Soil Erosion Measurements Under Natural Rainfall for Evaluating The Universal Soil Loss Equation in Manitoba

by

Ephantus Karuku Wahome

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DEDICATION

This thesis is dedicated to:

1. My boss, Mr. David Kenneth Andere, in profound admiration of his knowledge and courage in supporting effective natural resource management and conservation. This is also in appreciation of his well demonstrated commitment to hard work, patience, empathy and dedication to excellence. His refreshing and inspiring support and encouragement, in duty assignments and otherwise, have been highly motivating and rewarding, as is incumbent upon his able office in promoting productive performance on the part of his officers. This is one area in which he is deeply committed, and is well accomplished.

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ABSTRACT

Field experiments on soil erosion under natural rainfall were conducted in 1986 and 1987 on Gretna clay, Leary sandy loam, Ryerson sandy clay loam, and Carroll clay loam soils. The aim was to develop a data base for evaluating the soil erodibility (K) and the crop-management (C) factors of the Universal Soil Loss Equation (USLE) under Manitoba agricultural conditions. Experimental design conformed closely to that used when the USLE was developed. Crop-management treatments were continuous and included alfalfa, conventional tillage wheat, minimum tillage wheat, conventional tillage corn and summerfallow.

Rainfall data were measured with a tipping bucket rain gauge and were used to determine rainfall erosivity (R) values. Surface runoff and soil loss data measurements were done using a Coshocton sampling system. Crop cover measurements were done regularly with a modified point-line method to determine different crop growth stage periods. Antecedent soil moisture was measured using the gravimetric analysis method.

Soil losses were observed to be extremely variable among different crop-management treatments and soil types. This was mainly due to the extreme variability of rainfall erosivity, antecedent soil moisture, cultivation, crop cover changes, residual effects of mulch and previous crop cover and possible undersampling of soil loss. As a result, the measured K and C factor values were observed to be extremely variable. The measured K values were compared to those estimated using the USLE nomograph equation (NE) and the Modified Young and Mutchler Equation (MYME). The estimated values for both equations were not very different for most soils except Gretna clay soil. The average measured K values for Gretna clay and Leary sandy loam soils were quite comparable to the NE estimated values. These values showed that the two equations could possibly be underestimating the K values for these soils. The measured K values for Ryerson sandy clay loam and Carroll clay loam soils were extremely low, possibly due to the effects of the previous crop residues. The measured ratios of soil loss from the cropped treatments to that from summerfallow treatment were observed to be extremely variable among similar and different treatments for similar growth stages. These ratios were not easily comparable to the USLE estimated values, due to the differences in the crop-management systems for the experiments and those used when the USLE was developed.

The effects of antecedent soil moisture and cultivation in modifying observed soil losses and the measured K and C factor values were found to be important. This observation suggested the need for the modification of the USLE to account for the effects of these field factors so as to ensure accurate estimation of soil loss.

The results obtained reflect the need for long-term measurements of soil loss and influencing factors before effective evaluation of factor values can be obtained. The short-term duration of this study and the absence of comparable crop-management systems and proper summerfallow conditions in the experiments limited the ability of this study to come up with conclusive results.

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CONTENTS

Appendix page

LIST OF TABLES

LIST OF FIGURES

Chapter I

INTRODUCTION

Persistent accelerated soil erosion, especially due to rainfall, has for a long time been recognized as a potential threat to sustainable agricultural production. Reducing erosion rates to tolerable limits requires properly planned crop-management practices and soil conservation measures. Past research on soil erosion has made several attempts towards the development of mathematical models that can be effectively used as soil conservation tools in agricultural land use planning and management. This concerted effort culminated in the development of the Universal Soil Loss Equation (USLE), which has been tested in many parts of the world with local modifications and widespread acceptance.

The USLE is an empirically derived parametric erosion model which was developed with a comprehensive field data base primarily assembled in the United States. The development of the equation depended on the analysis of 10,000 plot years of data collected from 50 experimental locations distributed in 24 states east of the Rocky Mountains. The equation is universal because of the structuring of the factor components combinations, which makes it independent from the geographical and climatic oriented base. Factor components represent rainfall, soil type, topographical features (slope length and slope angle), crop-management practices and the supporting soil conservation measures, which are expressed in a multiplicative function. The equation was developed as an attempt to obtain a basis for predicting long-term average soil losses from specified agricultural fields with specific crop-management systems (Wischmeier and Smith 1978).

There are a number of field conditions relating to soil type and crop-management practices that may limit the accuracy of direct application of the USLE under Manitoba agricultural conditions. When compared to the soils for which the USLE was developed, the Canadian Prairie climatic and agronomic factors have contributed to high soil organic matter contents (Clayton et al. 1977). The maximum organic matter content considered in the Wischmeier et al. (1971) USLE Nomograph Equation (NE) for estimating soil erodibility (K) factor values is 4%, and most Manitoba soils have higher organic matter content. Therefore, the equation will possibly overestimate the K factor values for these soils. The soils were also developed from soil parent materials with a high montmorillonite clay content, resulting to montmorillonite as the dominant clay mineral (Clayton et al. 1977). Soils with high montmorillonite clay content have been observed to be better aggregated than soils where other clay minerals predominate and are, consequently more resistant to erosion (Young and Mutchler 1977). This will possibly affect the K values estimated using the Modified Young and Mutchler (1977) Equation (MYME).

Antecedent soil moisture content influences the time a soil takes to get saturated during a rainstorm before the initiation of surface runoff discharge. Pauls (1987) observed field conditions when soil loss was probably affected by antecedent soil moisture conditions. This situation arose when some rainstorm events occurring after prolonged dry periods produced no surface runoff. Therefore, there is a possibility that antecedent soil moisture has a substantial influence on field soil loss. In field situations, as existing in the Canadian Prairie conditions where large variations in soil moisture in the top 10 cm layer of soil depth are bound to occur, it may be important to quantify this influence. It is possible that this influence is related to the effect of antecedent soil moisture on infiltration rates and ponding. At some critical soil moisture content, e.g. at saturation point, infiltration rate would be reduced to zero and maximum soil loss would be expected to occur under these conditions. Since Manitoba soils probably have comparatively high average antecedent soil moisture levels, due to the cooler climate, the effect of this factor on measured soil loss would be expected to be important. Therefore, it would be essential to relate the measured erodibility of a soil per unit of a specific rainstorm erosivity to the difference between antecedent soil moisture and the moisture content at the soil saturation point.

