EFFECT OF PIPELINE CONSTRUCTION ON SOIL STRENGTHS OF SOIL HORIZONS IN ALBERTA : 1990 FINAL REPORT

LAND RESOURCES NETWORK LTD.

EFFECT OF PIPELINE CONSTRUCTION ON SOIL STRENGTHS OF SOIL HORIZONS IN ALBERTA : 1990 FINAL REPORT

Karen R. Cannon,

Nancy M. Finlayson

Land Resources Network Ltd.

and

S. Landsburg

NOVA Corporation of Alberta

Prepared for
NOVA Corporation of Alberta
Environment & Quality Management
P.O. Box 2535, Station 'M'
Calgary, Alberta
T2P 2N6

January 1991

FOREWORD

NOVA Corporation of Alberta is a major Canadian energy company involved in natural gas transportation and marketing, petroleum, petrochemical manufacturing, consulting and research. The Alberta Gas Transmission Division (AGTD) of NOVA is concerned with natural gas system design, pipeline construction, research and facility operations throughout the province of Alberta. In an effort to minimize the duplication of research efforts the AGTD is endeavoring to contribute to the body of scientific knowledge by providing to the public the results of non-confidential studies sponsored by NOVA.

The AGTD has an ongoing environmental research program and this report is a result of one project in that program. This report is published verbatim unless otherwise noted on the title page or in the Acknowledgements section.

Comments regarding this report may be submitted to NOVA Corporation of Alberta.

Please send comments to :

NOVA Corporation of Alberta
Alberta Gas Transmission Division
Environment and Quality Management
P.O. Box 2535, Postal Station 'M'
Calgary, Alberta
T2P 2N6

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Concluded)

LIST OF TABLES

LIST OF FIGURES

Figure | Page

LIST OF FIGURES (continued)

LIST OF FIGURES(concluded)

ABSTRACT

This study was initiated in 1988 to evaluate the effects of pipeline construction on soil strengths of various soils in the province of Alberta. The pipelines were scattered throughout Alberta on a number of different soils and were constructed using various techniques. At each of the fifteen 1989 study areas and at each of the eight 1988 study areas soil strength was monitored using a cone penetrometer in 15 depth increments to a depth of 52.5 cm. Soil strength measurements were taken from the trench, work side and spoil side locations of the rights-of-way, as well as an adjacent undisturbed location. Soil strength measurements on the spoil side locations of the rights-of-way were not monitored for the 1988 study sites. Soils were also analyzed to determine percent organic matter, moisture content and clay content.

Soil strength information from the twenty three study areas suggests that pipeline construction procedures can cause changes in soil strength on pipeline rights-of-way in Alberta. Significant soil changes were observed inboth topsoil and subsoil. Because of site differences, few similarities in soil strength trends occurred beteen study areas. There were no close correlations between soil strength and soil moisture, soil organic matter and clay content for combined site data for the years monitored.

Immediately following pipeline construction, decreases in soil strength across the right-of-way soils in the top 24.5 to 31.5 cm, most likley due to cultivation and harrowing of the right-of-way after construction occurred for fifteen of the twenty three study areas. Soil stength increases in the top 24.5 to 31.5 cm occurred for seven of the twenty three study areas. Two study areas had both increases and decreases in right-of-way soil strength measurements. There were no significant soil strength differences in the top 24.5 to 31.5 cm for only three study areas. Significant differences in right-of-way subsoil soil strength values below 24.5 to 31.5 cm were found in only four sites.

One year after construction, soil strength increases and decreases were not observed for as many depth increments or portions of the pipeline rights-of-way as for the sampling event immediately following construction. Data suggests a return of right-of-way soil strength to levels similar to those of the control in all but two study areas.

After three years of monitoring soils for soil strength, there is inconclusive data to determine the effects of soil moisture, soil texture, soil organic matter, soil classification, parent material and various pipeline construction methods on soil strength and compaction. Further research is needed to provide more information on which soils are most compactible and under what conditions.

ACKNOWLEDGEMENTS

The authors acknowledge the financial assistance of NOVA Corporation of Alberta which funded this project. Acknowledgements also go to Toby Entz from Lethbridge, Alberta for clarification of the statistical analyses required for this project.

1. INTRODUCTION

Increased concerns about soil compaction on pipeline rights-of-way (RsoW) have occurred with the introduction of heavier, more powerful construction equipment. RsoW are prone to compaction because of the repeated high traffic associated with construction procedures. Resultant soil compaction levels are higher due to heavier construction equipment and extend much deeper into the soil profile than levels due to conventional farm machinery. This subsurface compaction is not alleviated by regular tillage practice and is only slowly affected by natural seasonal freezing and thawing or periodic wetting and drying cycles.

Soil compaction can lead to poor root penetration, difficult cultivation, poor seedbed preparation, increased soil strength, reduced water infiltration, increased surface water runoff, and decreased soil porosity (Lull 1959, Swan et al. 1987). Root and crop growth can be affected because of limited root elongation and distribution due to restricted movement of gases, water, and nutrients. Where pipeline RsoW cross agricultural land there is the potential for landowner concerns resulting from reduced crop production caused by soil compaction.

Limited data is available on the effect of pipeline construction on soil compaction. This knowledge is important because each soil system can respond differently to various construction procedures. Degree of compaction depends mainly on variables including soil type and soil conditions as well as vehicle type and traffic density. Studies are needed to understand the problem of soil compaction so that it can be dealt with more effectively. The ability to predict which soil may be more susceptible to compaction would enable the implementation of preventative measures during pipeline construction.

1.1 OBJECTIVE

The objective of this study was to evaluate the effects of pipeline construction on the compaction of various soils in Alberta. In order to achieve the objective, a study was initiated to monitor soil strength on a number of NOVA pipeline RsoW immediately after construction had taken place. This study was expanded to include monitoring of soil strength on these same

NOVA pipeline RsoW one year after construction was completed. The pipelines were scattered throughout Alberta on a number of different soils and constructed using various techniques.

2. REVIEW OF RELATED LITERATURE

Conflicting information exists in the literature on the impacts of pipeline installation on soil compaction. Some studies have shown that pipeline construction can lead to soil compaction, whereas other studies have demonstrated that little or no compaction resulted from installation procedures. In some studies, reduction in soil bulk densities have been reported. Compaction can result because of repeated passage of equipment on the surface of a RoW, because of a denser subsoil being mixed with topsoil or because the soil was too wet during construction. Reductions in soil compaction can occur when a compacted horizon is broken up during the trenching operation. The amount of soil compaction depends on soil texture, moisture content, organic matter content, original soil structure as well as compactive effort.

A study to evaluate the effect of pipeline construction on agricultural land was carried out for two seasons on the Sarnia-Montreal oil pipeline (Stewart and MacKenzie 1979). The soils studied included a clay loam developed on lacustrine sediment, a clay loam developed on glacial till and a sandy soil developed on fluvio-aolian sand. The researchers found that surface (0 to 15 cm) bulk densities over all sites were higher on the RsoW than off, with the trench zone tending to have the highest bulk density. Bulk density values were similar for the two years studied indicating little or no change over that time. Bulk densities at 15 to 30 cm depths were less affected by zone of construction, but again there was higher compaction over the trench. Lower saturation water contents over the surface depths of the RsoW compared to control sites, indicated that total pore space was reduced. The lowered saturation water contents were consistent with soils of high bulk density. This effect was not noticeable over the trench zone. At lower depths, reduced saturation water contents were found only in the trench. Pipeline construction occurred in both fall and winter. During fall construction topsoil was salvaged, whereas during winter it was not possible to strip topsoil. Season of construction appeared to have little influence on compaction levels since results of this study showed that all construction zones on the RsoW were similarily compacted.

Considerable soil compaction had also been measured across the entire RoW on the same Sarnia-Montreal oil pipeline by Culley et al. (1982). Compaction was especially predominate on medium to fine-textured soils. However, compaction did not appear to be a problem on coarse-textured soils. Bulk densities were 10% greater on the RoW than in adjacent undisturbed fields. The work side of the RoW was found to have the highest bulk density which was in contrast to results reported by Stewart and MacKenzie (1979). Culley et al. (1982) found hydraulic conductivity decreased by an average of 38% in the trench and work side portions of the RoW as compared to the control. Research by Culley et al. (1982) also demonstrated that surface layers of the RoW had lower available water holding capacities than surface layers of control sites. This was similar to results reported by Stewart and MacKenzie (1979). This decrease in available water holding capacity was attributed to lowered total porosity. Strength of soil as measured by penetrometer resistance was greater on the RoW than off averaging 67% and 50% more over trench and work areas, respectively (Culley et al. 1982). This increase in soil strength was believed to be due to increased clay content and decreased organic matter in the soil after the trenching operation.

The potential severity of soil compaction on a RoW in southwestern Ontario was presented in a study by Moncrieff (1984). The extent of soil damage was evaluated when eight kilometers of a RoW were turned into a homogenous saturated mixture of topsoil and subsoil after being left to deteriorating weather conditions and heavy equipment movement. Crop yields on the RoW were approximately 40% lower than those on the adjacent field even after five years. These yield reductions were attributed to the conversion of the original structure of the B horizon into a massive structure. The result was reduced air and water movement which limited root penetration. Subsoiling procedures were necessary to break up the subsoil and provide surface drainage. This amelioration of the site led to improved yields which were found to be approaching and in some cases even exceeding those found on the adjacent undisturbed control.

Research in eastern Oklahoma on a fine sandy loam was conducted to study the extent to which physical characteristics of a soil were altered by a single ditch pipeline construction project (Zellmer et al. 1985). No attempt was made to separate or remove the topsoil during trenching and backfilling. This study concluded that surface (0 to 15 cm) bulk density was not increased by pipeline installation in a semi-arid environment. Bulk densities were not increased by construction traffic on the RoW. There was also no significant difference between the soil bulk densities from the work side transect and the soil in the adjacent control transect. Bulk densities were lower in the trench than on the adjacent undisturbed control site in 16 of 20 control sets of observations. Similar trends were observed for subsurface (to a depth of 50 cm) bulk densities. In the cultivated soil, bulk densities averaged approximately 1.56 Mg m^{-3} for the control site and 1.46 Mg m^{-3} in the trench. Similar trends for pasture land occurred with bulk densities averaging approximately 1.46 and 1.27 Mg m^{-3} for the control and trench locations, respectively. Lowered bulk densities for the pasture land were attributed to the extensive root system of the pasture when compared to the cultivated soil.

Results from earlier studies by de Jong and Button (1973) indicated that pipeline installation neither harmed nor improved the physical properties of Chernozemic soils. However, in Solonetzic soils, lowered bulk densities resulted in improved permeability and aeration of the Bnt horizon. The saturation permeability and air filled porosity of the Solonetzic Bnt horizon were considered undesirable prior to trenching. Trenching on Solonetzic soils tended to decrease the bulk density at depth, whereas trenching on Chernozemic soils occasionally resulted in increased bulk densities at depth. This compaction was thought to have occurred because of compaction by heavy machinery or by puddling of the exposed subsoil.

Research in central Alberta on cultivated land and pastured Orthic Dark Brown Chernozems and on cultivated Dark Brown Solonetz soils was done to study the effects of pipeline construction on agricultural soil quality ratings (Landsburg 1989). Bulk density of the Ap horizons was similar between the work side and the control for each of the three soils, indicating there was no compaction due to heavy equipment. Construction had little effect on the work side due to optimum weather conditions resulting in minimal soil rutting. There was also no significant difference between Ap horizons of the trench and controls for each of the soils studied. The cultivated Dark Brown Solonetz had a significantly increased bulk density on the spoil side

(1.22 Mg m^{-3}) compared to the control (1.09 Mg m^{-3}). This trend was also observed for the Orthic Dark Brown Chernozem on pasture land with bulk densities of 0.82 and 1.16 Mg m^{-3} for the control and spoil side, respectively. Increased bulk density on the Solonetz soil was attributed to the presence of spoil material on the B horizon before topsoil replacement, whereas increased bulk density for the Chernozem on pasture land was thought to be due to construction equipment during backfill. Results of this research indicated that the increased bulk densities posed no limitation to crop growth.

3. STUDY AREAS

In 1988 eight study areas were chosen to be monitored for soil compaction on a number of NOVA pipeline RsoW immediately after construction had taken place (Figure 1). Fifteen additional study areas were chosen in 1989 to be monitored for soil compaction (Figure 2). Detailed descriptions of these 23 study areas are presented in this section.

3.1 1988 STUDY AREAS

3.1.1 Craigmyle Lateral

The 6.3 km pipeline is located east of Hanna, Alberta (Figure 1) and runs from the Rowley Meter Station (SE13-32-19-W4M) to the Delia Meter Station (SE15-32-18-W4M). The climate of the area is continental and is characterized by warm summers and cold winters (Bowser et al. 1951). Topography varies from undulating on glacio-lacustrine sediments to strongly rolling on hummocky galcial moraine. Surficial materials include glacial tills, lacustrine sands and clays, glacio-fluvial sands and recent fluvial deposits (Environmental Affairs 1983). The pipeline was constructed in the summer of 1988 in wet soil conditions. The RoW was 19 m wide with the work side being 9 m and the spoil side being 10 m.

The legal description of the study plots is SW17-32-18-W4M. The soil monitored for compaction was a cultivated Dark Brown Solonetz developed on moderately fine textured weathered bedrock (Appendix 9.1). The topsoil (15 cm) was stripped from the trench and spoil storage area and placed on the far edge of the spoil side of the RoW. Subsoil removed from the trench was placed on the spoil side of the RoW at least one meter from the topsoil. Subsoil and topsoil replacement was followed by cultivation of the RoW.

3.1.2 Delia Lateral

The 6.4 km pipeline is located east of Hanna, Alberta (Figure 1) and runs from the Craigmyle Meter Station (SW8-32-17-W4M) to the Delia Meter Station (SE15-32-18-W4M). The pipeline is an extension of the Craigmyle Lateral. The climate of the area is continental and is characterized by warm summers and cold winters (Bowser et al. 1951). Topography varies from

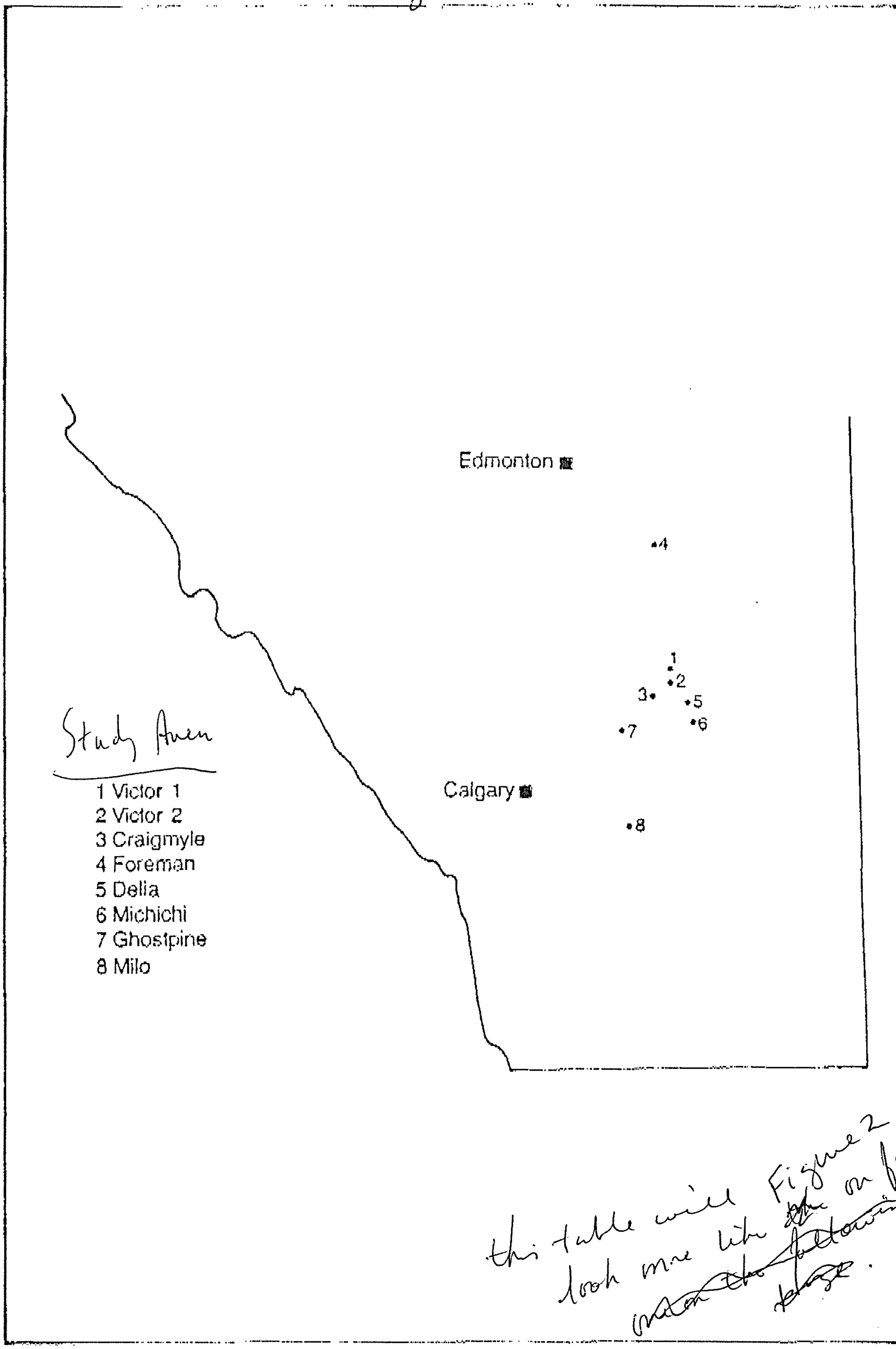
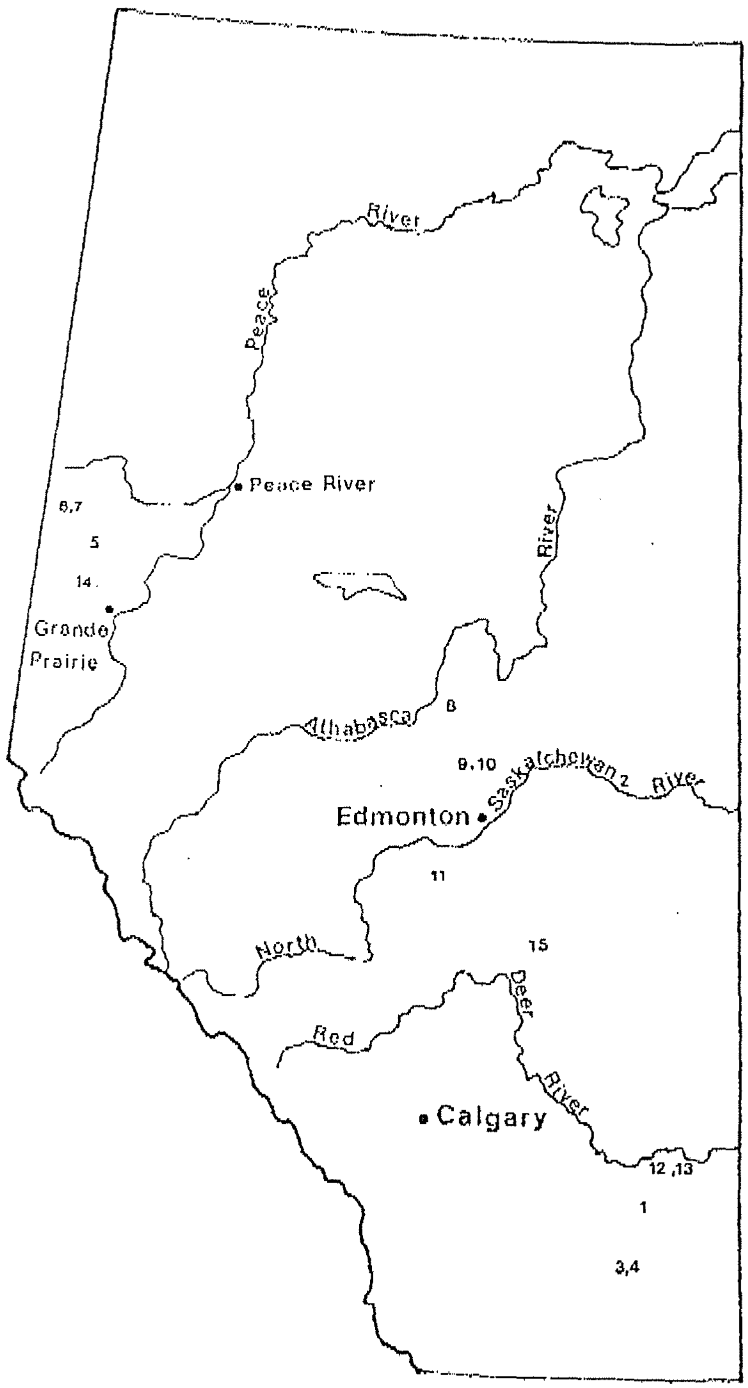


Figure 1. ~~Study area locations~~.
1988 study area locations



Study areas
1 Aeco 'C'
2 Foisey
3 Maleb 1
4 Maleb 2
5 Valhalla
6 Henderson 1
7 Henderson 2
8 Bolloque
9 Redwater 1
10 Redwater 2
11 Pigeon Lake
12 Atlee-Buffalo 1
13 Atlee-Buffalo 2
14 Albright
15 Ferintosh

Figure 2. ~~Study area locations.~~
1989 study area location

undulating on glacio-lacustrine sediments to strongly rolling on hummocky moraine. Surficial deposits include various glacial tills, lacustrine sands and clays, glacio-fluvial sands and recent fluvial deposits (Environmental Affairs 1983). The pipeline was constructed in the summer of 1988 in wet soil conditions. The RoW was 18 m wide with the spoil being 8 m and the work side being 10 m.

The legal description of the study plots is NW11-32-18-W4M. The soil monitored for compaction was a cultivated Dark Brown Gleyed Solonetzic Chernozem developed on a glacio-fluvial veneer overlying till (Appendix 9.1). One of the three replicates was an Orthic Dark Brown Chernozem developed on a medium textured glacio-fluvial veneer over moderately fine textured glacial till (Appendix 9.1). The topsoil (15 cm) was stripped from the trench and spoil storage area and placed on the far edge of the spoil side of the RoW. Subsoil removed from the trench was placed on the spoil side of the RoW. Wet weather conditions resulted in the RoW being rutted. Subsoil and topsoil replacement was followed by cultivation and seeding of the RoW.

3.1.3 Foreman Lateral

This 2.8 km pipeline is located southwest of Forestburg, Alberta (Figure 1) extending from 6-20-40-16-W4M to 5-22-40-16-W4M. The climate of the area is characterized by moderately warm summer and relatively cold winter temperatures (Bowser et al. 1947). Physiographically the area is gently undulating. Dominant surficial geological materials are fine-loamy textured till and coarse loamy textured veneers overlying till (Bessie 1988). The pipeline was constructed in the summer of 1988 in dry soil conditions. The RoW was 16 m wide with the work side being 9 m and the spoil side being 7 m.

The legal description of the study plots is SW20-40-16-W4M. The soil monitored for compaction was an Orthic Dark Brown Chernozem developed on a medium textured glacio-fluvial veneer overlying till (Appendix 9.1). The plots were located on pasture land. The topsoil (20 cm) was stripped from the trench only (1.2 m) and placed on the spoil side of the RoW. The pipeline was plowed in using the plow-in technique, where the plow creates its own trench into which the pipeline is fed. The plow-in technique creates a narrower trench than normal pipeline construction procedures. After the plow has passed, the soil settles back into the trench. The material over the trench was packed, the topsoil replaced and then the RoW was cultivated.

3.1.4 Ghostpine Extension Lateral

The 28.5 km pipeline runs from the Ghostpine Meter Station (NE2-32-21-W4M) to the Rumsey Meter Station (SE31-33-20-W4M) (Figure 1). Climatically the area falls within the Agro-climatic Subregion 2A, established by Bowser (1967). This subregion indicates an area where low precipitation is limiting to crop growth in at least 50% of the years. Frost damage rarely occurs. Physiographically the area is undulating to gently rolling. Surficial deposits are mainly fine-textured, stone-free, lacustrine sediments blanketing undulating moderately fine-textured glacial till (Finlayson 1988). The pipeline was constructed in the summer of 1988 in wet soil conditions. The RoW was 18 m wide with the work side being 10 m and the spoil side being 8 m.

The legal description of the study plots is NW7-33-20-W4M. The soil monitored for compaction was a cultivated Orthic Dark Brown Chernozem developed on undulating to rolling medium to moderately fine textured moraine (Appendix 9.1) The topsoil (15 cm) was stripped from the trench and spoil side and was placed on the far side of the spoil side on the RoW. Subsoil removed from the trench was placed on the spoil side of the RoW. Subsoil and topsoil replacement was followed by cultivation of the RoW.

3.1.5 Michichi Lateral

The pipeline is located north of Drumheller, Alberta (Figure 1) running southwest for 7.4 km from the Michichi Meter Station (SW8-31-18-W4M) to the Morrin Meter Station (SW33-30-19-W4M). The climate of the area is continental and characterized by warm summers and cold winters (Bowser et al. 1951). Physiographically the pipeline runs across an area that ranges from gently undulating to moderately rolling. Surficial deposits are mainly clayey textured glacio-lacustrine material which is stone-free to slightly stony (Twardy and Dowgray 1988). Till, which is slightly to very stony, weakly calcareous and fine loamy in texture also occurs along the route. The pipeline was constructed in the summer of 1988 in dry soil conditions. The

RoW was 18 m wide with the work side being 10 m and the spoil side being 8 m.

The legal description of the study plots is SE7-31-18-W4M. The soil monitored for compaction was a cultivated Dark Brown Solonetz developed on a moderately fine to fine textured glacio-lacustrine blanket (Appendix 9.1). The topsoil (15 cm) was stripped from the trench and spoil side of the RoW and stored on the far edge of the spoil side. Subsoil removed from the trench was also stored on the spoil side. Subsoil and topsoil replacement was followed by cultivation of the RoW.

3.1.6 Milo Lateral

The pipeline is located near Brooks, Alberta (Figure 1) mainly on native rangeland. The 38.5 km pipeline runs from the Muskateer Energy Limited gas plant (4-31-18-19-W4M) to NOVA's South Lateral (9-13-16-17-W4M). Climatically the area falls within Agro-climatic Subregion 3A, established by Bowser (1967). This subregion indicates an area where low precipitation has usually been a severe limiting factor to crop growth. Frost is not considered a hazard to cereal crop production. Topography is gently undulating to undulating (0 to 5% slopes) in the central and southwestern portions and moderately rolling to hilly (10 to 45% slopes) in the northwestern portion. Surficial deposits consist of stone-free to slightly stony glacio-fluvial, sandy textured veneers in the southeast portion and loam to clay loam textured till in the central and northwestern portions (Pedology Consultants 1985). The pipeline was constructed in the summer and fall of 1988 in dry soil conditions. The RoW was 18 m wide with the spoil side being 8 m and the work side being 10 m.

The legal location of the study plots is SW17-17-17-W4M. The soil monitored for compaction was a cultivated Solonetzic Brown Chernozem developed on glacio-fluvial material (Appendix 9.1). One of the three replicates was classified as a Brown Calcareous Chernozem developed on medium glaciofluvial over moderately fine textured morainal material (Appendix 9.1). The topsoil (20 cm) was stripped from the trench and spoil side of the RoW and placed on the far edge of the spoil side of the RoW. Subsoil removed from the trench was placed on the spoil side of the RoW. Subsoil and topsoil replacement was followed by cultivation of the RoW.

3.1.7 Victor Lateral

The pipeline runs north 8.5 km from the Delia Meter Station (SE15-32-18-W4M) to the Victor Meter Station (SW11-33-18-W4M). Climatically the pipeline falls in Agro-climatic Subregion 2A (Bowser 1967) which indicates an area where low precipitation is limiting to crop production in at least 50% of the years, but where frost damage rarely occurs. Parent materials of the area are of lacustrine origin and form a relatively stone-free veneer over glacial till (Finlayson 1988). In a few locations till occurs at the surface. The pipeline was constructed in the summer of 1988 in dry soil conditions. THe RoW was 18 m wide with the work side being 10 m and the spoil side being 8 m.

The legal location of the study plots is NE22-32-18-W4M. Two sites were monitored for compaction on this pipeline. The soil at the first site (Victor 1) was a cultivated Orthic Humic Gleysol developed on moderately fine to fine textured lacustrine material (Appendix 9.1). The soil at the second site (Victor 2) was a cultivated Orthic Dark Brown Chernozem developed on moderately fine textured lacustrine material (Appendix 9.1). The topsoil (15 cm) was stripped from the trench and spoil side of sthe RoW and stored on the far edge of the spoil side. Subsoil removed from the trench was also stored on the spoil side of the RoW. Subsoil and topsoil replacement was followed by cultivation of the RoW. Wet weather conditions prevailed prior to final cleanup but topsoil was not replaced until dry.

3.2 1989 STUDY AREAS

3.2.1 Aeco 'C' Lateral Loop

The 6.9 km pipeline is located northeast of Brooks, Alberta (Figure 2) and runs from SE4-19-9-W4M to SE2-19-10-W4M. Climatically the area falls within Agro-climatic Subregion 3A, established by Bowser (1967). This subregion indicates an area where low precipitation has usually been a severe limiting factor to crop growth. Frost is not considered a hazard to cereal crop production. Physiographically the area is gently undulating to undulating (0 to 5% slopes) (Bessie 1988). Surficial deposits are mainly till which is moderately calcareous, sodic and moderately stony. Glacio-fluvial lacustrine pockets also occur along the route. The pipeline was constructed in the fall of 1988 in dry soil conditions. Final cleanup occurred in the spring of 1989. The RoW was 23 m wide with the work side being 14 m and the spoil side being 9 m.

The legal description of the study plots is SE5-19-9-W4M. The soil monitored for compaction was a cultivated Brown Solodized Solonetz developed on till (Appendix 9.1). One of the three replicates was a Brown Solonetzic Chernozem developed on till (Appendix 9.1). During construction, the topsoil (15 cm) was stripped from the trench and spoil side of the RoW and placed on the far edge of the spoil side. Subsoil removed from the trench was also stored on the spoil side of the RoW. Subsoil and topsoil replacement was followed by harrowing in the spring.

3.2.2 <u>Foisy Lateral</u>

The 1.9 km pipeline is located northeast of Two Hills, Alberta (Figure 2) and runs from the Foisey Meter Station (SW30-56-11-W4M) to the Saddle Lake Lateral (NW25-56-12-W4M). Climatically the area falls within Agro-climatic Subregion 3H (Bowser 1967). This subregion indicates an area where heat units are moderately limiting to crop growth. Parent materials of the area are glacial deposits, mainly till, which are yellowish brown to greyish brown in colour and clay loam in texture (Landsburg 1988). The pipeline was constructed in the spring of 1989 in dry soil conditions. The RoW was 18 m wide with the work side being 10 m and the spoil side being 8 m.

The legal location of the study plots is NW25-56-12-W4M. The soil monitored for compaction was a cultivated Orthic Dark Grey Chernozem developed on till (Appendix 9.1). The topsoil (20 cm) was stripped from the trench and spoil side of the RoW and was stored on the far edge of the spoil side. Subsoil removed from the trench was also stored on the spoil side of the RoW. Subsoil and topsoil replacement was followed by cultivation of the RoW.

