organic residues, mulches or manures decreases the bulk density of cultivated fields (Williams and Cook, 1961; Ferguson, 1967; Black, 1973; Black and Siddoway, 1979).

4.4.3 Porosity and Aeration:

Porosity is an index of the relative pore volume in the soil. Coarse textured soils tend to be less porous than fine textured soils, although the mean size of the individual pore is greater in the former than in the latter. In clayey soils, the porosity is highly variable as the soil alternately swells, shrinks, aggregates, disperses, compacts and cracks (Hillel, 1982).

Porosity is related inversely to bulk density (Finney and Knight, 1973). Cultivation tends to increase bulk density; as a result the total pore space in the soil decreases. Coote and Ramsey (1983) and Mbagwu et al. (1983) reported a decrease in total porosity in tilled soils. Both studies suggested that cultivation, which decreases organic matter and causes soil compaction, can be expected to affect the porosity of the soil. Aina (1979) found that the highest total porosity and air-filled pore-space was present in native grassland soil. He attributed this to the rooting pattern of the grass and its ability to improve soil structure. Low (1972) reported a reduction in air-filled pores to 1/3 that of undisturbed soils after 4 years of cultivation.

The size and continuity of individual pore spaces, rather than the total pore space volume, are the most important factors influencing aeration (De Kimpe et al., 1982). Several studies have shown that cultivation can reduce the macropore space by at least one-half that of virgin soils (Page and Willard, 1946; Laws and Evans, 1949; Bolton and Aylesworth, 1959; Webber, 1964; Low, 1972; Bolton et al., 1979; Aina, 1979; Coote and Ramsey, 1983).

Aeration has been defined as the gaseous cycle involving the interchange of carbon-dioxide and oxygen between living organisms, soil and the aerial atmosphere. It varies inversely both with bulk density and soil water content. The diffusion of gases through soil is dependent upon the continuity of air pore space, the quantity of air pore space and tortuosity (defined as the average ratio of the actual roundabout path to the apparent, or straight, flow path, i.e. it is the ratio of the average length of the pore passages to the length of the soil specimen) (Hillel, 1982:100).

Soil aeration can be characterized by measuring the diffusion rate of a gas in the soil or by measuring the air filled pore spaces of the soil. Ayres et al. (1972) suggested that 10-12% by volume of air in soil is the lower limit for optimum growth of most common crops. They also suggested that no diffusion of gases takes place when air-filled pore space is less than 10-15% by volume, due to the discontinuity of the pores.

4.4.4 Water Content and Availability:

Porosity and pore space distribution influence the water storage and water transport characteristics of a soil. Undisturbed grassland soils have larger porosities than cultivated soils, thus they can hold more water at saturation than cultivated soils. Tillage changes the pore size distribution by pulverizing the soil aggregates, allowing them to resettle and pack more tightly thereby reducing the number of large pores. Infiltration and percolation rates are reduced because of the increased number of smaller pores. As a result, cultivated soils generally are subject to more drainage problems than undisturbed soils (Cameron et al, 1981).

Tillage, particularly of soils originally high in organic matter, often results in a reduction of large or macropore spaces. Macropores are classified as the larger pores that allow ready movement of air and percolating water (Brady, 1984). In contrast, micropores can impede air movement and restrict water movement to slow capillary movement.

Goss et al. (1978) found that water content of surface soils is often greater in undisturbed soil than in tilled soil. They suggested that water infiltrates faster in undisturbed soils due to the mulch of plant debris on the soil surface and greater earthworm activity. They also reported that surface stability was greater in undisturbed soils, which reduced the extent to which channels (i.e. pores, earthworm casts, root channels, etc.) became blocked by fine material. This factor also enhanced rapid infiltration of water.

Under drier conditions (higher negative tensions), however, a number of researchers have found that cultivated soils retained more water than virgin soils, due to the larger number of small pores (Dreibelbis and Post, 1943; Shaykewich, 1980; Millette et al., 1980; Coote and Ramsey, 1983). Much of this water, however, is not available to plants due to the strong adhesive and cohesive bonds which form as the soil becomes drier (Foth, 1978).

Cameron et al. (1981) stressed that differences in soil texture and organic matter content must be taken into account when interpreting data related to the effect of cultivation on water holding capacity. However, regression analysis relating available water holding capacity to texture and organic matter could account only for 40% of the variability, suggesting 60% of the variability may be due to the effects of cultivation (Shaykewich, 1980).

4.4.5 Particle Size Distribution:

Soil is composed of mineral particles of different sizes. Based on their size, soil particles are divided into three separates: sand, silt and clay. The combined proportions of these three separates, otherwise known as the particle-size distribution, determine the textural grouping of any given soil. No soil is made up of only one separate (Foth, 1978).

Changes in particle-size distribution resulting from cultivation have been noted by several researchers. Dorman (1980) said that cultivation decreased clay content in the top layer of fine textured soils but increased it in the same layer of coarse textured soils. Aina (1979) noted more sand and less silt in the top 15 cm. of cultivated soils as compared to undisturbed soils. He attributed this increase in coarseness of the cultivated soils partly to the downward eluviation of silt and clay particles resulting from the breakdown of the soil structure. Millette et al. (1980) found that there was a greater quantity of clay-size particles associated with the cultivated soils in their study. Skidmore et al. (1975) noted an increase in the clay and sand and a decrease in the silt content of the Ap horizon of their soil samples. The resulting change in particle size distribution was significant enough to cause an alteration in the soil texture classification. In the study conducted by Alderfer and Merkle (1941), high sand and silt content and low clay content were reported from the Ap horizons of 10 soils which had been cultivated for several years, compared to native forest soils of the same type.

4.4.6 pH and Salinity:

The pH of a given soil is caused by a particular set of chemical conditions. Therefore, a determination of soil pH is considered one of the most important tests that can be made to assist in assessing the condition of a soil. The major effects of soil pH are biological. Some organisms have rather small tolerances to variations in pH, while other organisms tolerate a wide pH range. Studies have shown that the actual concentrations of hydrogen ions and hydroxyl ions are not very important except under extreme circumstances. It is the associated conditions of a certain pH value that are most important, such as the influence of pH on the availability of plant nutrients. The availability of certain elements can increase or decrease depending on the pH of a soil (Foth, 1978).

Most field crops prefer a soil pH between 5.0 and 8.0 (Alberta Agriculture, 1981). The pH of the surface horizons of Chernozemic soils in Alberta ranges from 6.5 to 8.0, which falls within the optimum range (Bowser and Odynsky, 1960). Variations in the changes of pH in soil horizons affected by cultivation have been reported by some researchers. Dormaar et al. (1979) recorded slight increases in the pH in the Ah horizons of cultivated soils while Aina (1979) showed a decrease. Millette et al. (1980) reported a large increase in soil pH in the upper 20 cm. of the soil profile but attributed it to intense liming of the soils in their study area.

In agricultural terms, soils which have excessive concentrations of soluble salts, exchangeable sodium or both, are regarded as problem soils which require special measures and management practices if they are to become productive. A soil generally is considered to be saline if the saturated extract of the soil has a conductivity value of 4 mmhos/cm. However, the decision to use this figure to delimit a saline soil is complicated by the fact that there is no sharp change in the properties of the soil as the degree of saturation passes this value. The salt content of soil depends on several factors, among which are the texture of the soil, the distribution of the salt in the profile, the composition of the salt and the type of plants growing on the soil surface (Richards, 1954).

Soluble salts produce harmful effects upon plants by increasing the degree of saturation of the soil with exchangeable sodium thus repressing the availability of several nutrients needed by plants, such as iron, manganese, zinc and phosphorous (Cairns and Bowser, 1977). In addition, high concentrations of salts may interfere with the absorption of water by plants by developing a higher osmotic pressure in the soil solution than exists in the root cells. This may result in the inability of the plants to absorb needed nutrients thus causing nutritional deficiencies in the plants (Foth, 1978).

The relative tolerance of various plants to the level of salinity of a soil varies greatly, as does the detrimental effect of salt on a plant. McKeague (1981:156) presents a table of plant response to increasing levels of salts in soils. The table shows that above 5.0 mmhos/cm. plants begin to show the effects of an increase in salt content through stunted growth. Above 12.5 mmhos/cm. normal plant growth ceases. In addition, he has calculated the salt content of the soil in parts per million. This calculation is only approximate since salt content of a soil is highly dependent on its texture. For example, a fine textured soil with a conductivity value of 4.0 may only have a 0.2% salt content, where as a coarse soil with 0.2% salt content would have a conductivity value around 12.0.

Richards (1954:9) presents a similar table to that of McKeague, with slightly different divisions. Comparison of the two tables is seen in Table 4.1, below.

TABLE 4.1

PLANT RESPONSE TO CONDUCTIVITY

McKeague Conductivity (mmhos/cm.) and Approx. Salt Content (pts/million)		Plant Response	Richards Conductivity (mmhos/cm.)	Plant Response
			0.0 to 2.0	Salinity effects mostly negligible
2.5	150	Suitable for most plants.		
3.0	210			
3.5	310		2.0 to 4.0	Yields of very sensitive crops may be restricted.
4.0	400			
4.5	500			
5.0	600	May result in a slightly stunted condition in most plants.		
5.5	650			
6.0	750		4.0 to 8.0	Yields of many crops restricted.
6.5	850			
7.0	940			
7.5	1050	Slight to severe burning in most plants.		
8.0	1120			
8.5	1225			
9.0	1300			
9.5	1400			
10.0	1500		8.0 to 16.0	Only tolerant crops yield satisfactorily.
12.5	1950	Excessive salts. Prevents normal growth in most plants.		
15.0	2400			
17.5	2850			
20.0	3300			
25.0	4200		> 16.0	Only a few very tolerant crops yield satisfactorily.
30.0	5100			
40.0	7150			
50.0	9200			
60.0	11200			

4.4.7 Soil Compaction:

The effects of soil compaction occur slowly and are not always noticeable. In the agronomic context, soil is considered to be compacted when the total porosity and the air filled porosity are low enough to restrict aeration; and when the soil is packed so tightly and the pores are so small that root penetration and drainage are impeded (Hillel, 1982).

Soil compaction can result from excessive tillage and wheel tracking in intensive cropping systems, untimely field operations on soils that are drained inadequately and inadequate design of certain farm equipment (i.e. the weight of the vehicle and the amount of slippage which occurs during tillage). Batey and Davis (1972) and Martel and Mackenzie (1980) associate soil compaction with the deterioration of structural properties of soil resulting from the loss of organic matter. Tillage of wet soil is probably the main cause for compaction, due to the low resistance of a soil to deformation at that time (Voorhees, 1977).

Soil resistance to deformation and compaction results from frictional forces which resist the sliding of soil particles and cohesion forces which hold the particles together. The strength of these forces is determined by the properties of the soil material, the extent and condition of the interparticle areas of contact, and the strength of the moisture bonds holding the soil particles together. These factors vary within and between soils (Mirreh and Ketcheson, 1972).

At one time it was assumed that overwinter freezing and thawing would ameliorate any compaction which had occurred during the previous cropping season (Kucera and Promersberger, 1960; Phillips and Kirkham, 1962; Wittsell and Hobbs, 1965). However, Saini (1966) and Voorhees et al. (1978) stated that one year's overwintering does not ameliorate the soil compaction caused by present agricultural practices.

Compaction of a soil can result in changes to many of its physical properties. Adams et al. (1960) found that bulk density increased, air permeability decreased, and air space was reduced from approximately 15% to 9%. Investigations into the effect of compaction and settling on bulk density and water-transmitting capability by De Kimpe et al. (1982) reported a reduction in soil compaction (as observed by the lower bulk densities and the increase in the water-transmitting capability of the study samples) in soils which had higher organic matter contents. De Kimpe et al. concluded that optimum field conditions for trafficability and workability of a soil cannot be based on moisture conditions alone, but also must take into account organic matter content and texture.

Saini and Grant (1980) investigated compactibility due to monoculture and increased size of agricultural machines. They found that the effects of compaction included an increase in bulk density and soil strength while aeration and water movement were reduced. In addition, they found that organic matter content did not seem to affect bulk density; heavy equipment will compact the soil irrespective of its organic matter content. In a study conducted by Gill and Reeves (1956), 90% of the increase in bulk density which occurred as a result of traffic was attributed to the first passage. Davies et al. (1973) reported that 84% could be attributed to the first passage.

4.4.8 Soil Aggregation:

Soil structure is the aggregation of primary soil particles (sand, silt, clay) into compound particles, which are separated from one another by planes of weakness (Day, 1983:76). These compound particles are called aggregates or peds, and are classified into four basic shapes; granular, platy, blocky and prismatic. Aggregates can range in size from <1mm. to >100 mm. (Day, 1983).

Two types of aggregates have been identified by Chepil (1958): primary aggregates or water stable aggregates, and secondary aggregates or clods. Water stable aggregates seldom exceed 5 mm. in diameter and are held together by water-insoluble cements composed of clay particles and inorganic and organic colloids. Water stable aggregates possess a high level of coherence and stability against disruptive forces.

Secondary aggregates, or clods, are less mechanically stable than primary aggregates. They are formed from numerous primary aggregates held together in the dry state by water-dispersible cements resulting from the pressure of depth and time. These clods eventually break down as a result of disruptive forces such as weather, wind erosion and tillage (Chepil, 1958).

The aggregation of a soil is important to the pore space relationships within the soil. The size and arrangement of the aggregates form interaggregate spaces or pores that are much larger than those that exist between the primary sand, silt and clay particles. The movement of air and water is facilitated through these larger pore spaces, which also serve as corridors for root extension. These conditions facilitate the existence of an air-moisture regime that is favorable to plant growth and microbiological activity (Harris et al., 1966).

Cultivation tends to exert a detrimental effect on soil aggregation by disrupting the natural supply of organic matter needed to maintain soil aggregation, increasing the rate of organic matter decomposition and physically disruption the aggregates themselves (Tisdall and Oades, 1982).

In order for aggregates to form, there must be some mechanism by which particles group together into clusters and also some means by which this clustering persists. Harris et al. (1966) identified several factors which they felt control aggregate production: vegetation and its residues, clay content, microorganisms, cultivation practices and climate. However, they also stated that these same factors are responsible for aggregate degradation.

In the literature reviewed, much of the emphasis placed on soil aggregation by plants has centered on the role played by their root systems. The pressure exerted on the soil as the roots extend through it has been associated with both aggregate breakdown and formation. Weaver (1937) stated that the uptake of water by plant roots also affected the formation of aggregates by shrinking and stabilizing the aggregate bonds through dehydration.

Most natural grasses have the ability to regenerate a granular type of soil structure, although the differences in their structure forming ability is highly variable. Comparative studies have shown that grain and root crops are the least effective in maintaining soil aggregation. Heltzer (1934), Johnston et al. (1942) and Gish and Browning (1948) reported that grasses and legumes improved the aggregation of soils as compared to crops that required periodic cultivation. Malik et al. (1965) found that water stable aggregation in grassland soil was significantly higher than in three long-term crops: corn, continuous wheat and alfalfa. In addition, the size of the aggregates in the grassland soil was larger. They attributed the improved stability of the grassland soils to the interlacing and clutching of the particles of soil by the grass roots, resulting in their compression into granules. In addition, they suggested that factors such as periodic disturbance or the type of root system of the vegetation in an area may have more effect on soil aggregation than the presence of organic carbon.

In a study on the effects of grasses and legumes on dry aggregation or cloddiness, Siddoway (1963) reported that although the use of grasses and legumes generally is believed to improve the overall physical condition of the soil, his results indicated that dry aggregation, erodibility by wind and, to a lesser extent, aggregate stability, were affected adversely.

Many soil scientists have stressed the importance of clay as the predominant binding agent in soil aggregation (Martin et al., 1955). Other theories of soil aggregation suggest a variety of binding agents including dehydrated silicates adsorbed on the surface of clay minerals, dehydrated iron and aluminum oxide and hydroxide gels, the presence of soil organic components such as fats, waxes and resins, as well as organic compounds forming bonds with the surfaces of clay particles (Harris et al., 1966). However, Dormaar (1983) suggests that it is not just one specific agent or process which is responsible for soil aggregation at any one time or place, but several occurring simultaneously. He states that diverse organic and inorganic constituents participate in the binding of soil particles.

4.5 Summary

A number of general conclusions are apparent from the literature reviewed for this research. As soil is cultivated the structure is disturbed and the individual aggregates are broken and pulverized. The smaller particles are reoriented, packing more tightly as they settle. The inherent loss of organic matter with continued tillage causes further deterioration of the soil and aggregate stability. These changes affect other soil structural measurements such as particle size distribution, bulk density, porosity, aeration, soil water storage and compaction.

Numerous studies have shown that cultivation of virgin soils tends to break soil aggregates down, compact the soil, increase bulk density and decrease soil porosity. The result often is seen in reduced aeration and infiltration and increased mechanical impedance. Shearing and pulverizing, resulting from cultivation, exposes new surfaces to microbial oxidation causing rapid decomposition of organic matter and loss of soil fertility. Soil compaction can result from excessive tillage, untimely field operations and the forces exerted on the soil by the weight of machinery used for cultivation. The results of compaction are seen in the reduction of aggregation, aeration and permeability and an increase in bulk density and the mechanical strength of the soil.

CHAPTER V

METHODOLOGY

5.1 Introduction

The research process for this study involved test site selection, field testing, laboratory testing and data analysis. The test sites were selected on a reconnaissance trip to the Special Areas during the first two weeks of May, 1984. The data collection was accomplished by both field and laboratory methods. The excavation of the soil pits was completed and the field data were gathered during May and June, 1985. Following that, lab tests were run from July to November, 1985, on samples collected from the study plots. Finally, data synthesis and statistical analysis of the test results were undertaken during the winter of 1985-86.

5.2 Selection of Study Parameters

The selection of the soil properties investigated during this study was based on the information gathered during the review of the literature presented in Chapter IV. A deliberate attempt was made to select properties which frequently were used by other researchers to ensure that a large research base would be available for comparison to the results of this study. Properties also were chosen which appeared to compliment or influence one another and provide additional information from their combination (for example, organic matter content, total porosity and bulk density were chosen due to the relationship that exists between them). In addition, properties which also showed fairly consistent and apparent differences between cultivated and uncultivated soils were also included in the selection criteria.

The field and laboratory methods used in this study were selected from a review of literature on soil research methods, as well as by trial runs of various methods conducted for comparison purposes in the fall of 1984.

5.3 Selection of the Test Sites

The initial phase of the research involved the selection of 15 test sites within the Special Areas. A reconnaissance trip was undertaken with Mr. Arthur Spencer (Range Manager, Consort Region, Special Areas) during the first two weeks in May, 1984, to become familiar with the topography, land use and ownership in the northeast portion of the Special Areas. That particular part of the Special Areas was selected on the recommendation of Mr. Abner Grover, Chairman of the Special Areas Board and Mr. Arthur Spencer. The reasons for their recommendation were two fold. First, the soil in the Consort area is more productive than in the rest of the Special Areas. Second, the type of land use practiced there is more conducive to the proposed study. Much of the land around Consort had been used for ranching since it was homesteaded and therefore, had never been broken or cultivated. As a result, a good mixture of cultivated and uncultivated land existed in this area.

The selection of the test sites involved three tasks. Research was conducted on the land use history of the Consort area through the review of the tax records kept by the Special Areas Board and a government publication which mapped land use in the Special Areas from 1937 to 1940 (Stewart and Porter, 1942). Blocks of land within the Consort area which contained both cultivated and virgin soil were identified. From those blocks, a further selection was made by direct observation of specific sites to ensure that the lands identified as uncultivated in the tax records and government publication had not been broken since the last tax assessment. A sufficient number of sites were found within a 32 km. (20 mile) radius of Consort to satisfy the study criteria.

Final selection of the 15 test sites was made on the basis of topography and accessability. Each site contained fairly homogeneous soil and topography, as well as the two soil states (i.e. cultivated and uncultivated). Approval for locating the plots and conducting the tests on the selected test sites was obtained from the owners and lessors of the land. Two study plots of 5x5 m. were situated in each of the test sites, such that one was located on cultivated land and the other was located on uncultivated land. The two plots were spaced no more than ten meters apart, to maintain homogeneity of the soil between the plots as much as possible.

5.4 Data Collection

5.4.1 Field Methods:

A 1x1 m. soil pit was excavated to a depth of 50 cm. in each of the study plots; one on the virgin land and one on the cultivated land. The soil profiles were examined, measured and recorded according to the CanSIS Manual for Describing Soils in the Field (Day, 1983). The soils were identified to the subgroup level based on field examination and a soil key (Strong and Limbird, 1981).

To distinguish between the information gathered from the cultivated and uncultivated sites, and the two levels of the soil profile which were sampled within each pit, an identification scheme was developed. Each of the 15 test sites was numbered consecutively as it was investigated in the field (e.g. the first test site visited and worked was designated as "1", the second test site visited and worked as "2", and so on). The soil pit on the uncultivated land was always dug first, so it was designated "A". The soil pit on the cultivated land was given the designation "B". The part of the soil profile which this study was concerned with was the top 40 cm. Two levels within this 40 cm. depth were defined, the first between 0-20 cm. and the second between 20-40 cm. This division was chosen because the plow layer in the cultivated pit was usually 20 cm. deep or less. Beneath 20 cm. there was no sign of disturbance in any of the cultivated pits. Following the above explanation, the description "1A(0-20) should be interpreted as: Site 1, uncultivated soil pit, including all soil in the profile from the soil surface (0 cm.) down to 20 cm. below the surface.

Tests were undertaken in the field at each of the soil pits to assist in determining bulk density and compactibility. Each of the tests was conducted twice at each pit to avoid errors and ensure correct results.

Bulk Density. Bulk density is a widely used value. It is needed, for example, for converting water percentage by weight to content by volume, for calculating porosity when the particle density is known and for estimating the weight of a volume of soil too large to weigh conveniently. However, the principle use for the bulk density test is in the documentation of field compaction.

Bulk density is not an invariant property of soil but changes with the structural condition of the soil.

Compaction, in particular affects bulk density. For this reason bulk density often is used as a measure of soil structure. In most agricultural work, it is expressed in grams per cubic centimetre (g/cm^3).

Soil bulk density is the ratio of the mass to the macroscopic volume of the soil particles plus pore space (Blake, 1965). There are several methods that can be used to measure bulk density. The method selected for this study was the Core Method, described by McKeague (1981:30-31). The general procedure for determining in-place soil density is to determine the weight and the volume of an in-place soil sample, from which the density is computed.

To accomplish that, a cylindrical metal sampler is pressed or driven into a smooth, undisturbed vertical soil surface far enough to fill the cylinder but not so far that the soil becomes compressed. The sampler is then carefully removed so that the sample of soil remains intact. The filled cylinder is examined for obvious disturbance to the sample, (i.e. compression, shattering, holes left by roots or stones). If no disturbance is noted, the excess soil is trimmed flush against each end of the cylinder. The sample then is removed carefully from the cylinder and weighed immediately to obtain field water content. (This measurement can later be used to calculate the water content of the soil.)

Finally, the sample is stored carefully in a closed plastic bag and transferred back to the lab. Once there, the sample is oven dried to a consistent weight at 105°C. The bulk density of the soil is calculated by dividing the mass of the soil sample (oven dried weight) by the volume of the sample.

<u>Compaction.</u> The difference in compaction between the cultivated and uncultivated soils was analyzed by two methods. The first method compared the bulk densities of the uncultivated soils and the cultivated soils by calculating their percent difference. That figure was used to represent the increase in the compaction that occurred in the cultivated soil.

The second measure of compactibility was obtained using a penetrometer, according to the method described by Davidson (1965). Penetrometers were designed to give quantitative measures of soil penetration resistance for a more precise correlation with soil physical properties such as tilth, relative density, shear strength, or a better correlation with the rolling resistance or trafficability of wheels or crawler tracks on soil.

Three readings were taken for each of the two levels in both the cultivated and uncultivated soil. The three readings then were averaged to give one value per level. A ratio of the penetrometer reading for the uncultivated soil and the reading from the cultivated soil was used to calculate the percent change between the two readings. That value also was used to represent the increase in compaction that had occurred in the cultivated soil.

A comparison of the two sets of values obtained from the two methods was made to determine if they were consistent with one another.

5.4.2 Laboratory Methods:

Laboratory tests included the measurement of pH, conductivity, organic matter content, particle size analysis, water content, water holding capacity, water availability, particle density, total porosity, dry aggregates and wet aggregates. Two soil samples were collected from each of the soil pits to allow the laboratory testing to be carried out. Within each pit one soil sample was taken between 0 and 20 cm. (measured from the surface and approximating the plow zone) and a second sample was taken between 20 and 40 cm.

pH and Conductivity. The pH of a soil is caused by a particular set of chemical conditions. The determination of soil pH is considered to be one of the fundamental tests in determining the general condition of a soil and in the diagnosis of plant growth problems (Peech, 1965; McLean, 1982). There has been much disagreement among scientists as to the proper ratio of soil to water that should be used in the preparation of the soil solution for pH measurement. The method used in this study was the 1:2 soil to water ratio described by McKeague (1981:155).

The soils in the Special Areas of Alberta tend to contain large amount of salts (Kjearsgaard, 1976). As a result, many farmers in the area are concerned about the effects of cultivation on the translocation of salt from lower horizons of the soil into the solum by capillary movement and evaporation. A conductivity measurement to determine the salinity of the soil was made on both levels of the uncultivated and cultivated soil in each of the individual study plots, according to the methodology for a 1:2 soil/water ratio presented by McKeague (1981:155). The results of those readings were used in determining whether or not an increase in the salinity of the 0-20 cm. level of the cultivated plots had occurred. In addition, the conductivity readings were compared to Table 4.1 in Chapter IV to determine the effect of the salt content in the soil on plant growth.

Organic Matter Content. Organic matter plays an important role in soil development and maintenance. It influences soil structure and tends to promote a desirable physical condition. As has been noted by several soil scientists throughout the world, cultivation tends to quicken the breakdown of organic matter by exposing it to the atmosphere (Alberta Agriculture, 1981).

Organic carbon makes up a large portion of the total carbon of a soil. If carbonates are absent, or removed from a soil sample prior to analysis, the measurement obtained for total carbon may reasonably represent total organic carbon. Carbon is the chief element of soil organic matter that can be measured quantitatively. As a result, estimates of organic matter frequently are based on organic carbon content.

A comparison of the organic matter content between the cultivated and uncultivated soil within each plot was accomplished by measuring the content of each according to the Walkley-Black Method used at the Agriculture Canada Research Station in Lethbridge, Alberta (adapted from C.S. Piper, 1942:223-227). In this method, oxidizable matter in a soil sample is oxidized by $Cr_2O_7^{2-}$, and the reaction is facilitated by the heat generated when 2 volumes of H_2SO_4 are mixed with 1 volume of 1N $K_2Cr_2O_7$ solution. The excess $Cr_2O_7^{2-}$ is determined by titration with standard $FeSO_4$ solution, and the quantity of substances oxidized is calculated from the amount of $Cr_2O_7^{2-}$ reduced.

A number of assumptions are made in this process, three of which are: 1) organic carbon is the only substance present that reduces dicromate, 2) 75% of the organic matter present is oxidized and 3) organic matter is 58% carbon. As a result the organic carbon and percent organic matter calculated from this method are considered to be approximations; however, they are adequate for most uses (McKeague, 1981:116).

Particle Size. The particle size distribution of a soil expresses the proportions of the various sizes of particles which it contains. The proportions commonly are represented by the relative numbers of particles within stated size classes, or by the relative weights of such classes. Determination of a particle size distribution commonly is referred to as a particle size analysis. Particle size analysis is widely used in the classification of soils. It is one of the most stable soil characteristics and is not modified significantly by cultivation or other soil disturbing practices (Day, 1965).

Particle size analysis was conducted for this study by the hydrometer method used at the Agriculture Canada Research Station in Lethbridge Alberta (adapted from Day, 1965:562-566). The theory of the hydrometer method is based upon the fact that differential sedimentation of soil particles in a solution occurs because the particles which make up a specific soil sample have different densities. Consequently, when soil is placed in solution, the suspension density of that solution will change through time as the particles begin to settle out. The resulting buoyant force applied to the hydrometer is used to measure the suspension density, which is needed to determine the particle density of the solution at any given time (Day, 1965). Particle size analysis was used in this study as the basis for determining the texture of soil in each of the study plots.

<u>Water Content.</u> In soil research, water content, traditionally, has been expressed as the ratio of the mass of the water present in a sample to the mass of the sample after it has been dried to a constant weight, or as the volume of water present in a unit volume of the sample. To determine this, the water must be removed and measured, or the mass of the sample must be determined before and after the removal of the water (Gardner, 1965).

The method selected for use in this study is presented by McKeague (1981:42); however, one minor alteration to this method was made. To ensure that the water content of the soil was measured accurately, the samples were weighed as soon as they were removed from the ground. Consequently, any loss of water due to evaporation which occurred while transporting the samples to the laboratory did not affect the results.

Water Holding Capacity and Availability. The capacity of soils to absorb and retain water determines the size of the reservoir from which water may be drawn upon by plants. The water retention properties of soils and the extraction of water from soils by plants have been studied extensively. As a result, various soil-water constants have been defined and used as an index of the range of holding capacities for soils. Of these, the properties defining the range of the amount of water available for plant use have been most widely accepted. The moist end of the range is defined by the field capacity and the dry end, by the wilting point (Peters, 1965).

Field capacity is the amount of water held in the soil after the excess gravitational water has drained away. Wilting point is defined as the percentage of water remaining in the soil when plants growing in that soil are reduced to a wilted condition from which they cannot recover (Peters, 1965).

The available water in a soil is the amount of water that can be used or removed from the soil by plants. It is estimated by determining the difference between the water content of the soil at field capacity and the water content at the permanent wilting point. Water availability can be expressed either as the differences between the water percentages or the percentage values can be converted into centimeters of water, if the bulk density is known (Peters, 1965).

The method used to determine the field capacity of the soils from the study plots was the pressure plate extraction (1/3 bar) described by McKeague (1981:45). The wilting point of the soils was determined by the pressure membrane extraction method (15 bars), also described by McKeague (1981:45). Water availability was calculated by subtracting the percent water at wilting point from the percent water at field capacity for each soil sample.

Comparisons of the water content, field capacities, wilting points and available water were made between the cultivated soils and the uncultivated soils for each of the study plots.

Particle Density. The density of the solid particles of a soil sample is referred to as particle density. This measurement is expressed as the ratio of the total mass of the solid particles to their total volume, excluding the pore spaces between the particles. Particle density is used most when interrelationships of porosity, bulk density and air space are being considered.

The particle density of the soils investigated in this study was determined to facilitate an accurate calculation of the total porosity of the soils from their bulk density values. Particle density is calculated from the mass of the sample and its volume. The mass is determined by weighing the soil sample, and the volume is determined from the mass and density of the water displaced by the sample (Blake, 1965:371-373). The method used to determine particle density was described by McKeague (1981:36-37, adapted from Blake, 1965). This method is very precise if volumes and weights are measured carefully.

Total Porosity. Determination of the pore system of a soil is important in understanding the storage and movement of water and gases within the soil medium. However, this system is complex and difficult to understand because pores differ greatly from one another in shape, tortuosity, continuity, lateral dimension, etc. Despite this complexity descriptions of the pore system tend to be in relatively simple terms. The reason for this simplicity is the principle on which the various methods employed to determine porosity are based, i.e. the bulk volume occupied by a given mass of soil consists of the bulk volume occupied by the solid particles and the remainder occupied by air (Vomocil, 1965:299).

Determining total porosity yields the simplest partial characterization of the soil pore system. The porosity of soil is the fraction of the soil space not occupied by soil particles. The porosity may be calculated from the equation:

$$n=(Dp-Db)/Dp$$

if the bulk density (Db) and the particle density (Dp) is known (Richards, 1954:122).

<u>Aggregate Analysis.</u> An aggregate is defined as a group of two or more primary particles which cohere to each other more strongly than to the surrounding particles (Kemper and Chepil, 1965:499). The disintegration of a soil mass into aggregates results from a disrupting force. Units of soil which form into aggregates upon disruption are those in which the cohesive forces between the particles are greater than the disruptive forces. If measurements of aggregation are to have practical field significance, the forces used to disrupt them in laboratory tests should be similar to the forces experienced in the field.

Methods of aggregate analysis fall into two distinct classes, those which attempt to determine the size distribution of the aggregates actually present in the field and those that attempt to determine the size distribution of the water stable aggregates. Dry aggregate analysis is in the first class (Chepil, 1962).

Dry aggregate analysis is simple and rapid. A soil sample is obtained from the test site by means of a spade being pushed under the body of soil and the soil lifted, attempting to disturb the soil sample as little as possible. The sample is placed in a suitable tray and left to dry. Once the soil has dried the sample is placed in the hopper of the sieve. The sieving is automatic. The various soil fractions are weighed after the soil has gone through the sieve. Sieving of the sample is repeated to obtain some idea of the relative resistance of the soil to breakdown by mechanical forces such as tillage, which is known as mechanical stability. The size distribution and mechanical stability of the aggregates are determined at the same time (Chepil, 1962:4-6).

Wetting of dry aggregates causes considerable disruption which results in the formation of water stable aggregates. The arrangement and size of these water stable clusters is an important aspect of soil structure. Several methods for measuring the water stability of soil aggregates have been proposed, the most common being the wet sieving method proposed by Yoder in 1936 (Richards, 1954). This technique involves wetting a 50 gm. sample of soil and then separating aggregates into various sizes by sieving the sample through a nest of sieves under water.

The major factor affecting the size of the water stable aggregates is the method by which they are wetted. Direct immersion of dry soil in water at atmospheric pressure causes great disruption of the large aggregates. Therefore, it is best to allow the soil to be moistened by capillary rise prior to wet sieving. This is accomplished by putting the soil sample into a small plastic cup with a fine mesh bottom into which a filter paper has been placed.

This cup is then placed in a tray which is filled with about 2-3 cm. of water and the soil sample is left to soak for 3-5 min. (Malik et al., 1965). Once the soil has moistened it can then be transferred to the nest of sieves and the wet sieving process can proceed.

5.5 Data Analysis

Analysis of the results of the field and laboratory tests was conducted in two ways. The first was a descriptive analysis of the differences observed in the test results. That included a comparison of the differences between the results of the uncultivated and cultivated soils within each study plot (presented in Chapter VI) and a comparison of the results between the uncultivated and cultivated soils throughout the study area (which forms the first portion of Chapter VII).

The second method of analysis was done with the use of two statistical analysis techniques. The methods chosen for the analysis were the F-test and the Student's T-test. Both tests determine whether the variance that occurs between two sets of data is statistically significant.

These two tests assume that the samples being compared are drawn from the same normally-distributed population, whose variance is independent of its mean (non-contiguous distribution). Methods associated with the normal distribution found in large data sets (n > 50) cannot be applied directly to small samples. However, the F-test and the Student's T-test are two methods that can be used to compare two small samples whose values have been transformed. (Suitable transformations of the values can be obtained by transforming observed values into their negative binomial or logarithmic equivalents) (Elliott, 1977).

The F-test is used to compare the variance between two samples. This test determines whether the variation which occurs between the two data sets falls within that which would be expected in a normally distributed population. The two variance estimates are tested by the "variance ratio," where the largest of the two variances is divided by the smaller one. The result of the ratio, which is always greater than 1, is compared to F-test tables to determine the level of significance (Wonnacott and Wonnacott, 1969).

The Student's T-test is used to determine the significant difference of the mean and the variance between two samples. This test also determines if the differences in the means and the variances of the two data sets fall within that which could be expected in a normally distributed population. The variation is tested by dividing the difference between the means by the standard error of the difference. The results of those calculations are then compared to the T-test tables to determine the significance. If the Student's T-test is being used to determine the significant difference between only the means of two samples, the F-test usually is run first to avoid misinterpretation of the results of the T-test, since a significant difference between variances will produce a significant value for "t" (Wonnacott and Wonnacott, 1969).

Once completed, the results obtained from the statistical tests were compared to the results of the descriptive analysis. Variations which occurred between the results and inferences of the analytical procedures (i.e. descriptive and statistical) are discussed in Chapter VII.

CHAPTER VI

DATA AND RESULTS

6.1 Introduction

This chapter presents data on the soils of each of the test sites and the results of the field and laboratory tests conducted for this study. The following discussion of the test results is organized into sections according to test site number, beginning with test site 1 and ending with test site 15. The section on each test site is organized further into three main subsections: a general discussion of the nature of the soils in the two soil pits, A and B (uncultivated and cultivated), located at each test site; a discussion of the specific soil characteristics which were investigated; and a table which presents quantitative data on the test site in a concise form. The terms used to describe the various characteristics of the soil are consistent with the definitions provided in the CANSIS Manual for Describing Soils (Day, 1983).

Although the area in which the test sites are located primarily has a hummocky surface expression, the soil pits were located on nearly level surfaces with slopes between .5% and 2%. All of the soil pits were orientated so that the profile wall always was facing directly south. Within each of the 15 test sites the uncultivated land was being used as native pasture and the cultivated land had been worked for at least 50 years, either as part of a rotation cropping system or a continuous cropping system. The cultivated fields selected for test site location had all been worked in the 1985 growing season prior to conducting the field work for this study.

6.2 Test Site Descriptions

6.2.1 Test Site 1:

Test site 1 is located 5.6 km. (3.5 miles) north of Veteran in S.W.5-36-8 W.4M (see Fig. 6.1 for test site locations). The soil profile of pit 1-A meets both the colour and physical criteria for classification as an Eluviated Dark Brown Chernozem (see Appendix A for detailed soil profile descriptions). The texture of the soil in both 1-A(0-20) and 1-A(20-40) is loam. The pH of the top 20 cm. of the profile is approximately the same as for the 20-40 cm. depth; however, the soil in 1-A has a higher salinity in the 0-20 cm. level than in the 20-40 cm. level.

The texture of the soil in 1-B(0-20) is sandy loam. A slight increase in the clay content of the 20-40 cm. level changes the texture to sandy clay loam. The soil in pit 1-B is classified as an Eluviated Dark Brown Chernozem because of the colour and physical characteristics of the profile. The pH of the soil in pit 1-B increases with depth from the 0-20 cm. level to the 20-40 cm. level, but

Fig. 6.1 Location of Test Sites

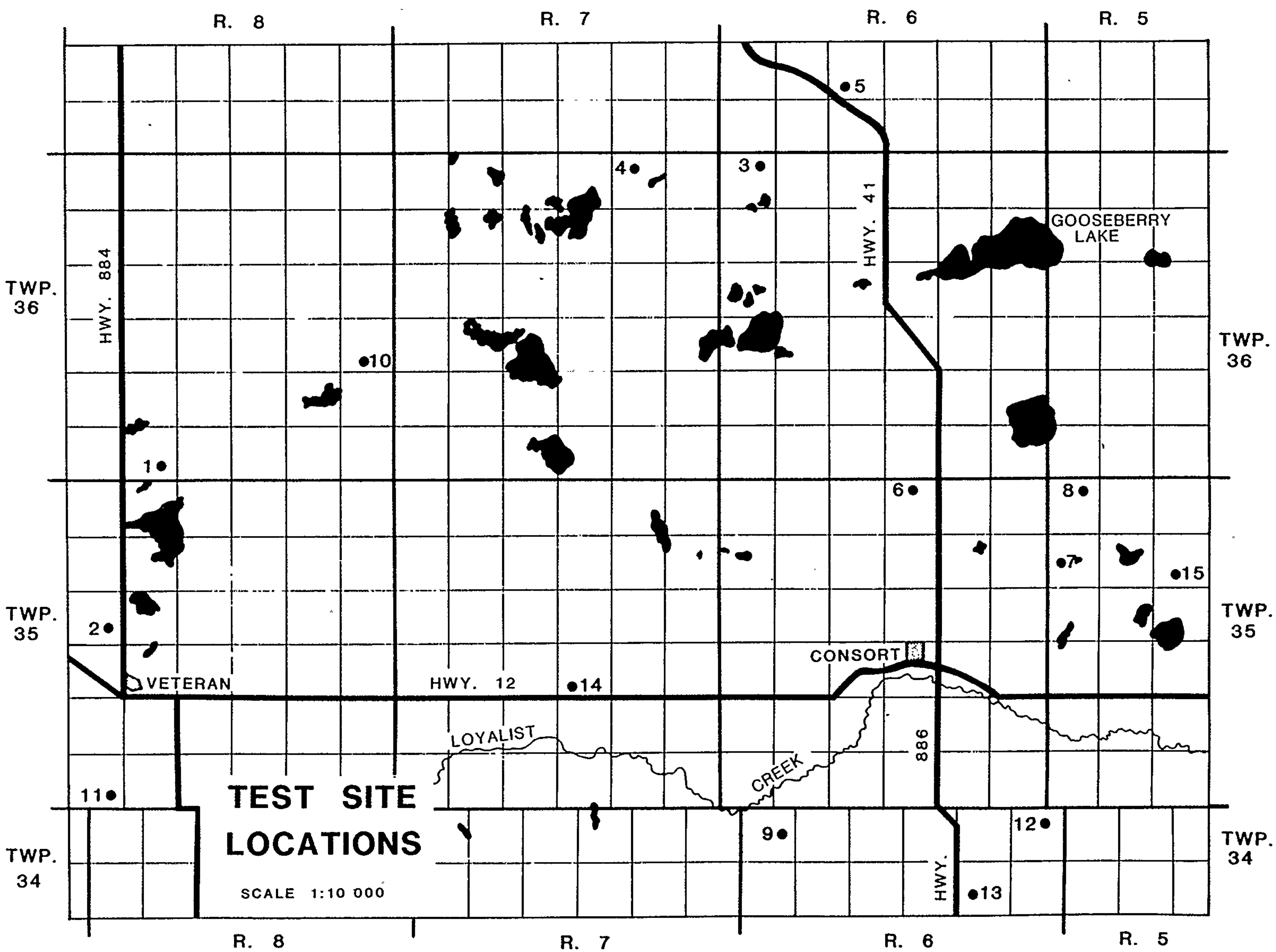


TABLE 6.1

TEST SITE 1 SOIL DATA

	Uncultivated		Cultivated	
	0-20cm.	20-40cm.	0-20cm.	20-40cm.
pH	5.6	5.7	5.9	6.6
Conductivity (mmhos.)	1.40	.55	1.14	.74
% Water Content	10.4	4.7	5.8	4.2
% Available Water	6.1	4.2	3.5	3.8
% Organic Matter Content	2.4	1.8	2.1	1.6
% Total Porosity	52.94	46.13	40.89	37.64
Bulk Density (g/cm.3)	1.28	1.46	1.59	1.64
Texture				
- % sand	46.10	51.27	57.57	63.69
- % silt	36.20	30.02	23.72	14.49
- % clay	17.70	18.71	18.71	21.82
Penetrometer	2.1	2.7	2.2	2.1
Wet Aggregate				
- % total >.10 mm.	71.94	64.58	51.26	63.28
- % >1.0 mm.	53.58	25.62	17.40	27.00
Dry Aggregate				
- % >.85 mm. (1st run)	68.4	68.0	72.9	76.4
- % >.85 mm. (2nd run)	65.4	61.9	70.0	72.3
- % difference	3.0	6.4	2.9	4.1

the salinity decreases.

