TECHNOLOGY EVALUATION AND DEVELOPMENT SUB-PROGRAM

EFFECTS OF MANAGEMENT ON SOIL HYDRAULIC PROPERTIES:

FINAL REPORT

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EXECUTIVE SUMMARY

A new and particularly useful field instrument, the Guelph Pressure Infiltrometer has been developed for determining in-situ measurements of soil hydraulic properties. The objectives of this study were to assess the effects of management on changes in surface hydraulic properties. Specific objectives were:

1. To further test the relationship between rainfall runoff (from rainfall simulation experiments) and predicted runoff using measurements of K_{fs}, ϕ_m, $\Delta\theta$, and Tp from the pressure infiltrometer.
2. To examine the temporal changes in hydraulic properties measured with the pressure infiltrometer under two tillage systems and compare them to temporal changes in surface runoff (simulated).
3. To examine the effects of different cropping/tillage systems on changes in surface hydraulic properties.

Measurements were taken on 5 Tillage-2000 sites and also at the Elora Research Station, Univ. of Guelph. At the field scale sites, paired benchmarks were selected to cover the major soil and topographic changes in the field. A pressure infiltrometer attachment for the Guelph permeameter was used to obtain measurements of field saturated hydraulic conductivity K_{fs} and matric flux potential ϕ_m on each of the tillage/soil landscape combinations. Undisturbed soil cores were taken to determine bulk density, total porosity, saturated hydraulic conductivity, moisture retention curves, and an estimate of macro-porosity.

At three of the T2000 sites rainfall simulation studies were also carried out as part of a Ministry of Environment project. The rainfall simulation trials gave steady runoff, infiltration rates, and soil loss rates to compare to the pressure infiltrometer and undisturbed core measurements. Detailed measurements at three times during the year were taken at one of the sites (D. Lobb's).

The detailed measurements at D. Lobb's site indicated that no-tillage (9 yrs) resulted in;

1. higher bulk density
2. lower total porosity
3. lower macro-porosity
4. lower saturated hydraulic conductivity

5. lower field saturated hydraulic conductivity
6. lower matric flux potential
7. shorter times to ponding and runoff, and
8. lower infiltration rates (higher runoff)

compared to a moldboard treatment. The results were consistent across all measurement times. Similar effects of no-tillage compared to a minimum tillage treatment were also observed at a second site. No significant differences between no-till and other tillage systems were found at the remaining sites. Comparisons of minimum tillage and moldboard tillage treatments also indicated no influence of tillage on surface hydraulic properties.

At every site where both rainfall simulation and Guelph pressure infiltrometer measurements were taken, the data from both methods were comparable. Thus, the pressure infiltrometer should be a reliable, cost effective instrument for evaluating management effects on hydraulic properties. The portability and minimum site disturbance of the permeameter make it a good choice for small plot experiments.

The data suggest that there is a risk of increased surface runoff on no-tillage plots. The main factors resulting in decreased soil loss in no-till appear to be increased surface protection and decreased particle detachment, not decreased runoff. The risk of increased surface water runoff may be significant for the movement of non-adsorbed chemicals or soil additions (such as manure).

The increased runoff and decreased infiltration rates in the no-till does not support the hypothesis that no-till increases the risk of movement of chemicals to the groundwater.

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Glossary of Terms

GP = Guelph Permeameter - instrument used to determine saturated hydraulic parameters in a field soil (auger hole method). Calculations are based on the 3D solution of infiltration in an unsaturated soil.

GPI = Guelph Pressure Infiltrometer - attaches to the body of the GP and allows for surface measurement of soil hydraulic parameters.

GTI = Guelph Tension Infiltrometer - attaches to the body of the GP and a second Mariotte bottle to apply negative head for flow from a porous disk.

K_{fs} = "field-saturated" hydraulic conductivity (units – $m•s^{-1}$)

ϕ_m = matric flux potential or the unsaturated component of flown soil (units = $m^2•s^{-1}$)

Ksat = "saturated" hydraulic conductivity usually determined in a laboratory from an intact soil core or one artificially packed to a known bulk density.

α = alpha parameter calculated from the ratio K_{fs}/ϕ_m (units = m^{-1})

θ_v = volumetric moisture content measured with a Tectronix 1502B cable tester (e.g units = 4.3% = 0.043 $m^3•m^{-3}$).

Tp = estimated time to ponding calculated from soil parameters measured with the GPI.

Total Porosity = total volume of pore space expressed as a percentage of the total volume of soil.

Macroporosity = large soil pores, corresponding to pore size >0.12 mm diameter, which drain when put under pressure 0-25 mb.

Bulk Density = (ρ_b) mass of soil per volume of soil (units $g•cm^{-3}$)

1.0 INTRODUCTION

1.1 Background

The trend during the past several decades in soil physics has been towards field experimentation. Many of the principles of water and solute transport had been thoroughly tested in the laboratory during the previous decades, primarily using air-dried, sieved soil. At times, "undisturbed" soil cores were used. However, applying these laboratory determined hydraulic and solute transport parameters to field situations often underestimated the travel times of water and solutes to various depths (and ultimately to groundwater). What once was perceived to be one dimensional flow appeared to actually be a complex two (or three) dimensional flow under field conditions. Macropores, consisting of cracks, fractures, decayed root passageways, worm holes, etc., can lead to preferential vertical flow, particularly under conditions of surface ponding. Fingering effects, brought about by textural/structural discontinuities, can also lead to two or three dimensional flow. What was once perceived to be rather straightforward, one dimensional flow has turned out to be much more complex in nature.

A new and particularly useful field instrument, the Guelph Pressure Infiltrometer (GPI), provides a technique for determining valid in-situ measurements of soil hydraulic properties such as saturated hydraulic conductivity and matrix flux potential. The GPI has advantages over the more labour intensive laboratory techniques since it provides data that is more pertinent to the field situation, allowing immediate on-site estimates while the investigators are still at the study area. A detailed discussion and field testing of the GPI has been given in a previous TED research report (Kachanoski et al. 1989) and serves as an appendix to this report. Briefly the study had the following conclusions and recommendations.

1.2 Conclusions From 1988 TED Study

The pressure infiltrometer is a fast, reliable method for estimating surface field saturated hydraulic conductivity K_{fs}. The K_{fs} values correlated significantly with the more labour intensive, slower, undisturbed core laboratory method for measurement of saturated hydraulic conductivity K_{sat}, $r = 0.92$). The pressure infiltrometer can also be used to estimate the unsaturated flow component, the Matric Flux Potential ϕ_m, and subsequently an estimate of the effective time to ponding (Tp) for a given rainfall rate. An estimate of the average flow weighted capillary length scale can also be obtained. The predicted effective time to ponding Tp was significantly correlated $r = 0.88$) to measured surface runoff from rainfall simulation studies. The regression relationship was almost identical to the theoretical equation for predicted runoff potential. The error in predicted runoff was negligible in the no-till treatment (1.65 cm predicted vs. 1.73 cm measured) but significant in the moldboard treatment on two out of four sites where substantial erosion occurred.

Matric Flux Potential ϕ_m measurements from the pressure infiltrometer were significantly lower in the 8 year no-till compared to the 1 year no-till, at similar initial soil water contents suggesting a decrease in macroporosity in the 8 year no-till. Soil core measurements substantiated the Om measurement indicating a significant decrease in total porosity in the 8 year no-till. In nearly all cases this decrease in total porosity for the 8 year no-till, as compared to the moldboard and 1 year no-till, was explained by a decrease in macroporosity (pore sizes greater than 0.12 mm in diameter). This decrease in macroporosity was the cause of the significant decrease in field saturated hydraulic conductivity K_{fs} in the 8 year no-till, measured with the pressure infiltrometer: On average K_{fs} in the 8 year no-till plots was 7x lower than the moldboard treatment and 4x lower than the 1 year no-till. This provides direct evidence of the degree of consolidation occurring over time after tillage.

The pressure infiltrometer has proven to be a reliable instrument for providing useful information on saturated and unsaturated flow, and can be used to estimate the effective time to ponding Tp, which appears to be a useful parameter for assessing management effects on potential runoff generation. A combination of the K_{fs}, ϕ_m, $\Delta\theta$ and calculated Tp, along with the stability index f_s would provide you with an extremely useful set of information for assessing the effects of management on surface hydraulic properties. More data is needed, however, to confirm the relationship between effective time to ponding Tp and runoff.

The macroporosity estimates from the surface cores were very useful invalidating the cause of the decreased K_{fs} in the no-till. However, a measurement of total porosity, which could be estimated from bulk density, along with a measurement of K_{fs} from the pressure infiltrometer would give approximately the same conclusion since K_{fs} is sensitive to macropores. The estimate of macroporosity using pressure plate apparatus and undisturbed cores is expensive and very time consuming. For monitoring purposes an estimate of bulk density (fast and simple) coupled with measurements from the pressure infiltrometer may be sufficient.

1.3 Objectives

The general objective of the 1989-1990 study was to use the pressure infiltrometer to assess the effects of management on surface hydraulic properties. Specific objectives were:

1. To further test the relationship between rainfall runoff (from rainfall simulation experiments) and predicted runoff using measurements of K_{fs}, ϕ_m, $\Delta\theta$ and Tp from the pressure infiltrometer.

2. To examine the temporal changes in hydraulic properties measured with the pressure infiltrometer under two tillage systems and compare them to temporal changes in surface runoff (simulated).

3. To examine the effects of different cropping/tillage systems on changes in surface hydraulic properties.

2.0 THEORY

A detailed summary of the theory and methodology of using the surface pressure and tension infiltrometers has been presented in the previous TED report (Kachanoski et al. 1989), which is in turn a summary of Reynolds and Elrick (1990). This section is included to review the existing body of knowledge and to include any recent additions to the theory.

The flux of water in soils is well described by the relationship generally attributed to Darcy (1856) and later extended to unsaturated soil by Buckingham (1907):

$$J_w = - K (\psi) \nabla\psi_h \tag{1}$$

where J_w (LT^{-1}) is the volume flux density of water, K (LT^{-1}) is the hydraulic conductivity and is a function of the soil water potential ψ (L), and ψ^h (L) is the hydraulic head. L and T stand for the dimensions of length and time respectively. The relationship between the potentials is given by

$$\psi_h = \psi + \psi_z \tag{2}$$

where ψ_z (L) is the gravitational potential. If the vertical coordinate z is defined to be positive upwards, then Eq. (1), for one dimensional flow, can be written as

$$J_w = -K(\Psi)\, \partial\Psi_h / \partial z = -K(\Psi)\, \partial\Psi/\partial z - K(\Psi) = -D(\theta)\, \partial\theta/ \partial z - K(\theta) \tag{3}$$

In Eq. (3) we have made use of the relationship between water content, θ ($L^3 L^{-3}$), and the water potential, ψ and have also introduced the soil water diffusivity, D ($L^2 T^{-1}$) where

$$D = K(\psi)\, \partial\psi/\partial\theta \tag{4}$$

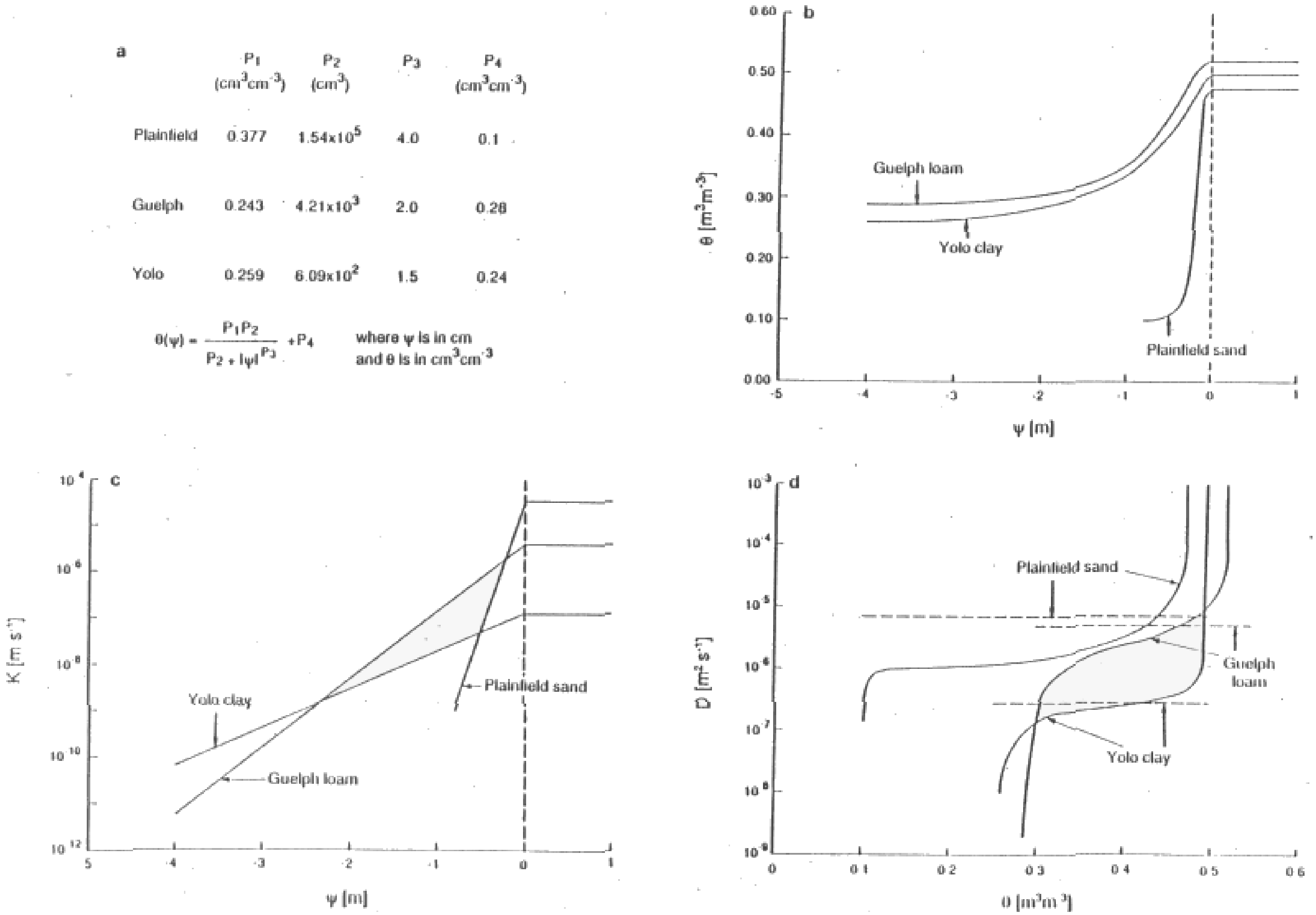
Note that the use of D(θ) limits the application of the diffusivity form to unsaturated soil only as D(θ) becomes undefined as the water content approaches saturation. There is no such restriction on the use of K(θ) (or K(ψ)).

Some typical values for these micro-hydrological parameters are given in Fig. 1. The empirical relationships between the water content and water potential for three arbitrarily chosen soils are given in Fig. la and shown graphically in Fig. 1b. The relationship between hydraulic conductivity and water potential for the three soils is shown in Fig. 1c and was assumed to have the useful empirical form (Gardner, 1958):

$$K(\psi) = K_{fs}\, e^{\alpha\psi} \; ; \quad \psi \leq 0 \qquad (5)$$

where α is the slope of ln K vs ψ. For plain field sand, Guelph loam and Yolo clay, K_{fs} and a were assigned values of 3.44×10^{-5} m•s^{-1}, 3.67×10^{-6} m•s^{-1}, 1.23×10^{-7} m•s^{-1} and 13.06, 3.36 and 1.88 respectively. The $D(\theta)$ relationship shown in Fig. 1d was obtained from Eq. 4. These values are typical of air-dried, sieved and repacked soils as determined from laboratory studies. We show later that these micro-hydrological characteristics can be somewhat different under field conditions where macropores may be present and where the flow boundary conditions are considerably different from that of a laboratory core. Unfortunately, good field data is generally not available primarily because of the lack of a good methodology.

As shown in Eq. (1) and (3), the volume flux density of water is given by the product of the soil hydraulic property (hydraulic conductivity or soil water diffusivity) and the appropriate gradient(s). The hydraulic properties applicable to flow from an auger hole in which ponded water is present (Fig. 2a) and from a pressure infiltrometer (Fig. 2b) in which water is supplied to the surface at a positive pressure involve both the saturated and unsaturated components of the hydraulic conductivity (Fig. 2 and 3). In Fig. 2, the extent of the saturated bulbs and the position of the wetting fronts are shown for some arbitrary times which are sufficiently large that steady flow has essentially been established at the



	P_1 (cm³cm⁻³)	P_2 (cm³)	P_3	P_4 (cm³cm⁻³)
Plainfield	0.377	1.54×10^5	4.0	0.1
Guelph	0.243	4.21×10^3	2.0	0.28
Yolo	0.259	6.09×10^2	1.5	0.24

$$\theta(\psi) = \frac{P_1 P_2}{P_2 + |\psi|^{P_3}} + P_4$$

where ψ is in cm
and θ is in cm³cm⁻³

Figure 1: Typical values for the microhydrologlcal parameters for three arbitrarily chosen soils:(a) the soil parameters; (b) the water content-water potential relationships; (c) the hydraulic conductivity-water potential relationships; and (d) the soil water diffusivity-water Content relationships.

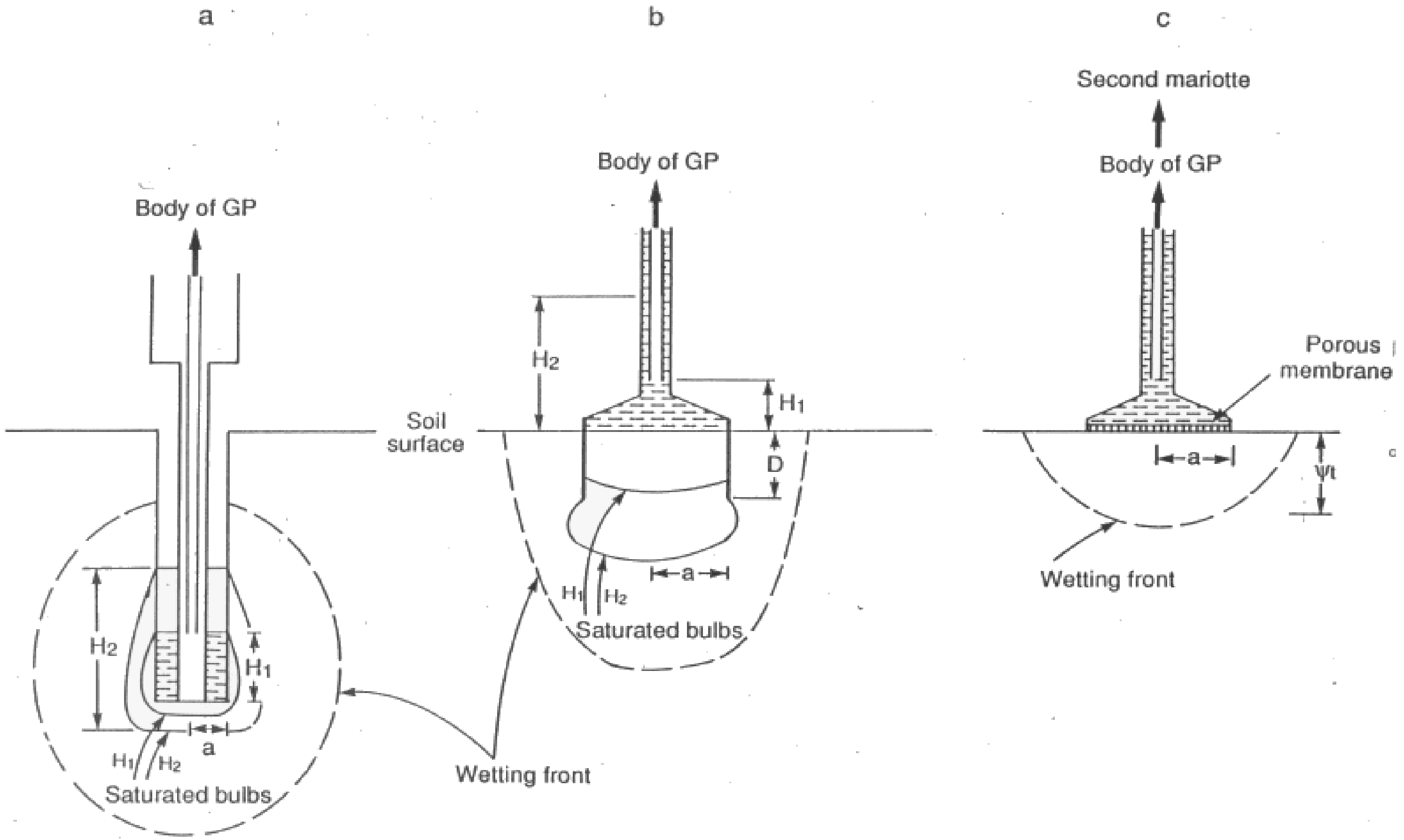


FIGURE 2. Field techniques for measuring the hydraulic conductivity of soils: (a) the Guelph Permeameter; (b) the Guelph Pressure Infiltrometer and; (c) the tension infiltrometer. In (a) and (b) the approximate positions of the steady state saturated bulbs for two ponded heights, H_1 and H_2, are shown. No saturated bulb develops under the tension infiltrometer.