3.2.3 Maleb Lateral

The 20.2 km pipeline is located 20 km southeast of Bow Island, Alberta (Figure 2) and runs from the Maleb Meter Station (SW24-9-10-W4M) to an existing line (SE24-9-8-W4M). Climatically the area falls within Agro-climatic Subregion 3A (Bowser 1967). This subregion indicates an area where low precipitation has usually been a severe limiting factor to crop growth. Frost is not considered a hazard to cereal crop production. Topography of the area varies from undulating on till to undulating to moderately rolling slopes on glacio-fluvial deposits (Twardy 1988a). Surficial materials are mainly tills which are loam textured, moderately to very stony and non-saline and non-sodic. The pipeline was constructed in the spring of 1989 in dry soil conditions. The RoW was 18 m wide with the work side being 10 m and the spoil side being 8 m.

Two sites were monitored for compaction on this pipeline. The legal location of the study plots at the first site is SE22-9-9-W4M and at the second site is SE24-9-10-W4M. The soil at the first site (Maleb 1) was a cultivated Gleyed Brown Chernozem developed on till (Appendix 9.1). One of the three replicates was an Orthic Humic Gleysol developed on till (Appendix 9.1). The soil at the second site (Maleb 2) was a fallowed Orthic Brown Chernozem developed on till (Appendix 9.1). At both study sites the topsoil (15 cm) was stripped from the trench and spoil side of the RoW and was stored on the far edge of the spoil side. Subsoil removed from the trench was also stored on the spoil side of the RoW. Subsoil and topsoil replacement was followed by cultivation of the RoW.

3.2.4 Valhalla East Lateral

The 6.4 km pipeline is located northwest of Grande Prairie, Alberta (Figure 2) and runs east-west from SW9-75-9-W6M to SE12-75-9-W6M. Climatically the area falls within Agro-climatic Subregions 3H to 4H (Bowser 1967) indicating areas where heat units are moderately to severely limiting to crop growth. Parent materials of the area include lacustro-till, till and a fluvial veneer over till (Can-Ag Enterprises 1989a). The pipeline was constructed in the spring of 1989 in dry soil conditions. The RoW was 18 m wide with the work side being 10 m and the spoil side being 8 m.

The legal location of the study plots is SW10-75-9-W6M. The soil monitored for compaction was a cultivated Gleyed Dark Grey Luvisol developed on till (Appendix 9.1). One of the three replicates was a Dark Grey Luvisol developed on till (Appendix 9.1). The topsoil (10 cm) was stripped from the trench and spoil side of the RoW and was stored on the far edge of the spoil side. Subsoil removed from the trench was also stored on the spoil side of the RoW. Subsoil and topsoil replacement was followed by cultivation of the RoW.

3.2.5 Henderson Creek Lateral Loop

The 8.5 km pipeline is located near Gordondale, Alberta (Figure 2) and runs in a northwesterly direction from the Gordondale Sales Meter Station (SE12-79-12-W6M) to the Henderson Creek Meter Station (NW34-79-12-W6M). Climatically the area falls within Agro-climatic Subregion 3H to 4H (Bowser 1967) indicating an area where heat units are moderately to severely limiting to crop growth. Parent materials of the area are mainly dark coloured heavy clay loams to clays of lacustro-till origin overlying till (Can-Ag Enterprises 1988). The pipeline was contructed in the spring of 1989 in dry soil conditions. The RoW was 18 m wide with the work side being 10 m and the spoil side being 8 m.

Two sites were monitored for compaction on this pipeline. The legal location of first site is SW34-79-12-W6M and of the second site is SE14-79-12-W6M. The soil at the first site (Henderson 1) was a cultivated Solonetzic Dark Grey Luvisol developed on till (Appendix 9.1). The soil at the second site (Henderson 2) was a cultivated Dark Grey Luvisol developed on till (Appendix 9.1). At both study areas, the topsoil (15 cm) was stripped from the trench and spoil side of the RoW and stored on the far edge of the spoil side. Subsoil removed from the trench was also stored on the spoil side of the RoW. Subsoil and topsoil replacement was followed by cultivation of the RoW.

3.2.6 Bolloque East LAteral

The 11.7 km pipeline is located east of Fawcett, Alberta (Figure 2) and runs in a northeasterly direction from NE23-64-26-W4M to NE2-65-25-W4M.

Climatically the area falls within Agro-climatic Subregion 4H (Bowser 1967) indicating an area where heat units are severely limiting to crop growth. Parent materials of the area are mainly clay loams to loams of till origin (Can-Ag Enterprises 1989b). A fluvial veneer over till occurs occasionally. The pipeline was constructed in the summer of 1989 in moist to wet soil conditions. The RoW was 18 m wide with the work side being 10 m and the spoil side being 8 m.

The legal location of the study plot is SE29-64-25-W4M. The soil studied for compaction on this pipeline was a Dark Grey Luvisol developed on till (Appendix 9.1). The plot was located on native pasture land. Topsoil (varying in depth from 5 to 15 cm) was stripped from the trench and spoil side of the RoW and stored on the far edge of the spoil side. Subsoil removed from the trench was also stored on the spoil side of the RoW. Subsoil and topsoil replacement was followed by harrowing and cultivation of the RoW.

3.2.7 Redwater Lateral Loop

The 21.7 km pipeline is located north of Clyde, Alberta (Figure 2) and runs from SE7-62-25-W4M to NE26-60-24-W4M. Climatically the area falls within Agro-climatic subregion 3H (Bowser 1967), indicating an area where heat units are moderately limiting to crop growth. Topography of the area varies as follows: from undulating to gently rolling in the southeastern portion of the pipeline; from level to undulating in the central portion of the pipeline; and level to undulating and undulating to moderately rolling on the northwestern portion of the pipeline (Twardy 1988b). Parent materials in the southeastern portion of the pipeline consist of sandy textured galcio-fluvial deposits. In the central portion of the pipeline parent materials include well drained glacio-fluvial veneers overlying morainal deposits and poorly drained glacio-fluvial silts and fine sands. Parent materials in the northwestern portion of the pipeline consist mainly of moderately well to imperfectly drained, slightly to moderately stony, fine loamy textured till deposits and poorly drained, glacio-fluvial silts and fine sands. The pipeline was constructed in the summer of 1989 in moist to wet soil conditions. The RoW was 18 m wide with the work side being 10 m and the spoil side being 8 m.

Two sites were monitored for compaction on this pipeline. The legal location of the first site is SE18-61-24-W4M and of the second site is NW26-61-25-W4M. The soil at the first site (Redwater 1) was a cultivated Gleyed Black Chernozem developed on glacio-fluvial material (Appendix 9.1). The soil at the second site (Redwater 2) was an Eluviated Dark Grey Chernozem developed on glacio-fluvial material overlying till (Appendix 9.1). The plots were located on pasture land. The topsoil (40 cm at Redwater 1 and 15 cm at Redwater 2) was stripped from the trench and spoil side of the RoW and stored on the far side of the spoil side. Subsoil removed from the trench was also stored on the spoil side of the RoW. Subsoil and topsoil replacement was followed by harrowing and cultivation of the RoW. Topsoil replacement occurred during dry soil moisture conditions.

3.2.8 Pigeon Lake Lateral

The 5.9 km pipeline is located soutwest of Edmonton, Alberta (Figure 2) and runs south from Pigeon Lake Meter Station (SW35-45-27-W4M) to the Falun Meter Station (NW11-45-27-W4M). Climatically the area falls within Agro-climatic Subregions 2H to 3H (Bowser 1967) indicating an area where heat units are slightly to moderately limiting to crop growth. Topography of the area is undulating (Monenco Consultants Limited 1989). Parent materials of the area are till and sandy alluvial soils. The pipeline was constructed in the summer of 1989 in moist soil conditions. The RoW was 18 m wide with the work side being 10 m and the spoil side being 8 m.

The location of the study plots is NW23-45-27-W4M. The soil monitored for compaction was a cultivated Eluviated Dark Grey Chernozem developed on till (Appendix 9.1). The topsoil (15 cm) was stripped from the trench and spoil side of the RoW and stored on the far edge of the spoil side. Subsoil removed from the trench was also stored on the spoil side. Subsoil and topsoil replacement was followed by cultivation of the RoW.

3.2.9 Atlee-Buffalo Lateral Loop

The 8.7 km pipeline is located north of the Suffield Military Reserve in southeastern Alberta (Figure 2) and runs south from Atlee-Buffalo Meter Station (SE13-21-7-W4M) to an existing pipeline (SE24-20-7-W4M).

Climatically the area falls within Agro-climatic Subregion 3A (Bowser 1967) which indicates an area where low precipitation has usually been a severe limiting factor for crop growth. Frost is not considered a hazard to cereal crop production. Topography of the area varies from undulating to strongly rolling (Twardy 1989a). Surficial deposits of the area mainly consist of fine loamy to coarse loamy textured till. In the northern portion of the pipeline, deposits are coarse loamy textured glacio-fluvial veneers overlying till. The till varies from slightly to exceedingly stony and is non-saline and non-sodic except in poorly drained areas. The pipeline was constructed in the summer of 1989 in very dry soil moisture conditions. The RoW was 18 m wide with the work side being 10 m and the spoil side being 8 m.

Two sites were monitored for compaction on this pipeline. The legal location of the first site is SW12-21-7-W4M and of the second site is SW36-20-7-W4M. Both sets of study plots were located on native pasture land. The soil at the first site (Atlee-Buffalo 1) was an Orthic Humic Gleysol developed on lacustrine material overlying till (Appendix 9.1). The soil at the second site (Atlee-Buffalo 2) was an Orthic Brown Chernozem developed on glacio-fluvial material overlying till (Appendix 9.1). At both sites, the topsoil (10 cm) was stripped from the ditchline with a step blade and stored on the work side. Subsoil removed from the trench was stored on the spoil side of the RoW. Subsoil and topsoil replacement was followed by levelling of the RoW and harrowing of the spoil and trench areas.

3.2.10 Albright Lateral Extension

The 15 km pipeline is located near Beaverlodge, in northern Alberta (Figure 2) and runs southeast from NE21-73-10-W6M to SW17-72-9-W6M. Climatically the area falls within Agro-climatic Subregions 3H to 4H (Bowser 1967). These regions indicate areas where heat units are moderately to severely limiting to crop growth. Topography of the area is level to gently undulating (Riddell 1988). Surficial material consists of two types of lacustro-till. The dominant lacustro-till is clay textured, dark grey and contains small rounded pebbles (Riddell 1988). The other lacustro-till is characterized by alternating bands of dark grey clay and yellowish brown, clay loam, till like material. The pipeline was constructed in the summer and fall of 1989 in dry to moist soil conditions. The RoW was 23 m wide with the work side being 14 m and the spoil side being 9 m.

The legal location of the study plots is NE19-72-9-W6M. The soil monitored for compaction was a fallowed Orthic Humic Gleysol developed on glacio-fluvial material overlying till (Appendix 9.1). The topsoil (15 cm) was stripped from the trench and spoil side of the RoW and stored on the far edge of the spoil side. Subsoil removed from the trench was also stored on the spoil side of the RoW. The topsoil was left to dry prior to replacement. Subsoil and topsoil replacement was followed by cultivation of the RoW.

3.2.11 Ferintosh North Lateral Loop

The 13.6 km pipeline is located near Ferintosh, Alberta (Figure 2). The pipeline runs from SE29-45-21-W4M to SE17-44-21-W4M. Climatically the area falls within Agro-climatic Subregion 2H (Bowser 1967) which indicates an area where heat units are slightly limiting to crop growth. Topography of the northern portion of the Ferintosh North Lateral Loop is undulating whereas the topography of the southern portion is gently to moderately rolling (Twardy 1989b). Parent materials of the northern portion of the Ferintosh North Lateral Loop consist of loamy textured stone-free glacio-lacustrine deposits, whereas parent material of the southern portion consist of fine loamy textured, slightly to moderately stony till (Twardy 1989b). The pipeline was constucted in the summer and fall of 1989 in dry to moist soil conditions. The RoW was 18 m wide with the work side being 10 m and the spoil side being 8 m.

The legal location of the plots is SE5-45-21-W4M. The soil monitored for compaction was a cultivated Orthic Black Chernozem developed on fluvial material overlying till (Appendix 9.1). The topsoil (30 cm) was stripped from the trench and spoil side of the RoW and stored on the far edge of the spoil side. Subsoil removed from the trench was also stored on the spoil side of the RoW. Subsoil and topsoil replacement was followed by cultivation of the RoW.

4. MATERIALS AND METHODS

4.1 EXPERIMENTAL DESIGN

Twenty three study areas were moniotored for soil strength immediately following pipeline construction. Seedbed preparation had taken place on all study areas. Only the Delia study area had been seeded at the time of the initial monitoring event. One year after construction was completed the 23 study areas were again moniotred for soil strength. Only one study area (Michichi) was monitored for soil strength two years following construction.

Study areas along a RoW were chosen with the following criteria in mind: 1) soils were uniform within an area long enough to accommodate three adjacent monitoring plots; 2) soils were representative of the major soil type(s) occurring along the pipeline route; and 3) pipeline construction techniques and conditions were representative of that occurring throughout the length of the line. As wide a range of soil subgroups as possible were monitored.

Once a suitable site was chosen, three replicates were laid out, each being 2 m wide running across the RoW 5 m into an adjacent undisturbed control. Each replicate was separated by a distance of 15 m (Figure 3).

4.2 FIELD ANALYSES

A Bush Recording Soil Penetrometer (Mark I Model) was used to measure soil strength 'in situ' with a 12.9 mm diameter core. Soil strength was measured by determining the resistance of soil to the penetrating cone-shaped tip of the cone penetrometer as it was pushed into the ground at a rate of 3 cm/s. The property measured is termed cone resistance or cone index and was recorded in units of pressure (kg). An overload protection was provided by an audible bleeper at 50 kg allowing readings from 0 to 50 kg. The penetrometer was unable to penetrate into soils with soil strengths greater than 50 kg. For a 12.9 mm diameter cone the cone resistance in bars is equivalent to the load measured in kg multiplied by 0.762 (Findlay, Irving Ltd. 1979).

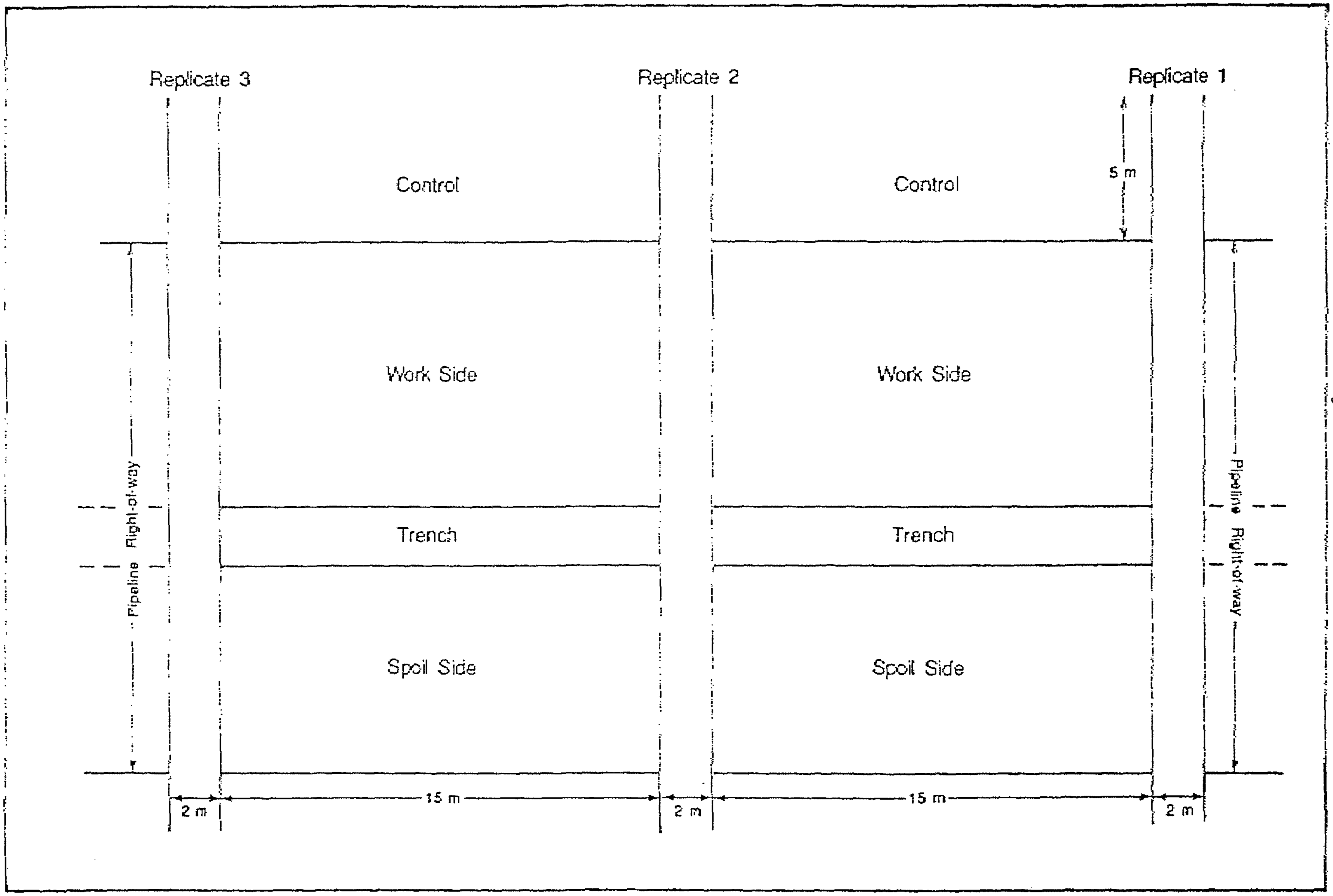


Figure 3. Experimental design of the plots monitored at each study area.

Ten soil strength measurements were taken in 3.5 cm increments from 0 to 52.5 cm within each of the three replicates at each study area. Measurements were taken from the trench, work side, and spoil side portions of the RoW, as well as an adjacent control area. In 1988 the spoil side of the RoW at the eight study areas was not monitored for compaction. However, in 1989 a decision was made to monitor the spoil side of the RoW of all future chosen study areas because of the potential effects of traffic on compaction of the soil.

Soil samples were collected from the trench, spoil side, work side and control locations from each of the three replicates from each study area. Samples were taken by horizon from the soil surface down to 50 cm. A detailed soil classification was also conducted at each control sampling location (Appendix 9.1). Soils were classified using the Canadian System of Soil Classification (Canada Soil Survey Committee 1978).

During the 1989 sampling year the data storage unit of the Bush Recording Soil Penetrometer failed to record data properly for the first of the three control replicates for the Atlee-Buffalo 1 and Atlee-Buffalo 2 study areas as well as for the 1988 study areas, being monitored for soil strength one year after pipeline construction. These study areas were remonitored for compaction, soil moisture, and soil organic matter contents approximately one week following initial sampling.

4.3 LABORATORY ANALYSES

Samples were analyzed using procedures outlined by McKeague (1978) for soil moisture (2.411), organic matter (3.611), and particle size analysis (2.12). Soil moisture and soil organic matter contents were determined for each sampling event whereas particle size analysis was only done for the sampling event immediately following pipeline construction.

When soil moistures on the trench, workside, or spoil side of the RoW were significantly different from the control soil, soil strength values were adjusted using methods outlined in section 4.3.1, starting with the 1989 sampling year.

4.3.1 Soil Strength Adjustment Based on Moisture

When soil moistures on the trench, work side, and spoil side of the RoW were significantly different from the control soil, soil strengths were adjusted using methods outlined in Thacker and Johnson (1989). Soil strength values (as measured by cone penetrometer) are dependent on soil moisture (Taylor and Gardner 1963; Frietag 1971; Ayers and Perumpral 1982). Soil strength adjustments using methods outlined in Thacker and Johnson (1989) allow soil strength values made at one moisture tension to be used to estimate soil strengths at another moisture tension. Therefore soil strength measurements made at soil moisture contents significantly different from control soils can be adjusted to correspond to the equivalent moisture contents of the control soil, and comparisons can be made between the two soils.

The soil strength of a soil at any given moisture tension can be predicted from one measured strength and one measured soil moisture tension using the following equation (Thacker and Johnson 1989):

$$Yt = Ab * Zt/Xb$$

where Yt is the predicted (or adjusted) soil strength at desired moisture tension; Ab is actual soil strength at measured moisture tension; Zt is the normalized strength at desired moisture tension; and Xb is the normalized strength at measured moisture tension. Normalized means that all measured soil strength values were divided by the soil value at 15 bars moisture tension (Thacker and Johnson 1989).

Soil strength adjustments were made only on those soils on the RoW where soil moisture contents were significantly different from control soils. In order to make the adjustment the following procedures were followed:

- moisture contents of the control soil were measured at various moisture tensions (1, 3, 6, 9, and 15 bars);
- graphs plotting percent moisture and moisture tensions were made for each soil where soil moistures were significantly different from control soils;
- moisture tension, in bars, was determined for each soil at the measured moisture control (soil moisture at time of sampling that was significantly different from the control soil moisture)

and at the desired soil moisture content (control soil moisture at time of sampling);

- using the figure in Thacker and Johnson (1989) that graphs normalized soil strength versus moisture tension, Xb was determined by reading the normalized soil strength at the measured soil tension (soil moisture tension at time of sampling) and Zt was determined by reading the normalized soil strength at the desired soil tension (control soil moisture tension at time of sampling);
- Yt was determined from the equation; and
- 't' tests were done to determine if the adjusted soil strength measurements (Yt) were significantly different from control soil strengths.

If soil moisture contents of soil on the RoW are lower than those of the control, then adjusted soil strengths of soils on the RoW will be decreased compared to actual soil strengths. If soil moisture of soils on the RoW are greater than those of the control then adjusted soil strengths of soil on the RoW will be increased compared to actual soil strengths.

Further work is needed to define the relationship between soil strength and moisture tension in soils of different texture contents to determine whether a single moisture strength relationship is valid over the range of texture contents that occur in soils of Alberta.

4.4 STATISTICAL EVALUATION

For each depth increment monitored for soil strength and horizon sampled for soil moisture and soil organic matter, treatments were compared using the Students' 't' test for unpaired data to determine whether the difference between means was significant at $p < 0.05$ (Zalik 1978). For each soil and pipeline, the trench, work, and spoil sides of the RoW were compared to the control. Cone resistance, soil organic matter, and soil moisture values used for statistical comparisons are given in Appendix 9.2 and Appendix 9.3.

Regression analyses were also done to determine if there was a relationship between soil strength and soil moisture, organic matter, or clay content for the 1989 and 1990 sampling years. Analyses were made using the SAS System (SAS Institute Inc. 1985). The RSREG procedure was used and the model statements were soil strength = soil moisture, soil strength = soil organic matter, soil strength = clay content, and soil strength = soil moisture*soil organic matter*clay content.

Although a low correlation (r value) may be statistically significant, the correlation may not be meaningful. A correlation with $r > 0.7$ ($r^2 = 0.49$) is considered to be close (Zalik 1978). In this study the coefficient of determination (r^2 values) explains the percentage of the variation in soil strength associated with soil moisture, soil organic matter and or clay content.

5. RESULTS AND DISCUSSION

In 1990 soil moisture, soil organic matter and soil strength were monitored only for the 1989 study areas in order to determine levels one year following pipeline construction. Michichi study area was also monitored in 1990 for soil moisture, soil organic matter and soil strength since work side and trench soil strength values were significantly increased one year following construction compared to control soil strength values. Craigmyle study area also had significantly increased trench soil strength at 21 to 28 cm when compared to the control soil one year following construction (1989 sampling year) but the cone penetrometer was unable to penetrate past the 7 cm depth during the 1990 sampling.

The 1988, 1989 and 1990 sampling year data for soil moisture, soil organic matter, clay content and regression anlyses are presented in the Appendices. The 1990 sampling year data is discussed in detail in this report. Details of the 1988 and 1989 sampling data were discussed in the 1988 and 1989 annual reports (Cannon et al. 1989; Cannon et al. 1990).

5.1 SOIL MOISTURE

Soil moistures for those study areas indicating significant differences between RoW and control soils immediately following construction or one year following construction are presented in Table 1. Regression analyses suggested there was little correlation between soil strength and soil moisture for this study. These findings were in contrast to those of Gerard (1982), Taylor et al. (1966) and Ayers and Persumpral (1982) which indicated that soil strength increases as soil moisture decreases. As well, research in Alberta has shown that average minespoil strength at 15 bars moisture tension was 2.5 times that at 1/3 bar moisture tension. However, these authors also found that the effect of moisture on absolute penetration resistance was different for different minespoils and that texture must be taken into account.

5.1.1 Soil Moisture Immediately Following Construction

In four of the eight study areas monitored in 1988 there were no significant changes in soil moisture between soils on and off the RoW. These

Table 1. Soil moistures for those study areas and depths indicating significant differences immediately following construction or one year following construction.

STUDY AREA	DEPTH (cm)	SOIL MOISTURE[1] %			
		Control	Work side	Trench	Spoil side
1988 Study Areas					
Craigmyle YEAR 1[2]	15-40	33.3	32.3	25.0*3	-
Delia YEAR 1	0-15	20.9	19.7	11.9*	-
Foreman YEAR 0	20-35	12.3	10.6*	9.2*	-
	35-50	12.0	9.8	8.8*	-
Ghostpine YEAR 0	0-15	25.5	18.0*	17.2	-
YEAR 1	0-15	21.7	17.6*	19.0	-
Michichi YEAR 1	15-40	19.2	14.2*	14.1*	-
Milo YEAR 0	15-30	10.3	5.8*	5.5*	-
	30-50	8.4	4.3*	5.7*	-
Victor 1 YEAR 0	15+	35.1	38.6*	38.0	-
Victor 2 YEAR 1	0-15	15.5	21.9*	15.1	-
1989 Study Areas					
Atlee-Buffalo 1 YEAR 0	0-11	17.7	26.8	10.3*	28.4*
YEAR 1	0-10	14.2	9.3*[3]	14.9	14.4
Aeco 'C' YEAR 0	17-35	24.6	19.9	21.0*	17.1*
	35-50	26.0	23.7	20.3*	17.6*

continued......

Table 1. Concluded.

STUDY AREA	DEPTH (cm)	SOIL MOISTURE[1] % Control	Work side	Trench	Spoil side
Albright					
YEAR 0	0-18	25.8	19.4*	18.1*	20.4*
	18-35	25.7	18.1	19.5*	22.4
Bolloque					
YEAR 0	0-20	19.1	25.7	31.3*	28.9*
Ferintosh					
YEAR 0	0-15	34.2	30.7	28.1*	27.1*
	15-32	30.2	21.6	23.7*	25.7
Foisey					
YEAR 0	0-19	16.8	13.8	12.5*	16.7
Henderson 1					
YEAR 0	0-21	11.0	15.1*	15.8*	14.3*
Maleb 1					
YEAR 0	30-50	16.7	26.6*	19.4	23.9*
Maleb 2					
YEAR 0	0-15	15.0	9.9*	6.9*	9.1*
Pigeon Lake					
YEAR 0	0-18	14.4	17.7*	22.1*	18.4*
Redwater 1					
YEAR 0	20-40	5.7	12.4*	13.0*	15.3*
Redwater 2					
YEAR 0	0-20	12.1	14.1	16.4*	13.8

[1]Average of three replicates, underlined values have only one replicate.

[2]YEAR 0 = sampling event immediately following construction,
YEAR 1 = sampling event one year following construction.

[3]Means are significantly different from control at $p < 0.05$.

four sites were Craigmyle, Delia, Michichi and Victor 2. In the other four sites, when soil moisture was changed, in all but one observation (Victor 1 study area), soil moisture was significantly less for soils on the RoW compared to soil off the RoW indicating drying of the soil possibly due to pipeline construction. The three study areas where RoW soil moistures were lower than off RoW soil Moistures were Foreman, Ghostpine and Milo. Since soil strength increases as bulk density increases or soil moisture decreases (Gerard 1982, Taylor et al. 1966a), this drying of the soil could affect the emergence of a seeded crop especially in areas such as Milo where low precipitation is already a limiting factor to crop growth in 50% of the years.

During 1989, for the fifteen new sites chosen to be monitored, sites that had significantly increased soil moistures on soils of the RoW compared to soils off the RoW were sites that were sampled during the summer and had an established crop growing on the control or were in pasture land. These conditions affected the study areas at Maleb 1, Henderson 1, Bolloque, Redwater 1, Redwater 2, and Pigeon Lake. Sites with decreased soil moisture on the RoW included Atlee-Buffalo 1, Aeco 'C', Albright, Ferintosh, Foiey, and Maleb 2. These decreased soil moistures indicated drying of the soil possibly due to pipeline construction. This drying could affect emergence of a seeded crop especially at Atlee-Buffalo 1, Aeco 'C', and Maleb 2 where low precipitation is already a severe limiting factor to crop growth.

In 1989 regression analyses using all 1989 study area data indicated that there was no close correlation between soil strength and soil moisture (r^2 =0.02). When soil moisture, organic matter and clay content were placed into the regression equation together, the r^2 value was 0.04. Individual site data was also used to determine the relationship between soil strength and soil moisture. Coefficients of determination (r^2 values) were below 0.42 for all sites when determining the relationship between soil strength and soil moisture, except for Pigeon Lake (r^2 = 0.68) and Ferintosh (r^2 = 0.56). Both these sites had trench and spoil side soil moistures that were significantly different from those of the control, but it was difficult to speculate why these sites had greater r^2 values than other sites with significant differences in RoW soil moistures.

5.1.2 Soil Moisture One Year After Construction

During the 1989 sampling year, in three of the eight study areas monitored one year after pipeline construction was completed, there were no significant differences in soil moisture between soils on and off the RoW. The three site were Foreman, Milo and Victor 1. In the other five sites, when soil moisture was changed, in all but one observation (Victor 2 study area), soil moisture was significantly less for soils on the RoW compared to soil off the RoW, indicating drying of the soil due to pipeline construction. The four study areas than had RoW soil moistures significantly lower than off RoW soil moistures were Craigmyle, Delia, Ghostpine and Michichi. This drying of the soil could affect the emergence of a seed crop especially in agroclimatic areas where low precipitation is already a limiting factor to crop growth in 50% of the years.

In 1989 regression analyses using all 1988 study area data indicated that there was no close correlation between soil strength and soil moisture (r^2 = 0.03). Individual site data was also used to determine the relationship between soil strength and soil moisture. Values of r^2 were below 0.29 for all sites when determining the relationship between soil strength and soil moisture except for Craigmyle (r^2 =0.63). Craigmyle had trenvh soil moistures that were significantly different from those of the control, but it was difficult to speculate why this site had a greater r^2 value than other sites with significantly different RoW soil moistures.

In 1990 there were no significant differences in soil moisture between soils on the RoW and those off the RoW for all but one of the study areas monitored. At Atlee-Buffalo 1 soil moisture was significantly lower in the work side at 0 to 10 cm (9.3%) when compared to the control soil moisture (14.2%). In the previous sampling year (1989) the work side soil moisture had not been significantly different from that of the control. This decreased soil moisture indicates drying of the soil possibly due to pipeline construction and could affect emergence of a seeded crop since low precipitation is already a severe limiting factor to crop growth at Atlee-Buffalo 1.