The water content of the soil at test site 1 is greater in both the 0-20 cm. and 20-40 cm. levels of the uncultivated soil than it is in the cultivated soil. The laboratory tests conducted to determine the available water capacity of the soil (i.e. field capacity - wilting point), show that the uncultivated soil has a greater storage potential for available water in both levels than the cultivated soil (see Appendix B for gm. H20/ gm. soil). Organic matter content and total porosity are higher in both the 0-20 cm. and 20-40 cm. level of the uncultivated soils than in the cultivated soil which contributes to the lower bulk density of the uncultivated soil. The results of the penetrometer readings show the 0-20 cm. level of the uncultivated soil is less resistant to penetration than the cultivated soil but the 20-40 cm. level is slightly more resistant.

The results of the wet sieve analysis indicate that the uncultivated soil has more water stable aggregates in both the 0-20 cm. and the 20-40 cm. levels than the cultivated soil (see Appendix B for corresponding weight in grams). Larger aggregates (>1.0 mm.) are more predominant in the top 20 cm. of the uncultivated soil than in the cultivated soil, but slightly less predominant in the 20-40 cm. level. The results of the dry aggregate analysis show that larger aggregates (>.85 mm.) are less predominant in the uncultivated soil than in the cultivated soil. In addition, the aggregates in the uncultivated soil were slightly less mechanically stable than those in the cultivated soil when the soil was put through the dry sieve the second time (see discussion on mechanical stability, Chapter V, section 5.3.2 Aggregate Analysis).

6.2.2 Test Site 2:

Test site 2 is located 1.6 km. (1 mile) north of Veteran in S.E.19-35-8 W.4M. The physical characteristics and colour of the soil profile of pit 2-A meet the requirements for classification as a Brown Solodized Solonetz. The texture of the soil in 2-A(0-20) is loam. The clay content in pit 2-A increases substantially with depth resulting in a clay loam texture of the soil in the 20-40 cm. level. The pH of the soil increases rapidly with depth from the 0-20 cm. level to the 20-40 cm. level, as does the salinity.

The texture of the soil in 2-B(0-20) is sandy loam. Due to a substantial increase in the clay content of the soil in the 20-40 cm. level, the texture of the soil in 2-B(20-40) changes to a clay. The soil in pit 2-B is classified as a Brown Solodized Solonetz due to the colour and physical characteristics of the profile. The pH of the soil increases rapidly with depth, as does the salinity.

The water content of the soil at test site 2 is lower

TABLE 6.2

TEST SITE 2 SOIL DATA

	Uncultivated		Cultivated	
	0-20cm.	20-40cm.	0-20cm.	20-40cm.
pH	5.7	9.0	5.8	8.7
Conductivity (mmhos.)	.51	6.00	1.41	3.99
% Water Content	2.3	3.5	3.8	6.6
% Available Water	4.1	12.5	3.4	6.9
% Organic Matter Content	2.1	2.0	1.8	1.6
% Total Porosity	45.35	46.47	44.36	44.06
Bulk Density (g/cm.3)	1.47	1.44	1.48	1.46
Texture				
- % sand	49.20	40.92	56.45	36.78
- % silt	33.12	19.67	25.87	20.70
- % clay	17.68	39.41	17.68	42.52
Penetrometer	4.5	2.7	4.5	2.7
Wet Aggregate				
- % total >.10 mm.	72.66	68.86	60.90	48.40
- % >1.0 mm.	31.48	0.76	22.28	31.94
Dry Aggregate				
- % >.85 mm. (1st run)	61.4	88.2	75.1	85.9
- % >.85 mm. (2nd run)	54.0	86.3	66.3	84.8
- % difference	7.4	1.9	8.8	1.1

in both levels of the uncultivated soil than it is in the cultivated soil. The potential for storing available water in the uncultivated soil is higher in both levels than it is in the cultivated soil. Both the organic matter content and total porosity are higher in both levels of the uncultivated soil than in the cultivated soil. The bulk density of the soils in both pits is approximately the same, with the uncultivated soil being only slightly less dense than the cultivated soil. The results of the penetrometer readings were identical for the uncultivated and cultivated soils.

The results of the wet sieve analysis show a greater tendency for water stable aggregation, as well as a predominance of large aggregates (>1.0 mm.) in both levels of the uncultivated soil when compared to the cultivated soil. The dry aggregate analysis results show larger aggregates (>.85 mm.) are less predominant in the top 20 cm. of the uncultivated soil than in the corresponding level of the cultivated soil, but more predominant in the 20-40 cm. level. However, the large aggregates in the 0-20 cm. level of the uncultivated soil tend to be more mechanically stable than those in the cultivated soil. At the 20-40 cm. level, the aggregates in the cultivated soil were more stable than those in the uncultivated soil.

6.2.3 Test Site 3:

Test site 3 is located 14.5 km. (9 miles) north and 4.0 km. (2.5 miles) west of Consort in N.E.31-36-6 W.4M. The soil profile of pit 3-A meets both the colour and physical criteria for classification as a Dark Brown Solodized Solonetz. The texture of the soil in 3-A(0-20) is clay loam, which changes in 3-A(20-40) to heavy clay due to an increase in the clay content of the soil at that level. The pH of the soil remains relatively stable throughout the profile but the salinity increases sharply in the 20-40 cm. level.

The texture of the soil in 3-B(0-20) is clay loam, which changes to clay in 3-B(20-40) due to an increase in the clay content of the soil. The soil in pit 3-B is classified as a Dark Brown Solodized Solonetz because of the colour and physical characteristics of the profile. The pH of the soil increases slightly with depth, whereas the salinity of the soil increases significantly in the 20-40 cm. level.

The water content is lower in both levels of the uncultivated soil at test site 3 than in the cultivated soil; however, the potential for storing available water is higher. Organic matter content and total porosity, are higher in both levels of the uncultivated soil. Bulk density is lower in the 0-20 cm. level of the uncultivated soil than in the cultivated soil, but higher in the

TABLE 6.3

TEST SITE 3 SOIL DATA

	Uncultivated		Cultivated	
	0-20cm.	20-40cm.	0-20cm.	20-40cm.
pH	7.2	7.7	6.6	7.0
Conductivity (mmhos.)	1.20	25.00	.75	6.65
% Water Content	6.6	8.0	7.5	8.3
% Available Water	12.5	9.2	9.9	7.6
% Organic Matter Content	2.8	2.6	1.3	1.0
% Total Porosity	46.04	51.47	45.35	49.62
Bulk Density (g/cm.3)	1.43	1.32	1.47	1.34
Texture				
- % sand	30.57	24.36	42.99	35.75
- % silt	30.02	10.35	22.77	22.77
- % clay	39.41	65.29	34.24	41.48
Penetrometer	3.6	3.0	1.7	2.1
Wet Aggregate				
- % total >.10 mm.	74.70	71.40	86.36	48.06
- % >1.0 mm.	55.14	40.40	17.90	19.24
Dry Aggregate				
- % >.85 mm. (1st run)	85.8	91.9	93.0	85.5
- % >.85 mm. (2nd run)	83.6	90.6	92.2	83.2
- % difference	2.2	1.3	0.8	2.3

20-40 cm.

level. The penetrometer readings for the uncultivated soil are higher than those for the cultivated soil, which indicates more resistance to penetration.

The wet sieve analysis results show a lower percentage of water stable aggregation in the 0-20 cm. level of the uncultivated soil as compared to the same level in the cultivated soil, but a higher degree in the 20-40 cm. level. However, a higher percentage of large aggregates (>1.0 mm.) are predominant in both levels of the uncultivated soil. The results of the dry aggregate analysis indicate that larger aggregates (>.85 mm.) are less predominant in the 0-20 cm. level of the uncultivated soil than in the cultivated soil, but are more predominant in the 20-40 cm. level. In addition, the aggregates in the uncultivated soil are less mechanically stable in the 0-20 cm. level than those in the cultivated soil, but more stable in the 20-40 cm. level.

6.2.4 Test Site 4:

Test site 4 is located 14.5 km. (9 miles) north and 8.0 km. (5 miles) west of Consort. The uncultivated pit is located in N.W.35-36-7 W.4M, and the cultivated pit is located in N.E.34-36-7 W.4M. The profile of pit 4-A meets both the colour and physical requirements for classification as an Orthic Dark Brown Chernozem. The texture of the soil in 4-A(0-20) is sandy clay loam. A

TABLE 6.4

TEST SITE 4 SOIL DATA

	Uncultivated		Cultivated	
	0-20cm.	20-40cm.	0-20cm.	20-40cm.
pH	5.5	6.3	5.2	5.8
Conductivity (mmhos.)	1.74	.63	1.16	.55
% Water Content	1.8	4.2	6.4	3.9
% Available Water	4.6	5.4	3.7	3.5
% Organic Matter Content	4.9	1.4	4.7	1.1
% Total Porosity	53.11	40.81	48.50	39.93
Bulk Density (g/cm.3)	1.28	1.61	1.37	1.64
Texture				
- % sand	61.62	51.27	65.76	57.48
- % silt	21.74	19.67	19.67	18.63
- % clay	16.64	29.06	14.57	23.89
Penetrometer	3.5	2.1	3.6	3.3
Wet Aggregate				
- % total >.10 mm.	71.48	66.80	71.52	43.00
- % >1.0 mm.	30.26	33.72	16.24	14.22
Dry Aggregate				
- % >.85 mm. (1st run)	66.5	80.1	70.3	76.9
- % >.85 mm. (2nd run)	57.1	77.6	59.0	73.7
- % difference	8.4	2.5	11.3	3.2

decrease in the amount of clay in the soil in 4-A(20-40) results in a texture of sandy loam at that level. The pH of the soil profile increases with depth in pit 4-A, but the salinity decreases.

The texture of the soil in 4-B(0-20) and 4-B(20-40) is sandy clay loam. The soil in pit 4-B is classified as an Orthic Dark Brown Chernozem due to the colour and physical characteristics of the profile. The pH of the soil profile is relatively constant throughout the profile with only a slight increase in the 20-40 cm. level. The salinity of the soil in 4-B(0-20) is higher than that of 4-B(20-40).

The water content of the soil at test site 4 is much lower in the 0-20 cm. level of the uncultivated soil than it is in the cultivated soil, but slightly higher in the 20-40 cm. level. The storage potential for available water is higher in both levels of the uncultivated soil than in those of the cultivated soil. The organic matter content and total porosity are slightly higher in both levels of the uncultivated soil, when compared to those of the cultivated soil, which contributes to the lower bulk density of the uncultivated soil. The penetrometer readings show less resistance to penetration in the uncultivated soil than in the cultivated soil.

The wet sieve analysis results show almost identical amounts of water stable aggregates in the 0-20 cm. level of both the uncultivated and cultivated soils, whereas in the

20-40 cm. level, the uncultivated soil shows a higher percentage of water stable aggregates. Each level of the uncultivated soil has a higher percentage of large aggregates (>1.0 mm.) than the cultivated soil. The results of the dry sieve analysis indicate that the uncultivated soil contains fewer large aggregates (>.85 mm.) in the 0-20 cm. level than does the cultivated soil, but more in the 20-40 cm. level. However, the aggregates are more mechanically stable in both levels of the uncultivated soil than they are in the two levels of the cultivated soil.

6.2.5 Test Site 5:

Test site 5 is located 16.1 km. (10 miles) north and 1.6 km. (1 mile) west of Consort in S.W.9-37-6 W.4M. The soil profile of pit 5-A meets both the colour and physical criteria for classification as an Orthic Dark Brown Chernozem. The texture of the soil in 5-A(0-20) is sandy clay loam. The alteration of the texture in 5-A(20-40) to a sandy clay is due to an increase in the clay content of the soil at that level. The pH of the soil increases with depth, while the salinity decreases.

The texture of the soil in 5-B(0-20) and 5-B(20-40) is sandy clay loam. The colour and physical characteristics of the soil profile in pit 5-B meet the criteria for an Orthic Dark Brown Chernozem. The pH of the soil increases

TABLE 6.5

TEST SITE 5 SOIL DATA

	Uncultivated		Cultivated	
	0-20cm.	20-40cm.	0-20cm.	20-40cm.
pH	5.6	6.5	5.4	6.6
Conductivity (mmhos.)	.80	.39	1.40	.50
% Water Content	4.3	4.3	6.7	4.3
% Available Water	6.2	5.0	6.3	4.5
% Organic Matter Content	3.6	1.5	3.2	0.9
% Total Porosity	52.94	49.06	46.13	41.44
Bulk Density (g/cm.3)	1.28	1.35	1.46	1.54
Texture				
- % sand	47.76	45.06	48.17	46.10
- % silt	22.14	19.67	23.80	21.73
- % clay	30.10	35.27	28.03	32.17
Penetrometer	4.2	4.0	2.5	3.0
Wet Aggregate				
- % total >.10 mm.	77.98	72.86	55.04	48.10
- % >1.0 mm.	47.36	41.64	17.88	13.94
Dry Aggregate				
- % >.85 mm. (1st run)	80.2	82.1	85.7	86.5
- % >.85 mm. (2nd run)	76.7	79.5	83.3	81.1
- % difference	3.5	2.6	2.4	5.4

with depth, but the salinity decreases.

The water content of the uncultivated soil at test site 5 is lower in the 0-20 cm. level than in that level of the cultivated soil, but the same in the 20-40 cm. level. The potential for storing available water is also lower in the 0-20 cm. level of the uncultivated soil than in that level of the cultivated soil, but higher in the 20-40 cm. level. The organic matter content and the total porosity are higher in both levels of the uncultivated soil than in those of the cultivated soil contributing to the lower bulk density of the uncultivated soil. The penetrometer readings show more resistance to penetration in the uncultivated soil than in the cultivated soil.

The results of the wet sieve analysis indicate that the uncultivated soil contains more water stable aggregates and a higher percentage of large aggregates (>1.0 mm.) than the uncultivated soil. The dry aggregate analysis results show the uncultivated soil has less large aggregates (>.85 mm.) at both levels than does the cultivated soil. Although the large aggregates in the 0-20 cm. level of the uncultivated soil are less mechanically stable than those in the cultivated soil, the large aggregates are more stable in the 20-40 cm. level of the uncultivated soil.

6.2.6 Test Site 6:

Test site 6 is located 4.0 km. (2.5 miles) north of Consort. The uncultivated pit is located in N.E.34-35-6 W.4M and the cultivated pit is located in N.W.34-35-6 W.4M. The soil profile in pit 6-A meets both the colour and physical criteria for classification as an Orthic Dark Brown Chernozem. The texture of the soil in 6-A(0-20) and 6-A(20-40) is sandy clay loam. The pH of the soil in pit 6-A increases from the 0-20 cm. level to the 20-40 cm. level, as does the salinity.

The texture of the soil in 6-B(0-20) and 6-B(20-40) is sandy clay loam. The soil in pit 6-B is classified as an Orthic Dark Brown Chernozem due to the colour and physical characteristics of the profile. The pH and salinity of the soil increase downwards through the profile.

The water content of the soil at test site 6 is lower in the 0-20 cm. level of the uncultivated soil as compared to that level of the cultivated soil, but slightly higher in the 20-40 cm. level. The potential for storing available water is greater in both the 0-20 cm. and the 20-40 cm. level in the uncultivated soil than in those of the cultivated soil. Organic matter content and total porosity are higher in both levels of the uncultivated soil than in those of the cultivated soil contributing to the lower bulk density of the uncultivated soil. The penetrometer readings show higher readings (more resistance

TABLE 6.6

TEST SITE 6 SOIL DATA

	Uncultivated		Cultivated	
	0-20cm.	20-40cm.	0-20cm.	20-40cm.
pH	7.2	8.4	5.8	8.3
Conductivity (mmhos.)	1.08	1.20	1.08	1.30
% Water Content	3.9	4.5	5.1	4.4
% Available Water	3.6	3.4	3.2	3.1
% Organic Matter Content	4.0	1.6	2.6	1.1
% Total Porosity	50.75	46.44	49.63	45.28
Bulk Density (g/cm.3)	1.22	1.43	1.35	1.45
Texture				
- % sand	59.18	50.90	59.18	51.94
- % silt	18.63	20.70	18.63	23.80
- % clay	22.19	28.40	22.19	24.26
Penetrometer	4.0	3.5	2.3	2.6
Wet Aggregate				
- % total >.10 mm.	87.34	74.78	74.36	77.54
- % >1.0 mm.	46.90	33.62	22.62	31.64
Dry Aggregate				
- % >.85 mm. (1st run)	82.8	80.7	75.8	73.7
- % >.85 mm. (2nd run)	82.6	74.4	57.1	69.9
- % difference	0.2	6.3	18.7	3.8

to penetration) in the uncultivated soil than in the cultivated soil.

The results of the wet sieve analysis show a higher percentage of water stable aggregates in the 0-20 cm. level of the uncultivated soil when compared to the cultivated soil, but a lower percentage in the 20-40 cm. level. However, both levels of the uncultivated soil contain a higher percentage of large aggregates (>1.0 mm.) than do the levels in the cultivated soil. The dry sieve analysis results indicate that both levels of uncultivated soil have more large aggregates (>.85 mm.) than those of the cultivated soil. The aggregates in the 0-20 cm. level of the uncultivated soil are more mechanically stable than in the cultivated soil, but in the 20-40 cm. level they are not.

6.2.7 Test Site 7:

Test site 7 is located 1.6 km. (1 mile) north and 3.2 km. (2 miles) east of Consort. The uncultivated pit is located in S.W.30-35-5 W.4M and the cultivated pit is located in N.W.30-35-5 W.4M. The soil profile of pit 1-A meets both the colour and physical criteria for classification as an Orthic Dark Brown Chernozem. The texture of the soil in 7-A(0-20) is loam. The texture of the soil in 7-A(20-40) is sandy loam. The pH of the soil profile increases slightly with depth, while the salinity

TABLE 6.7

TEST SITE 7 SOIL DATA

	Uncultivated		Cultivated	
	0-20cm.	20-40cm.	0-20cm.	20-40cm.
pH	6.5	6.7	5.7	6.5
Conductivity (mmhos.)	.70	.40	.91	.56
% Water Content	4.7	3.4	6.1	4.8
% Available Water	5.1	3.7	3.2	3.3
% Organic Matter Content	4.2	1.2	2.9	0.9
% Total Porosity	56.65	55.56	47.13	43.41
Bulk Density (g/cm.3)	1.14	1.16	1.38	1.46
Texture				
- % sand	47.80	52.97	51.94	40.55
- % silt	27.94	31.05	20.70	32.09
- % clay	24.26	15.98	27.36	27.36
Penetrometer	4.5	3.0	2.8	3.4
Wet Aggregate				
- % total >.10 mm.	84.36	72.78	64.38	59.50
- % >1.0 mm.	63.10	33.82	17.90	20.80
Dry Aggregate				
- % >.85 mm. (1st run)	74.4	78.1	71.2	79.3
- % >.85 mm. (2nd run)	70.1	74.4	64.5	72.9
- % difference	4.3	3.7	6.7	6.4

decreases slightly.

The texture of the soil in 7-B(0-20) is sandy clay loam, which changes to a loam in 7-B(20-40) due to an increase in the silt content of the soil. The soil in pit 7-B is classified as an Orthic Dark Brown Chernozem due to the colour and physical characteristics of the profile. The pH of the soil increases downwards through the profile, but the salinity decreases.

The water content is lower in both levels of the uncultivated soil than it is in those of the cultivated soil at test site 7, whereas the potential for storing available water is higher. The organic matter content and total porosity are higher in the uncultivated soil than in the cultivated soil contributing to a lower bulk density in the uncultivated soil. The penetrometer reading in the 0-20 cm. level of the uncultivated soil is higher (more resistant to penetration) than that of the cultivated soil; however, the reading in the 20-40 cm. level of the uncultivated soil is lower.

The results of the wet sieve analysis show the uncultivated soil contains a higher percentage of water stable aggregates than the cultivated soil. In addition, the uncultivated soil also contains a higher percentage of large aggregates (>1.0 mm.). The results of the dry aggregate analysis indicate that the 0-20 cm. level of the uncultivated soil contains more large aggregates (>.85 mm.)

than the cultivated soil, but the reverse is true for the 20-40 cm. level. The dry aggregates in the uncultivated soil are more mechanically stable than those in the cultivated soil.

6.2.8 Test Site 8:

Test site 8 is located 4.8 km. (3 miles) north and 4.0 km (2.5 miles) east of Consort in N.E.31-35-5 W.4M. The soil profile of pit 8-A meets both the colour and physical criteria for classification as an Orthic Dark Brown Chernozem. The texture of the soil in 8-A(0-20) and 8-A(20-40) is sandy clay loam. Both the pH and salinity of the soil increase from the 0-20 cm. level to the 20-40 cm. level.

The texture of the soil in 8-B(0-20) and 8-B(20-40) is profile in pit 8-B result in the soil being classified as loam. The colour and physical characteristics of the an Orthic Dark Brown Chernozem. Both the pH and salinity of the soil increase downward through the profile.

The water content of the soil at test site 8 is lower in the 0-20 cm. level of the uncultivated soil than in the cultivated soil, but higher in the 20-40 cm. level. However, the reverse is true for the potential for storing available water. Both the organic matter and total porosity of both levels of the uncultivated soil are higher than the cultivated soil which contribute to the lower bulk

TABLE 6.8

TEST SITE 8 SOIL DATA

	Uncultivated		Cultivated	
	0-20cm.	20-40cm.	0-20cm.	20-40cm.
pH	6.1	7.8	5.5	6.3
Conductivity (mmhos.)	.91	1.15	1.20	.38
% Water Content	3.4	4.5	5.9	3.8
% Available Water	4.6	3.2	1.4	3.8
% Organic Matter Content	3.6	1.5	3.2	1.1
% Total Porosity	50.38	53.46	45.59	49.62
Bulk Density (g/cm.3)	1.32	1.21	1.42	1.33
Texture				
- % sand	48.83	52.97	46.76	50.90
- % silt	22.77	22.77	34.16	30.02
- % clay	28.40	24.26	19.08	19.08
Penetrometer	4.5	4.0	3.4	2.2
Wet Aggregate				
- % total >.10 mm.	86.12	85.48	72.90	70.08
- % >1.0 mm.	53.82	46.34	26.12	17.62
Dry Aggregate				
- % >.85 mm. (1st run)	71.3	70.2	73.6	70.3
- % >.85 mm. (2nd run)	67.2	66.8	70.1	61.7
- % difference	4.1	3.4	3.5	8.6

density of the uncultivated soil. The penetrometer readings show a higher level of resistance to penetration in the uncultivated soil than in the cultivated soil.

The results of the wet sieve analysis indicates the uncultivated soil contains more water stable aggregates than the cultivated soil. In addition, the uncultivated soil contains more large aggregates (>1.0 mm.) than the cultivated soil. The results of the dry aggregate analysis show a slightly lower percentage of large aggregates (>.85 mm.) in the uncultivated soil than in the cultivated soil. The dry aggregates in the 0-20 cm. level of the uncultivated soil are less mechanically stable than the dry aggregates in the cultivated soil, but the reverse is true in the 20-40 cm. levels.

6.2.9 Test Site 9:

Test site 9 is located 5.6 km. (3.5 miles) south and 3.6 km. (2.25 miles) west of Consort. The uncultivated pit is located in N.E.31-34-6 W.4M and the cultivated pit is located in S.E.31-34-6 W.4M. The soil profile of pit 9-A meets both the colour and physical criteria for classification as an Orthic Dark Brown Chernozem. The texture of the soil in 9-A(0-20) is sandy clay loam. The texture of 9-A(20-40) is sandy loam. The pH of the soil decreases with depth in the profile, while the salinity increases.

TABLE 6.9

TEST SITE 9 SOIL DATA

	Uncultivated		Cultivated	
	0-20cm.	20-40cm.	0-20cm.	20-40cm.
pH	5.9	6.4	5.5	7.7
Conductivity (mmhos.)	.31	.37	1.00	1.30
% Water Content	1.9	1.8	3.8	3.2
% Available Water	8.4	0.3	9.5	0.1
% Organic Matter Content	2.9	1.5	2.5	1.0
% Total Porosity	48.87	50.96	47.53	43.82
Bulk Density (g/cm.3)	1.36	1.28	1.38	1.50
Texture				
- % sand	52.97	55.04	57.11	48.83
- % silt	26.91	25.88	27.95	24.84
- % clay	20.12	19.08	14.94	26.33
Penetrometer	4.2	3.5	3.7	3.3
Wet Aggregate				
- % total >.10 mm.	78.22	66.00	43.44	54.20
- % >1.0 mm.	54.06	17.94	9.52	38.56
Dry Aggregate				
- % >.85 mm. (1st run)	68.8	62.0	70.2	86.1
- % >.85 mm. (2nd run)	51.0	55.8	66.2	84.9
- % difference	17.8	6.2	4.0	1.2

The texture of the soil in 9-B(0-20) is sandy loam. An increase in the clay content of the soil in 9-B(20-40) results in a texture of sandy clay loam. Due to the colour and physical characteristics of the profile in pit 9-B the soil is classified as an Eluviated Dark Brown Chernozem. Both the pH and salinity of the soil decrease with depth.

The water content of the soil in test site 9 is lower in both levels of the uncultivated soil than in the cultivated soil. The potential for storing available water is lower in the 0-20 cm. level of the uncultivated soil than in that level of the cultivated soil, but slightly higher in the 20-40 cm. level. Both organic matter content and total porosity are slightly higher in both levels of the uncultivated soil compared to the cultivated soil which contributes to the lower bulk density of the uncultivated soil. The penetrometer readings show the uncultivated soil has a higher resistance to penetration than the cultivated soil.

The results of the wet sieve analysis indicate that the uncultivated soil contains more water stable aggregates in both levels than does the cultivated soil. However, although the 0-20 cm. level of uncultivated soil contains more large aggregates (>1.0 mm.) than does the cultivated soil, the reverse is true for the 20-40 cm. level. The results of the dry aggregate analysis show that the uncultivated soil contains less large aggregates (>.85 mm.)

than does the cultivated soil. In addition, the dry aggregates in the uncultivated soil are less mechanically stable than those in the cultivated soil.

6.2.10 Test Site 10:

Test site 10 is located 8.9 km. (5.5 miles) north and 5.6 km. (3.5 miles) east of Veteran in S.W.13-36-8 W.4M. The soil profile of pit 10-A meets both the colour and physical criteria for classification as an Eluviated Dark Brown Chernozem. The texture of the soil in 10-A(0-20) is sandy loam which alters to a sandy clay loam in 10-A(20-40), due to an increase in the clay content of the soil at that level. Both the pH and the salinity of the soil increase downwards through the profile.

The texture of the soil in 10-B(0-20) is sandy loam. An increase in the clay content of the soil in 10-B(20-40) results in a change of texture to clay loam at that level. The colour and physical characteristics of the soil profile in pit 10-B meet the requirements for classification as an Eluviated Dark Brown Chernozem. The pH of the soil increases from the 0-20 cm. level to the 20-40 cm. level, while the salinity decreases.

The water content of the uncultivated soil at test site 10 is lower in the 0-20 cm. level but slightly higher in the 20-40 cm. level than it is in the cultivated soil. The potential for storing available water is higher in the

TABLE 6.10

TEST SITE 10 SOIL DATA

	Uncultivated		Cultivated	
	0-20cm.	20-40cm.	0-20cm.	20-40cm.
pH	5.7	9.1	5.1	6.9
Conductivity (mmhos.)	.54	1.82	1.30	1.28
% Water Content	3.3	3.9	5.4	3.8
% Available Water	5.9	1.8	3.3	4.0
% Organic Matter Content	4.4	1.2	2.5	0.9
% Total Porosity	53.73	37.55	43.35	35.71
Bulk Density (g/cm.3)	1.24	1.51	1.49	1.71
Texture				
- % sand	57.11	63.32	60.22	35.38
- % silt	26.91	15.52	23.80	31.05
- % clay	15.98	21.16	15.98	33.57
Penetrometer	3.0	3.0	2.2	2.0
Wet Aggregate				
- % total >.10 mm.	80.50	52.02	44.82	9.30
- % >1.0 mm.	39.22	13.74	12.96	41.34
Dry Aggregate				
- % >.85 mm. (1st run)	61.1	87.6	66.5	90.7
- % >.85 mm. (2nd run)	51.8	85.3	56.4	89.2
- % difference	9.3	2.3	10.1	1.5

0-20 cm. level of the uncultivated soil than in the cultivated soil, but lower in the 20-40 cm. level. Both organic matter content and total porosity are higher in both levels of the uncultivated soil compared with the cultivated soil which contributes to the lower bulk density of the uncultivated soil. The penetrometer readings showed the uncultivated soil has more resistance to penetration than does the cultivated soil.

The results of the wet sieve analysis indicate that the uncultivated soil contains more water stable aggregates than does the cultivated soil in the 0-20 cm. level, but less in the 20-40 cm. level. The uncultivated soil also contains more large aggregates (>1.0 mm.) than the cultivated soil in the 0-20 cm. level, but less in the 20-40 cm. level. The results of the dry aggregate analysis show both levels of the uncultivated soil contain less large aggregates (>.85 mm.) than do those of the cultivated soil. In addition, the dry aggregates contained in the 0-20 cm. level of the uncultivated soil are more mechanically stable than those in the cultivated soil, but this is not the case for the 20-40 cm. level.

6.2.11 Test Site 11:

Test site 11 is located 2.4 km. (1.5 miles) south of Veteran in S.E.6-35-8 W.4M. The soil profile of pit 11-A meets both the colour and physical requirements for

TABLE 6.11

TEST SITE 11 SOIL DATA

	Uncultivated		Cultivated	
	0-20cm.	20-40cm.	0-20cm.	20-40cm.
pH	5.8	6.3	5.6	6.5
Conductivity (mmhos.)	.99	.35	1.00	.40
% Water Content	5.2	2.8	3.4	2.0
% Available Water	1.4	3.5	2.3	2.7
% Organic Matter Content	4.3	1.6	3.2	1.0
% Total Porosity	46.21	46.04	43.61	43.02
Bulk Density (g/cm.3)	1.42	1.43	1.59	1.51
Texture				
- % sand	47.51	52.68	51.65	53.72
- % silt	28.98	23.81	24.84	18.63
- % clay	23.51	23.51	23.51	27.65
Penetrometer	3.4	3.1	2.9	2.6
Wet Aggregate				
- % total >.10 mm.	67.28	77.08	45.20	59.56
- % >1.0 mm.	40.62	45.24	9.96	20.94
Dry Aggregate				
- % >.85 mm. (1st run)	78.4	76.2	77.1	80.1
- % >.85 mm. (2nd run)	74.2	72.3	74.0	76.2
- % difference	4.2	3.9	3.1	4.1

classification as an Orthic Dark Brown Chernozem. The texture of the soil in 11-A(0-20) is loam. The texture of the soil in 11-A(20-40) is sandy clay loam. The pH of the soil increases downward through the profile, while the salinity decreases.

The texture of the soil in 11-B(0-20) and 11-B(20-40) is sandy clay loam. The soil in pit 11-B is classified as an Orthic Dark Brown Chernozem due to the colour and physical characteristics of the profile. The pH of the soil increases from the 0-20 cm. level to the 20-40 cm. level, but the salinity decreases.

The water content at test site 11 is greater in both levels of the uncultivated soil than in those of the cultivated soil. The potential for storing available water is lower in the 0-20 cm. level of the uncultivated soil than in that level of the cultivated soil, but higher in the 20-40 cm. level. Both the organic matter and total porosity of the uncultivated soil are higher than that of the cultivated soil contributing to the lower bulk density of the uncultivated soil. The penetrometer readings show the uncultivated soil resists penetration more than the cultivated soil.

The results of the wet sieve analysis show the uncultivated soil contains more water stable aggregates in both levels than the cultivated soil. In addition, both levels of uncultivated soil have a higher percentage of large aggregates (>1.0 mm.). The results of the dry sieve analysis show that the 0-20 cm. level of the uncultivated soil contains a higher percentage of large aggregates (>.85 mm.) than does that level of the cultivated soil, but the reverse is the case in the 20-40 cm. level. The dry aggregates in the 0-20 cm. level of the uncultivated soil are less mechanically stable than those in the cultivated soil, but more stable in the 20-40 cm. level.

6.2.12 Test Site 12:

Test site 12 is located 4.0 km. (2.5 miles) south and 2.8 km. (1.75 miles) east of Consort in N.E.36-34-6 W.4M. The soil profile of pit 12-A meets the colour and physical requirements for classification as an Orthic Dark Brown Chernozem. The texture of the soil in 12-A(0-20) and 12-A(20-40) is loam. The pH of the soil decreases slightly downwards through the profile, while the salinity increases slightly.

The texture of the soil in 12-B(0-20) and 12-B(20-40) is loam. The colour and physical characteristics of the soil profile in pit 12-B meets the requirements for classification as an Orthic Dark Brown Chernozem. The pH of the soil increases with depth in the profile, as the salinity decreases.

The water content of the soil at the 0-20 cm. level of test site 12 is greater in the uncultivated soil than in

TABLE 6.12

TEST SITE 12 SOIL DATA

	Uncultivated		Cultivated	
	0-20cm.	20-40cm.	0-20cm.	20-40cm.
pH	5.8	6.0	5.2	6.2
Conductivity (mmhos.)	.42	.35	.82	.37
% Water Content	5.6	4.5	5.4	4.5
% Available Water	2.5	2.5	4.0	2.5
% Organic Matter Content	4.3	1.3	3.5	1.1
% Total Porosity	47.71	49.62	44.70	39.69
Bulk Density (g/cm.3)	1.37	1.42	1.46	1.58
Texture				
- % sand	51.65	48.54	43.37	38.19
- % silt	30.01	27.95	34.15	38.30
- % clay	18.34	23.51	22.48	23.51
Penetrometer	2.8	1.7	3.2	3.1
Wet Aggregate				
- % total >.10 mm.	78.72	53.32	57.74	49.78
- % >1.0 mm.	31.96	12.88	5.56	5.16
Dry Aggregate				
- % >.85 mm. (1st run)	64.9	76.9	73.6	0.5
- % >.85 mm. (2nd run)	57.8	73.2	70.9	57.6
- % difference	7.1	3.7	2.7	2.9

the cultivated soil, but the same in the 20-40 cm. level. The potential for storing available water is lower in the 0-20 cm. level of the uncultivated soil than it was in the cultivated soil but the same in the 20-40 cm. level. Both the organic matter content and the total porosity of each level are higher in the uncultivated soil than in the cultivated soil which contributes to the lower bulk density of the uncultivated soil. The penetrometer readings show the uncultivated soil is less resistant to penetration than the cultivated soil.

The results of the wet sieve analysis indicate that both levels of the uncultivated soil contain more water stable aggregates than do those of the cultivated soil. In addition, both levels of the uncultivated soil contain a higher percentage of large aggregates (>1.0 mm.). The dry sieve analysis results show the 0-20 cm. level of the uncultivated soil contains more large aggregates (>.85 mm.) than does that of the cultivated soil, but this is not the case for the 20-40 cm. level. In both levels of the uncultivated soil the dry aggregates are less mechanically stable than those in the cultivated soil.

6.2.13 Test Site 13:

Test site 13 is located 7.2 km. (4.5 miles) south and .4 km. (.25 miles) east of Consort. The uncultivated pit is located in S.W.26-34-6 W.4M, and the cultivated pit is

TABLE 6.13

TEST SITE 13 SOIL DATA

	Uncultivated		Cultivated	
	0-20cm.	20-40cm.	0-20cm.	20-40cm.
pH	6.1	6.4	7.0	7.7
Conductivity (mmhos.)	.25	.16	.94	.65
% Water Content	2.1	1.9	1.4	1.5
% Available Water	2.2	1.8	1.2	1.4
% Organic Matter Content	3.5	2.1	1.1	0.8
% Total Porosity	44.91	40.75	42.26	37.50
Bulk Density (g/cm.3)	1.46	1.57	1.53	1.65
Texture				
- % sand	82.70	83.73	86.84	87.87
- % silt	11.38	8.28	5.17	4.14
- % clay	5.92	7.99	7.99	7.99
Penetrometer	4.5	3.1	2.6	1.9
Wet Aggregate				
- % total >.10 mm.	74.72	76.32	91.98	87.03
- % >1.0 mm.	33.42	30.24	37.68	23.08
Dry Aggregate				
- % >.85 mm. (1st run)	46.5	55.2	32.8	36.5
- % >.85 mm. (2nd run)	40.1	43.5	26.7	26.1
- % difference	6.4	11.7	6.4	10.4

located in N.W.26-34-6 W.4M. The soil profile of pit 13-A meets the colour and physical criteria for classification as a Rego Dark Brown Chernozem. The texture of the soil in 13-A(0-20) and 13-A(20-40) is loamy sand. The pH of the soil increases very slightly downward through the profile, as the salinity decreases very slightly.

The texture of the soil in 13-B(0-20) and 13-B(20-40) is loam. The soil in pit 13-B is classified as a Rego Dark Brown Chernozem due to the colour and physical characteristics of the profile. The pH of the soil increases slightly from the 0-20 cm. level to the 20-40 cm. level, but the salinity decreases.

The water content of the uncultivated soil at test site 13 is lower than that of the cultivated soil; however, the potential for storing available water is higher. Both the organic matter content and total porosity are higher in the uncultivated soil than in the cultivated soil contributing to the lower bulk density of the uncultivated soil. The penetrometer readings show the uncultivated soil is more resistant to penetration than the cultivated soil.

The results of the wet sieve analysis show the uncultivated soil contains a lower percentage of water stable aggregates than does the cultivated soil. The uncultivated soil contains less large aggregates (>1.0 mm.) in the 0-20 cm. level than does the cultivated soil, but more in the 20-40 cm. level. The dry sieve analysis results indicate that the uncultivated soil contains more large aggregates (>.85 mm.) than the cultivated soil does. However, the dry aggregates in the uncultivated soil are less mechanically stable than those in the cultivated soil.

6.2.14 Test Site 14:

Test site 14 is located 9.6 km. (6 miles) west of Consort in S.W.15-35-7 W.4M. The soil profile of pit 14-A meets both the colour and physical criteria for classification as an Orthic Dark Brown Chernozem. The texture of the soil in 14-A(0-20) is sandy loam. The texture of the soil in 14-A(20-40) is sandy clay loam. The pH and salinity of the soil increase with depth in the profile.

The texture of the soil in 14-B(0-20) and 14-B(20-40) is sandy loam. The soil in pit 14-B is classified as an Orthic Dark Brown Chernozem because of the colour and physical characteristics of the profile. The pH and salinity of the soil increase downwards through the profile.

The water content and storage potential for available water of the uncultivated soil in the 0-20 cm. at test site 14 are lower than that of the cultivated soil, but higher in the 20-40 cm. level. Both the organic matter content and the total porosity of the uncultivated soil are higher than that of the cultivated soil contributing to the

TABLE 6.14

TEST SITE 14 SOIL DATA

	Uncultivated		Cultivated	
	0-20cm.	20-40cm.	0-20cm.	20-40cm.
pH	6.9	8.3	7.0	8.1
Conductivity (mmhos.)	.65	.96	.87	.89
% Water Content	3.2	4.7	5.0	3.9
% Available Water	3.2	3.4	3.3	3.0
% Organic Matter Content	2.9	1.6	2.8	1.3
% Total Porosity	45.21	46.74	44.23	42.53
Bulk Density (g/cm.3)	1.43	1.49	1.45	1.50
Texture				
- % sand	60.96	57.86	65.10	58.89
- % silt	21.74	19.66	16.55	21.74
- % clay	17.30	22.48	18.34	19.37
Penetrometer	3.1	2.6	2.6	3.0
Wet Aggregate				
- % total >.10 mm.	85.10	82.58	80.60	78.22
- % >1.0 mm.	44.84	47.47	34.26	32.32
Dry Aggregate				
- % >.85 mm. (1st run)	68.4	71.5	62.9	63.8
- % >.85 mm. (2nd run)	64.0	68.3	55.3	59.1
- % difference	4.4	3.2	7.6	4.7

lower bulk density of the uncultivated soil. The penetrometer readings in the 0-20 cm. level show that the uncultivated soil is more resistant to penetration, but the readings in the 20-40 cm. level show that the cultivated soil is more resistant to penetration.

The results of the wet sieve analysis indicate that the uncultivated soil contains more water stable aggregates than the cultivated soil. In addition, larger aggregates (>1.0 mm.) are more predominant in the uncultivated soil. The dry sieve analysis results show the uncultivated soil contains more large aggregates (>.85 mm.) than the cultivated soil. The dry aggregates in the uncultivated soil are also more mechanically stable than those in the cultivated soil.

6.2.15 Test Site 15:

Test site 15 is located 8.0 km. (5 miles) east and 1.6 km. (1 mile) north of Consort. The uncultivated pit is located in S.E.28-35-5 W.4M, and the cultivated pit is located in S.W.28-35-5 W.4M. The soil profile of pit 15-A meets the colour and physical requirements for classification as a Dark Brown Solodized Solonetz. The texture of the soil in 15-A(0-20) is clay loam, which changes to a heavy clay in 15-A(20-40) due to a large increase in the clay content of the soil at that level. Both the pH and salinity of the soil increase with depth

TABLE 6.15

TEST SITE 15 SOIL DATA

	Uncultivated		Cultivated	
	0-20cm.	20-40cm.	0-20cm.	20-40cm.
pH	6.7	8.5	7.5	9.3
Conductivity (mmhos.)	.72	30.00	.94	5.90
% Water Content	12.7	11.0	8.4	5.4
% Available Water	3.3	11.7	6.2	11.7
% Organic Matter Content	2.9	1.1	2.8	1.5
% Total Porosity	40.38	38.11	43.89	40.68
Bulk Density (g/cm.3)	1.55	1.64	1.47	1.56
Texture				
- % sand	26.81	13.35	24.74	18.53
- % silt	38.29	25.88	38.59	28.98
- % clay	34.90	60.77	36.97	52.49
Penetrometer	4.2	2.2	2.2	2.3
Wet Aggregate				
- % total >.10 mm.	64.22	69.72	47.38	51.00
- % >1.0 mm.	49.14	23.20	15.78	27.86
Dry Aggregate				
- % >.85 mm. (1st run)	85.2	92.5	89.2	91.2
- % >.85 mm. (2nd run)	82.5	91.6	87.6	89.8
- % difference	2.7	0.9	1.6	1.4

through the profile.

The texture of the soil in 15-B(0-20) is clay loam which alters to a clay in 15-B(20-40) as a result of an increase in the clay content of the soil at that level. The colour and physical characteristics of the profile in pit 15-B result in the soil being classified as a Dark Brown Solodized Solonetz. Both the pH and salinity of the soil increase with depth through the profile.