Cultivation is another factor that seems to have a substantial influence on field soil loss (Jones et al. 1985). Field conditions resulting from cultivation contribute to high infiltration rates and ponding , due to surface roughness, which reduce soil loss during low rainstorms. This will also increase soil loss during high rainstorms by enhancing the process of detachment and transportation of soil sediment, due to the presence of large amounts of loose surface soil. These conditions will affect the accuracy of the estimated K and C factor values obtained using the existing methods and need to be considered when estimating these values.

Many of the crops grown under the Canadian Prairie conditions are different from those grown in the United States to the south, due to the differences in crop species and length of the growth period. This will result in different crop cover changes and growth stages during the growing season which will affect the accuracy of the growth stages provided by Wischmeier and Smith (1978). Also, changing crop-management practices from conventional tillage to minimum tillage and crop rotations as a means of reducing farm operation costs and soil loss may affect surface residue cover and antecedent soil moisture levels. These will in turn affect surface runoff flow rates and consequent soil loss during a rainstorm. Therefore, the crop-management (C) factor values as proposed by Wischmeier (1960) have limitations that will affect the accuracy of direct application of these values under Manitoba agricultural field conditions. The existing field conditions need to be considered when estimating these values so as to ensure accurate estimation of the factor values.

The purpose of this study effort was to develop a field data base on soil loss due to natural rainfall that could be effectively used in evaluating the accuracy of the USLE application under Manitoba agricultural conditions. The scope of the study embraced two major objectives:
1) The short-term objective was to evaluate the K and C factor values.
2) The long-term objective was to develop a comprehensive field data base on soil loss events due to natural rainfall that would be necessary for making effective recommendations for soil conservation practices in Manitoba.

Chapter II

LITERATURE REVIEW

2.1 SOIL EROSION DUE TO RAINFALL

2.1.1 Soil Erosion Processes

Soil erosion processes due to rainfall consist of two phases: detachment and transportation of soil sediment from the surface soil mass by raindrop splash effect and surface runoff (Ellision 1947). Deposition of the transported sediment occurs as a third phase when transportion energy due to surface runoff flow rate decreases. Raindrop splash effect is the most important detaching agent, and is influenced by the size and number of raindrops striking a bare soil surface. Surface runoff flow concentrations resulting from channelized flow also provide a powerful erosive agent, but raindrop splash effects are potentially more erosive than surface runoff. Local variability in infiltration rates, due to differences in soil structure, crust formation, antecedent soil moisture content, nature of soil profile, and the condition of soil surface as influenced by tillage and vegetative cover density provide important controls for surface runoff initiation and flow rates. Since detachment and transportation processes are necessary for soil erosion to occur, raindrop splash effect and surface runoff comprise the two most important components of the process. Erosion processes occur in different forms and depend on the concentration and velocity of surface runoff. These forms are: sheet erosion due to the washing of surface soil, rill erosion due to surface runoff flow concentrations into small rivulets of channelized flow, gully erosion when the eroded channels in the rills are larger, and streambank erosion when rivers or streams are cutting into the beds and banks.

Transported sediment may be deposited down-slope in depressions or behind obstacles in the same field or watershed. About 25% of total sediment produced finally ends up in streams and rivers (Office of Technology Assessment 1982). Erosion rate varies with soil types and land management practices and occurs as geological and accelerated erosion. Geological erosion occurs over long periods of time and is commonly referred to as normal or natural erosion, and forms an important component of the formation process of land surface features. Accelerated erosion results from human land use activities. It is the most serious form of erosion, due to the associated detrimental effects on land productivity through loss of top soil (Soil Science Society of America 1984).

2.1.2 Factors Affecting Severity of Soil Erosion

Field tillage practices make soils more susceptible to erosion by enhancing the detachment and transportion process. Jones et al. (1985) found runoff from cultivated watersheds with 1.5% slope to be five times greater than losses from rangeland watersheds without cultivation. They also found sediment loss from a 152 mm rainfall to be 6.5 t ha^{-1} from fallow watershed, while sediment loss from a rangeland watershed was only 0.3 t ha^{-1}.

Crop-management practices influence the soil physical properties by providing the protection from erosion by canopy effects and the modification of soil structure by root action. Thick growing crops grown in rotation with row crops have been observed to reduce runoff and erosion. Carreker and Barnett (1949) showed that in Cecil sandy-loam soil, cotton grown in rotation with two years of oats and lespedeza lost 11.0 cm water as runoff during a seven-month period as compared with 16.3 cm from continuous cotton. Therefore, reduction in runoff by inclusion of thick growing crops in rotation with row crops has an important crop-management effect for soil conservation.

Terminal infiltration rate of Cecil sandy-loam under eight years of continuous cropping with alfalfa was found to be 5.1 cm h^{-1} compared to 2.3 cm h^{-1} for clean cultivated continuous corn (Carreker et al. 1968). Also the alfalfa plots had 44% aggregates >0.25 mm while the latter had only 22%. Inclusion of grasses and clover in the rotation and leaving corn stalks at the surface improved soil aggregation and infiltration rates with significant reduction of subsequent erosion rates.

Hussain et al. (1988) observed that the rate of splash detachment of soil sediment under continuous corn was higher than from soil under crop rotations of soybean after corn. Visual observations also showed that soils with continuous corn had greater crust formation due to raindrop destruction of aggregates than soil with crop rotations. Soils under continuous corn appeared to have higher erosion potential than soils under crop rotations.

Soil loss associated with snow-melt and rain on frozen ground has been observed to be significant in cooler climates like those prevailing under Manitoba conditions. Burwell et al. (1975) found that 6.8% of total annual soil loss on Minnesota fallow soils was due to snow-melt. Wischmeier and Smith (1978) found that in the Pacific Northwest of the United States, 50 - 90% of total annual soil loss can occur under surface thawing and snow-melt conditions. Goettel et al. (1981) estimated soil loss due to snow-melt for Northern Alberta and found it to be 80% of total annual soil loss.