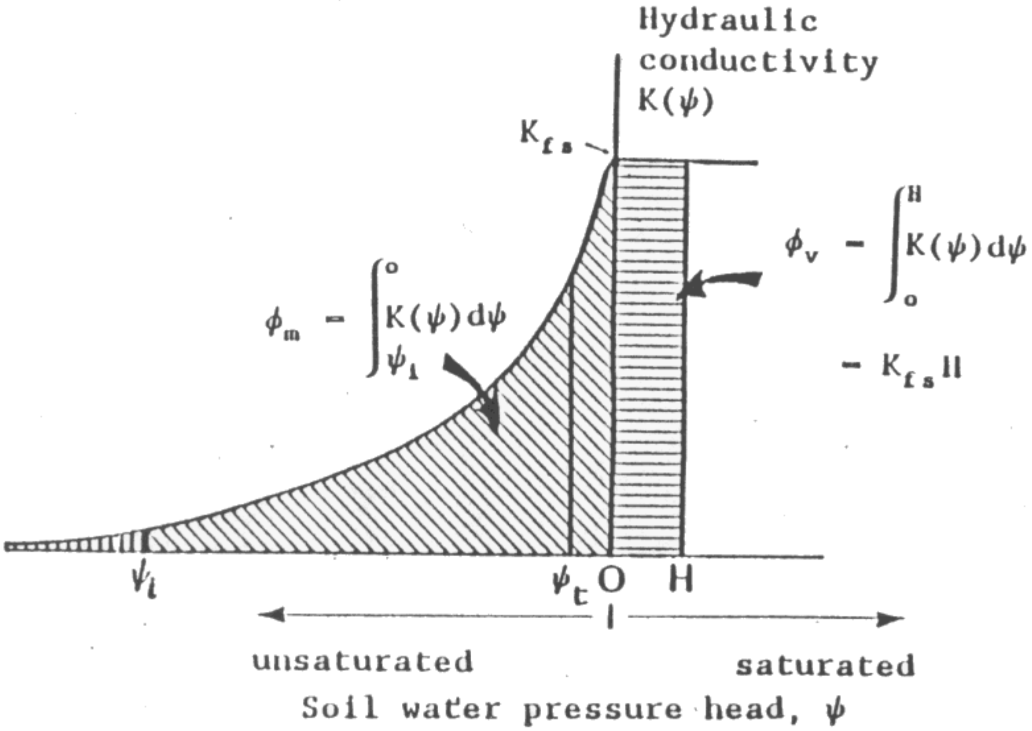


Figure 3: An Idealized relationship between hydraulic conductivity and soil water potential.

two heights. At true steady state, which occurs as time approaches infinity, the wetting front would theoretically extent to infinity (or to boundaries established for a numerical solution). At true steady state, the size of the saturated bulb remains finite and essentially the same as those depicted in Fig. 2a and 2b. There is no saturated bulb under the tension infiltrometer (Fig. 2c).

The relationship between hydraulic conductivity, K and water potential Ψ is shown in Fig. 3. In our approximate analytical analysis, it is the integral properties of the $K(\Psi)$ relationship that we show later to be of importance. We define the driving flux potential, ϕ_d, as follows:

$$\phi_d = \int_{\psi_i}^{H} K(\psi)\,d\psi = \int_{\psi_i}^{0} K(\psi)\,d\psi + \int_{0}^{H} K(\psi)\,d\psi = \phi_m + \phi_v \tag{6}$$

where ψ (L) is the soil water pressure head. The matric flux potential, ϕ_m, is defined as

$$\phi_m = \int_{\psi_i}^{0} K(\psi)\,d\psi \tag{7}$$

and ϕ_v, the velocity (flux) potential (Kirkham and Powers, 1972) is defined as

$$\phi_v = \int_{0}^{H} K(\psi)\,d\psi = K_{fs} \cdot H \tag{8}$$

In a soil in which the initial or background soil water pressure head Ψ_i, corresponding to an initial water content θ_i, the driving flux potential is given by $\phi_d = \phi_m + \phi_v$, (the sum of the areas shown in Fig. 3) and is the value of ϕ_d at the bottom surface of the test well. Note that the α parameter ($0 < \alpha < \infty$) of Eq. (5) is the slope of ln K vs Ψ. We may set

$$\lambda_c = \alpha^{-1} \tag{9}$$

where α is called the sorptive number and λ_c the macroscopic capillary (or sorptive) length scale (White and Perroux, 1987).

Substituting (5) into (7) gives

$$\alpha = (K_{fs} - K_i) / \phi_m \tag{10}$$

For this analysis we are more interested in α^*, the ratio of K_{fs} to ϕ_m, where

$$\alpha^* = K_{fs} / \phi_m = \alpha/(1-K_i/K_{fs}) \tag{11}$$

Thus the relationship between α^* and α depends upon Ψ_i. For all soils when Ψ_i is at or below the field capacity value (i.e at the field capacity water content or drier) then $K_i << K_{fs}$ and $\alpha^* = \alpha$. However, in soils where Ψ_i approaches zero (soils very close to saturation), which can occur in very wet and in poorly drained soils, then α^* can be larger than α.

It should be noted that α^* can also be interpreted as the suction at the wetting front of the Green-Ampt model:

$$| \Psi_f | = 1/\alpha^* \tag{12}$$

where Ψ_f is the wetting front potential (Mein and Farrell, 1974).

The steady state flow of water from the pressure infiltrometer can be approximated by equations of the form (Reynolds et al., 1985; Philip, 1985; Reynolds and Elrick, 1990):

$$Q = f(h,a)\, K_{fs} + g(H,a)\, \phi_m \tag{13}$$

where Q (L^3T^{-1}) is the <u>steady</u> intake rate of water, H (L) is the constant height of ponded water, a (L) is the radius of the well or infiltrometer, K_{fs} (LT^{-1}) is the field saturated hydraulic conductivity and ϕ_m (L^2T^{-1}) is the matric flux potential. Note that it is the integral properties of the $K(\Psi)$ relationship that are of importance when determining the steady state flow. From Fig. 3 it is shown that ϕ_m and ϕ_v represent the unsaturated and saturated areas under the $K(\Psi)$ curve; however, it is easy to obtain K_{fs} directly from ϕ_v because the rectangular area is given by $K_{fs} \bullet H$ and H is known. Thus the important integral properties are K_{fs}, ϕ_m and their ratio α^*.

2.1 Pressure Infiltrometer

The most recent theory on the pressure infiltrometer has recently been accepted for publication and a copy of the final manuscript can be seen in Appendix 1 (Reynolds and Elrick, 1990). A brief outline of the theory is outlined here.

The Guelph Permeameter (GP) is a useful, field portable instrument that can provide valid in-situ measurements of soil hydraulic properties such as saturated hydraulic conductivity and matric flux potential. The method is simply a constant-head well technique with the GP apparatus being an in-hole Mariotte bottle (Fig. 2a). Calculations of K_{fs} and ϕ_m are based on a steady state three dimensional solution of infiltration from a well into unsaturated soil (Baumgartner et al., 1987).

More recent advances in the theory have led to the development of the pressure infiltrometer which is designed specifically to measure K_{fs} and ϕ_m at the soil surface, with minimal disturbance to the soil surface itself. A schematic diagram of the pressure infiltrometer is shown in Fig. 2b. In practice, a 10 cm diameter sealed ring is driven a known distance into the soil (from 1 to 5 cm depending on the soil properties) and a constant head (from 3 to 25 cm) is applied. Flow measurements are then taken until near steady state is obtained. Within limitations, the soil surface need not be disturbed and measurements can be taken on a grass or stubble surface.

The approximate analytical solution describing the flow process is given by (Reynolds and Elrick, 1990):

$$Q = (aH/G + \pi a^2)\, K_{fs} + (a/G)\, \phi_m \qquad (14)$$

$$= (aK_{fs} / G)H + \pi a^2)\, K_{fs} + a\, \phi_m /G \qquad (15)$$

where G is a dimensionless shape parameter and is determined from numerical solutions of the Richards equation.

Although not particularly obvious, the pressure infiltrometer approach has a number of advantages over that of the constant head well-permeameter (subsurface Guelph permeameter). If a two head technique is used, then the volume of soil occupied by the saturated bulb at the second height is simply the volume occupied by the saturated bulb at the first height plus the expanded portion at the bottom of the first bulb. At the second height the water must first flow through the saturated bulb that developed at the first ponded height and thus the effect of soil heterogeneity in the two volumes is minimized. The situation is complicated in that the wetted but unsaturated soil volumes of the wetting front also influence the steady flow rates. By comparison, the saturated bulb developed at the second ponded height in the constant head well permeameter includes new soil above the H_1 level which is in contact with the wetted surface of the well. Therefore, if the soil hydraulic properties are different in the enlarged saturated bulb (at the second ponded height) the effects of soil heterogeneity are maximized with regard to the steady flow obtained at the second ponded height. The effects of soil heterogeneity are important because the analysis assumes the soil properties to be homogeneous for both ponded height measurements.

From the theoretical point-of-view the pressure infiltrometer equation offers several advantages over the comparable equation for the constant head well permeameter. Most importantly, the coefficient G in Eq. (14) and (15) has been found to be essentially independent of H and the soil hydraulic properties (i.e. K_{fs} and ϕ_m) for a fixed radius a and depth of insertion, D. Therefore, if G can be taken to be constant then Eq. (15) gives a linear relationship between Q and H, with the slope determined for K_{fs} only. This provides an excellent two height technique for determining K_{fs} and if $(Q_2 - Q_1/(H_2 - H_1)$ is positive (which is realistic unless in the presence of an impeding layer for Q_2) then K_{fs} must be positive. If K_{fs} is determined from the slope, then ϕ_m can be determined from the Q intercept or from a given Q value, preferably Q_2. Preliminary measurements of Q vs. H, both from numerical simulations (based on the Richards equation) and from field tests, give a linear relationship between Q and H.

An alternative procedure is to use the one height approach and estimate α^*. The appropriate equations for K_{fs} and ϕ_m are therefore:

$$K_{fs} = GQ/ (aH + \pi a^2G + a/\alpha^*) \tag{16}$$

$$\phi_m = GQ/ (aH + \pi a^2G)\ \alpha^* + a \tag{17}$$

If desired, the pressure infiltrometer could be used for depth measurements by excavating a sufficiently large hole.

A 20 cm diameter pressure infiltrometer has been tested on very slowly permeable materials such as compacted earthen liners. Preliminary results indicate that hydraulic conductivities of the order of 10^{-9} m•s^{-1} can be measured using ponded heights up to 50 cm and an additional constant head burette system capable of measuring water volumes to 0.01 cm^3. For these slowly permeable soils measurements may take as long as one or several days before steady state flow is reached.

2.2 Tension Infiltrometer

The tension infiltrometer supplies water at a negative potential to the soil surface and thereby eliminates the effects of highly conducting macropores (if present) such as surface cracks, root passageways and worm channels. The instrument is useful for soil management studies where tillage or other practices affect surface structure. A schematic diagram of the tension infiltrometer is shown in Fig. 2b. Measurements at negative heads require good contact between the porous disk and the field soil - in fact, it is essential. A very thin layer of fine sand is helpful in ensuring good contact (Clothier and White, 1981; Watson and Luxmoore, 1986; Perroux and White, 1988).

The approximate analytical solution describing the flow under the tension infiltrometer is given by:

$$Q = \pi a^2 K_t + (a/G)\, \phi_t \tag{18}$$

where $K_t = K(\Psi_t)$ and

$$\phi_t = \int_{\Psi_i}^{\Psi_t} K(\Psi)\, d\Psi \tag{19}$$

The different approaches towards analyzing the data from the tension infiltrometer have already been discussed in the TED report (Kachanoski et al. 1989). Recent developments in the theory suggest that a more simple approach would be to use a single disk at two or more tensions (similar to the pressure infiltrometer approach but with a second mariott bottle) thus obtaining all of the necessary hydraulic properties. As will be discussed, the tension infiltrometer was used on a 10 m transect (20 cm intervals and at three depths) at the Delhi Research Station during the 1989 field season. In the 1989 report, it was suggested that soil moisture conditions should be well below saturation for the tension infiltrometer to function properly. Therefore, the Delhi soil provided a suitable location (i.e a well drained, loamy sand) for testing the tension infiltrometer. At this time, however, the data from the Tension Infiltrometer will not be included in this report because it is still being analyzed as per these recent developments in the theory. A supplementary report will follow upon completion of the analysis.

2.3 Instrument Availability

A commercial constant head well permeameter (the Guelph permeameter) is available from Soil Moisture Equipment Corporation, P.O. Box 30025, Santa Barbara, California 95104, U.S.A. A prototype pressure infiltrometer has been developed recently and should be commercially available by 1991.

3.0 MATERIALS AND METHODS

3.1 Site Selection and Characterization

This project is a continuation from the previous fall (1988) where both hydraulic properties characterization and rainfall simulation were carried out at D. Lobb's farm near Clinton, Ontario. Further studies at this site were undertaken to estimate both the spatial and temporal variation in hydraulic properties.

During the 1989 field season extensive use was also made of different tillage/cropping systems. Table 1 describes the sites where both GPI measurements and rainfall simulation were completed, and the existing management systems. Table 2 shows those sites where only the characterization of hydraulic properties was completed in order to compare the effects of management over a range of textural classes and management schemes.

3.2 Methods

As with the 1988 study, paired tillage sites were selected to cover the major soil and topographic changes in the field. Prototype (first generation) pressure infiltrometer attachments for the Guelph permeameter were used to obtain measurements of K_{fs}, ϕ_m and α on each of the tillage treatments for each of the soil landscape positions. Approximately 4-5 replications were taken in each tillage treatment, with two pressure heads being applied for each replication. At each head, flow was recorded in 30 second intervals until steady state was reached (approximately 15 minutes on average). The steady state flow was recorded and used along with the pressure head to calculate the hydraulic parameters for each replicate (see appendices). Initial and final soil volumetric moisture content was also recorded using the Time Domain Reflectrometry (TDR) method

Table 1. Description of 1989 field sites sampled for hydraulic properties and rainfall simulation.

Cooperating Farmer	Location	Tillage*	Soil Texture
Don Lobb (T-2000)	Clinton	MB, NT	SiCL-fSL
David Ghent (T-2000)	Mt. Forest	MIN, NT	SiL
Frank Anthony (T-2000)	Halton Hills	MIN, MB	L

min = minimum till
MB = moldboard
NT = no-till

Table 2: Description of 1989 field sites sampled for characterization of hydraulic properties only.

Cooperating Farmer	Location	Tillage*	Soil Texture
Elora Research Station	Elora	MB, NT	SiL
Al Jones (T-2000)	Fingal	RT, SS, MB, NT	SiL
Paisley Johnson (T-2000)	Guelph	DC, NT	L-S

MB = moldboard
NT = no-till
RT = ridgetill
SS = soil-save
DC = disk

developed by C. Topp. A field portable Tectronix 1502B cable tester was used, along with two 20 cm TDR probes to measure soil water content. The change in soil water content $\Delta\theta$, along with the measured value of ϕ_m, was used to predict the time to ponding, Tp during a constant rainfall rate Vo using the equation (Kutilek, 1980):

$$Tp = (\Delta\theta)\, \phi_m / Vo^2 \tag{20}$$

To compare the pressure infiltrometer values to standard laboratory methods, undisturbed cores (50 mm diam. x 50 mm depth) were taken immediately adjacent to the GPI field reading for determination of K_{sat}, bulk density, total porosity, soil water characteristic curves $\theta(\Psi)$, and estimated pore size distributions. Saturated hydraulic conductivity K_{sat} was determined using either a constant or falling head method as outlined in Klute et al.(1986).

Soil water characteristic curves were measured using a standard pressure plate apparatus. The undisturbed cores were brought to equilibrium at 0, 10, 25, 50, 100, 330, and 15,000 cm pressure values and soil water content determined by water loss from gravimetric weighing. Bulk density was determined from the final oven dry weight of the undisturbed core. Total porosity was calculated from the saturated weight and bulk density calculations. Effective pore size distribution was calculated from capillary rise theory and the soil water characteristic curve, where pore radius, r, is given by:

$$r = 0.15\, \Psi_m^{-1} \tag{21}$$

Macroporosity was estimated from the pore size distributions.

The rainfall simulation work that was carried out on three of the sites (Lobb, Ghent and Anthony) used a version of the Guelph Portable Rainfall Simulator (GRSII). The runoff work is part of a Ministry of the Environment research project. A summary of the method is given in Tossell et al. (1987). Two rainfall intensities, low (0.68 $mm•min^{-1}$) and high (2.8 $mm•min^{-1}$) were applied to each tillage treatment. Runoff hydrographs were obtained by measuring runoff in 1 minute intervals. All of the sediment was collected for subsequent analysis of particle size distribution and total phosphorus. The runoff water was filtered on site during the runoff simulation and the water was analyzed for ortho-phosphorus and total hydrolizable phosphorus. Measurement of time to ponding, time to runoff and final steady state infiltration rates were obtained from the rainfall simulation hydrographs. A summary of the data from the 1989 rainfall simulation experiments is given in the 1990 progress report to MOE (J. Eddy).

For this report, each site will be discussed individually, with the appropriate summary tables, while the raw field and laboratory data for each site can be found in separate appendices.

4.0 RESULTS AND DISCUSSION FOR 1989 FIELD SEASON

4.1 Temporal Changes in Surface Hydraulic Properties

4.1.1 Site Description - D. Lobb, T-2000 Site, Clinton Ontario

One of the main objectives of this study was to examine the effects of tillage on surface hydraulic properties. The 1989 TED report indicated that surface hydraulic conductivity was generally lower in the long term no-till plots compared to the moldboard plough treatment. These measurements were taken immediately prior to fall ploughing. To study the effects of fall tillage on changes in hydraulic properties and runoff characteristics, measurements were again taken in early April before seeding and 3-4 weeks after seeding (i.e June) to estimate any changes with time.

The site selected for the temporal comparison of hydraulic properties was the T-2000 site at Don Lobb's farm, located on concession road 15-16 Goderich Township, just north of Clinton, Ontario (Fig. 4). A detailed description of the site is given in the 1989 TED report. The site has one of the longest running field scale tillage comparisons in Ontario. A no-till system vs. fall moldboard plough has been carried out for 9 years.

The field study was done at the same location as the permanent runoff installations and runoff simulations which are part of the Ministry of the Environment (MOE) research project on event based soil and phosphorous loss. The site is also a Tillage 2000 site and has been benchmarked for detailed soil-tillage-erosion measurements under a different TED project. The surface soil texture changes from a fine sandy loam at the front of the field to a silty clay loam and clay loam at the back of the field.

Four paired tillage sites (soil landscapes) were chosen to cover the. major soil and topographic changes in the field. These sites were located at the same locations as those discussed in the 1989 TED report. Each of the sites had two tillage treatments, fall

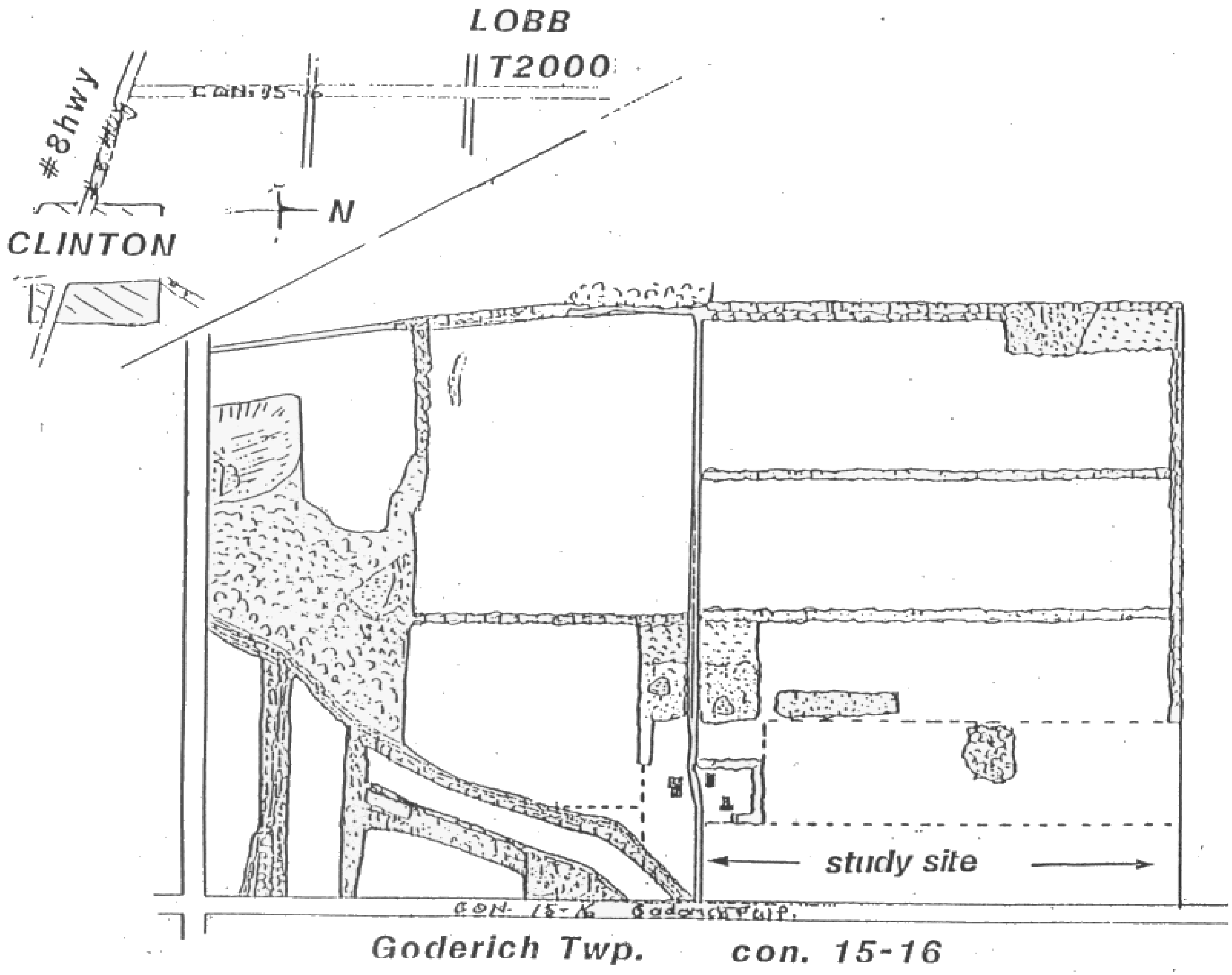


Figure 4. Farm and study site location for D. Lobb T-2000 Site, Clinton, Ontario.

moldboard plough and 9-year no-till (the one year no-till from the previous year had been ploughed). Sampling in April was carried out on two adjacent plot locations, a 10 m x 1.6 m permanent runoff plot and 1m x 1m rainfall simulation plot. In June, 1989 only the permanent plots were monitored. The information collected allows for a temporal as well as spatial comparison of surface hydraulic properties in the two tillage systems.

