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Project Report

THE EFFECTS OF SUBSOILING AND DRAINAGE TREATMENTS ON SOIL AND CROP CHARACTERISTICS

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AFDA PROJECT TDP - 071

THE EFFECT OF SUBSOILING AND DRAINAGE TREATMENTS ON SOIL AND CROP CHARACTERISTICS

FINAL REPORT

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ABSTRACT

The project compared conventional tile drainage with small bore, closely spaced tile drainage. It also evaluated subsoiling before and after tile installation versus conventional tile drainage.

The project site was a level field of imperfectly drained Debert 22 soil which consists of 45 cm of friable sandy loam soil over compact subsoil.

Four treatments, arranged in a completely randomized design with three replications, were as follows: (1) conventional tile (100 mm) at 10 m spacing; (2) subsoiling to a depth of 70 cm prior to installation of conventional tile at 10 m spacing; (3) subsoiling to a depth of 50 cm following the installation of conventional tile at 10 m spacing; and (4) closely spaced (3 m), small bore (50 mm) tile.

Soil and crop parameters evaluated included: soil density, hydraulic conductivity, moisture, temperature, trafficability, watertable fluctuations, alfalfa yields, carrot yields and alfalfa plant counts. Tile drainage discharge and the potential obstruction of tile lines by alfalfa roots were also examined.

High subsoil moisture prevented the optimum reduction in soil density from subsoiling. Although internal drainage was improved, no effect was noticed after the first winter. Drainage performance, soil characteristics and crop production showed no benefits as a result of subsoiling in the three growing seasons following subsoiling.

The small bore, closely spaced tile treatment removed water quicker, especially when the soil was completely saturated, and kept the watertables about 5 cm lower than the conventional tile drainage with 10 m spacing. There was no significant differences in carrot production among the treatments but the small bore close spaced tile drainage produced significantly higher forage yields than the other treatments.

ACKNOWLEDGEMENTS

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INTRODUCTION

Crop production in Atlantic Canada is hampered by climatic and soil conditions. The agricultural soils in this area are limited by low fertility, high acidity and rooting zone problems associated with compacted subsoils. In Nova Scotia, more than 70% of the agricultural soils have a compacted subsoil located 30 to 60 cm deep. Soils with shallow, dense subsoils are droughty in dry periods during the summer and wet in the spring and fall.

Throughout Nova Scotia it is common to see vigorous crop growth over tile lines and poor crop growth between tile lines (Figure 1) (Madani et al. 1993, Langille 1980, Holmstrom et al. 1993, and Bosveld 1989). The good growth over tile lines is likely due to improved soil drainage and soil structure caused by the shattering of soil by the drainage plow during installation (Chow et al. 1993). Therefore, it seems logical that subsoiling (which is a method of deep tillage that shatters the soil without inverting it) should improve the soil structure and water holding capacity of the dense subsoil. Subsoiling perpendicular to existing tile lines may improve the function of subsurface drainage and result in increased yields.

Figure 1. Vigorous alfalfa growth over tile lines and poor growth between tile lines.

Subsoiling perpendicular to existing tile drainage shatters an area of soil shown in Figure 2. This leaves large areas of undisturbed subsoil. However, subsoiling prior to tile installation could be done at deeper depths resulting in greater areas of shattered subsoil. It is important that subsoiling be done above the critical depth and when the soil moisture level is not too high, otherwise little or no shattering will occur (Owen 1988 and Michilica 1984).

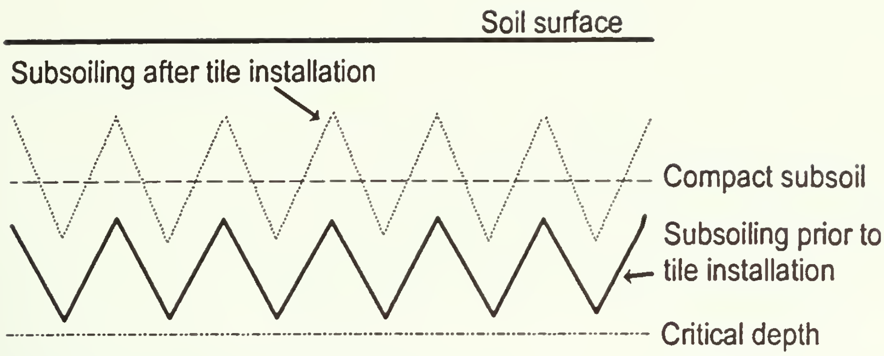

Figure 2. Area of soil shattered by subsoiling.

Several research projects in Nova Scotia have shown improved soil conditions due to subsoiling. Soil density decreases of approximately 0.2 g cm^{-3} were reported by van der Leest (1977) and Holmstrom et al. (1993) on Queens, Truro, Nappan, Woodville and Hansford soils after subsoiling. Holmstrom et al. 1993 also found that subsoiling improved hydraulic conductivity in the first year after subsoiling. However, these improvements were not evident after three years. In an evaluation of the McConnel Shakaerator (vibrating subsoiler) by Rodd et al. (1989), subsoiling decreased penetration resistance by more than 500 KPa and improved soil aeration for one year.

Results from some demonstration projects on the dense basal till and fragipan soils of northern Nova Scotia have shown no improvement in forage or grain yields from subsoiling. Goit and Mellish (1981), observed no yield increases with grain from a subsoiled site. However, the site was subsoiled parallel to the tile lines because the tile lines were installed too shallow. Langille (1980), found no increase in alfalfa yield three years after subsoiling. The site was subsoiled at right angles to the tile lines in the fall after a summer of fallow. Goit (1983) found no improvements in grain yield for six years after subsoiling. The site was subsoiled perpendicular to the existing tile lines but the soil moisture content was unknown at the time of subsoiling.

A replicated experiment by Rodd et al. (1989) showed no increase in forage yield during the first two years after subsoiling. The field had been subsoiled in the summer but was not tile drained. Holmstrom et al. (1993) found that subsoiling in combination with tile drainage did not significantly improve forage yields although there was a trend of higher yields with deeper subsoiling (50 mm) versus shallow subsoiling (35 mm).

Hilchey (1976), however, reported increases in forage yields and an increase in root counts as a result of subsoiling. The increased forage yields may have been due to the favourable chemical environment of the subsoil (pH of 7.6 and greater). This theory was shared by Webster and Jones (1986) who found that incorporating lime into subsoil excavated from a 2 m deep trench and then replaced, increased grain yield. Neither soil disturbance to 2 m or deep incorporation of peat was found to have any benefit. They surmised that the primary constraint to deep root penetration was chemical in nature.

Subsurface drainage has improved crop yields in shallow, compacted soils of Nova Scotia

(Goit and Mellish, 1981; Hilchey, 1976; Langille and Goit, 1981). Experiments with drain spacings ranging from 9 to 32 m have shown that narrower drain spacings provided a better crop environment with quicker watertable drawdown and lower watertable depths on Queens soils (Higgins, 1978 and Cochrane, 1983). Goit (1983) found that drain spacings of 12 m increased grain yields by 870 kg ha^{-1} over non-drained land and speculated that drain spacings of 3 m could possibly increase yields by 1200 kg ha^{-1} over no drainage. Madani et al. (1993) reported that drain spacings of 3 m improved crop yields over the 12 m spacing in a shallow Queens soil, however, increases were not significant. They concluded that 12 m spacing was the most cost effective spacing.