2.1.3 Effects of Soil Erosion

Effects and severity of erosion rates are judged relative to soil profile depth and the rate of soil formation, and if properties such as nutrient status, texture and thickness of soil profile remain unchanged through time, the assumption is that the rate of soil formation balances with the rate of soil loss. This constitutes the basis for soil loss tolerance, which is the erosion rate that can occur while still allowing the soil to sustain production through time (Morgan 1986). Geological erosion is not detrimental to land productivity and would be expected to contribute to the soil formation process through weathering of soil parent material. Non-agricultural human activities which accelerate the erosion process are hardly significant, since agriculture is more widespread and agricultural activities which alter and accelerate the erosion process are more significant (Hudson 1971). Therefore, soil erosion is an environmental hazard traditionally associated with agricultural practices, but the importance of the problem has also been recognized in other land use practices associated with forestry, range management, mining and road transportation systems.

Past work has shown that the extent and impact of persistent accelerated soil erosion by rainfall is a problem of serious magnitudes with a range of detrimental effects. These effects are mainly associated with the reduction of sustained agricultural production and environmental degradation. On-site effects of erosion on long-term soil productivity are caused by loss of fine clays, plant nutrients and organic matter, reduction of water retention capacity, degradation of soil structure and non-uniform removal of top soil (USDA 1981), reduction of plant rooting depth, mixing of clayey sub-soil into silty top-soil, increased bulk density, lower pH and a tendency to crust formation (Frye 1987). Frye et al. (1982) and Leeper et al. (1974) concluded that the value of soil to crop growth was primarily related to soil properties that influence available water. The recognized major effects of persistent erosion are discussed in the following sections.

2.1.3.1 Loss of Soil Productivity

Soil constitutes a basic component of the total agricultural resource base and persistent loss of top-soil leads to a progressive reduction of soil productivity. Soil productivity is defined as the capacity of a soil, in its normal environment, to produce a particular plant or sequence of plants under a specified management system (Soil Science Society of America 1975). Soil formation is a slow process, since the development of 2.5 cm of top-soil, rich with organic matter, necessary for efficient and sustained production of most plants takes 30 years or more under the most ideal natural conditions (Pimental et al. 1976).

Erosion depletes soil productivity but the relationship between erosion and soil productivity is not well defined (Lengdale and Shrader 1981; Pesek 1980). Topsoil removal through erosion has mainly been associated with reduction in sustained crop yields, and long-term agricultural development cannot be achieved if the productive capacity of the farmlands is destroyed. Hairston et al. (1988) found that the grain yields of soybean (Glycine max L. Merr.) depended mainly on soil depth. Other associated soil parameters were organic matter content and seasonal rainfall distribution. Soil depth was found to be a better predictor of yield for soils with low organic matter content, especially when rainfall was low. This could have been due to the reduction of soil water holding capacity through loss of organic matter due to erosion.

The National Committee of the USDA, Science and Education Administration, Agricultural Research (1981) indicated the following effects of erosion on reduction of soil productivity: 1) loss of plant-available soil-water capacity by changing the soil water-holding characteristics of the root zone or by reducing the root zone, 2) loss of plant nutrients, 3) degradation of the soil structure leading to increased soil erodibility, surface sealing and crusting, and 4) non-uniform removal of soil within a field. Individual soil characteristics can strongly affect the quantitative effects of erosion on soil productivity. Recognition of a reliable relationship between soil erosion and soil productivity would make it possible to select more effective crop-management practices for maximizing long-term sustained crop production. Yield losses due to erosion have been hard to quantify, since several soil parameters are altered at the same time. Also, some crops are more sensitive than others to these changes, and technological advances in many areas of agriculture have masked much of the associated effects (Bennett 1940; Meyer et al. 1985).

Ives (1985) and Kenyon (1987) showed through simulated erosion that crop yields decreased consistently with the amount of topsoil removed. These studies also showed that higher rates of fertilizer application than recommended were needed to restore the yields to expected levels, except for coarse-textured soils. This result was attributed to physical or chemical characteristics present in the subsoil, which were limiting to plant growth. The studies have clearly shown that persistent erosion will either increase production costs or permanently reduce the productive capacity of a soil, depending on the soil type.

Erosion has also been shown to contribute to soil crusting which in turn has detrimental effects on crop emergence and water infiltration rates (Miller et al. 1988). These effects were observed to be influenced by the degree of previous erosion, since moderately eroded soils had more serious crusting effects with the lowest emergence and highest penetration resistance. More eroded soils had the lowest infiltration rates and higher soil loss rates than the slightly eroded soils. Moderately eroded soils had the lowest infiltration rates and the highest erosion rates. This was due to the smaller aggregate size and lower stability of aggregates in the moderately eroded soil, and the greater clay dispersion in both moderate and severe erosion classes which contributes to the formation of relatively impermeable crusts.

2.1.3.2 Loss of Plant Nutrients

Demand for increase in food production and the depletion of native soil nutrients through crop growth and erosion has resulted in high use of commercial fertilizers. Nitrogen (N), phosphorous (P) and potassium (K) are the major elements of commercial fertilizers essential to normal plant growth. Dense growth of vegetation along natural waterways and at the base of agricultural fields is often attributed to the transportation of nutrients through erosion and surface runoff. Quantitative loss of these nutrients due to erosion when heavy rainstorms occur shortly after fertilizer application on sloping lands is not very well documented (Kilewe and Ulsaker 1984). Crop-management practices greatly influence the N and P losses through erosion from fertilized agricultural fields. Timmons et al. (1973) found that losses of N and P were greater when fertilizer was applied to the surface than when mixed into soil. Soil cover and seasonal periods have also been shown to influence N and P losses (Burwell et al. 1975). Efficiency in fertilizer application is highest when applied just before or during the period of vigorous plant growth (Stanford et al. 1970), and split application of fertilizer, timed to meet crop needs, reduces fertilizer losses from the plant root zone through erosion.

Lowrance and Williams (1988) found that organic carbon (C) loss through erosion contributes to the depletion of soil organic matter in continuously cultivated soils. Continuous loss of organic C has important effects on soil fertility, since organic C serves as a major source of cation exchange capacity (CEC), a source of mineral N, and as sink for fertilizer N (Gilliam et al. 1983 ; Longdale and Lowrance 1984 ; Schreiber and McGregor 1979). Soil organic C is one of the first soil constituents removed by erosion, since it is relatively of low density and is concentrated on or near the soil surface (Lucas et al. 1977). Loss of organic C by water erosion will affect nutrient availability both directly by loss of nutrients associated with the organic C and indirectly by loss of soil CEC.