4.1.2 Results and Discussion - April Sampling Period

A summary of the data collected for each individual replication of the GPI, along with the calculated hydraulic parameters, is given for both the permanent runoff and 1m x 1m plots in Appendices 2a and 2b respectively. Calculated porosity indices are given in Appendices 2c and 2d for the same plots. Included are measurements of bulk density, soil water content versus matric flux potential ϕ_m, and calculated pore size distributions for all undisturbed cores sampled in April, 1989.

The field saturated hydraulic conductivity K_{fs} values measured with the GPI during the April sampling period in the permanent runoff plots are given in Table 3. The geometric and arithmetic means were both calculated since K_{fs} generally has a log-normal probability distribution in the field. The data is highly variable within a slope/tillage treatment, but the coefficients of variation are similar to those found in the 1988 TED study at this site, and the data are likely representative of the natural variability in the field. The values for K_{fs} on Hill 1 MB are higher at the lower slope position due to the coarser texture (fine sandy loam) at this site versus that found at the upper slope (silty clay loam). The measured K_{fs} values between treatments at each slope position are generally higher in the moldboard

Table 3: Summary of K_{fs} from pressure infiltrometer April 1989 - D. Lobb, Clinton, Ontario (Permanent Plots).

			Field Saturated Hydraulic Conductivity (m•s^{-1} x 10^{-5})									
			Replication Number						Geometric		Arithmetic	
Site/Slope/Tillage			1	2	3	4	5	6	$\bar{X}$	S	X	S
Hill 1	Lower	MB	1.84	1.22	1.84	1.07		-	1.45	1.32	1.49	0.41
		NT	0.475	0.512	0.146	1.36	-	-	0.47	2.49	0.62	0.52
	Upper	MB	0.329	0.091	0.117	-	-	-	0.152	1.98	0.18	0.13
		NT	7.35	0.439	0.165	-	-	-	0.81	7.18	2.65	4.07
Hill 2	Lower	MB	0.39	0.073	4.9	-	-	-	0.52	8.31	1.79	2.70
		NT	0.054	0.216	0.182	0.038	0.035	-	0.08	2.39	0.10	0.09
	Upper	MB	11.02	9.0	6.88	8.33	0.117	-	3.67	6.91	7.07	4.16
		NT	0.072	0.887	0.600	1.96	0.534	3.65	0.72	3.86	1.28	1.32
Overall Average		MB	3.15a[1]	(3.82)								
		NT	1.04^{b}	(1.81)								

(standard deviation)

[1] Values in the same column with different letters are significantly different at 0.025 probability level

when compared to the 9 year no-till treatment. The one exception is the Hill 1 upper slope position where the situation is reversed. Over the entire site however, the K_{fs} value for the moldboard was 2x higher than the 9 year no-till (significant at the 0.025 probability level).

A comparison of the in-situ GPI measurements with the undisturbed cores in the permanent runoff plots is given in Table 4. The K_{sat} values are the average of 3-6 replicates per slope/tillage site. The cores were taken immediately adjacent to the GPI measurements. The correlation coefficient for K_{fs} taken with the GPI versus K_{sat} from the cores is r = 0.42 (significant at 0.05 probability level). In the 1988 study the higher correlation r = 0.92) was most likely due to the wet soil conditions that existed. Thus the K_{fs} values would more closely approximate the full saturated K values from the core methods (Kachanoski et al., 1989). n this study, initial moisture conditions were much lower, yet the same trends hold with the K_{sat} values for the MB treatment being significantly higher (0.05 probability) than the NT values.

The results for the GPI readings taken in the smaller 1m x 1m rainfall simulation plots are given in Table 5. These sampling locations are located at the same landscape position and immediately adjacent to the permanent runoff plots and are therefore included as additional replications. It should also be noted that the values for the 9 year no-till plots are missing for Hill 2 due to equipment repair problems. The trend in the data is consistent with the previous data. The moldboard plough treatment has a significantly higher average K_{fs} value than the 9 year no-till treatment (0.05 probability level). A comparison of the K_{fs} and K_{sat} (core) values from the 1m x 1m plots (Table 6) gave a similar correlation r = 0.47

Table 4: Comparison of K_{fs} from pressure infiltrometer and K_{sat} from undisturbed cores at Clinton, Ontario, April 1989. (Permanent Plots)

Site/Slope/Tillage			Average K_{fs} (Y) ($m \bullet s^{-1} \times 10^{-5}$)	Undisturbed Core K_{sat} (X) ($m \bullet s^{-1} \times 10^{-5}$)
Hill 1	Lower	MB	1.49 (0.41)	163.1 (215.7)
		NT	0.62 (0.52)	0.62 (0.2)
	Upper	MB	0.179 (0.13)	1.38 (2.29)
		NT	2.65 (4.07)	2.17 (1.28)
Hill 2	Lower	MB	1.79 (2.7)	37.3 (50.3)
		NT	0.105 (0.09)	5.51 (5.03)
	Upper	MB	7.07 (4.16)	98.3 (86.2)
		NT	1.28 (1.32)	60.3 (104)
Overall Average		MB	3.15^{a1}	75.0^{a}
		NT	1.04^{b}	15.7^{b}

(standard deviation)

[1] Values in the same column with different letters are significantly different (0.05 probability level)

Correlation of Y on X r = 0.42
n = 8

Table 5: Summary of K_{fs} for 1m x 1m plots at D. Lobb - April, 1989.

			K_{fs} from pressure infiltrometer ($m \cdot s^{-1} \times 10^{-5}$)	
Site/Slope		Code	Moldboard (MB)	No Till (NT)
Hill 2	Lower	7	0.62	-
		8	0.23	-
		9	-	-
Hill 2	Upper	10	1.84	-
		11	0.73	-
		12	6.12	-
Hill 1	Upper	13	8.05	0.12
		14	3.67	0.07
		15	1.86	0.62
			$\bar{x}$ = 4.53	$\bar{x}$ = 0.27
Hill 1	Lower	16	2.76	1.84
		17	0.41	0.11
		18	0.22	0.40
			$\bar{x}$ = 1.13	$\bar{x}$ = 0.78
Overall Average			2.41^{a1} (2.6)	0.53^{b} (0.68)

(standard deviation)

[1] Values in the same row with different letters are significantly different at 0.05 probability level

Table 6: Comparison of K_{fs} from pressure infiltrometer and K_{sat} from undisturbed cores at D. Lobb (April 1989) for 1m x 1m plots.

Site No.	Average K_{fs} (Y) ($m \cdot s^{-1}$ x10^{-5}) MB	NT	K_{sat} (X) ($m \cdot s^{-1}$ x10^{-5}) MB	NT
7	0.62	-	7.0	-
8	0.23	-	14.0	-
9	-	-	29.4	-
10	1.84	-	3.65	-
11	0.73	-	16.0	-
12	6.12	-	385.0	-
13	8.05	0.12	26.9	0.081
14	3.67	0.07	23.2	0.051
15	1.86	0.62	3.2	0.245
16	2.76	1.84	4.9	0.596
17	0.41	0.11	5.5	1.73
18	0.22	0.40	34.8	129.0
Overall Average	2.41^{a1}	0.53^{b}	46.1^{a}	21.9^{b}
S.D.	2.60	0.68	107.3	52.4

Correlation of Y on X r = 0.47
n = 17

[1] Values in the same row with different letters are significantly different at the 0.05 probability level

(significant at 0.05 probability level) as the comparison in the large runoff plots (Table 4).

A summary of the average K_{fs} measurements for April, 1990 for both large and small runoff plots is given in Table 7. Both the GPI measurements and data from the standard core method suggest that less, not more water may infiltrate into the no-till treatment. This is identical to the conclusions from the fall data. The data also indicate that the spatial variability of K_{fs} is significantly higher in the MB than in the NT treatment. The standard deviation of the MB is 2x that of the NT treatment.

The GPI method, when combined with measurements of initial and final soil water content measurements in the saturated bulb area (taken with the TDR) also allow other parameters to be calculated which relate to surface runoff. One of these parameters is a predicted effective time to ponding Tp, under steady rainfall. The value of Tp, as discussed earlier in this report, was estimated from (Kutilek, 1980):

$$Tp = ((\theta_f - \theta_i)\ \phi_m) / Vo^2 \qquad (22)$$

where Tp = time to ponding (s), θ_f and θ_i = final and initial soil water content ($m^3 \bullet m^{-3}$), ϕ_m = soil matric flux potential ($m^2 \bullet s^{-1}$). The matric flux potential is the unsaturated flow component of steady infiltration and was. calculated along with the K_{fs} for each replication, as seen in Appendix 2. A summary of the measured data for predicted Tp at each sampling location for the permanent plots is given in Tables 8 and 9, and summarized in Table 10. Similar calculations for estimated Tp were done for the 1m x 1m plots during the April sampling period and are given in Table 11 and 12, respectively.

Table 7: Overall average of K_{fs} readings for moldboard plough versus no-till by slope position at D. Lobb ($m \bullet s^{-1} \times 10^{-5}$) - April, 1989.

		Texture	Moldboard		No Till	
			$\bar{X}$	S	$\bar{X}$	S
Hill 1	Lower	fSL	1.34	0.89	0.69	0.65
	Upper	L	2.35	3.12	1.46	2.89
Hill 2	Lower	SiCL	1.24	2.05	0.105	0.09
	Upper	SiCL	5.50	4.11	1.28	1.32
Overall Average		MB	2.83[a1]	3.32[a]	0.91[b]	1.61[b]

[1] Values in same row with different letters are significantly different at 0.01 probability level

Table 8: Measured data for calculation of predicted time to ponding, Tp for D. Lobb (permanent plots) April 1989 (Hill 1).

Site Hill 1	Mgt	Rep	Soil Water Content θ_i	θ_v	$\Delta\theta$	ϕ_m	Calculated Time for Ponding (s) Low	High
			($m^3 \cdot m^{-3}$)		($m^2 \cdot s^{-1} \times 10^{-6}$)		Intensity	
Lower	MB	1	.224	.372	.148	1.37	1579	93
		2	.240	.320	.08	0.425	265	16
		3	.232	.307	.075	1.37	800	47
		4	.214	.279	.065	1.26	638	38
		$\bar{X}$	.227	.319	.092	1.11	820	48
	NT	1	.305	.339	.034	0.392	104	6
		2	.300	.339	.039	0.821	249	15
		3	.285	.310	.025	0.365	71	4
		4	.264	.315	.051	1.82	723	43
		$\bar{X}$	.288	.326	.037	0.849	287	17
Upper	MB	1	.279	.330	.051	0.465	185	11
		2	.290	.344	.054	0.032	13	<1
		3	.295	.330	.035	0.065	18	1
		$\bar{X}$	.288	.335	4.7	0.187	72	4
	NT	1	.274	.350	.076	4.27	2527	149
		2	.269	.363	.094	0.62	454	27
		3	.264	.344	.080	0.434	270	16
		$\bar{X}$	.269	.352	.083	1.77	1084	64

Low Intensity Rainfall Rate = 0.68 mm • min^{-1}
High Intensity Rainfall Rate = 2.8 mm • min^{-1}

Table 9: Measured data for calculation of predicted time to ponding, Tp, for D. Lobb (permanent plots) April 1989 Hill 2.

			Soil Water		Content		Calculated Time for Ponding (s)	
Site	Mgt	Rep	θ_i $(m^3 \bullet m^{-3})$	θ_v	$\Delta\theta$ $(m^2 \bullet s^{-1} X 10^{-6})$	ϕ_m	Low Intensity	High
Hill 2								
Lower	MB	1	.274	.358	0.084	0.390	255	15
		2	.279	.344	0.065	0.073	37	2
		3	.274	.354	0.080	4.89	3047	180
	$\bar{X}$		.276	.352	0.076	1.78	1113	66
	NT	1	.295	.339	0.044	0.034	12	<1
		2	.330	.376	0.046	0.190	68	4
		3	.305	.344	0.039	0.100	30	2
		4	.310	.344	0.034	0.020	6	<1
		5	.279	.330	0.051	0.022	9	<1
	$\bar{X}$		.304	.347	0.043	0.073	25	1
Upper	MB	1	.320	.390	0.070	10.69	5828	345
		2	.305	.406	0.101	19.1	15024	889
		3	.335	.381	0.046	6.88	2465	146
		4	.269	.354	0.085	6.10	4038	239
		5	.274	.344	0.070	0.102	55	3
	$\bar{X}$		.301	.375	0.074	8.57	5482	324
	NT	1	.315	.363	0.048	0.129	48	3
		2	.344	.376	0.032	1.58	394	23
		3	.354	.385	0.031	0.989	239	14
		4	.325	.372	0.047	1.69	619	37
		5	.315	.385	0.070	0.936	510	30
		6	.295	.422	0.127	7.03	6953	411
	$\bar{X}$		.325	.384	0.059	2.06	1460	86

Low Intensity Rainfall Rate = 0.68 $mm \bullet min^{-1}$
High Intensity Rainfall Rate = 2.8 $mm \bullet min^{-1}$

Table 10: Comparison of predicted time to ponding for tillage treatments at D. Lobb April 1989 (permanent plots).

Site/Slope		Rain Intensity	Calculated Time to Ponding Tp (s)	
			MB	NT
Hill 1	Lower	Low	820 (553)	287 (301)
		High	48 (32)	17 (18)
	Upper	Low	72 (98)	1084 (1253)
		High	4 (6)	64 (74)
Hill 2	Lower	Low	1113 (1678)	25 (26)
		High	66 (99)	1 (1)
	Upper	Low	5482 (5740)	1460 (2698)
		High	324 (340)	86 (159)
Overall Average		Low	1872^{a1} (2446)	714^{a} (671)
		High	110^{a} (145)	42^{a} (40)

(standard deviation)

[1] Values in the same row with different letters are significantly different at the 0.05 probability level

Table 11: Measured data for calculation of predicted time to ponding, Tp for D. Lobb (1m x 1m plots) April 1989.

Site No.			Soil Water Content				Calculated Time to Ponding (s)	
			(m^3 • m^{-3})		ϕ_m (m^2 • s^{-1} x 10^{-6})		Low	High
							Intensity	
MB	7		.315	.358	.043	0.285	95	6
	8		.305	.325	.020	0.224	35	2
	9		.335	.394	.059	0.314	144	8
		$\overline{X}$	.318	.359'	.041	0.274	91	5
	10		.259	.349	.090	1.98	1388	82
	11		.310	.426	.116	2.88	2602	154
	12		.320	.390	.070	3.34	1821	108
		$\overline{X}$	.296	.388	.092	2.74	1937	115
	13		.274	.390	.116	5.84	5276	312
	14		.269	.398	.129	1.52	1527	90
	15		.310	.402	.092	0.605	433	26
		$\overline{X}$	.284	.397	.112	2.65	2412	143
	16		.253	.376	.123	1.45	1389	82
	17		.232	.320	.088	0.577	395	23
	18		.274	.344.	.070	0.091	50	3
		$\overline{X}$	.253	.347	.094	0.706	611	36
NT	13		.295	.349	.055	0.219	94	5
	14		.295	.330	.044	0.039	13	<1
	15		.274	.354	.080	0.903	563	33
		$\overline{X}$	.288	.347	.060	0.387	223	13
	16		.253	.349	.096	4.43	3312	196
	17		.285	.354	.069	0.082	44	3
	18		.269	.339	.070	0.264	144	8
		$\overline{X}$	.269	.347	.078	1.59	1167	69

Low Intensity Rainfall Rate = 0.68 mm •min^{-1}
High Intensity Rainfall Rate = 2.8 mm •min^{-1}

Table 12. Comparison of predicted time to ponding for tillage treatments at D. Lobb (1m x 1m plots) - April, 1989.

			Calculated Time to Ponding Tp (s)	
Site/Slope		Rain Intensity	MB	NT
Hill 1	Lower	LOW	611 (695)	1167 (1858)
		HIGH	36 (41)	69 (110)
	Upper	LOW	2412 (2540)	223 (297)
		HIGH	143 (150)	13 (17)
Hill 2	Lower	LOW	91 (55)	-
		HIGH	5 (3)	-
	Upper	LOW	1937 (615)	-
		HIGH	115 (36)	-
Overall Average		LOW	1263[a1] (1091)	695 (667)
		HIGH	75[a] (90)	41[a] (77)

(standard deviation)

[1] Values in the same row with different letters are significantly different at the 0.05 probability level.

The overall average Tp for each slope position over both large and small plots is given for each treatment in Table 13. The data predicts that on average time to ponding would be much lower in the 9 year no-till treatment than in the moldboard. The Tp values are quite variable between sites which negated any statistical difference, but all sites at both intensities had lower Tp for the NT compared to MB. This data can now be compared to the observed data from the rainfall simulation experiments carried out under the Ministry of the Environment (MOE) project on the same soil landscape positions. During the April sampling period rainfall simulation trials were completed only on the 1m x 1m plots. Table 14 illustrates the observed runoff at the high (2.8 mm•min^{-1}) rainfall intensity for the 1m x 1m plots. The data are consistent with that reported in the 1989 TED study from the site where the no-till results in higher runoff rates (lower infiltration) than the moldboard system. However, as in the fall data, the total soil loss and phosphorus loss from the moldboard treatment were higher.

The low intensity data for Lobb during the April sampling period is not summarized because the low intensity storm failed to generate any runoff or soil loss from the moldboard site.. Thus under very low intensity rains, no-till may have higher soil and P loss rates because runoff is generated in the no-till and not in the moldboard. For high intensity storms the moldboard again generates less water runoff than the no-till, but the water which runs off is laden with sediment and phosphorus. This illustrates the need to interpret single event data very carefully and depending on the event characteristics you would reach opposite conclusions.

The runoff data in Table 14 are consistent with the predicted values for Tp and measured surface hydraulic properties. A comparison of the measured time to runoff T_R and

Table 13: Comparison of overall average predicted time to ponding for April sampling period (D. Lobb).

Site/Slope			Calculated Time to Ponding Tp (s)	
		Rain Intensity	MB	NT
Hill 1	Lower	Low	715	727
		High	42	43
	Upper	Low	1242	653
		High	73	38
Hill 2	Lower	Low	602	25
		High	35	1
	Upper	Low	3709	1460
		High	219	86
Overall Average		Low	1567[a1] (1455)	726[a] (587)
		High	92[a] (86)	42[a] (35)

(standard deviation)

[1] Values in the same row with different letters are significantly different at 0.05 probability level.

Table 14: Runoff characteristics of Lobb simulation (2.8 mm min^{-1} for 12 min.) in April, 1989.

Site/Slope/Tillage			Time to Ponding (sec)	Water runoff (cm)	Steady-state runoff rate (cm/hr)	Steady-state infiltration (cm/hr)	Soil loss (t/ha)	Total Phosphorus Loss(kg/ha)
Hill 1	Lower	MB	49	1.18	9.3	7.5	3.9	5.9
		NT	30	1.53	11.4	5.4	1.72	1.25
	Upper	MB	25	0.71	8.1	8.7	4.2	1.30
		NT	22	1.70	12.4	4.4	0.5	0.36
Hill 2	Lower	MB	10	0.33	3.1	13.7	1.39	0.45
		NT	13	0.84	7.4	9.4	0.85	0.57
	Upper	MB	12	0.19	2.0	14.8	0.65	0.26
		NT	11	1.21	10.4	6.4	1.70	1.28
	Avg	MB	24	0.60	5.6	11.2	2.5	1.98
		NT	19	1.32	10.4	6.4	1.2	0.87

predicted time to ponding are given in Table 15 and indicate a good relationship. Even the zero runoff from the moldboard treatment under low intensity is predicted by the Tp estimate.