Regression analyses using all 1989 study area data indicated that there were no close correlations between soil strength and soil moisture (r^2 =

0.01). Individual site data was also used to determine the relationship between soil strength and soil moisture. Coefficients of determination (r^2 values) were below 0.25 for all sites except for Pigeon Lake (r^2 = 0.73) and Valhalla (r^2 = 0.61). It was difficult to speculat why these two sites had greater r^2 values than other sites especially since there were no significant differences in soil moistures between soil on and off the RoW.

5.2 SOIL ORGANIC MATTER

Soil organic matter contents for those study areas indicating significant differences between RoW and control soils immediately following construction or one year following construction are presented in Table 2. Regression analyses suggested there was little correlation between soil strength and soil organic matter.

Soil quality deteriorates quickly at organic matter levels below 2.0% (Alberta Soils Advisory Committee 1987). Organic matter is important to agricultural soils as it contributes to the nutrient pool, structure, workability, and water holding capacity of the soil. Other literature indicated that minimum acceptable quantity of soil organic matter is 1.0% for the Ap 0 to 15 cm depth (Alberta Soil Advisory Committee n.d.). Additions of organic matter to compacted soils has been shown to result in lower shear strengths at any given compaction level for all of the moisture levels considered (Ohu et al. 1986). These results suggest that lowered organic matter levels could result in increased soil strengths.

5.2.1 Soil Organic Matter Immediately Following Construction

In four of the eight study areas monitored in 1988 there were no changes in soil organic matter contents between soil on and off the RoW. In the other four study areas (Craigmyle, Ghostpine, Milo and Victor 1), levels were always significantly lower for soils on the RoW compared to soils off the RoW suggesting that subsoil was being mixed with topsoil or that there was a loss of topsoil. The levels of soil organic matter for all the study areas except the Milo trench soil, exceeded 2%. The level of soil organic matter in the trench at Milo for the 0 to 15 cm depth was 1.4% and for the 15 to 30 cm depth was 0.8%, suggesting that there may be some agronomic implications.

Table 2. Soil organic matter contents for those study areas and depths indicating significant differences immediately following construction or one year following construction.

STUDY AREA	DEPTH	SOIL ORGANIC MATTER[1] (%)			
	(cm)	Control	Work side	Trench	Spoil side
1988 Study Areas					
Craigmyle YEAR 0[2]	0-13	5.5	2.4*[3]	2.9	-
Ghostpine YEAR 0	0-15	6.3	6.0	3.8*	-
YEAR 1	0-15	6.05	4.55*	5.08	-
Michichi YEAR 1	0-15	5.01	2.70*	4.51	-
YEAR 2	0-20	4.27	5.32*	5.50*	-
Milo YEAR 0	0-15	2.5	2.0*	1.4*	-
Victor YEAR 0	0-15	4.1	3.6	3.1*	-
1989 Study Areas					
Atlee-Buffalo 1 YEAR 0	0-11	6.79	8.11*	3.83	9.71
Bolloque YEAR 0	0-20	2.27	3.67	5.05*	3.84
Ferintosh YEAR 1	0-15	9.30	8.44*	8.00	9.13
Foisey YEAR 1	0-20	6.06	3.26*	4.42*	4.56*
Maleb 1 YEAR 0	0-15	4.95	3.79*	1.93*	2.87*

[1]Average of three replicates.
[2]YEAR 0 = sampling event immediately following construction,
YEAR 1 = sampling event one year following construction,
YEAR 2 = sampling event two years following construction.
3Means are significantly different from control at $p < 0.05$.

organic matter content for 0 to 15 cm (8.44%) was significantly lower than the control soil organic matter content of 9.30%. At Foisey the work side, trench and spoil side soil organic matter contents at 0 to 20 cm (3.26, 4.42 and 4.56%, respectively) were significantly lower than that of the control (6.06%). At Michichi the work side and trench soil organic matter contents at 0 to 20 cm (5.32 and 5.50%) were significantly greater than the control soil organic matter content of 4.27%. Decreased soil organic matter contents at Ferintosh and Foisey suggest that subsoil had been mixed with topsoil or that there was a loss of topsoil. It was difficult to speculate why increased RoW soil organic matter contents occurred at Michichi since the whole field is farmed in a similar manner. Levels of soil organic matter for all study areas monitored in 1990 except the Atlee-Buffalo2 work side soil, the Aeco 'C' work side and trench soils, the Henderson 2 work side, trench and spoil side soils, and the Maleb 2 control, work side, trench and spoil side soils exceeded 2%. Only the soil organic matter in the Atlee-Buffalo 2 work side soil was below 1% suggesting there may be some agronomic implications.

Regression analyses using all 1989 study area data indicated that there was no close correlation between soil strength and soil organic matter ($r^2 = 0.01$).

5.3 CLAY CONTENT

Clay content was only monitored on the 23 study area for the sampling event immediately following pipeline construction. Percent clay for those study areas that had significant differences on the RoW as compared to the control are presented in Table 3. Regression analyses suggested there was little correlation between soil strength and clay content.

In five of the eight study areas monitored in 1988 there were no significant differences in clay content between soils on and off the RoW. In two study areas, when clay content was changed, it was significantly less for trench soils at the 30 to 50 cm depth when compared to the control soil. Both these study areas were developed on glaciofluvial veneers. At the final study area, both trench and work side clay contents were increased compared to the control soils for the 0 to 15 cm depth only, suggesting some mixing of subsoil

Table 3. Percent clay for those study areas indicating significant differences on the RoW as compared to the control.

STUDY AREA	DEPTH (cm)	CLAY[1] (%) Control	Work side	Trench	Spoil side
1988 Study Areas					
Delia	0-15	20.4	11.9	15.4	-
	15-30	22.2	15.2	11.5	-
	30-50	30.2	25.3	11.9*[2]	-
Ghostpine	0-15	22.9	26.9*	30.2*	-
	15-25	32.2	38.4	32.2	-
	25-50	35.9	35.8	33.2	-
Milo	0-15	16.3	15.5	16.6	-
	15-30	30.6	16.7	16.8	-
	30-50	28.1	18.4*	16.8*	-
1989 Study Areas					
Atlee-Buffalo 1	0-11	21.7	20.4	23.7	21.7
	11-20	35.1	28.4*	28.4*	34.4
Bolloque	0-20	12.9	12.5	13.2	11.9
	20-35	21.2	21.2	21.5	27.2
	35-50	27.9	34.9	22.5*	23.7
Ferintosh	0-15	19.5	18.8	19.1	16.1
	15-32	14.5	18.8	19.8*	17.1
	32-50	22.8	17.5	28.1	26.5
Foisey	0-19	14.9	16.9*	17.2*	20.1
	19-40	24.9	29.1	25.7	26.1
	40-50	30.2	33.7	28.6	29.4
Henderson 1	0-21	20.9	23.3	23.6	24.9*
	21-35	49.6	45.9	33.3*	57.9
	35-50	52.6	-	-	51.6
Henderson 2	0-18	19.3	25.0	21.7	19.7
	18-34	33.2	32.3	40.3	28.7
	34-50	39.3	46.0	54.0*	44.0

continued......

Table 3. Concluded.

STUDY AREA	DEPTH (cm)	CLAY[1] (%) Control	Work side	Trench	Spoil side
Maleb 1	0-15	32.2	34.5*	32.9	34.9*
	15-30	37.9	35.5	32.9*	36.2
	30-50	36.9	39.7	32.9	37.5
Maleb 2	0-15	23.7	23.4	24.1	23.5
	15-33	28.4	24.1*	28.8	23.5*
	33-50	27.1	24.8*	<u>28.8</u>	26.5

[1]Average of three replicates, underlined values have only one replicate.

[2]Means are significantly different from control at $p < 0.05$.

with topsoil. However, data from this research study suggested little mixing of subsoil and topsoil during pipeline construction.

In 1989 few significant differences in clay content occurred between surface soils on the RoW and those off the RoW for the fifteen new study areas chosen to be monitored. Surface clay contents for Foisey work side and trench soils, Henderson 1 spoil side soil and Maleb 1 work side and spoil side soils were significantly greater than the corresponding control clay contents suggesting some mixing of subsoil with topsoil. Most significant differences in clay content occurred below the surface horizons. Generally data from this research study suggested little mixing of subsoil and topsoil during pipeline construction.

In 1989 regression analyses using all 1989 study area data indicated that there was no close sorrelation between soil strength and clay content (r^2 = 0.06). When soil moisture, organic matter and clay content were placed into the regression equation together, the r^2 value was 0.04. Individual site data were used to determine the relationships between soil strength and clay content. Coefficients of determination (r^2 values) were below 0.41 for all sites when determining the relationship between soil strength and clay content, except for Pigeon Lake (r^2 = 0.49) and Valhalla (r^2 = 0.65). It was difficult to speculate why these two sites had greater r^2 values than other sites especially since there were no significant diferences in clay cotnet between soils on and off the RoW.

5.4 SOIL STRENGTH

Actual soil strength values for 1988, 1989 and 1990 sampling years were compiled and entered into Appendix 9.5 for each study site and sampling depth increment. Statistical significance is indicated in these tables. As well figures showing soil strength values for the 1988 and 1989 sampling years are presented in Appendix 9.6. Depth increments 1 through 15 correspond to the following depths: 1) 0 to 3.5 cm; 2) 3.5 to 7.0 cm; 3) 7.0 to 10.5 cm; 4) 10.5 to 14.0 cm; 5) 14.0 to 17.5 cm; 6) 17.5 to 21.0 cm; 7) 21.0 to 24.5 cm; 8) 24.5 to 28.0 cm; 9) 28.0 to 31.5 cm; 10) 31.5 to 35.0 cm; 11) 35.0 to 38.5 cm; 12) 38.5 to 42.0 cm; 13) 42.0 to 45.5cm; 14) 45.5 to 49.0 cm; and 15) 49.0

to 52.5 cm. Only statistical differences ($p < 0.05$) between the control versus work side, spoil side and trench will be reported in this section.

5.4.1 Atlee-Buffalo 1

There were no differences in soil strength measured between soils on and off the RoW in the 1990 sampling year (Figure 4). Trench and spoil side soil moistures were not significantly different when compared to those of the control. Increased work side soil strength would have been expected as a result of the significantly lowered soil moisture at 0 to 11 cm. There were also no significant differences in soil organic matter contents between soils on the RoW and the control soil. The cone penetrometer could not penetrate past the 21 cm depth for the control, past the 7 cm depth for the trench or past the 17.5 cm depth for the work side or spoil side indicating soil strengths greater than 38 bars at these depths.

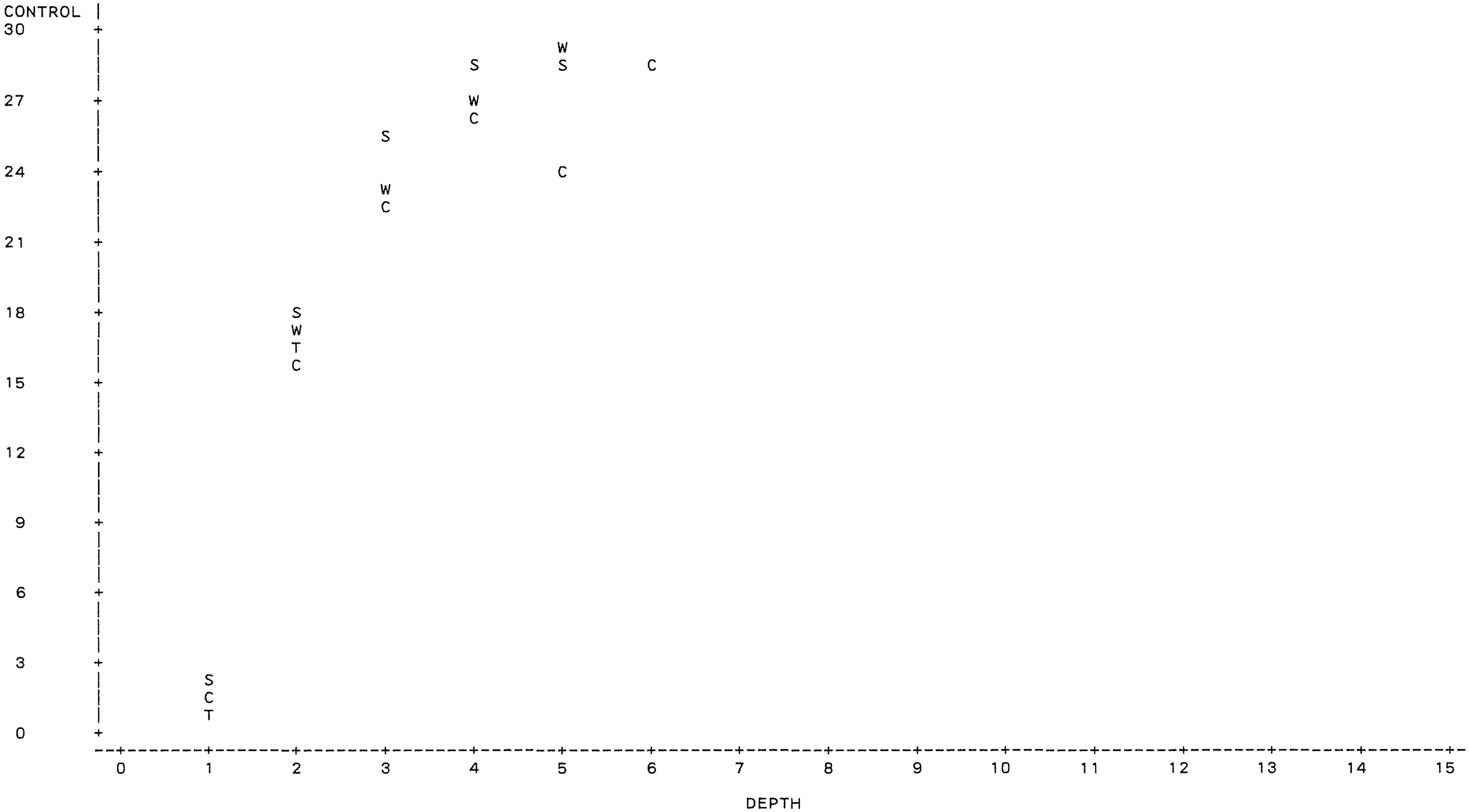
As in 1990, in the previous year (1989) there were no differences in actual soil strength between soils on and off the RoW at the Atlee-Buffalo 1 study area (Cannon et al. 1990). Spoil side soil moisture and work side soil organic matter were significantly increased at 0 to 11 cm when compared to the control values. However trench soil moisture and both work side and trench clay contents were significantly decreased when compared to those of the control. Decreased soil strength would have been expected to result because of increased soil moisture and soil organic matter and decreased clay content while increased soil strength would have been expected as a result of lowered soil moisture. The cone penetrometer could not penetrate either the work or spoil side past the 10.5 cm depth, the trench past the 14 cm depth or the control past the 28 cm depth indicating soil strengths greater than 38 bars at these depths.

There were no differences in soil strength in either moniotring year (Table 4.) The cone penetrometer was unable to penetrate to depth in either case making comparisons between RoW soils and off RoW soils below 17.5 cm impossible.

5.4.2 Atlee-Buffalo 2

SITE=AB1

PLOT OF CONTROL*DEPTH   SYMBOL USED IS C
PLOT OF TRENCH*DEPTH   SYMBOL USED IS T
PLOT OF WORK*DEPTH   SYMBOL USED IS W
PLOT OF SPOIL*DEPTH   SYMBOL USED IS S



NOTE: 42 OBS HAD MISSING VALUES OR WERE OUT OF RANGE   1 OBS HIDDEN

Fig. 4.

Table 4. Summary of statistical data for the Atlee-Buffalo 1 study area.[1]

SAMPLING EVENT[2]	DEPTH INCREMENT[3]														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
YEAR 0															
Work side				–	–	–	–	–	–	–	–	–	–	–	–
Trench					–	–	–	–	–	–	–	–	–	–	–
Spoil side				–	–	–	–	–	–	–	–	–	–	–	–
YEAR 1															
Work side						–	–	–	–	–	–	–	–	–	–
Trench			–	–	–	–	–	–	–	–	–	–	–	–	–
Spoil side						–	–	–	–	–	–	–	–	–	–

[1] Orthic Humic Gleysol developed on lacustrine overlying till and constructed in dry soil conditions.
[2] Year 0: sampling event immediately following construction,
Year 1: sampling event one year following construction.
+W, +T and +S indicate soil strength increases for the work side, trench and spoil side, respectively, as compared to the control.
-W, -T and -S indicate soil strength decreases for the work side, trench and spoil side, respectively, as compared to the control.
[3] – = no penetration.

Table 5. Summary of statistical data for the Atlee-Buffalo 2 study area.[1]

SAMPLING EVENT[2]	DEPTH INCREMENT[3]														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
YEAR 0															
Work side		-W			–	–	–	–	–	–	–	–	–	–	–
Trench		-T	-T	-T						–	–	–	–	–	–
Spoil side			+S		–	–	–	–	–	–	–	–	–	–	–
YEAR 1															
Work side			–	–	–	–	–	–	–	–	–	–	–	–	–
Trench					–	–	–	–	–	–	–	–	–	–	–
Spoil side			–	–	–	–	–	–	–	–	–	–	–	–	–

[1] Orthic Brown Chernozem developed on glacio-fluvial material and constructed in dry soil conditions.
[2] Year 0: sampling event immediately following construction,
Year 1: sampling event one year following construction.
+W, +T and +S indicate soil strength increases for the work side, trench and spoil side, respectively, as compared to the control.
-W, -T and -S indicate soil strength decreases for the work side, trench and spoil side, respectively, as compared to the control.
[3] – = no penetration.

There were no differences in soil strength measured between soils on and off the RoW for the 1990 sampling year (Figure 5). There were also no significant differences in soil moistures or soil organic matter contents between soils on and off the RoW. However the cone penetrometer could not penetrate past 14 cm for the trench or past 7 cm for the control, work side and spoil side indicating soil strengths greater than 38 bars at these depths.

In the previous year (1989) decreased soil strengths were measured in the trench at the Atlee-Buffalo 2 study area for the top 14 cm of the profile when compared to the control (Cannon et al. 1990). Since there were no significant differences in organic matter, soil moisture, or clay content between the trench and the control, decreased soil strengths were attributed to the breaking up of a hard rangeland soil during the trenching procedures of pipeline construction. Work side soil strength was decreased at 3.5 to 7 cm when compared to the control. Decreases in soil strength could be a result of the harrowing of the RoW after construction was completed. Spoil side strength was greater at 7 to 10.5 cm when compared to the control. Increases in soil strength were thought to be a result of increased traffic on the spoil side. The cone penetrometer could not penetrate past the 14 cm depth for either the work or spoil side or past the 31.5 cm depth for either the control or trench soil indicating soil strengths greater than 38 bars at these depths.

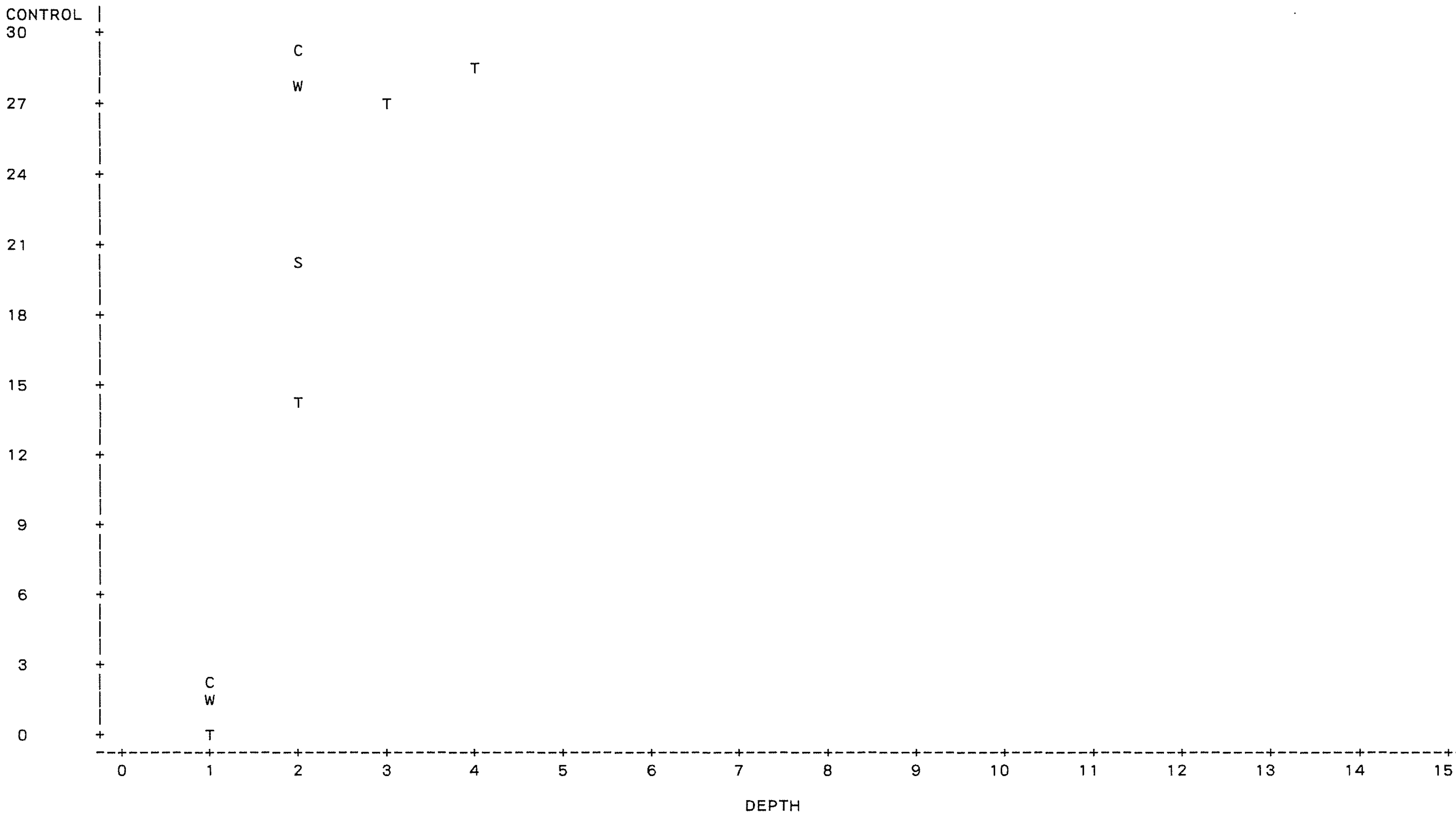
The two sampling years were difficult to compare because in 1990 the cone penetrometer could not penetrate as deeply as it did in 1989 (Table 5). This effect was most likely due to lower soil moisture contents in 1990. However decreased work side and trench soil strengths at 3.5 to 7 cm observed in 1989 were not observed in 1990.

5.4.3 Aeco 'C'

There were no differences in soil strength measured between soils on and off the RoW for the 1990 sampling year (Figure 6). There were also no significant differences in soil moisture or soil organic matter contents between soils on and off the RoW. However the cone penetrometer could not penetrate past the 14.0 cm depth for the control soil or past the 10.5 cm depth for the work side, trench or spoil side indicating soil strengths greater than 38 bars at these depths.

SITE=AB2

PLOT OF CONTROL*DEPTH   SYMBOL USED IS C
PLOT OF TRENCH*DEPTH   SYMBOL USED IS T
PLOT OF WORK*DEPTH   SYMBOL USED IS W
PLOT OF SPOIL*DEPTH   SYMBOL USED IS S



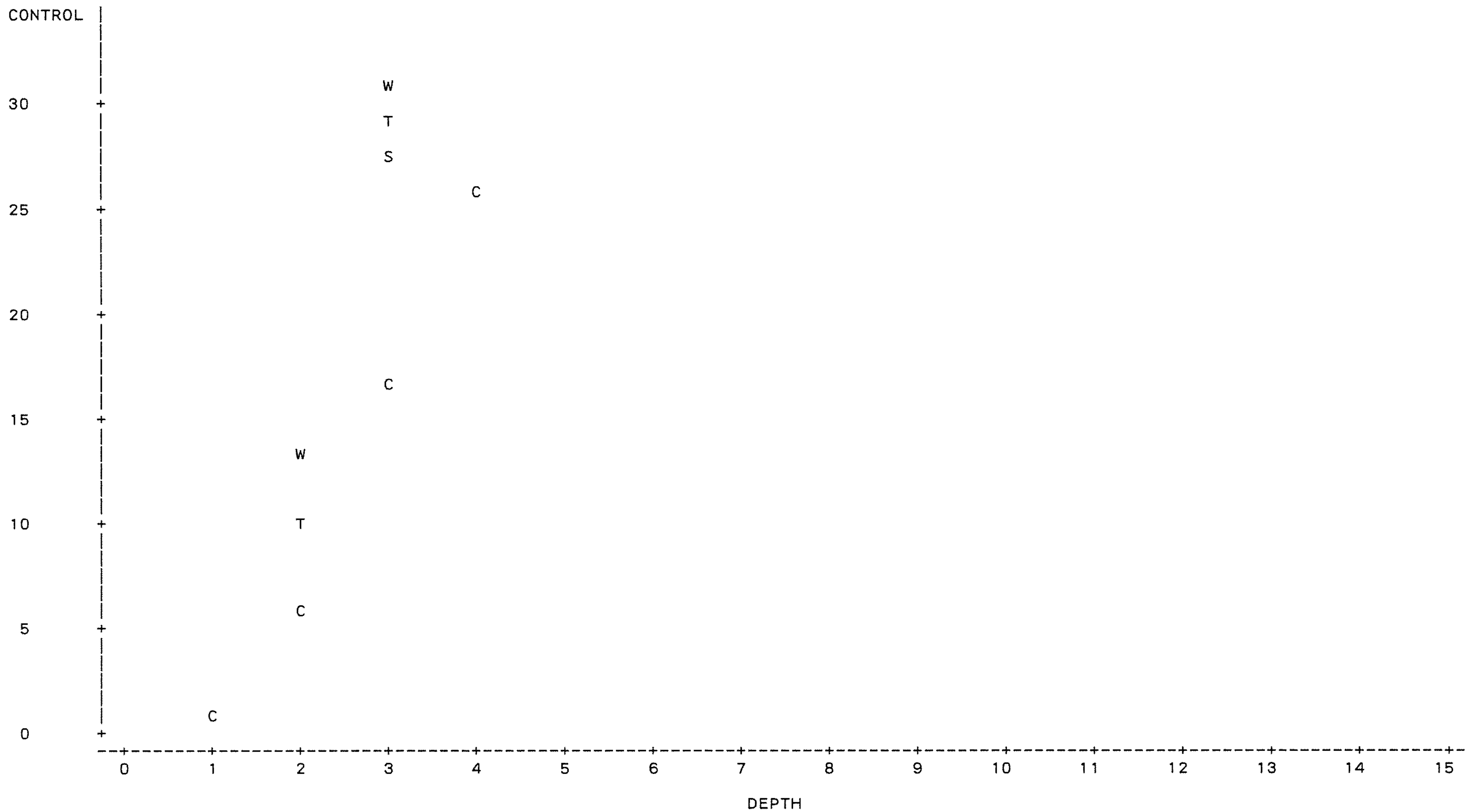
NOTE: 50 OBS HAD MISSING VALUES OR WERE OUT OF RANGE   1 OBS HIDDEN

4/3

Figure 5.

SITE=AC

PLOT OF CONTROL*DEPTH   SYMBOL USED IS C
PLOT OF TRENCH*DEPTH   SYMBOL USED IS T
PLOT OF WORK*DEPTH   SYMBOL USED IS W
PLOT OF SPOIL*DEPTH   SYMBOL USED IS S



NOTE: 47 OBS HAD MISSING VALUES OR WERE OUT OF RANGE   4 OBS HIDDEN

Figure 6.

44

In the previous year (1989) the actual work side, spoil side, and trench soil strengths were lower than those of the control for the top 7 cm (Cannon et al. 1990). These decreased soil strength values were thought to have occurred following cultivation of the RoW after construction was completed.

Actual soil strengths were lower in the trench at the Aeco 'C' study area below 14 cm for all depths except 28 to 31.5 cm when compared to the control for the 1989 sampling year (Cannon et al. 1990). Adjusted trench soil strength was lower at 28 to 31.5 cm when compared to control soil strength values. Trench soil moisture was significantly lower than that of the control at 17 to 50 cm, suggesting increased soil strengths would be expected. Therefore decreased trench soil strength was attributed to the breaking up of the dense and impermeable Bnt horizon of the Solonetzic soil. These results are similar to those of Naeth (1985) which indicated that bulk densities (as a measure of soil compaction) of the trench soil were decreased compared to control soils for Solonetzic rangeland in southern Alberta. In contrast, findings of Riddel and Knapik (1988b) indicated no significant differences in bulk densities between soils of the trench and control for Solonetzic soils.

In 1989 actual work side soil strengths were generally lower than control soil strengths at the Aeco 'C' study area, but these results were not significantly different except at the 42 to 45.5 cm depth (Cannon et al. 1990). These results are similar to those of a study on Solonetzic soils in central Alberta suggesting that there were no significant differences in work side bulk densities when compared to soils off RoW (Riddell and Knapik 1988b). The lack of significant differences between control and work side soils at the Aeco 'C' study area was attributed to construction procedures occurring in dry weather conditions. In contrast, results of a study by Naeth (1985) indicated bulk densities were increased on the work side of the RoW on Solonetzic rangeland in southern Alberta.

Increased actual soil strengths occurred for the spoil side at 28 to 35 cm when compared to the control for the 1989 sampling year (Cannon et al. 1990). The adjusted spoil side soil strength was not different from the control at these depths. Increases in soil strength were thought to have occurred because of increased construction traffic on the RoW, as well as to the lowered soil moisture contents for the soils on the RoW compared to those of the control.

It was difficult to compare the two sampling years because in 1990 the cone penetrometer could not penetrate as deeply as it did in 1989 (Table 6). This effect was most likely due to lower soil moisture contents in 1990. However the decreased soil strength for the RoW soils in the top 7 cm observed in 1989 were not observed in 1990, suggesting the effect of cultivation of the RoW immediately following construction was no longer present. It was impossible to determine if the decreased trench soil strengths at 14 to 52.5 cm observed in 1989 were still present in 1990.

5.4.4 Albright

There were no differences in soil strength between soils on the trench or spoil side and the control soil for the 1990 sampling year (Figure 7). Work side soil strength at depth increment 1 (0.6 bars) was greater than the soil strength of the control soil (0.2 bars). There were no significant differences in soil moisture and soil organic matter contents between soils on and off the RoW. Therefore increased work side soil strength at 0 to 3.5 cm was attributed to tillage traffic. The cone penetrometer could not penetrate past the 21 cm depth for the control, past the 24.5 cm depth for the spoil side or past the 17.5 cm depth for either the work side or trench indicating soil strengths greater than 38 bars at these depths.

In the previous year (1989) actual work side and spoil side soil strengths at the Albright study area were greater than those of the control at 10.5 to 24.5 cm (Cannon et al. 1990). The trench soil strength was only increased at 14 to 21 cm when compared to the control. Actual spoil side soil strength was also greater than that of the control at 28 to 31.5 cm. Adjusted work side soil strengths at 10.5 to 17.5 cm and adjusted trench soil strength at 14 to 21 cm were not different from control soil strengths. Increases in soil strength for the spoil side and work side were attributed to increased construction traffic on the RoW in dry to moist soil conditions. Increased soil strength for soils on the RoW could also be attributed to lowered soil moisture contents compared to those of the control.