The water content of the soil at test site 15 is greater in both levels of the uncultivated soil than in those of the cultivated soil. The potential for storing available water is lower in the 0-20 cm. level of the uncultivated soil than it is in the cultivated soil, but the same in the 20-40 cm. level. Organic matter content is slightly higher in the 0-20 cm. level of the uncultivated soil, but lower in the 20-40 cm. level. Total porosity is lower in the uncultivated soil as compared to the cultivated soil contributing to the higher bulk density in the uncultivated soil. The penetrometer readings show that the uncultivated soil resists penetration more than the cultivated soil in the 0-20 cm. level, but less in the 20-40 cm. level.

The results of the wet sieve analysis show both levels of the uncultivated soil contain more water stable aggregates than do those in the cultivated soil. The 0-20 cm. level of the uncultivated soil has a greater predominance of large aggregates (>1.0 mm.) than that of the cultivated soil, but the reverse is true for the 20-40 cm. level. The dry sieve analysis results indicate that large aggregates (>.85 mm.) are less predominant in the 0-20 cm. level of the uncultivated soil than in that of the cultivated soil, but they are more predominant in the 20-40 cm. level. The aggregates in the 0-20 cm. level of the uncultivated soil are less mechanically stable than those in the cultivated soil, but are more stable in the 20-40 cm. level.

6.3 Summary

A large variation exists in the physical factors being investigated between the cultivated and uncultivated soils at each individual test site. These changes can be attributed, in part, to the disturbance of the soil by cultivation which results in a variety of physical alterations of the soil, as discussed in Chapter IV. Although the alterations which occur in the soil in each of the test sites are significant in themselves, the identification of trends in the changes that occur in all of the cultivated soils also is important. These general trends can help to indicate which of the physical changes evident in the soil structure are the result of cultivation. An analysis of the data presented in this chapter will be conducted in the following chapter to identify such trends and to determine which soil factors may be responsible for the variations in those trends.

CHAPTER VII

ANALYSIS AND DISCUSSION

7.1 Introduction

The effects of cultivation on soil may be determined by examining adjacent cultivated and uncultivated soils of different soil types and identifying recurring differences in various properties within those soils. Although the change in any particular property may not occur to the same extent in each soil, a general trend in the pattern of the alteration should exist if that property is being affected by the process of cultivation. To determine why the alteration of a particular property is occurring and why it is occurring in a particular way, one must return to the factors that are responsible for a soil's formation prior to cultivation and compare that natural condition to the environment which exists after disruption from cultivation.

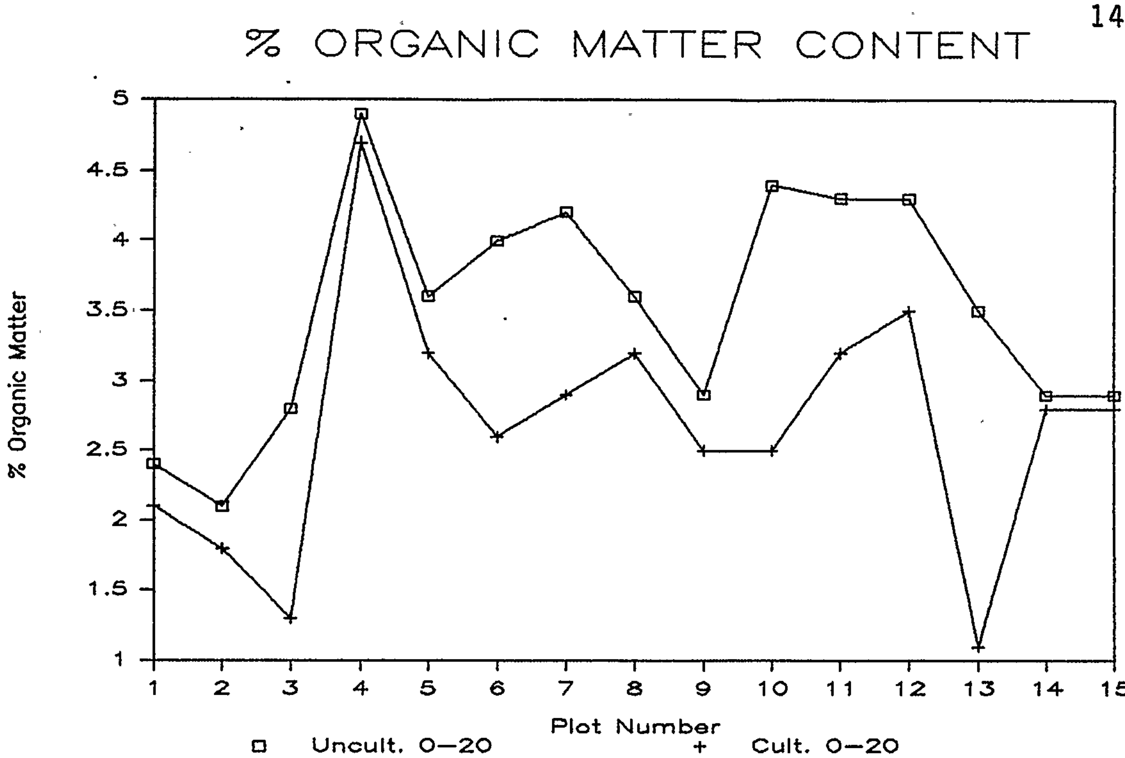
Whenever two groups of samples are compared, it is usually their differences, which are emphasized rather than their absolute values. In this study, two methods were used to analyse the sample data; one was a descriptive trend analysis and the second was a statistical analysis. In the first part of this chapter, the descriptive analysis has been used to discuss the trends in the changes that occurred in the various properties of the soils investigated in this study. Those trends were identified on the basis of visual differences noted from graphs of the numerical results of each soil property in both the 0-20 cm. and 20-40 cm. levels of the uncultivated and cultivated soils. The discussion of the trends identified from the graphs and an explanation of their occurrence were based on the information presented in Chapters III and IV.

In the final section of this chapter, the results obtained from two statistical tests, the F-test and the Student's T-test, are examined. Those two tests where used to determine if statistically significant differences existed between the soil properties investigated in this study for the cultivated soils and the uncultivated soils.

7.2 Discussion

7.2.1 Organic Matter Content:

The results of the Walkley-Black method for determining the organic matter content of a soil showed that the organic matter content of the uncultivated soil generally was higher than that of the cultivated soil (Fig. 7.1). On average, the 0-20 cm. level of the uncultivated soil contained more than twice as much organic matter as the cultivated soil. The 20-40 cm. level of the uncultivated soil contained about 30% more organic matter than did the same level of the cultivated soil. The



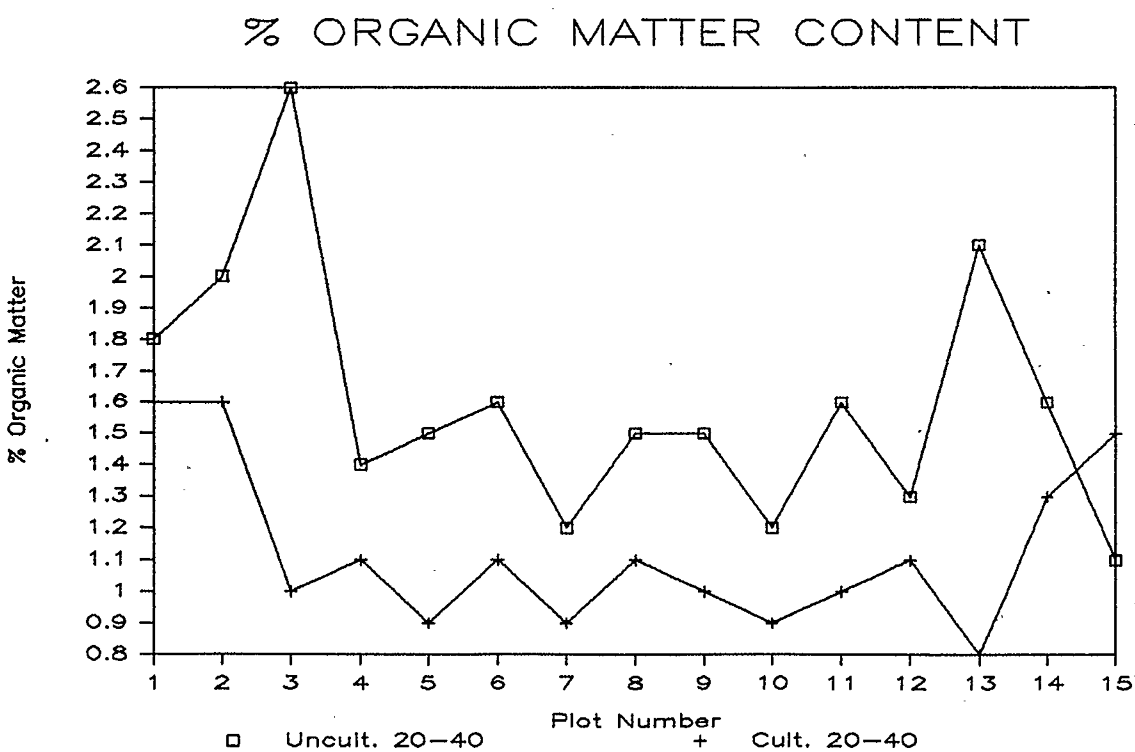


Fig. 7.1 % Organic Matter Content

highest amount of organic matter was found in the 0-20 cm. level of test site 4-A which had a content of 4.9%. The lowest amount (0.8%) was found in the 20-40 cm. level of test site 13-B.

The greatest difference in organic matter content in the 0-20 cm. level of cultivated and uncultivated soil was either seen in soils which contained a large amount of sand or between two soils where the sand content of the cultivated soil was higher. This finding supports Alderfer and Merkle (1941) who found that the loss of organic matter was influenced by the texture of the soil and that coarse textured soils experienced the greatest loss because those soil were aerated better, thus causing the organic matter to decompose more readily.

Part of the difference seen in the organic matter content in the uncultivated soils and the cultivated soils also can be attributed to the mixing of the Ah horizon with parts of the B horizon as the result of cultivation. Dormaar (1983) suggests that the mixing of the B horizon, which contains less organic matter, with the Ah horizon causes a dilution of the organic matter which lowers the content found in the resulting Ap horizon.

As indicated by Figure 7.1, the decrease in organic matter content in the 20-40 cm. level between the uncultivated soil and the cultivated soil was not as great as the decrease found in the 0-20 cm. level. One reason for that finding could be that the organic matter in the 20-40 cm. level was not exposed to the air by cultivation and therefore its decomposition was not hastened as it was in the upper level. No evidence was found to indicate that soil at the 20-40 cm. level had been disturbed physically by cultivation; therefore, any decrease in organic matter must have been due to factors other than those resulting from the direct effects of cultivation. The most likely reason for the decrease in organic matter present in the 20-40 cm. level of the cultivated soil was a decrease in the input of organic material. Natural perennial vegetation supplies soil with a consistent supply of organic matter in the form of decomposing plant remains and continuous and expanding root growth (Harris et al., 1966). However, field crops are present only in an area for a year and the majority of their mass is not returned to the soil due to harvesting. In addition, the root systems of the cultivated crops do not develop the mass or the length that natural grassroots do. As a result, less root matter is present in the soil under crops than under natural vegetation, especially with increasing depth (Foth, 1978:40). This decrease in the amount of plant material returned to the soil in the form of decomposing plant matter and roots results in a lower organic matter content throughout the cultivated soil profile, but is most evident in the lower undisturbed levels where the influence of other factors is reduced.

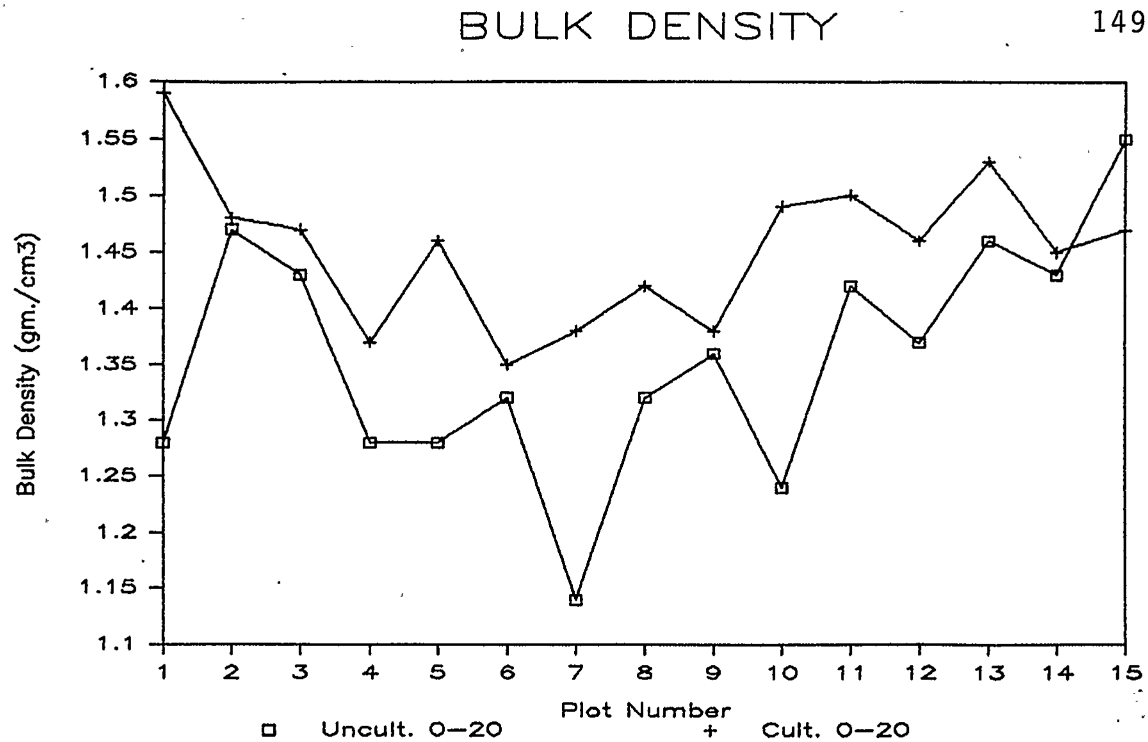
Only one exception was found to the general trend of more organic matter in the uncultivated soil than in the cultivated soil between the 20-40 cm. levels ; soil pits 15-A and 15-B. Both soils in those two pits were classified as Dark Brown Solodized Solonetz; however, the 20-40 cm. level of the uncultivated soil had an extremely high conductivity reading of 30 mmhos. while the conductivity reading of the cultivated soil was only 5.9 mmhos. According to Table 4.1 in Chapter IV, few plants could tolerate the extremely high salt content of the 20-40 cm. level of the uncultivated soil. In comparison, the salt content of the cultivated soil (15-B) might have restricted the growth of some plants but not to as great an extent as it would have in the uncultivated soil (15-A). As a result, more plants would be able to grow in the cultivated soil than in the uncultivated soil, and therefore more roots should have penetrated the 20-40 cm. level of the cultivated soil. The impact of an increase in root matter of the 20-40 cm. level in the cultivated soil would be seen subsequently in an increase in its organic matter.

The effect of cultivation on the upper level of the cultivated soil in pit 15-B also may have affected the amount of organic matter in the 20-40 cm. level of that soil pit. In the uncultivated soil, 15-A, plant growth was inhibited also by its hard, columnar structure which prevented root penetration and development. The effect of cultivation on the soil in pit 15-B was to break up and loosen the upper part of the B-horizon, which would allow plant roots to penetrate it and develop. In addition, water could infiltrate and percolate easier through the disturbed soil and leach away much of the salt. The results of cultivation in pit 15-B would improve the environment for plant growth and subsequently, increase the amount of organic matter present in the soil.

7.2.2 Bulk Density and Compaction:

The results of the bulk density analysis on the soils from the 15 test sites showed that in all cases, except one, bulk density had increased in the cultivated soil, which suggests that the compaction could have been due in part to cultivation (Fig. 7.2). The average increase was slightly higher in the 0-20 cm. level (7%) than it was in the 20-40 cm. level (6%). The range in the increase in bulk density between the uncultivated and cultivated soils in the 0-20 cm. level was from .68% to 24.22%. The range in the 20-40 cm. level was between .67% and 25.86%.

An exception to that general trend was found in test site 15. In both levels of the profile, the cultivated soil had a lower bulk density than did the uncultivated soil. In the 20-40 cm. level of the cultivated soil, that



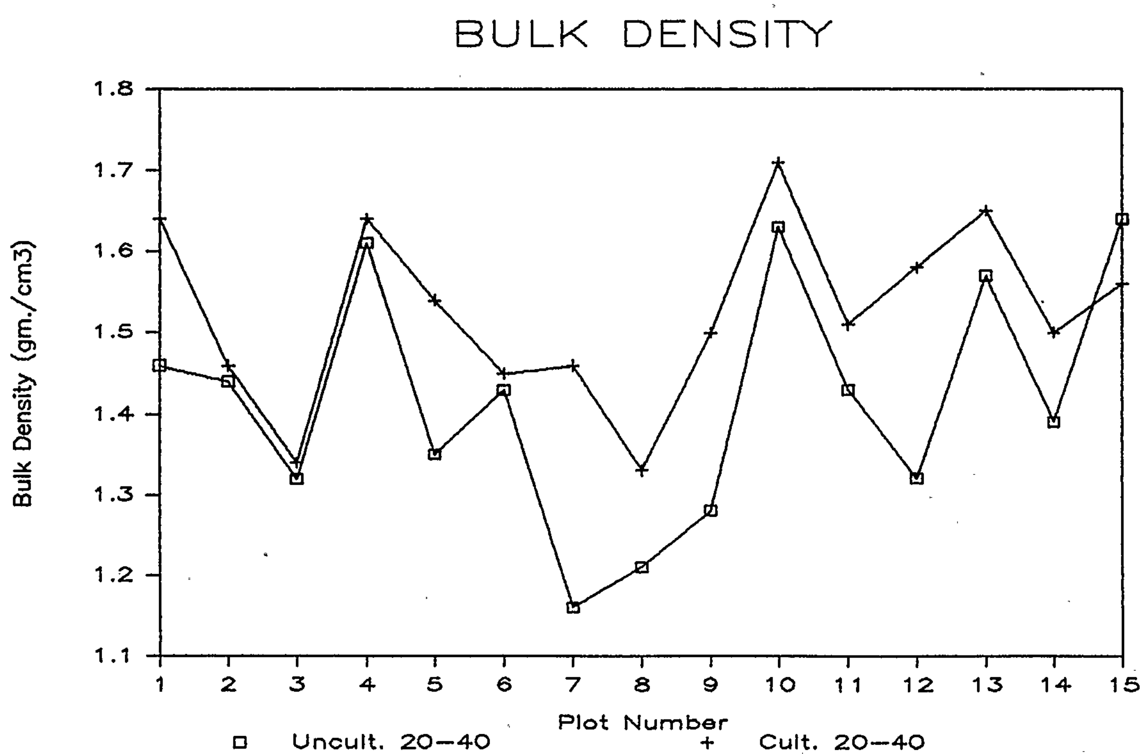


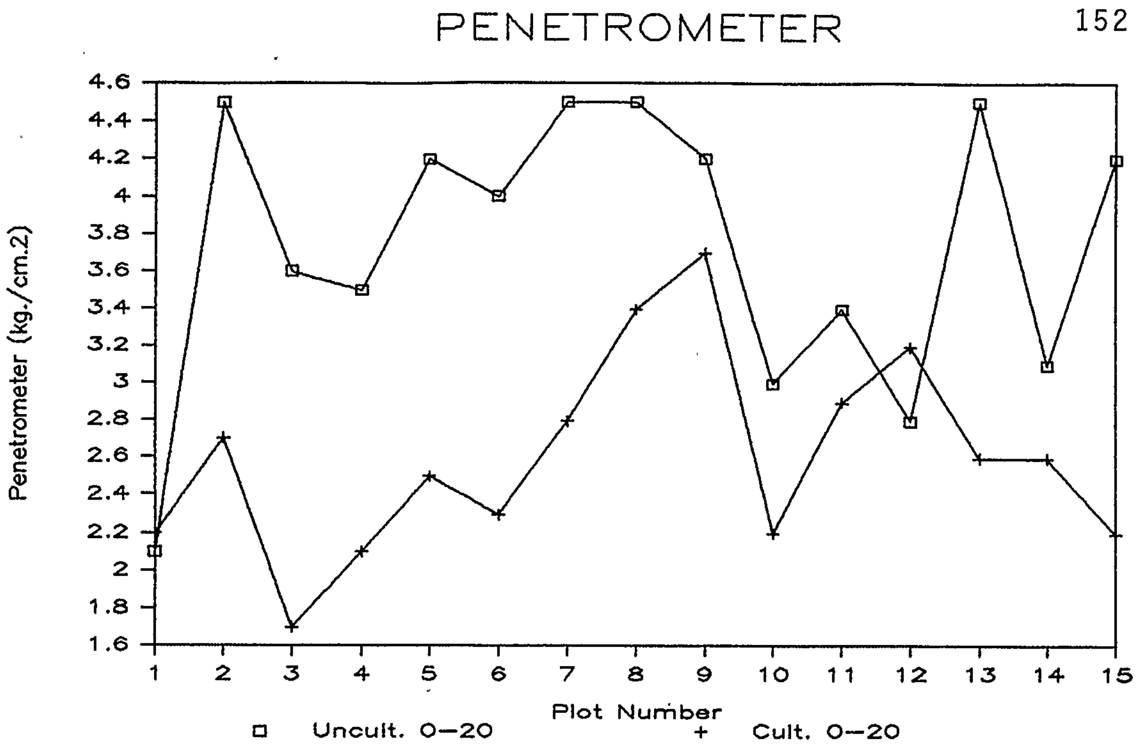
Fig. 7.2 Bulk Density

decrease could be related to the higher organic matter content of that level. However, that was not the case for the 0-20 cm. level, where the organic matter content was slightly lower in the cultivated soil.

Saini (1966) stated that bulk density is related to the structure of a soil; its looseness or degree of compaction, which is in turn, dependent on the clay content and wetness of the soil. The 0-20 cm. level of the soil in test site 15-A contained a large amount of clay and had a higher water content than most of the other soils that were investigated. The soil also had a very hard, columnar B horizon, part of which lay in the 0-20 cm. level of the soil pit. In comparison, the 0-20 cm. level of the soil in test site 15-B had less clay, a lower water content and the upper portion of the B horizon had been broken and loosened by the cultivation, all of which may have contributed to the lower bulk density reading obtained for that soil.

As was noted in Chapter V, an increase in the organic matter content of a soil generally results in a decrease in the bulk density of the soil. That was also the trend found in the results of this investigation. In the majority of cases, where the organic matter content was higher in the uncultivated soil than in the cultivated soil, the bulk density of the uncultivated soil was lower. However, it was not a relative relationship where a large difference in the organic matter content between a cultivated and an uncultivated soil resulted in a large difference in the two respective bulk density readings. Instead, it appeared that the bulk density of each soil was influenced by the individual combinations of clay content, water content and organic matter content (as well as other factors not investigated in this study). As a result, no patterns were found (such as an increase in the clay content) which would explain the specific changes in bulk density between an uncultivated soil and the corresponding cultivated soil in any one test site.

The results of the penetrometer readings did not support the findings of the bulk density analysis (Fig. 7.3). The penetrometer readings were taken to provide a quantitative measure of soil penetration resistance which theoretically should have correlated with the compaction of the soil. The results of that method showed a general trend towards the uncultivated soil being more resistant to penetration than the cultivated soil. This would mean that the uncultivated soil showed signs of being more compacted than the cultivated soil. However, the penetrometer readings likely were not a good expression of the compaction of the soil in the test sites for two main reasons. First, all the water contents of the uncultivated and cultivated soils in the test sites were different. Since soil is more susceptible to deformation when it is moist, it would follow that moist soil would be



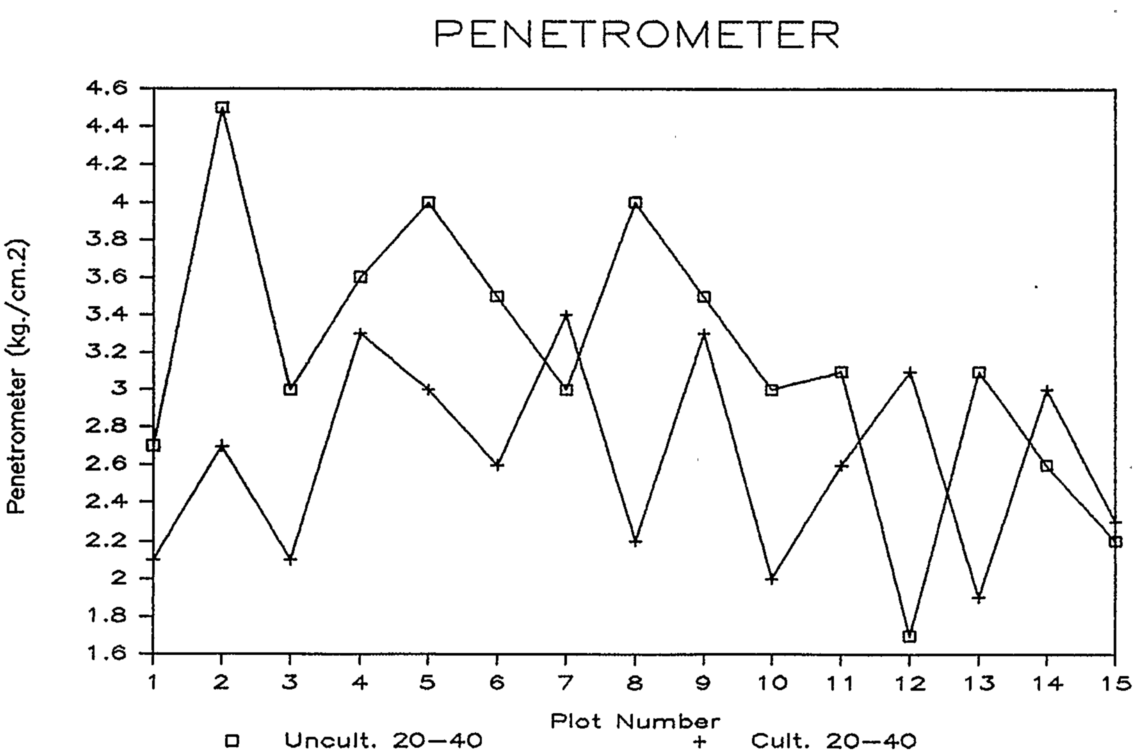


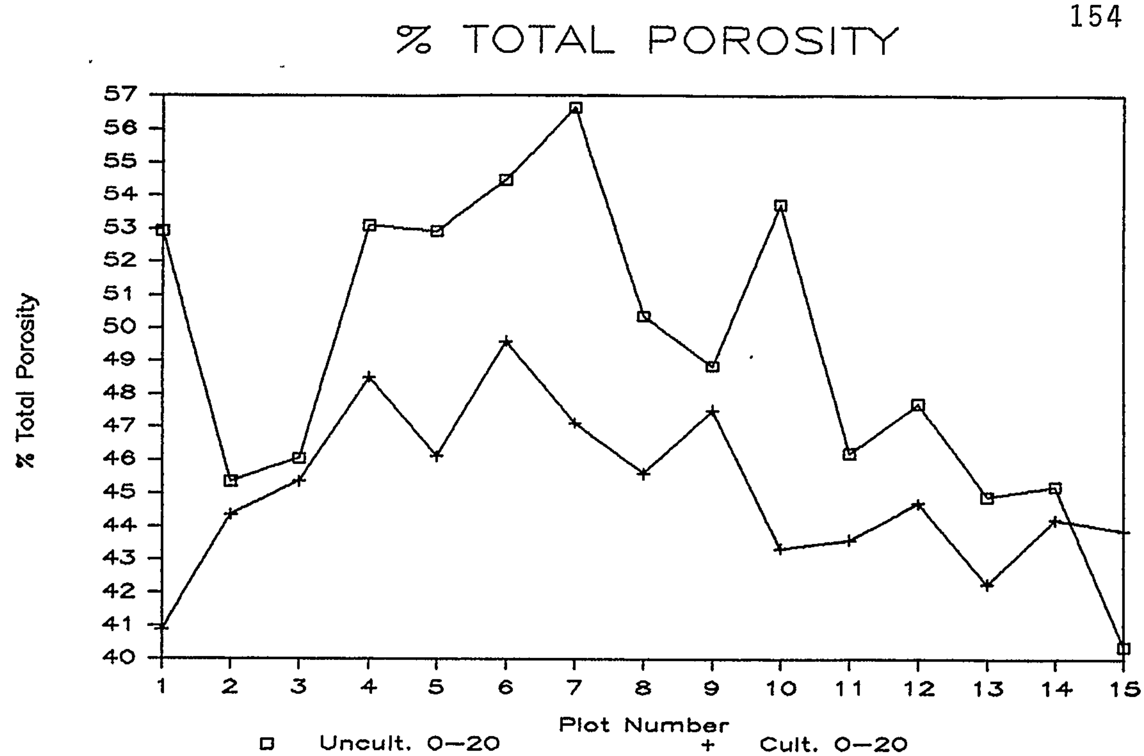
Fig. 7.3 Penetrometer

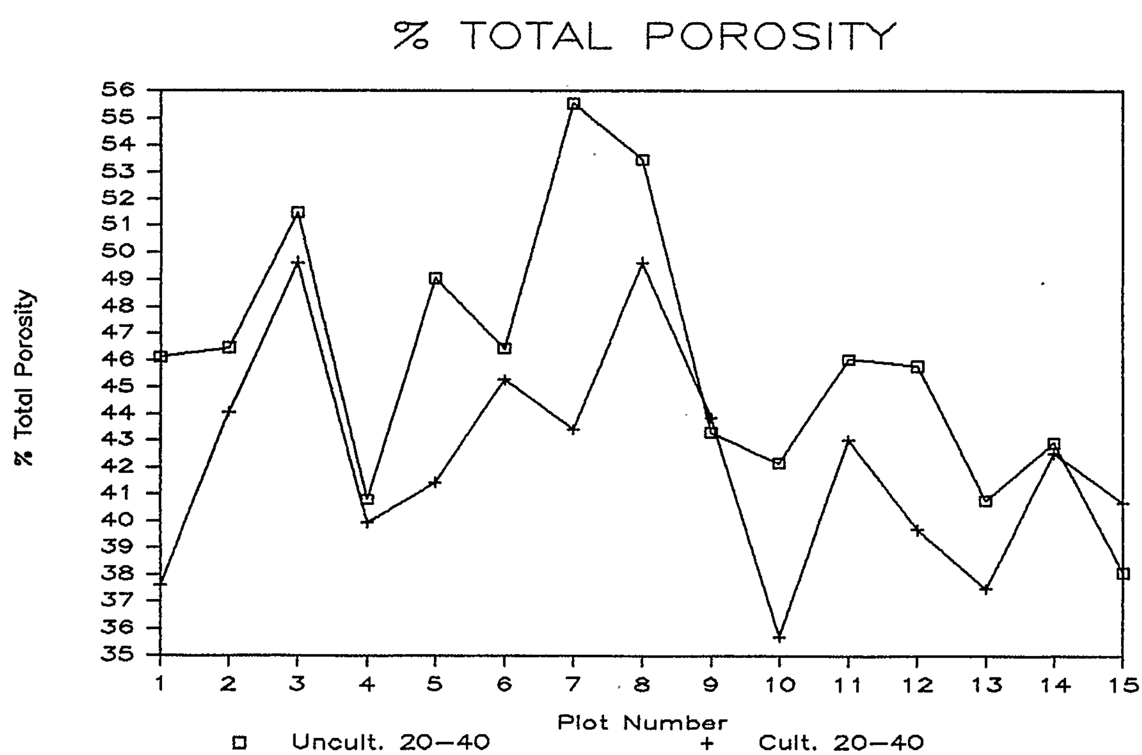
easier to penetrate than dry soil. In many of the test sites the cultivated soil had a higher water content than did the uncultivated soil which likely would have resulted in inconsistent readings between the two soils. Secondly, cultivation would disrupt the chemical and organic bonding agents in the soil, thus loosening its structure and making penetration easier. As a result of these two factors the penetration results have not been considered valid and therefore have not been used in determining the degree of compaction of the soil.

7.2.3 Total Porosity:

The results of the total porosity analysis showed that the total porosity of the soil in the test sites was related inversely to bulk density (Fig. 7.4). As cultivation tended to increase the bulk density of the soils by decreasing the organic matter content and causing soil compaction, it tended to decrease the total porosity of the soil. Conversely, the total porosity of the individual soils reflected their organic matter content and tended to be higher in the uncultivated soils than in the cultivated soils. The total porosity also tended to be higher in the coarser textured soils than in the finer textured soils, a finding which supports Hillel (1982).

Test site 15 provided the single exception to the general trend of higher total porosity in the uncultivated





7.4 % Total Porosity

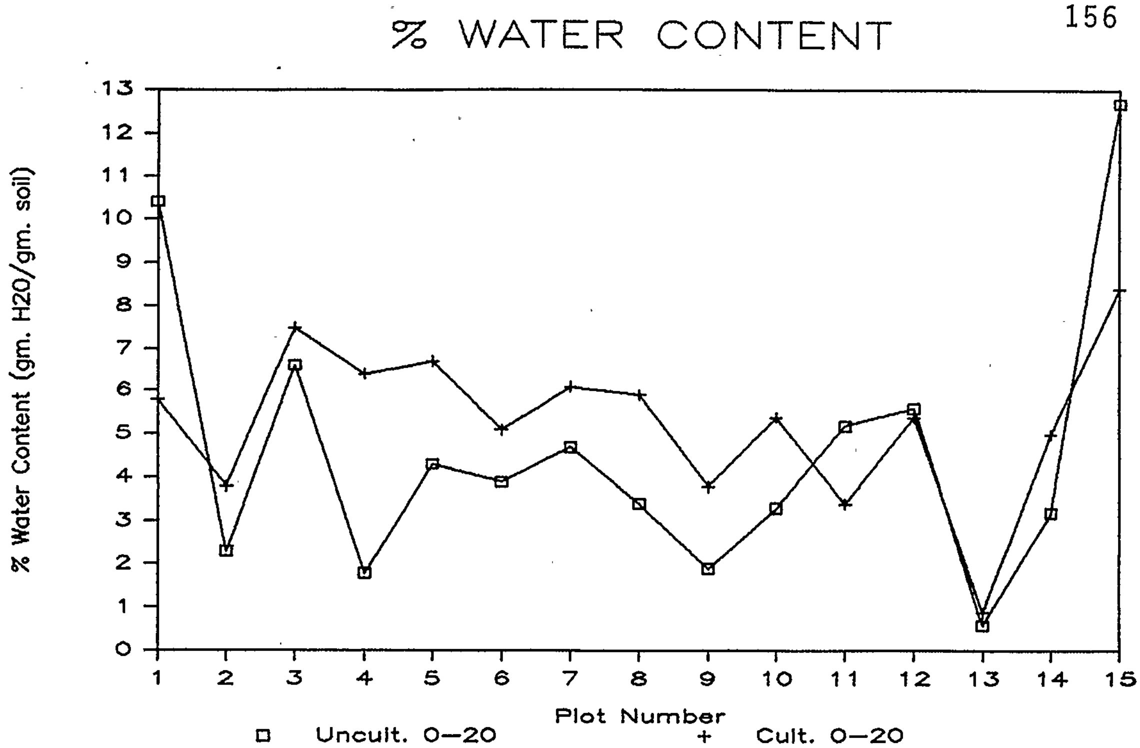
soils. That was expected since total porosity is the inverse of bulk density and bulk density was higher in the uncultivated soil than in the cultivated soil at that test site.

A reduction in the total porosity of a soil affects soil aeration characteristics. Ayres et al. (1972) suggested that an air-filled pore space of less than 10-15% by volume was the lower limit for optimum plant growth. However, all of the soils in the test sites are well above this minimum and therefore, air and water movement would not be expected to debilitate plant growth.

7.2.4 Water Content and Availability:

There was a large variation in the water content of the soils in the test sites; however, the general trend in the 0-20 cm. level of the soil was for the cultivated soil to have a higher water content than the uncultivated soil (Fig. 7.5). In the 20-40 cm. level of the soil, the trend was not as clear, as 8 of the 15 test sites showed the uncultivated soil as having a higher water content than the cultivated soil (Fig. 7.5).

Brady (1984) suggested that tillage breaks down the macropores in the soil, which subsequently inhibits the movement of water and air through a soil. Evidence of that was found in this study in the increase in potential storage capability for available water in the 0-20 cm.



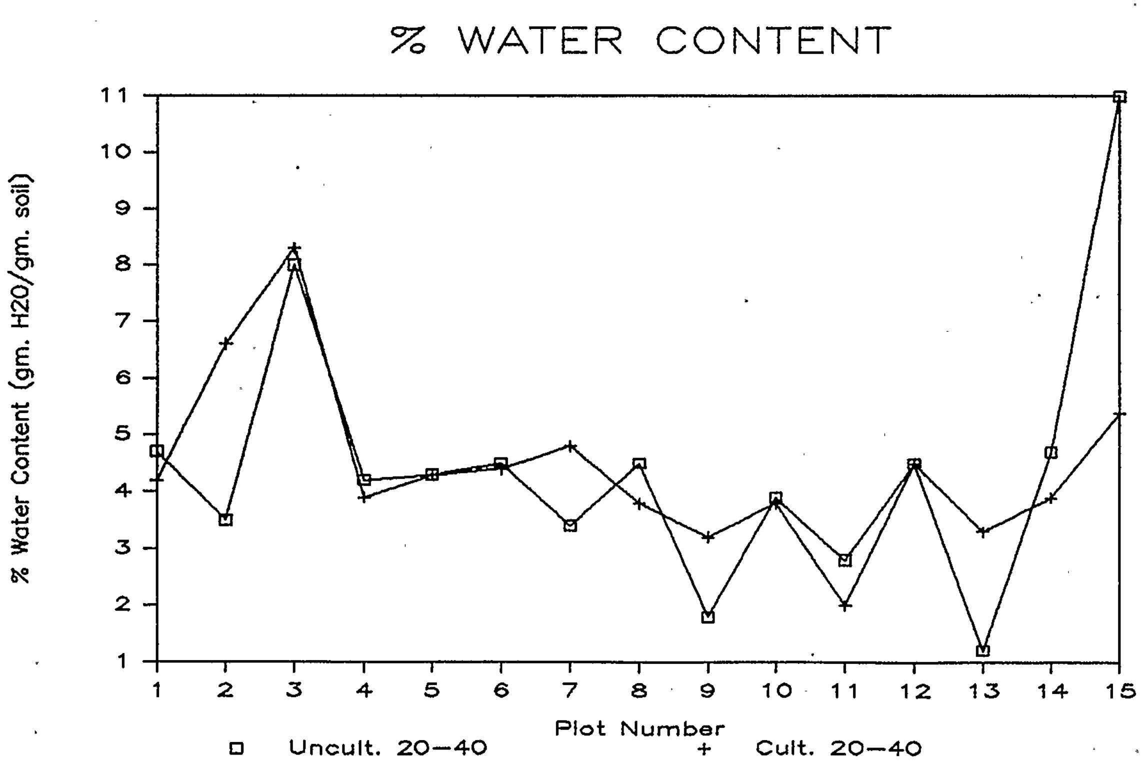
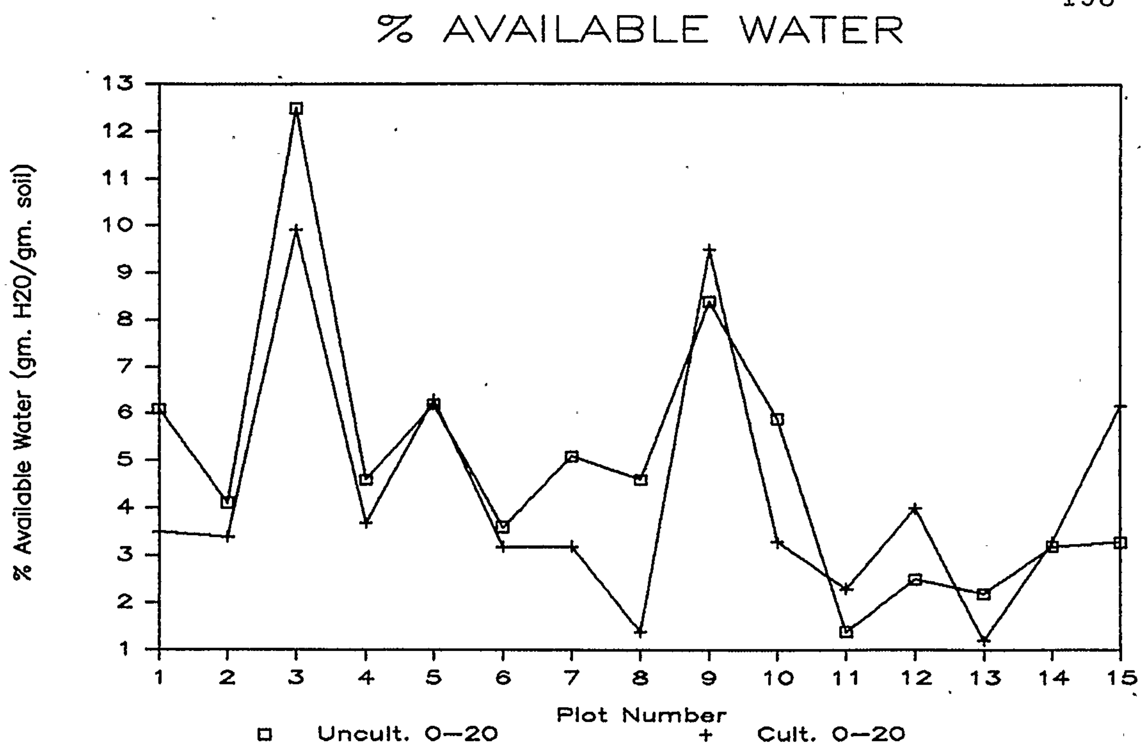


Fig. 7.5 % Water Content

level of the uncultivated soil as compared to that of the same level of the cultivated soil (Fig. 7.6). That increase was attributed to the presence of larger pore spaces and the higher total porosity of the uncultivated soil. Conversely, the ability of the cultivated soils to retain more moisture in the field may be due to an abundance of small pore spaces. As noted in Chapter IV, a number of researchers have found that under dry conditions (higher negative tensions), cultivated soil tends to retain more water because of the formation of strong cohesive and adhesive bonds in the small pores of the cultivated soils as the soils dry out. However, due to the strength of these bonds much of the water retained is not available to plants. Both of the above pieces of evidence tend to support Brady's suggestion that cultivation disrupts the macropores present in the soil which in turn affects the water and air regimes of the soil.