Both the values for K_{fs} and K_{sat} indicate that more runoff would be expected in the no-till treatment. The overall average K_{sat} and K_{fs} values for the April period (Table 16) are 1.9x and 4.3x higher, respectively in the moldboard compared to the 9 year no-till plots though the difference was not significant (0.05 probability level). This is similar to the 1.8x higher steady state infiltration rate in the moldboard (Table 14). In addition, the soil matric flux potential ϕ_m is also lower (significant at 0.05 probability level) in the no-till compared to the moldboard (Tables 17,18 and 19). The lower ϕ_m and higher initial soil water contents in the no-till resulted in considerably shorter predicted time to ponding, which was also observed in the rainfall simulation trials.

The changes in surface hydraulic properties and subsequent effects on the runoff and soil loss are probably a result of increased bulk density and lower overall soil porosity in the no-till compared to moldboard as shown in the 1989 TED study. The measured porosity indices for each of the soil cores taken in both the permanent and 1m x 1m plots are given in Tables 20 and 21 respectively. A summary of this data are given in Table 22. The average bulk density values in the no-till is 12% higher than the moldboard and the total porosity of the no-till is 0.45 $m^3 \bullet m^{-3}$ compared to 0.494 $m^3 \bullet m^{-3}$ in the MB treatment. The decrease of 0.045 $m^3 \bullet m^{-3}$ of total porosity in the no-till is identical to the measured decrease n the macroporosity of 0.045 $m^3 \bullet m^{-3}$, in the NT compared to the MB treatment. The decreased macroporosity would therefore account for the decreased infiltration, K_{sat}, K_{fs} and increased water runoff observed in the no-till plots.

Table 15 : Comparison of measured time to runoff T_R and predicted time to ponding T.

Rainfall Intensity	MB		NT	
	T_p	T_R	T_p	T_R
	-------------------------- sec -------------------------------			
Low	1567	>1500	716	726
High	92	183	42	98

Table 16: Comparison of K_{fs} and K_{sat} for overall average at D. Lobb, 1989.

Site/Slope/Tillage			Average K(Y) (m •s x 10^{-5})	Average K_{sat}
Hill 1	Lower	MB	1.34 (0.89)	99.67 (172)
		NT	0.69 (0.65)	19.12 (48.0)
	Upper	MB	2.35 (3.12)	8.4 (11.5)
		NT	1.46 (2.89)	1.29 (1.4)
Hill 2	Lower	MB	1.24 (2.05)	24.0 (29.0)
		NT	0.10 (0.09)	5.51 (5.0)
	Upper	MB	5.50 (4.11)	112.0 (134)
		NT	1.28 (1.32)	60.3 (104)
Overall Average		MB	2.61^a (1.99)	61.02^a (52)
		NT	0.88^a (0.62)	21.55^a (26)

(standard deviation)
Values in each column with different letters are significantly different 0.05 probability level
Correlation of Y on X r = 0.62 n = 8

Table 17: Summary of tillage effect on average Matric Flux Potential ϕ_m measurements for D. Lobb - April 1989 (permanent plots).

		Matric Flux Potential (m • s x 10^{-6})		Initial Soil Water Content (m^3 •m^{-3})	
		MB	NT	MB	NT
Hill 1	Lower	1.11	0.85	22.7	28.8
	Upper	0.19	1.77	28.8	26.9
Hill 2	Lower	1.78	0.07	27.6	30.4
	Upper	8.57	2.06	30.1	32.5
Overall Average [1]		3.55 a**	1.19 ^{b} **	27.4a *	30.1
	S.D.	5.38	1.79	3.44	2.64

[1] Values for each treatment with different letters are significantly different at: (1) * 0.01 probability level; (2)** 0.05 probability level

Table 18: Summary of tillage effects on average matric flux potential ϕ_m for D. Lobb - 1m x 1m plots (April 1989).

		Matric Flux Potential ($m^2 \bullet s^{-1} \times 10^{-6}$)		Initial Soil Water Content (%)	
		MB	NT	MB	NT
Hill 1	Lower	0.71	1.59	25.3	26.9
	Upper	2.65	0.39	28.4	28.8
Hill 2	Lower	0.27	-	31.8	-
	Upper	2.74	-	29.6	-
Overall Average		1.59^{a1}	0.99^{a}	28.8^{a}	27.8*
	S.D.	1.72	1.71	3.19	1.64

[1] Values in same row with different letters are significantly different at 0.05 probability level.

Table 19: Summary of tillage effects on overall average matric flux potential ϕ_m for D. Lobb, April sampling period.

		Matric Flux Potential ($m^2 \bullet s^{-1} \times 10^{-6}$)		Initial Soil Water Content (%)	
		MB	NT	MB	NT
Hill 1	Lower	0.91	1.22	24.0	27.8
	Upper	1.42	1.08	28.6	27.8
Hill 2	Lower	1.02	0.07	31.8	30.4
	Upper	5.65	2.06	29.6	32.5
Overall Average [1]		2.68^{a*}	1.14^{b*}	28.0^{a*}	29.6^{b**}
	S.D.	4.22	1.73	3.35	2.60

[1] Values for each treatment with different letters are significantly different at: (1)* 0.05 probability level; (2)** at 0.025 probability level

Table 20: Summary of porosity indices from undisturbed cores for Clinton, Ontario April 1989 (Permanent Runoff Plots)

Site/Slope/Rep			Bulk Density (g • m^{-3})		Porosity (m^3 • m^{-3})		Macroporosity (m^3 • m^{-3})		Relative Macroporosity (%)	
			MB	NT	MB	NT	MB	NT	MB	NT
Hill 1	Lower	1	1.45	1.43	0.474	0.476	0.069	0.048	14.5	10.1
		2	1.39	1.41	0.467	0.473	0.066	0.044	14.1	9.3
		3	1.43	1.50	0.458	0.446	0.061	0.042	13.3	9.4
		4	1.52	1.57	0.433	0.398	0.039	0.039	9.0	9.8
	$\overline{X}$		1.45	1.48	0.458	0.448	0.059	0.043	4.7	9.6
	Upper	1	1.50	1.61	0.452	0.452	0.045	0.070	9.9	15.5
		2	1.57	1.67	0.424	0.390	0.046	0.037	10.8	9.5
		3	.1.62	1.56	0.414	0.458	0.049	0.063	11.8	13.7
		4	1.53	1.70	0.416	0.449	0.029	0.074	7.0	16.1
	$\overline{X}$		1.55	1.63	0.426	0.437	0.042	0.061	9.9	13.8
Hill 2	Lower	1	1.32	1.77	0.534	0.425	0.162	0.036	30.3	8.5
		2	1.48	1.63	0.498	0.472	0.087	0.063	17.5	13.3
		3	-	1.62	-	0.446	-	0.045	-	10.1
		4	-	1.64	-	0.431	-	0.050	-	11.6
	$\overline{X}$		1.4	1.66	0.516	0.443	0.124	0.048	23.9	10.9
	Upper	1	1.46	1.50	0.507	0.461	0.103	0.034	22.3	7.4
		2	1.23	1.44	0.532	0.484	0.173	0.054	32.5	11.1
		3	1.39	-	0.514	-	0.107	-	20.8	-
		4	1.36	1.62	0.537	0.442	0.137	0.030	25.5	6.8
		5	1.44	1.65	0.515	0.457	0.124	0.040	24.1	8.7
		6	-	1.50	-	0.497	-	0.077	-	15.5
	$\overline{X}$		1.38	1.54	0.521	0.468	0.129	0.047	25.0	8.4

Table 21: Summary of porosity indices for undisturbed cores - Clinton, Ontario April, 1989 (1m x 1m plots)

Site/Slope/Rep.			Bulk Density (g •m^{-3})		Porosity (m^{3} •m^{-3})		Macroporosity (m^{3} •m^{-3})		Relative Macroporosity (%)	
			MB	NT	MB	NT	MB	NT	MB	NT
Hill 1	Lower	18	1.33	1.48	0.502	0.459	0.066	0.042	13.1	9.1
		17	1.31	1.41	0.499	0.476	0.078	0.052	15.6	10.9
		16	1.30	1.37	0.514	0.491	0.071	0.056	13.8	11.4
	$\overline{x}$		1.31	1.42	0.505	0.475	0.072	0.050	14.2	10.5
	Upper	15	1.44	1.72	0.472	0.394	0.088	0.031	18.6	7.1
		14	1.38	1.65	0.497	0.409	0.138	0.051	'27.8	12.5
		13	1.36	1.56	0.490	0.426	0.107	0.043	21.8	10.1
	$\overline{x}$		1.39	1.64	0.486	0.410	0.111	0.042	22.7	10.2
Hill 2	Upper	12	1.19		0.526		0.140		26.6	
		11	1.41		0.528		0.095		18.0	
		10	1.39		0.535		0.085		15.9	
	$\overline{x}$		1.33		0.530		0.107		20.2	
	Lower	9	1.25		0.547		0.160		29.2	
		8	1.40		0.537		0.115		21.4	
		7	1.42		0.488		0.074		15.2	
	$\overline{x}$		1.36		0.524		0.116		21.9	

Table 22. Summary of average treatment effects on porosity indices from all cores sampled at D. Lobbs - April 1989 sampling period.

Site/Slope		Bulk Density ($g \bullet cm^{-3}$)		Total Porosity ($m^3 \bullet m^{-3}$)		Macroporosity ($m^3 \bullet m^{-3}$)		Relative Macroporosity (%)	
		MB	NT	MB	NT	MB	NT	MB	NT
Hill 1	Lower	1.39	1.45	0.478	0.460	0.065	0.046	13 4	10.0
	Upper	1.48	1.64	0.452	0.425	0.016	0.051	16.3	12.0
Hill 2	Lower	1.37	1.54	0.521	0.443	0.12	0.048	22.0	10.9
	Upper	1.36	1.66	0.524	0.468	0.118	0.047	22.1	8.4
Average		1.4^{a1}	1.57^{b}	0.494^{a}	0.449^{b}	0.093^{a}	0.048^{b}	18.4^{a}	10.3^{b}
	S.D.	0.10	0.11	0.039	0.03	0.04	0.013	4.32	1.52

[1] Values for each soil parameter with different letters are significantly different at the 0.01 probability level

4.1.3 D. Lobb - June Sampling Period

The Lobb site was again sampled in June of 1989 after the crop had emerged to see the effects of time, secondary tillage and planting on the surface hydraulic properties. A third sampling location, Hill No. 3 was also sampled because of its different texture (i.e clay loam). During this sampling period, only the permanent runoff plots were sampled because the 1m x 1m sites had been disturbed by field crews working in the area. Raw field data from the GPI readings are seen in Appendix 2e. All readings were taken near the middle of the corn row to reduce disturbance of the emerging corn crop. Undisturbed cores were not taken at this time so as to minimize site disturbance for future rainfall simulation runs.

A summary of the measured K_{fs} values for each replicate are seen in Table 23. The overall average K_{fs} indicates that the moldboard treatment is approximately 2.5x higher than the no-till.

Table 24 and 25 show the measured values for. calculation of the predicted time to ponding Tp for Hill 1 and 2, respectively. A summary of this data can be found in Table 26. The matric flux potential is again lower in the no-till compared to the moldboard (Table 27). The lower ϕ_m and higher initial soil water contents in the no-till result in a shorter predicted time to ponding in the no-till which is consistent with the other sampling periods.

The measured data from the rainfall simulation experiments seen in Table 28 are consistent with the measured hydraulic properties for this site. Infiltration rates in the no-till were on average higher, but not significantly different than those in the moldboard plots.

Table 23: Summary of field saturated hydraulic conductivity from pressure infiltrometer for D. Lobb, June 1989 sampling period.

Site/Slope/ Tillage			Field saturated K_{fs}($m \bullet s^{-1}$ x 10^{-5}) Replication Number					Geometric		Arithmetic	
			1	2	3	4	5	$\bar{x}$	S	$\bar{x}$	S
Hill 1	Lower	MB	1.17	0.915	0.986	2.26	-	2.18	3.20	3.83	4.93
		NT	4.47	5.51	0.145	5.02	-	2.06	5.87	3.79	2.46
	Upper	MB	0.059	2.62	3.17	0.037	-	0.37	10.90	1.47	1.66
		NT	0.073	0.355	2.74	1.16	-	0.53	4.81	1.08	1.20
Hill 2	Lower	MB	28.00	3.61	0.816	--	-	4.35	5.90	1.08	14.9
		NT	0.667	3.17	1.46	--	-	1.46	2.18	1.76	1.28
	Upper	MB	4.53	0.146	0.013	19.6	2.66	0.85	18.9	5.39	8.16
		NT	0.580	0.013	0.195	0.854	-	0.19	6.61	0.41	0.38
Hill 3	Upper	MB	2.35	1.28	0.195	0.203	-	0.59	3.58	1.01	1.03
		NT	0.382	3.23	1.07	--		1.10	2.91	1.56	1.49
Overall Average		MB	4.50[a1]	(7.28)							
		NT	1.72[a]	(1.82)							

(standard deviation)

[1] Values with different letters are significantly different at the 0.05 probability level

Table 24: Measured data for calculation of predicted time to ponding Tp for D. Lobb, June 1989 (Hill 1)

Site		Mgt.	Rep.	Soil Water Content θ_i	θ_v ($m^3 \cdot m^{-3}$)	$\Delta\theta$	ϕ_m ($m^2 \cdot s^{-1} \times 10^{-6}$)	Calculated Time to ponding Tp(s) Low Intensity	High
Hill 1	Lower	MB	1	.206	.445	.239	16.52	30750	1819
			2	.211	.362	.151	1.23	1446	86
			3	.222	.344	.122	1.26	1197	71
			4	.296	.376	.170	1.63	2158	128
		×|		.211	.382	.1705	5.16	8888	526
		NT	1	.237	.398	.161	5.73	7185	425
			2	.200	.367	.167	6.45	8389	496
			3	.216	.315	.099	0.584	450	27
			4	.211	.367	.156	5.59	6791	402
		×|		.216	.362	.146	4.56	5704	337
	Upper	MB	1	.274	.353	.079	0.117	72	4
			2	.279	.353	.074	5.56	3204	190
			3	.259	.376	.117	5.85	5331	315
			4	.285	.358	.073	0.114	65	4
		×|		.274	.360	.086	2.91	2168	128
		NT	1	.264	.393	.129	0.076	76	4
			2	.274	.362	.088	0.308	211	12
			3	.290	.371	.081	3.21	2025	120
			4	.211	.289	.078	0.36	219	13
		×|		.260	.354	.094	0.99	633	37

Low Intensity Rainfall Rate = 0.68 mm $\cdot$min^{-1}

High Intensity Rainfall Rate = 2.8 mm $\cdot$min^{-1}

Table 25: Measured data for calculation of predicted Tp for D. Lobb, Hill 2, June, 1989 sampling period.

Site	Mgt	Rep	Soil Water Content θ_i	θ_v $(m^3 \cdot m^{-3})$	$\Delta\theta$	ϕ_m $(m^2 \cdot s^{-1} \times 10^{-6})$	Calculated Tp(s) Low Intensity	High Intensity
Hill 2								
Lower	MB	1	-	-	-	28.00	-	-
		2	-	-	-	7.29	-	-
		3	.285	.402	.117	0.816	743	44
		$\bar{X}$	.285	.402	.117	12.03	743	44
	NT	1	-	-	-	0.35	-	-
		2	.259	.418	.159	2.44	3021	179
		3	.264	.422	.158	0.728	896	53
		$\bar{X}$	.2615	.420	.1585	1.17	1959	116
Upper	MB	1	.339	.422	.083	3.51	2269	134
		2	.339	.422	.083	0.694	449	26
		3	.339	.422	.083	0.0089	6	<1
		4	-	-	-	12.50	-	-
		5				1.78		
		$\bar{X}$	.339	.422	.083	3.70	908	53

Low Intensity Rainfall Rate - 0.68 mm $\cdot$min^{-1}
High Intensity Rainfall Rate - 2.8 mm $\cdot$min^{-1}

Table 26: Comparison of average predicted Tp for tillage treatments at D. Lobb for June, 1989 sampling period.

Site	Slope	Rain Intens.	Calculated Time to ponding TD(s) Moldboard	NoTill
Hill 1	Lower	Low	8888	5704
		High	526	337
	Upper	Low	2168	633
		High	128	37
Hill 2	Lower	Low	743	1958
		High	44	116
	Upper	Low	908	1
		High	53	<1
Overall Average		Low	3176^{a1} (3860)	2074^{a*} (2554)
		High	187^{a} (229)	123^{a} (151)

(standard deviation)

[1] Values in same row with different letters are significantly different at 0.05 probability level

Table 27: Summary of tillage effects on average matric flux potential measurements at D. Lobb for June sampling period.

		Matric Flux Potential ($m^2 \cdot s^{-1} x 10^{-6}$)		Initial Soil Water Content (%)	
		MB	NT	MB	NT
Hill 1	Lower	5.2	4.6	21.1	21.6
	Upper	2.9	0.99	27.4	26.0
Hill 2	Lower	12.0	1.17	28.5	26.1
	Upper	3.7	0.25	33.9	-
Overall Average[1]		5.43^a	1.79^b	27.7^a	24.6^a
	S.D.	7.67	2.32	4.74	2.57

[1] Values for each treatment with different letters are significantly different at 0.05 probability level

Table 28: Runoff characteristics from D. Lobb rainfall simulation in June 1989 for large plots.

			Runoff Rate (cm/hr)	Infilt Rate (cm/hr)	Soil Loss (t/ha)	Time to Runoff (S)
Hill 1	Lower	NT	11.5	6.6	7.0	120
		MB	11.5	6.6	16.0	60
	Upper	NT	8.5	9.6	9.0	36
		MB	17.3	0.8	28.0	20
Hill 2	Upper	NT	13.7	4.4	16.0	90
		MB	12.9	5.2	23.0	94
	Lower	NT	8.1	10.0	3.0	60
		MB	9.0	9.1	7.0	50
Hill 3	Lower	NT	18.0	0.1	12.0	80
		MB	17.9	0.2	17.0	40
	Upper	NT	18.1	<0.11	6.0	80
		MB	17.9	0.2	15.0	67
Average		NT	12.0^{a} (4.8)	5.1^{a} (4.4)	8.8^{a}* (4.6)	78^{a} (28)
		MB	14.4^{a} (3.8)	3.7^{a} (3.8)	17.7^{b}* (7.2)	55^{a} (25)

Values in each column with different letters are significantly different at(1) 0.05 or (2) *0.025 probability level

4.1.4 Summary of Measurements at D. Lobb's

The summaries of the average hydraulic properties for each slope position and sampling date are given in Tables 29 to 32. An overall summary of the field averaged values for each sampling date are given in Table 33.

The data in Table 33 clearly show the consistent nature of the measurement over the three sampling dates. The long term no-till treatment is characterized by:

1) higher bulk density
2) lower total porosity
3) lower macroporosity
4) shorter time to ponding
5) lower matric flux potential
6) lower field saturated hydraulic conductivity
7) lower saturated hydraulic conductivity
8) higher runoff (lower infiltration rates)

compared to the long term moldboard plough treatment. These effects were consistent across all sampling times and were not dependent on the time of sampling.

Table 29: Comparison of average K_{fs} values from the GPI for D. Lobb 1988-89.

Site/Slope		Texture	Field Saturated Hydraulic Conductivity ($m \bullet s^{-1} \times 10^{-5}$)					
			Fall 1988		April 1989		June 1989	
			MB	NT-8	MB	NT-9	MB	NT-9
Hill 1	Lower	fSL	6.7	1.80	1.34	0.69	3.83	3.79
	Upper	L	13.60	2.82	2.35	1.46	1.47	1.08
Hill 2	Lower	SiCL	4.82	0.21	1.24	0.105	10.8	1.76
	Upper	SiCL	14.70	0.42	5.50	1.28	5.39	0.41
Hill 3	Lower	CL	8.50	1.73	-	-	-	-
	Upper	CL	-	-	-	-	1.01	1.56
Overall Average[1]			9.14^a	1.26^c	2.84^b	0.91c	4.5^b	1.72c
	S.D.		5.03	1.53	3.31	1.61	7.29	1.82

[1] Values in each row with different letters are significantly different at 0.01 probability level

Table 30. Comparison of tillage effects on average matric flux potential at D. Lobb for three sampling periods 1988-89.

Site/Slope/Tillage			ϕ_m ($m^2 \bullet s^{-1}$ x 10^{-6})			Initial θ_v (%)		
			Fall 1988	April 1989	June 1989	Fall 1988	April 1989	June 1989
Hill 1	Lower	MB	2.90	0.91	5.2	27.8	24.0	21.1
		NT	0.70	1.22	4.6	44.9	27.8	21.6
	Upper	MB	5.06	1.42	2.9	38.9	28.6	27.4
		NT	0.77	1.08	0.99	48.8	27.8	26.0
Hill 2	Lower	MB	21.1	1.02	12.0	42.8	31.8	28.5
		NT	0.1	0.07	1.17	48.3	30.4	26.1
	Upper	MB	9.00	5.65	3.7	39.8	29.6	33.9
		NT	0.16	2.06	0.25	46.2	32.5	40.2
Overall Avg.		MB	9.51 (8.12)^{a}	2.68 (4.22)a	5.43 (7.7)^{a}	37.3 (6.6)^{a}	28.0 (3.3)^{b*}	27.7 (4.7)^{b**}
		NT	0.42 (.35)^{a}	1.14 (1.73)^{a}	1.79 (2.3)^{a}	47.0 (1.82)^{a}	29.6 (2.6)^{b***}	24.6 (2.6)^{b***}

* Values for each soil parameter with different values are significantly different at: (1)0.025 probability level (2)
** 0.05 probability level, (3)*** 0.01 probability level.