Table 6. Summary of statistical data for the Aeco 'C' study area.[1]

SAMPLING EVENT[2]	DEPTH INCREMENT[3]														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
YEAR 0															
Work side	-W	-W											+W		
Trench	-T	-T			-T	-T	-T	-T	-T	-T	-T	-T	-T	-T	-T
Spoil side	-S	-S													
YEAR 1															
Work side				-	-	-	-	-	-	-	-	-	-	-	-
Trench				-	-	-	-	-	-	-	-	-	-	-	-
Spoil side				-	-	-	-	-	-	-	-	-	-	-	-

[1] Brown Solodized Solonetz developed on glacial till and constructed in dry soil conditions. Adjusted soil strengths were used.
[2] Year 0: sampling event immediately following construction,
Year 1: sampling event immediately following construction.
+W, +T and +S indicate soil strength increases for the work side, trench and spoil side, respectively, as compared to the control.
-W, -T and -S indicate soil strength decreases for the work side, trench and spoil side, respectively, as compared to the control.
[3] - = no penetration.

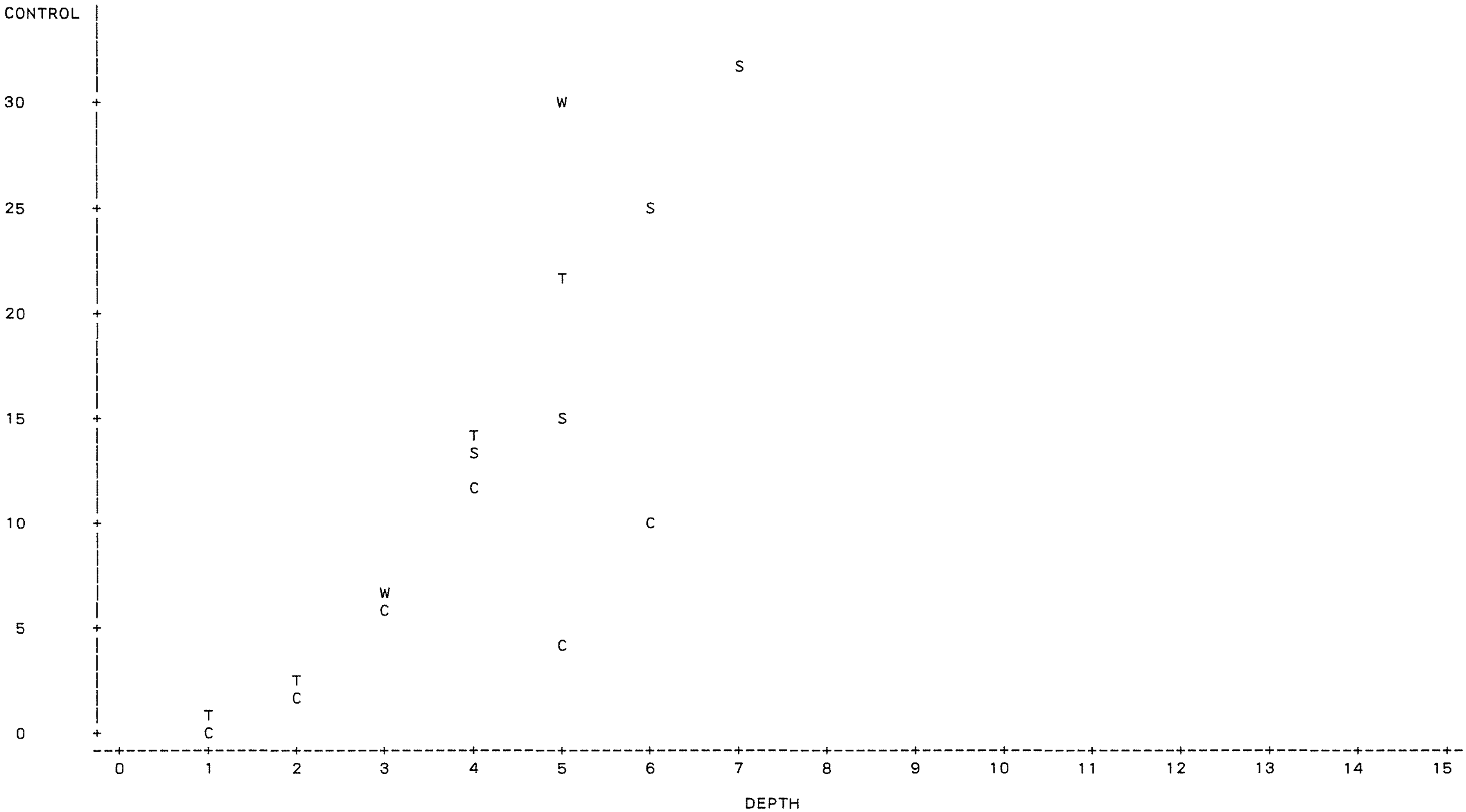
Table 7. Summary of statistical data for the Albright study area.[1]

SAMPLING EVENT[2]	DEPTH INCREMENT[3]														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
YEAR 0															
Work side						+W	+W								
Trench															
Spoil side				+S	+S	+S	+S		+S						
YEAR 1															
Work side	+W					-	-	-	-	-	-	-	-	-	-
Trench						-	-	-	-	-	-	-	-	-	-
Spoil side								-	-	-	-	-	-	-	-

[1] Orthic Humic Gleysol developed on glacio-fluvial material and constructed in dry to moist soil conditions. Adjusted soil strengths were used.
[2] Year 0: sampling event immediately following construction,
Year 1: sampling event one year following construction.
+W, +T and +S indicate soil strength increases for the work side, trench and spoil side, respectively, as compared to the control.
-W, -T and -S indicate soil strength decreases for the work side, trench and spoil side, respectively, as compared to the control.
[3] - = no penetration.

SITE=AL

PLOT OF CONTROL*DEPTH SYMBOL USED IS C
PLOT OF TRENCH*DEPTH SYMBOL USED IS T
PLOT OF WORK*DEPTH SYMBOL USED IS W
PLOT OF SPOIL*DEPTH SYMBOL USED IS S



NOTE: 37 OBS HAD MISSING VALUES OR WERE OUT OF RANGE 7 OBS HIDDEN

Figure 7.

The two sampling years were difficult to compare because in 1990 the cone penetrometer could not penetrate as deeply as it did in 1989 (Table 7). It was difficult to speculate why this occurred since soil moistures were similar for both sampling years. Increased work side soil strength at 17.5 to 21 cm and increased spoil side soil strengths at 10.5 to 21 cm observed in 1989 were not observed in 1990. However it was impossible to determine if the increased work side soil strength at 21 to 24.5 cm and spoil side soil strength at 21 to 31.5 cm observed in 1989 were still present in 1990.

5.4.5 Bolloque

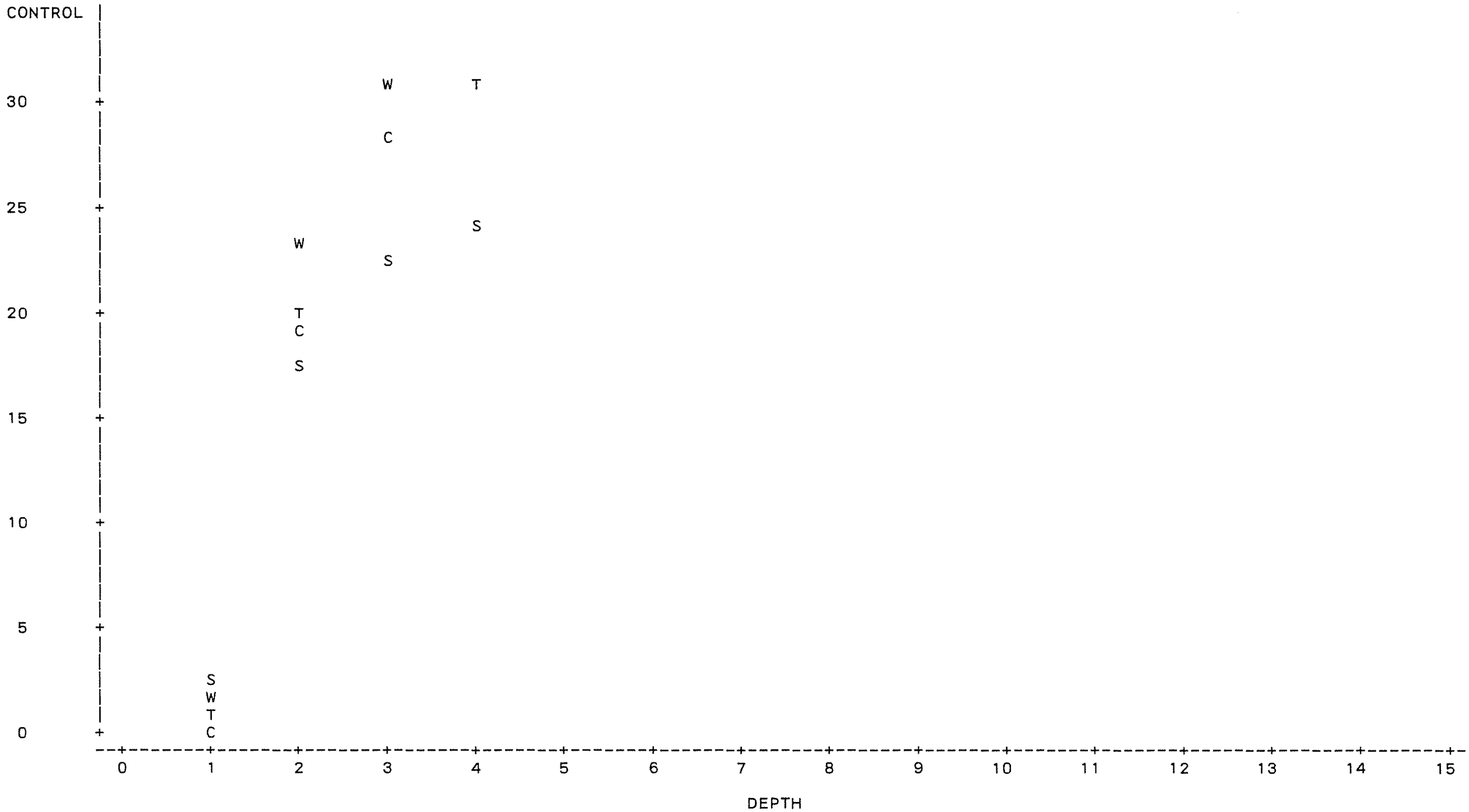
There were no differences in soil strength between soils on and off the RoW for the 1990 sampling year (Figure 8). As well there were no significant differences in soil moistures or soil organic matter contents between soils on and off the RoW. However the cone penetrometer could not penetrate past the 10.5 cm depth for either the control or work side or past the 14 cm depth for either the trench or spoil side indicating soil strengths greater than 38 bars at these depths.

In the previous year (1989) actual trench and spoil side soil strengths were lower from those of the control at 3.5 to 17.5 cm at the Bolloque study area (Cannon et al. 1990). As well the work side soil strength was lower from 3.5 to 10.5 cm when compared to the control. Adjusted trench soil strengths at 10.5 to 14 cm and adjusted spoil side soil strengths at 14 to 17.5 cm were not different from those of the control. Decreased soil strength was thought to be due to the cultivation of the RoW after construction and to the increased soil moisture of the trench and spoil sides compared to those of the control at 0 to 20 cm. The cone penetrometer could not penetrate the control soil past 17.5 cm indicating a soil strength greater than 38 bars at this depth.

It was difficult to compare the two sampling years because in 1990 the cone penetrometer could not penetrate as deeply as it did in 1989 (Table 8). This effect was most likely due to lower soil moisture contents in 1990. However the decreased RoW soil strengths at 3.5 to 14 cm observed in 1989 were not observed in 1990, suggesting the effect of cultivation of the RoW immediately following construction was no longer present.

SITE=BO

PLOT OF CONTROL*DEPTH   SYMBOL USED IS C
PLOT OF TRENCH*DEPTH   SYMBOL USED IS T
PLOT OF WORK*DEPTH   SYMBOL USED IS W
PLOT OF SPOIL*DEPTH   SYMBOL USED IS S



NOTE: 46 OBS HAD MISSING VALUES OR WERE OUT OF RANGE 1 OBS HIDDEN

Figure 8.

Table 8. Summary of statistical data for the Bolloque study area.[1]

SAMPLING EVENT[2]	DEPTH INCREMENT[3]														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
YEAR 0															
Work side		-W	-W												
Trench		-T	-T		-T										
Spoil side		-S	-S	-S											
YEAR 1															
Work side				-	-	-	-	-	-	-	-	-	-	-	-
Trench					-	-	-	-	-	-	-	-	-	-	-
Spoil side					-	-	-	-	-	-	-	-	-	-	-

[1] Dark Grey Luvisol developed on glacial till and constructed in moist to wet soil conditions. Adjusted soil strengths were used.
[2] Year 0: sampling event immediately following construction,
Year 1: sampling event one year following construction.
+W, +T and +S indicate soil strength increases for the work side, trench and spoil side, respectively, as compared to the control.
-W, -T and -S indicate soil strength decreases for the work side, trench and spoil side, respectively, as compared to the control.
[3] - = no penetration.

Table 9. Summary of statistical data for the Ferintosh study area.[1]

SAMPLING EVENT[2]	DEPTH INCREMENT[3]														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
YEAR 0															
Work side													-	-	-
Trench				-T	-T	-T	-T				+T		-	-	-
Spoil side													-	-	-
YEAR 1															
Work side	-W							-	-	-	-	-	-	-	-
Trench		+T			-T	-T	-T	-T							
Spoil side															

[1] Orthic Black Chernozem developed on fluvial material overlying till and constructed in dry to moist soil conditions.
[2] Year 0: sampling event immediately following construction,
Year 1: sampling event one year following construction.
+W, +T and +S indicate soil strength increases for the work side, trench and spoil side, respectively, as compared to the control.
-W, -T and -S indicate soil strength decreases for the work side, trench and spoil side, respectively, as compared to the control.
[3] - = no penetration.

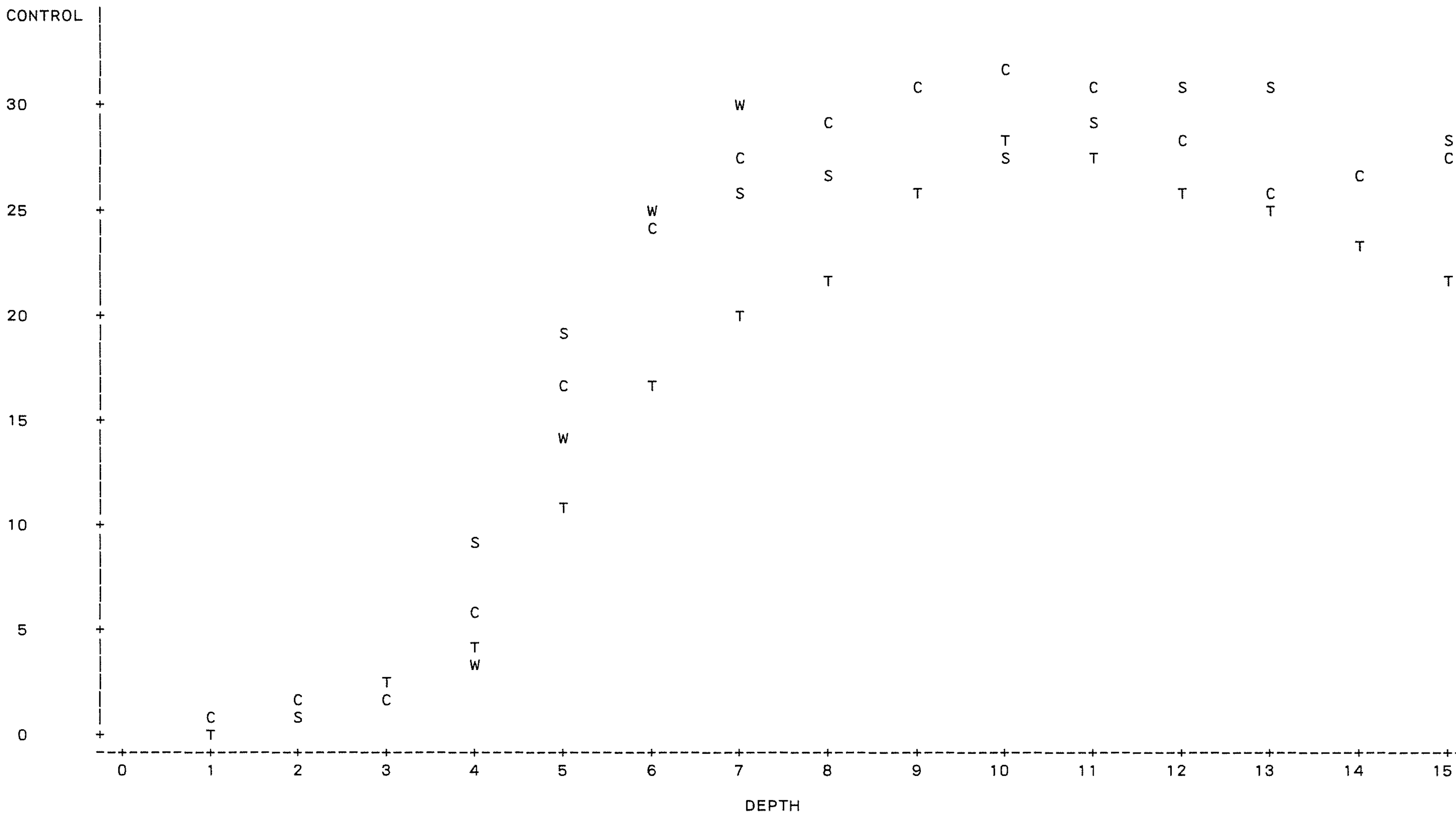
5.4.6 Ferintosh

There were no differences in soil strength between soils of the spoil side and the control for the 1990 sampling year (Figure 9). Work side soil strength at depth increment 1 (0.3 bars) was lower than that of the control (0.5 bars). However, the work side decrease in soil organic matter at 0 to 15 cm would have been expected to result in an increased soil strength value. Trench soil strength was greater at depth increment 2 (1.9 bars) compared to the control soil strength of 1.3 bars. However at depth increments 5, 6, 7, and 8 trench soil strengths (10.8, 17.0, 20.3, and 21.9 bars, respectively) were significantly lower than those of the control (16.5, 24.2, 27.4, and 29.5 bars, respectively). There were no significant differences in soil organic matter contents between soils of the trench and spoil side and the control soil. Since there were no significant differences in soil moisture between soils on and off the RoW, decreases in trench soil strengths were likely due to the breaking up of dense material during the trenching procedure. The decreased workside soil strength and the increased trench soil strength in the top 7 cm were attributed to tillage traffic. The cone penetrometer could not penetrate past the 24.5 cm depth of the work side indicating soil strengths greater than 38 bars at this depth.

In the previous year (1989) lower soil strengths were measured in the trench at the Ferintosh study area for the 10.5 to 24.5 cm depth when compared to the control (Cannon et al. 1990). There was a significant increase in clay and a significant decrease in moisture in the trench compared to the control at 15 to 32 cm, suggesting an increase in soil strength. Therefore, decreases in soil strength were attributed to breaking up of dense material during the trenching procedure. An increase in the trench soil strength at 35 to 38.5 cm compared to the control soil could be attributed to packing of the trench material during backfilling operations. There were no differences in soil strengths between soils of the control and soils of either the work or spoil side. These results are similar to those of Zellmer et al. (1985) in which bulk densities were found to be lower in the trench than on adjacent control soil in 16 of 20 control sets of observations in a fine sandy loam in Oklahoma. As well there were no significant differences between soil

SITE=FT

```
PLOT OF CONTROL*DEPTH     SYMBOL USED IS C
PLOT OF TRENCH*DEPTH      SYMBOL USED IS T
PLOT OF WORK*DEPTH        SYMBOL USED IS W
PLOT OF SPOIL*DEPTH       SYMBOL USED IS S
```



NOTE: 8 OBS HAD MISSING VALUES OR WERE OUT OF RANGE   9 OBS HIDDEN

53

Figure 9.

bulk densities from the work side and soil in the adjacent control (Zellmer et al. 1985). At the Ferintosh study area the cone penetrometer could not penetrate the control, work side, trench or spoil side past 42 cm indicating soil strengths greater than 38 bars at these depths.

Comparing the data from the two sampling years indicates that the trench soil strength at 14 to 28 cm was significantly lower than the control soil for both 1989 and 1990 sampling years (Table 9). The cone penetrometer could not penetrate the work side as deeply as it did in 1989. This effect is most likely due to lower work side soil moistures in 1990.

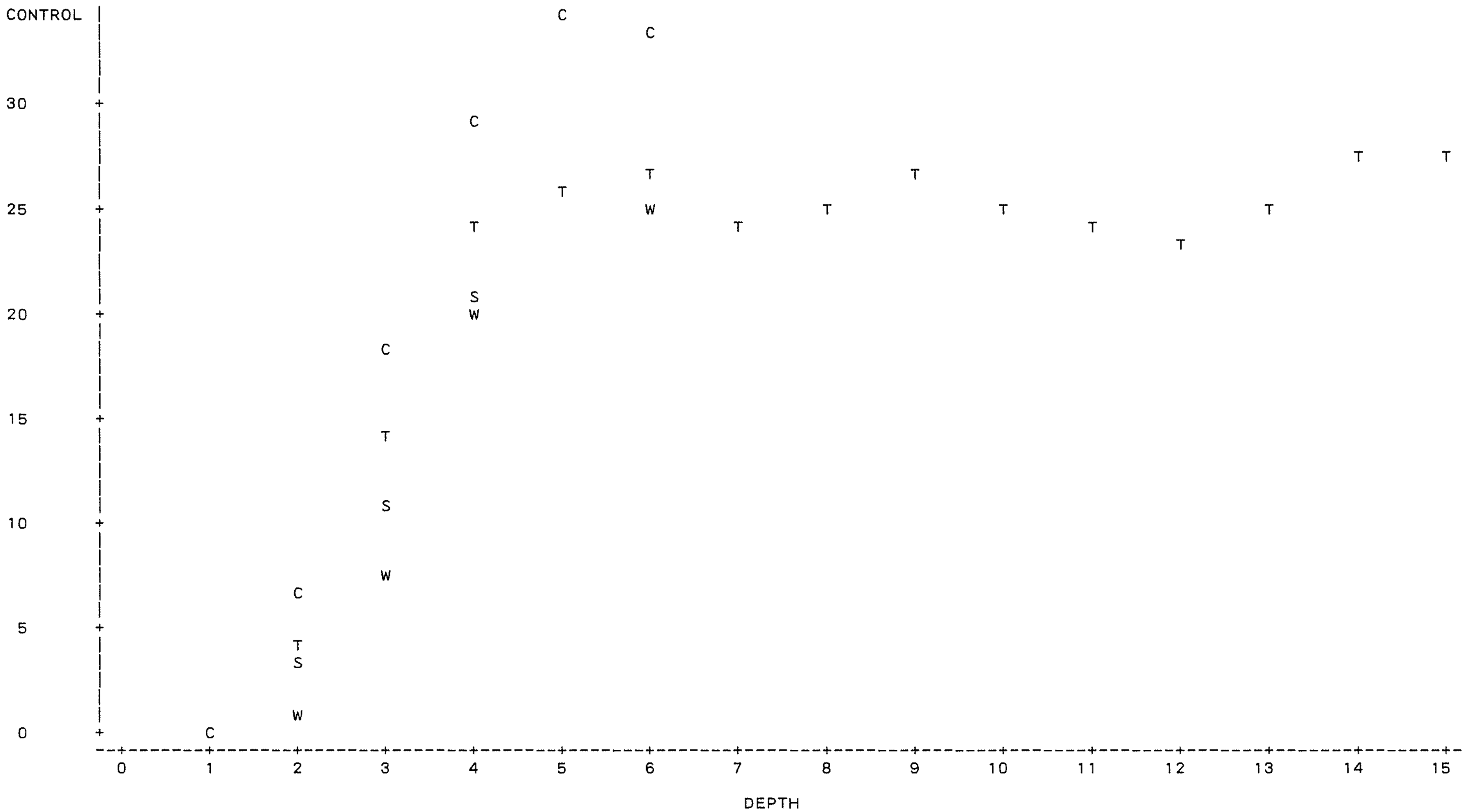
5.4.7 Foisey

There were no differences in soil strength between soils of the trench or spoil side and the control soil for the 1990 sampling year (Figure 10). Work side soil strength at depth increment 5 (25.6 bars) was lower than that of the control (34.1 bars). There were no significant differences in soil moisture between soils on and off the RoW. Soil organic matter contents for the work side, trench and spoil side were significantly lower than those of the control, therefore increased soil strengths would have been expected. It was difficult to speculate why the decreased work side soil strength at 14 to 17.5 cm occurred. The cone penetrometer could not penetrate past the 14 cm depth for the spoil side or past the 21 cm depth for the control or work side indicating soil strengths greater than 38 bars at these depths.

In the previous year (1989), at the Foisey study area, actual trench, spoil side, and work side soil strengths to a depth of 14 cm were generally lower than control soil strengths, but these results were not always statistically significant (Cannon et al. 1990). Significant decreases in soil strength were attributed to cultivation of the RoW after pipeline construction was completed since work side clay content and trench soil moisture were significantly greater than control values for the top 19 cm, suggesting an increase in work side soil strength and a decrease in trench soil strength would be expected. There were no significant differences in soil strengths below 14 cm between soil of the control and soils of either the work side or trench. However below 14 cm, spoil side soil strengths were generally lower than those of the control, but these results were not always significantly

SITE=FY

PLOT OF CONTROL*DEPTH   SYMBOL USED IS C
PLOT OF TRENCH*DEPTH   SYMBOL USED IS T
PLOT OF WORK*DEPTH   SYMBOL USED IS W
PLOT OF SPOIL*DEPTH   SYMBOL USED IS S



NOTE: 29 OBS HAD MISSING VALUES OR WERE OUT OF RANGE   4 OBS HIDDEN

55

Figure 10.

different. It was difficult to speculate why these decreases occurred. There were no significant differences between the soils on the RoW and those off the RoW for either clay content or soil moisture at 19 to 50 cm.

It was difficult to compare the two sampling years because in 1990 the cone penetrometer could not penetrate as deeply as it did in 1989 for the control, work side and spoil side soils (Table 10). It was difficult to speculate why this occurred since soil moistures were similar for both sampling years. However the decreased RoW soil strengths for the top 14 cm observed in 1989 were not observed in 1990. It was impossible to determine if the decreased spoil side soil stengths below 24.5 cm observed in 1989 were still present in 1990.

5.4.8 Henderson 1

There were no differences in soil strength between soils of the trench or spoil side and the control soil for the 1990 sampling year (Figure 11). Work side soil strength at depth increment 1 (1.5 bars) was greater than that of the control (0.6 bars). There were no significant differences in soil moistures or soil organic matter contents between soils on and off the RoW. Increased work side soil strength at 0 to 3.5 cm was attributed to tillage traffic. The cone penetrometer could not penetrate past the 21 cm depth for the control, work side and spoil side or past the 24.5 cm depth for the trench indicating soil strengths greater than 38 bars at these depths.

In the previous year (1989), at the Henderson 1 study area, actual work side, spoil side, and trench soil strengths were lower than those for the control at 3.5 to 17.5 cm (Cannon et al. 1990). Adjusted trench and work side soil strengths were not different from those of the control at 14 to 17.5 cm. Decreased soil strength for soils on the RoW was attributed to cultivation of the RoW after pipeline construction was completed as well as to greater soil moisture values for the top 17.5 cm when compared to control soils. The cone penetrometer could not penetrate the control soil past 17.5 cm, the work side or trench past 31.5 cm or the spoil side past 45.5 cm indicating soil strengths greater than 38 bars at these depths.

The two sampling years were difficult to compare because in 1990 the cone penetrometer could not penetrate as deeply as it did in 1989 (Table 11).

Table 10. Summary of statistical data for the Foisey study area.[1]

SAMPLING EVENT[2]	DEPTH INCREMENT[3]														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
YEAR 0															
Work side	-W			-W											
Trench	-T			-T											
Spoil side	-S	-S		-S				-S	-S	-S	-S				-S
YEAR 1															
Work side					-W		–	–	–	–	–	–	–	–	–
Trench															
Spoil side					–	–	–	–	–	–	–	–	–	–	–

[1] Orthic Dark Grey Chernozem developed on glacial till and constructed in dry soil conditions.
[2] Year 0: sampling event immediately following construction,
Year 1: sampling event one year following construction.
+W, +T and +S indicate soil strength increases for the work side, trench and spoil side, respectively, as compared to the control.
-W, -T and -S indicate soil strength decreases for the work side, trench and spoil side, respectively, as compared to the control.
[3] - = no penetration.

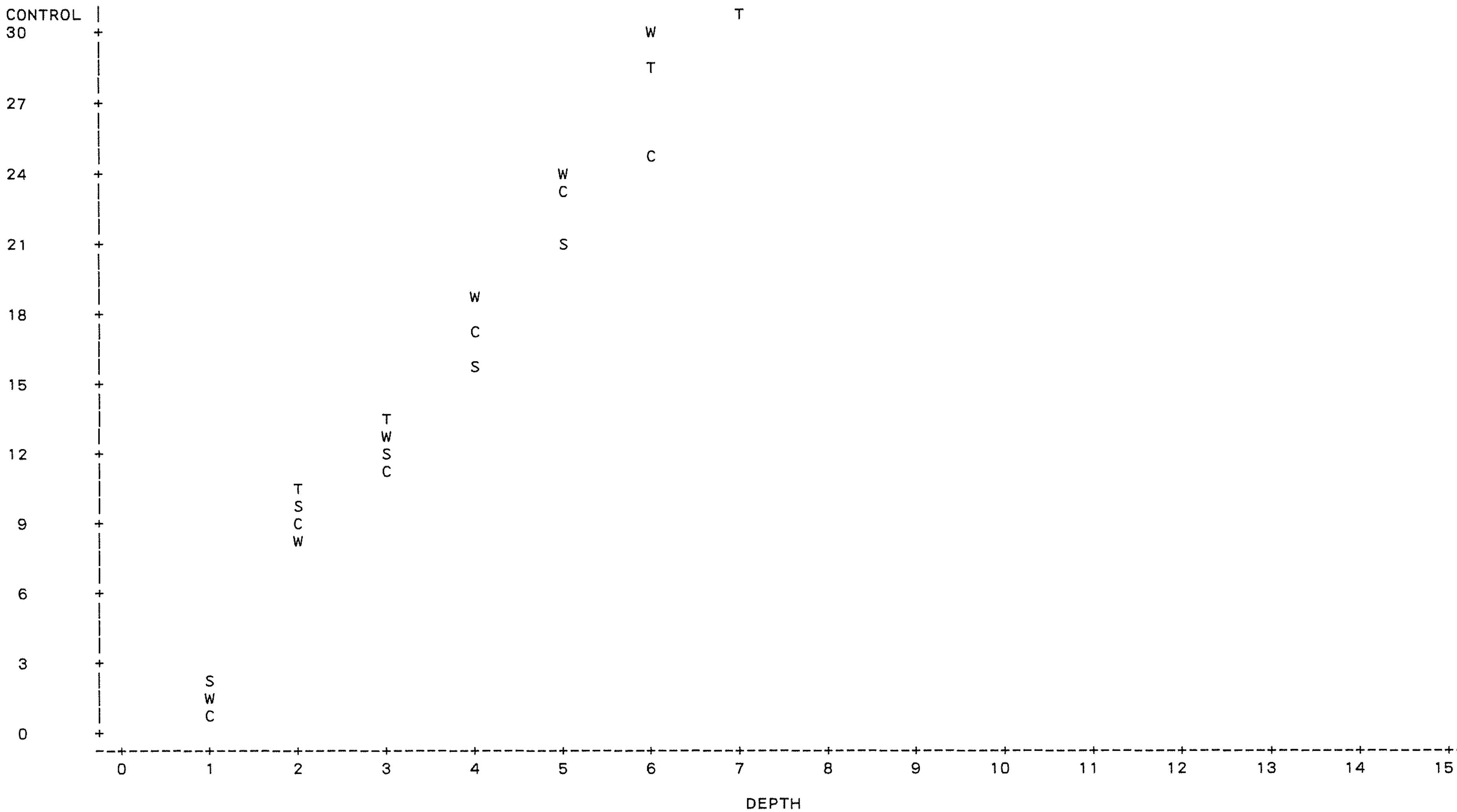
Table 11. Summary of statistical data for the Henderson 1 study area.[1]

SAMPLING EVENT[2]	DEPTH INCREMENT[3]														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
YEAR 0															
Work side		-W	-W	-W						–	–	–	–	–	–
Trench		-T	-T	-T						–	–	–	–	–	–
Spoil side		-S	-S	-S	-S									–	–
YEAR 1															
Work side	+W						–	–	–	–	–	–	–	–	–
Trench								–	–	–	–	–	–	–	–
Spoil side							–	–	–	–	–	–	–	–	–

[1] Solonetzic Dark Grey Luvisol developed on glacial till and constructed in dry soil conditions. Adjusted soil strengths were used.
[2] Year 0: sampling event immediately following construction,
Year 1: sampling event one year following construction.
+W, +T and +S indicate soil strength increases for the work side, trench and spoil side, respectively, as compared to the control.
-W, -T and -S indicate soil strength decreases for the work side, trench and spoil side, respectively, as compared to the control.
[3] - = no penetration.