2.1.3.3 Environmental Degradation

Off-site effects of soil erosion on environmental damage through pollution are associated with the transportion of sediment and agricultural chemical residues from farmlands to recreation areas, wells, reservoirs and aquatic ecosystems. Erosion effects are, therefore, felt not only in areas where topsoil is removed but also in areas down-slope where the ground becomes covered with sand and silt deposits, clogging of ditches and canals, and the silting up of wells and reservoirs with soil sediment. Eroded sediment and water components of the surface runoff are known to degrade the quality of surface waters with the transported sediment, nutrients and agricultural chemical residues. By volume, sediment is the greatest pollutant of surface waters (Robinson 1971; Burwell et al. 1975).

Agricultural chemical losses from the soil to surface runoff have been known to contribute to the decrease in the effectiveness of soil chemical treatment and to water quality hazard (Wallach et al. 1988). Studies have been conducted for the purpose of defining the influence of rainfall-runoff parameters on the release and transport of various chemicals from soil to surface runoff. These studies focused on the effects of rainfall intensity and duration, infiltration rate, slope length, degree of slope, surface cover, chemical solubility and soil adsorption characteristics on the extent of chemical loss (Ingram and Woolhiser 1980; Ahuja and Lehman 1983; Heathman et al. 1985; Snyder and Woohiser 1985). Increased accumulation of chemical residues, suspended and deposited sediment in water is associated with consequences that finally lead to eventual disruption of aquatic ecosystems and siltation of wells, water reservoirs and hydroelectric dams, with progressive reduction of the original water storage capacity (Robinson 1971; and Hudson 1979). When the concentration of transported plant nutrients in surface waters becomes too high the growth of aquatic plants becomes excessive, making the water undesirable for domestic and recreational use. There is little quantitative data available for evaluating the amounts and sources of the contribution of surface runoff to the accumulation of nutrients and chemical residues in surface waters (Kilewe and Ulsaker 1984). There is a need to understand the amounts of nutrients and chemical residues being transported from agricultural fields through surface runoff so that effective measures can be developed to reduce the associated losses below critical levels.

2.2 DEVELOPMENT OF SOIL LOSS PREDICTION EQUATIONS LEADING TO THE USLE

The development of the USLE was preceded by a generation of soil erosion research data collection, equation development, field testing and application of the developed equations. The process involved gradual but systematic improvement of the developed equations (Wischmeier and Smith 1960; Meyer 1984; Pauls 1987). Consequently, the USLE was a refinement of several previous consecutive empirical equations.

Wollny (1888) conducted the first study on soil erosion due to rainfall in Germany, and considered the soil physical properties that affect runoff and erosion. The study involved topographical factors (slope length and steepness), plant cover, soil type, direction of exposure, factors affecting percolation, evaporation and soil compaction. Sampson and co-workers (1918) made the first quantitative measurements of rainfall erosion in the United States on two ten-acre plots of overgrazed rangelands in Utah. Miller and colleagues initiated soil erosion plot research in 1917 at the Missouri Agricultural Experimental Station, and used experimental plot sizes of 27.66 m long and 1.83 m wide. Studies on soil degradation problems were started in the 1920's (Bennett and Chapline 1928), and involved the establishment of stations in nine states, using techniques developed earlier by Miller for measuring runoff and erosion. The studies used experimental plot sizes of 22.13 m long and 1.83 m wide and investigated a wider range of conditions influencing soil loss. Results from these studies were published in the 1930's, 1940's and 1950's. The 1930's and 1940's sparked a period when a greater perception of the problem of erosion and the need for soil erosion research was recognized (Nelson 1958). The establishment of the necessary procedures for soil erosion research was done but the techniques were yet to be perfected, since the runoff from various storm events was collected with large tanks, without a provision for runoff flow rate measurements. The experimental design excluded randomization or replication, and included only a limited range of treatments. Plot conditions differed from natural farming conditions and made it impossible to extrapolate plot information beyond the local experimental sites.

The development of the USLE was preceded by several soil loss prediction equations, each of which marked an improvement over the previous equation. Cook (1936) identified three major factors among the soil erosion controls and processes which provided a basis for developing soil loss equations. These included the susceptibility of soil to erosion, potential erosivity of rainfall and runoff, as influenced by the slope gradient, slope length, and the degree of protective ground surface cover provided by vegetation. Zingg (1940) developed the first soil loss equation using data from runoff plots of various sizes and soil types. This represented the first mathematical expression to relate observed soil erosion rates to topographical factors of slope length and slope gradient. The equation was developed as an attempt to obtain a scientific basis for terrace spacing, and was expressed as:

$$A = C \; S^{1.4} \, L^{0.6} \qquad (2.1)$$

where:
A = average soil loss per unit area (t ha^{-1})
C = constant of variation which represented the effect of soil and rainfall on soil loss
S = per cent slope (%)
L = slope length (m)

Smith (1941) made a slight modification to the equation by including crop and conservation management factors. The equation was proposed as a field guide for soil conservation purposes in the soils of the Southern Corn-Belt of the United States. The constant of variation included the influences not only of soil and rainfall but also of crop rotation and soil treatments. The data base was collected from natural runoff plots on Shelby loam soil, and the estimates of the constant of variation were required before the equation could be applied to other soils. The equation was expressed as:

$$A = C\ S^{1.14}\ L^{0.6}\ P \qquad (2.2)$$

where:

A = average soil loss per unit area (t ha^{-1})
C = constant of variation which now represents, effect of soil type, rainfall and crop rotation
S = percent slope (%)
L = slope length (m)
P = mechanical conservation practice

Browning et al. (1947) added the soil erodibility and crop-management factors to Smith's equation for application of the equation in Iowa State. Tables were also prepared for simplifying the field application of the equation, and the advances and adaptations by other researchers led to a slope-practice method for use in the Corn-Belt States.

Hays (1947) discovered a good relationship between the maximum amount of rainfall within any 30-min period of a rainstorm and the total soil loss during the entire rainstorm. This discovery was later corroborated at other experimental stations and provided information that was crucial in separating the effects of rainfall from those of soil type on erosion. The separation led to the development of the Musgrave equation (1947), in which the soil factor was represented as the depth of soil loss per year after adjustment for slope, rainfall and vegetative ground cover. The equation was the first mathematical expression to include rainfall and soil factors, relative to standard conditions for topography and rainfall, and was expressed as:

$$A = R^{1.75} S^{1.35} L^{0.35} C \ B \qquad (2.3)$$

where:

A = average soil loss per unit area ($t \ ha^{-1}$)

R = maximum 2 year-30 min intensity rainfall

S = slope gradient (%)

L = slope length (m)

C = 100 for continuous row crop or summerfallow, less for other crops

B = soil factor adjusted for rainfall, slope and cover

Shortcomings in Musgrave's equation included the inadequacy of the rainfall factor to explain local differences in rainfall erosivity, the reduced slope length factor which resulted in estimated erosion rates that were too low for some sets of data, and the continuous row-crop and summerfallow conditions that were found to be not interchangeable, since the cover of the former was highly variable. The equation was mainly applied in estimating soil erosion rates and flooding from large heterogeneous watersheds.