Table 31. Comparison of tillage effects on average predicted time to ponding for D. Lobb 1988-1989.

Site/Slope/Tillage			Rainfall Intensity					
			LOW			HIGH		
			1988	April 1989	June 1989	1988	April 1989	June 1989
Hill 1	Lower	MB	2256	632	8888	133	43	526
		NT	182	574	5704	11	39	337
	Upper	MB	2800	1075	2168	165	73	128
		NT	71	565	633	4	38	37
Hill 2	Lower	MB	5800	521	743	342	35	44
		NT	6	22	1958	1	2	116
	Upper	MB	3360	3593	908	200	246	53
		NT	31	1263	1	86	86	<1
Average		MB	3554^a (1564)	1567^a (1455)	3176^a (3860)	210^a (92)	92^a (86)	187^a (229)
		NT	72^a (78)	716^a (587)	2074^b (2554)	4^a (5)	42^a (35)	123^b (151)

(standard deviation)
Values in the same row with different letters are significantly different at 0.05 probability level.

Table 32: Comparison of average porosity indices for three sampling periods at D. Lobb, Clinton, Ontario, 1988-89.

Site/Slope/Tillage			Bulk Density (g • cm^{-3})		Total Porosity (m^3 •m^{-3})		Macroporosity (m^3 •m^{-3})		Relative Macroporosity (%)	
			1988	April 89	1988	April 89	1988	April 89	1988	April 89
Hill 1	Lower	MB	1.44	1.39	0.47	0.48	0.08	0.06	17	13.4
		NT	1.58	1.45	0.43	0.46	0.08	0.05	18	10.0
	Upper	MB	1.48	1.48	0.46	0.45	0.08	0.08	18	16.3
		NT	1.61	1.64	0.41	0.42	0.06	0.05	14	12.0
Hill 2	Lower	MB	1.31	1.37.	0.52	0.52	0.13	0.12	25	22.0
		NT	1.54	1.54	0.43	0.44	0.06	0.05	15	10.0
	Upper	MB	1.43	1.36	0.47	0.52	0.06	0.12	13	22.1
		NT	1.50	1.66	0.47	0.47	0.05	0.05	11	8.4
Average1		MB	1.42a*	1.40^{a*}	$.476^{a*}$	$.49^{a*}$	$.086^{a*}$	$.093^{a*}$	17.5^{a*}	18.4^{a*}
		NT	1.56a*	1.57^{a*}	$.432^{a*}$	$.45^{a*}$	$.063^{a**}$	$.049^{b**}$	14.6^{a**}	10.3^{b**}

[1] Values for each soil parameter with different letters are significantly different at: (1) *0.05 probability level; (2) ** 0.01 probability level

Table 33: Summary of hydraulic properties at D. Lobb's site for all measurement dates.

Hydraulic Property	Tillage	Oct. 1988	April 1989[*]	June 1989
K_{fs} (ms^{-1} x 10^{-5})	MB	9.14	2.84	4.50
	NT	1.26	0.91	1.72
K_{sat} (ms^{-1} x 10^{-5})	MB	9.89	60.55	N/A
	NT	0.94	18.80	N/A
ϕ_m (m^2 s x 10^{-6})	MB	4.04	2.68	5.43
	NT	0.22	1.14	1.79
α* (m^{-1})	MB	24.5	10.6	8.3
	NT	42.7	7.8	9.6
T_p (s)	MB	210	92	187
	NT	4	42	123
ρ_b	MB	1.40	1.40	N/A
	NT	1.54	1.57	N/A
θ_{sat}	MB	0.486	0.494	N/A
	NT	0.449	0.449	N/A
θ_{macro}	MB	0.097	0.093	N/A
	NT	0.063	0.048	N/A

4.2 Surface Hydraulic Properties

4.2.1 Site Description - D. Ghent T-2000 Site, Mt. Forest Ontario

A second T-2000 site was investigated where surface hydraulic properties were measured with the GPI in conjunction with rainfall simulation experiments. The farm of D. Ghent is located in Wellington County, Arthur Township, Lot 5, Concession 7 near Mt. Forest, Ontario. The site was chosen because it provided a minimum till (i.e fall chisel plough) versus no-till comparison on a medium textured soil (Perth silt loam). In 1988 clover was underseeded to the winter wheat crop. In 1989 the clover was left for a hay crop and was mowed for the rainfall simulation trials. All field measurements were done in October, 1989. Afterwards, 4-5 GPI measurements were taken on each paired treatment plot at two slope positions. Figures 5 and 6 (from Aspinall et al., 1987) show the location and layout of the site respectively. Each runoff plot measured 1.6m x 4.0m and was located near T-2000 Benchmarks 2 and 4.

4.2.2 Results and Discussion

A summary of the data collected for each individual replication of the GPI is given in Appendix 3a along with the calculated hydraulic parameters, K_{fs} and $\phi_{m.}$ The soil porosity indices measured in the laboratory from intact cores, including bulk density, soil water content vs. matric potential, and the calculated pore size distributions are given in Appendix 3b.

The measured values from each replication of the GPI are given in Table 34 and the data are summarized in Table 35. The average K_{fs} for the minimum till at the upper slope position was 2x higher than that measured in the no-till plot. Similarly, the average K_{fs} at the lower slope position was 6x higher in the minimum till as compared to the no-till

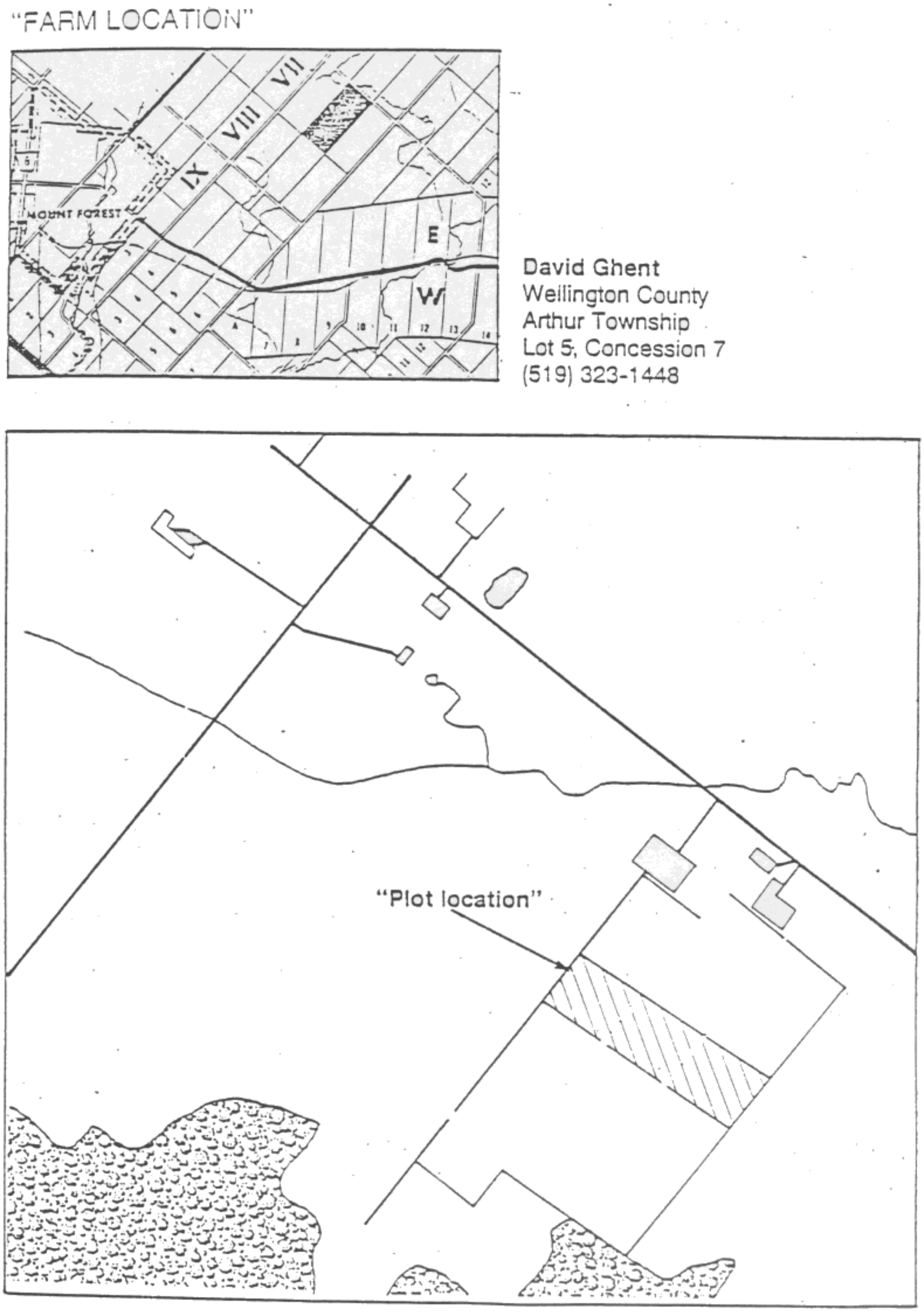


Fig. 5 Site location - D. Ghent T2000 Site, Mt. Forest Ontario

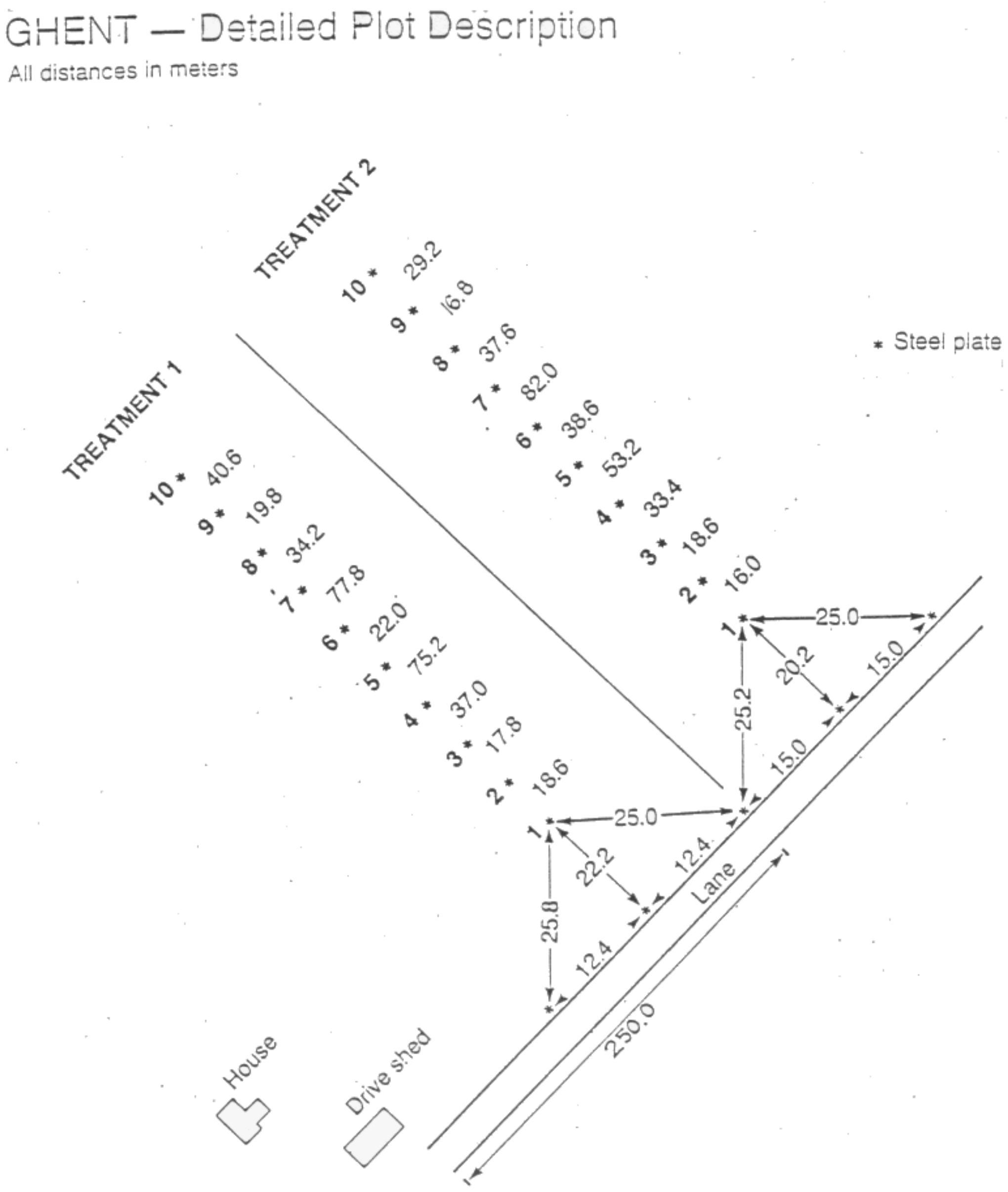


Fig.6 Detailed plot layout - D. Ghent T-2000 Site

Table 34: Measured K_{fs} from pressure infiltrometer for D. Ghent (T-2000)

		Field Saturated Hydraulic Conductivity K_{fs} ($m \bullet s^{-1} \times 10^{-6}$)								
Site/Slope/Tillage		Replication Number					Geometric		Arithmetic	
		1	2	3	4	5	X	S	X	S
1 Upper	MIN	35.1	13.0	19.5	6.35	6.4	12.96	20.8	16.08	11.93
	NT	1.2	15.9	4.0	10.24	0.6	3.44	0.60	6.40	6.55
2 Lower	MIN	34.2	70.3	18.4	137.6	180.5	64.3	41.3	88.19	69.0
	NT	71.1	0.03	0.92	0.22	0.34	0.67	12.5	14.5	31.6

Table 35: Summary of average field saturated hydraulic conductivity measured with the pressure infiltrometer (D. Ghent)

	Field Saturated Hydraulic Conductivity K_{fs} ($m \bullet s^{-1} \times 10^{-6}$)	
Site/Slope	MIN	No Till
1 Upper	16.1	6.4
2 Lower	88.2	14.5
Overall Average	52.1^{a1}	10.45^{b}
S.D.	60.2	21.96

(standard deviation)

[1] Values in the same row with different letters are significantly different at 0.05 probability level

treatment. Both sites exhibited a high coefficient of variation so that when the overall averages (both slope positions) were compared, K_{fs} in the minimum till was significantly higher (0.05 probability level) than that found in the no-till treatment. The spatial variability of K_{fs} was also 3x higher in the minimum till. The relative variation given by the coefficient of variation was higher in the NT plot. The K_{sat} data (Table 36) were inconsistent with the K_{fs} data (the only site where this is the case). The K_{sat} data indicate a higher K_{sat} in the no-till compared to minimum till (though the difference is not significant). While this certainly could be true, the other hydraulic properties from the cores (porosity, bulk density, macroporosity, etc.) all suggest that the K_{sat} should be lower. The presence of one or two large roots in the cores (the site was in clover since the previous fall) may have skewed the K_{sat} measurements.

The runoff data for the site are given in Table 37. The data are consistent with the measured K_{fs} values with much higher runoff rates in the no-till compared to the minimum till. In addition, the matric flux potential (Table 38) was 5x lower in the no-till (significant at the 0.025 probability level). This resulted in a considerably shorter predicted time to ponding. Table 39 contains the measured Tp values for each replication and the data are summarized in Table 40. The data are consistent with the measured K_{fs} and runoff values, confirming that the no-till had a significantly lower Tp than the minimum till treatment (significant at 0.01 probability level).

The differences in average K_{fs} and the measured effects on soil loss can be explained by the porosity indices given in Table 41 and 42. The NT plot had an average bulk density that was significantly higher compared to the minimum till treatment, and this

Table 36: Comparison of K_{fs} from pressure infiltrometer and K_{sat} from undisturbed cores (D. Ghent - T-2000)

Site/Slope/Tillage			Pressure Infiltrometer (Y) (m •s^{-1} x 10^{-5})	Ksat (X) (m •s^{-1} x 10^{-5})
1	Upper	MIN	1.61	15.89
		NT	0.64	24.2
2	Lower	MIN	8.82	7.8
		NT	1.45	12.92
Average		Min	5.21^{a}[1]	11.8^{a}
		NT	1.05^{a}	18.6^{a}

[1] Values with different letters are significantly different at 0.05 probability level

Table 37. Runoff data from rainfall simulation trails at D. Ghent (1989).

Site/Slope/Tillage		Time to Ponding (S)	Water Runoff (cm)	Steady State Runoff Rate (cm/hr)	Steady State Infiltration (cm/hr)	Soil Loss (+/ha)
1 Upper	MIN	150	0.4	2.3	10.2	0.03
	NT	120	1.2	3.6	8.9	0.03
2 Lower	MIN	600	0.4	0.5	12.1	0.45
	NT	90	1.0	6.4	6.1	0.03
Average	MIN	375	0.4	1.4	11.4	0.24
	NT	105	1.1	5.0	7.5	0.03

Table 38: Summary of tillage effects on average Matric Flux Potential ¢m measurements for D. Ghent (T-2000).

Site	Slope	Matric Flux Potential (m^{2} • s^{-1} x 10^{-6})		Initial Soil Water Content (m^{3} • m^{-3})	
		MIN	NT	MIN	NT
1	Upper	0.85	0.59	32.7	32.0
2	Lower	7.49	1.21	33.6	31.6
Overall Average [1]		4.17a	0.80^{b}	33.2^{a}	31.8^{a}
S.D.		4.58	1.85	2.66	0.36

[1] Values for each soil parameter with different letters are significantly different at 0.025 probability level

Table 39: Measured data for calculation of predicted time to ponding for D. Ghent (T-2000)

			Soil Water Content				Calculated Time to Ponding	
Site	Mgt.	Rep.	θ_i	θf (m^3•m^{-3})		ϕ_m ($m^2.s^{-1}$ x 10^{-6})	Low Intensity	High
1	MIN	1	.324	.402	.078	2.16	1312	78
		2	.305	.418	.113	0.619	545	32
		3	.339	.418	.079	0.928	571	34
		4	.339	.406	.067	0.302	157	9
		5	-	-	-	0.242	-	-
	X		.327	.411	.084	0.85	646	38
	NT	1	.319	.380	.061	0.0769	36	2
		2	.324	.389	.065	1.56	790	47
		3	.319	.385	.066	0.136	70	4
		4	.319	.398	.079	1.131	696	41
		5	.319	.398	.079	0.0374	23	1
	X		.320	.390	.070	0.588	323	19
2	MIN	1	.315	.406	.091	2.63	1864	110
		2	.315	.426	.111	5.41	4677	277
		3	.371	.414	.043	9.70	3248	192
		4	.376	.426	.050	5.80	2258	134
		5	.305	.389	.084	13.89	9087	538
	X		.336	.412	.076	7.49	4227	250
	NT	1	.319	.393	.074	5.92	3412	202
		2	.319	.398	.079	0.0024	1	< 1
		3	.319	.406	.087	0.0769	52	3
		4	.310	.389	.079	0.0182	11	< 1
		5	.315	.362	.047	0.0280	10	< 1
	X		.316	.390	.073	1.21	697	41

Low Intensity Rainfall Rate = 0.68 mm •min^{-1}
High Intensity Rainfall Rate = 2.8 mm •min^{-1}

Table 40: Comparison of predicted Tp for tillage treatments at D. Ghent (T-2000)

Site/Slope		Rain Intensity	Calculated Time to Ponding Tp (s) MIN Till	 No Till
1	Upper	LOW	646	323
		HIGH	38	19
2	Lower	LOW	4227	697
		HIGH	250	41
Overall		Low	2436[a1] (2532)	510[b] (264)
		High	144[a] (150)	30[b] (15)

(standard deviation)

[1] Values in same row with different letters are significantly different at 0.01 probability level

Table 41: Summary of porosity indices from undisturbed cores for D. Ghent (T-2000)

Site/Slope/Rep			Bulk Density (g.cm^{-3})		Total Porosity (m^3 • m^{-3})		Macroporosity (m^3 • m^{-3})		Relative Macroporosity (%)	
			MIN	NT	MIN	NT	MIN	NT	MIN	NT
1	Upper	1	1.33	1.36	0.519	0.532	0.142	0.097	27.4	18.2
		2	1.36	1.33	0.535	0.532	0.131	0.111	24.5	20.9
		3	1.29	1.32	0.559	0.530	0.107	0.098	19.1	18.5
		4	1.27	-	0.605	-	0.163	-	26.9	-
		5	1.35	1.44	0.571	0.538	0126	0.114	22.1	21.2
	X		1.32	1.36	0.558	0.533	0.134	0.105	24.0	19.7
2	Lower	1	1.32	1.46	0.538	0.520	0.012	0.089	20.8	17.1
		2	1.34	1.46	0.521	0.511	0.154	0.109	29.5	21.3
		3	-	1.39		0.449	-	0.076	-	16.9
		4	1.35	1.35	0.524	0.515	0.091	0.111	17.4	21.5
		5	1.27	-	0.599	-	0.178	-	29.7	-
	X		1.32	1.41	0.545	0.499	0.134	0.096	24.3	19.2

Table 42: Summary of average treatment effects in porosity indices from undisturbed cores for D. Ghent (T-2000)

Site	Slope	Bulk Density (g • cm^{-3})		Total Porosity (m^3 • m^{-3})		Macroporosity (m^3 • m^{-3})		Relative Macroporosity (m^3 • m^{-3})	
		MIN	NT	MIN	NT	MIN	NT	MIN	NT
1	Upper	1.32	1.36	0.558	0.533	0.134	0.105	24.0	19.7
2	Lower	1.32	1.41	0.545	0.499	0.134	0.096	24.3	19.2
Overall Average		1.32^a	1.38^b	0.552^a	0.516^b	0.123^a	0.101^b	24^a	19^b
	S.D.	0.03	0.06	0.03	0.03	0.05	0.01	4.55	1.91

Values in the same row with different letters are significantly different at 0.01 probability level was reflected in a significantly lower total porosity. This was attributed to a reduction in macroporosity and relative macroporosity (significant at 0.01 level). The decreased macroporosity would account for the decreased K_{fs}, the lowering of the steady state infiltration rate, and increased runoff rates in the no-till seen in Table 37. These results are consistent with the effects of no-till at D. Lobb's T-2000 site.