SITE=HE1

PLOT OF CONTROL*DEPTH SYMBOL USED IS C
PLOT OF TRENCH*DEPTH SYMBOL USED IS T
PLOT OF WORK*DEPTH SYMBOL USED IS W
PLOT OF SPOIL*DEPTH SYMBOL USED IS S



NOTE: 35 OBS HAD MISSING VALUES OR WERE OUT OF RANGE 4 OBS HIDDEN

58

Figure 11.

It was difficult to speculate why this occurred since soil moistures were similar for both sampling years. However the decreased RoW soil strengths at 3.5 to 17.5 cm observed in 1989 were not observed in 1990, suggesting the effect of cultivation of the RoW immediately following construction was no longer present.

5.4.9 Henderson 2

There were no differences in soil strength between soils on and off the RoW for the 1990 sampling year (Figure 12). There were also no significant differences in soil moistures or soil organic matter contents between soils on and off the RoW. However the cone penetrometer could not penetrate the control soil past 31.5 cm, the work or spoil sides past 21 cm or the trench past 28 cm indicating soil strengths greater than 38 bars at these depths.

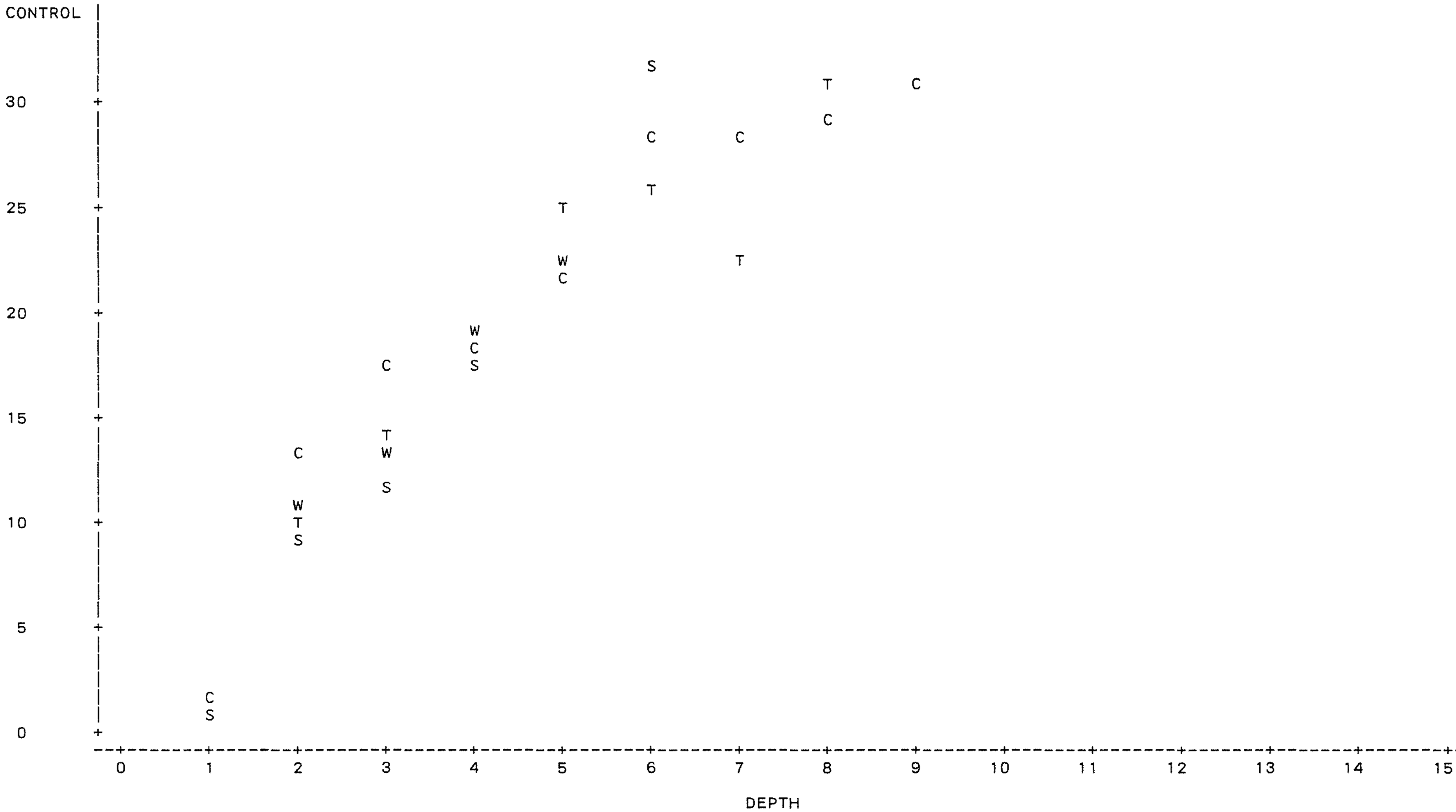
In the previous year (1989) lower actual soil strengths occurred in the trench and spoil side of the Henderson 2 study area from 3.5 to 21 cm when compared to the control (Cannon et al. 1990). As well work side soil strengths were lower from 3.5 to 17.5 cm when compared to the control. Again decreased soil strengths for soils on the RoW were attributed to cultivation of the RoW after pipeline construction was completed since there was no significant differences in organic matter, soil moisture, or clay content for any of the soils on the RoW when compared to the control soil at 0 to 34 cm. The cone penetrometer could not penetrate into the work side side past 38.5 cm indicating a soil strength greater than 38 bars at this depth.

The two sampling years were difficult to compare because in 1990 the cone penetrometer could not penetrate as deeply as it did in 1989 (Table 12). It was difficult to speculate why this occurred since soil moistures were similar for both sampling years. However the decreased RoW soil strenghts at 3.5 to 21 cm that were observed in 1989 were not observed in 1990, suggesting the effect of cultivation of the RoW immediately following construction was no longer present.

5.4.10 Maleb 1

SITE=HE2

PLOT OF CONTROL*DEPTH SYMBOL USED IS C
PLOT OF TRENCH*DEPTH SYMBOL USED IS T
PLOT OF WORK*DEPTH SYMBOL USED IS W
PLOT OF SPOIL*DEPTH SYMBOL USED IS S



NOTE: 31 OBS HAD MISSING VALUES OR WERE OUT OF RANGE 5 OBS HIDDEN

Figure 12.

Table 12. Summary of statistical data for the Henderson 2 study area.[1]

SAMPLING EVENT[2]	DEPTH INCREMENT[3]														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
YEAR 0															
Work side		-W	-W	-W	-W							–	–	–	–
Trench		-T	-T	-T	-T	-T									
Spoil side		-S	-S	-S	-S	-S									
YEAR 1															
Work side							–	–	–	–	–	–	–	–	–
Trench									–	–	–	–	–	–	–
Spoil side							–	–	–	–	–	–	–	–	–

[1] Dark Grey Luvisol developed on glacial till and constructed in dry soil conditions.
[2] Year 0: sampling event immediately following construction,
Year 1: sampling event one year following construction.
+W, +T and +S indicate soil strength increases for the work side, trench and spoil side, respectively, as compared to the control.
-W, -T and -S indicate soil strength decreases for the work side, trench and spoil side, respectively, as compared to the control.
[3] – = no penetration.

Table 13. Summary of statistical data for the Maleb 1 study area.[1]

SAMPLING EVENT[2]	DEPTH INCREMENT[3]														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
YEAR 0															
Work side		-W		-W	-W										
Trench		-T			-T										
Spoil side			-S												
YEAR 1															
Work side										-W	-W		-W	-W	-W
Trench				-T	-T						-T	-T	-T	-T	-T
Spoil side						+S					-S	-S	-S	-S	

[1] Gleyed Brown Chernozem developed on glacial till and constructed in dry soil conditions.
[2] Year 0: sampling event immediately following construction,
Year 1: sampling event one year following construction.
+W, +T and +S indicate soil strength increases for the work side, trench and spoil side, respectively, as compared to the control.
-W, -T and -S indicate soil strength decreases for the work side, trench and spoil side, respectively, as compared to the control.
[3] – = no penetration.

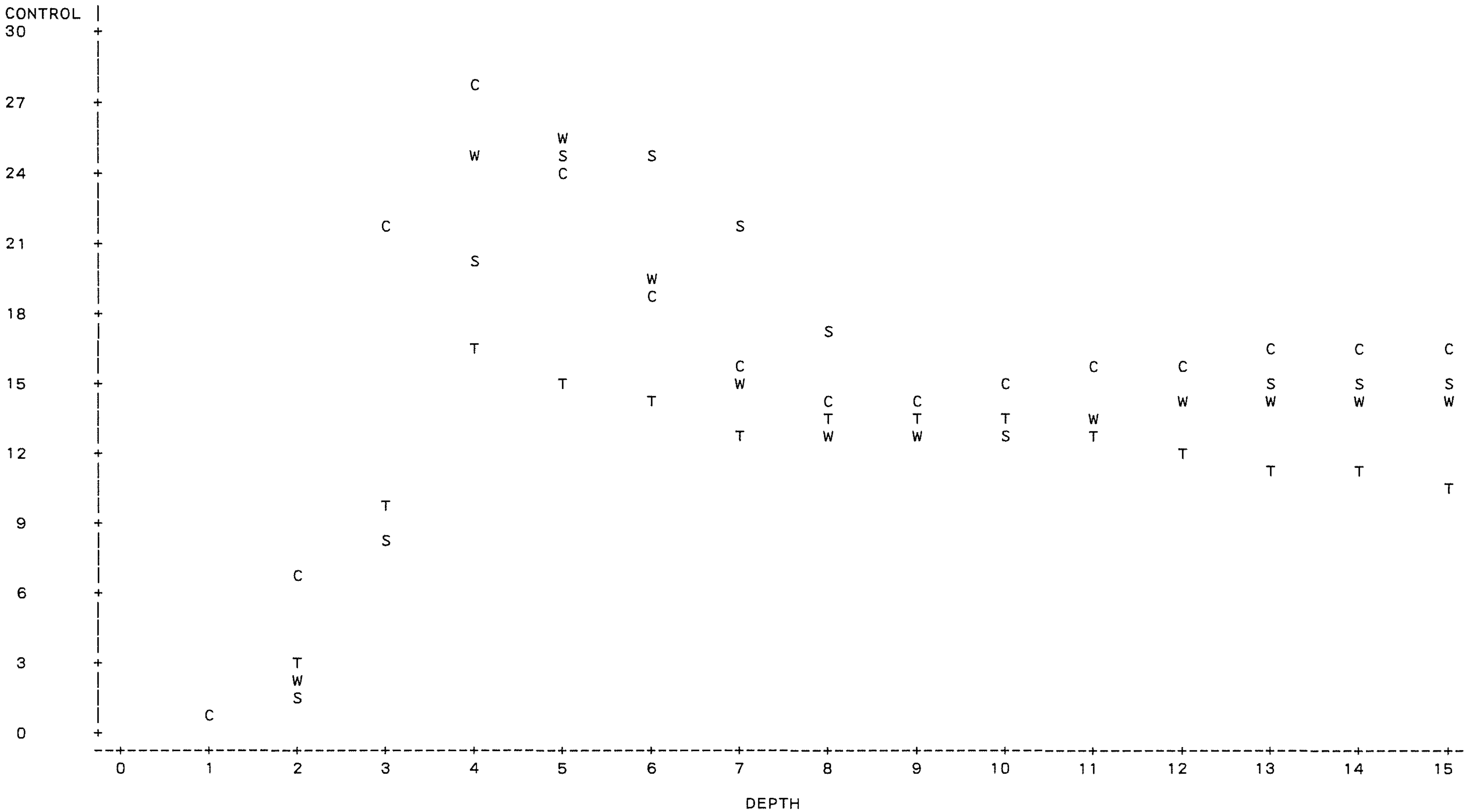
In 1990 work side soil strengths at depth increments 10, 11, 13, 14 and 15 (13.3, 13.6, 14.1, 14.3 and 14.1 bars, respectively) were lower than the control soil strengths at the same depths (15.0, 15.7 16.1, 16.3 and 16.5 bars, respectively) (Figure 13). Trench soil strengths at depth increments 4, 5 11, 12, 13, 14 and 15 (16.2, 15.1, 12.9, 11.6, 11.2 and 10.8 bars, respectively) were lower than those of the control (27.7, 24.0, 15.7, 16.0, 16.1, 16.3 and 16.5 bars, respectively). Spoil side soil strength at depth increment 6 (24.7 bars) was greater than that of the control at the same depth (18.6 bars). There were no significant differences in soil moistures or soil organic matter contents between soils on and off the RoW. It was difficult to speculate why the decreased soil strengths occurred for soils on the RoW at depths below 35.0 cm. The decreased trench soil strength at 10.5 to 17.5 cm was similar to that which occurred in the previous year. It was also difficult to speculate why the increased spoil side soil strength at 17.5 to 21 cm occurred.

In the previous year (1989) lower actual soil strengths occurred in the work side and trench soils of the RoW in the top 17.5 cm when compared to the control at the Maleb 1 study area (Cannon et al. 1990). As well the spoil side soil strength was lower than the control soil strength at 7 to 10.5 cm. In the top 15 cm soil organic matter levels were significantly decreased in soils across the RoW compared to those off the RoW, suggesting increased soil strengths would be expected. Clay content was significantly increased for the work and spoil sides of the RoW compared to the control values, also suggesting increased soil strengths. Therefore decreased soil strengths across the RoW for the top 17.5 cm were attributed to the harrowing of the RoW after pipeline construction was completed. The cone penetrometer could not penetrate the control soil past 21.0 cm indicating a soil strength of greater than 38 bars at this depth.

It was difficult to compare the two sampling years because the cone penetrometer was able to penetrate the control soil deeper in 1990 then it did in 1989. Therefore it was impossible to determine if the decreased RoW soil strengths below 31.5 cm observed in 1990 were pesent in 1989 (Table 13). The decreased work and spoil soil strengths at 3.5 to 17.5 cm observed in 1989 were not observed in 1990. Decreased work side and spoil side strengths

SITE=MB1

PLOT OF CONTROL*DEPTH SYMBOL USED IS C
PLOT OF TRENCH*DEPTH SYMBOL USED IS T
PLOT OF WORK*DEPTH SYMBOL USED IS W
PLOT OF SPOIL*DEPTH SYMBOL USED IS S



NOTE: 8 OBS HIDDEN

Figure 13.

within the top 17.5 cm of the RoW observed in 1989 were not observed in 1990. However decreased trench soil strengths were measured within the to 17.5 cm for both sampling years.

5.4.11 Maleb 2

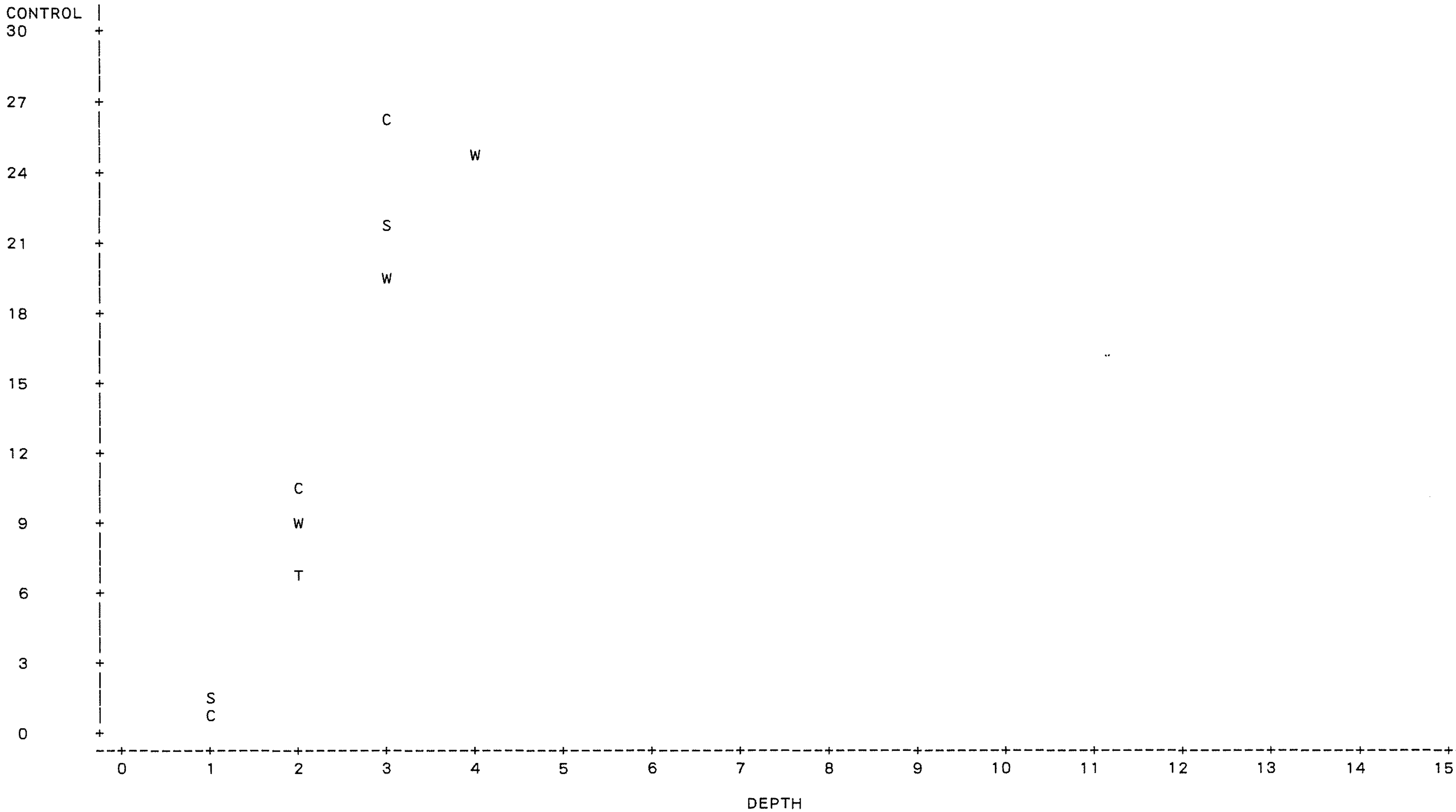
There were no differences in soil strength between soils on and off the RoW for the 1990 sampling year (Figure 14). There were also no significant differences in soil moisture and soil organic matter contents between soils on and off the RoW. However the cone penetrometer could not penetrate past the 14 cm depth for the work side or past the 10.5 cm depth for the control, trench or spoil side indicating soil strengths greater than 38 bars at these depths.

In the previous year (1989) actual work side soil strengths were greater for the surface 3.5 cm and at 17.5 to 24.5 cm when compared to the control (Cannon et al. 1990). Adjusted work side soil strengths were not different from the control for the surface 3.5 cm. Increased soil strengths on the work side of the RoW at the Maleb 2 study area were attributed to increased construction traffic on the RoW. Actual spoil side soil strengths at Maleb 2 were significantly increased at 3.5 to 21 cm and were significantly lower at 0 to 3.5 cm when compared to the control. Increased spoil side soil strengths were thought to be a result of either lower soil moisture contents on the spoil side compared to those of the control or to increased construction traffic on the RoW. However adjusted spoil side soil strengths were not different at 3.5 to 14 cm and were lower at 14 to 17.5 cm compared to the control indicating no compaction at these depths. There were no differences in actual soil strengths between soils of the control and trench, but adjusted trench soil strength for the top 3.5 cm was lower than control soil strength. Decreases in soil strength for the spoil side and for the trench soils for the top 3.5 cm were attributed to cultivation of the RoW after construction was completed. The cone penetrometer was not able to penetrate past 17.5 in the trench or 24.5 cm in the spoil side indicating soil strength greater than 38 bars at these depths.

It was difficult to compare the two sampling years since the cone penetrometer was not able to penetrate as deeply in 1990 as it did in 1989

SITE=MB2

PLOT OF CONTROL*DEPTH SYMBOL USED IS C
PLOT OF TRENCH*DEPTH SYMBOL USED IS T
PLOT OF WORK*DEPTH SYMBOL USED IS W
PLOT OF SPOIL*DEPTH SYMBOL USED IS S



NOTE: 43 OBS HAD MISSING VALUES OR WERE OUT OF RANGE 4 OBS HIDDEN

Figure 14.

(Table 14). This effect was most likely due to lower soil moistusres in 1990. Decreased trench and spoil side soil strengths at 0 to 3.5 cm observed in 1989 were not observed in 1990. It was impossible to determine if the increased work and spoil side soil strengths at 17.5 to 24.5 cm observed in 1989 were still present in 1990.

5.4.12 Pigeon Lake

There were no differences in soil strength between soils of the work side and the control for the 1990 sampling year (Figure 15). Trench soil strength at depth increment 8 (24.5 bars) was greater than the control soil strength of 15.9 bars. Spoil side soil strength at depth increment 2 (4.4 bars) was greater than that of the control (2.9 bars). There were no significant differences in soil moistures or soil organic matter contents between soils on and off the RoW. Increased trench soil strength at 24.5 to 28 cm could be attributed to settling of the trench material while increased spoil side soil strength at 3.5 to 7 cm could be attributed to tillage traffic. The cone penetrometer could not penetrate the spoil side soil past 31.5 cm indicating soil strengths greater than 38 bars at this depth.

In the previous year (1989) lower actual soil strengths occurred in both the trench and spoil sides of the RoW for the top 14 cm when compared to the control at the Pigeon Lake study area (Cannon et al. 1990). The work side soil strength was greater than the control for the top 3.5 cm, whereas the work side soil strength was lower than the control at 3.5 to 7 cm depth. Adjusted soil strengths for the trench at 0 to 3.5 cm and for the spoil side at 0 to 3.5 and 14 to 17.5 cm were not different from control soil strengths. Decreased soil strengths in the top 14 cm were attributed to the cultivation of the RoW after pipeline construction was completed. Decreased soil strengths in the top 14 cm could also be attributed to the increased soil moisture content for the RoW soils when compared to the control soils. Actual spoil side soil strength at 17.5 to 21 cm was lower than that of the control, while adjusted spoil side soil strength was not. Actual trench soil strength at 21 to 24.5 cm was significantly lower than that of the control. There were no significant differences in clay content or soil moistures between soils on the RoW and soils off the RoW at 18 to 35 cm. The cone penetrometer could not

Table 14. Summary of statistical data for the Maleb 2 study area.[1]

SAMPLING EVENT[2]	DEPTH INCREMENT[3]														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
YEAR 0															
Work side						+W	+W								
Trench	-T					-	-	-	-	-	-	-	-	-	-
Spoil side	-S				-S	+S		-	-	-	-	-	-	-	-
YEAR 1															
Work side					-	-	-	-	-	-	-	-	-	-	-
Trench				-	-	-	-	-	-	-	-	-	-	-	-
Spoil side				-	-	-	-	-	-	-	-	-	-	-	-

[1] Orthic Brown Chernozem developed on glacial till and constructed in dry soil conditions. Adjusted soil strengths were used.

[2] Year 0: sampling event immediately following construction,
Year 1: sampling event one year following construction.
+W, +T and +S indicate soil strength increases for the work side, trench and spoil side, respectively, as compared to the control.
-W, -T and -S indicate soil strength decreases for the work side, trench and spoil side, respectively, as compared to the control.

[3] - = no penetration.

Table 15. Summary of statistical data for the Pigeon Lake study area.[1]

SAMPLING EVENT[2]	DEPTH INCREMENT[3]														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
YEAR 0															
Work side	+W	-W			-	-	-	-	-	-	-	-	-	-	-
Trench		-T	-T	-T		-T				-	-	-	-	-	-
Spoil side		-S	-S							-	-	-	-	-	-
YEAR 1															
Work side															
Trench								+T							
Spoil side		+S								-	-	-	-	-	-

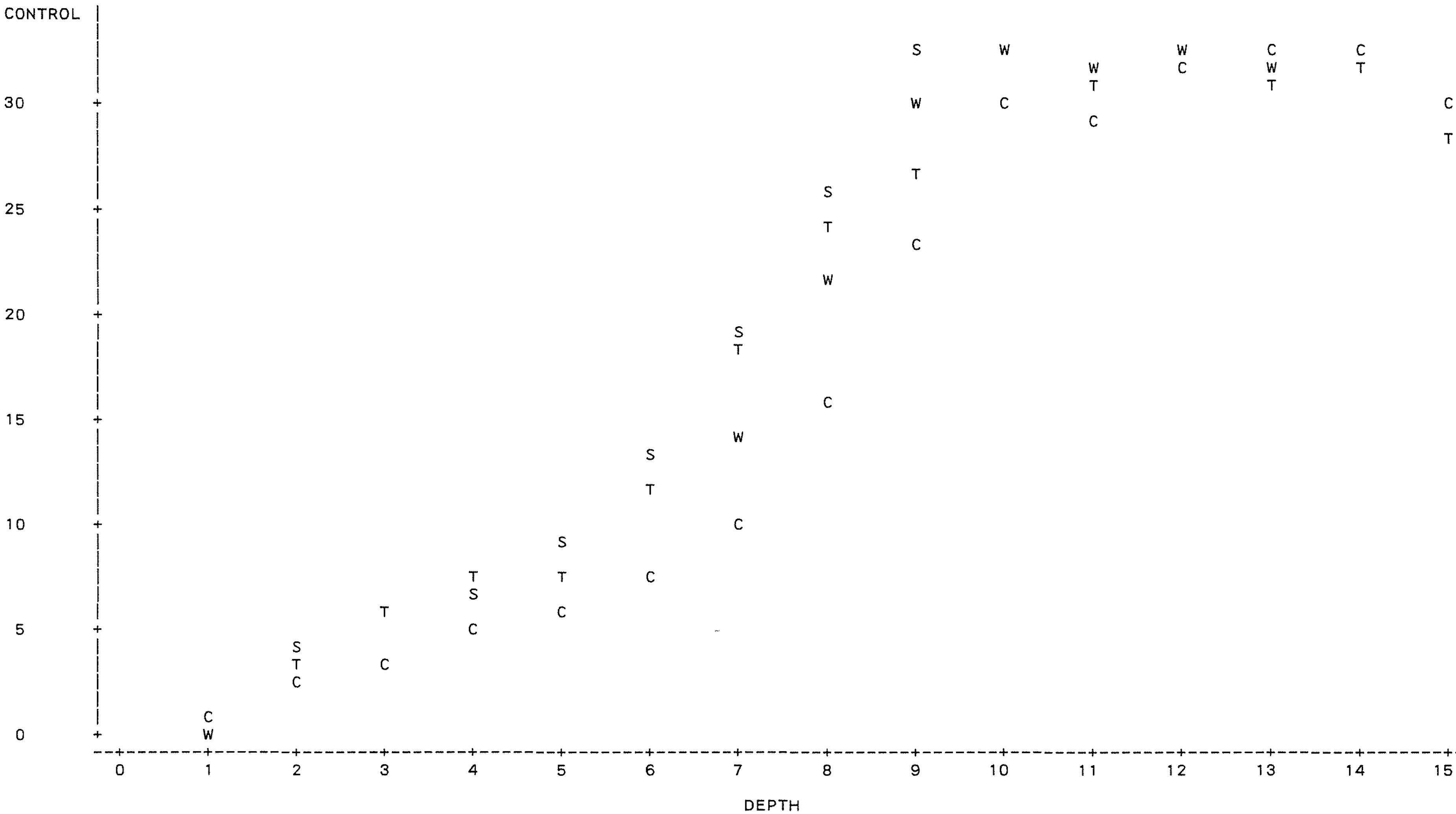
[1] Eluviated Dark Grey Chernozem developed on glacial till and constructed in moist soil conditions. Adjusted soil strengths were used.

[2] Year 0: sampling event immediately following construction,
Year 1: sampling event one year following construction.
+W, +T and +S indicate soil strength increases for the work side, trench and spoil side, respectively, as compared to the control.
-W, -T and -S indicate soil strength decreases for the work side, trench and spoil side, respectively, as compared to the control.

[3] - = no penetration.

SITE=PG

PLOT OF CONTROL*DEPTH   SYMBOL USED IS C
PLOT OF TRENCH*DEPTH   SYMBOL USED IS T
PLOT OF WORK*DEPTH   SYMBOL USED IS W
PLOT OF SPOIL*DEPTH   SYMBOL USED IS S



NOTE: 7 OBS HAD MISSING VALUES OR WERE OUT OF RANGE   11 OBS HIDDEN

Figure 15.

penetrate the control past 35 cm, the work side past 14 cm or the trench and spoil side past 31.5 cm indicating soil strengths greater than 38 bars at these depths.

It was difficult to compare the two sampling years because the cone penetrometer was able to penetrate the soil deeper in 1990 than it did in 1989 (Table 15). This effect was most likely due to wetter soil moistures in 1990. The decreased RoW soil strengths at 3.5 to 14 cm observed in 1989 were not observed in 1990 suggesting the effect of cultivation of the RoW immediately following construction was no longer present.