Smith and Whitt (1947, 1948) developed their factor system to simplify soil loss computation while comparing the principal factors influencing field soil loss process. Factors for slope, conservation practice, cropping and soil type were dimensionless multipliers and the rainfall factor was included if the area was characterized by a significant variation in rainfall intensity. The proposed modified equation was expressed as:

$$A = C \ S \ L \ K \ P \qquad (2.4)$$

where:

A = average soil loss per unit area ($t \ ha^{-1}$)

C = was based on average annual soil

loss from claypan soils for a
specific rotation on a 3% slope
27.43 m long cultivated up and
down-slope.

S = slope gradient factor
L = slope length factor
K = soil group factor
P = supporting conservation practice

Slope gradient (S), slope length (L), soil group (K), and conservation supporting practice (P) factors were dimensionless multipliers, and were used to adjust the C factor to other field conditions. Necessity for adding a rainfall factor to the equation was recognized with a view to making it applicable to a wider geographical area.

2.3 DEVELOPMENT OF THE USLE

The development of the USLE was preceded by more elaborate factor relationships, but did not properly allocate soil loss to the various constituent components, since it could not quantify the erosivity of individual rainstorms (Meyer 1984). This shortcoming was especially pronounced where soil loss was compared between areas having different rainfall characteristics and soil types. The USLE (Wischmeier and Smith 1960 and 1978) resembles the factor approach of Smith and Whitt (1948), but incorporates some considerable changes in factor definitions, due to the desire for a soil erosion prediction model that would be more widely applicable. Discovering that storm-to-storm variation in soil loss was highly correlated to the product of total rainfall energy and maximum 30 minute intensity of a storm (Wischmeier 1959) provided a more sound basis for separating soil type influences from those of storms. Several other factor definitions were revised after this, and standard or reference points to which actual conditions were compared were changed. The standard crop-management factor was changed from continuous corn to summerfallow and the topographical factor was changed from slope length of 27.6 m to 22.1 m and slope gradient of 3% to 9%.

The National Rainfall and Soil Loss Data Center, established in 1954 with W. H. Wischmeier as the Director, was expected to obtain and analyze runoff and soil loss data from various soil loss studies in the United States. Specific terms of reference for the center were to develop an equation whose factor components would be free from a geographical and climatic oriented base, and with a capability to predict soil loss from meteorological and soil survey data on site basis. The Center assembled data from 7,000 plot years and 500 watersheds years of precipitation, soil loss and other related processes. The exercise was completed by the end of the year 1956, and the state conservationists used the assembled data base in an attempt to reconcile differences among existing equations by extrapolating prediction capability techniques to areas where local data were not available. The resulting equation was expressed as:

$$A = C\ M\ S\ L\ P\ K\ E \qquad (2.5)$$

where: A = estimated soil loss (t ha^{-1})

C = crop rotation factor

M = management factor

S = percent slope factor

L = slope length factor

P = conservation practice factor

K = soil erodibility factor

E = previous erosion factor

The E factor was not evaluated but was considered when establishing the tolerable soil loss limits for different soil types. The equation excluded the rainfall factor because the data base available was insufficient.

Two important contributions were made to the development of the expected soil loss prediction equation at this stage. Wischmeier and Smith (1958, 1959), developed a rainfall erosivity (R) factor for the states east of the Rockies. This accounted for a greater proportion of soil loss variation from storm to storm. A method for evaluating the crop-management (C) factor was also developed. This combined the previous crop rotation and management (C and M) factors into a single crop-management (C) factor (Wischmeier 1960). These significant improvements resulted in the present day final expression of the equation known as the Universal Soil Loss Equation (USLE). The equation, is in its present form, composed of six integrated erosion influencing factors whose combination is structured in a multiplicative function. The equation was primarily developed in Imperial units, but methods are available for adapting it to metric (SI) units (Foster et al. 1981 and Pauls 1987). The equation is expressed as :

$$A = R\ K\ L\ S\ C\ P \qquad (2.6)$$

where: A = soil loss per unit area (t ha^{-1})

R = rainfall erosivity index

K = soil erodibility factor

L = slope length factor

S = slope angle factor

C = crop-management factor

P = soil conservation support practice factor

The USLE was developed as a soil conservation tool for predicting soil losses from specified agricultural fields with specific crop-management systems (Wischmeier and Smith 1978; Wischmeier 1984). The term "universal" is a means of distinguishing the equation from other existing regionalized soil loss estimating equations and to denote that none of the terms in the equation use any reference point with direct geographical orientation (Wischmeier 1984).

2.4 THE USLE FACTOR COMPONENTS

The following is a detailed description of the various factor components:

2.4.1 Rainfall Erosivity (R) Factor

The R (MJ mm ha^{-1} h^{-1}) factor is the total number of rainfall index units in a specific rainstorm event or year and represents a measure of the erosive potential of a specific rainstorm in detaching and transporting sediment from the surface soil mass. The factor value is determined by both total rainfall and kinetic energy subjected to the soil surface by the rain drop impact. It is a function of rainfall intensity and duration, the rain drop mass, diameter and terminal velocity. The factor is the product of rainfall energy (KE) and the maximum 30-minute intensity (I_{30}).