Close spaced drainage would be more economical if small diameter (50 mm) tile were used. Small bore tile cost about $0.30 per meter less than conventional tile (100 mm diameter). Contractors have been installing small bore tile in Nova Scotia for the past three years. In 1992 and 1993, small bore tile accounted for approximately 30 to 35 % of the drainage tile installed. However, hydraulic and structural performance of small diameter tile should be evaluated for different depths and spacings.

A demonstration project by Cooper (1987) showed drain discharge from small diameter (35 mm), 3 m spacing tile was two to three times greater than conventional drainage (100 mm at 12 m spacing). Drainage performance tests conducted by Madani et al. (1993) showed 100 mm diameter, close spaced tile had three to five times the drain discharge of conventional drainage for peak flow rates.

Forage trials by Bosveld (1989), showed no significant improvement of alfalfa yields with small bore, close spaced tile drainage over conventional drainage. This was found despite the small bore, close spaced tile drainage field having more alfalfa plants per unit area than the conventionally drained field.

The objectives of this project were to compare conventional tile drainage with small bore, closely spaced tile drainage and to evaluate the effects of subsoiling before and after tile installation versus conventional tile drainage with no subsoiling. Both objectives were evaluated using carrots and alfalfa/timothy forage crops. Various soil and crop parameters were evaluated in conjunction with tile discharge. Obstruction of tile lines by alfalfa roots was also evaluated.

MATERIALS AND METHODS

Site location and plot design

The site was located on a 4.5 ha field near Somerset, Kings County. The field had a one percent grade and was regarded, by the owner and farmers who have rented the field, to be one of the wettest agricultural fields in the area. The soil was an imperfectly drained, sandy loam soil with 45 cm of friable sandy loam soil over compact subsoil of the Debert 22 series (Langille et al. 1993). A brief description of the soil is given in Table 1.

Table 1. Soil description.

Horizon	Depth (cm)	% Sand	% Silt	% Clay	Consistence
Ap	0-26	66.7	23.2	10.1	Friable
Bg	26-45	63.2	27.8	9.0	Friable
C	45-100	64.4	26.5	9.1	Firm

The plots were arranged in a completely randomized design with three replications (Figure 3). The treatments were: (1) conventional tile (100 mm) at 10 m spacing (NSS); (2) subsoiling to a depth of 70 cm prior to installation of conventional tile at 10 m spacing (SST); (3) subsoiling to a depth of 50 cm following the installation of conventional tile at 10 m spacing (TSS); and (4) closely spaced (3 m), small bore (50 mm) tile (SBT). All drain lines were installed at approximately one percent grade and 60 cm deep. Buffer lines were installed around each plot.

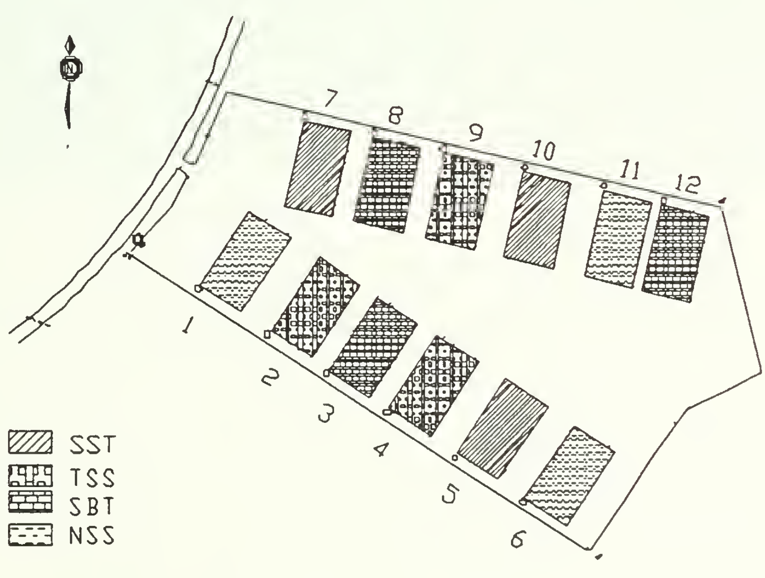

Figure 3. Plan of plot layout at the site.

Site preparation

Subsoiling and tile installation occurred in July and August of 1990. As recommended by Broughton (1976), the field was left fallow for the summer of 1990, in order to be able to

subsoil under optimum moisture conditions without disturbing an existing crop. The low soil moisture level required for effective shattering of the subsoil cannot be obtained in the spring before planting or in the fall after harvest. There was no rainfall at the site the week prior to subsoiling. Although a recommended practice was followed, subsoil moisture levels remained higher (27 %) than the recommended limit of 21 % (Read et al. 1991). A green crop should have been planted so more moisture could be extracted from the soil instead of leaving the field fallow. Subsoiling proceeded because of scheduling.

The field was smoothed with a land leveller prior to subsoiling and drain installation. In the fall of 1991, water ponded on the two plots located at the back of the field (plots 6 and 12) and damaged the alfalfa crop as shown in Figure 4.

Figure 4. Crop damage from water ponding on plots 6 and 12.

Subsoiling was accomplished using a 4 shank †Baldini vibrating ripper with shanks spaced 70 cm apart (Figure 5). The ripper tines were 9 cm wide with no lift or wings. This implement was pulled by a 4wd 5088 †International 135 h.p. tractor.

Optimum soil loosening had not occurred after the initial subsoiling and the plots that were subsoiled after the installation of tile drainage (TSS) were subsoiled again in September 1990. This time a subsoiler with wings attached to the shanks was used to generate greater shattering of the soil because of the vertical forces exerted by the wings. The wings were at an angle of 30 degrees from horizontal and provided a 30 cm cut.

† *Trade name is used to provide specific information and does not constitute endorsement by either the authors or their employers.*

Figure 5. Baldini vibrating ripper.

In October 1990, 30 tonnes of dolomitic limestone was spread to raise the soil pH to 6.6. Fall plowing was done shortly after. In early May 1991, the seedbed was prepared, 550 kg ha^{-1} of 5-20-20 + 0.2% boron starter fertilizer was incorporated and a forage mixture of 9 kg ha^{-1} of †Pioneer 5311 alfalfa and 7 kg ha^{-1} of †Basho timothy was seeded with a †Brillion seeder. In June and early July 1991, †Embutox 625 herbicide was applied at 2.5 litres ha^{-1} . The site was clipped to control heavy weed competition. Later in the fall, an application of 250 kg ha^{-1} 0-15-50 fertilizer was applied. In May 1992 and 1993, 550 kg ha^{-1} of 5-0-45 + 0.2% boron fertilizer was applied, an additional 300 kg ha^{-1} of 8-0-45 fertilizer was applied after the second cut of forage.