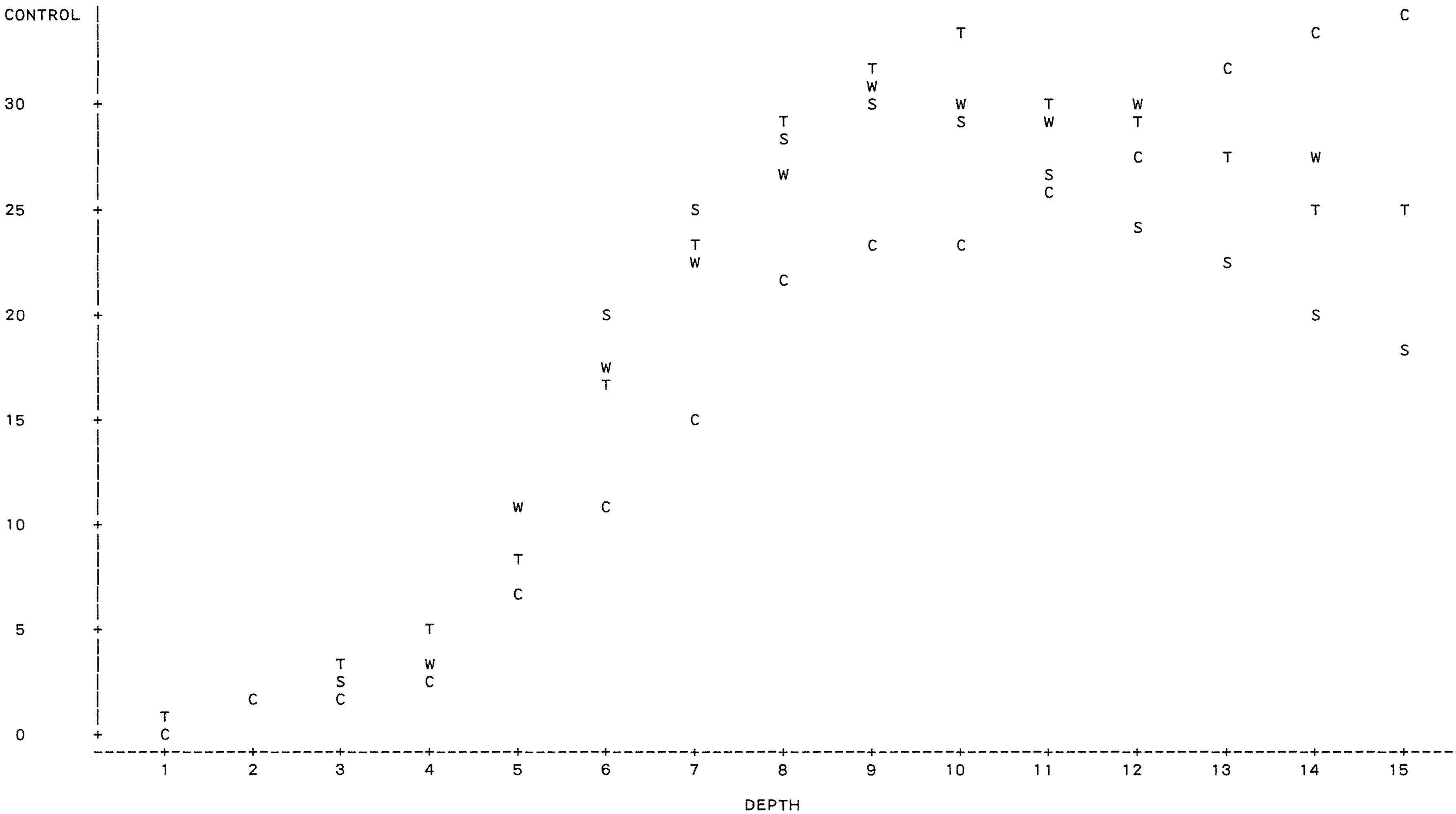
5.4.13 Redwater 1

There were no differences in soil strength between soils of the spoil side and the control for the 1990 sampling year (Figure 16). Trench soil strength at depth increments 3, 4 and 9 (3.5, 5.2 and 32.0 bars, respectively) were greater than the control soil strengths at the same depths (1.7, 2.6 and 30.4 bars, respectively). Work side soil strength at depth increment 9 (30.4 bars) was greater than the control soil strength of 23.0 bars. There were no significant differences in soil moisture or soil organic matter contents between soils on and off the RoW. Increased trench soil strengths were thought to have occurred because of settling of material in the trench, while the increased work side soil strength was attributed to tillage traffic.

In the previous year (1989) lower actual soil strength measurements occurred in the top 24.5 cm for soils on the RoW when compared to the control (Cannon et al. 1990). Adjusted soil strengths for the work side at 17.5 to 24.5 cm, for the trench at 21.0 to 24.5, and for the spoil side at 17.5 to 21.0 cm were not different form the control soil strengths. Since there were no significant differences in soil organic matter, clay content, or soil moisture between soils on the RoW and soils off the RoW at 0 to 20 cm, decreased soil strengths were attributed to the cultivation of the RoW after pipeline construction was completed. The cone penetrometer could not penetrate the control soil past 24.5 cm, the trench past 31.5 cm or the work side past 49 cm indicating soil strengths greater than 38 bars at these depths.

SITE=RW1

PLOT OF CONTROL*DEPTH   SYMBOL USED IS C
PLOT OF TRENCH*DEPTH   SYMBOL USED IS T
PLOT OF WORK*DEPTH   SYMBOL USED IS W
PLOT OF SPOIL*DEPTH   SYMBOL USED IS S



NOTE: 10 OBS HIDDEN

Figure 16.

The two sampling years were difficult to compare since the cone penetrometer was able to penetrate the soil deeper in 1990 than in 1989 (Table 16). This effect was most likely due to wetter soil moistures in 1990. The decreased RoW soil strength at 0 to 21 cm observed in 1989 were not observed in 1990 suggesting the effect of cultivation of the RoW immediately following construction was no longer present. However increased trench soil strength at 7 to 14 cm and increased work and trench soil strengths at 28 to 31.5 cm were measured in the 1990 sampling year.

5.4.14 Redwater 2

In 1990 work side and spoil side soil strengths at depth increment 1 (1.7 and 1.4 bars) were greater than that of the control (0.6 bars) (Figure 17). Work side, trench and spoil side soil strengths at depth increment 2 (18.8, 11.2 and 12.3 bars, respectively) were lower than that of the control (20.0 bars). As well spoil side soil strength at depth increment 3 (18.1 bars) was lower than the control soil strength (24.4 bars). There were no significant differences in soil moistures or soil organic matter contents between soils on and off the RoW. The significant differences in soil strength were attributed to the effects of cultivation of the RoW immediately after pipeline construction. However the cone penetrometer could not penetrate the control past 10.5 cm, the trench past 14 cm and the work or spoil sides past 17.5 cm indicating soil strengths greater than 38 bars at these depths.

In the previous year (1989) lower actual soil strengths were measured across the RoW for the top 14 cm at the Redwater 2 study area when compared to the control (Cannon et al. 1990). Adjusted trench soil strengths were not different from the control soil strengths at 0 to 3.5 and 7 to 14 cm. There were no statistical differences in soil organic matter or clay content between soils on the RoW and soils off the RoW for the top 20 cm. Soil moisture was increased only for the trench for the top 20 cm compared to the control area, suggesting decreased soil strengths would be expected only within the trench soil. Therefore significant decreases were attributed to the cultivation of the RoW after pipeline construction was completed. There were no differences in actual soil strengths below 14 cm between soils on and

Table 16. Summary of statistical data for the Redwater 1 study area.[1]

SAMPLING EVENT[2]	DEPTH INCREMENT[3]														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
YEAR 0															
Work side	-W	-W	-W	-W	-W										–
Trench		-T	-T	-T	-T	-T				–	–	–	–	–	–
Spoil side		-S	-S	-S	-S										
YEAR 1															
Work side									+W						
Trench			+T	+T					+T						
Spoil side															

[1] Gleyed Black Chernozem developed on glacio-fluvial material and constructed in moist to wet soil conditions. Adjusted soil strengths were used.
[2] Year 0: sampling event immediately following construction,
Year 1: sampling event one year following construction.
+W, +T and +S indicate soil strength increases for the work side, trench and spoil side, respectively, as compared to the control.
-W, -T and -S indicate soil strength decreases for the work side, trench and spoil side, respectively, as compared to the control.
[3] – = no penetration.

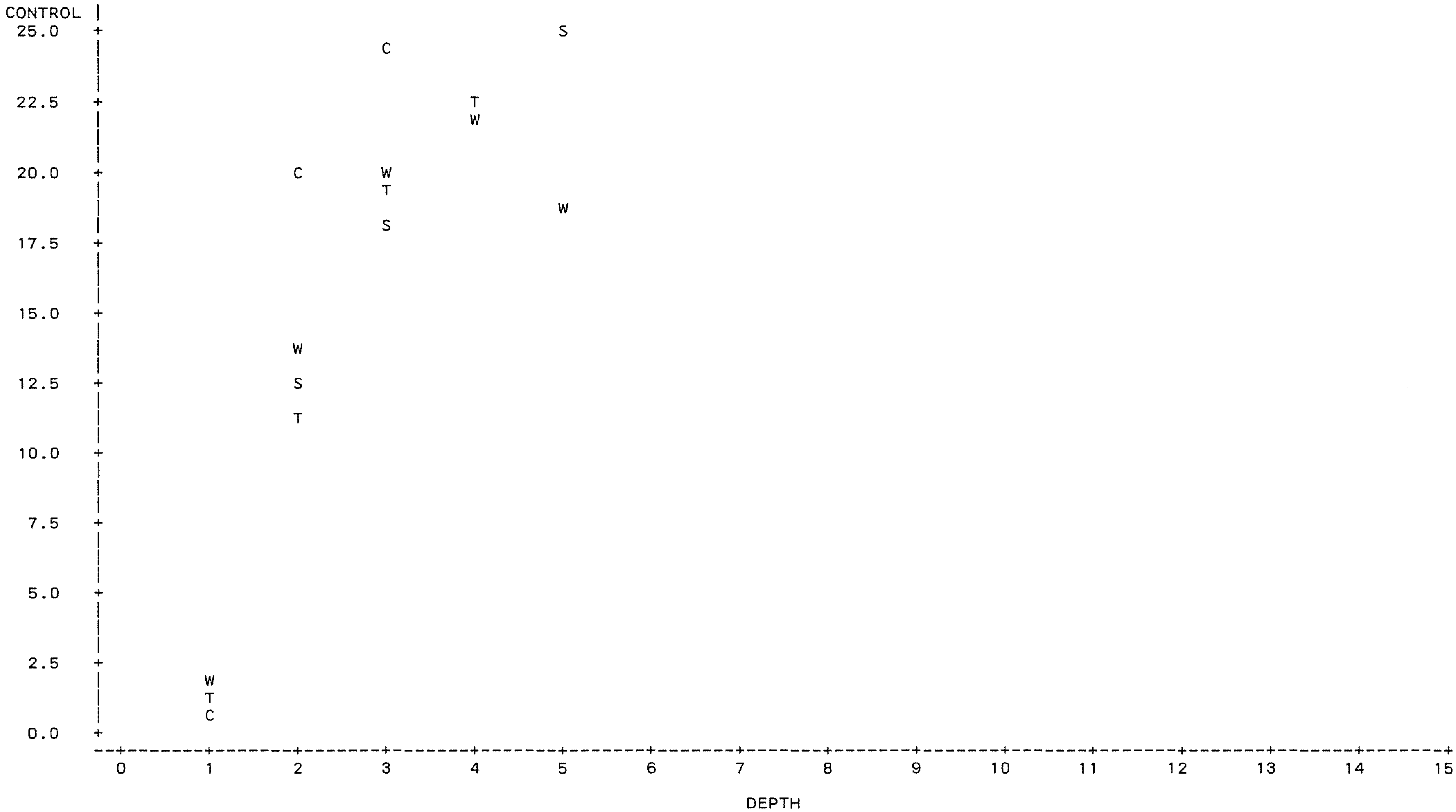
Table 17. Summary of statistical data for the Redwater 2 study area.[1]

SAMPLING EVENT[2]	DEPTH INCREMENT[3]														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
YEAR 0															
Work side		-W	-W	-W					–	–	–	–	–	–	–
Trench		-T						–	–	–	–	–	–	–	–
Spoil side	-S	-S	-S	-S					–	–	–	–	–	–	–
YEAR 1															
Work side	+W	-W				–	–	–	–	–	–	–	–	–	–
Trench		-T			–	–	–	–	–	–	–	–	–	–	–
Spoil side	+S	-S	-S			–	–	–	–	–	–	–	–	–	–

[1] Eluviated Dark Grey Chernozem developed on glacio-fluvial material overlying till and constructed in moist to wet soil conditions. Adjusted soil strengths were used.
[2] Year 0: sampling event immediately following construction,
Year 1: sampling event immediately following construction.
+W, +T and +S indicate soil strength increases for the work side, trench and spoil side, respectively, as compared to the control.
-W, -T and -S indicate soil strength decreases for the work side, trench and spoil side, respectively, as compared to the control.
[3] – = no penetration.

SITE=RW2

PLOT OF CONTROL*DEPTH   SYMBOL USED IS C
PLOT OF TRENCH*DEPTH   SYMBOL USED IS T
PLOT OF WORK*DEPTH   SYMBOL USED IS W
PLOT OF SPOIL*DEPTH   SYMBOL USED IS S



NOTE: 43 OBS HAD MISSING VALUES OR WERE OUT OF RANGE   2 OBS HIDDEN

Figure 17.

off the RoW. There were no significant differences in clay content or soil moisture between soils on the RoW and soils off the RoW at 20 to 35 cm. However, the cone penetrometer could not penetrate the control past 21 cm, the work side or spoil side past 28 cm, or the trench past 24.5 cm indicating soil strengths greater than 38 bars at these depths.

It was difficult to compare the two sampling years because the cone penetrometer was not able to pentrate the soil as deeply in 1990 as it did in 1989 (Table 17). This effect was most likely due to lower soil moistures in 1990. Decreased RoW soil strengths occurred for both sampling years within the top 10.5 cm. It was impossible to compare soil strengths in the soil profile because the cone penetrometer could not penetrate the control soil past 10.5 cm in 1990.

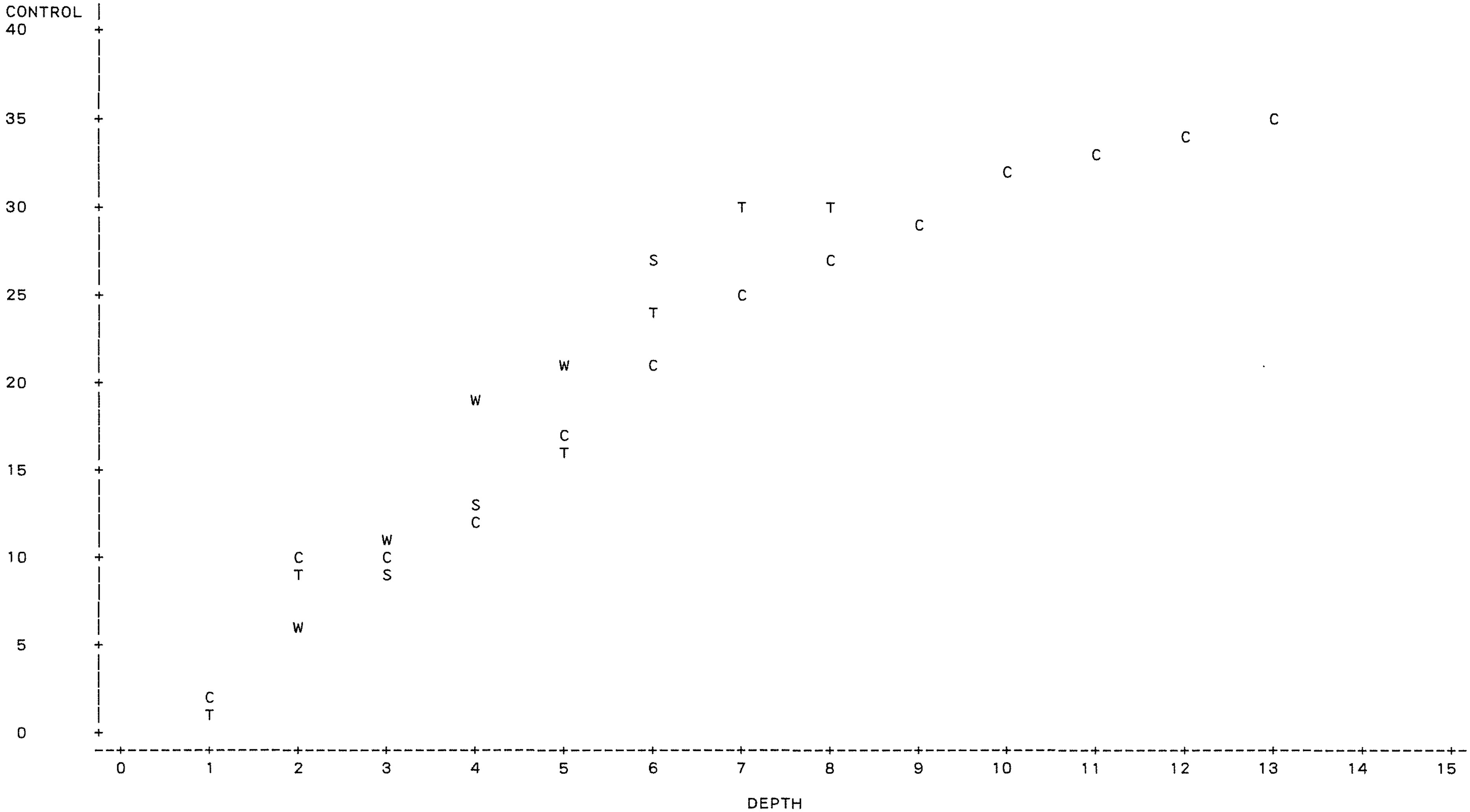
5.4.15 Valhalla

Work side, trench and spoil side soil strengths at depth increment 1 (0.9, 1.3 and 0.6 bars, respectively) were lower than the control soil strength of 1.8 bars for the 1990 sampling year (Figure 18). Work and spoil side soil strengths at depth increment 2 (5.9 and 5.6 bars) were lower than that of the control (9.8 bars). Work side soil strength at depth increment 3 (10.9 bars) was greater than the control soil strength of 9.8 bars. There were no significant differences in soil moistures or soil organic matter contents between soils on and off the RoW. It was difficult to speculate why the increases and decreases in RoW soil strength for the top 10.5 cm occurred since in the previous year there were no significant differences except for the trench. Decreased RoW soil strength was attributed to effects of tillage practices. The cone penetrometer could not penetrate past 45.5 cm for the control, 28 cm for the trench, past 21 cm for the spoil side or past 17.5 cm for the work side, indicating soil strengths greater than 38 bars at these depths.

In the previous year (1989) lower actual soil strengths occurred in the trench of the Valhalla study area from the 3.5 to 21 cm when compared to the control Cannon et al. 1990). Since there were no significant differences in organic matter, soil moisture, and clay content between soils of the control and trench, decreased soil strength of the trench was attributed to

SITE=VA

PLOT OF CONTROL*DEPTH SYMBOL USED IS C
PLOT OF TRENCH*DEPTH SYMBOL USED IS T
PLOT OF WORK*DEPTH SYMBOL USED IS W
PLOT OF SPOIL*DEPTH SYMBOL USED IS S



NOTE: 28 OBS HAD MISSING VALUES OR WERE OUT OF RANGE 6 OBS HIDDEN

Figure 18.

the breaking up of the dense and impermeable Bt horizon of the Luvisolic soils. Similar results occurred for Orthic Grey Luvisols and Gleyed Dark Grey Luvisols in northern Alberta (Cloutier 1988; Finlayson 1987). There were no differences in soil strengths between soils of the control and work side. These results again are similar to those of Cloutier (1988) and Finlayson (1987). Spoil side soil strengths were lower from those of the control at 14 to 17.5 cm. These results are similar to those of Finlayson (1987). At Valhalla there were no significant differences in organic matter, soil moisture or clay content between soils of the work or spoil side and the control soils at any of the depths monitored.

The two sampling years were difficult to compare because the cone penetrometer could not penetrate the soil as deeply in 1990 as it did in 1989 (Table 18). It was difficult to speculate why this occurred since soil moistures below 17 cm were similar for both sampling years. However decreased trench soil strenghts at 3.5 to 21 cm observed in 1989 were not observed in 1990, most likely due to settling of the trench material. Decreased RoW soil strengths for the top 7 cm were observed in 1990 but were not observed in 1989.

5.4.16 Michichi

Work side soil strength at depth increment 6 (29.6 bars) was greater than the control soil strength of 24.5 bars for the 1990 sampling year (Figure 19). Trench soil strength at depth increments 3 and 4 (18.0 and 22.3 bars) were greater than those of the control at the same depths (9.2 and 13.6 bars). It was difficult to speculate why increased work side soil strengths at 17.5 to 21 cm and trench soil strengths at 7 to 14 cm occurred since immediately following construction in 1988 there were no differences in soil strength between work side and control soils and between trench and control soils to a depth of 14 cm (Table 19). Increased soil strengths could be attributed to tillage traffic. The cone penetrometr could not penetrate the control, trench or work side past the 21 cm depth indicating soil strengths greater than 38 bars at this depth.

At the Michichi study area, one year following construction (1989 sampling year), soil strength was increased on the work side of the RoW for

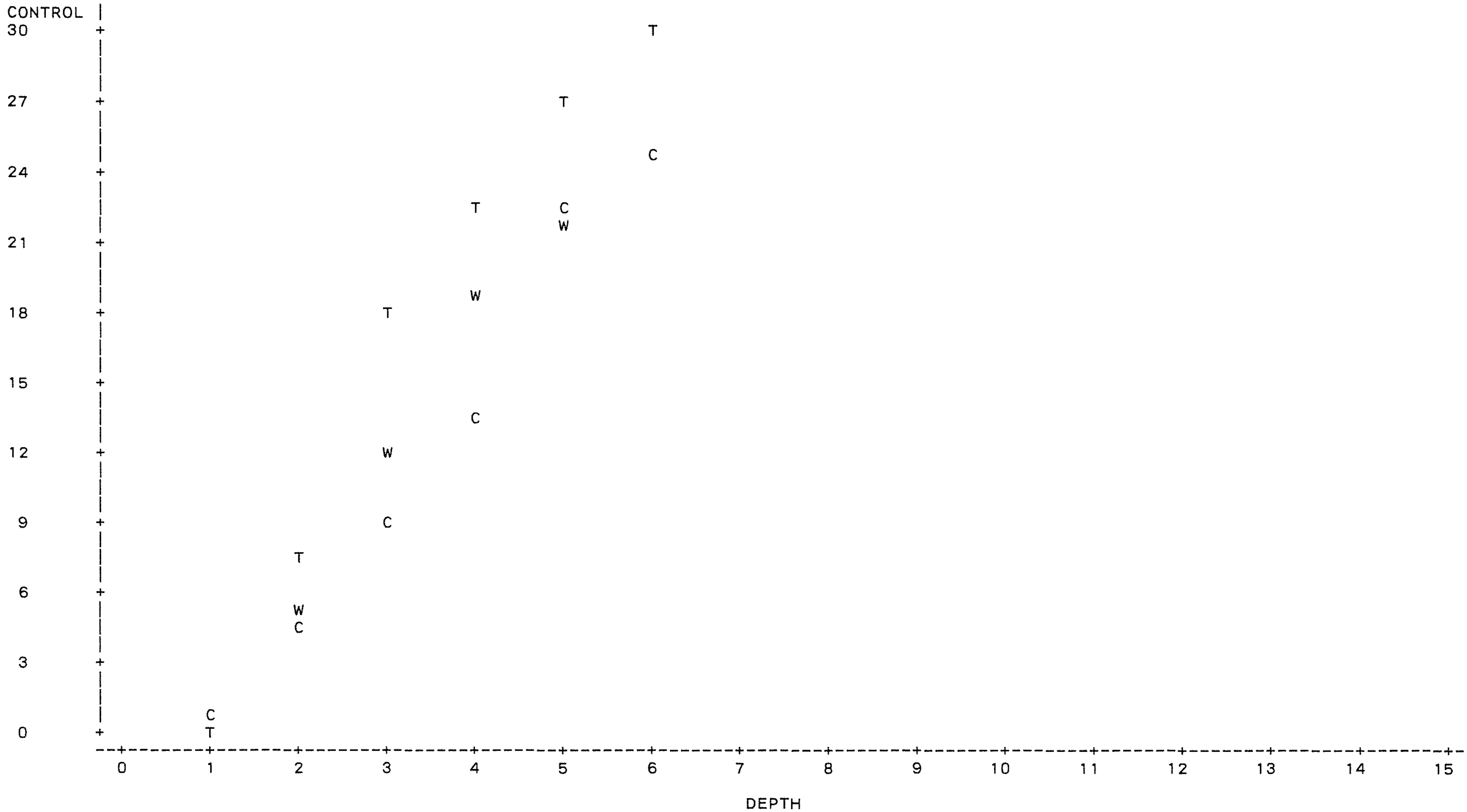
Table 18. Summary of statistical data for the Valhalla study area.[1]

SAMPLING EVENT[2]	DEPTH INCREMENT[3]														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
YEAR 0															
Work side													–	–	–
Trench		-T	-T	-T	-T	-T									
Spoil side					-S										–
YEAR 1															
Work side	-W	-W	+W			–	–	–	–	–	–	–	–	–	–
Trench	-T								–	–	–	–	–	–	–
Spoil side	-S	-S					–	–	–	–	–	–	–	–	–

[1] Gleyed Dark Grey Luvisol developed on glacial till and constructed in dry soil conditions.
[2] Year 0: sampling event immediately following construction,
Year 1: sampling event one year following construction.
+W, +T and +S indicate soil strength increases for the work side, trench and spoil side, respectively, as compared to the control.
-W, -T and -S indicate soil strength decreases for the work side, trench and spoil side, respectively, as compared to the control.
[3] – = no penetration.

SITE=MI

PLOT OF CONTROL*DEPTH   SYMBOL USED IS C
PLOT OF TRENCH*DEPTH   SYMBOL USED IS T
PLOT OF WORK*DEPTH   SYMBOL USED IS W
PLOT OF SPOIL*DEPTH   SYMBOL USED IS S



NOTE: 42 OBS HAD MISSING VALUES OR WERE OUT OF RANGE   2 OBS HIDDEN

Figure 19.

Table 19. Summary of statistical data for the Michichi study area.[1]

SAMPLING EVENT[2]	DEPTH INCREMENT[3]														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
YEAR 0															
Work side								–	–	–	–	–	–	–	–
Trench					–	–	–	–	–	–	–	–	–	–	–
YEAR 1															
Work side	+W							–	–	–	–	–	–	–	–
Trench		+T	+T							–	–	–	–	–	–
YEAR 2															
Work side						+W	–	–	–	–	–	–	–	–	–
Trench			+T	+T			–	–	–	–	–	–	–	–	–

[1] Dark Brown Solodized Solonetz developed on glacio-lacustrine and constructed in dry soil conditions.
[2] Year 0: sampling event immediately following construction,
Year 1: sampling event one year following construction,
Year 2: sampling event two years following construction.
+W and +T indicate soil strength increases for the work side and trench,
-W and -T indicate soil strength decreases for the work side and trench.
[3] – = no penetration.

the surface 3.5 cm as compared to the control (Cannon et al. 1990). Trench soil strength was also increased at 3.5 to 10.5 cm when compared to the control soil. The cone pentrometer could not penetrate past 31.5 cm of the control and trench soil or past 24.5 cm of the work side indicating soil strengths greater than 38 bars at these depths.

Immediately following construction in 1988 there were no differences in soil strengths between soils of the work side and control (Table 19). There were also no differences in soil strengths between soils of the trench and control to a depth of 14 cm (Cannon et al. 1989). The cone pentrometer had been unable to penetrate past the 14 cm depth of the trench or past the 24.5 cm depth of the work side. The 1989 and 1990 significant soil strength increases were thought to have occurred because of tillage traffic on the RoW.

5.1.17 Craigmyle

Increases in trench soil strengths were measured at 21 to 28 cm when compared to the control at the Craigmyle study area for the 1989 sampling year (Cannon et al. 1990). Similar results occurred in 1988 when trench soil strengths were greater at 17.5 to 21 cm and at 24.5 to 28 cm compared to the control (Table 20). These results contrast the findings of Naeth (1985) which indicated that bulk densities of trench soil were decreased compared to control soils for Solonetzic rangeland in southern Alberta. These results also contrast those of Riddell and Knapik (1988b) which indicated no significant differences in bulk densities between soils of the trench and the control for Solonetzic soils. Soil strength increases in the trench were thought to have occurred because of packing of the trench material during wet soil conditions. As well in 1988 trench soil strengths were lower at 7 to 10.5 cm compared to the control. This trend was not observed one year later in 1989, suggesting a return to predisturbed conditions at this depth. There were no differences between soil strength measurements of control soils and the work side for all depths monitored in the 1989 sampling year. In 1988, increases in work side soil strengths had been measured at 3.5 to 10.5 cm and at 24.5 to 28 cm when compared to the control soil (Cannon et al. 1989). Trends toward higher soil strengths in the top 28 cm of the work side were not

Table 20. Summary of statistical data for the Craigmyle study area.[1]

SAMPLING EVENT[2]	DEPTH INCREMENT[3]														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
YEAR 0															
Work side		+W	+W					+W							
Trench			-T			+T		+T							
YEAR 1															
Work side							+T	+T							
Trench															

[1] Dark Brown Solonetz developed on weathered bedrock and constructed in wet soil conditions.
[2] Year 0: sampling event immediately following construction,
Year 1: sampling event one year following construction,
+W and +T indicate soil strength increases for the work side and trench,
-W and -T indicate soil strength decreases for the work side and trench.
[3] - = no penetration.

Table 21. Summary of statistical data for the Delia study area.[1]

SAMPLING EVENT[2]	DEPTH INCREMENT[3]														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
YEAR 0															
Work side				+W	+W	+W	+W								
Trench						+T	+T	+T	+T			-	-	-	-
YEAR 1															
Work side												-	-	-	-
Trench								-	-	-	-	-	-	-	-

[1] Dark Brown Gleyed Solonetzic Chernozem developed on glacio-fluvial material overlying till and constructed in wet soil conditions.
[2] Year 0: sampling event immediately following construction,
Year 1: sampling event one year following construction,
+W and +T indicate soil strength increases for the work side and trench,
-W and -T indicate soil strength decreases for the work side and trench.
[3] - = no penetration.

observed one year following construction, suggesting a return to predisturbed conditions.

5.1.18 Delia

There were no differences in soil strengths between soils on the RoW and those off the RoW for the Delia study area in 1989, one year following pipeline construction (Cannon et al. 1990). However the cone penetrometer could not penetrate past 24.5 cm in the trench, or 38.5 cm in the work side or control soils indicating a soil strength greater than 38 bars at these depths. Soil moistures at time of sampling in 1989 were lower than those in 1988, suggesting increased soil strength due to decreased soil moistures. In the previous sampling year (1988), pipeline construction in very wet conditions had resulted in increases in soil strength on the work side of the RoW from 10.5 to 24.5 cm as compared to the control (Cannon et al. 1989). The trench soil strengths were also increased at 17.5 to 31.5 cm as compared to the control. It was difficult to compare the trench soil strengths between the two years (Table 21). However, trends towards increased soil strengths in both the trench and work side were not observed one year following pipeline construction, suggesting that compaction had been alleviated.