KE values of a storm event are based on the progressive increase in average drop size, terminal velocity and the changes in energy that occurs as rainfall intensity increases. Laws and Persons (1943) showed that mean drop size increased with rainfall intensity and Laws (1941) and Gunn and Kinzer (1949) showed that terminal velocity of a rain drop increased initially and then decreased as the drop size increased. Wischmeier and Smith (1958) used these relationships and proposed an equation for determining the KE of natural rainstorm events. The equation was expressed as:

$$Y = 916 + 331 \log_{10} X \tag{2.7}$$

where: Y = Kinetic Energy (foot/acre inch)

X = Rainfall Intensity (inches/hour)

The equation (in metric units) was expressed as:

$$KE = 11.87 + 8.73 \log_{10} I \tag{2.8}$$

where: KE = kinetic energy ($J\ m^{-2}\ mm^{-1}$)

I = rainfall intensity ($mm\ h^{-1}$)

For tropical rainstorms, Hudson (1965) developed an equation based on rainfall data from Zimbabwe expressed as:

$$KE = 29.8 - \frac{127.5}{I} \tag{2.9}$$

Zanchi and Torri (1980) carried out similar research in Italy and obtained an equation expressed as:

$$KE = 9.81 + 11.25 \log_{10} I \tag{2.10}$$

Wischmeier and Smith (1958) observed that total KE and (I_{30}) were the main rainfall characteristics associated with soil loss, and that the product of total KE and the maximum (I_{30}) was the most appropriate single variable in estimating soil loss. Products for these two values for different rainstorms were summed up to give a total value of the rainfall erosion index (EI) for a specific period. Rainfall intensity (I) was originally given no upper limit, but Carter et al. (1974) and Hudson (1971) showed that the medium drop size does not increase for intensities exceeding 76 mm h^{-1}. Hudson (1971) also found that rainstorms that were less than 25 mm resulted in little or no erosion. Equations 2.8 and 2.9 show that at rainfall intensities greater than 76 mm h^{-1}, the KE levels off at a value of about 28.3 J m^{-2} mm^{-1}, whereas equation 2.10 show energy value as high as 34 J m^{-2} mm^{-1} when the intensity is 150 mm h^{-1}. Wischmeier and Smith (1978) adopted 76 mm h^{-1} as the upper limit for rainfall intensities used in obtaining KE values where KE values equal 28.3 J m^{-2} mm^{-1} for all I values greater than 76mm h^{-1}.

Wischmeier and Smith (1978) defined an individual rainstorm as one separated by at least six hours of no measurable precipitation. Rainstorms of less than 12.7 mm were regarded as insignificant and were omitted in annual EI calculations, unless at least 6.4 mm fell in 15 minutes.

(EI_{30}) is, therefore, calculated for rainstorms that exceed 12.7 mm of total rainfall. Recording rain gauge charts provide the necessary data for dividing a rainstorm event into different intensities and duration by segmenting the curve into different slopes. Individual KE values for different segments are summed up to give total KE value for specific rainstorms. Maximum 30-minute intensity (I_{30}) value is also obtained from the charts.

2.4.1.1 R Factor Evaluation and Local Modification

The R factor has been evaluated and modified for application in different parts of the world for the purpose of ensuring effective local application of the USLE. Hudson (1971) found that KE greater than 25 index and total KE of rain falling at intensities of more than 25 mm h^{-1} provided the best estimate of R value in Zimbabwe. Elwell and Stocking (1975) expanded Hudson's work and found that EI_5 and EI_{15} which are the products of rainfall KE and its maximum 5- and 15-minute intensity, respectively, accurately estimated soil loss with high and medium ground surface cover, respectively. Lal (1976) observed a good correlation between soil loss and the product of total rainfall and maximum 30-minute intensity (AI_{30}) in Nigeria. The soil erosion process is influenced by both the raindrop splash effect and the concentrated surface runoff in the form of channelized or sheet flow. Foster et al. (1982) proposed a combined rainfall-runoff EIA, in place of R which was defined as the product of a storm maximum 30-minute intensity and the square root of the rainfall total multiplied by runoff volume.

Ulsaker and Onstad (1984) regressed soil losses on a tropical soil, using 15 erosivity factors, which included the USLE (EI_{30}), KE > 25 (Hudson 1971), EI_{15} (Elwell and Stocking 1975), EIA (Foster et al. 1982) and AI_{30} (Lal 1960a,b). The regression indicated the best rainfall erosivity factors as AI_{15}, $r^2 = 0.73$, AI_{30}, $r^2 = 0.72$, EI_{15}, $r^2 = 0.71$ and EI_{30}, $r^2 = 0.69$. Variables like EIA ($r^2 = 0.75$) which combined rainfall and runoff factors, were observed to be better estimators of erosion.

The method for calculating average annual R values was complicated and time consuming. Ateshian (1974) proposed a simpler, less time consuming procedure for determining R values for western and Northeastern states of the United States. The selection of the method was for computing the estimates of average annual R values as defined by Wischmeier and Smith (1958). The formula used was written as:

$$R = 0.41P^{2.2} \qquad (2.11)$$

where: R = average annual rainfall erosion index

P = the maximum 2-year 6-hour rainfall (mm)

The method depended on a generalized distribution curve for storm rainfall and the maximum once in two year six hour rainfall depth. Wischmeier and Smith (1978) used this method for extending the USLE Handbook rainfall erosion index map to the Great Plains of the United States. Van Vliet et al. (1976) used the same method for calculating annual R values for Southern Ontario. Wall et al. (1983) extended the same method to areas of Canada east of the Rocky Mountains. The same method was also applied in determining seasonal distribution patterns of monthly rainfall extremes. R values and distribution patterns of several stations close to the Canadian-United States border compared favourably to those obtained by Wischmeier and Smith (1965).

McKay (1970) and Hogg (1981) gave generalized distribution curves of storm rainfall which did not agree with that given by Ateshian (1974). The equations for these distribution curves were:

$$R = 0.17\ P^{2.2} \text{ (Mckay 1970)} \qquad (2.12)$$

$$R = 0.08\ P^{2.2} \text{ (Hogg 1981)} \qquad (2.13)$$

where: R = average annual rainfall erosion index

P = the maximum 2-year 6-hour rainfall (mm)

Hogg (1981) analyzed the time distribution of storm rainfall of one hour and 12 hour duration for 35 Canadian stations with 25 years records. He observed that contrary to Ateshian's findings, the distribution appeared to be independent of rainfall intensity, with substantial differences in distribution between regions. McKay's (1970) generalized distribution curve was specifically for large Prairie rainstorms. Kachanoski and de Jong (1985) found that the annual R value of 340 (SI units) for Saskatoon was well predicted using Mckay's approach (R = 350) compared to Ateshian's (R = 850) and Hogg's (R = 170) method. Kachanoski and de Jong also observed that Ateshian's Equation overestimated R values for Montana stations which Wall et al. (1983) used to verify the application of the procedure under the Prairie conditions. These observations suggested the need to obtain more accurate R values calculated from tipping bucket rain gauge data for the prairie provinces. Also, the need to develop a method for estimating soil erosion potential due to snowmelt which is independent of R was proposed.