The lowest reading for water content (0.6% water by volume) occurred at test site 13 in the soil which had the highest sand content of all the soils investigated in this study. The large percentage of sand would result in the formation of large intergranular pores throughout the soil which would allow rapid percolation of water and low water retention. The highest water content was recorded at test site 15, which contained 12.7% water by volume. That soil had a very high clay content which would tend to inhibit



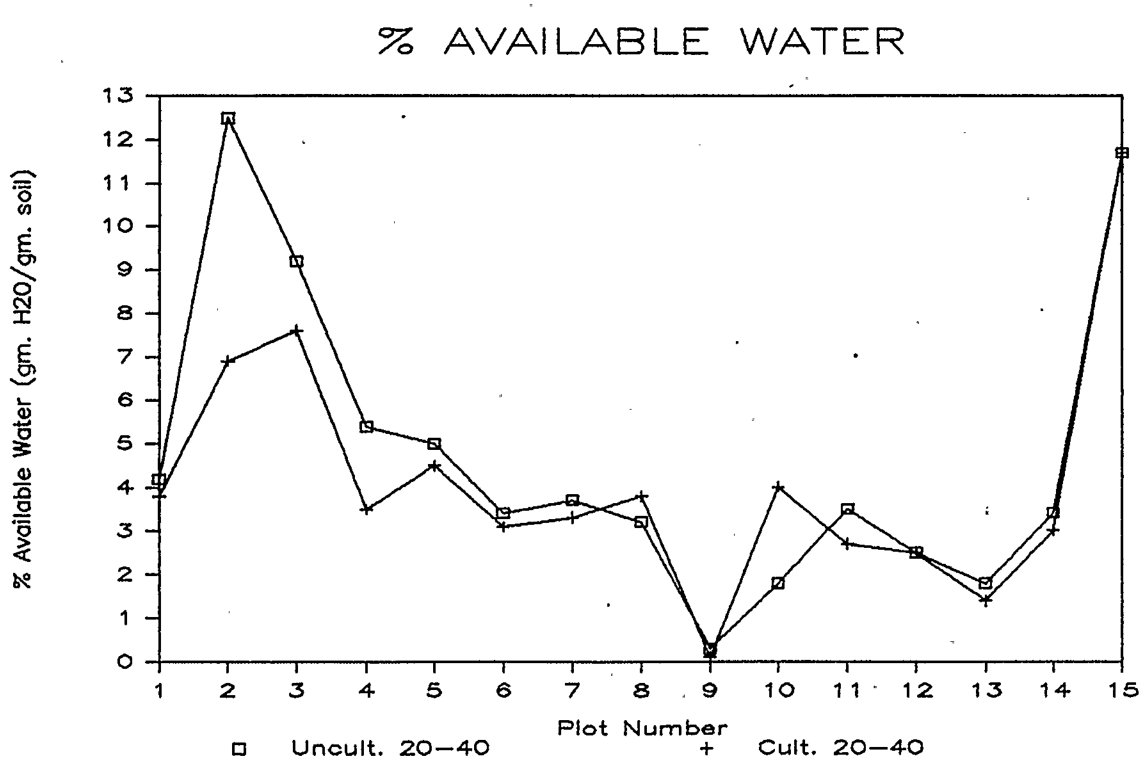
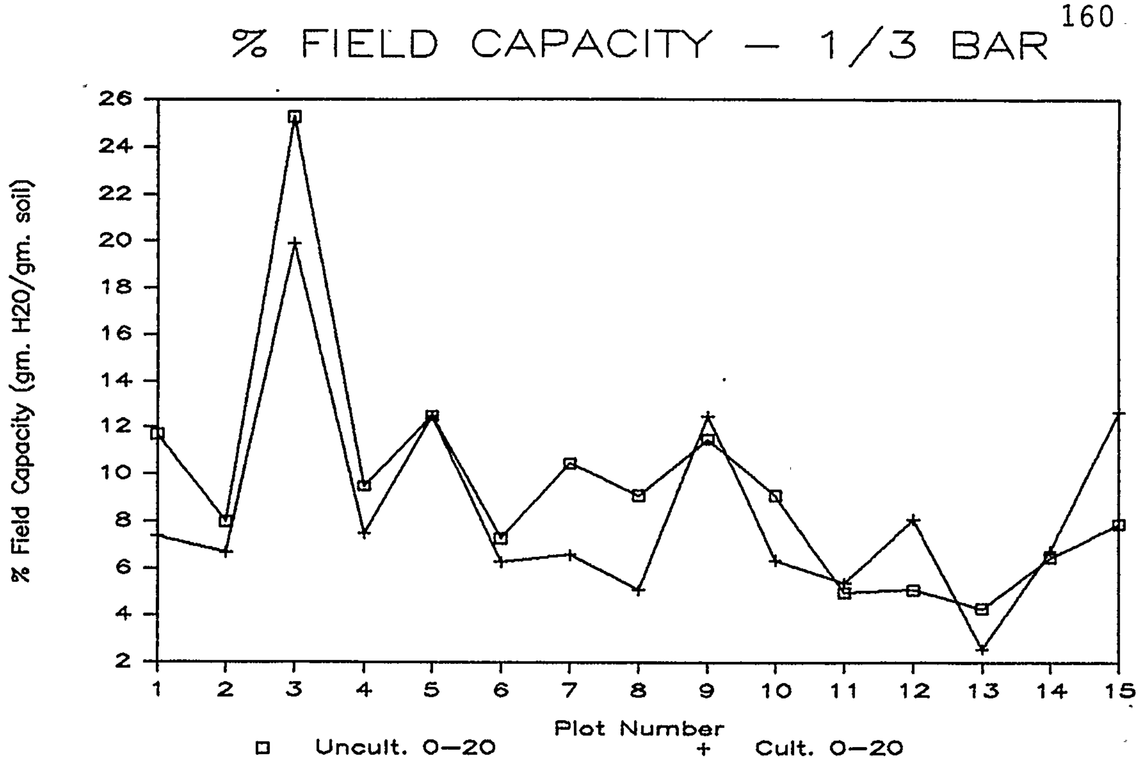


Fig 7.6 % Available Water

gravitational movement of water, retaining it in the upper portion of the soil for a longer period of time than would a soil with a lower clay content.

Except in the two cases described above, no single factor seemed to control the amount of water contained in any one soil. Cameron et al. (1981) stressed the importance of organic matter and soil texture in determining water content, but Shaykewich (1980) found that they only accounted for 40% of the variability. In the present study on the soils in the Special Areas, it appears that a number of interrelating factors affected the water content of the soils.

When comparing the actual water content of the soils to the laboratory results obtained for available water (Fig. 7.6), field capacity (Fig. 7.7) and wilting point, (Fig. 7.8) the information does not correspond well. Many of the readings for water content are below those of the wilting point yet the plants on those test sites were not wilted. This problem was discussed by Harris (1974) when he found a similar situation occurring in the Front Range of the Rocky Mountains. He suggested that the 15 bar wilting point was not a good reference point to use in areas where the plants are adapted to dry land conditions because they are capable of surviving at a lower water content than that represented by the wilting point of the soil.



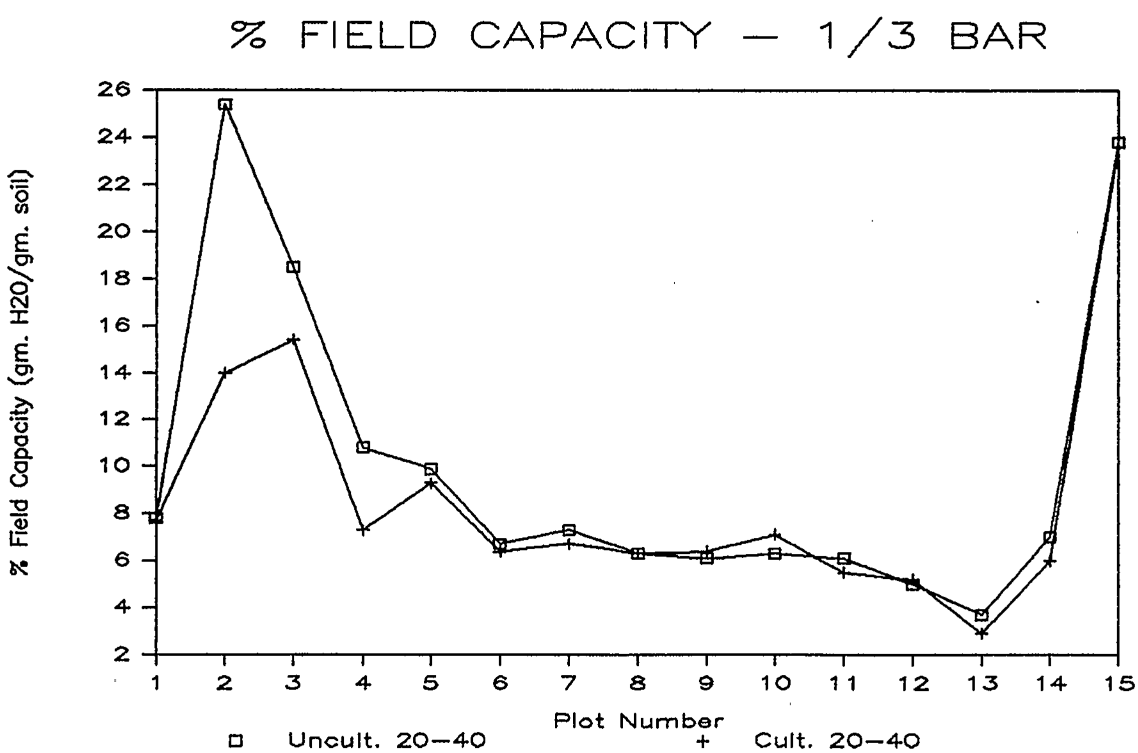


Fig. 7.7 % Field Capacity - 1/3 Bar

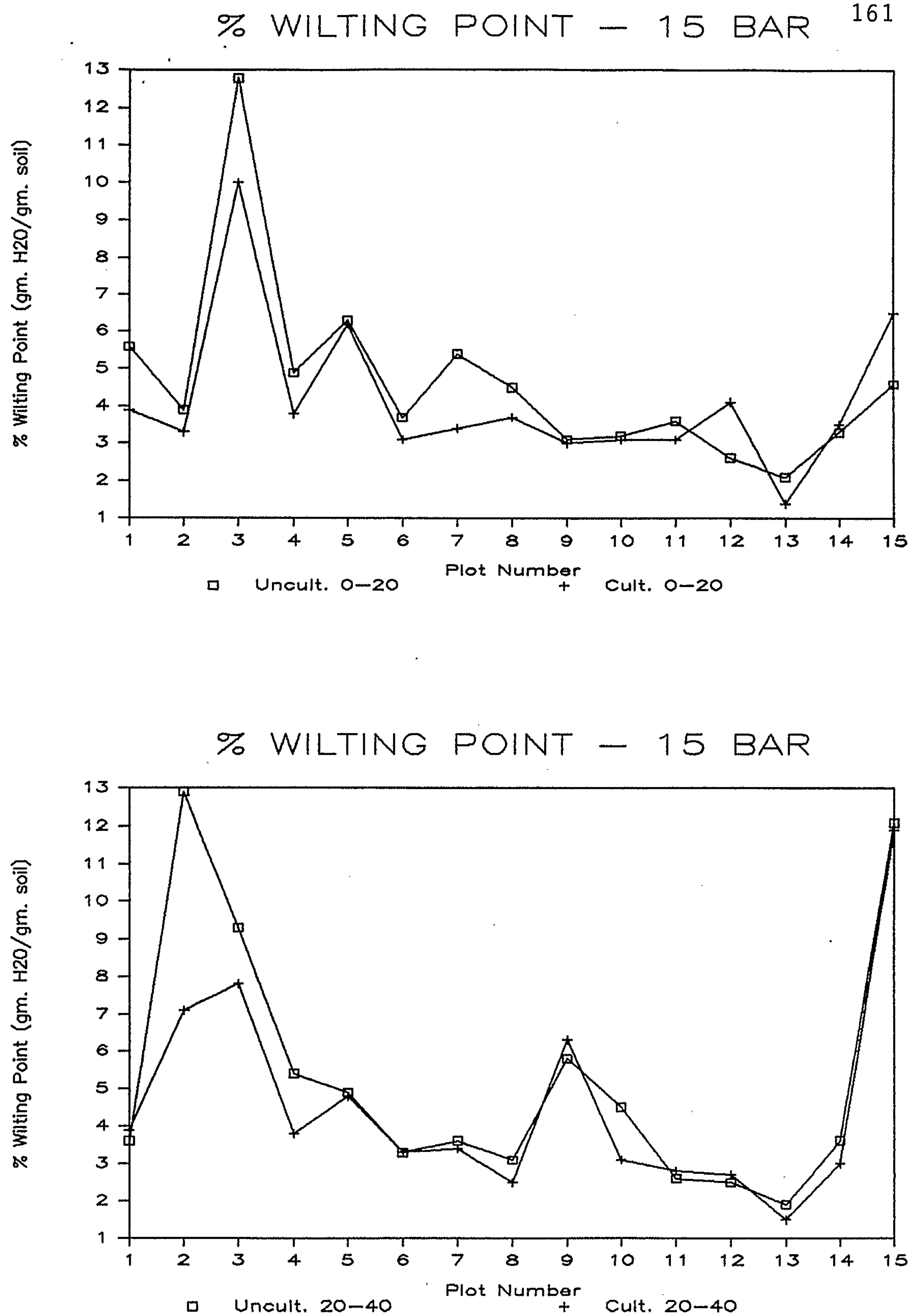


Fig. 7.8 % Wilting Point - 15 Bar

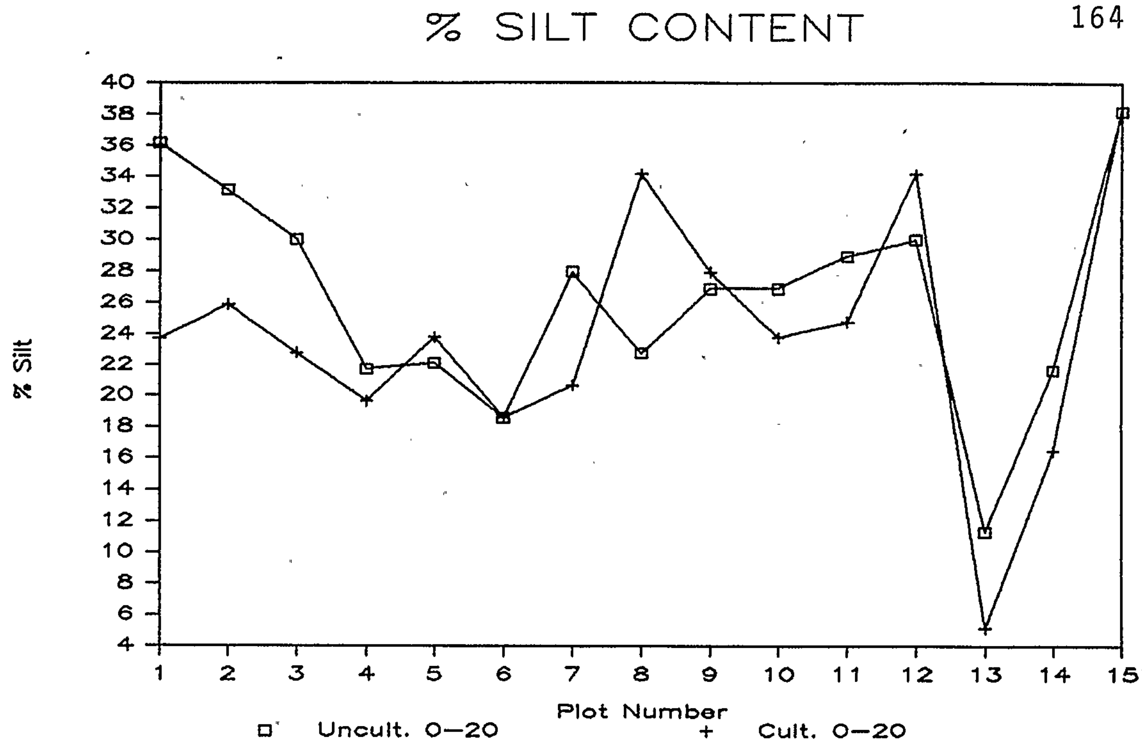
Harris's suggestion would explain the discrepancy between the wilting point of the soils investigated in this study and their water content in the field. If the wilting point for those soils is at a lower moisture level than that suggested by the results of the laboratory analysis, then the soils' potential for storing available water must be greater. That would suggest that more water would be available to the plants than was indicated by the test results which would further explain why the plants at the test site were not wilting.

Another factor which may have been responsible partially for the discrepancy between the laboratory results and the field results was the structure of the soil used in the laboratory tests. Due to the handling and preparation of the soil required for those laboratory tests, the soil no longer had the structure or pattern of pores that the soil in the field had and therefore the interrelationships between the size of the pores, the structure of the soil and the retention of water no longer existed. Consequently, the results of the laboratory tests should not be expected to mirror the results obtained in the field.

In analyzing the results of the laboratory tests the uncultivated soils tended to show a higher potential for storing available water than did the cultivated soils. This result is reasonable because the structure of the uncultivated soil probably is more conducive to holding water, due to its higher organic matter content, higher total porosity and possibly, the presence of larger pores. The fact that this is not reflected in the field situation may be attributed to the retention of water and the inhibition of its movement by the large number of micropores in the cultivated soil, as has been discussed above. It also may be because the amount of water needed to fill the available storage capacity of the soils in the study area usually is not available due to its dry climate. In addition, the presence of annual vegetation on the uncultivated land would also affect the amount of moisture in the soil, since that vegetation would be consuming water for a longer length of time than would crops growing on the cultivated land.

7.2.5. Particle Size Distribution

In reviewing the literature on changes in the particle size distribution of a soil resulting from cultivation, many variations in trends were noted in Chapter IV. However, in the results of this study, the most significant shift in particle size in the soils of the 15 test sites was seen in the silt component of the soil (Fig. 7.9). Although the sand fraction of the soils increased in the 0-20 cm. level in 10 of the 15 test sites, the increases were not large ones (Fig. 7.10), nor were any large changes



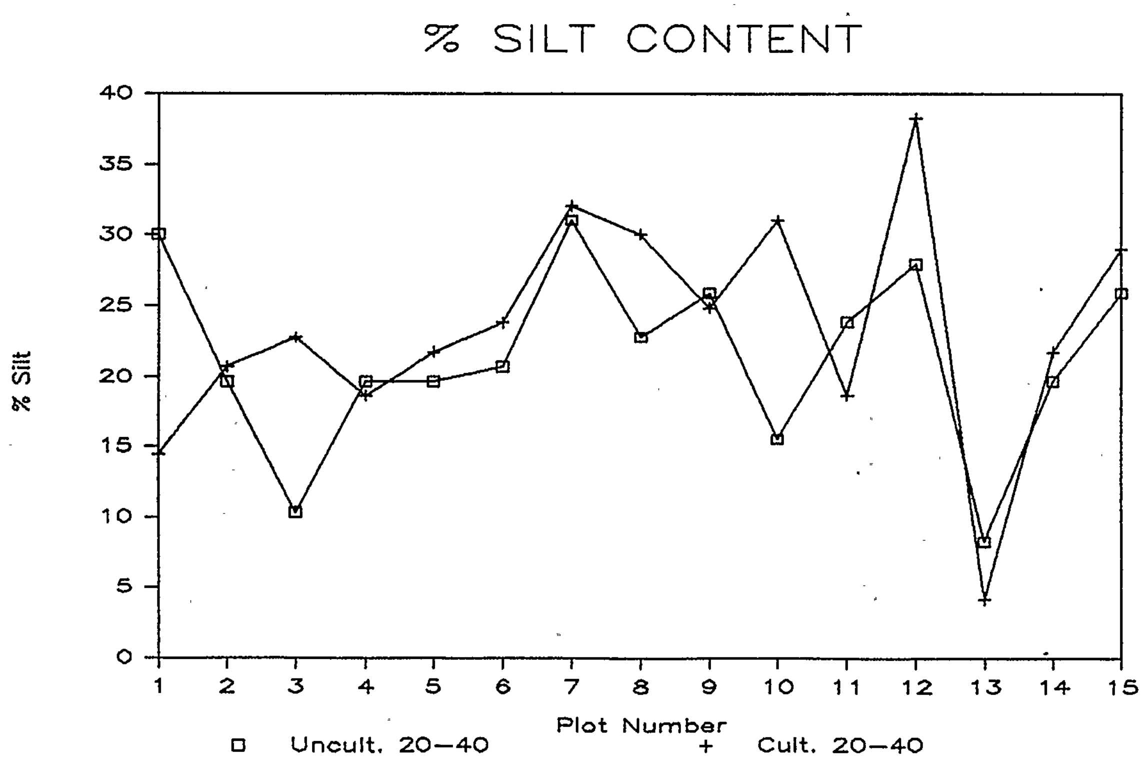
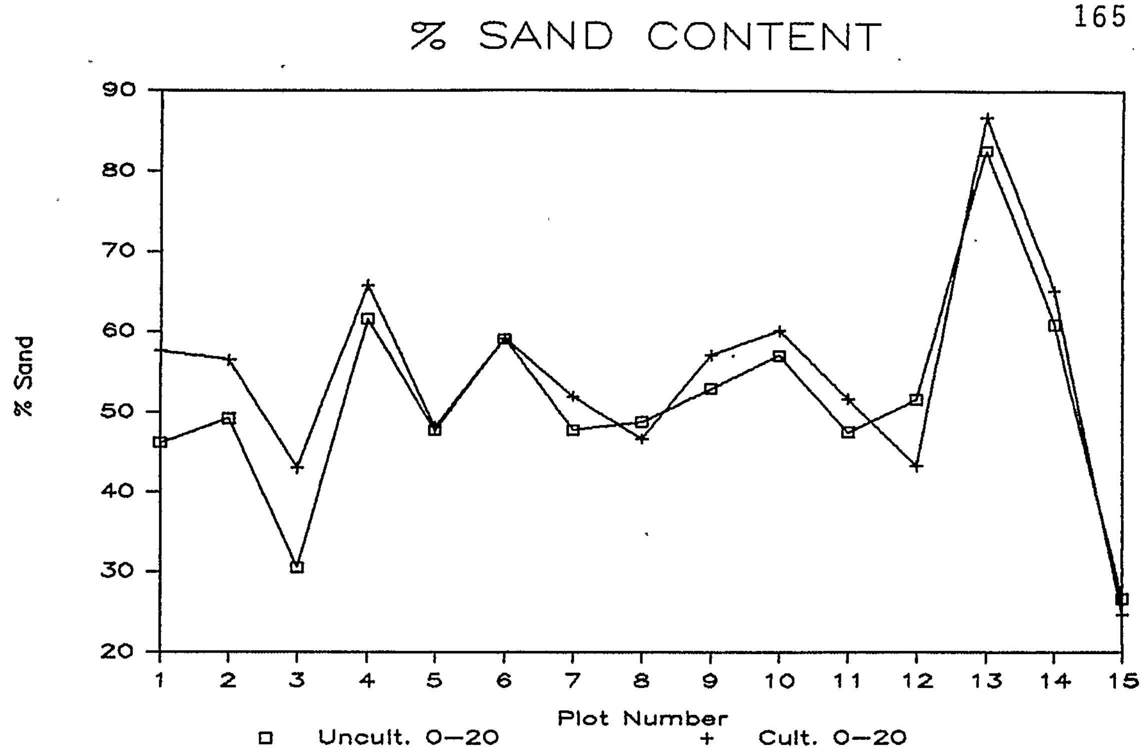


Fig. 7.9 % Silt Content



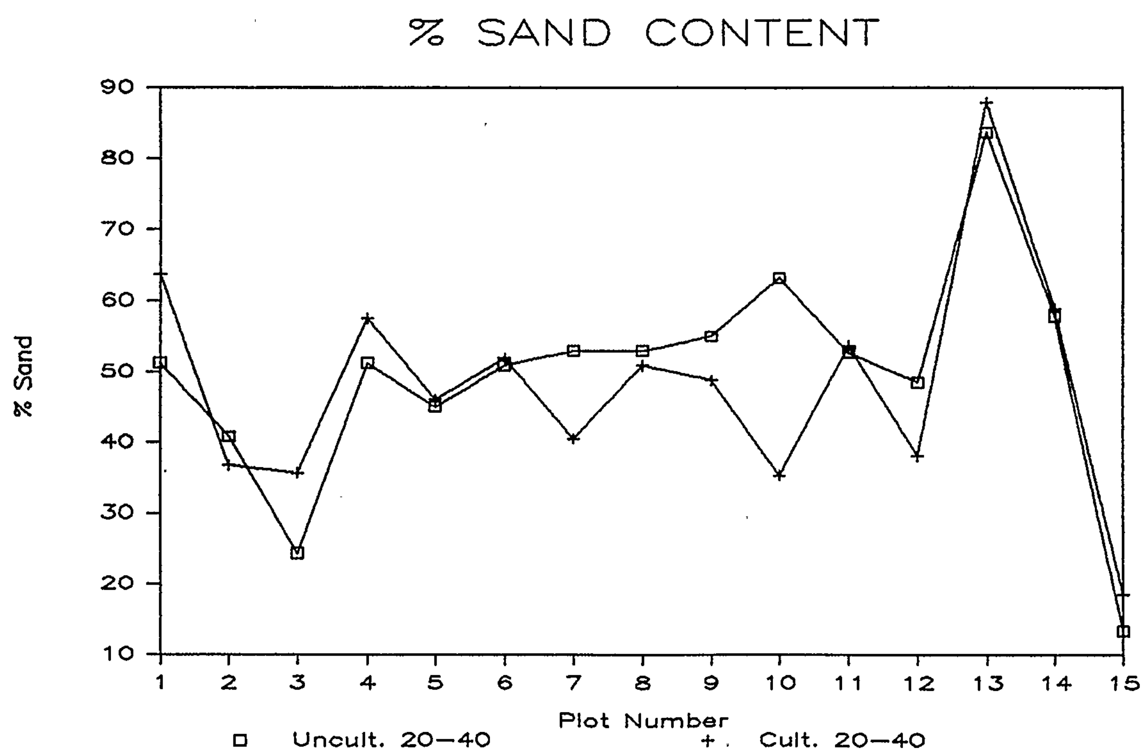
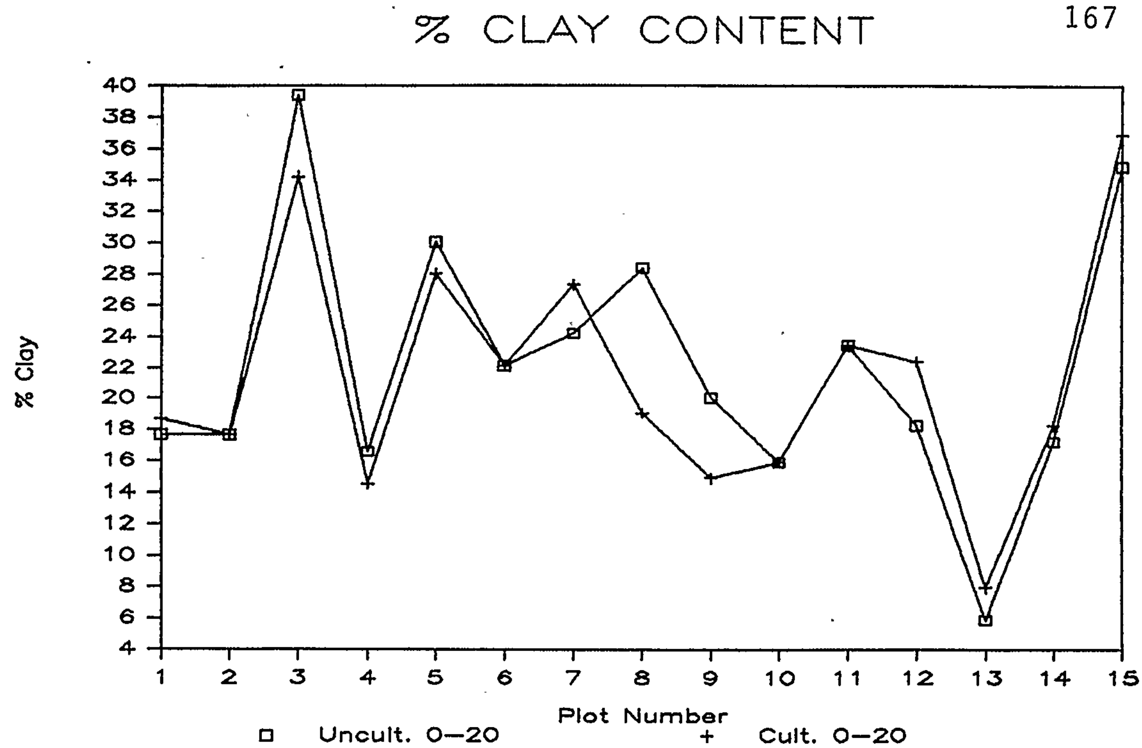


Fig. 7.10 % Sand Content

noted in the clay content between the uncultivated and corresponding cultivated soils (Fig. 7.11).

The change in the silt content of the soils was evident in a downward movement of the silt from the 0-20 cm. level of the cultivated soil to the 20-40 cm. level. The silt content of the cultivated soils generally was lower in the 0-20 cm. level than it was in the uncultivated soils but higher in the 20-40 cm. level. The lower silt content recorded in the 0-20 cm. level of the cultivated soils may be due, in part, to erosion of the silt fraction by wind when the fields were bare. However, this would not explain the increase in the silt content of the 20-40 cm. level in the cultivated soils. A possible explanation for that increase, would be the eluviation of the silt from the 0-20 cm. level to the 20-40 cm. level. The silt translocated from the 0-20 cm. level of the cultivated soil to the 20-40 cm. level, would have become available for transfer through the loosening and pulverizing of the soil structure by cultivation.

Why the silt component of the soil would be prone to eluviation and not the clay component, is another question which must be considered. Water is an important element involved in the chemical processes of a soil. Its molecules are attracted highly to soil particles, especially clay because of the large surface area available for adsorption of water molecules. Adhesive bonds that



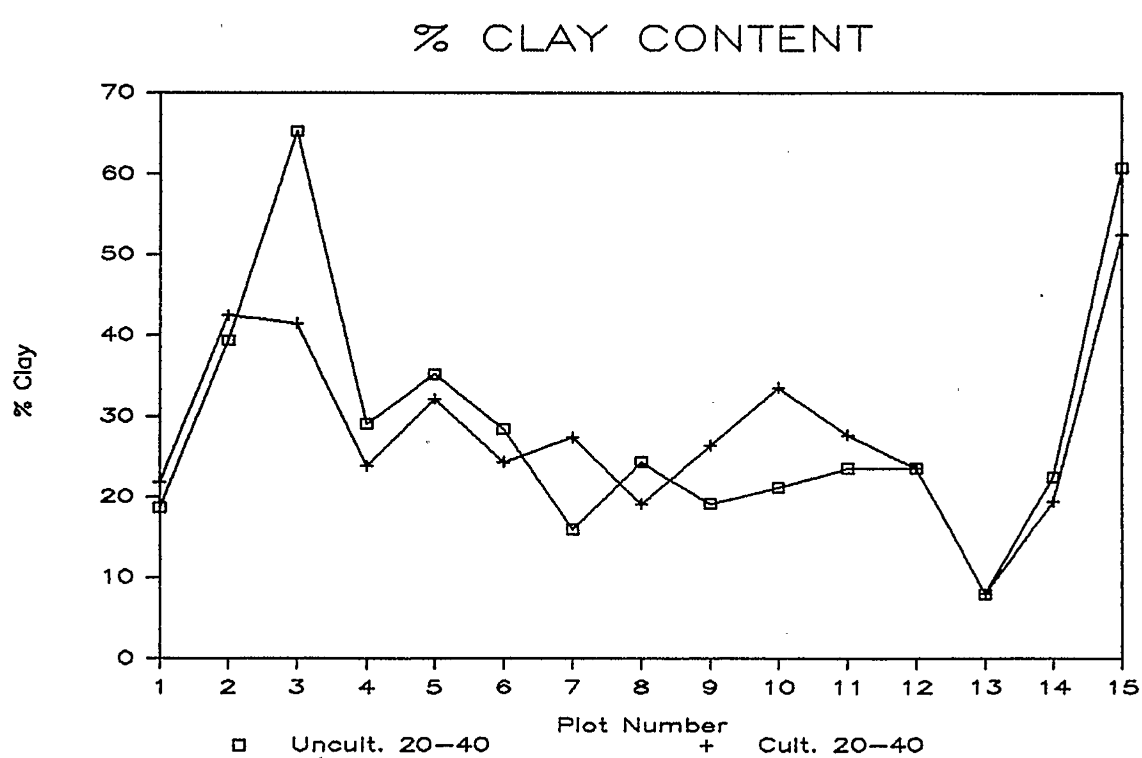


Fig. 7.11 % Clay Content

form between the water molecules and the soil particles become very strong in the soil as it begins to dry out. Since the water molecules are attracted more to the clay particles than to the silt particles, the bonding force is stronger between the water molecules and the clay particles. Therefore, the lack of clay movement into the 20-40 cm. level could be due partially to the ability of the strong adhesive bonds (resulting from the low water content of the soil) to hold the clay particles in place, while the silt particles (loosened by the effects of cultivation) are free to be translocated downward.

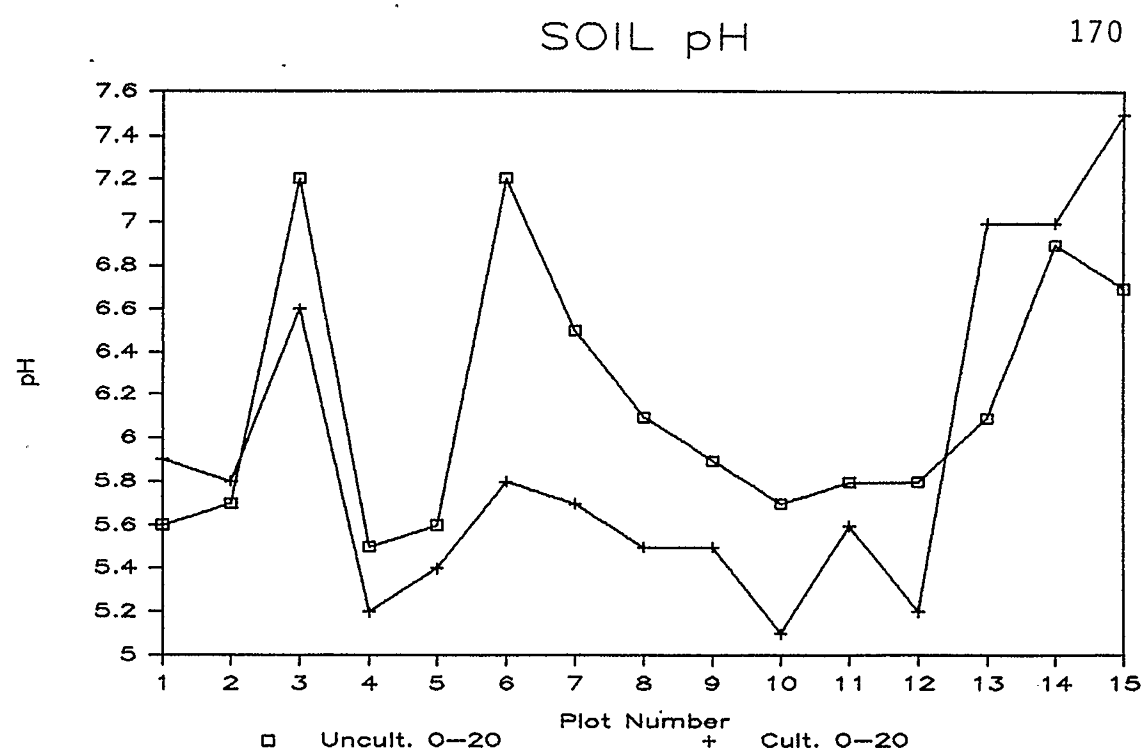
The resulting changes in the particle size distribution were significant enough between some of the cultivated soils and the uncultivated soils to have caused an alteration in the texture classification. A change occurred between the soils in the 0-20 cm. level in 6 of the test sites and between the soils in the 20-40 cm. level in 9 of the test sites. No predominance towards an increase or decrease in the coarseness of the texture of the soils was noted in those changes.

7.2.6 pH and Salinity:

Most field crops prefer a pH of between 5.0 and 8.0 (Alberta Agriculture, 1981). Since all of the pH values of the soils in the 0-20 cm. level are within this range, plant growth should not be inhibited because of the pH levels of those soils (Fig. 7.12). In the 20-40 cm. level nine of the soils had pH readings above 8.0 which is slightly more basic than is optimum for plant growth. Soils in the study area which have pH readings in the basic range normally are associated with excess exchangeable Na^+. The presence of excess Na^+ causes an increase in the OH^- ions present in the soil by the dissociation of water or hydrolysis. The Na^+ ion displaces and inactivates the H^+ ion in water but does not recombine with the OH^- ion. This results in raising the concentration of the OH^- ions above that of the H^+ ions, causing a basic reaction to occur (Hausenbuiller, 1978).

The pH of a soil can be affected by anything which alters the chemical conditions of a soil (for example, fertilizer). As a result, the differences seen in the pH between the cultivated and uncultivated soils can not be attributed completely to the effects of cultivation. However, due to its disruptive effects, cultivation does cause a change in the chemical properties of a soil (by altering the water regime or organic matter regime, for example) and therefore, is responsible for some alteration in the pH between the uncultivated and cultivated soil.

The results of the pH readings of the soils from the test sites generally showed a decrease in soil pH (or an increase in the acidity) in the 0-20 cm. level of the cultivated soils over that of the uncultivated soils.



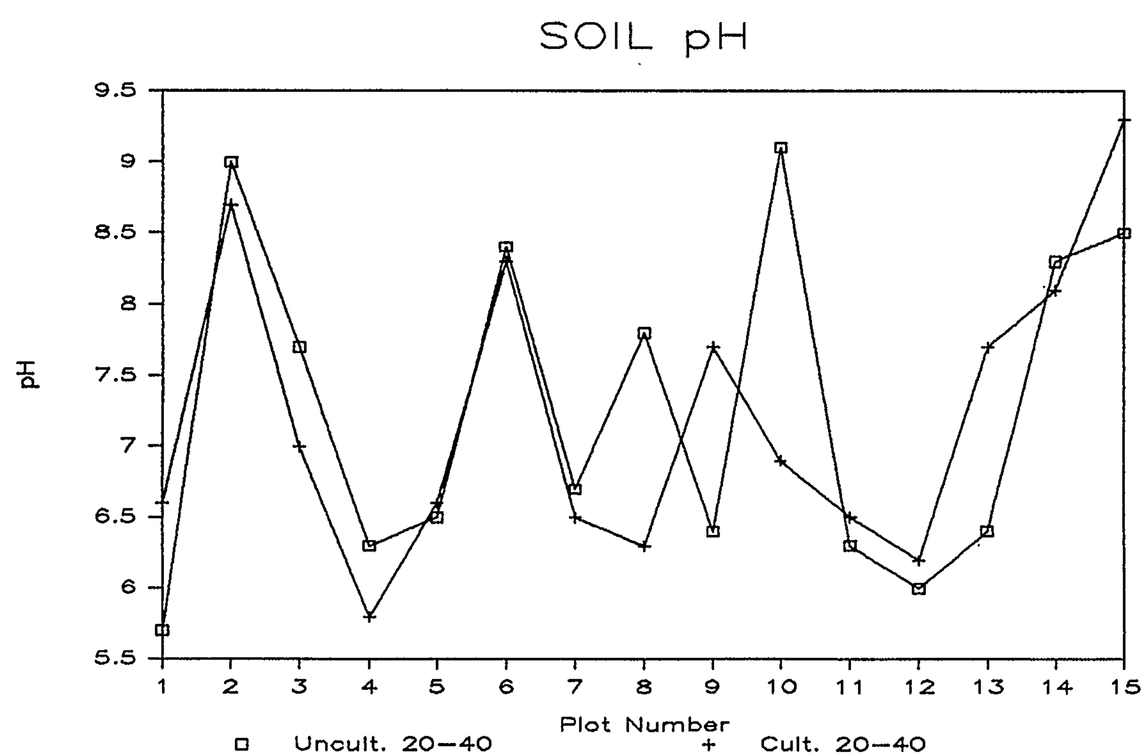


Fig. 7.12 Soil pH

Although no definite pattern was noted in the 20-40 cm. level between the uncultivated and corresponding cultivated soils, the soils at this level were generally more basic than the soils of the 0-20 cm. level in both the cultivated and uncultivated soils.

All of the soils in the 0-20 cm. levels had conductivity readings below the amount at which the salt concentration of the soil begins to affect the growth and development of plants (Fig. 7.13). However, in 10 of the 15 test sites the conductivity readings were higher in the cultivated soil than in the uncultivated soil, which indicates that the salt content of those soils was increasing. The movement of salt upwards to the surface of the soil by capillary action and the effect of cultivation on this movement was discussed in Chapter III. The evidence presented by the conductivity readings recorded from the soils in the study area would seem to indicate that a similar process had occurred in those soils.