5.1.19 Foreman

Immediately following construction in 1988, increased work side soil strength measurements occurred in the upper 28 cm of the soil profile as compared to the adjacent undisturbed soil (Cannon et al. 1989). One year later, in the 1989 sampling year, there were no differences in soil strength measurements between soils of the control and work side (Cannon et al. 1990) However the cone penetrometer was unable to penetrate the work side at the Foreman study area past 14 cm indicating a soil strength greater than 38 bars at this depth (Table 22). Soil moistures were lower in 1989 than in 1988. Soil strengths are dependent on soil moisture (Taylor and Gardner 1963; Frietag 1971; Ayers and Perumpral 1982), suggesting that the use of the pipeline plow-in technique for the Foreman pipeline had resulted in increases in soil strength of the trench at 17.5 to 28 cm when compared to the control immediately following pipeline construction in 1988 (Cannon et al. 1989). One

Table 22. Summary of statistical data for the Foreman study area.[1]

SAMPLING EVENT[2]	DEPTH INCREMENT[3]														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
YEAR 0															
Work side		-W				+W	+W	+W						+W	
Trench		-T	-T			+T	+T	+T	-	-	-	-	-	-	-
YEAR 1															
Work side					-	-	-	-	-	-	-	-	-	-	-
Trench					-	-	-	-	-	-	-	-	-	-	-

[1] Orthic Dark Brown Chernozem developed on glacio-fluvial material overlying till and constructed in dry soil conditions.
[2] Year 0: sampling event immediately following construction,
Year 1: sampling event one year following construction,
+W and +T indicate soil strength increases for the work side and trench,
-W and -T indicate soil strength decreases for the work side and trench.
[3] - = no penetration.

Table 23. Summary of statistical data for the Ghostpine study area.[1]

SAMPLING EVENT[2]	DEPTH INCREMENT[3]														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
YEAR 0															
Work side			+W	+W	+W	+W	+W	+W							
Trench					+T			+T	+T						
YEAR 1															
Work side															
Trench													-T	-T	-T

[1] Orthic Dark Brown Chernozem developed on glacial till and constructed in wet soil conditions.
[2] Year 0: sampling event immediately following construction,
Year 1: sampling event one year following construction,
+W and +T indicate soil strength increases for the work side and trench,
-W and -T indicate soil strength decreases for the work side and trench.
[3] - = no penetration.

year later, the cone penetrometer was not able to penetrate the trench soil past 14 cm, indicating a soil strength greater than 38 bars at this depth. Therefore no comparisons can be made for the trench between the two years. Soil moistures at time of sampling in 1989 were less than those following construction in 1988, suggesting increased soil strength measurements may have occurred due to decreased soil moistures.

5.1.20 Ghostpine

Immediately following construction in 1988, increased work side soil strength measurements occurred in the upper 28 cm of the soil profile as compared to the adjacent undisturbed soil (Cannon et al. 1989). One year later there were no differences between soil strength measurements of the control and work side soil (Cannon et al. 1990). Soil moisture contents for Ghostpine were similar for both sampling years. Trends towards higher soil strength measurements in the top 28 cm on the work side of were not observed one year following pipeline construction suggesting that compaction had been alleviated (Table 23).

At the Ghostpine study area one year following construction (1989 sampling year), trench soil strength was lower at 42 to 52.5 cm when compared to the control (Table 23). Soil strength decreases in the trench were attributed to shifting of the trench material during settling. Results from the previous year (1988) indicated that trench soil strength had been increased at 14 to 17.5 cm and generally was increased, although not always significantly, from 10.5 to 21 cm when compared to the control (Cannon et al. 1989). Soil moisture contents for Ghostpine were similar for both sampling years.

5.1.21 Milo

One year after construction there were no differences in soil strengths between soils on the RoW and those off the RoW for the Milo study area at all depths monitored (Table 24). After pipeline construction in 1988, lower soil strengths had been measured in the trench for the top 14 cm of the profile compared to the control (Cannon et al. 1989). In 1989 the cone penetrometer could not penetrate the control or trench past 17.5 or the work

1955

Table 24. Summary of statistical data for the Milo study area.[1]

SAMPLING EVENT[2]	DEPTH INCREMENT[3]														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
YEAR 0															
Work side						–	–	–	–	–	–	–	–	–	–
Trench	-T		-T	-T			–	–	–	–	–	–	–	–	–
YEAR 1															
Work side					–	–	–	–	–	–	–	–	–	–	–
Trench						–	–	–	–	–	–	–	–	–	–

[1] Solonetzic Brown Chernozem developed on glacio-fluvial material and constructed in dry soil conditions.
[2] Year 0: sampling event immediately following construction,
Year 1: sampling event one year following construction,
+W and +T indicate soil strength increases for the work side and trench,
-W and -T indicate soil strength decreases for the work side and trench.
[3] – = no penetration.

Table 25. Summary of statistical data for the Victor 1 study area.[1]

SAMPLING EVENT[2]	DEPTH INCREMENT[3]														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
YEAR 0															
Work side															
Trench															
YEAR 1															
Work side															
Trench															

[1] Orthic Humic Gleysol developed on lacustrine and constructed in dry soil conditions.
[2] Year 0: sampling event immediately following construction,
Year 1: sampling event one year following construction,
+W and +T indicate soil strength increases for the work side and trench,
-W and -T indicate soil strength decreases for the work side and trench.
[3] – = no penetration.

side past 14 cm indicating that the rangeland soil at Milo has a soil strength greater than 38 bars at these depths. Similar results occurred for the Milo study area in 1988. Soil moisture values were similar for both years. Trends towards lowered soil strengths in the top 14 cm of the trench were not observed one year following pipeline construction, suggesting a return to predisturbed conditions. These results were attributed to settling of trench material after pipeline construction procedures.

5.1.22 Victor 1

There were no differences in soil strengths between soils on the RoW and those off the RoW for the Orthic Humic Gleysol at Victor 1, one year following pipeline construction (Table 25). Similar results were observed in the previous year immediately following construction (Cannon et al. 1989).

5.1.23 Victor 2

Immediately following construction in 1988, increased work side soil strength measurements occurred in the upper 28 cm of the soil profile as compared to the adjacent undisturbed soil (Cannon et al. 1989) (Table 26). One year later there were no significant differences between soil strength measurements of the control and work side soils except for a significantly increased adjusted work soil strength for the Victor 2 site at 0 to 3.5 cm compared to the control (Cannon et al. 1990). The cone penetrometer was unable to penetrate the work side at Victor 2 past 35 cm indicating a soil strength greater than 38 bars at this depth. Soil moistures were lower in 1989 than in 1988. Soil strengths are dependent on soil moisture (Taylor and Gardner 1963; Frietag 1971; Ayers and Perumpral 1982), suggesting that increased soil strengths may have occurred due to decreased soil moistures. Trends towards higher soil strength measurements in the top 28 cm on the work side were not observed one year following pipeline construction suggesting that compaction had been alleviated.

Immediately following construction in 1988, increases in soil strength measurements at the Victor 2 study area were measured for the 3.5 to 7 cm and 10.5 to 14 cm depths of the trench as compared to the control (Cannon et al. 1989). One year after construction, there were no differences between

Table 26. Summary of statistical data for the Victor 2 study area.[1]

SAMPLING EVENT[2]	DEPTH INCREMENT[3]														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
YEAR 0															
Work side		+W	+W	+W	+W	+W		+W							
Trench		+T		+T											
YEAR 1															
Work side	+W										-	-	-	-	-
Trench													-	-	-

[1] Orthic Dark Brown Chernozem developed on lacustrine and constructed in dry soil conditions. Adjusted soil strengths were used.
[2] Year 0: sampling event immediately following construction,
Year 1: sampling event one year following construction,
+W and +T indicate soil strength increases for the work side and trench,
-W and -T indicate soil strength decreases for the work side and trench.
[3] - = no penetration.

soil strength measurements for the control, work side, and trench at any of the depths monitored (Table 26). The cone penetrometer could not penetrate the trench past 42 cm indicating a soil strength greater than 38 bars at this depth. Again soil moistures at time of sampling in 1989 were lower than those that occurred in 1988 at time of sampling, suggesting increased soil strengths may have occurred due to decreased soil moistures.

5.5 SOIL STRENGTH ADJUSTMENTS BASED ON MOISTURE

5.5.1 1990 Sampling Event

Soil strength adjustments were not done in the 1990 sampling year for any of the study areas, except Atlee-Buffalo 1, since there were no significant differences in soil moisture contents between soils on and off the RoW at any of the depths momitored. Adjusted soil strengths were determined for the work side soil at 0 to 10 cm for the Atlee-Buffalo 1 study area. Soil strength adjustments for moisture at the Atlee-Buffalo 1 study area did not result in any change in the statistical significance of soil strength difference. Actual and adjusted soil strength values were the same since soil moistures of the trench soil at time of sampling were below soil moisture values measured at 15 bars.

5.5.2 1989 Sampling Event

In 1989, for the 1989 study areas, soil strength adjustments were not done for Atlee-Buffalo 2, Henderson 2, Maleb 1 and Valhalla study areas since there were no significant differences in soil moisture contents between soil on and off the RoW at any of the depths monitored. Soil strength adjustments for moisture on Atlee-Buffalo 1, Ferintosh and Foisey did not result in any change in the statistical significance of soil strength difference. Soil strength adjustments for moisture did result in changes of statistical signifcance of soil strength difference for Aeco 'C', Bolloque, Maleb 2, Henderson 1, Pigeon Lake, Albright, Redwater 1, and Redwater 2. Soil strength adjustments are presented in Appendix 9.3.

Actual soil strengths were used in the discussion of the results for 1988 study areas in 1989, since soil strengths adjusted for percent moisture did not alter significance of comparisons to the control. The only exception was a significantly increased adjusted work side soil strength for the Orthic Brown Chernozem at Victor 2 for the 0 to 3.5 cm depth.

5.5.3 1988 Sampling Event

Soil strength adjustments were not done for the samples taken in the 1988 sampling year. The decision to make soil strength adjustments based on moisture was made after the 1989 sampling event, and the 1988 samples were no longer available.

5.6 LIMITATIONS OF THE CONE PENETROMETER

The cone penetrometer was used to determine soil stength, instead of bulk density measurements, as an indirect measure of soil compaction. Soil strength was measured by determining the resistance of soil to the penetrating cone-shaped tip of the cone penetrometer. The penetrometer is advanced into the soil at a steady rate and the applied force versus depth is measured. The applied force is indicative of the shear resistance of the soil. The advantages of the cone penetrometer include the relative simplicity, rapidity and cost-effectiveness of data collection (James 1981). The cone penetrometer, used to determine on and off RoW soil strength, is easy to carry out into and set up in the field. The cone penetrometer quickly collects a lot of data and is easily portable. Results can be quickly and easily determined. The main difficulty in conducting this test is to apply consistent pressure to the cone penetrometer.

Penetration resistance reflects the state of compaction and is influenced by moisture content and density as well as the size, shape and surface texture of the penetrating element (Freitag 1971). This method, like many indirect methods in determining the extent of compactive forces, requires a separate analysis before and after the compaction action. However some limitations to the use of the cone penetrometer were noticed during the course of this study and are listed below.

1. Multiple replications are required in order to determine a single soil strength reading, resulting in large amounts of data to be handled.

2. Soil strength measurements are influenced by moisture content and density (Frietag 1971) and by organic matter (Ohu et al. 1986), therefore soil samples have to be collected to determine soil moisture contents, soil organic matter contents and soil testure. However, the relationships between soil moisture, soil organic matter and soil texture are not clearly defined, making interpretations of soil strength data difficult in some situations.
3. The cone penetrometer used for this study can not penetrate into soils with soil strengths greater than 38 bars (50 kg), the upper limit of the equipment used. This limits the cone penetrometer use in dry areas or in dry years, making comparisons difficult between wet and dry years and between cropped versus uncropped soil.
4. The cone penetrometer shaft used in this study can only be pushed into the soil to a depth of 52.5 cm limiting the depth of soil strength measurements.
5. The cone penetrometer can not be used on stoney or gravelly soils or in soils with gravelly or compact lenses or horizons.

6. CONCLUSIONS

6.1 RESULTS IMMEDIATELY FOLLOWING CONSTRUCTION

Soil strength information from the 23 study areas indicated that pipeline construction procedures can cause some changes in soil strength on pipeline RsoW in Alberta. Significant soil strength differences from the control were observed in both topsoil and subsoil on all portions of the pipeline RsoW monitored, varying with depth and location from site to site. Few similarities in soil strength trends occurred between study areas, however, limiting the scope of conclusions. A number of specific conclusions which can be made of the statistical data for soil strength immediately following pipeline construction are listed below.

1. Few similarities in soil strength trends occurred within soil order groupings.
2. Soil strength measurements for the top 24.5 to 31.5 cm.

   a) Decreases in soil strength occurred across the RoW soils in the top 14 cm and sometimes as deep as 24.5 cm for the following soils (study area and soil moisture conditions in which construction occurred is in parentheses):

   . Gleyed Brown Chernozem developed on glacial till (Maleb 1, dry),

   . Gleyed Black Chernozem developed on glacio-fluvial (Redwater 1, moist to wet),

   . Orthic Dark Grey Chernozem developed on galcial till (Foisey, dry),

   . Eluviated Dark Grey Chernozem developed on glacio-fluvial overlying till (Redwater 2, moist to wet),

   . Eluviated Dark Grey Chernozem developed on glacial till (Pigeon Lake, moist),

   . Dark Grey Luvisol developed on glacial till (Bolloque, moist to wet),

   . Dark Grey Luvisol developed on glacial till (Henderson 2, dry),

   . Solonetzic Dark Grey Luvisol developed on glacial till (Henderson 1, dry),

. Brown Solodized Solonetz developed on glacial till (Aeco 'C', dry).

Decreased soil strength also occurred in the to 24.5 cm for the following soils (study area and soil moisture conditions in which construction occurred are in parethesis):

. Orthic Brown Chernozem developed on glacial till, in the trench and spoil side (Maleb 2, dry),

. Orthic Brown Chernozem developed on glacio-fluvial, in the work side and trench (Atlee-Buffalo 2, dry),

. Orthic Dark Brown Chernozem developed on glacio-fluvial overlying till, in the trench and work side (Foreman, dry),

Generally decreases in soil strength were observed for those study areas in which pipeline construction occurred in dry soil conditions. Exceptions included the Gleyed Black CHernozem at Redwater 1, the Eluviated Dark Grey Chernozem at Redwater 2, the Eluviated Dark Grey Chernozem at Pigeon Lake and the Dark Grey Luvisol at Bolloque. All these soils were developed on glacio-fluvial material or glacial till and were loam, sandy loam or sandy clay loam in texture.

b) Soil strength decreases occurred only within the trench top 24.5 cm for the Orthic Black Chernozem developed on fluvial material (Ferintosh) and constructed in dry to moist soil conditions, for the Gleyed Dark Grey Luvisol developed on glacial till (Valhalla) constructed in dry soil conditions or for the Solonetzic Brown Chernozem developed on glacio-fluvial (Milo) and constructed in dry soil conditions.

c) Isolated decreased soil strengths occurred within the trench of the Dark Brown Solonetz developed on weathered bedrock (Craigmyle) and constructed in wet soil conditions and in the spoil side of the Gleyed Dark Grey Luvisol developed on glacial till and constructed in dry soil conditions.

d) Soil strength increases for the top 24.5 to 31.5 cm were observed for the following soils (study area and soil moistures conditions in which construction occurred are in parentheses):

. Orthic Brown Chernozem developed on glacial till, in the spoil side and work side (Maleb 2, dry),
. Orthic Dark Brown Chernozem developed on glacio-fluvial overlying till, in the work side and trench (Foreman, dry),
. Orthic Dark Brown Chernozem developed on lacustrine, in the work side and trench (Victor 2, dry),
. Orthic Dark Brown Chernozem developed on glacial till, in the work side and trench (Ghostpine, wet),
. Dark Brown Gleyed Solonetzic Chernozem developed on glacio-fluvial overlying till, in the work side and trench (Delia, wet),
. Dark Brown Solonetz developed on weathered bedrock, in the work side and trench (Craigmyle, wet),
. Orthic Humic Gleysol developed on glacio-fluvial, in the work side and spoil side (Albright, dry to moist).

Generally increased soil strengths were observed in study areas where pipeline construction occurred in moist to wet soil conditions. Exceptions included the Orthic Brown Chernozem at Maleb 1 which also had decreased soil strengths measured in upper depth increments, the Orthic Dark Brown Chernozem at Foreman in which the piepline was constructed usding the plow-in technique and the Orthic Dark Brown Chernozem at Victor 2 for which it was difficult to speculate why incresed soil strengths occurred.

e) Isolated increased soil strengths occurred in the work side of the Eluviated Dark Grey Chernozem developed on glacial till (Pigeon Lake) and constructed in dry soil conditions and in the spoil side of the Orthic Brown Chernozem developed on glacio-fluvial material (Atlee-Buffalo 2) and constructed in dry soil conditions. These increased soil strenghts were attributed to increased treaffic on the RoW.

f) There were no significant soil strength differences following pipeline construction in the top 24.5 to 31.5 cm for the Dark Brown Solodized Solonetz developed on glacio-lacustrine (Michichi), for the Orthic Humic Gleysol developed on lacustrine (Atlee-Buffalo 1) or for the Orthic Humic Gleysol developed on glacial till (Victor 1). All three study areas were constructed in dry soil conditions.

3. Soil strength measurements below 24.5 to 31.5 cm.

   a) Significant differences in RoW subsoil soil strength values below 24.5 to 31.5 cm were found only in four sites.

   b) Decreases in soil strength of the trench in the Brown Solodized Solonetz (Aeco 'C') occurred at 17.5 to 52.5 cm compared to the control soil when constructed in dry soil conditions. These soil strength decreases were attributed to breaking up of the hard dense Bnt horizon.

   c) Decreases in soil strength below 24.5 cm also occurred in the spoil side of the Orthic Dark Grey Chernozem (Foisey) developed on glacial till. It was difficult to speculate why these soil strength decreases occurred.

   d) Isolated soil strength increases occurred at depth increments below 24.5 cm in the trench for the Orthic Black Chernozem developed on fluvial material overlying till (Ferintosh), in the spoil side for the Orthic Humic Gleysol developed on glacio-fluvial material (Albright), and in the work side for the Brown Solodized Solonetz developed on glacial till (Aeco 'C').

4. Soil moistures were significantly decreased on RoW soils compared to control soils for ten study areas. Decreased soil moistures indicated drying of the soil due to pipeline construction. This drying of the soil could affect the emergence of a seeded crop especially in agroclimatic areas where low precipitation is already a limiting factor to crop growth. Soil moistures were significantly increased on RoW soils compared to control soils for eight study areas. Increased soil moistures for five of these sites occurred when the sites were sampled during the summer and had an established crop growing on the control or were in pasture.

5. Soil organic matter levels for soils on the RoW were generally not significantly different from the control soils. Exceptions were two sites that had significantly higher organic matter

contents on portions of the RoW (one site on the work side and one site on the trench) and five sites that had significantly lower soil organic matter contents on portions of the RoW (two sites across the entire ROW, two sites on the trench and one site on the work side). Decreased soil organic matter contents suggested that subsoil had been mixed with topsoil or that there was a loss of topsoil. Increased topsoil organic matter contents were not indicative of topsoil and subsoil mixing since topsoil genrally contains more organic matter than subsoil. Increased topsoil organic matter contents may indicate uneven respreasding of topsoil across the RoW.

6. There were few significant differences in clay content between surface soils on the RoW and those off the RoW. Most significant differences occurred below the surface horizons. Generally clay contents were significantly greater than the controls for topsoils and significantly lower than the controls for subsoils. Data from this study suggested no mixing of subsoil and topsoil during pipeline construction for all but four sites.
7. There were no close correlations between soil strength and soil moisture, organic moisture and clay content for the combined 1989 study area data immediately following pipeline construction.

6.2 RESULTS ONE YEAR AFTER CONSTRUCTION

A number of specific conclusions in soil strength trends which can be made one year following pipeline construction are listed below.

1. Few similarities in soil strength trends occurred within soil order groupings.
2. Soil strength measurements for the top 24.5 to 31.5 cm.

   a) Decreases in soil strength for the top 24.5 to 31.5 cm occurred for the following soils (study area and soil moisture conditions in which construction occurred are in parentheses):

   . Orthic Black Chernozem developed on fluvial overlying till, in the trench and work side (Ferintosh, dry to moist),

. Eluviated Dark Grey Chernozem developed on glacio-fluvial overlying till, across the RoW (Redwater 2, moist to wet),

. Gleyed Dark Grey Luvisol developed on glacial till, across the RoW (Valhalla, dry).

Isolated decreased soil strengths occurred in the work side of the Orthic Dark Grey Chernozem developed on glacial till (Foisey) and constructed in dry soil conditions and in the trench of the Gleyed Brown Chernozem developed on glacial till (Maleb 1) and constructed in dry soil conditions.

b) Increases in soil strength for the top 24.5 to 31.5 cm occurred for the following soils (study area and soil moisture conditions in which construction occurred are in parentheses):

. Dark Brown Solonetz developed on weathered bedrock, in the trench (Craigmyle, wet),

. Dark Brown Solodized Solonetz developed on glacio-lacustrine, in the trench and work side (Michichi, dry),

. Gleyed Black Chernozem developed on glacio-fluvial, in the trench and work side (Redwater 1, moist to wet).

Isolated increased soil strengths occurred for the following soils (study area and soil moisture conditions in which construction occurred are in parentheses):

. Eluviated Dark Grey Chernozem developed on glacial till, in the trench and spoil side (Pigeon Lake, moist),

. Solonetzic Dark Grey Luvisol developed on glacial till, in the work side (Henderson 1, dry),

. Orthic Humic Gleysol developed on glacio-fluvial, in the work side (Albright, dry to moist),

. Orthic Black Chernozem developed on fluvial overlying till, in the trench (Ferintosh, dry to moist),

. Gleyed Brown Chernozem developed on glacial till, in the spoil side (Maleb 1, dry),

. Gleyed Dark Grey Luvisol developed on glacial till, in the work side (Valhalla, dry),

. Eluviated Dark Grey Chernozem developed on glacio-fluvial overlying till, in the work side and spoil (Redwater 2, moist to wet).

The isolated soil strength increases were attributed to tillage traffic.

3. Soil strengths below 24.5 to 31.5 cm.
Only decreased soil strengths below 24.5 to 31.5 cm were measured. Decreased trench soil strengths were observed for the Orthic Dark Brown Chernozem developed on glacial till (Ghostpine) for the 42 to 52.5 cm depths. Decreased RoW soil strengths were also observed for the Gleyed Brown Chernozem developed on glacial till (Maleb 1) below 35 cm. It was difficult to speculate why these decreased soil strengths were observed for the two sites.
4. Soil moistures were significantly decreased on RoW soils compared to control soils for five study areas and were signigicantly increased on RoW soils compared to control soil for only one study area.
7. Soil organic matter levels for three study areas were significantly decreased on the work side portion of the RoW and soil organic matter levels were significantly decreased across the entire RoW for only one study area.
8. There were no close correlations between soil strength and soil moisture or soil organic matter for either the combined 1989 study area data or for the combined 1988 study area data one year following pipeline construction.

6.3 COMPARISONS OF THE TWO SAMPLING YEARS

1. The cone penetrometer was unable to penetrate the soil one year following construction as deeply as it did immediately following construction for 10 sites most likely due to low soil moisture contents. In three sites the cone penetrometer was able to penetrate deeper the year following construction most likely due to higher soil moistures.

2. Those study areas that had similar results for the two years include:
   . Atlee-Buffalo 1 (Orthic Humic Gleysol),
   . Ferintosh (Orthic BLack Chernozem),
   . Maleb 1 (Gleyed Brown Chernozem),
   . Redwater 2 (Eluviated Dark Grey Chernozem) and
   . Victor 1 (Orthic Humic Gleysol).

   Those study areas that had fewer significant differences in RoW soil strength for the second sampling event include:
   . Atlee-Buffalo 2 (Orthic Brown Chernozem),
   . Aeco 'C' (Brown Solodized Solonetz),
   . Albright (Orthic Humic Gleysol),
   . Bolloque (Dark Grey Luvisol),
   . Foisey (Orthic Dark Grey Chernozem),
   . Henderson 1 (Solonetzic Dark Gray Luvisol),
   . Henderson 2 (Dark Grey Luvisol),
   . Maleb 2 (Orthic Brown Chernozem),
   . Pigeon Lake (Eluviated Dark Grey Chernozem),
   . Valhalla (Gleyed Dark Grey Luvisol),
   . Craigmyle (Dark Brown Solonetz),
   . Delia (Dark Brown Gleyed Solonetzic Chernozem),
   . Foreman (Orthic Dark Brown Chernozem),
   . Ghostpine (Orthic Dark Brown Chernozem),
   . Milo (Solonetzic Brown Chernozem) and
   . Victor 2 (Orthic Dark Brown Chernozem).

   Those soils that had increased significant differences in RoW soil strength one year following construction compared to immediately following construction include:
   . Redwater 1 (Gleyed Brown Chernozem) and
   . Michichi (Dark Brown Solodized Solonetz).
3. Soil strengths could not be compared between the two sampling years for four of the study areas because the cone penetrometer could not penetrate to the same depths each year.

a) Decreased RoW soil strengths below 31.5 cm observed one year following construction could not be observed immediately following construction for the Gleyed Brown Chernozem developed on glacial till (Maleb 1).

b) Decreased spoil side soil strengths below 24.5 cm observed immediately following construction could not be observed one year following construction for the Orthic Dark Grey Chernozem developed on glacial till (Foisey).

c) Decreased trench soil strenths at 14 to 52.5 cm observed immediately following construction could not be observed observed one year later for the Brown Solodized Solonetz developed on glacial till (Aeco 'C').

d) Increased trench and work side soil strengths below 17.5 cm observed immediately following construction could not be observed one year later for the the Orthic Dark Brown Chernozem developed on glacio-fluvial material overlying till (Foreman).

4. Generally soil strength increases and decreases one year following construction were not observed for as many depth increments or portions of the pipeline RsoW as for the sampling event immediately following construction. Also many of the isolated increases and decreases in soil strengths were attributed to tillage traffic.
5. Immediately following pipeline construction 16 study areas had RoW soil moistures significantly different from those of the control, while one year later only six sites had RoW soil moistures significantly different from the controls.
6. Immediately following pipeline construction seven study areas had RoW soil organic matter contents significantly different from those of the control, while one year later only four sites had RoW soil organic matter contents significantly different from the controls.
7. There were no close correlations between soil strength and soil moisture, soil organic matter, or clay content for the combined site data in either sampling year.

6.4 SUMMARY

After three years of monitoring soils for soil strength, there is inconclusive data to determine the effects of soil moisture, soil texture, soil organic matter, soil classification, parent material and various pipeline construction methods on soil strength and compaction. A number of specific conclusions in soil strength trends which can be made after three years of monitoring soils for soil strength are listed below.

1. Construction methods were similar at all the study areas except for the Foreman site where the plow-in technique was used. Increases in soil strength occurred immediately following construction for the work side and trench when the plow-in technique was used on an Orthic Brown Chernozem at the Foreman site, while both decreases and increases in RoW soil strength were observed for the other study areas.
2. There were no trends within soil classification in determining the effect of pipeline construction on soil strength.
3. There were no trends in whether soil conditions were wet or dry in determining the effect of pipeline construction on soil strength. Soils with pipeline construction occurring in wet conditions showed both increases and decreases in soil strength. Generally soils with pipeline construction occurring in dry soil conditions showed decreases in soil strength, although soil strength increases were also observed.
4. One year after pipeline construction, soil strength increases and decreases were not observed for as many depth increments or portions of the pipeline RsoW as in the sampling event immediately following construction. Data suggests a return of RoW soil strengths to levels similar to those of the control. Exceptions include the Gleyed Brown Chernozem at Redwater 1 and the Dark Brown Solodized Solonetz at Michichi. Many of the isolated soil strength increases and decreases that occurred for the study areas in the second sampling event were attributed to tillage traffic.

5. Data suggests a return of RoW soil moisture levels to those similar to the control soils.
6. Data suggests a return of RoW organic matter levels to those similar to the control soils most likely due to revegetation of the RoW.
7. Few significant differences occurred in clay content between surface soils on the RoW and those off the RoW. Data from this study suggested no mixing of subsoil and topsoil during pipeline construction for all but four sites.
8. There were no close correlations between soil strength and soil moisture, soil organic matter or clay content for combined site data for any of the years monitored. The relationships between soil moisture, soil organic matter and soil texture are not clearly defined, making interpretations of soil strength data difficult in some situations.

7. SUGGESTIONS FOR FURTHER STUDY

Further studies are needed to determine the effects of soil moisture, soil texture, soil organic matter, soil classification and parent material on soil strength and compaction are not clearly defined. Studies aimed at clarifying these relationships in both the field and in the laboratory would be beneficial, particularily to better define the relationship between soil strength and compaction. Further studies regarding pipeline activities and soil strength include:

1. It would be beneficial to monitor soil strengths on more soil types and soil orders constructed in various moisture conditions in order to provide more information on which soils are most compactible and under what conditions.
2. Monitoring could also be made 3 to 5 years following construction on those soils that still had soil strength increases or decreases compared to the control soils after two years of monitoring in order to determine the effect of time on soil strength. Soil strengths may be affected by freeze-thaw cycles, wetting-drying cycles, root growth of crops within the soil profile and by settling of soil in the soil profile especially in the trench portion of the RoW.
3. The effects of various pipeline construction methods such as the use of the plow-in technique, the use of either two or three-lift procedures on trench material, whether topsoil is stripped or not or on what portion of the RoW it is removed on RoW soil strengths needs to be assessed.
4. Detailed monitoring of some compacted sites on different soil over time would be benficial to asses how compaction is alleviated, naturally and artificially. The sites would be sites compacted during normal construction or artificially compacted and monitoring of a wide range of parameters such as bulk density, porosity and strength would be done.

8. REFERENCES CITED

Alberta Soil Advisory Committee. n.d. Agricultural soil quality. Alberta Agriculture. Edmonton, Alberta. 20 pp.

Alberta Soil Advisory Committee. 1987. Land capability classification for arable agriculture in Alberta (1987). Edited by W.W. Pettapiece. Alberta Agriculture. 103 pp, 5 maps.

Ayers, P.D. and J.V. Perumpral. 1982. Moisture and density effect on cone index. Trans. ASAE 25: 1169-1172.

Bessie, K. 1988. Soil survey and reclamation quality ratings for the Aeco 'C' Lateral Loop. Prepared for NOVA Corporation of Alberta. 12pp. plus append.

Bowser, W.E. 1967. Agro-climatic areas of Alberta. Alberta Institute of Pedology, University of Alberta. Edmonton, Alberta.

Canada Soil Survey Committee (CSSC). 1978. The Canadian system of soil classification. Can. Dept. Agric. Pub 1646. Supply and Services Canada. Ottawa, Ontario. 164 pp.

Can-Ag Enterprises Ltd. 1988. Soil and vegetation survey of the Henderson Creek Lateral Loop. Prepared for NOVA Corporation of Alberta. 16pp. plus append.

Can-Ag Enterprises Ltd. 1989a. Soil survey of the Valhalla East Lateral. Prepared for NOVA Corporation of Alberta. 13 pp. plus append.