4.2.3 Site Description - F. Anthony T-2000 Site, Halton Hills, Ontario

A third T-2000 site was chosen to provide a comparison of minimum till versus moldboard plough. The farm of F. Anthony is located in the Regional Municipality of Halton, Town of Halton Hills, Lot 26, Concession V, just to the west of the Town of Acton (Figures 7 and 8). The soil texture is loam (48% sand, 39% silt and 13% clay). Paired sites were selected at three slope positions which coincide with T-2000 Benchmark location 4, 5 and 9. Each plot was 1.6m x 4.0m for the rainfall simulation trials and 4-5 readings were taken with the GPI in each plot. Undisturbed cores were also taken to measure soil porosity indices.

4.2.4 Results and Discussion

A summary of the data collected for each individual replication if the GPI is given in Appendix 4a. along with the measured porosity indices for all undisturbed cores taken in the plots (Appendix 4b.). The measured ^{K}fs data from the GPI are summarized in Table 43. A high degree of variability exists within each slope position, though the results are similar to other field trials and again are probably representative of the natural variability. The overall averages for both treatments showed that MB had a significantly higher average K_{fs} than the SS treatment (0.05 probability level).

A comparison of K_{fs} from the GPI and Ksat from the undisturbed cores (Table 44) shows a correlation coefficient r = 0.54. The higher average Ksat values are again expected, since the field value is more affected by pore continuity than the undisturbed core where macropores would be vented at the bottom thus leading to higher K values. As well the core method measures the full saturated K value while the GPI measures a field

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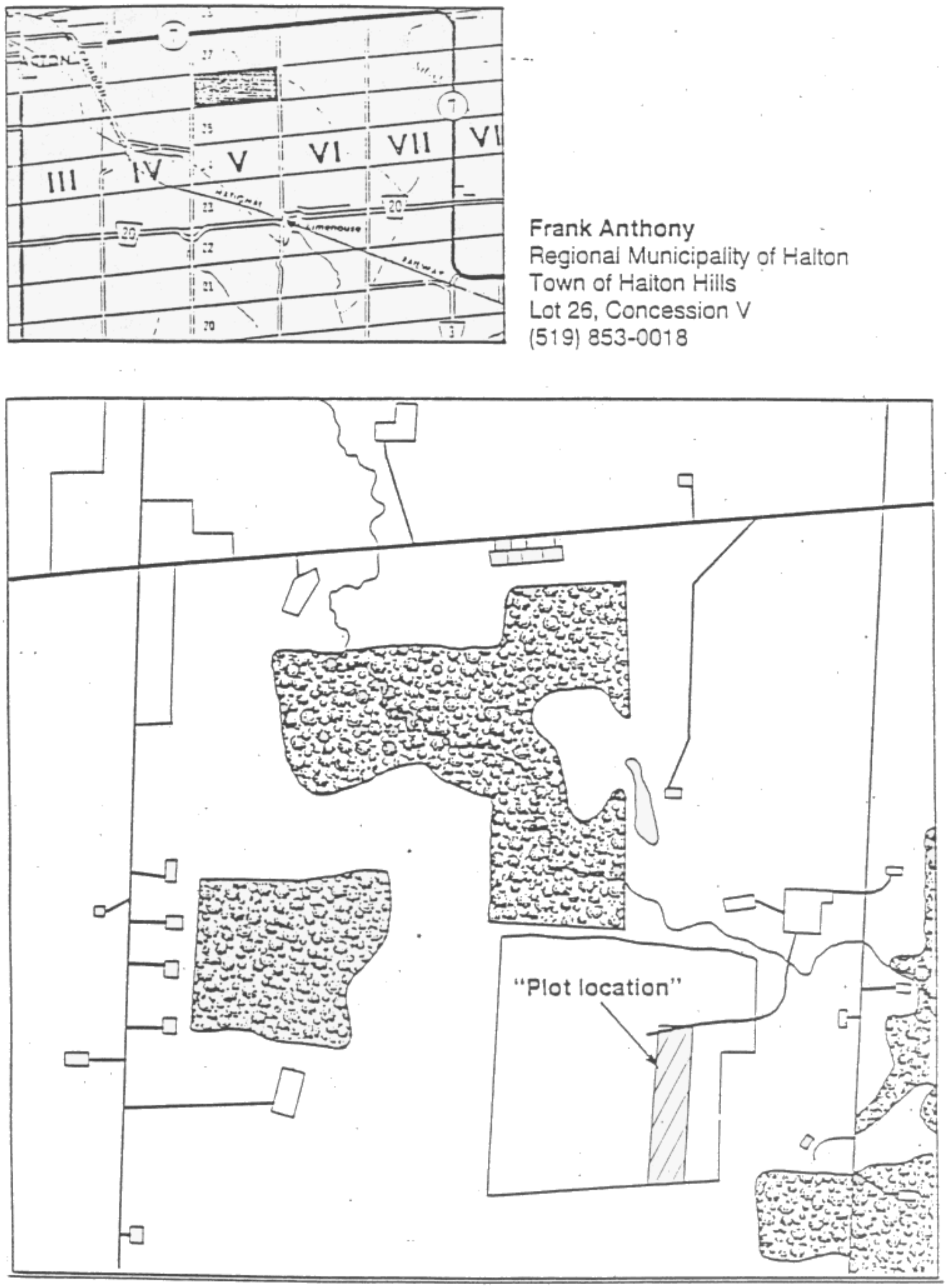

Frank Anthony
Regional Municipality of Halton
Town of Halton Hills
Lot 26, Concession V
(519) 853-0018

Fig. 7. Site location - F. Anthony T-2000 Site, Halton Hills Ontario

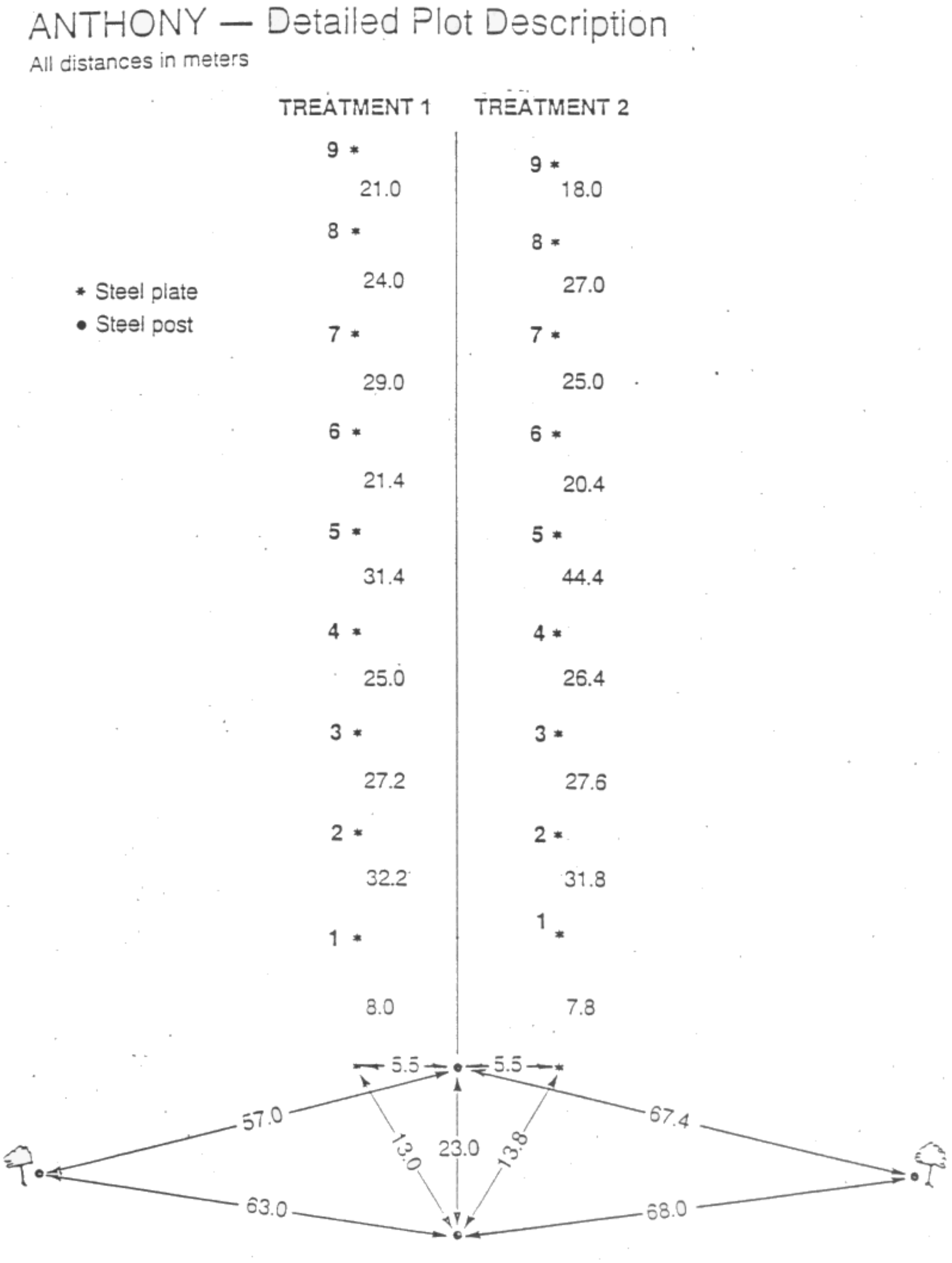

Fig. 8. Detailed plot layout - F. Anthony T-2000 Site, Halton HillsOntario

Table 43: Summary of saturated hydraulic conductivity from pressure infiltrometer for F. Anthony (T-2000).

Site/Slope/ Tillage			Field saturated Kf_s(m • s^{-1} x 10^{-5})								
			Replication Number					Geometric		Arithmetic	
			1	2	3	4	5	×I	S	×I	S
Hill 1	Lower	MB	6.35	4.63	0.575	11.45	7.98	4.34	3.25	6.2	4.03
		SS	16.84	1.75	8.28	7.08	8.21	6.77	2.29	8.43	5.41
	Upper	MB	1.41	0.945	0.526	11.41	21.34	2.79	5.07	7.13	9.15
		SS	1.24	0.314	0.465	0.044	0.074	0.22	3.91	0.43	0.49
Hill 2	Lower	MB	24.1	10.31	8.54	7.64	7.08	10.28	1.64	11.53	7.13
		SS	16.41	5.49	13.78	9.03	7.55	9.67	1.56	10.45	4.52
Overall	Average	MB	8.28a	(6.99)							
		SS	6.43^b	(5.86)							

(standard deviation)

Values with different letters are significantly different at 0.05 probability level

Table 44: Comparison of average hydraulic properties from GPI (K_{fs}) and undisturbed cores (K_{sat}) for F. Anthony (T-2000).

Site/Slope		Field Saturated K_{fs} ($m \bullet s^{-1} x 10^{-5}$) MB		SS	
		Kfs(Y)	Ksat (X)	Kfs(Y)	Ksat (X)
Hill 1	Lower	6.2	6.58	8.43	3.24
	Upper	7.13	13.43	0.43	2.38
Hill 2	Lower	11.53	14.83	10.45	51.43
Overall Average		8.29	11.61	6.44	19.02
	(S.D.)	(6.99)	(11.61)	(5.86)	(42.6)

Correlation of Y on X r = 0.54
n = 6

saturated K value.

The measured runoff data from the Anthony site for the high intensity storm are given in Table 45. The moldboard infiltration rates are only marginally higher than the soil save treatment. The total soil and phosphorus loss measured from the rainfall simulation experiment were also higher in the soil-save compared to the moldboard treatment. The similarity in runoff rates is consistent with the detailed measurements of hydraulic properties found with the pressure infiltrometer. The overall effect of tillage on average hydraulic properties was therefore minimal.

The measured matric flux potential ϕ_m was also only slightly lower in the soil save treatment (Table 46). Table 47 shows the calculated values for Tp based on the measured GPI values. The data are summarized in Table 48 and indicated the predicted time to ponding is slightly lower in the soil-save treatment compared to the moldboard, though the difference is not significant (0.05 probability level). This data was consistent with the observed values from the rainfall simulation trials with measured Tp slightly lower in the soil-save treatment.

The individual measured porosity indices for each core are found in Table 49 and the data are summarized in Table 50. Little difference was found between treatments at this site. The soil save treatment had a marginally lower average bulk density (1.27 vs 1.29 $g \bullet cm^{-3}$) but the difference was not significant at the 0.05 probability level. Both treatments had a similar average total porosity. The slightly lower macroporosity in the soil save treatment (0.105 vs. 0.12 in the MB) and subsequent lower relative macroporosity may explain the slightly lower average K_{fs} values in the soil save plots. The core data are consistent with

Table 45: Runoff measurements on Anthony simulation (2.8 mm min $^{-1}$) in Sept., 1989.

Site/Slope/Tillage			Time to Ponding (sec)	Water runoff (cm)	Steady-'state runoff rate (cm/hr)	Steady-state infiltration (cm/hr)	Soil loss (t/ha)	Total Phosphorus Loss (kg/ha)
4	Upper	min.	184	1.1	5.1	7.4	0.36	1.71
		MB	240	1.3	6.0	6.5	0.61	1.55
5	Mid	min	180	1.0	4.5	8.0	0.77	2.59
		MB	195	0.8	3.8	8.7	0.61	1.83
9	Lower	min		1.1	2.8	9.7	0.42	1.01
		MB	60	0.6	1.8	10.7	0.15	0.42
	Avg	min	182^{a}	1.06^{a}	4.1^{a}	8.4^{a}	0.52^{a}	1.77^{a}
		MB	165^{a}	0.90^{a}	3.9^{a}	8.6^{a}	0.46^{a}	1.27^{a}

Values in same column with different letters are significantly different at 0.05 probability level

Table 46: Summary of tillage effects on average Matric Flux Potential Om measurements for F. Anthony (T-2000)

		Matric Flux Potential ($m^2 \cdot s^{-1}$ x 10^{-5})		Initial Soil Water Content ($m^3 \cdot m^{-3}$)	
		MB	SS	MB	SS
Hill 1	Lower	2.51	5.64	-	-
	Upper	3.76	0.53	22.5	27.8
Hill 2	Lower	7.00	3.29	25.3	23.4
Overall Average		4.42^a	3.15'	23.9'	25.6^a
S.D.		4.2	3.4	3.18	3.24

Values for each soil parameter with different letters are significantly different at 0.05 probability level.

Table 47: Measured data for calculation of predicted Tp for F. Anthony

Site/Slope/Mgt.	Rep.	θ_i	θ_v (m^3• m^{-3})	$\Delta\theta$	ϕ_m (m^2•s^{-1}x 10^{-6}	Calculated Tp(s) Low Intensity	High
Hill 1 Upper MB	1	.232	.385	.153	0.930	1108	66
	2	.242	.358	.116	0.525	474	28
	3	.179	.305	.126	0.292	286	17
	4	.242	.353	.111	5.23	4521	267
	5	.232	.353	.121	11.85	11167	661
$\overline{X}$		.225	.351	.125	3.76	3511	208
SS	1	.284	.367	.083	1.55	1002	59
	2	.279	.334	.055	0.176	75	4
	3	.269	.334	.065	0.581	294	17
	4	.279	'.349	.069	0.219	118	7
	5	.279	.380	.101	0.115	90	5
$\overline{X}$		.278	.353	.075	0.528	316	18
Hill 2 Lower MB	1	.242	.362	.120	12.68	11850	701
	2	.216	.376	.160	10.76	13408	793
	3	.299	.398	.099	2.72	2097	124
	4	.232	.376	.144	4.02	4508	267
	5	.274	.389	.115	4.80	4299	254
$\overline{X}$		.253	.380	.128	7.00	7232	428
SS	1	.179	.367	.188	5.89	8623	510
	2	.242	.344	.102	1.66	1319	78
	3	.232	.376	.144	4.17	4677	277
	4	.269	.367	.098	2.46	1878	111
	5	.248	.367	.119	2.29	2122	126
$\overline{X}$		.234	.364	.130	3.29	3724	220

Low Intensity Rainfall Rate = 0.68 mm•min^{-1}
High Intensity Rainfall Rate = 2.8 mm•min^{-1}

Table 48: Comparison of predicted Tp for tillage treatments at F. Anthony (T-2000)

Site/slope		Rain Intensity	Calculated time to ponding Tp(s)	
			Moldboard	Soil Saver
Hill 1	Lower	Low	-	-
		High	-	-
	Upper	Low	3511	316
		High	208	18
Hill 2	Lower	Low	7232	3724
		High	428	220
Overall Average		Low	5371[a] (2631)	2020[a] (2410)
		High	318[a] (155)	119[a] (143)

(standard deviation)

Values in the same row with different letters are significantly different at 0.05 probability level

Table 49: Summary of porosity indices from undisturbed core measurements for F. Anthony T-2000

Site/Slope/Rep			Bulk Density (g •cm^{-3})		Total Porosity (m^3 •m^{-3})		Macroporosity (m^3 •m^{-3})		Relative Macroporosity (%)	
			MB	SS	MB	SS	MB	SS	MB	SS
Hill 1	Lower	1	1.41	1.21	0.403	0.481	0.084	0.100	20.8	20.8
		2	1.23	1.42	0.479	0.439	0.072	0.079	15.0	18.0
		3	1.28	1.27	0.526	0.481	0.121	0.088	23.0	18.3
		4	1.21	1.38	0.685	0.486	0.265	0.087	38.7	17.9
		5	1.23	1.05	0.591	0.466	0.178	0.071	30.1	18.2
	$\bar{x}$		1.27	1.27	0.537	0.471	0.144	0.085	25.5	18.0
	Upper	1	1.35	1.47	0.472	0.422	0.076	0.055	16.1	13.0
		2	1.37	1.40	0.490	0.473	0.096	0.064	19.6	13.5
		3	1.44	1.22	0.366	0.508	0.104	0.075	28.4	14.8
		4	1.39.	1.35	0.469	0.571	0.127	0.123	27.1	21.5
		5	1.18	1.17	0.446	0.525	0.068	0.100	15.2	19.0
	$\bar{x}$		1.35	1.32	0.449	0.500	0.094	0.083	21.3	16.4
Hill 2	Lower	1	1.26	1.19	0.524	0.551	0.121	0.181	23.1	32.8
		2	1.26	1.24	0.508	0.517	0.125	0.122	24.6	23.6
		3	1.35	1.28	0.492	0.531	0.099	0.106	20.1	20.0
		4	1.17	1.17	0.476	0.519	0.107	0.153	22.5	29.5
		5	1.25	1.20	0.511	0.542	0.159	0.165	31.1	30.4
	$\bar{x}$		1.26	1.22	0.502	0.532	0.122	0.145	24.3	27.3

Table 50: Summary of average treatment effects in porosity indices from undisturbed cores for F. Anthony (T-2000)

Site/Slope		Bulk Density (g•cm^{-3})		Total Porosity (m^3•m^{-3})		Macroporosity (m^3•m^{-3})		Relative Macroporosity (%)	
		MB	SS	MB	SS	MB	SS	MB	SS
Hill 1	Lower	1.27	1.27	0.537	0.471	0.144	0.085	25.5	18.0
	Upper	1.35	1.32	0.449	0.500	0.094	0.083	21.3	16.4
Hill 2	Lower	1.26	1.22	0.502	0.532	0.122	0.145	24.3	27.3
Overall Average		1.29^a	1.27^a	0.496^a	0.501^a	0.120^a	0.105^a	23.7^a	20.7^a
	S.D	0.09	0.11	0.07	0.04	0.05	0.04	6.6	6.0

Values for each soil parameter with different letters are significantly different at 0.05 probability level the measured steady state infiltration rates and suggests that the minimum till system resulted in a slight increase in runoff and a lower rate of infiltration into the soil matrix at the higher rainfall intensity.

5.0 <u>STUDY SITES WITH ONLY AN ASSESSMENT OF SURFACE PROPERTIES</u>

5.1 Elora Research Station

5.1.1 Site Description

During the 1989 field season, extensive use was also made of different tillage/cropping systems. One site of particular interest are the long-term tillage trials at the Elora Research Station near Guelph. These plots were initiated by Professor J.W. Ketcheson in 1969 and are located on a Conestoga silt loam (Gleyed Grey Brown Luvisol). The plot layout and the soils at this site have been previously described by Ketcheson (1980). The tillage experiment was a randomized complete block design with four replications. Each tillage plot was 47 m x 7.6 m. Two tillage systems were used, a fall moldboard plough followed by harrowing twice in the spring, and no-till on an adjacent site. Both treatments have been in continuous corn since 1969.