In May 1993 †Paramount carrots were planted in a 10 m wide strip through the middle of all the plots (perpendicular to the drain lines) after chisel plowing to a depth of 30 cm. Beds were 23 cm high and 60 cm apart with 75 plants per meter. †Furdan insecticide was applied at planting and †Lorex herbicide was sprayed in late June and again in early July. †Sevin XLR insecticide, †Bravo herbicide and †Polyram herbicide were applied in late July and early August.

A plan of a 10 m drain spacing plot with the locations of the drain lines, the metal crock for monitoring tile outflow, watertable wells, soil temperature thermistors and soil moisture probes is shown in Figure 6.

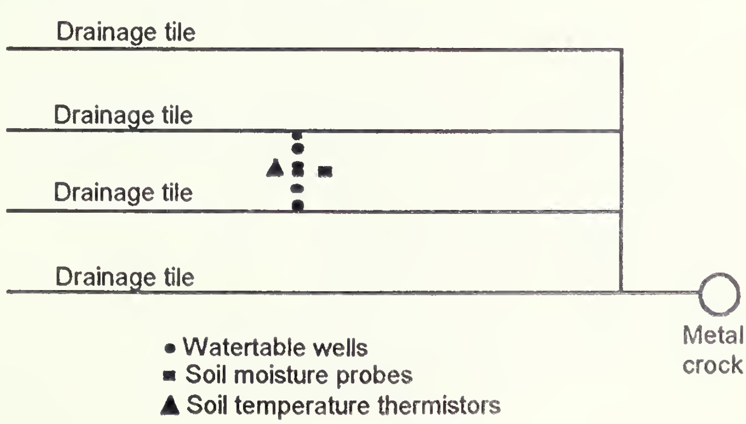

Figure 6. Schematic diagram of a 10 m drain spacing plot layout.

Soil density

Soil density data were collected in the summer of 1990 before and after subsoiling and in the summer of 1993 using a †Campbell Pacific Nuclear (CPN) MC-3 Portaprobe. Data was collected for three depths (15-20 cm, 15-30 cm, and 15-45 cm) at 6 locations in each plot. A schematic diagram and a brief description of the CPN MC-3 Portaprobe is included in Appendix A.

Statistical analysis using the analysis of variance procedure (ANOVA) was performed on the soil density data. The results are significant at a 0.05 confidence level.

Hydraulic conductivity

Hydraulic conductivity was measured at depths of 30 and 45 cm using a †Guelph permeameter. Data was collected at the same time and locations as the soil density. A schematic diagram and a brief description of the Guelph permeameter is included in Appendix A.

Watertable

Watertable fluctuations were monitored with a blow tube, three or four times a week throughout the 1991, 1992 and 1993 growing seasons. Six wells per plot were monitored. The wells were made of 4 cm pvc pipe with 2 mm holes drilled along their lengths. The location of the wells with respect to the drain lines for the conventional tile and the small bore tile treatments is shown in Figure 7. Wells C and F are located at the midspacing between the two center drain lines of each treatment for the conventional tile and small bore tile plots, respectively. Wells A and D are located 0.5 m from the nearest drain while wells B and E are located 2.5 and 0.76 m from the nearest drain, respectively.

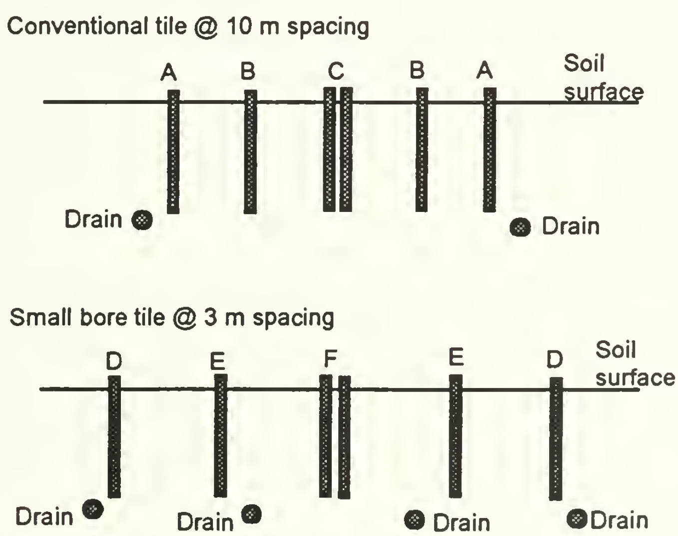

Figure 7. Watertable well locations.

Tile outflow

The tile lines from each plot were connected to one main line which had an outlet in the metal crocks located at the front of the plots (Figure 8). Tile discharge measurements for every plot were collected by measuring the total outflow from the outlets over a one minute period. These outflow measurements were collected at regular intervals over a three day period following a rainfall event.

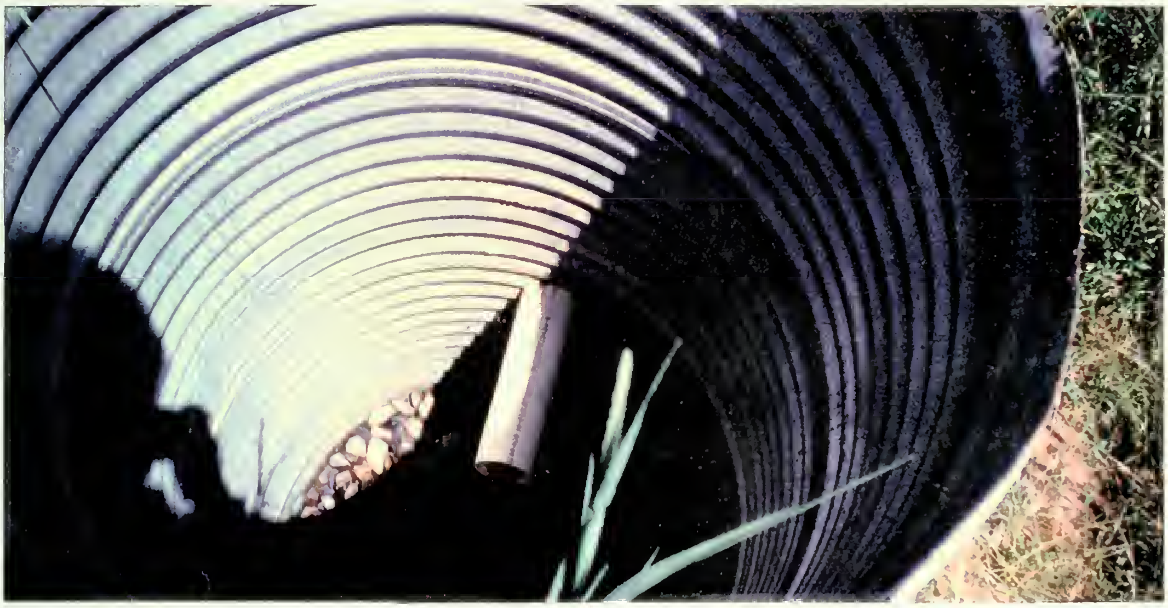

Figure 8. Outlet pipe and metal crock where tile discharge measurements were collected.