In the 20-40 cm. level of the soils, five readings were found to be above the amount at which the salt concentration in the soil begins to affect plant growth. Two of the test sites, 3-A and 15-A, displayed readings which showed excessive concentrations of salts that would prevent normal growth in most plants. The conductivity readings of the soils at test sites 1 and 4 to 14 were all below the amount at which the salt concentration in the

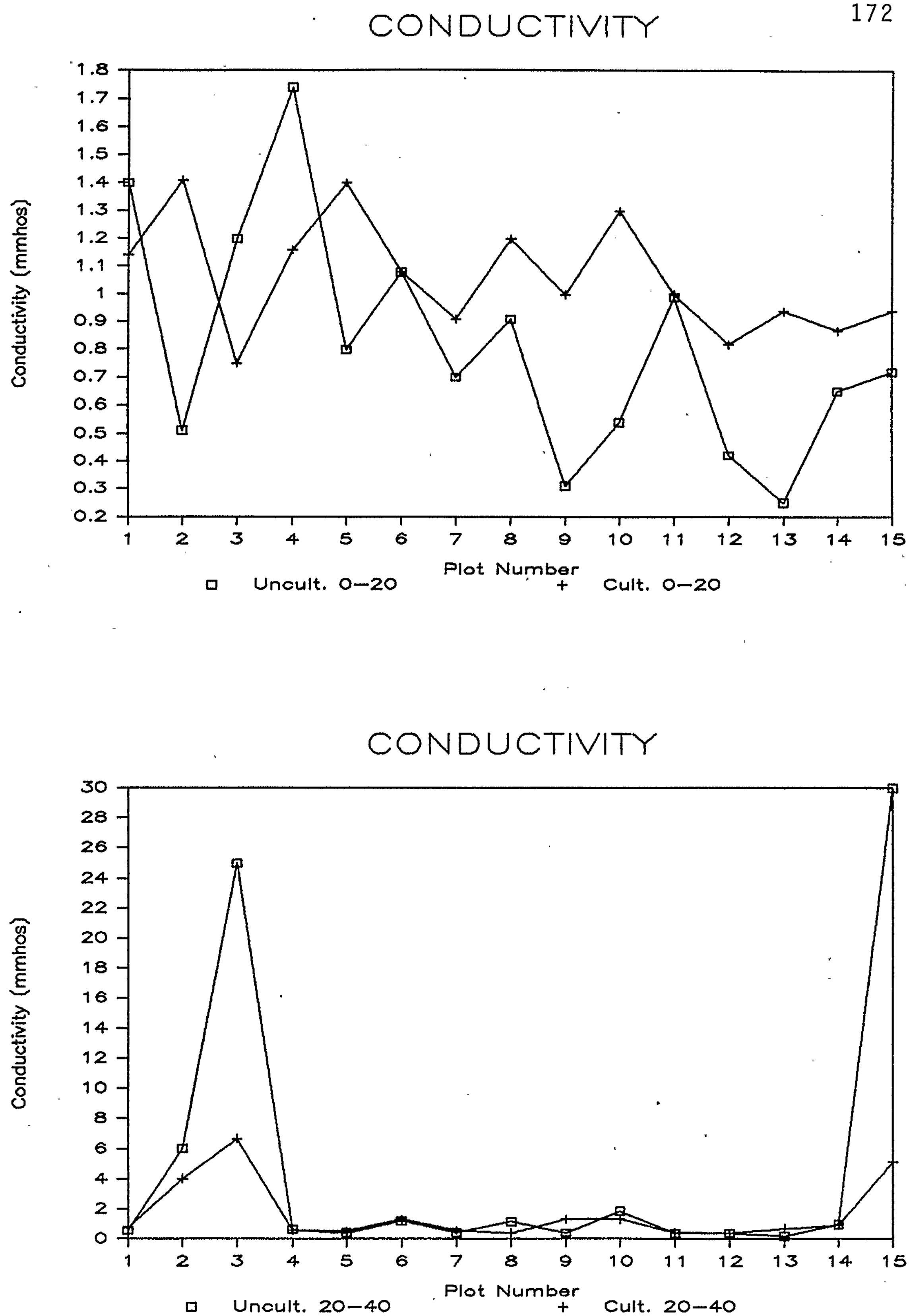


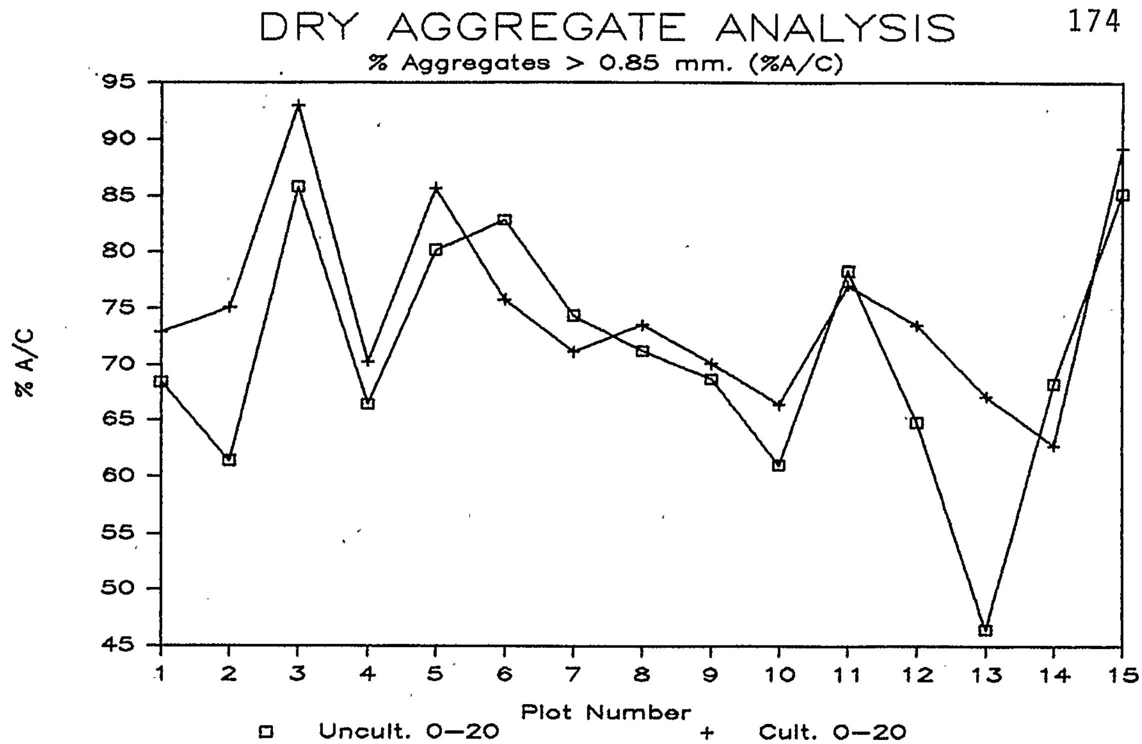
Fig. 7.13 Conductivity

soil would affect the growth of plants. The conductivity readings at those test sites generally were higher in the cultivated soils than in the uncultivated soils.

7.2.7 Aggregate Analysis:

Two methods of aggregate analysis were used in this research: dry aggregate analysis and wet aggregate analysis. The first method was used to determine the size distribution of the aggregates actually present in the field. The results of the dry aggregate analysis on the 0-20 cm. level of the soils at the test sites showed a trend towards more large dry aggregates being present in the cultivated soil than in the uncultivated soil (Fig. 7.14). There was no trend noted in the 20-40 cm. level of the soils.

The occurrence of more large dry aggregates in the cultivated soil in this study appears to concur with Siddoway's (1963) findings that rather than improving soil condition, grasses and legumes actually adversely affected it. However, this author would disagree with that interpretation. Recently, farmers have been selecting soil cultivation techniques and equipment which do not pulverize the soil completely, but rather maintain a cloddy surface structure (Alberta Agriculture, 1981). As an alternate interpretation, this author suggests that the presence of more dry aggregates in the cultivated soils than in the



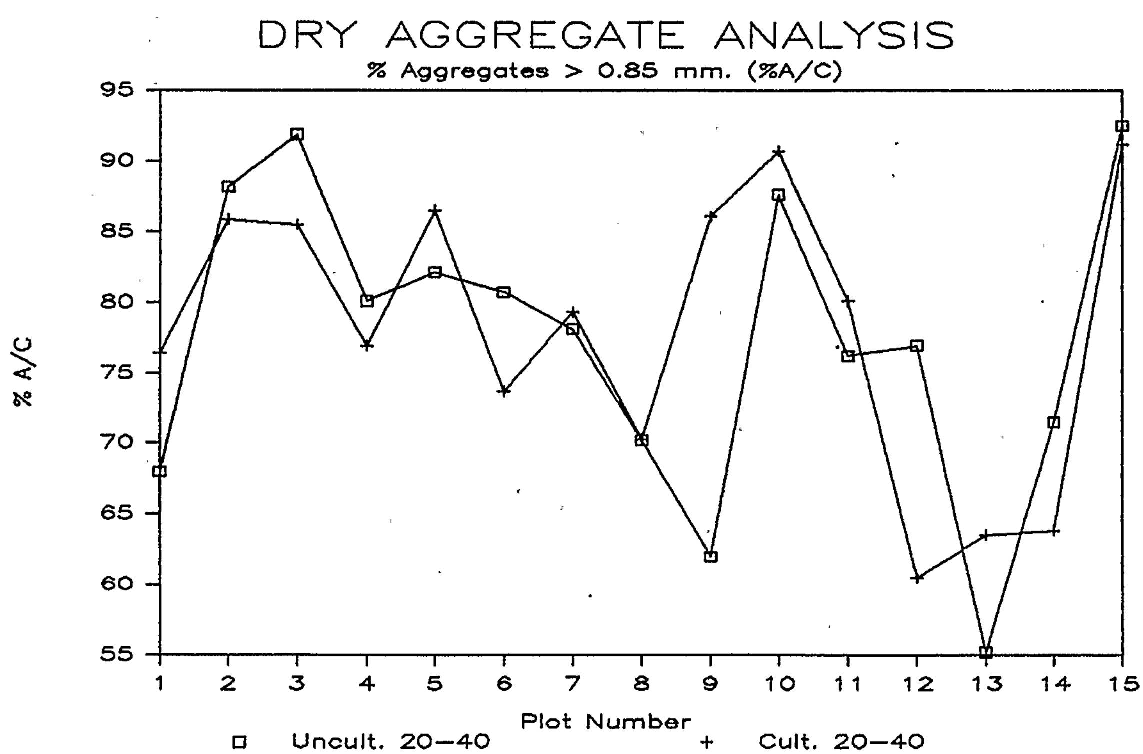
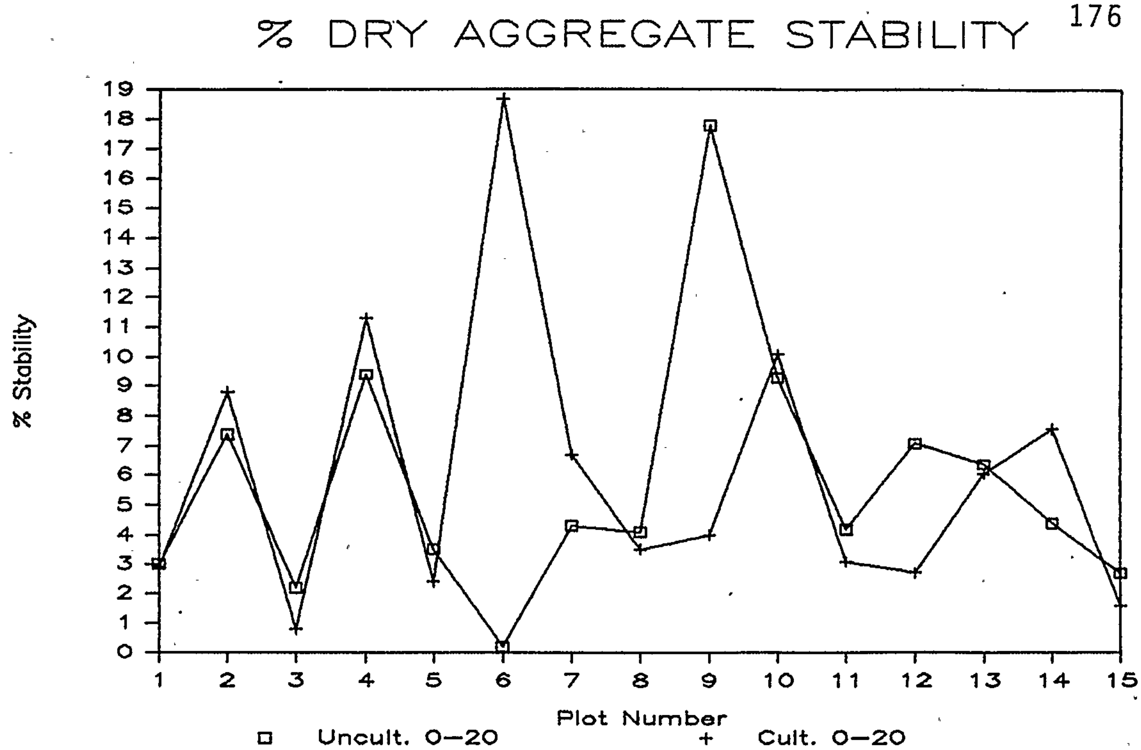


Fig. 7.14 Dry Aggregate Analysis

uncultivated soils is due more to the process of cultivation itself than to any possible destructive effect of grasses or legumes on dry aggregates in the uncultivated soil. A cultivation process that attempts to maintain a cloddy texture may be responsible for artificially producing large dry clods which makes the cultivated soils appear as though their physical condition is better than that of the uncultivated soils.

The analysis of the mechanical stability of the soils showed that the large dry aggregates present in the 0-20 cm. level of the uncultivated soils tended to be more mechanically stable than those in the cultivated soils (Fig. 7.15). That result tends to support the suggestion that although there are more large dry aggregates in the 0-20 cm. level of the cultivated soil, it may not be in better physical condition than the uncultivated soil because the aggregates present in the uncultivated soil are less susceptible to disruption and are of a more permanent nature. No trend was noted in the results obtained for the 20-40 cm. level of the soil (Fig. 7.15).

Due to a preference by farmers in recent years towards cultivation methods which maintain a cloddy soil surface, it is felt that the results obtained through the use of the dry aggregate analysis may not give a true representation of the physical condition or the state of aggregation of a soil. Because of this and because dry aggregates are



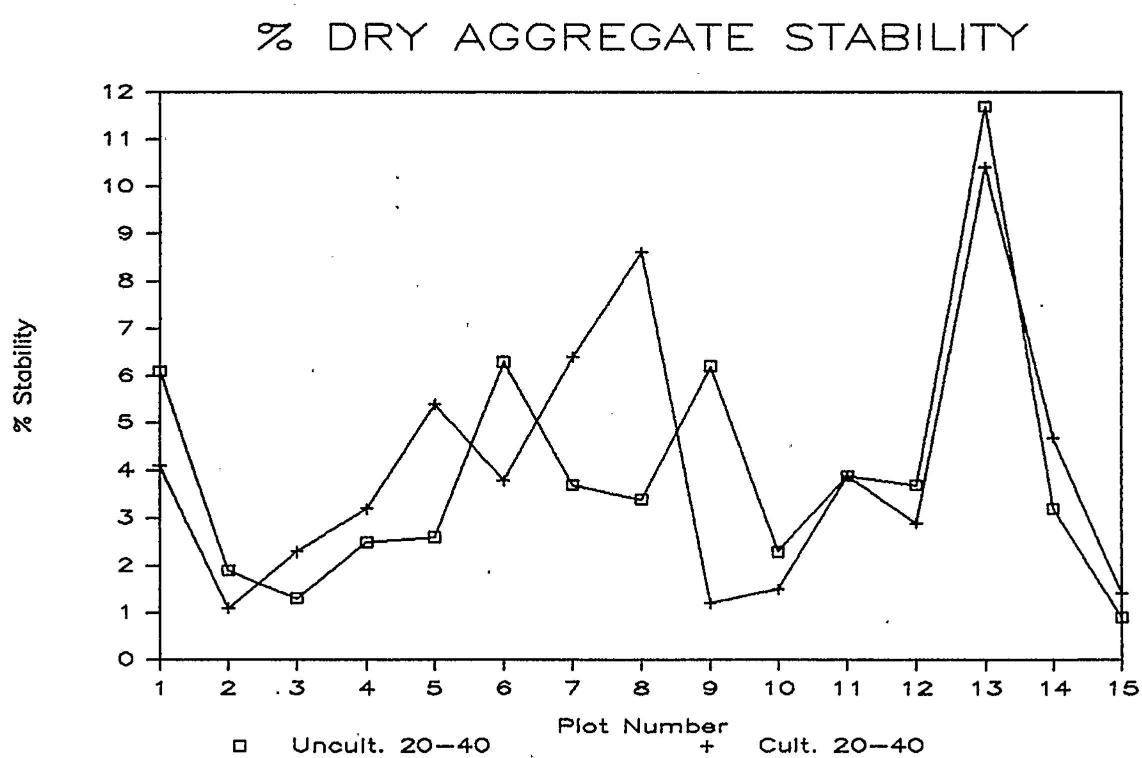


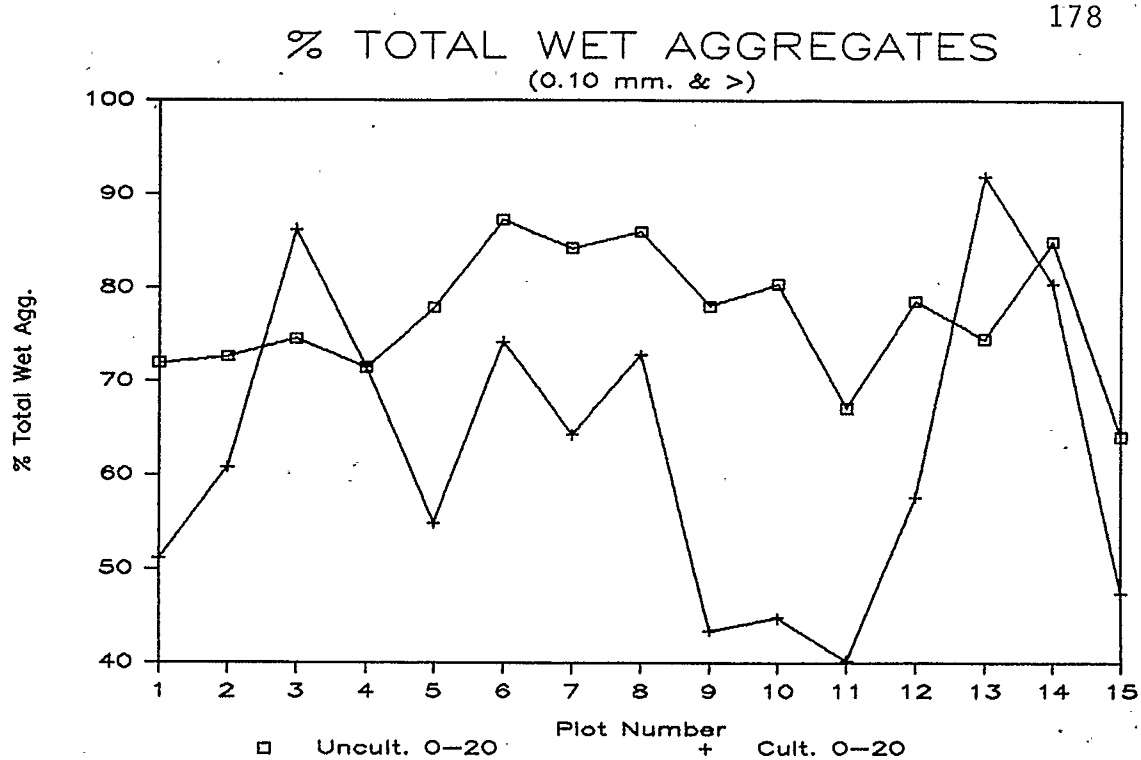
Fig. 7.15 % Dry Aggregate Stability

highly susceptible to disruption from sources other than cultivation (e.g. shrinking and swelling, freezing and thawing, wetting and drying), due to the weak bonds holding them together, it was not felt that the results obtained from this method were a valid measurement of the effects of cultivation on soil aggregation. Instead, the wet aggregate analysis results were used for this purpose because of their more stable nature.

The results of the wet aggregate analysis showed a trend towards more aggregation in the 0-20 cm. and the 20-40 cm. levels of the uncultivated soil than in those of the cultivated soil (Fig. 7.16). In addition, there generally was a predominance of larger aggregates (1.00 mm. & >) in the uncultivated soil, as well (Fig. 7.17).

The two exceptions to those trends were recorded in test sites 3 and 13. In both of these test sites, more water stable aggregates were recorded in the cultivated soil than in the uncultivated soil. In addition, the soil in test site 3 had the highest percentage of clay while the soil in test site 13 had the lowest. As a result of the findings for those two test sites, it was determined that the clay content of a soil alone does not influence the degree of aggregation found in any one soil.

The organic matter content of the soils in the test sites was higher in all of the uncultivated soils than in



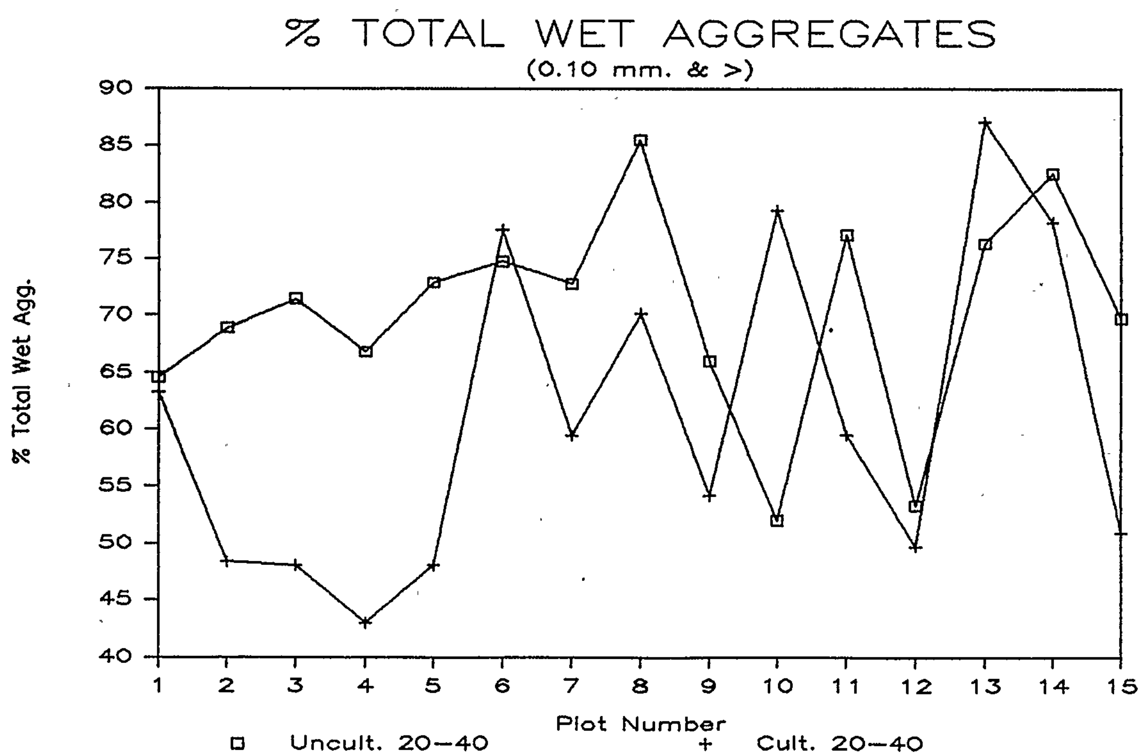
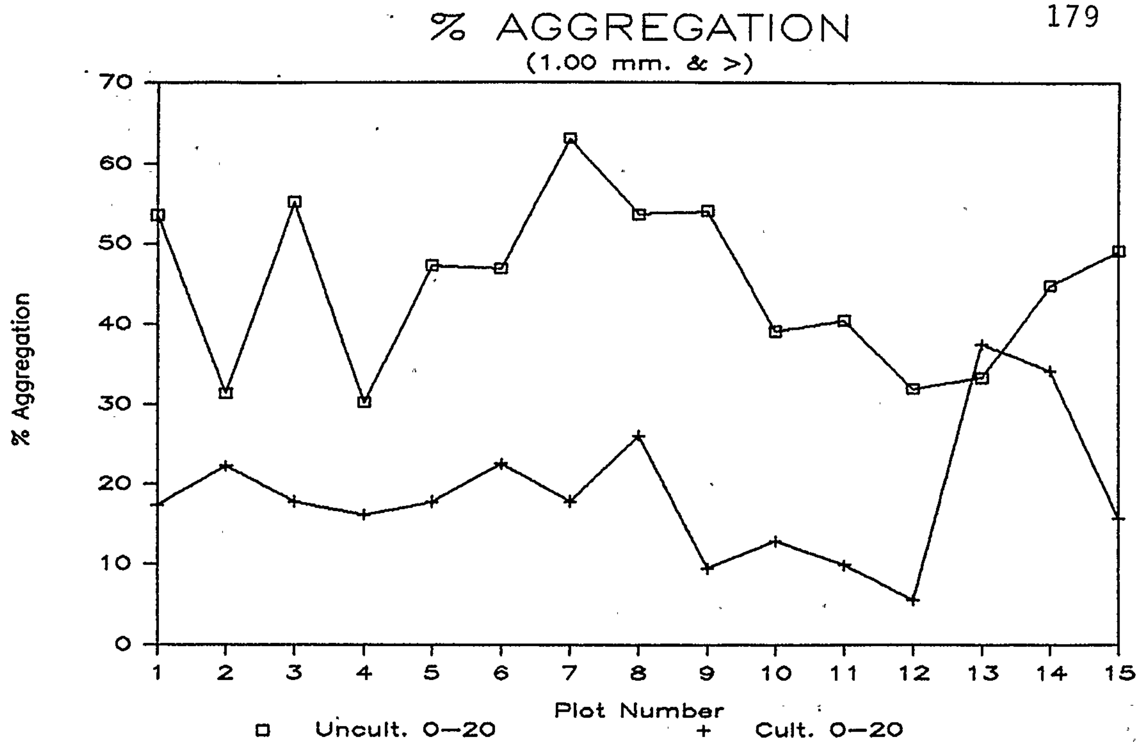


Fig. 7.16 % Total Wet Aggregates



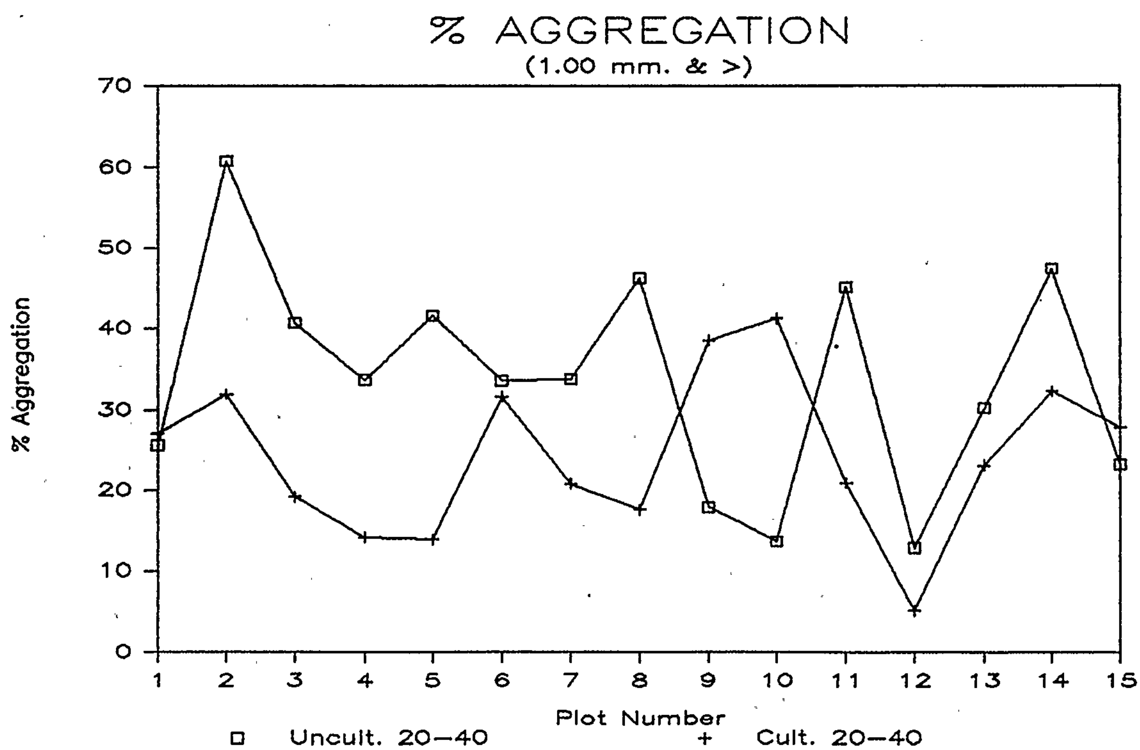


Fig. 7.17 % Aggregation

the cultivated soils except in the 20-40 cm. level of test site 15. Since the aggregation of the soils was not higher in all of the test sites except the 20-40 cm. level of test site 15, it was determined that the variation in aggregation could not be explained completely by the organic matter content of the soils either.

The presence of permanent living root systems in the uncultivated soils of the test sites may be responsible for the higher degree of aggregation found in those soils as compared to that found in the cultivated soils. It has been suggested by several researchers that the root systems of plants affect soil aggregation by exerting pressure, which forms and breaks down aggregates. Malik et al. (1965) attributed the structural stability of soils under undisturbed grassland to the continual presence of the root systems of perennial plants. In addition, they stated that periodic disturbance of the soil or the type of root system present in the soil may have more effect on aggregation than the organic matter content.

The 0-20 cm. level of the soil in test site 15 showed up as a complete anomaly in the results of the wet aggregate analysis. Although its organic matter content was lower, its bulk density was higher and its clay content was lower, the uncultivated soil still showed a higher rate of aggregation than the cultivated soil. It also showed a predominance of large aggregates over the cultivated soil.

As a result of the findings in that test site, it would appear that more factors influenced the aggregation of the soils in the study area than those investigated in this research. As was stated by Dormaar (1983), soil aggregation does not result from just one specific agent or process but from several occurring simultaneously.

7.3 Statistical Analysis

Two statistical methods were applied to the data collected during this research; the Student's T-test and the F-test (see Chapter V, Section 5.5, for discussion of statistical tests). The null hypothesis for both tests is that the samples are both from the same population and therefore differences between the sample mean and the variances are within the accepted error of the population. That null hypothesis was rejected in the T-test if there was a significant difference in the means of the two populations and it was rejected in the F-test if there was a significant difference in the variance of the two populations.

The results of the F-test, showed a significant difference in the variance of the data in only 5 of the 15 soil factors investigated in this study. A highly significant difference (99%) resulted between the conductivity readings of the 0-20 cm. levels of the uncultivated and cultivated soils and a significant

TABLE 7.1

STATISTICAL ANALYSIS SUMMARY

	F-test		T-test	
	0-20cm.	20-40cm.	0-20cm.	20-40cm.
pH	1.6	1.3	0.1	0.0
Log	1.7	1.3	0.1	0.0
Conductivity	4.1	23.3	0.3	0.2
Log	8.1**	2.7*	0.3	0.0
% Water Content	3.2	2.5	0.1	0.0
Log	2.0	2.6*	0.2	0.1
% Wilting Point	1.6	1.6	0.1	0.1
Log	1.0	1.2	0.1	0.1
% Field Capacity	1.4	1.7	0.1	0.1
Log	0.8	1.3	0.1	0.1
% Available Water	1.1	1.6	0.1	0.1
Log	0.8	0.7	0.1	0.1
Bulk Density	2.9	1.5	0.4	0.3
Log	3.5*	1.7	0.4	0.3
Total Porosity	3.8	1.5	0.4	0.3
Log	3.3*	1.2	0.4	0.3
% Sand	1.1	1.0	0.1	0.0
Log	1.0	0.7	0.1	0.0
% Silt	1.3	1.6	0.1	0.1
Log	2.4	2.0	0.1	0.0
% Clay	1.2	2.1	0.0	0.0
Log	1.4	1.4	0.0	0.0
% Organic Matter	1.2	2.3	0.4	0.5
Log	2.3	1.1	0.3	0.6
Penetrometer	1.9	1.9	0.6	0.3
Log	1.2	1.5	0.6	0.3

** - Highly significant difference (99%).
* - Significant difference (95%).

TABLE 7.1 (CONT.)

	F-test		T-test	
	0-20cm.	20-40cm.	0-20 cm.	20-40cm.
Dry Aggregate				
% A/C (run 1)	1.59	1.15	0.15	0.02
Log	2.16	1.19	0.16	0.02
% A/C (run 2)	1.39	1.61	0.14	0.06
Log	1.84	1.92	0.15	0.07
% Stability	0.79	1.01	0.02	0.01
Log	1.47	1.15	0.03	0.00
Wet Aggregate				
% Total Aggregate (0.10mm.&>)	5.53	2.33	0.41	0.28
Log	8.27**	2.65*	0.43	0.30
% Aggregation (1.00mm.&>)	1.35	1.91	1.00	0.29
Log	0.23	0.78	0.89	0.25

** - Highly significant difference (99%).

* - Significant difference (95%).

difference (95%) occurred between the readings of the 20-40 cm. level. Because the results of the F-test on this factor may have been affected by the presence of the three Solonetzic soils sampled in this study and the large difference which occurred in the salt content between the cultivated and uncultivated Solonetzic soils, the strength of the significance obtained for this factor may be questionable.

A significant difference was seen in the variance that occurred in the data for the water content between the uncultivated and cultivated soils in the 20-40 cm. level. The results recorded for the bulk density and total porosity in the 0-20 cm. level of the soils also showed a significant difference. However, since bulk density and total porosity are the inverse of one another, one would expect that if one of these factors showed a significant difference, the other would as well.

The final factor that showed a significant difference in the variance of the data was the total aggregation results of the wet aggregate analysis. The difference seen between the 0-20 cm. level of the cultivated and uncultivated soils was highly significant while the 20-40 cm. level showed a significant difference.

The results of the Student's T-test on the data presented in this study, did not show any significant difference between the means of the soil factor data collected for the uncultivated and cultivated soils, and therefore the null hypothesis was accepted (see Appendix C for results of statistical tests). This suggests that the data collected does not represent two distinct soil populations, but instead, falls within the variance that could occur within a single population.

Overall, the results of the statistical tests suggest that, with the exception of a few factors, the trends previously noted from the graphs of the soil factor data may not be statistically significant enough to conclude that cultivation has affected the soil to the point where the changes noted in the factors investigated are substantially different from those changes which would normally occur in any soil. However, the fact that the trends noted from the graphs all indicate changes in one direction (e.g. a decrease in pH, an increase in water content or a decrease in organic matter) suggests that a pattern of change does in fact exist between the cultivated and uncultivated soil. Statistical tests do not identify patterns of change, they only identify numerical change and if that numerical change is not large enough or the statistical test is not sensitive enough, then the change will not be identified.

As was stated by Elliott (1977:95), "A statistical test is not an infallible guide and can never prove a particular hypothesis. There is always a possibility that an alternative hypothesis exists." In this study, the statistical evidence does not support the hypothesis that cultivation affects soil and causes changes in soil factors. However, the trends identified from the graphs presented in this chapter do indicate differences exist, even though the differences may be small.

7.4 Summary

The results of the statistical analysis conducted on the data collected for this study did not show any significance difference occurring between the means of the uncultivated soil properties and the cultivated soil properties. In addition, only five factors showed any statistical difference in their variance; they were water content (20-40 cm. level only), total aggregation, bulk density (0-20 cm. level only), total porosity (0-20 cm. level only) and conductivity (both 0-20 cm. and 20-40 cm. levels). However, the results of the descriptive trend analysis indicated that in fact differences do exist between the uncultivated and cultivated soil properties. Decreases were identified in pH, organic matter, total porosity, water content and in both the percentage and size of wet aggregates of the cultivated soil as compared to the uncultivated soil. In addition, increases in bulk density, salinity and the potential for storing available water also were seen in the cultivated soil. It is suggested that statistical tests may not always be able to identify small or subtle changes that occur between two sample groups which can be discerned from visual representations of the same data.

CHAPTER VIII

CONCLUSIONS AND RECOMMENDATIONS

8.1 Study Findings

This thesis has examined the effects of cultivation on soils in the Special Areas of Alberta. An analysis of the results of field and laboratory tests conducted on selected properties of the soils in the study area has shown that differences do exist between soil properties of uncultivated soils and cultivated soils. In addition, trends were observed in the differences which occurred between the uncultivated and cultivated soil properties in the 15 test sites. Those trends were identified in all 0-20 cm. levels of the soils and in all but two of the 20-40 cm. levels. However, the differences that occurred in the soil properties were greater in the 0-20 cm. levels of the soils than in the 20-40 cm. level.

Organic matter was found to be higher in the uncultivated soils than in the cultivated soils. The sand content of the soil appeared to have some effect on the amount of organic matter loss that occurred in the cultivated soils. Cultivated soils which had higher sand contents than the corresponding uncultivated soils tended to experience greater losses. Part of the decrease in organic matter content in the 0-20 cm. level of the cultivated soil was attributed to the diluting effect caused by the mixing of the Ah and B horizons through cultivation.

Bulk density and total porosity are inversely related soil factors which are affected by the organic matter content of a soil. This study found that as the organic matter content of the cultivated soils decreased, the bulk density tended to increased. Total porosity tended to be higher in the uncultivated soils than in the cultivated soils, while the bulk density was lower.

The water content of the cultivated soils tended to be higher than that of the uncultivated soils even though the potential storage capacity for available water was lower in the cultivated soils. This discrepancy was attributed to the development of strong adhesive and cohesive bonds in the smaller pores of the cultivated soil as it dries out, as well as to the general lack of water available in the study area and the presence of annual vegetation on the uncultivated land.

The change in the particle size distribution between the uncultivated soil and the cultivated soil was noted in the shift in the silt content from the 0-20 cm. level to the 20-40 cm. level of the cultivated soil. The lack of clay translocation to the lower level was attributed to strong bonds which develop between the clay particles and the water molecules in dry soil.

The general decrease in the pH of the cultivated soils was not attributed to cultivation alone; however, it was noted that cultivation would have been responsible for some of the change that occurred. It was suggested that the increase in the salinity of the cultivated soils was due to the increase in the upward movement of water and salt by capillary action, as discussed in Chapter III. Exceptions to this increase were seen in the 20-40 cm. level of the Solonetzic soils, where the solodized B horizon was loosened by cultivation, allowing water to percolate through it and leach away some of the salt.

The results of the wet aggregate analysis showed the uncultivated soil contained more, and larger, aggregates than did the cultivated soil. Since no pattern was discerned which showed a predominant influence of any one factor on soil aggregation, it was concluded that many agents and processes were involved simultaneously in soil aggregation.

Two statistical tests for variance were conducted on the data collected from the two sample groups. The T-test showed no significant difference exists between the means of the uncultivated and cultivated data. The results of the F-test showed that only five of the factors showed any significant difference between the variance occurring within the two sample groups. Although the two tests did not show that cultivation had affected the soil in the study area, the trends identified from the graphs of the soil factors indicate that differences do exist.

8.2 Implications of the Study Findings

The soils of the Special Areas, as discussed in Chapter III, are a product of the environment of that area. The climate is dry, the vegetation is sparse and the bedrock and surficial deposits that form the parent material of the soils tend to have a high clay and salt content. As a result, the soils of the study area tend to have low organic matter content, low water content, high clay content and high salt content. All of these factors, and more, determine the characteristics of the virgin soils of that area.

The soils in the Special Areas generally have been classified as marginal or unsuited to cultivation due to the poor quality of the soil and it's sensitivity to disruption and subsequent degradation. As was observed in the results of this study, the effects of cultivation negatively impacted the properties investigated. However, the results of that impact affect not only those specific properties, but also the overall structure and physical condition of the soil and the soil-plant relationships of the cultivated land.

Although the changes observed in the soil properties between the uncultivated and cultivated soils were small, the effects of those changes may be as pronounced as larger changes would be in more fertile soils. For example, since the soils in the Special Areas are generally low in organic matter in a virgin state, any decrease in organic matter that occurs due to cultivation would worsen an already poor situation. A similar decrease in a more fertile soil with higher organic matter content may not impact the soil as severely because it is in better condition to begin with.

Any decrease in the organic matter of the soil in the Special Areas also would affect other properties of the cultivated soil, resulting in changes such as an increase in the bulk density and a decrease in the total porosity. Those changes would, in turn, inhibit the movement of air and water through the soil and make it more difficult for plant roots to penetrate into the soil. The decrease in the size and numbers of soil aggregates observed in the cultivated soils would compound those problems because the smaller aggregates and the fine, loose material present in the soil would pack together more closely.

Plants also are affected by changes in the pH of a soil or in the salinity. Both of these factors affect the chemical regime of the soil; a paramount factor in plant growth. A change in either of these factors can affect a plant's ability to obtain the necessary nutrients required for optimum growth.

Although the water content was higher in the cultivated soils, that water was not necessarily available to the plants, as explained in Chapter VII. The results of the pressure plate analysis indicated that the uncultivated soils had a greater potential for storing available water than the cultivated soils. Therefore, if the climate of the study area was not as dry and more moisture was available for storage in the soil, the uncultivated soil would be expected to contain more water than the cultivated soil. However, under the existing conditions, the lower water content of the uncultivated soil may indicate that plants are able to remove more water from the uncultivated soil (due to the availability of the water in the larger pores present in the uncultivated soil, as discussed in Chapter IV) thus leaving it drier than the cultivated soil.

8.3 Recommendations

A primary objective of this study was to provide some assistance to the Special Areas Board in gaining further knowledge of the soils in that region and in determining which lands should be placed under cultivation leases or sold to the public (thereby removing those lands from direct Board control of land use).

The results of this study are felt to be representative of the characteristics of the soils in the western and northern portions of the Special Areas, or that area which approximates the Dark Brown soil zone.

However, these results do not necessarily represent the characteristics of the soils in the southern portions of the Special Areas and the use of them for planning purposes in that region is not recommended. As was discussed in Chapter II, the environment of the southern portion of the Special Areas varies from that of the north. Less moisture is received in the south and the vegetation cover is sparser. As a result, the soils of that region contain a lower percentage of organic matter than the dark brown soils to the north and west. Because of these differences, it is likely that the characteristics and properties of the southern soils would vary from those of the north. To determine the effect of cultivation on the soils in the southern portion of the Special Areas it is recommended that a similar study be carried out in that region.

The primary recommendation to the Special Areas Board and the farmers working in the Special Areas would be to continue to operate in the area with the understanding that the soils in this area are generally of lower fertility and quality than those in other portions of the province. Because of the nature of these soils, even a small deterioration in the physical condition of the soils in this area can cause losses in soil fertility and degradation of soil properties.

This study found that, in terms of the response of specific soils to the effects of cultivation, test site 13, which contained the soil with the highest sand content, showed the poorest soil condition of the uncultivated soils. The cultivated soil in this test site showed the greatest negative impact from cultivation, as well. This finding suggests that sandy soils should not be used for long term cropping, and cultivation should be avoided.

The Solonetzic soils in the study area seemed to respond well to cultivation. In many cases the condition of these soils seemed to improve after cultivation, especially in the case of test site 15. That would suggest that these soils might benefit from long term cultivation if managed properly.

In determining which lands should be made available for public sale, the Special Areas Board will need to give due regard to the highly variable nature of the soils in the Special Areas. Due to that highly variable nature, assessing which pieces of land would be suitable for public sale, as well as what caveats should be attached to the sale, could be difficult and involved. Any one quarter-section of land which is considered for sale could contain a variety of soil types; some of which are conducive to cultivation and some of which may not be. To discover whether or not this is the case, a very detailed soil survey would have to be conducted to identify the various soil types. Then, the response of each soil type to long term cultivation would have to be determined.

If the results of those investigations show that only a portion of the land is sensitive to cultivation or if scattered areas through out the quarter section are sensitive, then a decision would have to be made whether or not the land would be too "sensitive" for sale. If an error is made in the decision to sell and/or appropriate caveats have not placed on the use of the land, serious problems (both environmental and legal) could result. The government would no longer have control over the land and therefore would not be in a position to ensure a corrective course of action is undertaken.