5.1.2 Results and Discussion

A summary of the data collected for each individual replication of the pressure infiltrometer is given in Appendix 5a. along with the calculated hydraulic parameters. A listing of the bulk density, soil water content versus matric flux potential ϕ_m measurements, and the calculated pore size distribution (volumetric), for all the undisturbed cores are given in Appendix 5b.

The field saturated hydraulic conductivity values, K_{fs}, measured with the GPI are given in Table 51. The arithmetic and geometric mean values were again calculated since K_{fs} generally has a log-normal probability distribution in the field.

As with the 1988 TED study, the GPI values for all three treatment blocks showed considerable variability in measured K_{fs}. In Block 1, average

Table 51: Measured K_{fs} from pressure infiltrometer for Elora Research Station

		Field saturated hydraulic conductivity ($m \bullet s^{-1}$ x 10^{-6})										
		Replicate							Geometric		Arithmetic	
Block	Mgt/Yr	1	2	3	4	5	6	7	X	S	X	S
1	MB 20	1.48	7.19	244.1	4.45	1.102	-	-	6.62	8.66	51.7	107..6
	NT 20	4.39	0.0927	52.74	41.66	41.50	43.11	1.41	8.08	11.22	26.4	23.2
2	MB 20	28.1	2.22	6.6	284.0	22.6			19.2	6.66	68.7	120.8
	NT 20	30.8	4.68	117.0	4.0	1.07			9.37	6.37	31.5	49.3
3	MB 20	1.19	7.39	0.074	0.593	-			0.79	6.7	2.31	3.42
	NT 20	20.82	15.92	5.19	21.44	14.09			13.9	1.8	15.5	6.56

K_{fs} values in the moldboard plots were much higher than those found in the no-till, but with a very high standard deviation. The difference was not found to be statistically significant at the 0.05 probability level.

Additional replicates taken in Blocks 2 and 3 showed the same high variability within each treatment block. In Table 52, the overall average for the moldboard treatment indicated a K_{fs} that was 75% higher than the no-till, which was consistent with the results found at D. Lobb's in 1988. The difference, however, was not significant (0.05 probability) and after twenty years, tillage has not had a very significant effect. These readings were taken, however, after the plots had been idle for one year (18 months since last ploughing), allowing for some consolidation in the plough layer. This could reduce the difference between treatments. The K_{fs} and K_{sat} values (Table 53) were poorly correlated ® = 0.16).

A summary of the Matric Flux Potential, ϕ_m (Table 54) indicated a slightly higher potential for unsaturated flow in the moldboard site, though again this was not significant at the 0.05 probability level.

The differences between treatments can be partially explained by looking at the measured porosity indices from the undisturbed cores (Tables 55, 56, and 57). These data are summarized in Table 58. The no-till treatment had a slight but significant (0.01 probability level) increase in bulk density which was reflected by the decrease in total porosity. The slight difference in K_{fs} and other hydraulic properties can thus be explained by the slight but significant decrease in porosity and macroporosity in the no-till treatment.

Table 52: Summary of average K_{fs} for Elora Research Station

Block	Field Saturated Hydraulic Conductivity K_{fs} ($m \bullet s^{-1} x 10^{-6}$) Texture	MB20	NT20
1	L	51.7	26.4
2	L	68.7	31.5
3	L	2.31	15.5
Overall Average		43.6[a]	24.7[a]
	S.D.	94.1	29.4

Values with different letters are significantly different at 0.05 probability level.

Table 53: Comparison of Average K_{fs} (from GPI) and K_{sat} (from undisturbed cores) for Elora.

Block	Tillage	K(GPI) ($m \bullet s^{-1}$ x 10^{-6}) (Y)	K(Core) ($m \bullet s^{-1}$ x 10^{-6}) (X)
1	MB20	51.7 (107.6)	1875.1 (2306.8)
	NT20	26.4 (23.2)	962.9 (1848.1)
2	MB20	68.7 (120.8)	93.8 (201.3)
	NT20	31.5 (49.3)	95.1 (133.6)
3	MB20	2.31 (3.42)	41.2 (69.1)
	NT20	15.5 (6.6)	17.5 (28.9)

Correlation of Y on X r=0.16

Table 54: Summary of tillage effects on average matric flux potential measurements for Elora Research Station.

Site	Mgt	Matric Flux Potential ($m^2 \bullet s^{-1} \times 10^{-6}$)	Initial Soil Water Content ($m^3\ m^{-3}$)
1	MB20	9.9	39.0
	NT20	3.35	39.6
2	MB20	3.14	37.3
	NT20	3.41	39.6
3	MB20	0.12	39.8
	NT20	0.90	39.5
Average	MB20	6.52^a (4.78)	38.7^a (1.28)
	NT20	2.55^a (1.43)	39.6^a (0.06)

Values in each column with different letters are significantly different at 0.05 probability level.

Table 55: Summary of porosity indices for Elora from undisturbed cores - Block 1.

Tillage/Rep		Bulk Density (g• cm^3)	Total Porosity (m^3 • m^{-3})	Macroporosity (m^3 • m^{-3})	Relative Macroporosity (%)
MB20	1	1.25	0.530	0.089	16.8
	2	1.17	0.544	0.112	20.6
	3	1.23	0.551	0.086	15.6
	4	1.30	0.520	0.041	7.9
	5	1.39	0.533	0.049	9.2
$\bar{X}$		1.27	0.533	0.075	14.0
NT20	1	1.39	0.498	0.053	10.6
	2	1.32	0.499	0.053	10.6
	3	1.28	0.523	0.053	10.1
	4	1.37	0.515	0.054	10.5
	5	1.44	0.477	0.023	4.8
	6	1.48	0.497	0.068	13.7
	7	1.40	0.507	0.038	7.5
$\bar{X}$		1.38	0.502	0.049	9.7

Table 56: Summary of porosity indices for Elora from undisturbed cores - Block 2.

Tillage/Rep		Bulk Density (g• cm^{3})	Total Porosity (m^{3} • m$^{-3)}$	Macroporosity (m^{3} • m^{-3})	Relative Macroporosity (%)
MB20	1	1.28	0.529	0.058	11.0
	2	1.28	0.513	0.075	14.6
	3	1.27	0.522	0,061	11.7
	4	1.25	0.536	0.050	9.3
	5	1.25	0.552	0.083	15.0
$\overline{X}$		1.27	0.530	0.065	12.3
NT20	1	1.32	0.545	0.055	10.1
	2	1.27	0.529	0.045	8.5
	3	1.25	0.541	0.073	13.5
	4	1.39	0.508	0.046	9.0
	5	1.34	0.529	0.040	7.6
$\overline{X}$		1.31	0.530	0.052	9.7

Table 57: Summary of porosity indices for Elora from undisturbed cores - Block 3.

Tillage/Rep		Bulk Density (g• cm^3)	Total Porosity (m^3 • m^{-3})	Macroporosity (m^3 • m^{-3})	Relative Macroporosity (%)
MB20	1	1.47	0.486	0.041	8.4
	2	1.42	0.508	0.051	10.0
	3	1.38	0.483	0.025	5.2
	4	-	-	-	-
	5		-	-	-
	$\overline{X}$	1.42	0.492	0.039	7.9
NT20	1	1.28	0.515	0.042	8.1
	2	1.44	0.510	0.042	8.2
	3	1.32	0.550	0.070	12.7
	4	-	-	-	-
	5	-	-	-	-
	$\overline{X}$	1.35	0.525	0.051	9.7

Table 58: Summary of average treatment effects in porosity indices for Elora Research Station.

Site	MGT		Bulk Density (g• cm^{3})	Total Porosity (m^{3} • m$^{-3)}$	Macroporosity (m^{3} • m^{-3})	Relative Macroporosity (%)
1	MB20		1.27	0.533	0.075	14.0
	NT20		1.38	0.502	0.049	9.7
2	MB20		1.27	0.530	0.065	12.3
	NT20		1.35	0.525	0.052	9.7
3	MB20		1.42	0.492	0.039	7.9
	NT20		1.35	0.525	0.051	9.7
Overall Average		MB	1.32^{a}	0.518^{a}	0.06^{a}	11.4^{a}
		NT	1.36^{b}	0.517^{a}	0.05^{b}	9.7^{b}

Values in each column with different levels are significantly different at 0.01 probability level

5.2 A. Jones T-2000 Site, Fingal Ontario

5.2.1 Site Description

The T-2000 site of Al and Paul Jones is located in Elgin County, Southwold Township, Lot 11, Concession East Branch on the south side of Talbot Road (Figure 9). This site was chosen because four tillage systems have been in place for four years and it has a slightly heavier soil texture (silt loam). The four paired tillage systems include two minimum tillage systems; ridge and soil saver, along with a no-till and moldboard plough treatment. The topography is flat (slope <1-2%) with a Beverly silt loam soil. GPI readings were taken near T-2000 benchmarks 2 and 3, with 4 to 5 replications spaced randomly in each treatment (Figure 10).

5.2.2 Results and Discussion

The K_{fs} measurements from the GPI are given in Appendix 6a. The moisture retention curve data from the undisturbed cores are included in Appendix 6b. A summary of the K_{fs} values measured with the pressure infiltrometer are given in Table 59, with corresponding K_{sat} values from undisturbed cores taken immediately adjacent to the GPI reading. Both the geometric and arithmetic means are reported for each treatment.

Each of the four treatments had a high coefficient of variation for both K_{fs} and K_{sat}, which may be due to both natural variability and the fact that sampling locations were chosen randomly within a corn row without avoiding wheel tracks, cracks, etc. The general trend indicated that moldboard, no-till and ridge till have similar average hydraulic conductivities while the soil saver is much higher by 4-7x. However, because of the high variability, there was not any significant difference between any two treatments at the 0.05 probability level (Table 60).

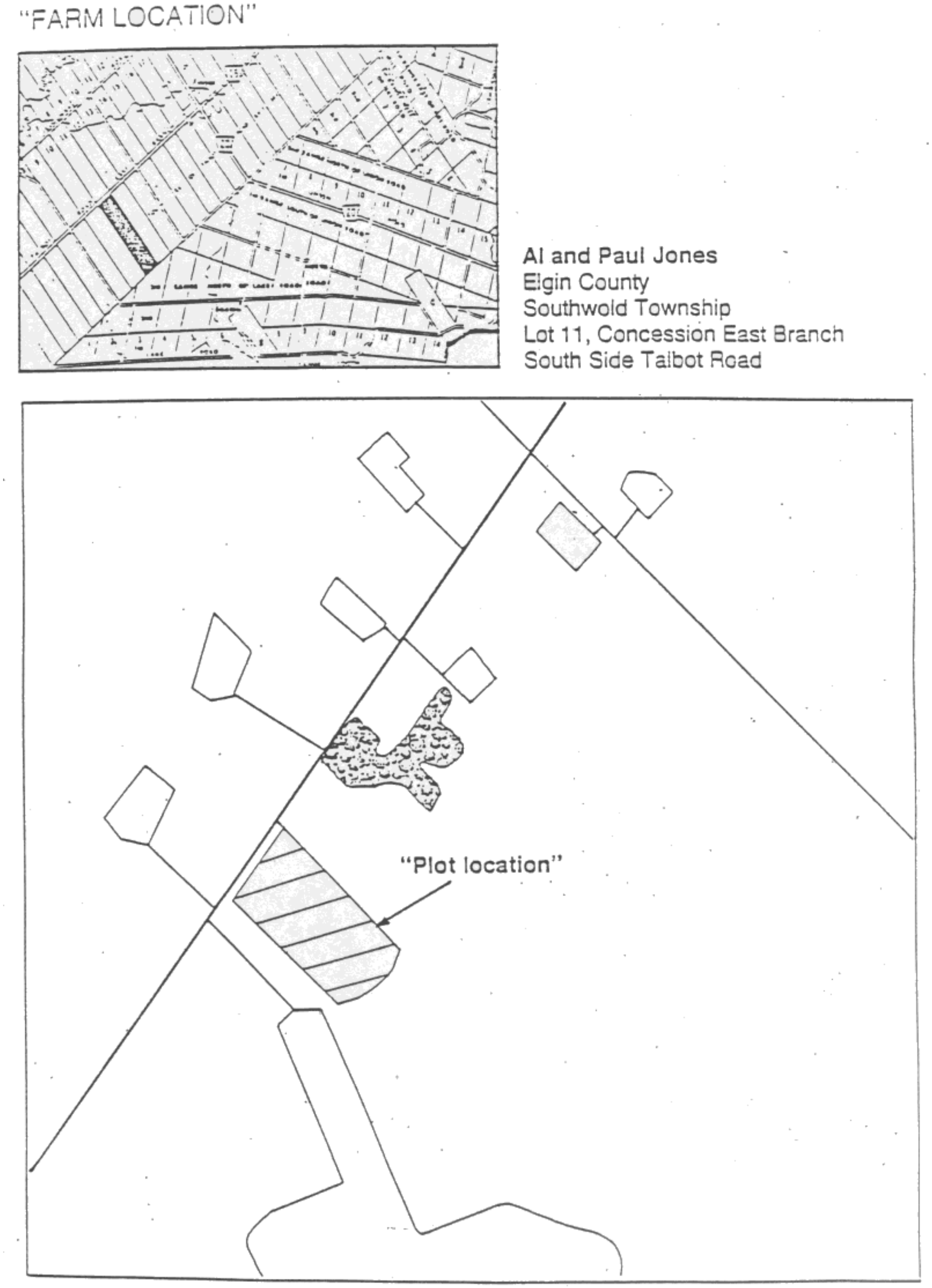

Fig. 9. Site location - A. Jones T-2000 Site, Fingal Ontario

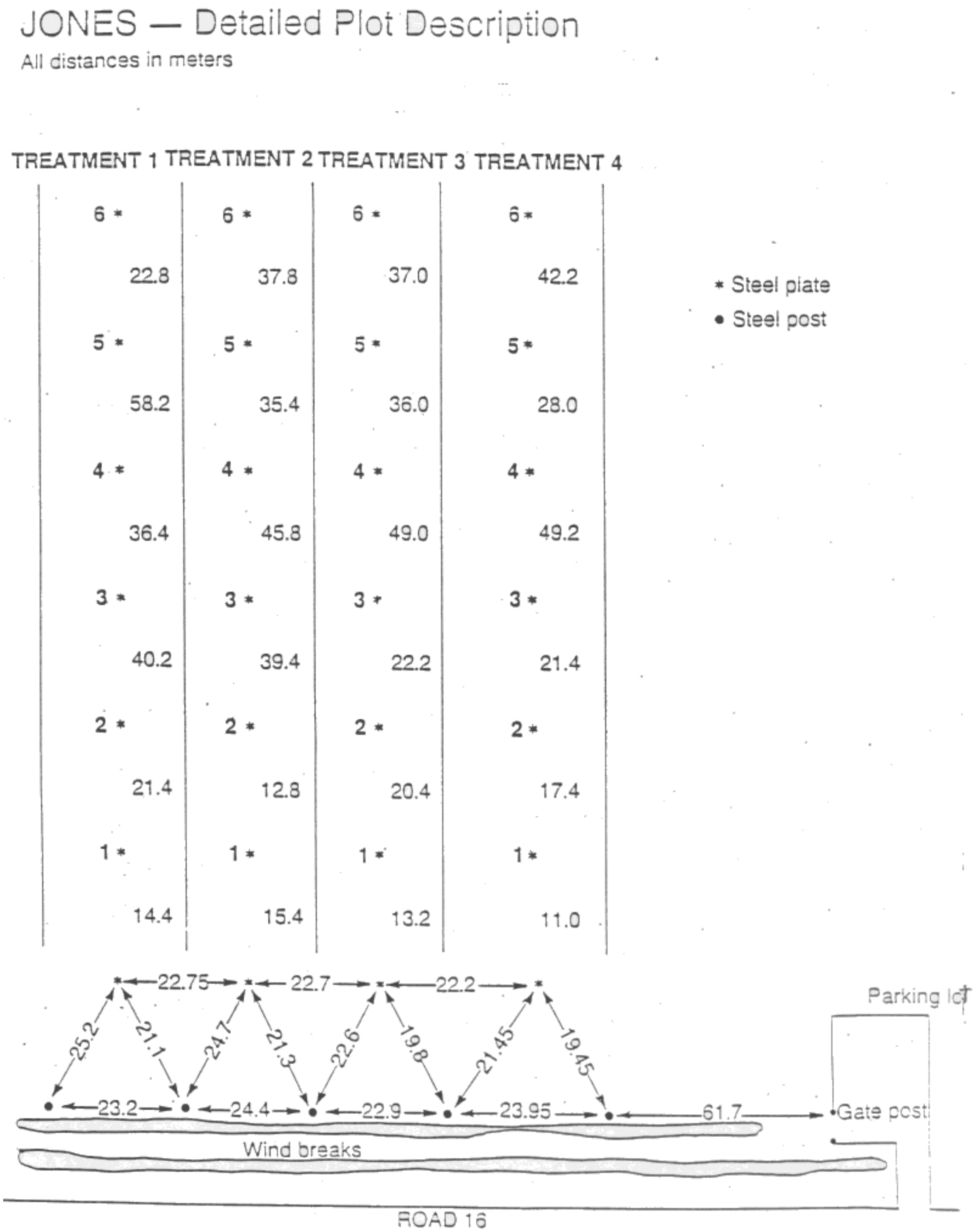

Fig. 10. Detailed plot layout - A. Jones T-2000 Site, Fingal Ontario

Table 59: Measured hydraulic properties from pressure infiltrometer (K_{fs}) and undisturbed cores (K_{sat}) for A. Jones (T-2000)

		Hydraulic Conductivity ($m \cdot s^{-1} \times 10^{-5}$)								
Tillage System		Replication Number					Geometric		Arithmetic	
		1	2	3	4	5	$\bar{x}$	S	$\bar{x}$	S
Ridge Till	Kfs	2.39	1.46	0.95	3.6	-	1.86	1.79	2.101	1.16
	Ksat	0.14	27.0	0.53	2.1		1.42	9.55	7.43	13.1
Soil Saver	Kfs	40.02	0.53	6.59	12.06	35.27	9.03	5.76	18.9	17.7
	Ksat	9.31	5.73	0.32	16.8	25.4	5.91	5.65	11.5	9.8
No Till	Kfs	13.01	0.009	1.84	1.32	0.98	1.0	8.7	3.44	5.4
	Ksat	-	0.18	0.13	23.5	0.59	0.75	10.83	6.09	11.6
Moldboard	Kfs	0.92	0.08	11.29	9.37	0.34	1.21	8.51	4.40	5.47
	Ksat	53.0	1.53	4.35	0.18	1.61	2.53	7.82	12.13	22.9

Table 60. Summary of field saturated hydraulic conductivity K_{fs} for A. Jones, Fingal, Ontario.

Tillage	K_{fs} ($m \bullet s^{-1} \times 10^{-5}$)
Ridge Till	2.10^a
Soil Saver	18.9^a
No Till	3.44^a
Moldboard	4.40^a

Values in the same column with different letters are significantly different at 0.05 probability level

A comparison of the in-situ K_{fs} measurements and the laboratory measured K_{sat} values from undisturbed cores (Table 61) show poor correlation r = 0.56). The K_{sat} values are typically higher than measured K_{fs}, except in the soil-save site suggesting that the mean K_{fs} for the soilsave site may be artificially high.

The porosity indices, obtained from the individual undisturbed cores, are shown in Table 62 and summarized in Table 63. The results suggest that the no-till had a significantly higher average bulk density and lower total porosity than the other three treatments. This was not reflected in a slightly lower average no-till K_{sat} or K_{fs} value. Two of the replicates in the no-till site were also very high and increased the mean value in the NT twofold Similarly, macroporosity values in the no-till were 2x lower than in the other three, as was the relative macroporosity. The high variability at this site suggests more intensive sampling is required to characterize the surface hydraulic properties at this site. It was difficult to achieve a good data set because of the severe cracking of the soil surface. This caused some surface venting of the permeameter flow, and in some replicates only a single head measurement was possible because of high flow. The radially symmetric 3D flow pattern of the permeameter theory was probably violated under these field conditions.