Soil moisture

Soil moisture data were collected throughout the 1991, 1992 and 1993 growing seasons. Data were collected for five depths: 0-15 cm, 0-20 cm, 0-30 cm, 0-40 cm, and 0-50 cm using a †TRASE moisture meter. Data were collected at sites located at the midpoint of the two center drains for each plot. A schematic diagram and a brief description of the TRASE moisture meter is included in Appendix A.

Soil temperature

Soil temperatures were monitored at the same time as the soil moisture and watertable readings. Temperatures were monitored with †YSI precision thermistors connected to a †Beckman Tech 300 multimeter at 5 depths (2 cm, 5 cm, 10 cm, 20 cm, and 50 cm) in each plot . The sites were located between the two center drain lines for each plot. A schematic diagram and a brief description of the soil temperature monitoring set up is given in Appendix A.

Soil trafficability

Soil trafficability was assessed by measuring soil strength. Initially a †Rimik cone penetrometer was used to measure soil penetration, but the device did not work in the cool, damp conditions of April and May. A †Geonor H60 field inspection vane tester

shear vane was then used to measure soil shear strength for the 0 to 5 cm and 5 to 10 cm depth. Readings were taken each day over a three day period following several spring and fall rainfall events in 1991 and 1992. Vanes were four bladed of either 20 by 40 mm or a 25.4 by 50.8 mm size. The larger and smaller vanes were used when the soil had low and high shear strengths, respectively. A minimum of three readings were taken for each plot. Readings were taken at the midpoint between drain lines. A schematic diagram and a brief description of the Geonor H60 field inspection vane tester is included in Appendix A.

Yields

Forage yield measurements were taken in June, late July and September, 1992 and June and late July 1993 using a plot mower and hand scale method. Three 2 square metre quadrants per plot were clipped to within 30 mm of the ground, weighed and a 500 gm subsample taken for dry matter determination.

The carrots were harvested in October 1993 with a †Univerco harvester. A yield sample from a 110 square meter area per plot, was put into bulk bins and weighed on platform scales at †Cobi Foods in Berwick. The carrots were then graded into three marketable size categories and four unmarketable classes.

Statistical analysis (ANOVA) was performed on the alfalfa and carrot yield data. The results are significant at a 0.05 confidence level.

Plant counts

On October 21, 1991 alfalfa and timothy population counts were taken using a rope transect method. Counts for each plot were taken from four 0.1 square metre quadrants at three areas (directly over tile lines, 2 metres away from tile line and midway between tile lines). This was repeated in August, 1992.

Alfalfa roots in tile

In October 1993, a backhoe excavated sections of drainage tile (conventional and small bore) in the field. The tile was cut open and the inside of the tile was inspected for presence of roots.

Climatological monitoring

The ambient air temperature was monitored using a †Campbell Scientific 107 thermistor and precipitation was monitored using a tipping bucket rain gauge. All of the data was collected on an hourly basis and stored on a Campbell Scientific CR-10 data logger. All climatological data was collected from late April to mid October over the 3 years of the project.

RESULTS AND DISCUSSION

At the time of subsoiling in 1990, the top soil (0-10 cm) was very dry, however, the subsoil was relatively moist (27% moisture). The high moisture content in the Bg and C horizon was the result of keeping the field fallow for the summer as there was no crop to extract the moisture from the soil. High moisture contents in the subsoil decreases the effective soil disturbance between the vibrating shanks of the subsoiler.

Soil density

Soil density data collected within a few days after subsoiling in 1990, revealed no significant differences among the treatments for the 15-20 cm soil depth (Table 2). At the 15-30 cm depth, the two subsoiled treatments (TSS and SST) had soil densities of 1.50 g cm^{-3} which was approximately 0.1 g cm^{-3} lower than 1.58 and 1.65 g cm^{-3} soil densities of the two non-subsoiled treatments. This improvement in soil density was not to the level desired by the project team although it did lower the soil densities below the critical limit of 1.6 g cm^{-3} believed to restrict the growth of plant roots. The soil densities at the 30-45 cm depth for the SST and TSS treatments were 1.58 and 1.62 g cm^{-3} respectively which was lower than the 1.70 and 1.76 g cm^{-3} densities of the nonsubsoiled treatments. The two subsoiled treatments (TSS and SST) had significantly lower soil densities than the SBT treatment for the 15-30 and 30-45 cm soil depths immediately after subsoiling.

The soil densities for the TSS treatment at all three depths after the second subsoiling were identical to the readings collected after the initial subsoiling.

In 1993, three years after subsoiling, there was no significant difference in soil density among the treatments at the 15-20 cm and 15-30 cm depths. At the 30-45 cm depth, the SST treatment had significantly lower density than the SBT and TSS treatments.

Table 2. Average soil densities (g cm^{-3}) for each treatment in 1990 and 1993 .

Treatment	1990 (before subsoiling)			1990 (after subsoiling)			1993		
	Depth (cm)			Depth (cm)			Depth (cm)		
	15-20	15-30	30-45	15-20	15-30	30-45	15-20	15-30	30-45
NSS	1.38	1.62	1.76	1.36	1.58	1.70	1.31	1.58	1.74
SBT	1.41	1.62	1.79	1.39	1.65	1.76	1.24	1.57	1.76
TSS	1.43	1.61	1.78	1.36	1.50	1.62	1.27	1.59	1.77
SST	1.34	1.60	1.73	1.36	1.50	1.58	1.27	1.55	1.69
*SEM	0.033	0.021	0.020	0.016	0.033	0.032	0.039	0.027	0.023

* *Standard error of mean.*

Hydraulic conductivity

Hydraulic conductivity measurements, collected immediately following subsoiling in 1990 for the 30 and 45 cm depths, showed the treatments subsoiled before and after tile installation (SST and TSS) had 3 to 5 times more water movement through the soil than the non-subsoiled treatments (SBT and NSS).

Three years after subsoiling there was no difference in hydraulic conductivity among the treatments (Table 3). The improvements in hydraulic conductivity and soil density caused by subsoiling were only temporary. Whether the improvements lasted until the 1991 or 1992 growing season was not determined in this study.

Table 3. Average hydraulic conductivities (cm hr^{-1}) for each treatment in 1990 and 1993 .

Treatment	1990 (before subsoiling)		1990 (after subsoiling)		1993	
	Depth (cm)		Depth (cm)		Depth (cm)	
	20-30	35-45	20-30	35-45	20-30	35-45
NSS	0.10	0.53	0.58	0.30	0.51	0.19
SBT	0.20	0.11	0.43	0.23	0.50	0.17
TSS	0.04	0.33	2.08	1.57	0.45	0.15
SST	0.51	0.21	2.04	1.27	0.64	0.20

Watertable

The density data showed that soil density increased with soil depth (Table 2). Increased density generally indicates a reduced pore space and water holding capacity along with slower water movement in the soil. This decrease in water movement is supported by the hydraulic conductivity data for the 20-30 cm and 35-45 cm depth (Table 3). Slow water movement in the subsoil results in water ponding and drainage occurring in predominantly a horizontal direction.