However, the author feels that, due to the history of the Special Areas and the continuous guidance and support from the Special Areas Board, the farmers in the area have become very conscious of the fragility of the land they are working. As a result, they are very concerned about their land and show a great interest in learning about improved methods and techniques in soil conservation. That attitude may be the key to resolving many of the concerns involved in selling portions of the Special Areas, since the Board is limiting land sales to farmers in the Special Areas who are very familiar with farming conditions there.

The farmers who work in the Special Areas do not want to see the land, and, consequently, their livelihood destroyed. Mr. Abe Grover, Chairman of the Special Areas Board, stated, "since the 1930's, residents have become aware of how to live with this land and are practicing good dryland farming and grazing practices". As a result, "very little land (in the Special Areas) is subject to erosion and I don't think we suffered from the '84 drought as much as other areas." (Alberta Environment, 1986:11).

In conclusion, this author would recommend that the Special Areas Board proceed cautiously with land sales, initially. No land sales have occurred as yet, however, when land sales begin, monitoring should be carried out to determine if any problems in land use develop. In that way information gleaned from earlier land sales could be used to fine tune or modify the land sales program.

The working relationship between the Special Areas Board and the farmers in this area appears to be a good one. Over the years, the Special Areas Board has developed a wealth of knowledge of the land and land management in the Special Areas. Perhaps that expertise could be maintained and the existing relationship between the farmers and the Board could continue after the sales begin so that both sides can benefit and gain experience for use in the future.

8.4 Recommendations for Further Research

A great deal of research has been conducted on the effects of cultivation on various soil properties; however, little work has been conducted on the soils of the Special

Areas. Additional work in this area would assist in determining which soils are suitable for long term cultivation and which soils should be kept for grazing purposes. It also would help to establish which pieces of land could be considered for sale and which are too sensitive to be removed from government control.

The results of this study suggest a number of areas where further research could assist our understanding of the soils of the Special Areas. For example, in this study, the sample population consisted of different soil orders and soils with different textures. Future research which held those two factors constant could provide more detailed information on the effects of cultivation on soils which exhibit specific soil properties. In addition, those studies also would provide more detailed information to assist the Special Areas Board and area farmers to determine which lands should be cultivated and which should be used only for natural pasture. In future research, increasing the sample population (closer to 50, which is defined as the minimal optimum sample size by Elliott, 1977:95) also would assist in establishing the statistical significance of the study results.

The method of cultivation used, the machinery used and the field conditions at the time of cultivation, should be taken into account in future research on the effect of cultivation on the soils in this area. Those factors may be responsible for a large part of the difference observed between uncultivated and cultivated soils. One final suggestion is that areas of abandoned land be included in future research to determine if the effects of cultivation result in permanent alterations, whether the soils revert to their original state or whether they form a third soil state, different from both the virgin soil and the cultivated soil in the Special Areas.

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APPENDIX "A"

SOIL DESCRIPTIONS

SOIL DESCRIPTION - SOIL PIT 1-A

Legal Description: S.W.5-36-8 W.4M.

Soil Classification: Eluviated Dark Brown Chernozem

Landform Classification: Hummocky moraine

Parent Material: Morainal (clayey, cobbly till)

Slope: Nearly level, .5 - 2% slope

Aspect: 215^{o}, S./S.W.

PROFILE DESCRIPTION:*

Ah	0-15 cm.; dark brown (10YR 4/3) loam; well formed, medium to coarse subangular blocky; friable; clear boundary; medium acid (5.6).
Ae	15-25 cm.; dark yellowish brown (10YR 4/4) loam; well formed, medium to coarse subangular blocky; friable; gradual boundary; medium acid (5.7).
Btj	25-37 cm.; dark brown (10YR 3/3) loam; well formed, coarse to very coarse subangular blocky; firm; gradual boundary; medium acid (5.7).
Bm	37-40+ cm.; dark brown (10YR 3/3) loam; well formed coarse to very coarse subangular blocky; firm; medium acid (5.8)

* (Soil pit excavations were limited to a depth of 45 cm., therefore the data required for the descriptions of the C horizons are not available, except for test site 13.)

SOIL DESCRIPTION - SOIL PIT 1-B

Legal Description: S.W.5-36-8 W.4M.

Soil Classification: Eluviated Dark Brown Chernozem

Landform Classification: Hummocky moraine

Parent Material: Morainal (clayey, cobbly till)

Slope: Nearly level, .5 - 2% slope

Aspect: 215^{o}, S./S.W.

PROFILE DESCRIPTION:

Ap	0-16 cm.; dark brown (10YR 4/3) sandy loam; well formed, medium to coarse subangular blocky; friable; clear boundary; medium acid (5.9).
Ae	16-25.5 cm.; dark yellowish brown (10YR 4/4) sandy loam; well formed, medium to coarse subangular blocky; friable; irregular boundary; slightly acid (6.2).
Btj	25.5- 36.5 cm.; dark brown (10YR 3/3) sandy clay loam; well formed, coarse to very coarse subangular blocky; firm; gradual boundary; neutral (6.6).
Bm	36.5-40+ cm.; dark brown (10YR 3/3) sandy clay loam; well formed, coarse to very coarse subangular blocky; firm; neutral (6.6).

SOIL DESCRIPTION - SOIL PIT 2-A

Legal Description: S.E.19-35-8 W.4M.

Soil Classification: Brown Solodized Solonetz

Landform Classification: Ground moraine

Parent Material: Weathered Soft Rock and Morainal (clayey, cobbly till)

Slope: Level, 0 -.5% slope

Aspect: n.a.

PROFILE DESCRIPTION:

Ah	0-11 cm.; brown (10YR 5/3) loam; weakly formed, medium to fine subangular blocky; very friable; clear boundary; medium acid (5.7).
Ae	11-17 cm.; pale brown (10YR 6/3) loam; moderately formed, fine platy; friable; abrupt boundary, slightly acid (6.1).
Bnt	17-40+ cm.; dark brown (10YR 3/3) clay loam; strongly formed, coarse columnar; very firm; strongly alkaline (9.0).

SOIL DESCRIPTION - SOIL PIT 2-B

Legal Description: S.E.19-35-8 W.4M.

Soil Classification: Brown Solodized Solonetz

Landform Classification: Ground moraine

Parent Material: Weathered Soft Rock and Morainal (clayey, cobbly till)

Slope: Level, 0 - .5% slope

Aspect: n.a.

PROFILE DESCRIPTION:

Ap	0-10 cm.; brown (10 YR 5/3) sandy loam; weakly formed, fine to medium, subangular blocky; friable; clear boundary; medium acid (5.8).
Ae	10-28 cm.; pale brown (10YR 6/3) sandy loam; moderately well formed, fine platy; friable; clear boundary; slightly acid (6.3).
Bnt	28-40+ cm.; dark brown (10 YR 3/3) clay; strongly formed coarse columnar; firm; slightly acid (6.3).

SOIL DESCRIPTION - SOIL PIT 3-A

Legal Description: N.E.31-36-6 W.4M.

Soil Classification: Dark Brown Solodized Solonetz

Landform Classification: Ground moraine

Parent Material: Weathered Soft Rock and Morainal (clayey, cobbly till)

Slope: Very gentle, 2 - 5% slope

Aspect: 155^{o}, S.E.

PROFILE DESCRIPTION:

Ah	0-7 cm.; dark brown (10YR 3/3) clay loam; strongly formed, fine subangular blocky; firm; clear boundary; neutral (7.2).
Ae	7-13 cm.; brown (10YR 5/3) clay loam; well formed, fine platy; friable; wavy boundary; mildly alkaline (7.4).
Bnt	13-25 cm.; very dark grayish brown (10YR 3/2) heavy clay; strongly formed, coarse columnar; firm; irregular boundary; mildly alkaline (7.7).
IIBnt	25-40+ cm.; dark brown (10YR 3/3) heavy clay; strongly formed, coarse columnar; firm; mildly alkaline (7.7).

SOIL DESCRIPTION - SOIL PIT 3-B

Legal Description: N.E.31-36-6 W.4M.

Soil Classification: Dark Brown Solodized Solonetz

Landform Classification: Ground moraine

Parent Material: Weathered Soft Rock and Morainal (clayey, cobbly till)

Slope: Very gentle, 2 - 5% slope

Aspect: 155^{o}, S.E.

PROFILE DESCRIPTION:

Ap	0-16 cm.; dark brown (10YR 3/3) clay loam; moderately well formed, fine to medium subangular blocky; friable; clear boundary; neutral (6.6).
Bnt	16-25 cm.; very dark grayish brown (10YR 3/2) clay; strongly formed, coarse columnar; firm; clear boundary; neutral (7.0).
IIBnt	25-40+ cm.; dark brown (10YR 3/3) clay; strongly formed, coarse columnar; firm; neutral (7.0).

SOIL DESCRIPTION - SOIL PIT 4-A

Legal Description: N.W.35-36-7 W.4M.

Soil Classification: Orthic Dark Brown Chernozem

Landform Classification: Hummocky moraine

Parent Material: Morainal (clayey, cobbly till)

Slope: Very gentle, 2 - 5% slope

Aspect: 220^{0}, S./S.W.

PROFILE DESCRIPTION:

Ah 0-15 cm.; dark brown (10YR 3/3) sandy clay loam; moderately well formed, medium to course subangular blocky; friable; gradual boundary; strongly acid (5.5).

Bm 15-40+ cm.; dark brown (10YR 4/3) sandy loam; well formed, coarse subangular blocky; friable; slightly acid (6.3).

SOIL DESCRIPTION - SOIL PIT 4-B

Legal Description: N.E.34-36-7 W.4M.

Soil Classification: Orthic Dark Brown Chernozem

Landform Classification: Hummocky moraine

Parent Material: Morainal (clayey, cobbly till)

Slope: Very gentle, 2 - 5% slope

Aspect: 220^{0}, S./S.W.

PROFILE DESCRIPTION:

Ap	0-20 cm.; dark brown (10YR 3/3) sandy clay loam; moderately well to strongly formed; fine to coarse subangular blocky; friable; abrupt boundary; strongly acid (5.2).
Bm	20-40+ cm.; dark brown (10YR 4/3) sandy clay loam; well to strongly formed; medium to coarse subangular blocky; friable; medium acid (5.8).

SOIL DESCRIPTION - SOIL PIT 5-A

Legal Description: S.W.9-37-6 W.4M.

Soil Classification: Orthic Dark Brown Chernozem

Landform Classification: Hummocky moraine

Parent Material: Morainal (clayey, cobbly till)

Slope: Very gentle, 2 - 5% slope

Aspect: 100^{0}, E./S.E.

PROFILE DESCRIPTION:

Ah	0-12 cm.; dark grayish brown (10YR 4/2) sandy clay loam; moderately well formed, medium subangular blocky; friable; gradual boundary; medium acid (5.6).
Btj	12-26 cm.; dark yellowish brown (10YR 4/4) sandy clay; well to strongly formed, fine prismatic; firm; wavy boundary; slightly acid (6.1).
Bm	26-40+ cm.; dark brown (10 YR 3/3) sandy clay; moderately well to well formed, fine prismatic; friable; slightly acidic (6.5).

SOIL DESCRIPTION - SOIL PIT 5-B

Legal Description: S.W.9-37-6 W.4M.

Soil Classification: Orthic Dark Brown Chernozem:

Landform Classification: Hummocky moraine

Parent Material: Morainal (clayey, cobbly till)

Slope: Very gentle, 2 - 5% slope

Aspect: 100^{o}, E./S.E.

PROFILE DESCRIPTION:

Ap	0-16.5 cm.; dark grayish brown (10YR 4/2) sandy clay loam; weakly formed, fine to medium subangular; friable; clear boundary; strongly acid (5.4).
Bm	16.5-40+ cm.; dark yellowish brown (10YR 4/4) sandy clay loam; weakly formed, fine prismatic; friable; neutral (6.6).

SOIL DESCRIPTION - SOIL PIT 6-A

Legal Description: N.E.34-35-6 W.4M.

Soil Classification: Orthic Dark Brown Chernozem

Landform Classification: Hummocky moraine

Parent Material: Morainal (clayey, cobbly till)

Slope: Nearly level, .5 - 2% slope

Aspect: 120^{o}, E./S.E.

PROFILE DESCRIPTION:

Ah	0-11 cm.; dark brown (10YR 4/3) sandy clay loam; moderately well formed, fine to medium subangular; firm; gradual boundary; neutral (7.2).
Bm	12-20 cm.; dark yellowish brown (10YR 4/5) sandy clay loam; moderately well formed, fine prismatic; friable; irregular boundary, mildly alkaline (7.7).
IIBm	20-40+ cm.; grayish brown (10YR 5/2) sandy clay loam; well formed, fine prismatic; friable; moderately alkaline (8.4).

SOIL DESCRIPTION - SOIL PIT 6-B

Legal Description: N.W.34-35-6 W.4M.

Soil Classification: Orthic Dark Brown Chernozem

Landform Classification: Hummocky moraine

Parent Material: Morainal (clayey, cobbly till)

Slope: Very gentle, .5 - 2% slope

Aspect: 120^{o}, E./S.E.

PROFILE DESCRIPTION:

Ap	0-13 cm.; dark grayish brown (10YR 4/2) sandy clay loam; weak to moderately well formed; medium to coarse subangular blocky; firm; abrupt boundary; medium acid (5.8).
Bm	13-32.5 cm.; dark yellowish brown (10YR 4/4) sandy clay loam; moderately well formed, medium to coarse subangular blocky; firm; gradual boundary; mildly alkaline (7.6).
IIBm	32.5-40+ cm.; dark brown (10YR 4/3) sandy clay loam; moderately well formed, fine prismatic; firm; moderately alkaline (8.4).

SOIL DESCRIPTION - SOIL PIT 7-A

Legal Description: S.W.30-35-5 W.4M.

Soil Classification: Orthic Dark Brown Chernozem

Landform Classification: Hummocky moraine

Parent Material: Morainal (clayey, cobbly till)

Slope: Level, 0 - .5% slope

Aspect: n.a.

PROFILE DESCRIPTION:

Ah	0-11.5 cm.; dark grayish brown (10YR 4/2) loam; moderately well formed; medium to coarse subangular blocky; friable; clear boundary; slightly acid (6.5).
Bm	11.5-19 cm.; dark brown (10YR 4/3) sandy loam; weakly to moderately well formed; medium to course subangular blocky; friable; irregular boundary; neutral (6.7).
IIBm	19-40+ cm.; dark yellowish brown (10YR 4/4) sandy loam; moderately well formed; medium to course subangular blocky; friable; neutral (6.7).

SOIL DESCRIPTION - SOIL PIT 7-B

Legal Description: N.W.30-35-5 W.4M.

Soil Classification: Orthic Dark Brown Chernozem

Landform Classification: Hummocky moraine

Parent Material: Morainal (clayey, cobbly till)

Slope: Level, 0 - .5% slope

Aspect: n.a.

PROFILE DESCRIPTION:

Ap 0-20 cm.; dark brown (10YR 3/3) sandy clay loam; moderately well formed; fine to medium subangular blocky; friable; clear boundary; medium acid (5.7).

Bm 20-40+ cm.; dark yellowish brown (10YR 4/4) loam; moderately well formed; medium subangular blocky; friable; slightly acid (6.5).

SOIL DESCRIPTION - SOIL PIT 8-A

Legal Description: N.E.31-35-5 W.4M.

Soil Classification: Orthic Dark Brown Chernozem

Landform Classification: Hummocky moraine

Parent Material: Morainal (clayey, cobbly till)

Slope: Nearly level, .5 - 2% slope

Aspect: n.a.

PROFILE DESCRIPTION:

Ah	0-7 cm.; dark brown (10YR 4/3) sandy clay loam; moderately well to strongly formed, fine to medium subangular blocky; firm; gradual boundary; slightly acid (6.1).
Bm	7-35 cm.; dark yellowish brown (10YR 4/4) sandy clay loam; well to strongly formed, medium prismatic; firm; wavy boundary; neutral (6.9).
IIBm	35-40+; dark yellowish brown (10YR 4/5) sandy clay loam; well to strongly formed, medium prismatic; firm; mildly alkaline (7.8).

SOIL DESCRIPTION - SOIL PIT 8-B

Legal Description: N.E.31-35-5 W.4M.

Soil Classification: Orthic Dark Brown Chernozem

Landform Classification: Hummocky moraine

Parent Material: Morainal (clayey, cobbly till)

Slope: Nearly level, .5 - 2% slope

Aspect: n.a.

PROFILE DESCRIPTION:

Ap	0-17 cm.; dark grayish brown (10YR 4/2) loam; weakly formed; fine to medium subangular blocky; friable; clear boundary; strongly acid (5.5).
Bm	17-28 cm.; brown (10YR 4.5/3) loam; moderately well formed, medium subangular blocky; firm; gradual boundary; medium acid (5.8).
IIBm	28-40+ cm.; dark yellowish brown (10YR 4/4) loam; moderately well formed; medium prismatic; firm; slightly acid (6.3).

SOIL DESCRIPTION - SOIL PIT 9-A

Legal Description: N.E.31-34-6 W.4M.

Soil Classification: Orthic Dark Brown Chernozem

Landform Classification: Hummocky moraine

Parent Material: Morainal (clayey, cobbly till)

Slope: Nearly level, .5 - 2% slope

Aspect: 163^{o}, S./S.E.

PROFILE DESCRIPTION:

Ah   0-12 cm.; dark grayish brown (10YR 4/2) sandy clay loam; moderately well formed, fine to medium subangular blocky; friable; gradual boundary; medium acid (5.9).

Bm   12-40+ cm.; brown (10YR 5/3) sandy loam; weakly to moderately well formed, fine to medium subangular blocky; friable; slightly acid (6.4).

SOIL DESCRIPTION - SOIL PIT 9-B

Legal Description: S.E.31-34-6 W.4M.

Soil Classification: Eluviated Dark Brown Chernozem

Landform Classification: Hummocky moraine

Parent Material: Morainal (clayey, cobbly till)

Slope: Nearly level, .5 - 2% slope

Aspect: 163^{o}, S./S.E.

PROFILE DESCRIPTION:

Ap 0-20 cm.; dark brown (10YR 4/3) sandy loam; moderately well formed, fine to medium subangular blocky; friable; abrupt boundary; strongly acid (5.5).

Ae 20-27 cm.; yellowish brown (10YR 5/4) sandy loam; moderately well formed, fine to medium subangular blocky; friable; irregular boundary; slightly acid (6.1).

Btj 27-40+ cm.; dark yellowish brown (10YR 4.4) sandy clay loam; moderately well to strongly formed, medium subangular blocky; firm; mildly alkaline (7.7).

SOIL DESCRIPTION - SOIL PIT 10-A

Legal Description: S.W.13-36-8 W.4M.

Soil Classification: Eluviated Dark Brown Chernozem

Landform Classification: Hummocky moraine

Parent Material: Morainal (clayey, cobbly till)

Slope: Very gentle, 2 - 5% slope

Aspect: 352^{o}, N./N.W.

PROFILE DESCRIPTION:

Ah	0-18 cm.; dark grayish brown (10YR 4/2) sandy loam; weakly formed, fine to moderate subangular blocky; very friable; gradual boundary; medium acid (5.7).
Ae	18-26 cm.; grayish brown (10YR 5/2) sandy loam; weak to moderately formed, fine platy; very friable; clear boundary; slightly acid (6.3).
Btj	26-40+ cm.; dark yellowish brown (10YR 3/4) sandy clay loam; moderately well formed, fine to medium subangular blocky; friable; strongly alkaline (9.1).

SOIL DESCRIPTION - SOIL PIT 10-B

Legal Description: S.W.13-36-8 W.4M.

Soil Classification: Eluviated Dark Brown Chernozem

Landform Classification: Hummocky moraine

Parent Material: Morainal (clayey, cobbly till)

Slope: Very gentle, 2 - 5% slope

Aspect: 352°, N./N.W.

PROFILE DESCRIPTION:

Ap	0-16 cm.; dark grayish brown (10YR 4/2) sandy loam; moderately well formed, medium subangular blocky; friable; clear boundary; strongly acid (5.1).
Ae	16-20 cm.; grayish brown (10YR 5/2) sandy loam; moderately well formed, fine platy; friable; irregular boundary; medium acid (6.0).
Btj	20-34 cm.; dark brown (10YR 3/3) clay loam; moderately well to strongly formed, medium to coarse subangular blocky; friable; gradual boundary; neutral (6.6).
Bm	34-40+ cm.; dark yellowish brown (10YR 3/4) loam; moderately well formed, medium to coarse subangular blocky; friable; neutral (6.9).

SOIL DESCRIPTION - SOIL PIT 11-A

Legal Description: S.E.6-35-8 W.4M.

Soil Classification: Orthic Dark Brown Chernozem

Landform Classification: Hummocky moraine

Parent Material: Morainal (clayey, cobbly till)

Slope: Very gentle, 2 - 5% slope

Aspect: 174^{o}, S./S.E.

PROFILE DESCRIPTION:

Ah	0-17 cm.; dark grayish brown (10YR 4/2) loam; moderately well formed, medium to coarse subangular blocky; friable; clear boundary; medium acid (5.8).
Bm	17-40+ cm.; dark yellowish brown (10YR 4/4) sandy clay loam; moderately well to well formed, medium to coarse subangular blocky; friable; slightly acid (6.3)

SOIL DESCRIPTION - SOIL PIT 11-B

Legal Description: S.E.6-35-8 W.4M.

Soil Classification: Orthic Dark Brown Chernozem

Landform Classification: Hummocky moraine

Parent Material: Morainal (clayey, cobbly till)

Slope: Very gentle, 2 - 5% slope

Aspect: 174^{o}, S./S.E.

PROFILE DESCRIPTION:

Ap   0-14 cm.; dark brown (10YR 4/3) sandy clay loam; weakly formed, medium subangular blocky; friable; clear boundary; medium acid (5.6).

Bm   14-40+ cm.; dark yellowish brown (10YR 4/4) sandy clay loam; weakly formed, medium subangular blocky; friable; slightly acid (6.5).

SOIL DESCRIPTION - SOIL PIT 12-A

Legal Description: N.E.36-34-6 W.4M.

Soil Classification: Orthic Dark Brown Chernozem

Land Classification: Hummocky moraine

Parent Material: Morainal (clayey, cobbly till)

Slope: Very gentle 2 - 5% slope

Aspect: 25^{0}, N./N.E.

PROFILE DESCRIPTION:

Ah	0-11 cm.; dark brown (10YR 3/3) loam; moderately well formed, medium to coarse subangular blocky; very friable; gradual boundary; medium acid (5.8).
Bm	11-40+ cm.; dark yellowish brown (10YR 3/4) loam: moderately well formed, medium to coarse subangular blocky; friable; medium acid (6.0).

SOIL DESCRIPTION - SOIL PIT 12-B

Legal Description: N.E.36-34-6 W.4M.

Soil Classification: Orthic Dark Brown Chernozem

Landform Classification: Hummocky moraine

Parent Material: Morainal (clayey, cobbly till)

Slope: Very gentle, 2 - 5% slope

Aspect: 25^{o}, N./N.E.

PROFILE DESCRIPTION:

Ap	0-15 cm.; dark grayish brown (10YR 4/2) loam; moderately well formed, medium to coarse subangular blocky; firm; clear boundary; strongly acid (5.2).
Bm	15-40+ cm.; dark brown (10YR 4/3) loam; moderately well formed, medium to coarse subangular blocky; firm; slightly acid (6.2).

SOIL DESCRIPTION - SOIL PIT 13-A

Legal Description: S.W.26-34-6 W.4M.

Soil Classification: Rego Dark Brown Chernozem

Landform Classification: Hummocky moraine

Parent Material: Morainal (clayey, cobbly till)

Slope: Very gentle, 2 - 5% slope

Aspect: 173^{0}, S./S.E.

PROFILE DESCRIPTION:

Ah — 0-11 cm.; dark brown (10YR 3/3) loamy sand; weak to moderately well formed, fine to medium subangular blocky; very friable; clear boundary; sightly acid (6.1).

C — 11-40+ cm.; dark yellowish brown (10YR 4/4) loamy sand weak to moderately well formed, fine to medium subangular blocky; very friable; slightly acid (6.4).

SOIL DESCRIPTION - SOIL PIT 13-B

Legal Description: N.W.26-34-6 W.4M.

Soil Classification: Rego Dark Brown Chernozem

Landform Classification: Hummocky moraine

Parent Material: Morainal (clayey, cobbly till)

Slope: Very gentle, 2 - 5% slope

Aspect: 173°, S./S.E.

PROFILE DESCRIPTION:

Ap	0-13 cm.; dark brown (10YR 4/3) loam; weakly formed, fine to medium subangular blocky; very friable; gradual boundary; neutral (7.0).
C	13-40+ cm.; dark yellowish brown (10YR 4/4) loam; weakly formed, fine to medium subangular blocky; very friable; mildly alkaline (7.7).

SOIL DESCRIPTION - SOIL PIT 14-A

Legal Description: S.W.15-35-7 W.4M.

Soil Classification: Orthic Dark Brown Chernozem

Landform Classification: Hummocky moraine

Parent Material: Morainal (clayey, cobbly till)

Slope: Nearly level, .5% - 2% slope

Aspect: 177^{o}, S.

PROFILE DESCRIPTION:

Ah 0-14 cm.; dark brown (10YR 4/3) sandy loam; moderately well formed, medium to coarse subangular blocky; friable; clear boundary; neutral (6.9).

Bm 14-40+ cm.; dark yellowish brown (10YR 4/4) sandy clay loam; strongly formed, medium to coarse subangular blocky; firm; moderately alkaline (8.3).

SOIL DESCRIPTION - SOIL PIT 14-B

Legal Description: S.W.15-35-7 W.4M.

Soil Classification: Orthic Dark Brown Chernozem

Landform Classification: Hummocky moraine

Parent Material: Morainal (clayey, cobbly till)

Slope: Nearly level, .5 - 2% slope

Aspect: 177^{o}, S.

PROFILE DESCRIPTION:

Ap 0-18 cm.; dark brown (10YR 4/3) sandy loam; weakly formed, fine subangular blocky; friable; clear boundary, neutral (7.0).

Bm 18-40+ cm.; dark yellowish brown (10Yr 4/4) sandy loam; weakly formed, fine to medium subangular blocky; friable; moderately alkaline (8.1).

SOIL DESCRIPTION - SOIL PIT 15-A

Legal Description: S.E.28-35-5 W.4M.

Soil Classification: Dark Brown Solodized Solonetz

Landform Classification: Ground moraine

Parent Material: Weathered Soft Rock and Morainal (clayey, cobbly till)

Slope: Level, 0 - .5% slope

Aspect: n.a.

PROFILE DESCRIPTION:

Ah	0-8 cm.; dark yellowish brown (10YR 4/4) clay loam; moderately well formed, fine to medium in texture; friable; clear boundary; neutral (6.7).
Ae	8-15 cm.; light grayish brown (10YR 6/2) clay loam; moderately well formed, fine to medium subangular blocky; friable; irregular boundary; neutral (6.6)
Bnt	15-29 cm.; very dark grayish brown (10YR 3/2) heavy clay; strongly formed, coarse columnar; very firm; abrupt boundary; strongly alkaline (8.5).
Bmk	29-40+ cm.; very dark grayish brown (10Yr 3/2) heavy clay; strongly formed, coarse blocky; very firm; moderately alkaline (8.3).

SOIL DESCRIPTION - SOIL PIT 15-B

Legal Description: S.W.28-35-5 W.4M.

Soil Classification: Dark Brown Solodized Solonetz

Landform Classification: Ground moraine

Parent Material: Weathered Soft Rock and Morainal (clayey, cobbly till)

Slope: Level, 0 - .5% slope

Aspect: n.a.

PROFILE DESCRIPTION:

Ap	0-17 cm.; dark brown (10YR 4/3) clay loam; strongly formed, fine to coarse, subangular blocky; firm; clear boundary; mildly alkaline (7.5).
Ae	17-30 cm.; light brownish gray (10YR 6/2) clay loam; strongly formed, fine to coarse subangular blocky; firm; clear boundary; mildly alkaline (7.7).
Bnt	30-40+ cm.; dark brown (10YR 4/3) clay; strongly formed, coarse columnar; very firm; strongly alkaline (9.3).

APPENDIX "B"

SOIL DATA

SOIL DATA

	pH	Cond. (mmhos)	% Water Content	15 bar (gm. H2O/ gm. soil)	% Water (15 bar)	1/3 bar (gm. H2O/ gm. soil)	% Water (1/3 bar)	Available Water (F.C.-W.P.)	% Avail. Water
1A (0-20)	5.6	1.40	10.4	0.056	5.6	0.117	11.7	0.061	6.1
1A (20-40)	5.7	0.55	4.7	0.036	3.6	0.078	7.8	0.042	4.2
1B (0-20)	5.9	1.14	5.8	0.039	3.9	0.074	7.4	0.035	3.5
1B (20-40)	6.6	0.74	4.2	0.039	3.9	0.077	7.7	0.038	3.8
2A (0-20)	5.7	0.51	2.3	0.039	3.9	0.080	8.0	0.041	4.1
2A (20-40)	9.0	6.00	3.5	0.129	12.9	0.254	25.4	0.125	12.5
2B (0-20)	5.8	1.41	3.8	0.033	3.3	0.067	6.7	0.034	3.4
2B (20-40)	8.7	3.99	6.6	0.071	7.1	0.140	14.0	0.069	6.9
3A (0-20)	7.2	1.20	6.6	0.128	12.8	0.253	25.3	0.125	12.5
3A (20-40)	7.7	25.00	8.0	0.093	9.3	0.185	18.5	0.092	9.2
3B (0-20)	6.6	0.75	7.5	0.100	10.0	0.199	19.9	0.099	9.9
3B (20-40)	7.0	6.65	8.3	0.078	7.8	0.154	15.4	0.076	7.6
4A (0-20)	5.5	1.74	1.8	0.049	4.9	0.095	9.5	0.046	4.6
4A (20-40)	6.3	0.63	4.2	0.054	5.4	0.108	10.8	0.054	5.4
4B (0-20)	5.2	1.16	6.4	0.038	3.8	0.075	7.5	0.037	3.7
4B (20-40)	5.8	0.55	3.9	0.038	3.8	0.073	7.3	0.035	3.5
5A (0-20)	5.6	0.80	4.3	0.063	6.3	0.125	12.5	0.062	6.2
5A (20-40)	6.5	0.39	4.3	0.049	4.9	0.099	9.9	0.050	5.0
5B (0-20)	5.4	1.40	6.7	0.062	6.2	0.125	12.5	0.063	6.3
5B (20-40)	6.6	0.50	4.3	0.048	4.8	0.093	9.3	0.045	4.5
6A (0-20)	7.2	1.08	3.9	0.037	3.7	0.073	7.3	0.036	3.6
6A (20-40)	8.4	1.20	4.5	0.033	3.3	0.067	6.7	0.034	3.4
6B (0-20)	5.8	1.08	5.1	0.031	3.1	0.063	6.3	0.032	3.2
6B (20-40)	8.3	1.30	4.4	0.033	3.3	0.064	6.4	0.031	3.1
7A (0-20)	6.5	0.70	4.7	0.054	5.4	0.105	10.5	0.051	5.1
7A (20-40)	6.7	0.40	3.4	0.036	3.6	0.073	7.3	0.037	3.7
7B (0-20)	5.7	0.91	6.1	0.034	3.4	0.066	6.6	0.032	3.2
7B (20-40)	6.5	0.56	4.8	0.034	3.4	0.067	6.7	0.033	3.3
8A (0-20)	6.1	0.91	3.4	0.045	4.5	0.091	9.1	0.046	4.6
8A (20-40)	7.8	1.15	4.5	0.031	3.1	0.063	6.3	0.032	3.2
8B (0-20)	5.5	1.20	5.9	0.037	3.7	0.051	5.1	0.014	1.4
8B (20-40)	6.3	0.38	3.8	0.025	2.5	0.063	6.3	0.038	3.8
9A (0-20)	5.9	0.31	1.9	0.031	3.1	0.115	11.5	0.084	8.4
9A (20-40)	6.4	0.37	1.8	0.058	5.8	0.061	6.1	0.003	0.3
9B (0-20)	5.5	1.00	3.8	0.030	3.0	0.125	12.5	0.095	9.5
9B (20-40)	7.7	1.30	3.2	0.063	6.3	0.064	6.4	0.001	0.1

SOIL DATA (cont.)

	pH	Cond. (mmhos)	% Water Content	15 bar (gm. H2O/ gm. soil)	% Water (15 bar)	1/3 bar (gm. H2O/ gm. soil)	% Water (1/3 bar)	Available Water (F.C.-W.P.)	% Avail. Water
10A (0-20)	5.7	0.54	3.3	0.032	3.2	0.091	9.1	0.059	5.9
10A (20-40)	9.1	1.82	3.9	0.045	4.5	0.063	6.3	0.018	1.8
10B (0-20)	5.1	1.30	5.4	0.031	3.1	0.064	6.4	0.033	3.3
10B (20-40)	6.9	1.28	3.8	0.031	3.1	0.071	7.1	0.040	4.0
11A (0-20)	5.8	0.99	5.2	0.036	3.6	0.050	5.0	0.014	1.4
11A (20-40)	6.3	0.35	2.8	0.026	2.6	0.061	6.1	0.035	3.5
11B (0-20)	5.6	1.00	3.4	0.031	3.1	0.054	5.4	0.023	2.3
11B (20-40)	6.5	0.40	2.0	0.028	2.8	0.055	5.5	0.027	2.7
12A (0-20)	5.8	0.42	5.6	0.026	2.6	0.051	5.1	0.025	2.5
12A (20-40)	6.0	0.35	4.5	0.025	2.5	0.050	5.0	0.025	2.5
12B (0-20)	5.2	0.82	5.4	0.041	4.1	0.081	8.1	0.040	4.0
12B (20-40)	6.2	0.37	4.5	0.027	2.7	0.052	5.2	0.025	2.5
13A (0-20)	6.1	0.25	0.6	0.021	2.1	0.043	4.3	0.022	2.2
13A (20-40)	6.4	0.16	1.2	0.019	1.9	0.037	3.7	0.018	1.8
13B (0-20)	7.0	0.94	0.9	0.014	1.4	0.026	2.6	0.012	1.2
13B (20-40)	7.7	0.65	3.3	0.015	1.5	0.029	2.9	0.014	1.4
14A (0-20)	6.9	0.65	3.2	0.033	3.3	0.065	6.5	0.032	3.2
14A (20-40)	8.3	0.96	4.7	0.036	3.6	0.070	7.0	0.034	3.4
14B (0-20)	7.0	0.87	5.0	0.035	3.5	0.068	6.8	0.033	3.3
14B (20-40)	8.1	0.89	3.9	0.030	3.0	0.060	6.0	0.030	3.0
15A (0-20)	6.7	0.72	12.7	0.046	4.6	0.079	7.9	0.033	3.3
15A (20-40)	8.5	30.00	11.0	0.121	12.1	0.238	23.8	0.117	11.7
15B (0-20)	7.5	0.94	8.4	0.065	6.5	0.127	12.7	0.062	6.2
15B (20-40)	9.3	5.90	5.4	0.119	11.9	0.236	23.6	0.117	11.7

SOIL DATA (cont.)

	Bulk Density (g/cm3)	Particle Density (g/cm3)	% Total Porosity	Texture Class	% Sand	% Silt	% Clay	Organic Matter	Pene-trometer
1A (0-20)	1.28	2.72	52.94	L	46.10	36.20	17.70	2.4	2.1
1A (20-40)	1.46	2.71	46.13	L	51.27	30.02	18.71	1.8	2.7
1B (0-20)	1.59	2.69	40.89	SL	57.57	23.72	18.71	2.1	2.2
1B (20-40)	1.64	2.63	37.64	SCL	63.69	14.49	21.82	1.6	2.1
2A (0-20)	1.47	2.69	45.35	L	49.20	33.12	17.68	2.1	4.5
2A (20-40)	1.44	2.69	46.47	CL	40.92	19.67	39.41	2.0	4.5
2B (0-20)	1.48	2.66	44.36	SL	56.45	25.87	17.68	1.8	2.7
2B (20-40)	1.46	2.61	44.06	C	36.78	20.70	42.52	1.6	2.7
3A (0-20)	1.43	2.65	46.04	CL	30.57	30.02	39.41	2.8	3.6
3A (20-40)	1.32	2.72	51.47	HC	24.36	10.35	65.29	2.6	3.0
3B (0-20)	1.47	2.69	45.35	CL	42.99	22.77	34.24	1.3	1.7
3B (20-40)	1.34	2.66	49.62	C	35.75	22.77	41.48	1.0	2.1
4A (0-20)	1.28	2.73	53.11	SL	61.62	21.74	16.64	4.9	3.5
4A (20-40)	1.61	2.72	40.81	SCL	51.27	19.67	29.06	1.4	3.6
4B (0-20)	1.37	2.66	48.50	SL	65.76	19.67	14.57	4.7	2.1
4B (20-40)	1.64	2.73	39.93	SCL	57.48	18.63	23.89	1.1	3.3
5A (0-20)	1.28	2.72	52.94	SCL	47.76	22.14	30.10	3.6	4.2
5A (20-40)	1.35	2.65	49.06	SC	45.06	19.67	35.27	1.5	4.0
5B (0-20)	1.46	2.71	46.13	SCL	48.17	23.80	28.03	3.2	2.5
5B (20-40)	1.54	2.63	41.44	SCL	46.10	21.73	32.17	0.9	3.0
6A (0-20)	1.22	2.68	54.48	SCL	59.18	18.63	22.19	4.0	2.3
6A (20-40)	1.43	2.67	46.44	SCL	50.90	20.70	28.40	1.6	2.6
6B (0-20)	1.35	2.68	49.63	SCL	59.18	18.63	22.19	2.6	2.3
6B (20-40)	1.45	2.65	45.28	SCL	51.94	23.80	24.26	1.1	2.6
7A (0-20)	1.14	2.63	56.65	L	47.80	27.94	24.26	4.2	4.5
7A (20-40)	1.16	2.61	55.56	SL	52.97	31.05	15.98	1.2	3.0
7B (0-20)	1.38	2.61	47.13	SCL	51.94	20.70	27.36	2.9	2.8
7B (20-40)	1.46	2.58	43.41	L	40.55	32.09	27.36	0.9	3.4
8A (0-20)	1.32	2.66	50.38	SCL	48.83	22.77	28.40	3.6	4.5
8A (20-40)	1.21	2.60	53.46	SCL	52.97	22.77	24.26	1.5	4.0
8B (0-20)	1.42	2.61	45.59	L	46.76	34.16	19.08	3.2	3.4
8B (20-40)	1.33	2.64	49.62	L	50.90	30.02	19.08	1.1	2.2
9A (0-20)	1.36	2.66	48.87	SCL	52.97	26.91	20.12	2.9	4.2
9A (20-40)	1.48	2.61	43.30	SL	55.04	25.88	19.08	1.5	3.5
9B (0-20)	1.38	2.63	47.53	SL	57.11	27.95	14.94	2.5	3.7
9B (20-40)	1.50	2.67	43.82	SCL	48.83	24.84	26.33	1.0	3.3

SOIL DATA (cont.)

	Bulk Density (g/cm3)	Particle Density (g/cm3)	% Total Porosity	Texture Class	% Sand	% Silt	% Clay	Organic Matter	Pene-trometer
10A (0-20)	1.24	2.68	53.73	SL	57.11	26.91	15.98	4.4	3.0
10A (20-40)	1.51	2.61	42.15	SCL	63.32	15.52	21.16	1.2	3.0
10B (0-20)	1.49	2.63	43.35	SL	60.22	23.80	15.98	2.5	2.2
10B (20-40)	1.71	2.66	35.71	CL	35.38	31.05	33.57	0.9	2.0
11A (0-20)	1.42	2.64	46.21	L	47.51	28.98	23.51	4.3	3.4
11A (20-40)	1.43	2.65	46.04	SCL	52.68	23.81	23.51	1.6	3.1
11B (0-20)	1.50	2.66	43.61	SCL	51.65	24.84	23.51	3.2	2.9
11B (20-40)	1.51	2.65	43.02	SCL	53.72	18.63	27.65	1.0	2.6
12A (0-20)	1.37	2.62	47.71	L	51.65	30.01	18.34	4.3	2.8
12A (20-40)	1.42	2.62	45.80	L	48.54	27.95	23.51	1.3	1.7
12B (0-20)	1.46	2.64	44.70	L	43.37	34.15	22.48	3.5	3.2
12B (20-40)	1.58	2.62	39.69	L	38.19	38.30	23.51	1.1	3.1
13A (0-20)	1.46	2.65	44.91	LS	82.70	11.38	5.92	3.5	4.5
13A (20-40)	1.57	2.65	40.75	LS	83.73	8.28	7.99	2.1	3.1
13B (0-20)	1.53	2.65	42.26	LS	86.84	5.17	7.99	1.1	2.6
13B (20-40)	1.65	2.64	37.50	LS	87.87	4.14	7.99	0.8	1.9
14A (0-20)	1.43	2.61	45.21	SL	60.96	21.74	17.30	2.9	3.1
14A (20-40)	1.49	2.61	42.91	SCL	57.86	19.66	22.48	1.6	2.6
14B (0-20)	1.45	2.60	44.23	SL	65.10	16.55	18.34	2.8	2.6
14B (20-40)	1.50	2.61	42.53	SL	58.89	21.74	19.37	1.3	3.0
15A (0-20)	1.55	2.60	40.38	CL	26.81	38.29	34.90	2.9	4.2
15A (20-40)	1.64	2.65	38.11	C	13.35	25.88	60.77	1.1	2.2
15B (0-20)	1.47	2.62	43.89	CL	24.74	38.59	36.97	2.8	2.2
15B (20-40)	1.56	2.63	40.68	C	18.53	28.98	52.49	1.5	2.3

WET AGGREGATE ANALYSIS

		5.00mm.	2.00mm.	1.00mm.	0.50mm.	0.25mm.	0.10mm.	Total Aggr. (0.10mm. & >)
1 A (0-20)	Wt of Aggr.	14.58	7.37	4.84	5.52	3.31	0.35	35.97
	% Aggr.	29.16	14.74	9.68	11.04	6.62	0.70	71.94
1 A (20-40)	Wt. of Aggr.	5.00	4.73	3.08	7.41	5.95	6.12	32.29
	% Aggr.	10.00	9.46	6.16	14.82	11.90	12.24	64.58
1 B (0-20)	Wt. of Aggr.	3.45	3.01	2.24	4.66	6.65	5.62	25.63
	% Aggr.	6.90	6.02	4.48	9.32	13.30	11.24	51.26
1 B (20-40)	Wt. of Aggr.	3.76	5.41	4.33	7.03	5.58	5.53	31.64
	% Aggr.	7.52	10.82	8.66	14.06	11.16	11.06	63.28
2 A (0-20)	Wt. of Aggr.	5.25	6.81	3.64	5.43	6.01	9.19	36.33
	% Aggr.	10.50	13.62	7.28	10.86	12.02	18.38	72.66
2 A (20-40)	Wt. of Aggr.	28.71	1.44	0.23	0.48	0.99	2.58	34.43
	% Aggr.	57.42	2.88	0.46	0.96	1.98	5.16	68.86
2 B (0-20)	Wt. of Aggr.	4.39	4.18	2.57	3.95	5.79	9.57	30.45
	% Aggr.	8.78	8.36	5.14	7.90	11.58	19.14	60.90
2 B (20-40)	Wt. of Aggr.	12.09	2.48	1.40	1.54	2.11	4.58	24.20
	% Aggr.	24.18	4.96	2.80	3.08	4.22	9.16	48.40
3 A (0-20)	Wt. of Aggr.	11.51	9.79	6.27	5.77	3.35	0.66	37.35
	% Aggr.	23.02	19.58	12.54	11.54	6.70	1.32	74.70
3 A (20-40)	Wt. of Aggr.	4.40	7.56	8.42	8.93	4.33	2.06	35.70
	% Aggr.	8.80	15.12	16.84	17.86	8.66	4.12	71.40
3 B (0-20)	Wt. of Aggr.	2.60	4.24	2.11	3.51	3.98	5.15	43.18
	% Aggr.	5.20	8.48	4.22	7.02	7.96	10.30	86.36
3 B (20-40)	Wt. of Aggr.	0.42	3.36	5.84	7.48	5.24	1.69	24.03
	% Aggr.	0.84	6.72	11.68	14.96	10.48	3.38	48.06
4 A (0-20)	Wt. of Aggr.	5.62	6.42	3.09	5.33	5.74	9.54	35.74
	% Aggr.	11.24	12.84	6.18	10.66	11.48	19.08	71.48
4 A (20-40)	Wt. of Aggr.	8.62	5.32	2.92	4.08	4.51	7.95	33.40
	% Aggr.	17.24	10.64	5.84	8.16	9.02	15.90	66.80
4 B (0-20)	Wt. of Aggr.	2.62	3.25	2.27	5.60	8.98	13.04	35.76
	% Aggr.	5.24	6.50	4.54	11.20	17.96	26.08	71.52
4 B (20-40)	Wt. of Aggr.	0.51	3.23	3.37	5.98	8.41	11.79	21.50
	% Aggr.	1.02	6.46	6.74	11.96	16.82	23.58	43.00

WET AGGREGATE ANALYSIS (cont.)