Existing methods of estimating R values do not account for erosion resulting from snow-melt. Wischmeier and Smith (1978) recommended addition of subfactor (Rs) to annual R, which would be equal to 1.5 multiplied by local December to March precipitation. Seasonal distribution of R would be altered to reflect higher annual R values and the rate of thaw surface runoff. If an area had an annual R value of 100 (in Imperial units), and a water equivalent of 5 inches for December to March precipitation, the adjusted R value would be equal to 100 + 5(1.5) = 107.5. Accuracy for a wide application of the method was limited by insufficient data base. Van Vliet and Wall (1981) measured winter soil loss on spring ploughed corn plots in Southern Ontario and found the December soil loss to be about 10% of annual loss compared to the 17% predicted by USLE.

Wall et al. (1983) developed a rainfall isoerodent map for Canada and used a modified method developed by McCoal et al. (1976) for determining soil loss on Pacific Northwest soils. The method was for determining R factor values for winter months using the Ateshian (1974) approximation, and represented the combined effects of splash and runoff detachment and water movement from rain falling on thawing ground, snow and on unfrozen ground without snow cover. The subfactor (Rs) was the cumulative erosivity index value during winter months when the soil was frozen expressed as a percentage of total annual erosivity value. Mapping of spatial distribution of percentages by which R values should be increased to reflect the degree of soil loss associated with winter conditions was provided. Winter erosivity index expressed in similar units as R was computed for different locations from (Rs/100) x R. Therefore, average annual erosivity index adjusted for winter conditions was obtained using the formula, R + (Rs . R/100). For example, for Southern Manitoba, with an R value of approximately 1,160 MJ mm ha^{-1} h^{-1} and an Rs value of 15%, the winter erosivity index would be obtained in units of R as 0.15 x 1,160 = 174 MJ mm ha^{-1} h^{-1}. Therefore, the average annual erosivity index for Southern Manitoba would be adjusted to 1,160 + 174 = 1,334 MJ mm ha^{-1} h^{-1} (Wall et al. 1983).

2.4.2 Soil Erodibility (K) Factor

The K ($t\ h\ MJ^{-1}\ mm^{-1}$) factor represents the susceptibility of soil to both detachment and transportation of sediment. It is the rate of soil loss per unit of rainfall erosivity index for a specific soil under continuous fallow on a 9% slope on a plot of 22.13 m in length and cultivated in an upslope-downslope direction. K factor values determine the rate at which different soils erode under similar field conditions with standardized rainfall, topographical features, vegetative cover, soil type and crop-management practices.

For a unit plot (22.13 m x 4.57 m on a 9% slope), USLE factors L, S, C and P are all numerically equal to 1.0 under fallow conditions. Therefore, the USLE is reduced to A = RK. Measured K, as determined by Olson and Wischmeier (1963) is, therefore, obtained by rearranging the reduced USLE as:

$$K = \frac{A\ (t\ ha^{-1})}{R\ (MJ\ mm\ ha^{-1}\ h^{-1})} \qquad (2.14)$$

$$= t\ h\ MJ^{-1}\ mm^{-1}$$

where:
K = measured soil erodibility factor
A = measured soil loss ($t\ ha^{-1}$)
R = measured rainfall erosivity index

Soil physical properties are the most important factors controlling the soil erodibility potential. Soil erodibility values have been observed to vary with soil particle size, aggregate stability, and organic matter content (Morgan, 1986). Silty and fine sandy soils have been observed to be least resistant to sediment detachment and transportation process, and are more highly susceptible to erosion. Richter and Negendmark (1977) showed that soils with 40 to 60% silt content are highly erodible. Evans (1980) examined soil erodibility as affected by clay content. He noted that soils with a restricted clay fraction between 9-30% are more highly erodible, since clay particles combine with organic matter to form soil aggregates whose stability determine the soil susceptibility to erosion.

Wischmeier et al. (1971) and Romkens (1985) developed an equation and a corresponding nomograph (Figure 1) for estimating K values for different soil types. The equation took into consideration soil physical properties of particle size, organic matter, soil structure and soil permeability.