The six wells located between two drain lines in the 10 m spacing treatments provide a profile of the watertable drawdown between the two drains. The watertable was highest at the midspacing between the drains and lowest closer to the drains. This elliptical watertable drawdown shape is shown in Figure 9 which shows the average watertable drawdown for three days following four storm events in 1991 for the conventional tile treatment (NSS).

The watertable receded to the compacted subsoil within three days after the soil was saturated for all treatments except the TSS treatment which had watertables about 5 to 10 cm higher than the other treatments.

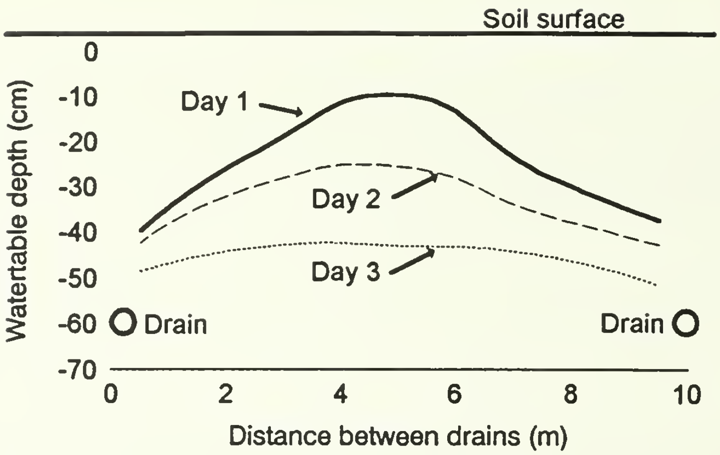

Figure 9. Average watertable drawdown for three days following storm events in 1991 for the NSS treatment.

Watertables were usually 5 cm lower on the small bore, closely spaced tile (SBT) treatment than the other treatments for the first two days after the soil was saturated. This can be seen in Figure 10 which shows the watertable and corresponding tile outflow for May 4 to 6 1991, after a 70 mm rainfall.

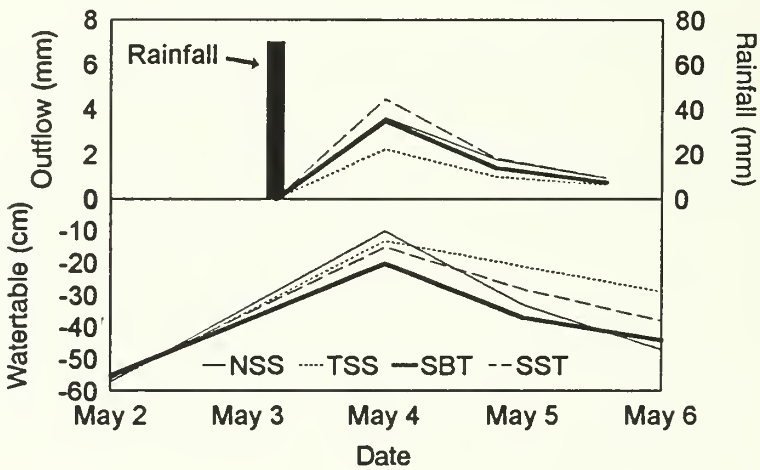

Figure 10. Average watertable and tile outflow for all treatments on May 4 to 6, 1991.

Watertable levels above a 45 cm depth (depth to the compact subsoil) were summed for the growing season (Table 4). This method of analyzing watertable data is referred to as the sum of the excess watertables (SEW). Days when the watertable was 10 cm below the soil surface resulted in an SEW value of 35 cm day^{-1} and days when the watertable was 25 cm below the soil surface resulted in an SEW value of 20 cm day^{-1}. Thus a lower SEW value is desired. The SBT treatment had considerably lower SEW values than the other treatments for the three growing seasons but due to high variability among replicates, was not significantly lower.

Table 4. Average SEW 45 values for three growing seasons (cm days^{-1}).

Treatment	1991	1992	1993
NSS	342.5	95.5	56.9
TSS	308.7	145.3	89.0
SBT	181.1	55.9	27.7
SST	263.3	90.8	45.2
*SEM	44.49	24.18	9.76

* *Standard error of mean*

In the spring of the 1991 growing season, the watertables for all treatments remained above the compact subsoil until the middle of May (Figure 11). The watertable did not appear in the top 45 cm of soil again until the middle of September. In the 1992 and 1993 growing seasons, the watertables for all treatments were within 45 cm of the soil surface until the middle of May but did not get above the subsoil for the rest of the growing season.

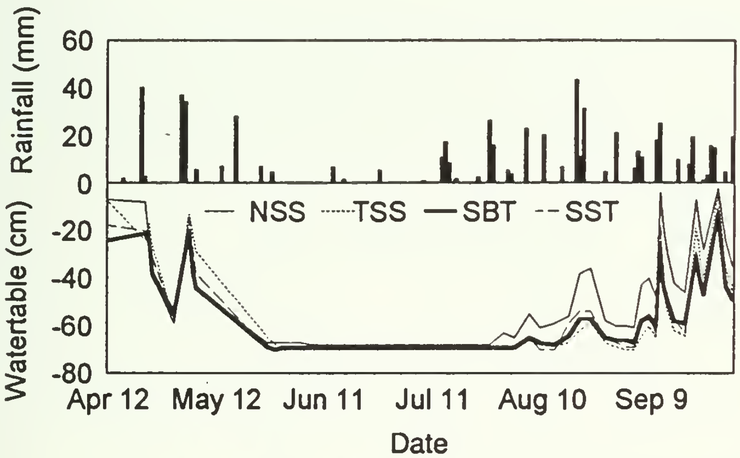

Figure 11. Average watertable for all treatments during the 1991 growing season.

Tile outflow

Tile outflow for all treatments corresponds to the midspacing watertable fluctuations. Tile outflows were highest when the watertable was near the soil surface and decreased as the watertable receded. Outflow was minimal three days after soil saturation when the watertable had receded to the compacted subsoil. This indicates that the subsoil had limited porosity and the slight improvement in soil structure caused by subsoiling was not evident in 1991 or afterwards.

At high outflows (>4.0 l min^{-1}), the small bore, closely spaced tile treatment removed more water from the soil than the other treatments. Figure 12 shows the average tile outflow and watertable for May 9 to 11, 1992 following a 10 mm rainfall. On May 9, the SBT treatment had 75 % more outflow than the other treatments.