		Aggregation (1.00mm. & <)	In Suspension (< 0.10mm.)
1 A (0-20)	Wt of Aggr.	26.79	14.03
	% Aggr.	53.58	28.06
1 A (20-40)	Wt. of Aggr.	12.81	17.71
	% Aggr.	25.62	35.42
1 B (0-20)	Wt. of Aggr.	8.70	24.37
	% Aggr.	17.40	48.74
1 B (20-40)	Wt. of Aggr.	13.50	18.36
	% Aggr.	27.00	36.72
2 A (0-20)	Wt. of Aggr.	15.70	13.67
	% Aggr.	31.40	27.34
2 A (20-40)	Wt. of Aggr.	30.38	15.57
	% Aggr.	60.76	31.14
2 B (0-20)	Wt. of Aggr.	11.14	19.55
	% Aggr.	22.28	39.10
2 B (20-40)	Wt. of Aggr.	15.97	25.80
	% Aggr.	31.94	51.60
3 A (0-20)	Wt. of Aggr.	27.57	12.65
	% Aggr.	55.14	25.30
3 A (20-40)	Wt. of Aggr.	20.38	14.30
	% Aggr.	40.76	28.60
3 B (0-20)	Wt. of Aggr.	8.95	28.41
	% Aggr.	17.90	56.82
3 B (20-40)	Wt. of Aggr.	9.62	25.97
	% Aggr.	19.24	51.94
4 A (0-20)	Wt. of Aggr.	15.13	14.26
	% Aggr.	30.26	28.52
4 A (20-40)	Wt. of Aggr.	16.86	16.60
	% Aggr.	33.72	33.20
4 B (0-20)	Wt. of Aggr.	8.14	14.24
	% Aggr.	16.28	28.48
4 B (20-40)	Wt. of Aggr.	7.11	28.50
	% Aggr.	14.22	57.00

WET AGGREGATE ANALYSIS (cont.)

		5.00mm.	2.00mm.	1.00mm.	0.50mm.	0.25mm.	0.10mm.	Total Aggr. (0.10mm. & >)
5 A (0-20)	Wt. of Aggr.	7.90	9.61	6.17	7.10	3.52	4.69	38.99
	% Aggr.	15.80	19.22	12.34	14.20	7.04	9.38	77.98
5 A (20-40)	Wt. of Aggr.	6.42	7.11	7.29	4.54	5.80	5.27	36.43
	% Aggr.	12.84	14.22	14.58	9.08	11.60	10.54	72.86
5 B (0-20)	Wt. of Aggr.	3.24	3.29	2.41	6.32	6.97	5.29	27.52
	% Aggr.	6.48	6.58	4.82	12.64	13.94	10.58	55.04
5 B (20-40)	Wt. of Aggr.	0.40	2.62	3.95	6.64	7.28	3.16	24.05
	% Aggr.	0.80	5.24	7.90	13.28	14.56	6.32	48.10
6 A (0-20)	Wt. of Aggr.	10.23	8.20	5.02	7.07	6.08	7.07	43.67
	% Aggr.	20.46	16.40	10.04	14.14	12.16	14.14	87.34
6 A (20-40)	Wt. of Aggr.	4.54	7.38	4.89	5.95	6.44	8.19	37.39
	% Aggr.	9.08	14.76	9.78	11.90	12.88	16.38	74.78
6 B (0-20)	Wt. of Aggr.	4.35	4.34	2.62	6.52	8.95	10.40	37.18
	% Aggr.	8.70	8.68	5.24	13.04	17.90	20.80	74.36
6 B (20-40)	Wt. of Aggr.	3.01	7.72	5.09	6.50	7.37	9.08	38.77
	% Aggr.	6.02	15.44	10.18	13.00	14.74	18.16	77.54
7 A (0-20)	Wt. of Aggr.	19.12	8.64	3.79	4.65	2.68	3.30	42.18
	% Aggr.	38.24	17.28	7.58	9.30	5.36	6.60	84.36
7 A (20-40)	Wt. of Aggr.	6.23	4.49	6.19	8.76	5.37	5.35	36.39
	% Aggr.	12.46	8.98	12.38	17.52	10.74	10.70	72.78
7 B (0-20)	Wt. of Aggr.	2.30	4.04	2.61	7.40	9.20	6.64	32.19
	% Aggr.	4.60	8.08	5.22	14.80	18.40	13.28	64.38
7 B (20-40)	Wt. of Aggr.	1.86	4.97	3.57	7.90	7.12	4.33	29.75
	% Aggr.	3.72	9.94	7.14	15.80	14.24	8.66	59.50
8 A (0-20)	Wt. of Aggr.	11.51	8.43	6.88	6.88	4.66	4.70	43.06
	% Aggr.	23.02	16.86	13.76	13.76	9.32	9.40	86.12
8 A (20-40)	Wt. of Aggr.	12.05	6.44	4.68	7.17	6.41	5.99	42.74
	% Aggr.	24.10	12.88	9.36	14.34	12.82	11.98	85.48
8 B (0-20)	Wt. of Aggr.	4.93	5.27	2.86	6.10	8.02	9.27	36.45
	% Aggr.	9.86	10.54	5.72	12.20	16.04	18.54	72.90
8 B (20-40)	Wt. of Aggr.	2.20	3.72	2.89	7.53	7.62	11.08	35.04

WET AGGREGATE ANALYSIS (cont.)

		Aggregation (1.00mm. & <)	In Suspension (< 0.10mm.)
5 A (0-20)	Wt. of Aggr.	23.68	11.01
	% Aggr.	47.36	22.02
5 A (20-40)	Wt. of Aggr.	20.82	13.57
	% Aggr.	41.64	27.14
5 B (0-20)	Wt. of Aggr.	8.94	22.48
	% Aggr.	17.88	44.96
5 B (20-40)	Wt. of Aggr.	6.97	25.95
	% Aggr.	13.94	51.90
6 A (0-20)	Wt. of Aggr.	23.45	6.33
	% Aggr.	46.90	12.66
6 A (20-40)	Wt. of Aggr.	16.81	12.61
	% Aggr.	33.62	25.22
6 B (0-20)	Wt. of Aggr.	11.31	12.82
	% Aggr.	22.62	25.64
6 B (20-40)	Wt. of Aggr.	15.82	11.23
	% Aggr.	31.64	22.46
7 A (0-20)	Wt. of Aggr.	31.55	7.82
	% Aggr.	63.10	15.64
7 A (20-40)	Wt. of Aggr.	16.91	13.61
	% Aggr.	33.82	27.22
7 B (0-20)	Wt. of Aggr.	8.95	17.81
	% Aggr.	17.90	35.62
7 B (20-40)	Wt. of Aggr.	10.40	20.25
	% Aggr.	20.80	40.50
8 A (0-20)	Wt. of Aggr.	26.82	6.94
	% Aggr.	53.64	13.88
8 A (20-40)	Wt. of Aggr.	23.17	7.26
	% Aggr.	46.34	14.52
8 B (0-20)	Wt. of Aggr.	13.06	13.55
	% Aggr.	26.12	27.10
8 B (20-40)	Wt. of Aggr.	8.81	14.96

		5.00mm.	2.00mm.	1.00mm.	0.50mm.	0.25mm.	0.10mm.	Total Aggr. (0.10mm. & >)
	% Aggr.	4.40	7.44	5.78	15.06	15.24	22.16	70.08
9 A (0-20)	Wt. of Aggr.	10.36	10.54	6.13	5.80	3.85	2.43	39.11
	% Aggr.	20.72	21.08	12.26	11.60	7.70	4.86	78.22
9 A (20-40)	Wt. of Aggr.	2.52	3.97	2.48	7.04	8.77	8.22	33.00
	% Aggr.	5.04	7.94	4.96	14.08	17.54	16.44	66.00
9 B (0-20)	Wt. of Aggr.	0.87	1.88	2.01	6.46	8.28	2.22	21.72
	% Aggr.	1.74	3.76	4.02	12.92	16.56	4.44	43.44
9 B (20-40)	Wt. of Aggr.	11.11	5.39	2.78	2.36	2.85	2.61	27.10
	% Aggr.	22.22	10.78	5.56	4.72	5.70	5.22	54.20
10 A (0-20)	Wt. of Aggr.	9.53	6.43	3.65	6.72	6.37	7.55	40.25
	% Aggr.	19.06	12.86	7.30	13.44	12.74	15.10	80.50
10 A (20-40)	Wt. of Aggr.	4.51	1.30	1.06	2.16	5.55	11.43	26.01
	% Aggr.	9.02	2.60	2.12	4.32	11.10	22.86	52.02
10 B (0-20)	Wt. of Aggr.	2.84	2.04	1.60	2.25	4.29	9.39	22.41
	% Aggr.	5.68	4.08	3.20	4.50	8.58	18.78	44.82
10 B (20-40)	Wt. of Aggr.	8.08	8.64	3.95	5.19	5.65	7.42	39.65
	% Aggr.	16.16	17.28	7.90	10.38	11.30	14.84	79.30
11 A (0-20)	Wt. of Aggr.	8.05	7.68	4.58	6.68	5.85	0.80	33.64
	% Aggr.	16.10	15.36	9.16	13.36	11.70	1.60	67.28
11 A (20-40)	Wt. of Aggr.	11.47	7.66	3.49	5.30	5.76	4.86	38.54
	% Aggr.	22.94	15.32	6.98	10.60	11.52	9.72	77.08
11 B (0-20)	Wt. of Aggr.	0.73	2.17	2.08	6.78	8.47	2.37	22.60
	% Aggr.	1.46	4.34	4.16	13.56	16.94	4.74	45.20
11 B (20-40)	Wt. of Aggr.	0.00	2.98	7.49	7.39	8.78	7.14	29.78
	% Aggr.	0.00	5.96	14.98	14.78	17.56	14.28	59.56
12 A (0-20)	Wt. of Aggr.	5.32	6.72	3.94	8.25	7.19	7.94	39.36
	% Aggr.	10.64	13.44	7.88	16.50	14.38	15.88	78.72
12 A (20-40)	Wt. of Aggr.	1.60	2.81	2.03	4.28	6.35	9.59	26.66
	% Aggr.	3.20	5.62	4.06	8.56	12.70	19.18	53.32
12 B (0-20)	Wt. of Aggr.	0.00	1.06	1.72	6.38	9.32	10.39	28.87
	% Aggr.	0.00	2.12	3.44	12.76	18.64	20.78	57.74

WET AGGREGATE ANALYSIS (cont.)

		Aggregation (1.00mm. & <)	In Suspension (< 0.10mm.)
	% Aggr.	17.62	29.92
9 A (0-20)	Wt. of Aggr.	27.03	10.89
	% Aggr.	54.06	21.78
9 A (20-40)	Wt. of Aggr.	8.97	17.00
	% Aggr.	17.94	34.00
9 B (0-20)	Wt. of Aggr.	4.76	28.28
	% Aggr.	9.52	56.56
9 B (20-40)	Wt. of Aggr.	19.28	22.90
	% Aggr.	38.56	45.80
10 A (0-20)	Wt. of Aggr.	19.61	9.75
	% Aggr.	39.22	19.50
10 A (20-40)	Wt. of Aggr.	6.87	23.99
	% Aggr.	13.74	47.98
10 B (0-20)	Wt. of Aggr.	6.48	27.59
	% Aggr.	12.96	55.18
10 B (20-40)	Wt. of Aggr.	20.67	10.35
	% Aggr.	41.34	20.70
11 A (0-20)	Wt. of Aggr.	20.31	16.36
	% Aggr.	40.62	32.72
11 A (20-40)	Wt. of Aggr.	22.62	11.46
	% Aggr.	45.24	22.92
11 B (0-20)	Wt. of Aggr.	4.98	27.40
	% Aggr.	9.96	54.80
11 B (20-40)	Wt. of Aggr.	10.47	20.22
	% Aggr.	20.94	40.44
12 A (0-20)	Wt. of Aggr.	15.98	10.64
	% Aggr.	31.96	21.28
12 A (20-40)	Wt. of Aggr.	6.44	23.34
	% Aggr.	12.88	46.68
12 B (0-20)	Wt. of Aggr.	2.78	21.13
	% Aggr.	5.56	42.26

WET AGGREGATE ANALYSIS (cont.)

		5.00mm.	2.00mm.	1.00mm.	0.50mm.	0.25mm.	0.10mm.	Total Aggr. (0.10mm. & >)
12 B (20-40)	Wt. of Aggr.	0.38	1.18	1.02	4.10	8.63	9.58	24.89
	% Aggr.	0.76	2.36	2.04	8.20	17.26	19.16	49.78
13 A (0-20)	Wt. of Aggr.	6.12	6.44	4.15	8.63	11.01	1.01	37.36
	% Aggr.	12.24	12.88	8.30	17.26	22.02	2.02	74.72
13 A (20-40)	Wt. of Aggr	4.58	6.50	4.04	10.11	11.99	0.94	38.16
	% Aggr.	9.16	13.00	8.08	20.22	23.98	1.88	76.32
13 B (0-20)	Wt. of Aggr.	6.03	8.80	4.01	10.33	12.69	4.13	45.99
	% Aggr.	12.06	17.60	8.02	20.66	25.38	8.26	91.98
13 B (20-40)	Wt. of Aggr.	1.55	5.08	4.91	11.68	18.59	1.73	43.54
	% Aggr.	3.10	10.16	9.82	23.36	37.18	3.46	87.08
14 A (0-20)	Wt. of Aggr.	9.45	8.52	4.45	6.68	6.33	7.12	42.55
	% Aggr.	18.90	17.04	8.90	13.36	12.66	14.24	85.10
14 A (20-40)	Wt. of Aggr.	10.66	8.48	4.59	5.35	5.84	6.37	41.29
	% Aggr.	21.32	16.96	9.18	10.70	11.68	12.74	82.58
14 B (0-20)	Wt. of Aggr.	6.73	7.29	3.11	6.20	7.96	9.14	40.30
	% Aggr.	13.46	14.58	6.22	12.40	15.92	18.28	80.60
14 B (20-40)	Wt. of Aggr.	5.15	6.50	4.51	6.33	8.31	8.31	39.11
	% Aggr.	10.30	13.00	9.02	12.66	16.62	16.62	78.22
15 A (0-20)	Wt. of Aggr.	14.13	6.37	4.07	3.60	2.44	1.52	32.11
	% Aggr.	28.26	12.74	8.14	7.20	4.88	3.04	64.22
15 A (20-40)	Wt. of Aggr.	1.40	5.93	4.27	7.98	8.76	6.52	34.86
	% Aggr.	2.80	11.86	8.54	15.96	17.52	13.04	69.72
15 B (0-20)	Wt. of Aggr.	0.42	2.76	4.71	8.19	5.78	1.83	23.69
	% Aggr.	0.84	5.52	9.42	16.38	11.56	3.66	47.38
15 B (20-40)	Wt. of Aggr.	5.39	4.75	3.79	5.39	4.60	1.58	25.50
	% Aggr.	10.78	9.50	7.58	10.78	9.20	3.16	51.00

WET AGGREGATE ANALYSIS (cont.)

		Aggregation (1.00mm. & <)	In Suspension (< 0.10mm.)
12 B (20-40)	Wt. of Aggr.	2.58	25.11
	% Aggr.	5.16	50.22
13 A (0-20)	Wt. of Aggr.	16.71	12.64
	% Aggr.	33.42	25.28
13 A (20-40)	Wt. of Aggr	15.12	11.84
	% Aggr.	30.24	23.68
13 B (0-20)	Wt. of Aggr.	18.84	4.01
	% Aggr.	37.68	8.02
13 B (20-40)	Wt. of Aggr.	11.54	6.46
	% Aggr.	23.08	12.92
14 A (0-20)	Wt. of Aggr.	22.42	7.45
	% Aggr.	44.84	14.90
14 A (20-40)	Wt. of Aggr.	23.73	8.71
	% Aggr.	47.46	17.42
14 B (0-20)	Wt. of Aggr.	17.13	9.57
	% Aggr.	34.26	19.14
14 B (20-40)	Wt. of Aggr.	16.16	10.89
	% Aggr.	32.32	21.78
15 A (0-20)	Wt. of Aggr.	24.57	17.87
	% Aggr.	49.14	35.74
15 A (20-40)	Wt. of Aggr.	11.60	15.14
	% Aggr.	23.20	30.28
15 B (0-20)	Wt. of Aggr.	7.89	26.31
	% Aggr.	15.78	52.62
15 B (20-40)	Wt. of Aggr.	13.93	24.50
	% Aggr.	27.86	49.00

DRY AGGREGATE ANALYSIS

Test Site	Run	>38.0mm.	38.0mm.- 12.7mm.	12.7mm.- 6.4mm.	6.4mm.- 2.0mm.	2.0mm.- 0.85mm.	Sub-total (A)	0.85mm.- 0.47mm.	<0.47mm.
1A (0-20)	1	105.10	480.10	246.20	348.80	125.90	1306.10	176.60	427.50
	2	100.30	430.90	241.10	349.50	126.70	1248.50	149.90	511.80
1A (20-40)	1	118.60	279.30	188.90	353.60	181.40	1121.80	242.30	286.20
	2	117.90	205.10	173.30	350.50	175.30	1022.10	195.90	432.30
1B (0-20)	1	0.00	333.30	409.30	505.00	152.70	1400.30	199.80	321.30
	2	0.00	317.00	382.80	500.40	145.00	1345.20	177.00	399.20
1B (20-40)	1	0.00	475.50	310.20	311.00	143.40	1240.10	196.60	185.50
	2	0.00	433.30	289.80	311.20	138.80	1173.10	139.60	309.50
2A (0-20)	1	410.70	234.30	134.20	246.80	131.40	1157.40	198.20	528.20
	2	278.10	266.10	119.50	227.20	126.50	1017.40	141.50	724.90
2A (20-40)	1	308.80	467.60	161.80	213.70	76.10	1228.00	77.30	87.20
	2	195.80	552.70	156.40	220.80	75.50	1201.20	58.70	132.60
2B (0-20)	1	167.20	466.00	163.90	262.60	120.50	1180.20	162.60	229.20
	2	0.00	510.30	156.10	260.70	115.70	1042.80	102.60	426.60
2B (20-40)	1	97.70	519.40	355.80	410.20	106.80	1489.90	110.70	134.10
	2	68.90	529.30	353.90	416.10	103.40	1471.60	73.40	189.70
3A (0-20)	1	705.50	332.50	108.80	165.60	97.50	1409.90	110.40	122.70
	2	628.00	345.50	117.00	183.50	99.30	1373.30	68.90	200.80
3B (20-40)	1	355.60	755.50	273.20	288.30	99.80	1772.40	88.50	67.60
	2	291.60	781.90	276.70	295.60	102.00	1747.80	66.10	114.60
3B (0-20)	1	750.10	581.20	165.90	177.00	70.20	1744.40	69.10	61.90
	2	735.10	570.00	172.40	182.20	70.20	1729.90	59.50	86.00
3B (20-40)	1	0.00	399.90	322.20	460.50	139.70	1322.30	129.00	95.50
	2	0.00	346.10	326.50	476.80	138.30	1287.70	74.20	184.90
4A (0-20)	1	118.90	315.40	170.90	258.10	129.80	993.10	177.20	323.70
	2	0.00	317.00	151.10	260.00	125.00	853.10	146.70	494.20
4A (20-40)	1	0.00	571.40	316.40	346.90	114.20	1348.90	138.90	195.50
	2	0.00	516.10	338.20	342.10	110.60	1307.00	90.30	286.00
4B (0-20)	1	129.90	398.80	239.10	330.60	121.70	1220.10	159.30	357.40
	2	0.00	379.20	214.10	316.20	115.30	1024.80	101.70	610.40

DRY AGGREGATE ANALYSIS (cont.)

Test Site	Run	Sub-total (B)	Total (C)	%A/C	%B/C	Mechanical (A{1}-A{2})	Stability (%) (%A/C{1}-%A/C{2})
1A (0-20)	1	604.10	1910.20	68.40	31.60		
	2	661.70	1910.20	65.40	34.60	57.60	3.00
1A (20-40)	1	528.50	1650.30	68.00	32.00		
	2	628.20	1650.30	61.90	38.10	99.70	6.10
1B (0-20)	1	521.10	1921.40	72.90	27.10		
	2	576.20	1921.40	70.00	30.00	55.10	2.90
1B (20-40)	1	382.10	1622.20	76.40	23.60		
	2	449.10	1622.20	72.30	27.70	67.00	4.10
2A (0-20)	1	726.40	1883.80	61.40	38.60		
	2	866.40	1883.80	54.00	46.00	140.00	7.40
2A (20-40)	1	164.50	1392.50	88.20	11.80		
	2	191.30	1392.50	86.30	13.70	26.80	1.90
2B (0-20)	1	391.80	1572.00	75.10	24.90		
	2	529.20	1572.00	66.30	33.70	137.40	8.80
2B (20-40)	1	244.80	1734.70	85.90	14.10		
	2	263.10	1734.70	84.80	15.20	18.30	1.10
3A (0-20)	1	233.10	1643.00	85.80	14.20		
	2	269.70	1643.00	83.60	16.40	36.60	2.20
3B (20-40)	1	156.10	1928.50	91.90	8.10		
	2	180.70	1928.50	90.60	9.40	24.60	1.30
3B (0-20)	1	131.00	1875.40	93.00	7.00		
	2	145.50	1875.40	92.20	7.80	14.50	0.80
3B (20-40)	1	224.50	1546.80	85.50	14.50		
	2	259.10	1546.80	83.20	16.80	34.60	2.30
4A (0-20)	1	500.90	1494.00	66.50	33.50		
	2	640.90	1494.00	57.10	42.90	140.00	9.40
4A (20-40)	1	334.40	1683.30	80.10	19.90		
	2	376.30	1683.30	77.60	22.40	41.90	2.50
4B (0-20)	1	516.70	1736.80	70.30	29.70		
	2	712.10	1736.80	59.00	41.00	195.30	11.30

DRY AGGREGATE ANALYSIS (cont.)

Test Site	Run	>38.0mm.	38.0mm.-12.7mm.	12.7mm.-6.4mm.	6.4mm.-2.0mm.	2.0mm.-0.85mm.	Sub-total (A)	0.85mm.-0.47mm.	<0.47mm.
4B (20-40)	1	0.00	365.00	324.50	128.20	359.50	1177.20	157.40	197.10
	2	0.00	319.10	329.70	122.20	357.50	1128.50	94.90	308.30
5A (0-20)	1	262.50	475.30	205.30	398.10	153.10	1494.30	167.40	200.70
	2	242.90	432.10	197.10	408.50	147.40	1428.00	105.20	329.20
5A (20-40)	1	0.00	615.10	272.80	387.60	137.50	1413.00	149.60	159.30
	2	0.00	536.60	300.70	396.10	134.70	1368.10	97.10	256.70
5B (0-20)	1	531.30	487.30	191.60	257.00	106.20	1573.40	123.40	138.50
	2	471.90	505.70	187.30	259.60	103.70	1528.20	81.40	225.70
5B (20-40)	1	117.20	513.10	356.30	400.10	132.90	1519.60	130.10	106.70
	2	0.00	497.50	379.40	416.50	131.50	1424.90	95.00	236.50
6A (0-20)	1	242.70	475.50	245.30	230.90	103.30	1297.70	136.50	132.70
	2	212.60	464.50	258.50	238.20	121.00	1294.80	97.30	174.80
6A (20-40)	1	105.80	602.10	282.90	331.70	121.40	1443.90	141.40	203.10
	2	0.00	614.30	273.40	326.00	117.20	1330.90	105.20	352.30
6B (0-20)	1	243.10	490.40	273.40	365.10	129.40	1501.40	170.10	310.20
	2	135.50	507.30	157.40	230.10	101.90	1132.20	137.80	711.70
6B (20-40)	1	0.00	386.50	271.00	501.60	156.70	1315.80	178.90	289.80
	2	0.00	351.30	247.20	498.70	149.80	1247.00	120.20	417.30
7A (0-20)	1	332.20	437.80	110.90	161.70	94.70	1137.30	122.20	270.10
	2	277.80	432.80	114.20	156.70	90.70	1072.20	86.00	371.40
7A (20-40)	1	0.00	648.30	310.70	459.30	155.80	1574.10	181.30	260.20
	2	0.00	587.60	303.90	463.60	145.40	1500.50	146.00	369.10
7B (0-20)	1	140.00	593.90	235.10	391.80	151.10	1511.90	225.90	385.40
	2	0.00	629.90	213.50	384.10	142.00	1369.50	186.20	567.50
7B (20-40)	1	79.50	448.70	308.90	389.10	152.60	1378.80	186.10	174.30
	2	0.00	446.30	297.00	381.30	143.10	1267.70	144.20	327.30
8A (0-20)	1	391.40	379.30	122.20	182.00	102.90	1177.80	141.00	332.70
	2	350.40	356.90	122.40	181.10	99.20	1110.00	131.50	410.00
8A (20-40)	1	321.90	412.00	179.40	265.90	127.40	1306.60	172.90	380.50
	2	305.40	386.90	169.40	260.90	120.70	1243.30	130.00	486.70

DRY AGGREGATE ANALYSIS (cont.)

Test Site	Run	Sub-total (B)	Total (C)	%A/C	%B/C	Mechanical (A{1}-A{2})	Stability (%) (%A/C{1}-%A/C{2})
4B (20-40)	1	354.50	1531.70	76.90	23.10		
	2	403.20	1531.70	73.70	26.30	48.70	3.20
5A (0-20)	1	368.10	1862.40	80.20	19.80		
	2	434.40	1862.40	76.70	23.30	66.30	3.50
5A (20-40)	1	308.90	1721.90	82.10	17.90		
	2	353.80	1721.90	79.50	20.50	44.90	2.60
5B (0-20)	1	261.90	1835.30	85.70	14.30		
	2	307.10	1835.30	83.30	16.70	45.20	2.40
5B (20-40)	1	236.80	1756.40	86.50	13.50		
	2	331.50	1756.40	81.10	18.90	94.70	5.40
6A (0-20)	1	239.20	1566.90	82.80	17.20		
	2	272.10	1566.90	82.60	17.40	2.90	0.20
6A (20-40)	1	344.50	1788.40	80.70	19.30		
	2	457.50	1788.40	74.40	25.60	113.00	6.30
6B (0-20)	1	480.30	1981.70	75.80	24.20		
	2	849.50	1981.70	57.10	42.90	369.20	18.70
6B (20-40)	1	468.70	1784.50	73.70	26.30		
	2	537.50	1784.50	69.90	30.10	68.80	3.80
7A (0-20)	1	392.30	1529.60	74.40	25.60		
	2	457.40	1529.60	70.10	29.90	65.10	4.30
7A (20-40)	1	441.50	2015.60	78.10	21.90		
	2	515.10	2015.60	74.40	25.60	73.60	3.70
7B (0-20)	1	611.30	2123.20	71.20	28.80		
	2	753.70	2123.20	64.50	35.50	142.40	6.70
7B (20-40)	1	360.40	1739.20	79.30	20.70		
	2	471.50	1739.20	72.90	27.10	111.10	6.40
8A (0-20)	1	473.70	1651.50	71.30	28.70		
	2	541.50	1651.50	67.20	32.80	67.80	4.10
8A (20-40)	1	553.40	1860.00	70.20	29.80		
	2	616.70	1860.00	66.80	33.20	63.30	3.40

DRY AGGREGATE ANALYSIS (cont.)

Test Site	Run	>38.0mm.	38.0mm.- 12.7mm.	12.7mm.- 6.4mm.	6.4mm.- 2.0mm.	2.0mm.- 0.85mm.	Sub-total (A)	0.85mm.- 0.47mm.	<0.47mm.
8B (0-20)	1	232.50	493.40	196.70	289.20	121.00	1332.80	166.30	310.90
	2	221.60	479.70	178.80	275.90	113.00	1269.00	102.10	438.90
8B (20-40)	1	80.50	359.10	264.10	350.60	142.80	1197.10	196.10	309.00
	2	0.00	353.30	236.10	339.40	122.30	1051.10	147.90	503.20
9A (0-20)	1	222.40	342.50	205.60	358.70	150.60	1279.80	194.60	387.10
	2	101.50	139.70	359.60	199.70	148.30	948.80	168.40	744.30
9A (20-40)	1	0.00	332.50	197.60	305.30	144.60	980.00	200.70	399.80
	2	0.00	282.00	169.40	292.80	138.00	882.20	139.20	559.10
9B (0-20)	1	146.90	458.80	213.60	317.30	142.40	1279.00	190.10	352.90
	2	152.50	410.20	207.60	302.20	132.80	1205.30	156.20	460.50
9B (20-40)	1	0.00	699.10	326.00	288.90	105.80	1419.80	108.80	120.40
	2	0.00	671.10	337.70	288.40	102.00	1399.20	86.00	163.80
10A (0-20)	1	199.10	245.70	130.40	243.00	117.20	935.40	208.50	386.60
	2	75.20	268.50	114.40	222.40	111.80	792.30	101.20	637.00
10A (20-40)	1	140.60	770.20	239.10	271.40	98.90	1520.20	104.50	111.40
	2	118.60	756.70	240.20	270.80	94.90	1481.20	89.40	165.50
10B (0-20)	1	262.90	282.60	173.30	301.20	124.70	1144.70	176.70	400.50
	2	164.90	289.40	162.00	285.60	69.70	971.60	129.70	620.60
10B (20-40)	1	379.50	840.90	242.90	223.20	83.10	1769.60	88.40	93.50
	2	352.10	834.00	251.10	221.70	80.90	1739.80	64.30	147.50
11A (0-20)	1	385.90	326.80	149.60	235.20	111.30	1208.80	136.50	195.90
	2	281.70	368.00	144.00	240.40	108.70	1142.80	88.20	310.20
11A (20-40)	1	169.90	418.30	183.10	253.60	111.30	1136.20	139.20	215.30
	2	164.10	360.30	189.60	255.90	107.40	1077.30	95.10	318.30
11B (0-20)	1	120.90	358.90	191.90	269.10	119.60	1060.40	148.80	166.80
	2	119.40	332.50	188.40	263.50	114.20	1018.00	93.30	264.70
11B (20-40)	1	133.20	418.00	293.60	367.50	151.40	1363.70	176.00	163.70
	2	132.00	384.50	272.10	364.60	144.80	1298.00	125.00	280.40
12A (0-20)	1	0.00	299.70	167.20	257.20	134.80	858.90	197.80	266.50
	2	0.00	252.90	137.30	245.70	129.50	765.40	156.40	401.40

Test Site	Run	Sub-total (B)	Total (C)	%A/C	%B/C	Mechanical (A(1)-A(2))	Stability (%) (%A/C(1)-%A/C(2))
8B (0-20)	1	477.20	1810.00	73.60	26.40		
	2	541.00	1810.00	70.10	29.90	63.80	3.50
8B (20-40)	1	505.10	1702.20	70.30	29.70		
	2	651.10	1702.20	61.70	38.30	146.00	8.60
9A (0-20)	1	581.70	1861.50	68.80	31.20		
	2	912.70	1861.50	51.00	49.00	331.00	17.80
9A (20-40)	1	600.50	1580.50	62.00	38.00		
	2	698.30	1580.50	55.80	44.20	97.80	6.20
9B (0-20)	1	543.00	1822.00	70.20	29.80		
	2	616.70	1822.00	66.20	33.80	73.70	4.00
9B (20-40)	1	229.20	1649.00	86.10	13.90		
	2	249.80	1649.00	84.90	15.10	20.60	1.20
10A (0-20)	1	595.10	1530.50	61.10	38.90		
	2	738.20	1530.50	51.80	48.20	143.10	9.30
10A (20-40)	1	215.90	1736.10	87.60	12.40		
	2	254.90	1736.10	85.30	14.70	39.00	2.30
10B (0-20)	1	577.20	1721.90	66.50	33.50		
	2	750.30	1721.90	56.40	43.60	173.10	10.10
10B (20-40)	1	181.90	1951.50	90.70	9.30		
	2	211.70	1951.50	89.20	10.80	29.80	1.50
11A (0-20)	1	332.40	1541.20	78.40	21.60		
	2	398.40	1541.20	74.20	25.80	66.00	4.20
11A (20-40)	1	354.50	1490.70	76.20	23.80		
	2	413.40	1490.70	72.30	27.70	58.90	3.90
11B (0-20)	1	315.60	1376.00	77.10	22.90		
	2	358.00	1376.00	74.00	26.00	42.40	3.10
11B (20-40)	1	339.70	1703.40	80.10	19.90		
	2	405.40	1703.40	76.20	23.80	65.70	3.90
12A (0-20)	1	464.30	1323.20	64.90	35.10		
	2	557.80	1323.20	57.80	42.20	93.50	7.10

DRY AGGREGATE ANALYSIS (cont.)

Test Site	Run	>38.0mm.	38.0mm.-12.7mm.	12.7mm.-6.4mm.	6.4mm.-2.0mm.	2.0mm.-0.85mm.	Sub-total (A)	0.85mm.-0.47mm.	<0.47mm.
12A (20-40)	1	0.00	440.10	203.10	301.10	125.20	1069.50	147.70	173.70
	2	0.00	404.90	205.50	291.10	117.10	1018.60	97.40	274.90
12B (0-20)	1	147.80	271.30	152.60	307.10	122.60	1001.40	150.70	208.10
	2	126.20	266.70	159.40	295.40	116.50	964.20	129.60	266.40
12B (20-40)	1	0.00	135.30	189.20	316.40	163.70	804.60	227.10	298.70
	2	0.00	113.90	198.30	300.30	153.70	766.20	170.20	394.00
13A (0-20)	1	256.20	265.60	91.60	178.60	116.10	908.10	243.10	800.40
	2	200.70	198.40	87.10	175.10	120.60	781.90	185.90	983.80
13A (20-40)	1	136.30	271.30	168.70	256.90	287.00	1120.20	380.40	527.90
	2	131.60	226.80	158.90	242.40	122.60	882.30	290.90	855.30
13B (0-20)	1	0.00	101.90	88.90	199.20	111.50	501.50	316.90	710.50
	2	0.00	77.50	66.60	159.80	104.20	408.10	278.30	842.50
13B (20-40)	1	66.30	112.90	91.00	183.50	131.60	585.30	407.70	610.30
	2	0.00	92.00	65.30	142.80	119.00	419.10	302.30	881.90
14A (0-20)	1	143.00	289.50	183.10	276.40	120.50	1012.50	163.10	304.10
	2	134.90	263.80	168.20	266.20	114.30	947.40	127.20	405.10
14A (20-40)	1	92.80	384.30	213.30	315.40	133.00	1138.80	180.40	274.50
	2	91.80	366.50	194.20	310.30	126.10	1088.90	166.10	338.70
14B (0-20)	1	0.00	235.50	218.60	292.20	144.80	891.10	166.70	358.90
	2	0.00	204.60	195.60	275.20	108.10	783.50	127.90	505.30
14B (20-40)	1	0.00	269.00	165.00	267.20	122.20	823.40	169.80	297.60
	2	0.00	236.00	158.60	253.20	114.90	762.70	106.30	421.80
15A (0-20)	1	730.30	409.00	100.50	143.40	251.00	1634.20	141.50	141.70
	2	681.60	376.20	104.00	270.10	149.10	1581.00	102.20	234.20
15A (20-40)	1	969.90	271.90	116.20	131.70	68.30	1558.00	68.80	58.20
	2	913.60	307.50	117.30	135.50	68.80	1542.70	60.20	82.10
15B (0-20)	1	232.80	589.90	202.30	288.60	108.80	1422.40	103.00	69.50
	2	199.90	580.60	209.20	108.40	299.00	1397.10	88.50	109.30
15B (20-40)	1	814.20	371.60	153.30	170.10	81.90	1591.10	80.50	72.80
	2	808.40	348.80	156.20	173.00	79.80	1566.20	62.20	116.00

DRY AGGREGATE ANALYSIS (cont.)

Test Site	Run	Sub-total (B)	Total (C)	%A/C	%B/C	Mechanical (A{1}-A{2})	Stability (%) (%A/C{1}-%A/C{2})
12A (20-40)	1	321.40	1390.90	76.90	23.10		
	2	372.30	1390.90	73.20	26.80	50.90	3.70
12B (0-20)	1	358.80	1360.20	73.60	26.40		
	2	396.00	1360.20	70.90	29.10	37.20	2.70
12B (20-40)	1	525.80	1330.40	60.50	39.50		
	2	564.20	1330.40	57.60	42.40	38.40	2.90
13A (0-20)	1	1043.50	1951.60	46.50	53.50		
	2	1169.70	1951.60	40.10	59.90	126.20	6.40
13A (20-40)	1	908.30	2028.50	55.20	44.80		
	2	1146.20	2028.50	43.50	56.50	237.90	11.70
13B (0-20)	1	1027.40	1528.90	32.80	67.20		
	2	1120.80	1528.90	26.70	73.30	93.40	6.10
13B (20-40)	1	1018.00	1603.30	36.50	63.50		
	2	1184.20	1603.30	26.10	73.90	166.20	10.40
14A (0-20)	1	467.20	1479.70	68.40	31.60		
	2	532.30	1479.70	64.00	36.00	65.10	4.40
14A (20-40)	1	454.90	1593.70	71.50	28.50		
	2	504.80	1593.70	68.30	31.70	49.90	3.20
14B (0-20)	1	525.60	1416.70	62.90	37.10		
	2	633.20	1416.70	55.30	44.70	107.60	7.60
14B (20-40)	1	467.40	1290.80	63.80	36.20		
	2	528.10	1290.80	59.10	40.90	60.70	4.70
15A (0-20)	1	283.20	1917.40	85.20	14.80		
	2	336.40	1917.40	82.50	17.50	53.20	2.70
15A (20-40)	1	127.00	1685.00	92.50	7.50		
	2	142.30	1685.00	91.60	8.40	15.30	0.90
15B (0-20)	1	172.50	1594.90	89.20	10.80		
	2	197.80	1594.90	87.60	12.40	25.30	1.60
15B (20-40)	1	153.30	1744.40	91.20	8.80		
	2	178.20	1744.40	89.80	10.20	24.90	1.40

APPENDIX "C"

STATISTICAL ANALYSIS

STATISTICAL ANALYSIS

Site Number	pH	LOG	Cond. (mmhos)	LOG	% Water Content	LOG	15 bar (gm. H20/ gm. soil)	LOG	% Water (15 bar)	LOG
1 A (0-20)	5.6	0.75	1.40	0.15	10.4	1.02	0.056	-1.25	5.6	0.75
2 A (0-20)	5.7	0.76	0.51	-0.29	2.3	0.36	0.039	-1.41	3.9	0.59
3 A (0-20)	7.2	0.86	1.20	0.08	6.6	0.82	0.128	-0.89	12.8	1.11
4 A (0-20)	5.5	0.74	1.74	0.24	1.8	0.26	0.049	-1.31	4.9	0.69
5 A (0-20)	5.6	0.75	0.80	-0.10	4.3	0.63	0.063	-1.20	6.3	0.80
6 A (0-20)	7.2	0.86	1.08	0.03	3.9	0.59	0.037	-1.43	3.7	0.57
7 A (0-20)	6.5	0.81	0.70	-0.15	4.7	0.67	0.054	-1.27	5.4	0.73
8 A (0-20)	6.1	0.79	0.91	-0.04	3.4	0.53	0.045	-1.35	4.5	0.65
9 A (0-20)	5.9	0.77	0.31	-0.51	1.9	0.28	0.031	-1.51	3.1	0.49
10 A (0-20)	5.7	0.76	0.54	-0.27	3.3	0.52	0.032	-1.49	3.2	0.51
11 A (0-20)	5.8	0.76	0.99	0.00	5.2	0.72	0.036	-1.44	3.6	0.56
12 A (0-20)	5.8	0.76	0.42	-0.38	5.6	0.75	0.026	-1.59	2.6	0.41
13 A (0-20)	6.1	0.79	0.25	-0.60	0.6	-0.22	0.021	-1.68	2.1	0.32
14 A (0-20)	6.9	0.84	0.65	-0.19	3.2	0.51	0.033	-1.48	3.3	0.52
15 A (0-20)	6.7	0.83	0.72	-0.14	12.7	1.10	0.046	-1.34	4.6	0.66
sample mean	6.2	0.8	0.8	-0.1	4.7	0.6	0.0	-1.4	4.6	0.6
sample variance	0.4	0.0	0.2	0.1	10.5	0.1	0.0	0.0	6.4	0.0
standard dev.	0.6	0.0	0.4	0.2	3.2	0.3	0.0	0.2	2.5	0.2
1 B (0-20)	5.9	0.77	1.14	0.06	5.8	0.76	0.039	-1.41	3.9	0.59
2 B (0-20)	5.8	0.76	1.41	0.15	3.8	0.58	0.033	-1.48	3.3	0.52
3 B (0-20)	6.6	0.82	0.75	-0.12	7.5	0.88	0.100	-1.00	10.0	1.00
4 B (0-20)	5.2	0.72	1.16	0.06	6.4	0.81	0.038	-1.42	3.8	0.58
5 B (0-20)	5.4	0.73	1.40	0.15	6.7	0.83	0.062	-1.21	6.2	0.79
6 B (0-20)	5.8	0.76	1.08	0.03	5.1	0.71	0.031	-1.51	3.1	0.49
7 B (0-20)	5.7	0.76	0.91	-0.04	6.1	0.79	0.034	-1.47	3.4	0.53
8 B (0-20)	5.5	0.74	1.20	0.08	5.9	0.77	0.037	-1.43	3.7	0.57
9 B (0-20)	5.5	0.74	1.00	0.00	3.8	0.58	0.030	-1.52	3.0	0.48
10 B (0-20)	5.1	0.71	1.30	0.11	5.4	0.73	0.031	-1.51	3.1	0.49
11 B (0-20)	5.6	0.75	1.00	0.00	3.4	0.53	0.031	-1.51	3.1	0.49
12 B (0-20)	5.2	0.72	0.82	-0.09	5.4	0.73	0.041	-1.39	4.1	0.61
13 B (0-20)	7.0	0.85	0.94	-0.03	0.9	-0.05	0.014	-1.85	1.4	0.15
14 B (0-20)	7.0	0.85	0.87	-0.06	5.0	0.70	0.035	-1.46	3.5	0.54
15 B (0-20)	7.5	0.88	0.94	-0.03	8.4	0.92	0.065	-1.19	6.5	0.81
sample mean	5.9	0.8	1.1	0.0	5.3	0.7	0.0	-1.4	4.1	0.6
sample variance	0.6	0.0	0.0	0.0	3.3	0.1	0.0	0.0	4.2	0.0
standard dev.	0.7	0.1	0.2	0.1	1.8	0.2	0.0	0.2	2.0	0.2
F test (s1/s2)	1.6	1.7	4.1	8.1	3.2	2.0	1.6	1.0	1.6	1.0
V1 (n1-1)	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
V2 (n2-1)	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
S=	0.7	0.0	0.3	0.2	2.6	0.3	0.0	0.2	2.3	0.2
T test	0.1	0.1	-0.3	-0.3	-0.1	-0.2	0.1	0.1	0.1	0.1
v	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0

STATISTICAL ANALYSIS (Cont.)