Table 61: Comparison of Average K_{fs} from pressure infiltrometer vs K_{sat} from undisturbed cores Jones T-2000 ($m \bullet s^{-1} \times 10^{-5}$)

Tillage	Pressure Infiltrometer (Y)	Undisturbed Core (X)
Ridge Till	2.10 (1.16)	7.43 (13.1)
Soil Saver	18.9 (17.7)	11.5 (9.8)
No Till	3.44 (5.4)	6.09 (11.6)
Moldboard	4.40 (5.47)	12.1 (22.9)

(standard deviation)

Correlation of Y on X r = 0.56

Table 62: Summary of porosity indices from undisturbed cores (A. Jones - T-2000)

Tillage		Bulk Density (g•cm^3)	Total Porosity (m^3•m^{-3})	Macroporosity (m^3•m^{-3})	Relative Macroporosity (%)
Ridge Till	1	1.28	0.541	0.125	23.1
	2	1.22	0.597	0.158	26.5
	3	1.46	0.505	0.095	18.8
	4	1.29	0.578	0.149	25.7
	5	-	-	-	
$\overline{X}$		1.31	0.555	0.132	23.5
Soil Saver	1	1.35	0.564	0.186	33.0
	2	1.48	0.488	0.083	17.0
	3	1.48	0.465	0.047	10.2
	4	1.30	0.518	0.165	31.8
	5	1.19	0.567	0.222	39.1
$\overline{X}$		1.36	0.520	0.141	26.2
No Till	1	-	-	-	-
	2	1.53	0.463	0.059	12.7
	3	1.63	0.438	0.053	12.1
	4	1.53	0.472	0.081	17.2
	5	1.58	0.413	0.035	8.5
$\overline{X}$		1.57	0.446	0.057	12.6
Moldboard	1	1.10	0.601	0.178	29.6
	2	1.19	0.606	0.157	25.9
	3	1.15	0.593	0.156	26.3
	4	1.19	0.591	0.161	27.2
	5	1.27	0.577	0.112	19.4
$\overline{X}$		1.18	0.594	0.153	25.7

Table 63: Summary of average treatment effects in porosity indices from undisturbed cores - A. Jones (T-2000)

Tillage	Bulk Density ($g\bullet cm^{-3}$)	Total Porosity ($m^3\bullet m^{-3}$)	Macroporosity ($m^3\bullet m^{-3}$)	Relative Macroporosity (%)
Ridge Till	1.31^a (0.1)	0.555^a (0.05)	0.132^a (0.03)	23.5^a (3.3)
Soil Saver	1.36^a (0.12)	0.52^a (0.04)	0.141^{abc} (0.07)	26.2^{ab} (12.1)
No Till	1.57^b (0.05)	0.446^b (0.03)	0.057^{bd} (0.02)	12.6^{bc} (3.7)
Moldboard	1.18^c (0.06)	0.594^a (0.24)	0.153^{acd} (0.02)	25.7^{ac} (4)

(standard deviation)

5.2.3 Site Description - P. Johnson T-2000 Site, Guelph Ontario

A third site was studied where a minimum versus no-till tillage system has been in place for four years. The farm of Paisley Johnson is located in Wellington County, Guelph Township, Lot 15, Concession 1 (Figure 11). Soil textures range from Guelph Loam to Granby sand. The minimum tillage was a fall soil-saver followed by discing in the spring. Tillage 2000 benchmarks No. 1, 3, 5, and 15 (Figure 12) were sampled on paired sites to determine field saturated hydraulic conductivities over the range of textures and landscape positions found at the site. On average 4-5 replicates were taken at each benchmark, with additional reps taken where high variability was found.

5.2.4 Results and Discussion

The raw data from the GPI measurements and the measured porosity indices are given in Appendices 7a. and 7b., respectively. The field saturated K_{fs} values are given in Table 64, along with the geometric and arithmetic means for each tillage treatment. At Benchmark 1, which is located near the crest of a hill, the no-till treatment had an average K_{fs} that was 4x that seen in the minimum till plot, but with a very high coefficient of variation. The next sampling location, Benchmark 3 was located at the mid-slope position. In this case the effect of tillage was reversed, with the minimum till being 4x greater than the no-till. At the lower slope position, the no-till was again higher and on the flat, poorly drained sandy soils at Benchmark 15, the two sites had similar average K_{fs} values. When the overall average for all 18-20 reps was considered, the difference between means was not significant at the 0.05 probability level (Table 64).

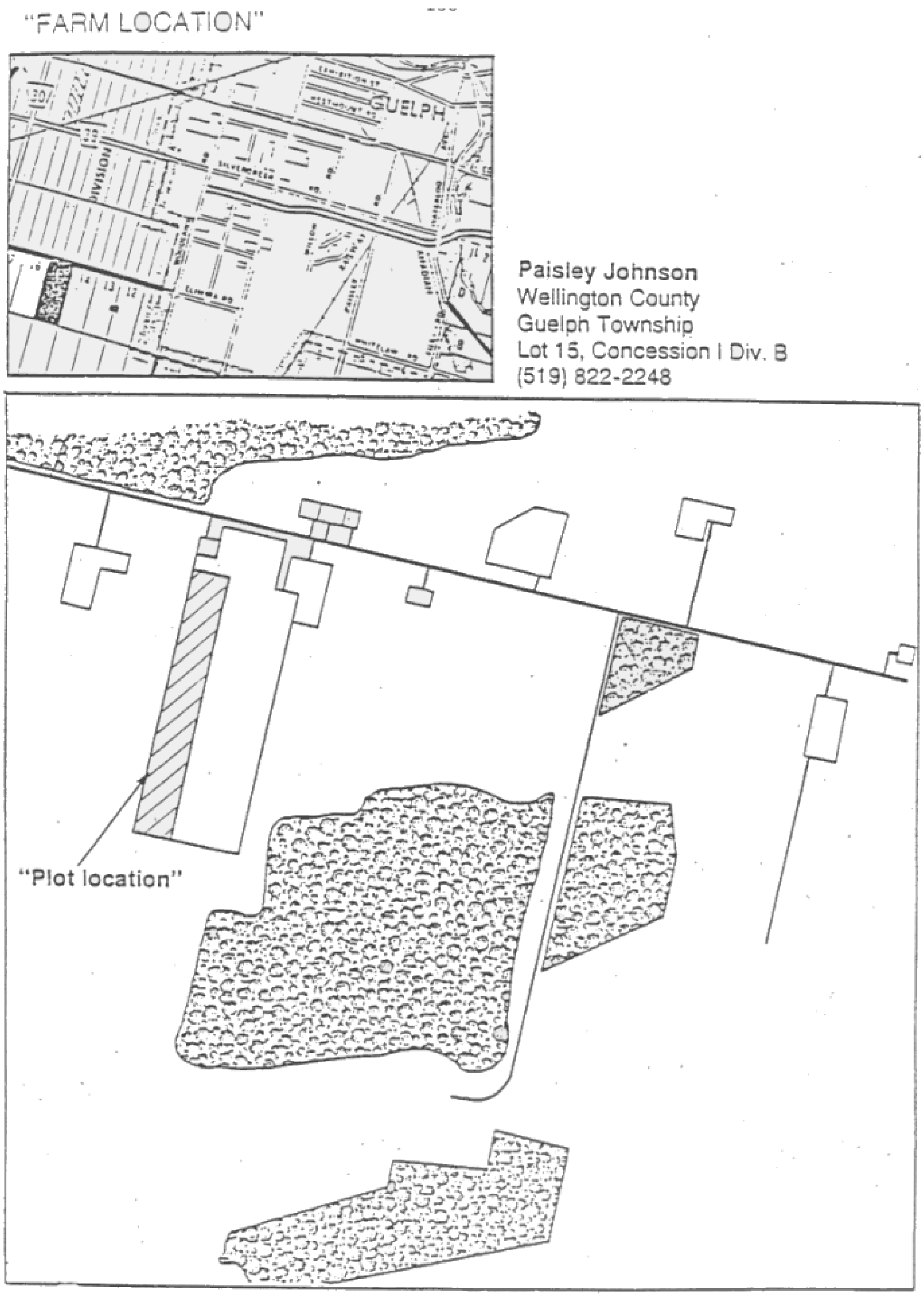

Fig.11. Site location P. Johnson T-2000 Site, Guelph Ontario

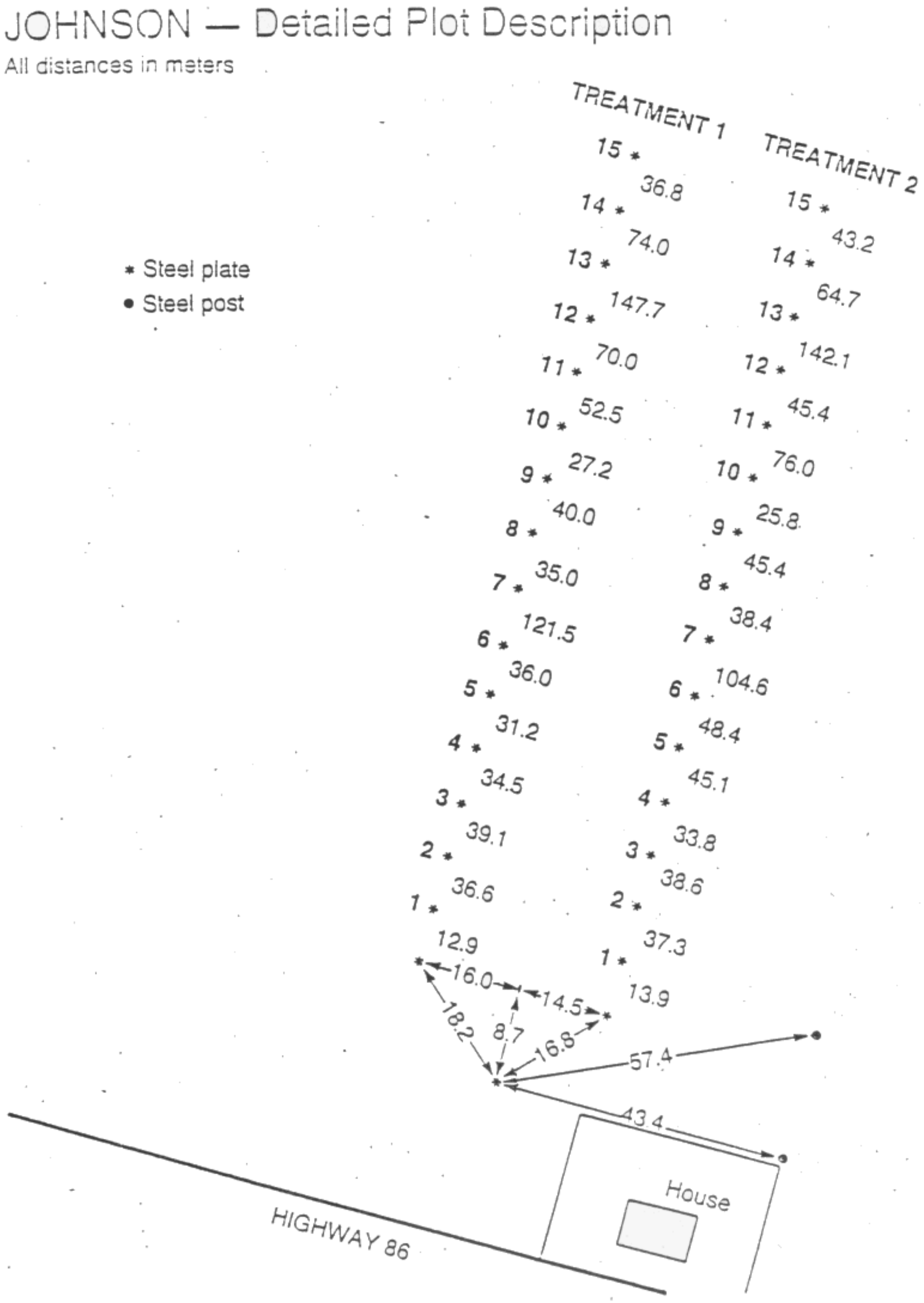

Fig.12. Detailed plot layout - P. Johnson T-2000 Site

Table 64. Measured K_{fs} from pressure infiltrometer for P. Johnson T-2000 Site

Site/Tillage		Field saturated hydraulic conductivity (m•s^{-1} x 10^{-6}) Replication Number							Geometric		Arithmetic	
		1	2	3	4	5	6	7	X^{-}	S	X^{-}	S
1	Min	3.52	1.72	7.93	5.37	-			4.01	1.92	4.63	2.65
	NT	0.66	3.11	82.99	15.26	1.78			5.41	6.71	20.8	35.3
3	Min	14.83	2.56	31.12	6.71				9.39	2.91	13.8	12.6
	NT	3.45	7.93	0.219	2.44	-			1.95	4.67	3.51	3.24
5	Min	3.84	0.731	1.51	51.45	5.21			4.08	5.02	12.56	21.8
	NT	17.91	12.25	0.995	31.85	38.26			12.16	4.35	20.2	15.0
15	Min	0.742	0.914	8.3	25.54	16.48	39.81	51.26	9.01	5.69	20.43	19.5
	NT	42.87	15.87	19.6	15.05	12.04			18.91	1.63	21.1	12.5
Overall Average			Min	13.98^{a}	(16.8)							
			NT	17.08^{a}	(20.4)							

Values with different letters are significantly different at 0.05 probability level

Table 65: Comparison of K_{fs} with K_{sat} from undisturbed cores for P. Johnson T-2000 site.

Site/Slope/Tillage			Average K_{fs} ($m \bullet s^{-1} \times 10^4$) (Y)	Undisturbed Core K_{sat} ($m \bullet s^{-1} \times 10^{-6}$)
1	Crest	MIN	4.63 (2.65)	3.36 (2.19)
		NT	20.8 (35.3)	5.29 (7.62)
3	Mid.	MIN	13.8 (12.6)	2.44 (1.94)
		NT	3.51 (3.24)	129.6 (183.1)
5	Lower	MIN	12.56 (21.8)	3.04 (2.27)
		NT	20.20 (15.0)	3.37 (2.11)
15	Flat	MIN	20.4 (19.5)	296.6 (567.4)
		NT	21.1 (12.5)	126.0 (264.4)
Average		MIN	13.98^a (16.8)	105.7^a (349.7)
		NT	17.08^a (20.4)	62.7^a (158.7)

(standard deviation)

Values in each column with different letters are significantly different at 0.05 probability level.

Correlation of Y on X r = 0.20

The matric flux potential, ϕ_m, and initial soil moisture values (Table 66) revealed very little difference between treatments, with the minimum till having a slightly lower ϕ_m and θ_v than the no-till but the difference was not significant.

The summary of porosity indices from the undisturbed cores (Table 67 and 68) verified that little difference between minimum and no-till existed at this site. The no-till had a slightly higher bulk density on average overall sampled benchmark locations, as well as a lower total porosity. The slightly higher K_{fs} values in the no-till may be related to the higher average macroporosity, though the differences were not significant. The core values are consistent with the GPI measurements.

Table 66: Summary of tillage effects on average matric flux potential ϕ_m measurements (P. Johnson).

Site	Matric Flux Potential ($m^2 \bullet s^{-1} \times 10^{-6}$)		Initial Soil Water Content (%)	
	MIN	NT	MIN	NT
1	0.8	1.36	38.1	36.8
3	1.6	2.0	34.1	34.8
5	0.71	2.71	40.0	40.9
15	1.55	0.83	39.3	42.1
Overall Average	1.24[a]	1.79[a]	38.2[a]	38.9[a]
S.D.	1.46	2.33	2.55	3.50

Values for each soil parameter with different letters are significantly different at 0.05 probability level.

Table 67. Calculated porosity indices from undisturbed core measurements(Johnson T-2000)

Site/Slope/Replication			Bulk Density ($g\bullet cm^{-3}$)		Total Porosity ($m^3\bullet m^{-3}$)		Macroporosity ($m^3\bullet m^{-3}$)		Relative Macroporosity (%)	
			MIN	NT	MIN	NT	MIN	NT	MIN	NT
1	Crest	1	1.45	1.51	0.474	0.453	0.045	0.340	9.5	7.5
		2	1.42	1.47	0.462	0.499	0.037	0.075.	8.0	15.0
		3	1.47	1.53	0.484	0.465	0.036	0.032	7.4	6.9
		4	1.39	1.52	0.490	0.465	0.048	0.029	9.8	6.2
		5		1.52	-	0.458	-	0.041		8.9
	×I		1.43	1.51	0.477	0.468	0.041	0.042	8.7	8.9
3	Mid.	1	1.45	1.33	0.467	0.511	0.040	0.111	8.6	21.7
		2	1.57	1.50	0.445	0.455	0.046	0.032	10.3	7.0
		3	1.40	1.58	0.477	0.436	0.058	0.040	12.1	9.2
		4	1.58	1.61	0.470	0.425	0.035	0.033	7.4	7.8
		5		-	-	-	-	-		
	×I		1.5	1.51	0.465	0.457	0.045	0.034	9.6	11.4
5	Lower	1	1.48	1.37	0.482	0.491	0.054	0.046	11.2	9.4
		2	1.47	1.47	0.497	0.464	0.075	0.043	15.1	9.3
		3	1.46	1.57	0.485	0.540	0.036	0.050	7.4	9.2
		4	1.46	1.50	0.475	0.448	0.047	0.031	9.9	6.9
		5	1.34	1.47	0.504	0.491	0.076	0.088	15.1	17.9
	×I		1.44	1.48	0.489	0.487	0.058	0.060	11.7	10.5
15	Flat	1	1.09	1.08	0.580	0.591	0.065	0.099	11.2	16.7
		2	0.93	1.03	0.646	0.587	0.145	0.066	28.6	11.2
		3	1.04	1.08	0.644	0.632	0.116	0.130	18.0	20.6
		4	1.13	1.05	0.599	0.628	0.081	0.097	13.5	15.4
		5	1.06	1.09	0.605	0.592	0.095	0.097	15.7	16.4
		6	1.08	-	0.590	-	0.089	-	15.1	-
		7	1.10	-	0.598	-	0.076	-	12.7	-
	×I		1.06	1.07	0.609	0.606	0.095	0.098	16.4	16.1

Table 68. Summary of porosity indices from undisturbed cores for P. Johnson T-2000

Site	Slope Position	Tillage	Bulk Density (g• cm^{-3})	Porosity (m^{3}• m$^{-3)}$	Macroporosity (m^{3}• m$^{-3)}$	Relative Macroporosity (%)
1	Crest	MIN.	1.43	0.477	0.081	8.7
		NT	1.51	0.468	0.042	8.9
3	Mid.	MIN	1.50	0.465	0.045	9.6
		NT	1.51	0.457	0.054	11.4
5	Lower .	MIN	1.44	0.489	0.058	11.7
		NT	1.48	0.487	0.060	10.5
15	Top	MIN	1.06	0.609	0.095	16.4
		NT	1.07	0.606	0.098	16.1
	$\bar{x}$	MIN	1.32^{a}	0.524^{a}	0.065^{a}	12.25^{a}
	S	MIN	0.20	0.067	0.03	5.09
	$\bar{x}$	NT	1.38^{a}	0.507^{a}	0.078^{a}	11.7^{a}
	S	NT	0.205	0.067	0.07	5.12

Values in each column with different letters are significantly different at 0.05 probability level

6.0 Summary

The Technology Evaluation and Development (TED) sub-program was developed with a view towards providing information to farmers about soil conservation.' However, little information has been given regarding the effects of management options on surface runoff generation and soil loss. Conservation tillage is associated with greater surface crop residue levels, increased infiltration and decreased runoff and erosion as compared to conventional tillage (Baeumer and Bakermans, 1973; Blevins et al. 1983).However, studies have also shown the opposite results with conventional tillage having higher infiltration rates and saturated hydraulic conductivity values, and lower runoff than minimum or zero-till (Lindstrom et al. 1981; Lindstrom and Onstad, 1984). Part of the reason for the conflicting results has been the lack of an easy, field portable method of assessing changes in surface soil hydraulic properties. The Guelph Pressure Infiltrometer (GPI) has proven to be a useful tool for providing accurate field data on saturated. and unsaturated flow. It can also be used to estimate the effective time to ponding Tp, which is quite a useful parameter for assessing management effects on potential runoff generation (Kachanoski et al. 1989).

The purpose of the 1989-90 study was to use the GPI to assess the effects of management (i.e. tillage) on surface hydraulic properties. Specific objectives were: to test the relationship between rainfall runoff and predicted runoff using soil parameters measured with the GPI; to examine spatial and temporal changes in soil hydraulic properties; and to characterize the nature of these changes under a range of cropping/tillage. systems.

Many of the major conclusions of the 1989-90 study have been given in the discussion of the measurements at each site but a number of observations can be made. Soil hydraulic parameters such as K_{fs} and ϕ_m exhibit high coefficients of spatial variation (both within and between treatments) that are similar to those found in the 1988 TED study. The data are therefore likely representative of the natural variation in the field.

Values for field saturated hydraulic conductivity were generally much higher in the MB versus either MIN or NT treatments. As well, measured ϕ_m values were consistently lower in the NT than those found in MB treatments. Estimated time to ponding Tp, calculated from ϕ_m and initial volumetric moisture content (θ_v), was considerably shorter in the NT treatments. Intact soil cores, taken at each site, showed that NT resulted in a decrease in total overall porosity and macroporosity, therefore accounting for the decrease in K_{fs} and subsequent lowering of steady state infiltration rates observed at each of the T-2000 rainfall simulation study sites (re: Lobb, Ghent and Anthony). These effects were consistent across all sampling periods and were not dependent on the time of sampling.

Measurements taken at a long-term tillage trial (20 year continuous corn on MB and NT) exhibited only marginal increases in K_{fs} in MB versus NT treatments. While the data were again highly variable, it appears that long-term tillage did not have a marked effect on K_{fs}.

The GPI proved reliable even on heavy soil textures (eg. A. Jones T-2000 site) yet under extremely dry soil conditions where surface cracking occurs it can be difficult to achieve a good data set without violating the boundary conditions for 3D radial flow in the GPI since the saturated bulb often is vented to the surface. It may be more appropriate to use the Tension Infiltrometer under these conditions. As well, the high variability may suggest the need for increased sampling frequency to properly characterize the spatial distribution of soil hydraulic parameters.

In general, the data may have important implications for soil management. While soil loss was lower in the NT vs both MIN or MB treatments, it did result in increased surface runoff rates. The data suggest that the primary mechanism for reduction of soil and phosphorus loss in NT systems is the protection of soil surfaces by crop residue. However this implies that movement of non-adsorbing chemicals or soil amendments such as manure are more likely to be transported by runoff under a no-till system. This agrees with the work by Bhatnagar (1977) and suggests future research may be needed to characterize the susceptibility of various soil amendments to movement under runoff conditions.

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