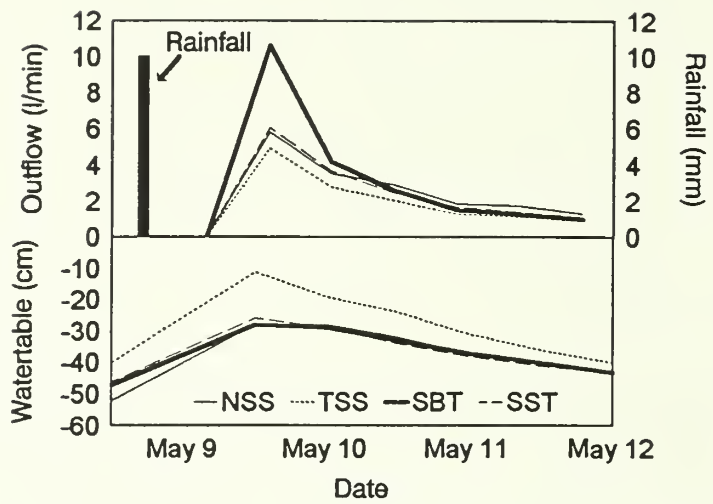

Figure 12. Average tile outflow and watertable for all treatments on May 9 to 11, 1992.

The cumulative tile outflows for all treatments for the 1991, 1992 and 1993 growing season are listed in Table 5. The tile outflow for the TSS treatment was significantly lower than the NSS treatment in 1991 but there were no significant differences among treatments in 1992 or 1993. Total tile outflow from the SBT treatment was similar to the other treatments even though the SBT treatment had larger peak outflows when the watertable was near the soil surface.

Table 5. Cumulative tile outflows for three growing seasons (l min^{-1}).

Treatment	1991	1992	1993
NSS	25.2	24.7	12.1
TSS	11.8	16.3	12.8
SBT	15.2	23.3	10.1
SST	21.7	20.0	13.5
*SEM	2.92	2.36	2.65

**Standard error of mean*

Soil moisture

Figure 11 shows the soil moisture at the 30-40 cm depth for all treatments from April 13 to September 28, 1992. The soil moisture content was highest in the SST treatment during wet spring conditions and lowest in the TSS treatment during dry summer conditions. This trend was not seen for any of the other soil depths. Data variability makes it impossible to draw any conclusions.

The moisture content at the 30-40 cm depth rarely dropped down to the 21% level (Figure 13) which is the maximum moisture content allowed to achieve optimum shattering from subsoiling. If tile drainage and forage production can not reduce the soil moisture to less than 21% then this would suggest that optimum conditions for subsoiling rarely occur in the dense subsoils of Nova Scotia.

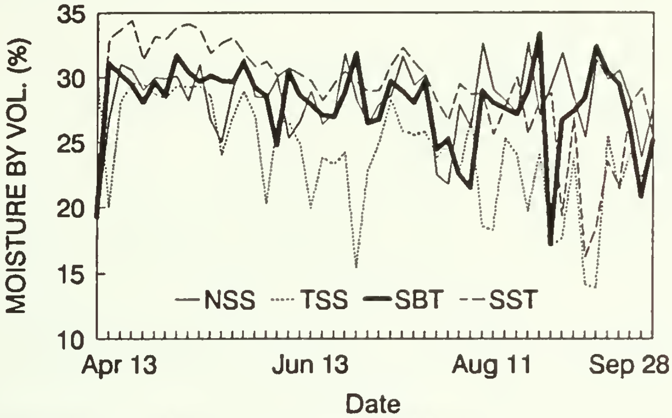

Figure 13. Average soil moisture for all treatments at the 30-40 cm depth from April 13 to September 28, 1992.

Soil temperature

The soil temperature data generally corresponded with the soil moisture data. As soil moisture increased, soil temperature decreased and as the soil dried out the soil temperature would increase (Figure 14).

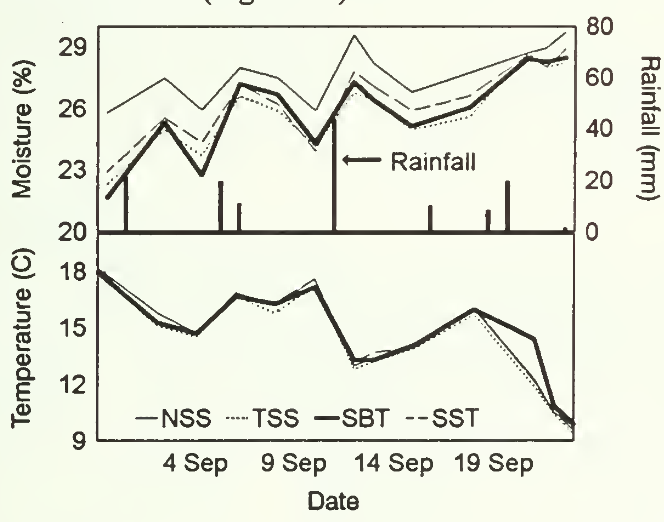

Figure 14. Soil moisture and soil temperature from August 30 to September 23, 1991.

There was no difference in soil temperature among the treatments for any depth in 1991, 1992 or 1993. This can be seen in the 1993 data shown in Figure 15.

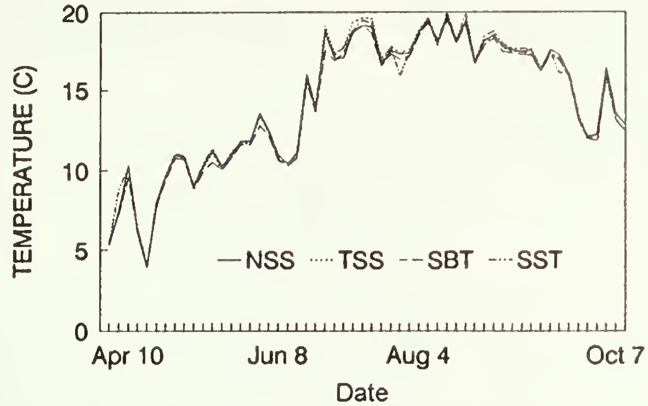

Figure 15. Average soil temperature for all treatments at the 20 cm depth for the summer of 1993.

Soil trafficability

Soil shear strength increased each day following a rainfall event. There was no difference in soil shear strength among the treatments. This was partly due to the high variability in the data caused by the sensitivity of the shear vane to roots, cracks and stones in the soil.

Yields

Forage yields for 1992 and 1993 and carrot yields for the 1993 growing season were determined from two plots for the NSS and SBT treatments. The crops on plot 6 (NSS) and plot 12 (SBT) were damaged as a result of water ponding during the growing season. Overall, yields for the 1992 and 1993 growing season were very good (Figure 16).

Figure 16. Forage yields for the 3rd cut in 1992.

Forage yields were significantly greater on the small bore, close spaced tile treatment (SBT) than the TSS and SST treatments for the second cut in 1992 and the 1993 season total (Table 6).

Table 6. Forage yields, carrot yields and % marketable carrots for all treatments.

Treatment	Forage yields (Dry Tonnes ha^{-1}) 1992 1st cut	1992 2nd cut	1992 3rd cut	1992 Total	1993 1st cut	1993 2nd cut	1993 Total	Carrot Yields ($MT\ ha^{-1}$) 1993	% Marketable 1993
NSS	4.28	3.47	2.13	9.88	5.43	3.25	8.68	43.36	85.64
SBT	4.16	3.91	2.08	10.15	5.43	4.01	9.44	42.66	74.31
TSS	4.24	3.32	2.25	9.81	4.82	3.59	8.41	43.13	82.86
SST	4.18	3.30	1.89	9.37	4.99	3.41	8.40	39.37	82.89
*SEM	0.194	0.106	0.190	0.386	0.142	0.168	0.229	1.284	

* *Standard error of mean.*

There was no significant difference in carrot yields among treatments. Carrot quality was similar for the NSS, TSS and SST treatments but the SBT treatment had about 10 % less marketable carrots than the other treatments.