Can-Ag Enterprises Ltd. 1989b. Soil survey of the Bolloque East Lateral. Prepared for NOVA Corporation of Alberta. 14 pp. plus append.

Cannon, K.R., N.M. Finlayson and S. Landsburg. 1989. Effect of pipeline construction on compaction of soil horizons in Alberta: 1988 Annual Report. Prepared for NOVA Corporation of Alberta. 42pp. plus append.

Cannon, K.R., N.M. Finlayson and S. Landsburg. 1990. Effect of pipeline construction on compaction of soil horizons in Alberta: 1989 Annual Report. Prepared for NOVA Corporation of Alberta. 95pp. plus append.

Cloutier, C.L. 1988. Soil handling during pipeline construction on Luvisolic soils in northern Alberta. In: Proceedings of the 25th annual Alberta Soil Science Workshop. Lethbridge, Alberta. pp 156-166.

Culley, J.L.B., K. Dow, E.W. Presant and A.J. Maclean. 1982. Recovery of productivity of Ontario soils disturbed by an oil pipeline installation. Can. J. Soil Sci. 62: 267-279.

de Jong, E. and R.G. Button. 1973. Effects of pipeline installation on soil properties and productivity. Can. J. Soil Sci. 53: 37-47.

James, W.H. 1988. An economical penetrometer for high strength soil. Presented at the Join Confernce of the Alberta Chapters of the Canadian Land Reclamation Association and the Soil and Water Conservation Society. Kananaskis, Alberta, Septmeber 22-23, 1988. 8 pp.

Findlay, Irvine Limited. 1979. Instruction manual for use of Bush Recording Soil Penetrometer Mark I. Model 1979. Findlay, Irvine Limited. Bog Road, Penicuik, Midlothian, Scotland. 18 pp. plus append.

Finlayson, N.M. 1987. Stoney Creek pipeline narrow ditch experiment. Volume 1: 1987 results. Can-Ag Enterprises Ltd. Technical report prepared for NOVA Corporation of Alberta. 37 pp. plus append.

Freitag, D.R. 1971. Methods of measuring soil compaction. pp 47-103. In: K.K. Barnes st al. (eds.). Compaction of agricultural soils. Am. Soc. Agric. Eng. St. Joseph, MO.

Gerard, C.J., P. Sexton and G Shaw. 1982. Physical factors influencing soil strength and root growth. Agron. J. 74: 875-879.

Landsburg, S. 1988. Foisey Lateral field notes. Unpublished data.

Landsburg, S. 1989. Effects of pipeline construction on Chernozemic and Solonetzic A and B horizons in central Alberta. Can. J. Soil Sci. 69: 327-336.

Larson, W.E., S.C. Gupta and R.A. Useche. 1980. Compression of agricultural soils from eight soil orders. Soil Sci. Soc. Am. J. 44: 450-457.

Lull, H.W. 1959. Soil compaction of forest and rangelands. U.S. Dept. Agri. Forest Service. Misc. Publ. 33pp.

McKeague, J.A. 1978. Manual on soil sampling and methods of analysis. Can. Soc. Soil Sci. 212pp.

Moneco Consultants Limited. 1989. Soil survey for Pigeon Lake Lateral Pipeline Project. Prepared for NOVA Corporation of Alberta. 15 pp. plus append.

Moncrieff, I. 1984. Soil rehabilitation after pipeline construction. Oilweek, November 5, 1984. pp 16-20.

Naeth, M.A. 1985. Ecosystem reconstruction and stabilization following pipeline construction through Solonetzic native rangeland in southern Alberta. M.Sc. Thesis. University of Alberta. Edmonton, Alberta. 213 pp.

Ohu, J.O., G.S.V. Raghavan and E. McKyes. 1985. Peatmoss effect on the physical and hydraulic characteristics of compacted soils. Transactions of the ASAE 28: 420-424.

Riddell, K.M. 1988. Soil survey and reclamation quality ratings of the Albright Lateral Extension. Prepared for NOVA Corporation of ALberta. 17 pp. plus append.

Riddell, K.M. and L.J. Knapik. 1988b. The Standard Lateral soil research project. Soil compaction, soil quality and crop yields four years after construction (1987). Pedocan Land Evaluation Ltd. Technical report prepared for NOVA Corporation of Alberta. 38 pp. plus append.

Saini, G.R., T.L. Chow and I. Ghanem. 1984. Compactibility indexes of some agricultural soils of New Brunswick, Canada. Soil Sci. 137: 33-38.

SAS Institute Inc. SAS User's Guide: Statistics, Version 5 Edition. Cary, NC. SAS Institute Inc., 1985. 956 pp.

Stewart, A.J. and A.F. Mackenzie. 1979. Effect of pipeline construction on soil and crops IV. Dept. Renewable Resources. Macdonald College, Quebec. 43 pp.

Swan, J.B., J.F. Moncrief and W.B Voorhees. 1987. Soil compaction: causes, effects and control. AG-BU 3115. Minnesota Extension Service. University of Minnesota. 12 pp.

Taylor, H.M. and H.R. Gardner. 1963. Penetration of cotton seedling taproots as influenced by bulk density, moisture content and strength of soil. Soil Sci. 96: 153-156.

Thacker, D.J. and R.L. Johnson. 1989. The factors influencing cone penetrometer resistance as a measure of compaction in mine spoils. Presented at the 14th Annual Canadian Land Reclamation Association Conference, Calgary, Alberta, August 27-31, 1989. 9 pp.

Twardy, A.G. 1988a. Soil survey and vegetation evaluation of the Maleb Lateral. Prepared for NOVA Corporation of Alberta. 13 pp. plus append.

Twardy, A.G. 1988b. Soil survey and vegetation evaluation of the Redwater Lateral Loop. Prepared for NOVA Corporation of Alberta. 15 pp. plus append.

Twardy, A.G. 1989a. Soil survey and reclamation quality ratings for the Atlee-Buffalo Lateral Loop. Prepared for NOVA Corporation of Alberta. 12 pp plus append.

Twardy, A.G. 1989b. Soil survey and reclamation quality ratings of the Ferintosh Lateral Loop and Ferintosh North Lateral Loop. Prepared for NOVA Corporation of Alberta. 15 pp. plus append.

Zalik, S. 1978. Outline of statistical methods for biological and medical research. University of Alberta. Edmonton, Alberta. 152 pp.

Zellmer, S.D., J.D. Taylor and R.P. Carter. 1985. Edaphic and crop production changes resulting from pipeline installation in semiarid agricultural ecosystems. Paper presented at the national meeting of the American Society for Surface Mining and Reclamation. Denver, Colorado. 9 pp.

9. APPENDICES

9.1 SOIL DESCRIPTIONS FOR EACH 1989 STUDY AREA

Representative profiles for soils in each of the 23 study areas are listed in Tables 27 to 95.

9.2 SUMMARIES OF LABORATORY RESULTS

Summaries of laboratory results for soil moisture, soil organic matter and clay content for the 1988, 1989 and 1990 sampling years are listed in Tables 96 to 105.

9.3 SOIL STRENGTH ADJUSTMENTS BASED ON MOISTURE

Soil strengths adjustments based on moisture for the 1989 sampling year are listed in Tables 106 and 107.

9.4 REGRESSION ANALYSES

Values of r^2 correlating soil strength to clay content and soil moisture for the 1989 and 1990 sampling years are listed in Tables 108 to 110.

9.5 COMPILED SOIL STRENGTH VALUES AND STATISTICAL SIGNIFICANCE

Compiled soil strength values and statistical significance for the 1988, 1989 and 1990 sampling events are listed in Tables 111 to 155.

9.6 FIGURES OF SOIL STRENGTH

Figures of soil strength for the 1988, 1989 and 1990 sampling events are presented in Figures 20 to 50.

9.7 PENETROMETER READINGS

The sampling depth increment and corresponding 10 penetrometer readings and their averages in kg (Ave 1) and in bars (Ave 2) are presented for the three replicates for each site in Tables 155 to   for the 1988, 1989 and 1990 sampling events.

9.8 LABORATORY RESULTS

Soil physical and chemical results for all study areas in 1988, 1989 and 1990 are listed in Tables to .

Table 96. Soil moistures for 1988 study areas (1989 data).

STUDY AREA	DEPTH (cm)	SOIL MOISTURE[1] (%) Control	Trench	Work Side
Craigmyle	0-13	27.1	23.0	27.6
	13+	27.2	20.5	31.8
Delia	0-15	33.7	27.0	28.4
	15-30	24.9	32.7	27.3
	30-50	29.2	27.3	24.8
Foreman	0-20	12.6	9.4	10.9
	20-35	12.3	9.2*[2]	10.6*
	35-50	12.0	8.8*	9.8
Ghostpine	0-15	25.5	17.2*	18.0*
	15-25	19.1	21.1	19.9
	25-50	18.9	21.1	15.5
Michichi	0-15	31.7	33.2	27.9
	15-40	29.6	32.7	31.0
	40-60	30.0	29.7	33.0
Milo	0-15	6.6	6.1	6.0
	15-30	10.3	5.5*	5.8*
	30-50	8.4	5.7*	4.3*
Victor 1	0-15	38.5	33.2	34.2
	15+	35.1	38.0	39.6*
Victor 2	0-15	29.5	27.2	27.7
	15+	30.4	30.6	31.9

[1]Average of three replicates.

[2]Means are significantly different from control at $p < 0.05$.

Table 97. Soil organic matter for 1988 study areas (1988 data).

STUDY AREA	DEPTH (cm)	SOIL ORGANIC MATTER[1] (%) Control	Trench	Work Side
Craigmyle	0-13	5.5	2.9	2.4*[2]
Delia	0-15	5.8	5.3	6.7
	15-30	3.3	2.2	2.0
	30-50	1.8	1.3	2.4
Foreman	0-20	4.0	4.6	4.7
	20-35	1.8	1.5	2.2
	35-50	0.8	1.0	0.5
Ghostpine	0-15	6.3	3.8*	6.0
	15-25	1.6	2.1	1.5
	25-50	0.6	2.9	0.9
Michichi	0-15	5.2	4.4	5.2
	15-40	2.6	1.8	3.0
	40-60	2.7	2.0	2.1
Milo	0-15	2.5	1.4*	2.0*
	15-30	1.8	0.8*	1.8
	30-50	2.2	0.8	1.5
Victor 1	0-15	4.1	3.1*	3.6
Victor 2	0-15	3.8	2.7	3.9

[1]Average of three replicates.

[2]Means are significantly different from control at $p < 0.05$.

Table 9B. Percent clay for 1988 study areas (1988 data).

STUDY AREA	DEPTH (cm)	CLAY[1] (%) Control	Trench	Work Side
Craigmyle	0-13	48.3	51.9	43.9
	13+	59.1	49.3	53.6
Delia	0-15	20.4	15.4	11.9
	15-30	22.2	11.5	15.2
	30-50	30.2	11.9*[2]	25.3
Foreman	0-20	8.1	8.2	8.4
	20-35	10.0	10.4	7.7
	35-50	13.2	9.3	12.0
Ghostpine	0-15	22.9	30.2*	26.9*
	15-25	32.2	32.2	38.4
	25-50	35.9	33.2	35.8
Michichi	0-15	35.4	39.8	37.6
	15-40	46.4	49.2	46.5
	40-60	47.5	54.8	47.1
Milo	0-15	16.3	16.6	15.5
	15-30	30.6	16.8	16.7
	30-50	28.1	16.8*	18.4*
Victor 1	0-15	51.3	52.6	53.6
	15+	59.1	56.7	54.4
Victor 2	0-15	43.8	45.4	44.2
	15+	47.7	48.7	47.6

[1]Average of three replicates.

[2]Means are significantly different from control at $p < 0.05$.

Table 99. Soil moisture for all 1989 study areas (1989 data).

STUDY AREA	DEPTH (cm)	SOIL MOISTURE[1] %			
		Control	Work side	Trench	Spoil side
Atlee-Buffalo 1	0-11	17.7	26.8	10.3*[2]	28.4*
	11-20	14.2	22.1	9.6	26.0
	20-35	14.4	-	-	-
Atlee-Buffalo 2	0-13	5.3	6.0	5.4	8.8
	13-35	6.3	5.7	2.7	7.6
	35-50	4.3	-	-	-
Aeco 'C'	0-17	16.7	17.9	18.2	17.1
	17-35	24.6	19.9	21.0*	17.1*
	35-50	26.0	23.7	20.3*	17.6*
Albright	0-18	25.8	19.4*	18.1*	20.4*
	18-35	25.7	18.1	19.5*	22.4
	35-50	24.0	22.0	19.6	23.1
Bolloque	0-20	19.1	25.7	31.3*	28.9*
	20-35	15.5	24.0	15.6	18.4
	35-50	18.1	26.1	13.8	16.6
Ferintosh	0-15	34.2	30.7	28.1*	27.1*
	15-32	30.2	21.6	23.7*	25.7
	32-50	14.3	12.9	19.7	18.7
Foisey	0-19	16.8	13.8	12.5*	16.7
	19-40	14.2	14.8	13.3	20.6
	40-50	13.9	16.0	12.8	14.0
Henderson 1	0-21	11.0	15.1*	15.8*	14.3*
	21-35	17.7	19.3	16.5	24.2
	35-50	19.5	-	-	22.0
Henderson 2	0-18	15.5	14.0	15.5	15.5
	18-34	14.6	16.1	16.2	14.3
	34-50	18.3	20.5	19.7	17.1
Maleb 1	0-15	13.6	12.6	10.7	11.8
	15-30	22.5	21.7	17.9	23.6
	30-50	16.7	26.6*	19.4	23.9*

continued......

Table 99. Concluded.

STUDY AREA	DEPTH (cm)	SOIL MOISTURE[1] % Control	Work side	Trench	Spoil side
Maleb2	0-15	15.0	9.9*	6.9*	9.1*
	15-33	16.8	14.0	8.7	13.5
	33-50	15.6	15.1	10.3	15.6
Pigeon Lake	0-18	14.4	17.7*	22.1*	18.4*
	18-35	13.6	-	14.0	13.9
	35-50	13.1	-	-	-
Redwater1	0-20	11.6	14.5	12.0	15.3
	20-40	5.7	12.4*	13.0*	15.3*
	40-50	8.1	13.4	-	16.1
Redwater2	0-20	12.1	14.1	16.4*	13.8
	20-35	8.8	10.8	9.8	11.3
	35-50	9.9	-	-	-
Valhalla	0-17	20.4	18.6	18.9	19.2
	17-33	16.7	19.0	14.9	18.0
	33-50	15.5	-	15.3	17.9

[1]Average of three replicates, underlined values have only one replicate.

[2]Means are significantly different from control at $p < 0.05$.

Table 100. Soil moistures for all 1988 study areas (1989 data).

STUDY AREA	DEPTH (cm)	SOIL MOISTURE[1] %		
		Control	Work side	Trench
Craigmyle	0-15	19.9	21.0	22.7
	15-40	38.3	32.3	25.0*[2]
Delia	0-15	20.9	19.7	11.9*
	15-30	22.2	12.8	10.0
	30-50	10.2	12.5	-
Foreman	0-20	9.4	8.7	5.3
	20-35	9.8	8.0	-
	35-50	10.5	8.0	-
Ghostpine	0-15	21.7	17.6*	19.0
	15-25	16.1	17.7	17.4
	25-50	16.9	17.7	17.1
Michichi	0-15	14.0	14.2	14.2
	15-40	19.2	14.2*	14.1*
Milo	0-15	6.4	5.5	8.4
	15-30	10.2	-	8.5
Victor 1	0-15	23.0	29.1	27.7
	15-40	30.6	31.8	26.3
Victor 2	0-15	15.5	21.9*	15.1
	15-40	22.7	21.2	23.1

[1]Average of three replicates.

[2]Means are significantly differnet from control at $p < 0.05$.

Table 101. Soil organic matter for all 1989 study areas (1989 data).

STUDY AREA	DEPTH	SOIL ORGANIC MATTER[1] (%)			
	(cm)	Control	Work side	Trench	Spoil side
Atlee-Buffalo 1	0-11	6.79	8.11*[2]	3.83	9.71
Atlee-buffalo 2	0-13	2.55	2.55	1.38	1.95
Aeco 'C'	0-17	1.86	2.08	0.99	2.06
Albright	0-18	4.70	4.56	3.93	3.56
Bolloque	0-20	2.27	3.67	5.05*	3.84
Ferintosh	0-15	9.23	9.28	8.44	8.87
Foisey	0-19	3.77	4.38	4.54	3.94
Henderson 1	0-21	3.97	4.46	3.73	3.44
Henderson 2	0-18	2.22	1.71	1.76	1.65
Maleb 1	0-15	4.95	3.79*	1.93*	2.87*
Maleb 2	0-15	2.09	1.93	1.60	2.06
Pigeon Lake	0-18	5.42	6.03	6.74	5.05
Redwater 1	0-20	3.72	3.70	3.20	3.12
Redwater 2	0-20	3.51	4.30	3.62	3.35
Valhalla	0-17	2.60	3.07	2.37	2.30

[1]Average of three replicates.

[2]Means are significantly different from control at $p < 0.05$.

Table 102. Soil organic matter for all 1988 study areas (1989 data).

STUDY AREA	DEPTH (cm)	SOIL ORGANIC MATTER[1] %		
		Control	Work side	Trench
Craigmyle	0-15	5.14	4.24	5.45
Delia	0-15	5.17	4.30	6.72
Foreman	0-20	3.74	4.02	4.27
Ghostpine	0-15	6.05	4.55*[2]	5.08
Michichi	0-15	5.01	2.70*	4.51
Milo	0-15	1.88	1.16	2.19
Victor 1	0-15	3.53	2.84	3.45
Victor 2	0-15	4.54	4.33	3.51

[1]Average of three replicates.

[2]Means are significantly different from control at $p < 0.05$.

Table 10C. Percent clay for all 1989 study areas (1989 data).

STUDY AREA	DEPTH	CLAY[1] (%)			
	(cm)	Control	Work side	Trench	Spoil side
Atlee-Buffalo 1	0-11	21.7	20.4	23.7	21.7
	11-20	35.1	28.4*[2]	28.4*	34.4
Atlee-Buffalo 2	0-13	7.7	6.7	8.4	7.4
	13-35	13.1	8.4	6.4	8.4
Aeco 'C'	0-17	23.0	23.7	27.0	23.0
Albright	0-18	18.9	7.7	8.4	3.1
	18-35	17.1	21.4	22.7	3.7
	35-50	36.1	34.1	32.4	4.1
Bolloque	0-20	12.9	12.5	13.2	11.9
	20-35	21.2	21.2	21.5	27.2
	35-50	27.9	34.9	22.5*	23.7
Ferintosh	0-15	19.5	18.8	19.1	16.1
	15-32	14.5	18.8	19.8*	17.1
	32-50	22.8	17.5	28.1	26.5
Foisey	0-19	14.9	16.9*	17.2*	20.1
	19-40	24.9	29.1	25.7	26.1
	40-50	30.2	33.7	28.6	29.4
Henderson 1	0-21	20.9	23.3	23.6	24.9*
	21-35	49.6	45.9	33.3*	57.9
	35-50	52.6	-	-	51.6
Henderson 2	0-18	19.3	25.0	21.7	19.7
	18-34	33.2	32.3	40.3	28.7
	34-50	39.3	46.0	54.0*	44.0
Maleb 1	0-15	32.2	34.5*	32.9	34.9*
	15-30	37.9	35.5	32.9*	36.2
	30-50	36.9	39.7	32.9	37.5
Maleb 2	0-15	23.7	23.4	24.1	23.5
	15-33	29.4	24.1*	28.8	23.5*
	33-50	27.1	24.8*	28.8	26.5

continued......

Table 103. Concluded.

STUDY AREA	DEPTH (cm)	CLAY[1] (%) Control	Work side	Trench	Spoil side
Pigeon Lake	0-18	21.9	22.2	22.9	23.5
	18-35	26.9	-	25.2	25.5
Redwater 1	0-20	14.5	16.1	16.1	16.8
	20-40	13.1	15.8	16.8	19.1
	40-50	13.8	15.7	-	20.1
Redwater 2	0-20	15.9	14.9	16.5	15.9
	20-35	18.2	19.5	19.2	19.9
Valhalla	0-17	26.7	25.0	26.7	27.0
	17-33	30.7	28.3	30.3	33.3
	33-50	33.0	-	34.0	40.3

[1]Average of three replicates, underlined values have only one replicate.

[2]Means are significantly different from control at $p < 0.05$.

Table 104. 1990 soil moisture data for 1989 study areas and Michichi.

STUDY AREA	DEPTH (cm)	SOIL MOISTURE[1] % Control	Work side	Trench	Spoil side
Atlee-Buffalo 1	0-10	14.2	9.3*[2]	14.9	14.4
	10-20	14.6	-	16.8	15.8
Atlee-Buffalo 2	0-10	1.8	1.6	1.9	1.8
Aeco 'C'	0-15	4.3	5.0	4.0	4.3
Albright	0-20	21.1	19.6	22.4	22.4
	20-35	19.0	-	17.2	-
Bolloque	0-20	8.6	14.7	13.9	14.5
Ferintosh	0-15	22.8	20.0	21.0	19.7
	15-30	23.5	21.3	21.0	21.4
	30-50	14.8	18.4	17.5	-
Foisey	0-20	9.9	11.5	18.6	13.8
	20-40	-	-	10.2	-
	40-50	-	-	10.4	-
Henderson 1	0-20	25.3	24.4	23.4	27.0
	20-35	15.0	17.9	12.9	18.7
Henderson 2	0-20	18.0	14.5	16.3	15.3
	20-34	17.0	14.4	15.0	11.3
Maleb 1	0-15	14.6	15.4	15.7	13.0
	15-30	21.9	20.0	19.4	23.5
	30-50	20.4	19.1	20.2	24.1
Maleb 2	0-15	5.6	5.8	5.8	5.2
Pigeon Lake	0-20	20.8	20.5	18.2	20.3
	20-35	17.0	16.4	15.5	15.1
	35-50	12.1	14.4	-	13.6
Redwater 1	0-20	14.0	13.4	11.8	13.2
	20-40	14.2	14.4	13.3	14.9
	40-50	15.5	22.7	17.4	17.7

continued......

Table 104. Concluded.

STUDY AREA	DEPTH (cm)	SOIL MOISTURE[1] % Control	Work side	Trench	Spoil side
Redwater 2	0-20	8.3	10.0	11.6	8.3
Valhalla	0-20	24.4	20.1	22.7	21.3
	20-35	16.0	14.2	13.7	-
	35-50	13.6	-	-	-
Michichi	0-20	15.2	19.1	-	19.3

[1]Average of three replicates, underlined values have only one replicate.

[2]Means are significantly different from control at $p < 0.05$.

Table 105. 1990 soil organic matter data for 1989 study areas and Michichi.

STUDY AREA	DEPTH (cm)	SOIL ORGANIC MATTER[1] (%)			
		Control	Work side	Trench	Spoil side
Atlee-Buffalo 1	0-10	6.57	5.27	8.41	8.35
Atlee-buffalo 2	0-10	2.05	0.84	2.18	3.81
Aeco 'C'	0-15	2.15	1.65	1.84	2.04
Albright	0-20	3.80	3.44	3.35	4.00
Bolloque	0-20	5.07	7.36	7.47	5.35
Ferintosh	0-15	9.30	8.44*[2]	8.00	9.13
Foisey	0-20	6.06	3.26*	4.42*	4.56*
Henderson 1	0-20	3.42	3.90	3.85	4.31
Henderson 2	0-20	3.75	1.77	1.65	1.90
Maleb 1	0-15	3.37	2.14	3.31	2.30
Maleb 2	0-15	1.74	1.51	1.69	1.45
Pigeon Lake	0-20	4.93	4.25	4.62	5.77
Redwater 1	0-20	4.50	4.34	4.03	4.21
Redwater 2	0-20	3.81	3.48	3.41	3.61
Valhalla	0-20	2.64	2.44	2.28	2.64
Michichi	0-20	4.27	5.32*	5.50*	-

[1]Average of three replicates.

[2]Means are significantly different from control at $p < 0.05$.

Table 106. Adjusted soil strengths for 1989 study areas (1989 data).

STUDY AREA	DEPTH INCREMENT	ADJUSTED SOIL STRENGTH[1] (bars) Control	Work side	Trench	Spoil side
Atlee-Buffalo 1	1	1.9	-	1.5	2.9
	2	20.3	-	17.6	28.0
	3	30.3	-	30.0	43.3
	4	30.8	-	29.4	-
Ferintosh	1	0.7	-	0.5	0.5
	2	3.1	-	2.1	2.0
	3	5.4	-	2.1	3.0
	4	8.8	-	1.8*[2]	5.4
	5	14.2	-	2.4*	11.3
	6	19.8	-	4.5*	-
	7	22.3	-	8.5*	-
	8	23.2	-	13.0	-
	9	24.2	-	16.5	-
	10	25.4	-	21.8	-
Foisey	1	2.4	-	0.6*	-
	2	6.9	-	4.9	-
	3	9.8	-	8.9	-
	4	22.3	-	10.9*	-
	5	26.5	-	21.0	-
	6	26.8	-	19.8	-
Aeco 'C'	6	23.9	-	11.0*	16.8
	7	20.7	-	10.5*	18.2
	8	18.5	-	10.6*	19.8
	9	17.8	-	10.2+[3]	19.8-[4]
	10	18.1	-	10.8*	19.2-
	11	18.7	-	8.1*	16.2
	12	19.2	-	7.9*	15.4
	13	20.5	-	7.9*	16.9
	14	21.8	-	8.4*	18.0
	15	22.8	-	8.4*	17.2
Bolloque	1	2.7	-	2.3	4.0
	2	25.6	-	11.5*	13.0*
	3	26.4	-	14.5*	16.1*
	4	28.3	-	17.4-	18.3+
	5	31.1	-	20.8*	24.9-

continued......

Table 10G. Continued.

STUDY AREA	DEPTH INCREMENT	ADJUSTED SOIL STRENGTH[1] (bars) Control	Work side	Trench	Spoil side
Maleb 2	1	1.0	0.9-	0.4+	0.4*
	2	1.8	2.4	1.6	3.0-
	3	4.6	4.7	2.7	5.7-
	4	11.5	7.4	7.4	9.9-
	5	16.9	12.8	7.1	14.2+
Henderson 1	1	2.9	1.1	1.5	1.0
	2	16.7	3.1*	3.5*	2.5*
	3	23.9	5.1*	4.9*	2.8*
	4	26.2	8.1*	7.4*	4.4*
	5	31.0	8.8-	11.1-	8.4*
Pigeon Lake	1	3.0	15.6*	1.2-	1.0-
	2	22.9	11.5*	5.4*	6.2*
	3	25.7	21.5	6.8*	10.7*
	4	24.6	28.6	9.6*	23.1-
	5	26.7	-	26.7	32.2
	6	31.0	-	43.2	34.1-
Albright	1	1.1	1.0	0.9	0.6
	2	5.1	4.7	4.8	3.7
	3	5.2	7.1	8.5	7.8
	4	5.7	9.5-	9.4	13.5*
	5	6.7	12.8-	12.6-	15.4*
	6	10.3	15.6*	15.2-	17.5*
	7	18.4	-	17.5	-
	8	21.4	-	18.3	-
	9	22.4	-	20.5	-
	10	24.8	-	21.9	-
Redwater 1	6	26.4	29.1-	8.4*	33.5-
	7	29.9	35.2-	30.4-	38.1

continued.....

Table 10G. Concluded.

STUDY AREA	DEPTH INCREMENT	ADJUSTED SOIL STRENGTH[1] (bars) Control	Work side	Trench	Spoil side
Redwater 2	1	3.4	--	1.7-	--
	2	25.0	--	8.2*	--
	3	28.1	--	15.8-	--
	4	30.0	--	26.6-	--
	5	<u>31.2</u>	--	37.6	--
	6	<u>34.2</u>	--	39.0	--

[1]Average of three replicates, underlined values have only one replicate.

[2]Adjusted soil strength means are significantly different from control at $p < 0.05$, as were means of actual soil strengths.

[3]Adjusted soil strength means are significantly different from control at $p < 0.05$, but means of actual soil strengths were not.

[4]Adjusted soil strength means are not significantly different from control at $p < 0.05$, whereas actual soil strengths were significantly different from control.

Table 107. Adjusted soil strengths for the 1988 study areas (1989 data).

STUDY AREA	DEPTH INCREMENT	ADJUSTED SOIL STRENGTH[1] (bars)		
		Control	Work side	Trench
Craigmyle	5	18.4	-	18.1
	6	20.5	-	23.2
	7	20.2	-	24.3*[2]
	8	20.2	-	24.1*
	9	21.3	-	25.3
	10	21.7	-	25.8
	11	21.9	-	26.6
	12	22.4	-	27.6
	13	24.3	-	28.2
	14	24.8	-	27.4
	15	24.5	-	25.9
Delia	1	0.8	-	0.7
	2	6.8	-	7.2
	3	14.4	-	11.7
	4	19.5	-	11.7
	5	22.1	-	17.3
Ghostpine	1	1.5	-	0.9
	2	7.6	-	7.9
	3	11.3	-	14.5
	4	17.2	-	20.9
	5	22.3	-	21.0
Michichi	5	10.7	11.8	13.2
	6	17.1	15.7	20.0
	7	27.1	-	25.2
Victor 2	1	0.3	0.8+[3]	-
	2	2.9	3.6	-
	3	7.0	4.9	-
	4	13.5	13.0	-
	5	19.4	22.8	-

[1]Average of three replicates, underlined values have only one replicate.

[2]Adjusted soil strength means are significantly different from control at $p < 0.05$, as were means of actual soil strengths.

[3]Adjusted soil strength means are significantly different from control at $p < 0.05$, but means of actual soil strengths were not.

Table 108. Values of r^2 correlating soil strength to clay content and soil moisture for the 1989 study areas (1989 data).

SITE	r^2 VALUES	
	clay	moisture
Atlee-Buffalo 1	0.23	0.07
Atlee-Buffalo 2	0.34	0.07
Aeco 'C'	0.04	0.03
Albright	0.23	0.22
Bolloque	0.24	0.35
Ferintosh	0.28	0.56
Foisey	0.41	0.00
Henderson 1	0.40	0.37
Henderson 2	0.37	0.18
Maleb 1	0.06	0.10
Maleb 2	0.37	0.18
Pigeon Lake	0.49	0.68
Redwater 1	0.20	0.06
Redwater 2	0.18	0.33
Valhalla	0.65	0.38

Table 109. Values of r^2 correlating soil strength to clay content and soil moisture for the 1988 study areas (1989 data).

SITE	r^2 VALUES
	moisture
Craigmyle	0.63
Delia	0.17
Foreman	0.19
Ghostpine	0.29
Michichi	0.29
Milo	0.01
Victor 1	0.21
Victor 2	0.44

Table 11O. Values of r^2 correlating soil strength to clay content and soil moisture for the 1989 study areas and Michichi (1990 data).

SITE	r^2 VALUES
	moisture
Atlee-Buffalo 1	0.25
Atlee-Buffalo 2	0.03
Aeco 'C'	0.00
Albright	0.17
Bolloque	0.01
Ferintosh	0.10
Foisey	0.17
Henderson 1	0.09
Henderson 2	0.03
Maleb 1	0.02
Maleb 2	0.01
Pigeon Lake	0.73
Redwater 1	0.19
Redwater 2	0.00
Valhalla	0.61
Michichi	0.03