Site Number	1/3 bar (gm. H2O/ gm. soil)	LOG	% Water (1/3 bar)	LOG	Available Water (F.C.-W.P.)	LOG	% Avail. Water	LOG	Bulk Density (g/cm3)
1 A (0-20)	0.117	-0.93	11.7	1.07	0.061	-1.21	6.1	0.79	1.28
2 A (0-20)	0.080	-1.10	8.0	0.90	0.041	-1.39	4.1	0.61	1.47
3 A (0-20)	0.253	-0.60	25.3	1.40	0.125	-0.90	12.5	1.10	1.43
4 A (0-20)	0.095	-1.02	9.5	0.98	0.046	-1.34	4.6	0.66	1.28
5 A (0-20)	0.125	-0.90	12.5	1.10	0.062	-1.21	6.2	0.79	1.28
6 A (0-20)	0.073	-1.14	7.3	0.86	0.036	-1.44	3.6	0.56	1.22
7 A (0-20)	0.105	-0.98	10.5	1.02	0.051	-1.29	5.1	0.71	1.14
8 A (0-20)	0.091	-1.04	9.1	0.96	0.046	-1.34	4.6	0.66	1.32
9 A (0-20)	0.115	-0.94	11.5	1.06	0.084	-1.08	8.4	0.92	1.36
10 A (0-20)	0.091	-1.04	9.1	0.96	0.059	-1.23	5.9	0.77	1.24
11 A (0-20)	0.050	-1.30	5.0	0.70	0.014	-1.85	1.4	0.15	1.42
12 A (0-20)	0.051	-1.29	5.1	0.71	0.025	-1.60	2.5	0.40	1.37
13 A (0-20)	0.043	-1.37	4.3	0.63	0.022	-1.66	2.2	0.34	1.46
14 A (0-20)	0.065	-1.19	6.5	0.81	0.032	-1.49	3.2	0.51	1.43
15 A (0-20)	0.079	-1.10	7.9	0.90	0.033	-1.48	3.3	0.52	1.55
sample mean	0.1	-1.1	9.6	0.9	0.0	-1.4	4.9	0.6	1.4
sample variance	0.0	0.0	25.3	0.0	0.0	0.1	7.7	0.1	0.0
standard dev.	0.1	0.2	5.0	0.2	0.0	0.2	2.8	0.2	0.1
1 B (0-20)	0.074	-1.13	7.4	0.87	0.035	-1.46	3.5	0.54	1.59
2 B (0-20)	0.067	-1.17	6.7	0.83	0.034	-1.47	3.4	0.53	1.48
3 B (0-20)	0.199	-0.70	19.9	1.30	0.099	-1.00	9.9	1.00	1.47
4 B (0-20)	0.075	-1.12	7.5	0.88	0.037	-1.43	3.7	0.57	1.37
5 B (0-20)	0.125	-0.90	12.5	1.10	0.063	-1.20	6.3	0.80	1.46
6 B (0-20)	0.063	-1.20	6.3	0.80	0.032	-1.49	3.2	0.51	1.35
7 B (0-20)	0.066	-1.18	6.6	0.82	0.032	-1.49	3.2	0.51	1.38
8 B (0-20)	0.051	-1.29	5.1	0.71	0.014	-1.85	1.4	0.15	1.42
9 B (0-20)	0.125	-0.90	12.5	1.10	0.095	-1.02	9.5	0.98	1.38
10 B (0-20)	0.064	-1.19	6.4	0.81	0.033	-1.48	3.3	0.52	1.49
11 B (0-20)	0.054	-1.27	5.4	0.73	0.023	-1.64	2.3	0.36	1.50
12 B (0-20)	0.081	-1.09	8.1	0.91	0.040	-1.40	4.0	0.60	1.46
13 B (0-20)	0.026	-1.59	2.6	0.41	0.012	-1.92	1.2	0.08	1.53
14 B (0-20)	0.068	-1.17	6.8	0.83	0.033	-1.48	3.3	0.52	1.45
15 B (0-20)	0.127	-0.90	12.7	1.10	0.062	-1.21	6.2	0.79	1.47
sample mean	0.1	-1.1	8.4	0.9	0.0	-1.4	4.3	0.6	1.5
sample variance	0.0	0.0	18.3	0.0	0.0	0.1	6.7	0.1	0.0
standard dev.	0.0	0.2	4.3	0.2	0.0	0.3	2.6	0.3	0.1
F test (s1/s2)	1.4	0.8	1.4	0.8	1.1	0.8	1.1	0.8	2.9
V1 (n1-1)	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
V2 (n2-1)	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
S=	0.0	0.2	4.7	0.2	0.0	0.2	2.7	0.2	0.1
T test	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	-0.4
v	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0

STATISTICAL ANALYSIS (Cont.)

Site Number	LOG	Particle Density (g/cm3)	LOG	% Total Porosity	LOG	Texture Class	% Sand	LOG	% Silt	LOG
1 A (0-20)	0.11	2.72	0.43	52.94	1.72	L	46.10	1.66	36.20	1.56
2 A (0-20)	0.17	2.69	0.43	45.35	1.66	L	49.20	1.69	33.12	1.52
3 A (0-20)	0.16	2.65	0.42	46.04	1.66	CL	30.57	1.49	30.02	1.48
4 A (0-20)	0.11	2.73	0.44	53.11	1.73	SL	61.62	1.79	21.74	1.34
5 A (0-20)	0.11	2.72	0.43	52.94	1.72	SCL	47.76	1.68	22.14	1.35
6 A (0-20)	0.09	2.68	0.43	54.48	1.74	SCL	59.18	1.77	18.63	1.27
7 A (0-20)	0.06	2.63	0.42	56.65	1.75	L	47.80	1.68	27.94	1.45
8 A (0-20)	0.12	2.66	0.42	50.38	1.70	SCL	48.83	1.69	22.77	1.36
9 A (0-20)	0.13	2.66	0.42	48.87	1.69	SCL	52.97	1.72	26.91	1.43
10 A (0-20)	0.09	2.68	0.43	53.73	1.73	SL	57.11	1.76	26.91	1.43
11 A (0-20)	0.15	2.64	0.42	46.21	1.66	L	47.51	1.68	28.98	1.46
12 A (0-20)	0.14	2.62	0.42	47.71	1.68	L	51.65	1.71	30.01	1.48
13 A (0-20)	0.16	2.65	0.42	44.91	1.65	LS	82.70	1.92	11.38	1.06
14 A (0-20)	0.16	2.61	0.42	45.21	1.66	SL	60.96	1.79	21.74	1.34
15 A (0-20)	0.19	2.60	0.41	40.38	1.61	CL	26.81	1.43	38.29	1.58
sample mean	0.1	2.7	0.4	49.3	1.7		51.4	1.7	26.5	1.4
sample variance	0.0	0.0	0.0	21.2	0.0		170.8	0.0	48.5	0.0
standard dev.	0.0	0.0	0.0	4.6	0.0		13.1	0.1	7.0	0.1
1 B (0-20)	0.20	2.69	0.43	40.89	1.61	SL	57.57	1.76	23.72	1.38
2 B (0-20)	0.17	2.66	0.42	44.36	1.65	SL	56.45	1.75	25.87	1.41
3 B (0-20)	0.17	2.69	0.43	45.35	1.66	CL	42.99	1.63	22.77	1.36
4 B (0-20)	0.14	2.66	0.42	48.50	1.69	SL	65.76	1.82	19.67	1.29
5 B (0-20)	0.16	2.71	0.43	46.13	1.66	SCL	48.17	1.68	23.80	1.38
6 B (0-20)	0.13	2.68	0.43	49.63	1.70	SCL	59.18	1.77	18.63	1.27
7 B (0-20)	0.14	2.61	0.42	47.13	1.67	SCL	51.94	1.72	20.70	1.32
8 B (0-20)	0.15	2.61	0.42	45.59	1.66	L	46.76	1.67	34.16	1.53
9 B (0-20)	0.14	2.63	0.42	47.53	1.68	SL	57.11	1.76	27.95	1.45
10 B (0-20)	0.17	2.63	0.42	43.35	1.64	SL	60.22	1.78	23.80	1.38
11 B (0-20)	0.18	2.66	0.42	43.61	1.64	SCL	51.65	1.71	24.84	1.40
12 B (0-20)	0.16	2.64	0.42	44.70	1.65	L	43.37	1.64	34.15	1.53
13 B (0-20)	0.18	2.65	0.42	42.26	1.63	LS	86.84	1.94	5.17	0.71
14 B (0-20)	0.16	2.60	0.41	44.23	1.65	SL	65.10	1.81	16.55	1.22
15 B (0-20)	0.17	2.62	0.42	43.89	1.64	CL	24.74	1.39	38.59	1.59
sample mean	0.2	2.6	0.4	45.1	1.7		54.5	1.7	24.0	1.3
sample variance	0.0	0.0	0.0	5.5	0.0		186.9	0.0	64.9	0.0
standard dev.	0.0	0.0	0.0	2.4	0.0		13.7	0.1	8.1	0.2
F test (s1/s2)	3.5	1.5	1.5	3.8	3.3		1.1	1.0	1.3	2.4
V1 (n1-1)	14.0	14.0	14.0	14.0	14.0		14.0	14.0	14.0	14.0
V2 (n2-1)	14.0	14.0	14.0	14.0	14.0		14.0	14.0	14.0	14.0
S=	0.0	0.0	0.0	3.7	0.0		13.4	0.1	7.5	0.2
T test	-0.4	0.1	0.1	0.4	0.4		-0.1	-0.1	0.1	0.1
v	28.0	28.0	28.0	28.0	28.0		28.0	28.0	28.0	28.0

Site Number	% Clay	LOG	% Organic Matter	LOG	Penetrometer Average	LOG
1 A (0-20)	17.70	1.25	2.4	0.38	2.1	0.32
2 A (0-20)	17.68	1.25	2.1	0.32	4.5	0.65
3 A (0-20)	39.41	1.60	2.8	0.45	3.6	0.56
4 A (0-20)	16.64	1.22	4.9	0.69	3.5	0.54
5 A (0-20)	30.10	1.48	3.6	0.56	4.2	0.62
6 A (0-20)	22.19	1.35	4.0	0.60	4.0	0.60
7 A (0-20)	24.26	1.38	4.2	0.62	4.5	0.65
8 A (0-20)	28.40	1.45	3.6	0.56	4.5	0.65
9 A (0-20)	20.12	1.30	2.9	0.46	4.2	0.62
10 A (0-20)	15.98	1.20	4.4	0.64	3.0	0.48
11 A (0-20)	23.51	1.37	4.3	0.63	3.4	0.53
12 A (0-20)	18.34	1.26	4.3	0.63	2.8	0.45
13 A (0-20)	5.92	0.77	3.5	0.54	4.5	0.65
14 A (0-20)	17.30	1.24	2.9	0.46	3.1	0.49
15 A (0-20)	34.90	1.54	2.9	0.46	4.2	0.62
sample mean	22.2	1.3	3.5	0.5	3.7	0.6
sample variance	70.2	0.0	0.7	0.0	0.6	0.0
standard dev.	8.4	0.2	0.8	0.1	0.7	0.1
1 B (0-20)	18.71	1.27	2.1	0.32	2.2	0.34
2 B (0-20)	17.68	1.25	1.8	0.26	2.7	0.43
3 B (0-20)	34.24	1.53	1.3	0.11	1.7	0.23
4 B (0-20)	14.57	1.16	4.7	0.67	2.1	0.32
5 B (0-20)	28.03	1.45	3.2	0.51	2.5	0.40
6 B (0-20)	22.19	1.35	2.6	0.41	2.3	0.36
7 B (0-20)	27.36	1.44	2.9	0.46	2.8	0.45
8 B (0-20)	19.08	1.28	3.2	0.51	3.4	0.53
9 B (0-20)	14.94	1.17	2.5	0.40	3.7	0.57
10 B (0-20)	15.98	1.20	2.5	0.40	2.2	0.34
11 B (0-20)	23.51	1.37	3.2	0.51	2.9	0.46
12 B (0-20)	22.48	1.35	3.5	0.54	3.2	0.51
13 B (0-20)	7.99	0.90	1.1	0.04	2.6	0.41
14 B (0-20)	18.34	1.26	2.8	0.45	2.6	0.41
15 B (0-20)	36.97	1.57	2.8	0.45	2.2	0.34
sample mean	21.5	1.3	2.7	0.4	2.6	0.4
sample variance	59.0	0.0	0.8	0.0	0.3	0.0
standard dev.	7.7	0.2	0.9	0.2	0.5	0.1
F test (s1/s2)	1.2	1.4	1.2	2.3	1.9	1.2
V1 (n1-1)	14.0	14.0	14.0	14.0	14.0	14.0
V2 (n2-1)	14.0	14.0	14.0	14.0	14.0	14.0
S=	8.0	0.2	0.9	0.1	0.6	0.1
T test	0.0	0.0	0.4	0.3	0.6	0.6
V	28.0	28.0	28.0	28.0	28.0	28.0

STATISTICAL ANALYSIS (Cont.)

Site Number	pH	LOG	Cond. (mmhos)	LOG	% Water Content	LOG	15 bar (gm. H20/ gm. soil)	LOG	% Water (15 bar)	LOG
1 A (20-40)	5.7	0.76	0.55	-0.26	4.7	0.67	0.036	-1.44	3.6	0.56
2 A (20-40)	9.0	0.95	6.00	0.78	3.5	0.54	0.129	-0.89	12.9	1.11
3 A (20-40)	7.7	0.89	25.00	1.40	8.0	0.90	0.093	-1.03	9.3	0.97
4 A (20-40)	6.3	0.80	0.63	-0.20	4.2	0.62	0.054	-1.27	5.4	0.73
5 A (20-40)	6.5	0.81	0.39	-0.41	4.3	0.63	0.049	-1.31	4.9	0.69
6 A (20-40)	8.4	0.92	1.20	0.08	4.5	0.65	0.033	-1.48	3.3	0.52
7 A (20-40)	6.7	0.83	0.40	-0.40	3.4	0.53	0.036	-1.44	3.6	0.56
8 A (20-40)	7.8	0.89	1.15	0.06	4.5	0.65	0.031	-1.51	3.1	0.49
9 A (20-40)	6.4	0.81	0.37	-0.43	1.8	0.26	0.058	-1.24	5.8	0.76
10 A (20-40)	9.1	0.96	1.82	0.26	3.9	0.59	0.045	-1.35	4.5	0.65
11 A (20-40)	6.3	0.80	0.35	-0.46	2.8	0.45	0.026	-1.59	2.6	0.41
12 A (20-40)	6.0	0.78	0.35	-0.46	4.5	0.65	0.025	-1.60	2.5	0.40
13 A (20-40)	6.4	0.81	0.16	-0.80	1.2	0.08	0.019	-1.72	1.9	0.28
14 A (20-40)	8.3	0.92	0.96	-0.02	4.7	0.67	0.036	-1.44	3.6	0.56
15 A (20-40)	8.5	0.93	30.00	1.48	11.0	1.04	0.121	-0.92	12.1	1.08
sample mean	7.3	0.9	4.6	0.0	4.5	0.6	0.1	-1.3	5.3	0.7
sample variance	1.4	0.0	89.2	0.5	5.6	0.1	0.0	0.1	11.8	0.1
standard dev.	1.2	0.1	9.4	0.7	2.4	0.2	0.0	0.2	3.4	0.2
1 B (20-40)	6.6	0.82	0.74	-0.13	4.2	0.62	0.039	-1.41	3.9	0.59
2 B (20-40)	8.7	0.94	3.99	0.60	6.6	0.82	0.071	-1.15	7.1	0.85
3 B (20-40)	7.0	0.85	6.65	0.82	8.3	0.92	0.078	-1.11	7.8	0.89
4 B (20-40)	5.8	0.76	0.55	-0.26	3.9	0.59	0.038	-1.42	3.8	0.58
5 B (20-40)	6.6	0.82	0.50	-0.30	4.3	0.63	0.048	-1.32	4.8	0.68
6 B (20-40)	8.3	0.92	1.30	0.11	4.4	0.64	0.033	-1.48	3.3	0.52
7 B (20-40)	6.5	0.81	0.56	-0.25	4.8	0.68	0.034	-1.47	3.4	0.53
8 B (20-40)	6.3	0.80	0.38	-0.42	3.8	0.58	0.025	-1.60	2.5	0.40
9 B (20-40)	7.7	0.89	1.30	0.11	3.2	0.51	0.063	-1.20	6.3	0.80
10 B (20-40)	6.9	0.84	1.28	0.11	3.8	0.58	0.031	-1.51	3.1	0.49
11 B (20-40)	6.5	0.81	0.40	-0.40	2.0	0.30	0.028	-1.55	2.8	0.45
12 B (20-40)	6.2	0.79	0.37	-0.43	4.5	0.65	0.027	-1.57	2.7	0.43
13 B (20-40)	7.7	0.89	0.65	-0.19	3.3	0.52	0.015	-1.82	1.5	0.18
14 B (20-40)	8.1	0.91	0.89	-0.05	3.9	0.59	0.030	-1.52	3.0	0.48
15 B (20-40)	9.3	0.97	5.09	0.71	5.4	0.73	0.119	-0.92	11.9	1.08
sample mean	7.2	0.9	1.6	0.0	4.4	0.6	0.0	-1.4	4.5	0.6
sample variance	1.1	0.0	3.8	0.2	2.2	0.0	0.0	0.1	7.3	0.1
standard dev.	1.0	0.1	2.0	0.4	1.5	0.1	0.0	0.2	2.7	0.2
F test (s1/s2)	1.3	1.3	23.3	2.7	2.5	2.6	1.6	1.2	1.6	1.2
V1 (n1-1)	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
V2 (n2-1)	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
S=	1.1	0.1	6.8	0.6	2.0	0.2	0.0	0.2	3.1	0.2
T test	0.0	0.0	0.2	0.0	0.0	-0.1	0.1	0.1	0.1	0.1
v	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0

Site Number	1/3 bar (gm. H2O/ gm. soil)	LOG	% Water (1/3 bar)	LOG	Available Water (F.C.-W.P.)	LOG	% Avail. Water	LOG	Bulk Density (g/cm3)
1 A (20-40)	0.078	-1.11	7.8	0.89	0.042	-1.38	4.2	0.62	1.46
2 A (20-40)	0.254	-0.60	25.4	1.40	0.125	-0.90	12.5	1.10	1.44
3 A (20-40)	0.185	-0.73	18.5	1.27	0.092	-1.04	9.2	0.96	1.32
4 A (20-40)	0.108	-0.97	10.8	1.03	0.054	-1.27	5.4	0.73	1.61
5 A (20-40)	0.099	-1.00	9.9	1.00	0.050	-1.30	5.0	0.70	1.35
6 A (20-40)	0.067	-1.17	6.7	0.83	0.034	-1.47	3.4	0.53	1.43
7 A (20-40)	0.073	-1.14	7.3	0.86	0.037	-1.43	3.7	0.57	1.16
8 A (20-40)	0.063	-1.20	6.3	0.80	0.032	-1.49	3.2	0.51	1.21
9 A (20-40)	0.061	-1.21	6.1	0.79	0.003	-2.52	0.3	-0.52	1.48
10 A (20-40)	0.063	-1.20	6.3	0.80	0.018	-1.74	1.8	0.26	1.51
11 A (20-40)	0.061	-1.21	6.1	0.79	0.035	-1.46	3.5	0.54	1.43
12 A (20-40)	0.050	-1.30	5.0	0.70	0.025	-1.60	2.5	0.40	1.42
13 A (20-40)	0.037	-1.43	3.7	0.57	0.018	-1.74	1.8	0.26	1.57
14 A (20-40)	0.070	-1.15	7.0	0.85	0.034	-1.47	3.4	0.53	1.49
15 A (20-40)	0.238	-0.62	23.8	1.38	0.117	-0.93	11.7	1.07	1.64
sample mean	0.1	-1.1	10.0	0.9	0.0	-1.5	4.8	0.5	1.4
sample variance	0.0	0.1	46.8	0.1	0.0	0.2	12.9	0.2	0.0
standard dev.	0.1	0.2	6.8	0.2	0.0	0.4	3.6	0.4	0.1
1 B (20-40)	0.077	-1.11	7.7	0.89	0.038	-1.42	3.8	0.58	1.64
2 B (20-40)	0.140	-0.85	14.0	1.15	0.069	-1.16	6.9	0.84	1.46
3 B (20-40)	0.154	-0.81	15.4	1.19	0.076	-1.12	7.6	0.88	1.34
4 B (20-40)	0.073	-1.14	7.3	0.86	0.035	-1.46	3.5	0.54	1.64
5 B (20-40)	0.093	-1.03	9.3	0.97	0.045	-1.35	4.5	0.65	1.54
6 B (20-40)	0.064	-1.19	6.4	0.81	0.031	-1.51	3.1	0.49	1.45
7 B (20-40)	0.067	-1.17	6.7	0.83	0.033	-1.48	3.3	0.52	1.46
8 B (20-40)	0.063	-1.20	6.3	0.80	0.038	-1.42	3.8	0.58	1.33
9 B (20-40)	0.064	-1.19	6.4	0.81	0.001	-3.00	0.1	-1.00	1.50
10 B (20-40)	0.071	-1.15	7.1	0.85	0.040	-1.40	4.0	0.60	1.71
11 B (20-40)	0.055	-1.26	5.5	0.74	0.027	-1.57	2.7	0.43	1.51
12 B (20-40)	0.052	-1.28	5.2	0.72	0.025	-1.60	2.5	0.40	1.58
13 B (20-40)	0.029	-1.54	2.9	0.46	0.014	-1.85	1.4	0.15	1.65
14 B (20-40)	0.060	-1.22	6.0	0.78	0.030	-1.52	3.0	0.48	1.50
15 B (20-40)	0.236	-0.63	23.6	1.37	0.117	-0.93	11.7	1.07	1.56
sample mean	0.1	-1.1	8.7	0.9	0.0	-1.5	4.1	0.5	1.5
sample variance	0.0	0.0	27.5	0.0	0.0	0.2	7.8	0.2	0.0
standard dev.	0.1	0.2	5.2	0.2	0.0	0.5	2.8	0.5	0.1
F test (s1/s2)	1.7	1.3	1.7	1.3	1.6	0.7	1.6	0.7	1.5
V1 (n1-1)	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
V2 (n2-1)	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
S=	0.1	0.2	6.1	0.2	0.0	0.4	3.2	0.4	0.1
T test	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	-0.3
v	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0

Site Number			LOG	Particle Density (g/cm3)	LOG	% Total Porosity	LOG	Texture Class	% Sand	LOG	% Silt	LOG
1	A	(20-40)	0.16	2.71	0.43	46.13	1.66	L	51.27	1.71	30.02	1.48
2	A	(20-40)	0.16	2.69	0.43	46.47	1.67	CL	40.92	1.61	19.67	1.29
3	A	(20-40)	0.12	2.72	0.43	51.47	1.71	HC	24.36	1.39	10.35	1.01
4	A	(20-40)	0.21	2.72	0.43	40.81	1.61	SCL	51.27	1.71	19.67	1.29
5	A	(20-40)	0.13	2.65	0.42	49.06	1.69	SC	45.06	1.65	19.67	1.29
6	A	(20-40)	0.16	2.67	0.43	46.44	1.67	SCL	50.90	1.71	20.70	1.32
7	A	(20-40)	0.06	2.61	0.42	55.56	1.74	SL	52.97	1.72	31.05	1.49
8	A	(20-40)	0.08	2.60	0.41	53.46	1.73	SCL	52.97	1.72	22.77	1.36
9	A	(20-40)	0.17	2.61	0.42	43.30	1.64	SL	55.04	1.74	25.88	1.41
10	A	(20-40)	0.18	2.61	0.42	42.15	1.62	SCL	63.32	1.80	15.52	1.19
11	A	(20-40)	0.16	2.65	0.42	46.04	1.66	SCL	52.68	1.72	23.81	1.38
12	A	(20-40)	0.15	2.62	0.42	45.80	1.66	L	48.54	1.69	27.95	1.45
13	A	(20-40)	0.20	2.65	0.42	40.75	1.61	LS	83.73	1.92	8.28	0.92
14	A	(20-40)	0.17	2.61	0.42	42.91	1.63	SCL	57.86	1.76	19.66	1.29
15	A	(20-40)	0.21	2.65	0.42	38.11	1.58	C	13.35	1.13	25.88	1.41
sample mean			0.2	2.7	0.4	45.9	1.7		49.6	1.7	21.4	1.3
sample variance			0.0	0.0	0.0	23.9	0.0		252.8	0.0	42.8	0.0
standard dev.			0.0	0.0	0.0	4.9	0.0		15.9	0.2	6.5	0.2
1	B	(20-40)	0.21	2.63	0.42	37.64	1.58	SCL	63.69	1.80	14.49	1.16
2	B	(20-40)	0.16	2.61	0.42	44.06	1.64	C	36.78	1.57	20.70	1.32
3	B	(20-40)	0.13	2.66	0.42	49.62	1.70	C	35.75	1.55	22.77	1.36
4	B	(20-40)	0.21	2.73	0.44	39.93	1.60	SCL	57.48	1.76	18.63	1.27
5	B	(20-40)	0.19	2.63	0.42	41.44	1.62	SCL	46.10	1.66	21.73	1.34
6	B	(20-40)	0.16	2.65	0.42	45.28	1.66	SCL	51.94	1.72	23.80	1.38
7	B	(20-40)	0.16	2.58	0.41	43.41	1.64	L	40.55	1.61	32.09	1.51
8	B	(20-40)	0.12	2.64	0.42	49.62	1.70	L	50.90	1.71	30.02	1.48
9	B	(20-40)	0.18	2.67	0.43	43.82	1.64	SCL	48.83	1.69	24.84	1.40
10	B	(20-40)	0.23	2.66	0.42	35.71	1.55	CL	35.38	1.55	31.05	1.49
11	B	(20-40)	0.18	2.65	0.42	43.02	1.63	SCL	53.72	1.73	18.63	1.27
12	B	(20-40)	0.20	2.62	0.42	39.69	1.60	L	38.19	1.58	38.30	1.58
13	B	(20-40)	0.22	2.64	0.42	37.50	1.57	LS	87.87	1.94	4.14	0.62
14	B	(20-40)	0.18	2.61	0.42	42.53	1.63	SL	58.89	1.77	21.74	1.34
15	B	(20-40)	0.19	2.63	0.42	40.68	1.61	C	18.53	1.27	28.98	1.46
sample mean			0.2	2.6	0.4	42.3	1.6		48.3	1.7	23.5	1.3
sample variance			0.0	0.0	0.0	16.2	0.0		254.2	0.0	67.3	0.1
standard dev.			0.0	0.0	0.0	4.0	0.0		15.9	0.2	8.2	0.2
F test (s1/s2)			1.7	1.6	1.6	1.5	1.2		1.0	0.7	1.6	2.0
V1 (n1-1)			14.0	14.0	14.0	14.0	14.0		14.0	14.0	14.0	14.0
V2 (n2-1)			14.0	14.0	14.0	14.0	14.0		14.0	14.0	14.0	14.0
S=			0.0	0.0	0.0	4.5	0.0		15.9	0.2	7.4	0.2
T test			-0.3	0.1	0.1	0.3	0.3		0.0	0.0	-0.1	0.0
V			28.0	28.0	28.0	28.0	28.0		28.0	28.0	28.0	28.0

STATISTICAL ANALYSIS (Cont.)

Site Number	% Clay	LOG	% Organic Matter	LOG	Penetrometer Average	LOG
1 A (20-40)	18.71	1.27	1.8	0.26	2.7	0.43
2 A (20-40)	39.41	1.60	2.0	0.30	4.5	0.65
3 A (20-40)	65.29	1.81	2.6	0.41	3.0	0.48
4 A (20-40)	29.06	1.46	1.4	0.15	3.6	0.56
5 A (20-40)	35.27	1.55	1.5	0.18	4.0	0.60
6 A (20-40)	28.40	1.45	1.6	0.20	3.5	0.54
7 A (20-40)	15.98	1.20	1.2	0.08	3.0	0.48
8 A (20-40)	24.26	1.38	1.5	0.18	4.0	0.60
9 A (20-40)	19.08	1.28	1.5	0.18	3.5	0.54
10 A (20-40)	21.16	1.33	1.2	0.08	3.0	0.48
11 A (20-40)	23.51	1.37	1.6	0.20	3.1	0.49
12 A (20-40)	23.51	1.37	1.3	0.11	1.7	0.23
13 A (20-40)	7.99	0.90	2.1	0.32	3.1	0.49
14 A (20-40)	22.48	1.35	1.6	0.20	2.6	0.41
15 A (20-40)	60.77	1.78	1.1	0.04	2.2	0.34
sample mean	29.0	1.4	1.6	0.2	3.2	0.5
sample variance	248.3	0.1	0.2	0.0	0.5	0.0
standard dev.	15.8	0.2	0.4	0.1	0.7	0.1
1 B (20-40)	21.82	1.34	1.6	0.20	2.1	0.32
2 B (20-40)	42.52	1.63	1.6	0.20	2.7	0.43
3 B (20-40)	41.48	1.62	1.0	0.00	2.1	0.32
4 B (20-40)	23.89	1.38	1.1	0.04	3.3	0.52
5 B (20-40)	32.17	1.51	0.9	-0.05	3.0	0.48
6 B (20-40)	24.26	1.38	1.1	0.04	2.6	0.41
7 B (20-40)	27.36	1.44	0.9	-0.05	3.4	0.53
8 B (20-40)	19.08	1.28	1.1	0.04	2.2	0.34
9 B (20-40)	26.33	1.42	1.0	0.00	3.3	0.52
10 B (20-40)	33.57	1.53	0.9	-0.05	2.0	0.30
11 B (20-40)	27.65	1.44	1.0	0.00	2.6	0.41
12 B (20-40)	23.51	1.37	1.1	0.04	3.1	0.49
13 B (20-40)	7.99	0.90	0.8	-0.10	1.9	0.28
14 B (20-40)	19.37	1.29	1.3	0.11	3.0	0.48
15 B (20-40)	52.49	1.72	1.5	0.18	2.3	0.36
sample mean	28.2	1.4	1.1	0.0	2.6	0.4
sample variance	120.5	0.0	0.1	0.0	0.3	0.0
standard dev.	11.0	0.2	0.3	0.1	0.5	0.1
F test (s1/s2)	2.1	1.4	2.3	1.1	1.9	1.5
V1 (n1-1)	14.0	14.0	14.0	14.0	14.0	14.0
V2 (n2-1)	14.0	14.0	14.0	14.0	14.0	14.0
S=	13.6	0.2	0.3	0.1	0.6	0.1
T test	0.0	0.0	0.5	0.6	0.3	0.3
V	28.0	28.0	28.0	28.0	28.0	28.0

STATISTICAL ANALYSIS (cont.)

Site Number	%A/C 1	log	Dry Aggregate %A/C 2	log	%Stab.	log	% T. Ag.	Wet Aggregate log	% Agg.	log
1 A(0-20)	68.40	1.84	65.40	1.82	3.00	0.48	71.94	1.86	53.58	1.73
2 A(0-20)	61.40	1.79	54.00	1.73	7.40	0.87	72.66	1.86	31.40	1.50
3 A(0-20)	85.80	1.93	83.60	1.92	2.20	0.34	74.70	1.87	55.14	1.74
4 A(0-20)	66.50	1.82	57.10	1.76	9.40	0.97	71.48	1.85	30.26	1.48
5 A(0-20)	80.20	1.90	76.70	1.88	3.50	0.54	77.98	1.89	47.36	1.68
6 A(0-20)	82.80	1.92	82.60	1.92	0.20	-0.70	87.34	1.94	46.90	1.67
7 A(0-20)	74.40	1.87	70.10	1.85	4.30	0.63	84.36	1.93	63.10	1.80
8 A(0-20)	71.30	1.85	67.20	1.83	4.10	0.61	86.12	1.94	53.64	1.73
9 A(0-20)	68.80	1.84	51.00	1.71	17.80	1.25	78.22	1.89	54.06	1.73
10 A(0-20)	61.10	1.79	51.80	1.71	9.30	0.97	80.50	1.91	39.22	1.59
11 A(0-20)	78.40	1.89	74.20	1.87	4.20	0.62	67.28	1.83	40.62	1.61
12 A(0-20)	64.90	1.81	57.80	1.76	7.10	0.85	78.72	1.90	31.96	1.50
13 A(0-20)	46.50	1.67	40.10	1.60	6.40	0.81	74.72	1.87	33.42	1.52
14 A(0-20)	68.40	1.84	64.00	1.81	4.40	0.64	85.10	1.93	44.84	1.65
15 A(0-20)	85.20	1.93	82.50	1.92	2.70	0.43	64.22	1.81	49.14	1.69
sample mean	70.94	1.85	65.21	1.81	5.73	0.62	77.02	1.88	44.98	1.64
sample variance	112.65	0.00	174.31	0.01	17.89	0.19	47.91	0.00	103.29	0.01
standard dev.	10.61	0.07	13.20	0.09	4.23	0.44	6.92	0.04	10.16	0.10
1 B(0-20)	72.90	1.86	70.00	1.85	2.90	0.46	51.26	1.71	17.40	1.24
2 B(0-20)	75.10	1.88	66.30	1.82	8.80	0.94	60.90	1.78	22.28	1.35
3 B(0-20)	93.00	1.97	92.20	1.96	0.80	-0.10	86.36	1.94	17.90	1.25
4 B(0-20)	70.30	1.85	59.00	1.77	11.30	1.05	71.52	1.85	16.28	1.21
5 B(0-20)	85.70	1.93	83.30	1.92	2.40	0.38	55.04	1.74	17.88	1.25
6 B(0-20)	75.80	1.88	57.10	1.76	18.70	1.27	74.36	1.87	22.62	1.35
7 B(0-20)	71.20	1.85	64.50	1.81	6.70	0.83	64.38	1.81	17.90	1.25
8 B(0-20)	73.60	1.87	70.10	1.85	3.50	0.54	72.90	1.86	26.12	1.42
9 B(0-20)	70.20	1.85	66.20	1.82	4.00	0.60	43.44	1.64	9.52	0.98
10 B(0-20)	66.50	1.82	56.40	1.75	10.10	1.00	44.82	1.65	12.96	1.11
11 B(0-20)	77.10	1.89	74.00	1.87	3.10	0.49	40.20	1.60	9.96	1.00
12 B(0-20)	73.60	1.87	70.90	1.85	2.70	0.43	57.74	1.76	5.56	0.75
13 B(0-20)	67.20	1.83	73.30	1.87	6.10	0.79	91.98	1.96	37.68	1.58
14 B(0-20)	62.90	1.80	55.30	1.74	7.60	0.88	80.60	1.91	34.26	1.53
15 B(0-20)	89.20	1.95	87.60	1.94	1.60	0.20	47.38	1.68	15.78	1.20
sample mean	74.95	1.87	69.75	1.84	6.02	0.65	62.86	1.78	18.94	1.23
sample variance	70.90	0.00	125.22	0.00	22.54	0.13	264.77	0.01	76.36	0.05
standard dev.	8.42	0.05	11.19	0.07	4.75	0.36	16.27	0.11	8.74	0.21
F test (s1/s2)	1.59	2.16	1.39	1.84	0.79	1.47	5.53	8.27	1.35	0.23
V1 (n1-1)	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00
V2 (n2-1)	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00
S=	9.58	0.06	12.24	0.08	4.50	0.40	12.50	0.09	9.48	0.17
T test	-0.15	-0.16	-0.14	-0.15	-0.02	-0.03	0.41	0.43	1.00	0.89
v	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00

STATISTICAL ANALYSIS (cont.)

Site Number	Dry Aggregate %A/C 1	log	%A/C 2	log	%Stab.	log	% T. Ag.	Wet Aggregate log	% Agg.	log
1 A(20-40)	68.00	1.83	61.90	1.79	6.10	0.79	64.58	1.81	25.62	1.41
2 A(20-40)	88.20	1.95	86.30	1.94	1.90	0.28	68.86	1.84	60.76	1.78
3 A(20-40)	91.90	1.96	90.60	1.96	1.30	0.11	71.40	1.85	40.76	1.61
4 A(20-40)	80.10	1.90	77.60	1.89	2.50	0.40	66.80	1.82	33.72	1.53
5 A(20-40)	82.10	1.91	79.50	1.90	2.60	0.41	72.86	1.86	41.64	1.62
6 A(20-40)	80.70	1.91	74.40	1.87	6.30	0.80	74.78	1.87	33.62	1.53
7 A(20-40)	78.10	1.89	74.40	1.87	3.70	0.57	72.78	1.86	33.82	1.53
8 A(20-40)	70.20	1.85	66.80	1.82	3.40	0.53	85.48	1.93	46.34	1.67
9 A(20-40)	62.00	1.79	55.80	1.75	6.20	0.79	66.00	1.82	17.94	1.25
10 A(20-40)	87.60	1.94	85.30	1.93	2.30	0.36	52.02	1.72	13.74	1.14
11 A(20-40)	76.20	1.88	72.30	1.86	3.90	0.59	77.08	1.89	45.24	1.66
12 A(20-40)	76.90	1.89	73.20	1.86	3.70	0.57	53.32	1.73	12.88	1.11
13 A(20-40)	55.20	1.74	43.50	1.64	11.70	1.07	76.32	1.88	30.24	1.48
14 A(20-40)	71.50	1.85	68.30	1.83	3.20	0.51	82.58	1.92	47.46	1.68
15 A(20-40)	92.50	1.97	91.60	1.96	0.90	-0.05	69.72	1.84	23.20	1.37
sample mean	77.41	1.88	73.43	1.86	3.98	0.52	70.31	1.84	33.80	1.49
sample variance	114.74	0.00	171.34	0.01	7.39	0.08	84.70	0.00	185.36	0.04
standard dev.	10.71	0.06	13.09	0.09	2.72	0.28	9.20	0.06	13.61	0.20
1 B(20-40)	76.40	1.88	72.30	1.86	4.10	0.61	63.28	1.80	27.00	1.43
2 B(20-40)	85.90	1.93	84.80	1.93	1.10	0.04	48.40	1.68	31.94	1.50
3 B(20-40)	85.50	1.93	83.20	1.92	2.30	0.36	48.06	1.68	19.24	1.28
4 B(20-40)	76.90	1.89	73.70	1.87	3.20	0.51	43.00	1.63	14.22	1.15
5 B(20-40)	86.50	1.94	81.10	1.91	5.40	0.73	48.10	1.68	13.94	1.14
6 B(20-40)	73.70	1.87	69.90	1.84	3.80	0.58	77.54	1.89	31.64	1.50
7 B(20-40)	79.30	1.90	72.90	1.86	6.40	0.81	59.50	1.77	20.80	1.32
8 B(20-40)	70.30	1.85	61.70	1.79	8.60	0.93	70.08	1.85	17.62	1.25
9 B(20-40)	86.10	1.94	84.90	1.93	1.20	0.08	54.20	1.73	38.56	1.59
10 B(20-40)	90.70	1.96	89.20	1.95	1.50	0.18	79.30	1.90	41.34	1.62
11 B(20-40)	80.10	1.90	76.20	1.88	3.90	0.59	59.56	1.77	20.94	1.32
12 B(20-40)	60.50	1.78	57.60	1.76	2.90	0.46	49.78	1.70	5.16	0.71
13 B(20-40)	63.50	1.80	73.90	1.87	10.40	1.02	87.08	1.94	23.08	1.36
14 B(20-40)	63.80	1.80	59.10	1.77	4.70	0.67	78.22	1.89	32.32	1.51
15 B(20-40)	91.20	1.96	89.80	1.95	1.40	0.15	51.00	1.71	27.86	1.44
sample mean	78.03	1.89	75.35	1.87	4.06	0.51	61.14	1.78	24.38	1.34
sample variance	99.84	0.00	106.56	0.00	7.45	0.09	197.54	0.01	97.19	0.05
standard dev.	9.99	0.06	10.32	0.06	2.73	0.30	14.05	0.10	9.86	0.23
F test (s1/s2)	1.15	1.19	1.61	1.92	1.01	1.15	2.33	2.65	1.91	0.78
V1 (n1-1)	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00
V2 (n2-1)	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00
S=	10.36	0.06	11.79	0.07	2.72	0.29	11.88	0.08	11.89	0.21
T test	-0.02	-0.02	-0.06	-0.07	-0.01	0.00	0.28	0.30	0.29	0.25
v	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00