Plant counts

Plant counts were taken to determine the survival rate of alfalfa and timothy plants. There was no difference among treatments for the plant counts taken in the year of planting. In the second year after planting it was difficult to differentiate individual plants from plants that had tillered. The only way to distinguish would involve extraction of the plants which was not practical. There was a good plant population for all treatments in 1991 and 1992.

Alfalfa roots in tile

The low soil densities and improved soil structure over tile lines allows for deeper root penetration for deep rooting crops such as alfalfa. This could lead to problems if the roots grow into the drainage tile and obstruct the flow of water. Tile inspection revealed only one alfalfa root for every 60 cm of tile. This quantity of root mass was thought to have no effect on the water flow in the drains, even in the small bore pipe. When the tile was inspected in October 1993, there had been no large flows through the tile since the spring. Large flows can break off roots and flush them out of the system or sometimes they will lodge at junctions in the system and cause blockage.

CONCLUSION

Subsoiling only slightly reduced subsoil compaction and improved the internal drainage of the soil in the initial year of subsoiling. This was thought to be the result of the high soil moisture content at the time of subsoiling. There was no difference between subsoiling before or after tile installation. Drainage performance, soil characteristics and crop production showed no benefits as a result of subsoiling in the three growing seasons following subsoiling. Soil density and hydraulic conductivity measurements taken three years after subsoiling revealed the subsoil had reconsolidated back to its original state before subsoiling. It was not determined if soil reconsolidation occurred in the winter and spring months before the crop was seeded or sometime in the next two years. Deep incorporation of soil amendments may reduce soil reconsolidation.

It is recommended that a crop be grown on the field in order to achieve a soil moisture content of 21 % or less for optimum shattering of the soil due to subsoiling. However, in the three years that the subsoil moisture content was monitored, the moisture content rarely approached the 21% level even though the field was tile drained and had good forage production.

The small bore, close spaced tile treatment had better drainage performance than the other treatments. It removed water more quickly, especially when the soil was completely saturated, and resulted in watertables about 5 cm lower than the conventional tile drainage with 10 m spacing. The small bore tile treatment also produced significantly better forage yields than the other treatments but had 10% less marketable carrots.

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APPENDIX A

CPN MC-3 Portaprobe

The MC-3 Portaprobe emits gamma radiation from a Cesium-137 source located at the end of the depth adjustable probe and determines soil density by the amount of radiation that passes through the soil to the detector on the bottom of the MC-3. A high density soil will absorb more gamma radiation than a low density soil.

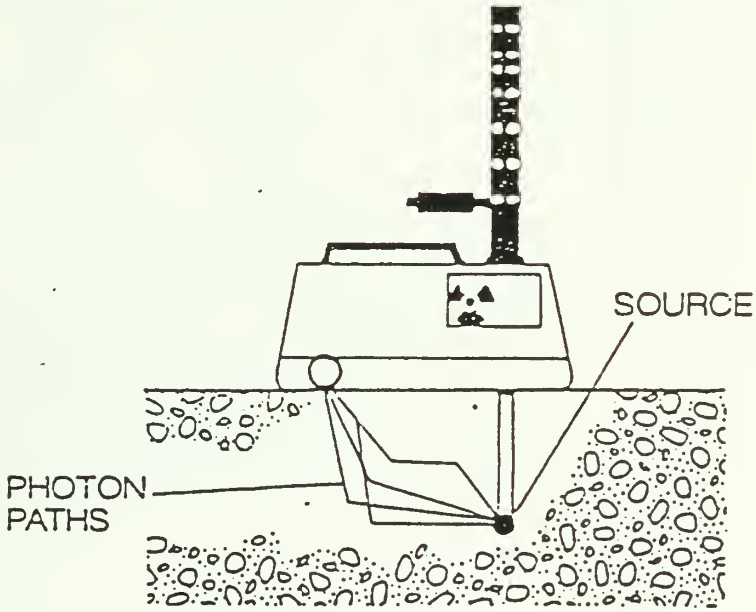

Figure 17. CPN MC-3 Portaprobe.

Guelph permeameter

The model 2800K1 Guelph permeameter is a constant-head device which operates on the Mariotte siphon principle and provides a quick and simple method for determining field saturated hydraulic conductivity.

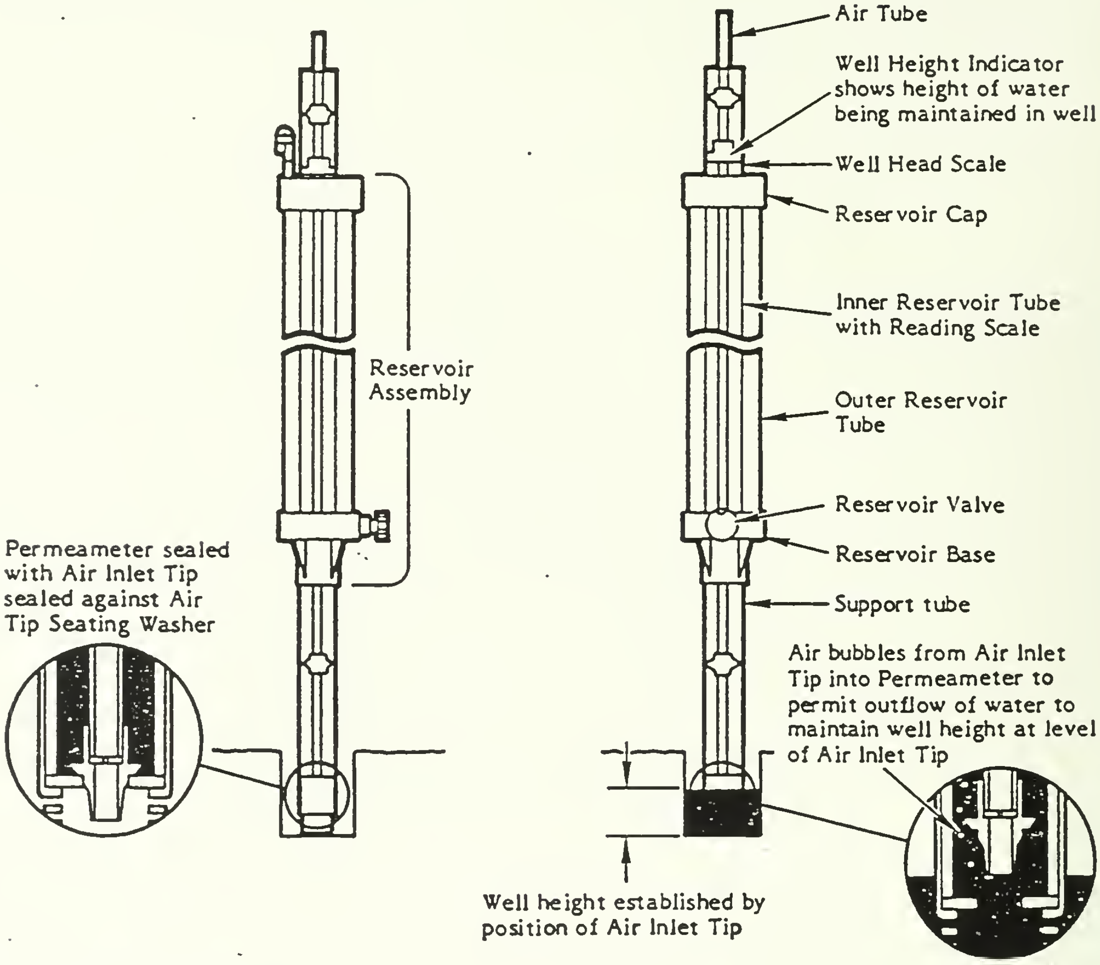

Figure 18. Guelph permeameter.

Trase moisture meter

The Model No. 6050X1 Trase system uses Time Domain Reflectometry to measure the volumetric water content of soil surrounding two parallel wave guides (metal rods). The principle of the TDR is based on the large difference in the dielectric constant of water and soil constituents makes it possible to determine soil moisture by the time it takes microwave pulses to travel down a parallel transmission line (metal rods). The higher the soil moisture content surrounding the metal rods, the slower the speed at which the microwave pulse travels.

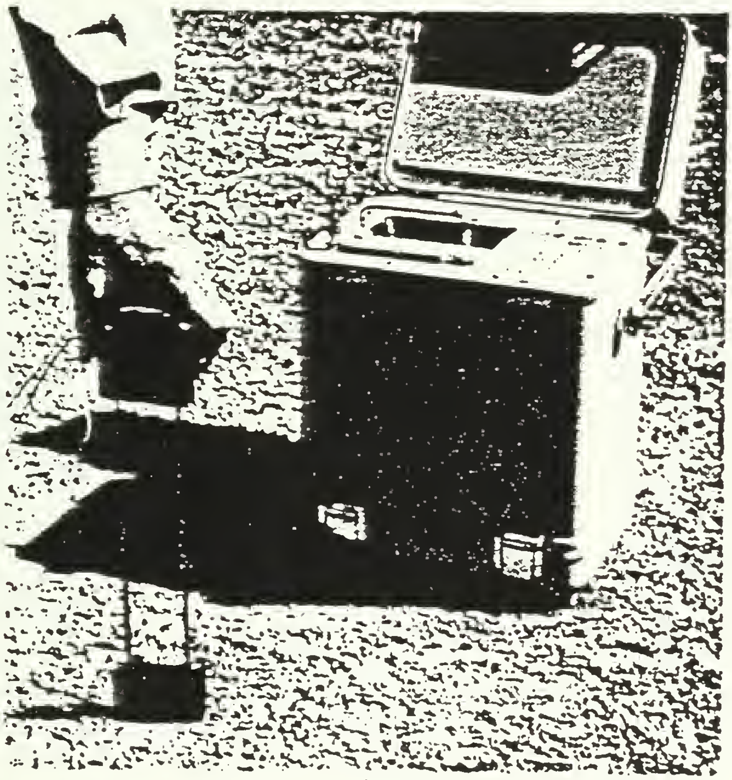

Figure 19. Trase moisture meter.

Thermistor and voltmeter system.

The soil temperature monitoring system consisted of a voltmeter and thermistors. Lead wires from the buried thermistors were located on a board above the soil surface. A voltmeter was connected to the leads and measures the resistance across the thermistor. Resistance is inversely proportional to the temperature.

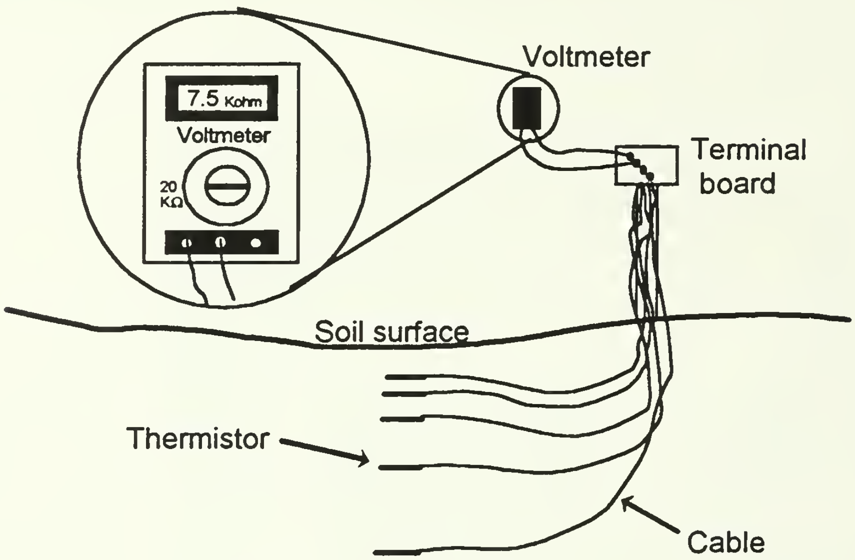

Figure 20. Thermistor and voltmeter system.

Geonor inspection vane tester H-60

The Geonor field inspection vane tester measures the shear strength of soils up to a maximum strength of 26 T m^{-2}. The shear vane works by pushing the vanes into the soil and turning the handle until the soil fails. A spiral-spring located between the upper and lower part of the shear vane handle measures the torque required to turn the vanes. A graduated scale on the shear vane handle shows the soil shear strength.

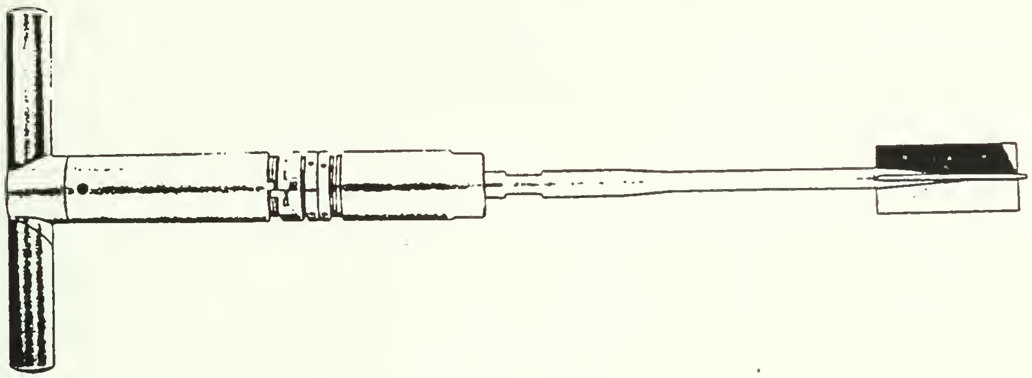

Figure 21. Geonor H-60 shear vane.