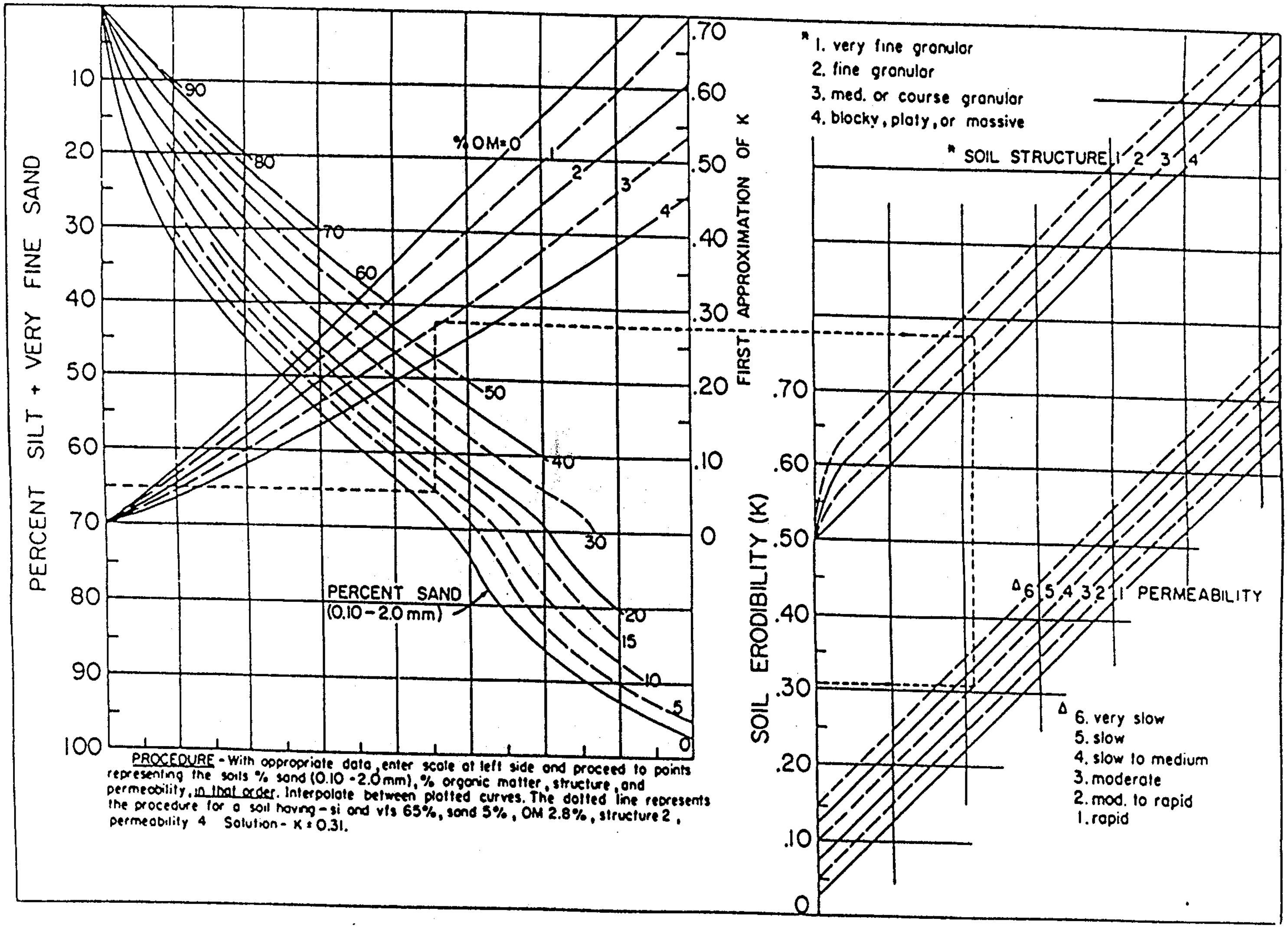
The development of the nomograph depended mainly on observations that soil erosion was highly correlated between two new soil parameters: (percent silt + percent very fine sand) and (percent silt + percent very fine sand) x (percent silt + percent sand). Very fine sand was observed to behave much like the silt fraction during the soil erosion process. The nomograph, therefore, made it possible to estimate K factor values from standard soil profile descriptions and laboratory determination of five soil parameters of percent new silt (0.002-0.1 mm), percent new sand (0.1-2.0 mm), organic matter, structure code, and permeability class. The algebraic expression of the nomograph was given as:

$$100K = 2.1M^{1.14}(10^{-4})(12-a) + 3.25(b-2) + 2.5(c-3) \qquad (2.15)$$

where: M = (percent new silt) x (percent new silt + percent new sand)

a = percent organic matter

b = structure code (1 to 4)



PROCEDURE - With appropriate data, enter scale at left side and proceed to points representing the soils % sand (0.10 - 2.0 mm), % organic matter, structure, and permeability, in that order. Interpolate between plotted curves. The dotted line represents the procedure for a soil having - si and vfs 65%, sand 5%, OM 2.8%, structure 2, permeability 4 Solution - K = 0.31.

Figure 1: Soil Erodibility Nomograph (After Wischmeier and Smith, 1978)

c = profile permeability class (1 to 6)

Determination of particle size, percent organic matter and structure code was done for the upper 15 cm layer of the soil profile. Permeability class was determined for the whole soil profile, since the controlling soil layer is mainly below the surface horizon. Ninety percent of K values estimated using the USLE Nomograph are expected to be within ± 0.04 of measured value and observed K values mainly range from 0.03 to 0.69. Differences between observed and estimated K factor values are largest in soils outside the medium texture range. M was observed to account for 85 percent of the variation in estimated K values.

2.4.2.1 K Factor Evaluation and Local Modification

The USLE Nomograph does not take into consideration soil parent material and soil genesis effects on estimated K factor values (wischmeier 1984). Wischmeier and Mannering (1969) found that the nomograph equation accurately predicted K values of some benchmark soils, even though montmorillonite clay content of several soils was higher than those used in deriving the equation. Trott and Singer (1983) measured soil loss on 20 west coast range and forest soils and found the combination of smectite and vermiculite clay mineralogy to be a more accurate means of predicting soil erodibility. This observation stressed the need to consider parent material and soil genesis in estimating the K factor.

The nomograph accuracy was tested on six clay subsoils (Romkens et al. 1975) and 13 Minessota surface soils (Young and Mutchler 1977). Both studies showed that the nomograph predictions underestimated K values for well aggregated soils. Conditions influencing surface aggregate formation are thought to be due to soils that contain clay minerals with expanding lattices or appreciable amounts of amorphous constituents. Young and Mutchler (1977) observed that for less weathered northern soils the measured K factor values were poorly correlated to the USLE Nomograph estimated values as compared to more weathered southern soils. It was suggested that this was due to higher montmorillonite clay content present in northern soils. Montmorillonite clay strengthens soil aggregate stability reducing the susceptibility of soil to erosion. Measured K factor values were obtained for 13 Minnesota soils to confirm this hypothesis. The USLE Nomograph estimated values were found to overestimate K values of three soils and underestimate the K values of six soils. Young and Mutchler (1977) proposed a new equation (YME) for estimating K values using soil aggregate characteristics rather than soil textural parameters as the important soil physical properties for predicting soil erodibility. The equation was composed of five factor variables, expressed as:

$$K = -0.204 + 0.385A - 0.013B + 0.247C + 0.003D - 0.005E \qquad (2.16)$$

$$(R^2 = 0.90)$$

where: K = soil erodibility index

A = aggregate index ratio

B = percent montmorillonite content in soil

C = soil bulk density ($g\ cm^{-3}$)

D = percent silt plus percent very fine sand

E = dipersion ratio

Soil aggregate index and percent montmorillonite clay content variables explained about 75% of observed variation among the 13 measured soils. Steele (1979) suggested that the equation may be more appropriate for application under Manitoba conditions, since the degree of weathering and percent montmorillonite content existing under Manitoba conditions would be more closely related to Minnesota soils than to soils from further south.

The Young and Mutchler (1977) Equation (YME) was developed as a multiple regression of variables influencing soil erodibility. The method used was suspected to be biased by use of an inconsistent number of replications for the 13 test soils (Pauls 1987). Eleven soils were replicated four times while two soils had five and 10 replications. The measured K values from each replication were used in developing the regression. Pauls (1987) regressed averaged K values with soil property values for each soil and obtained a Modified Young and Mutchler (1977) Equation (MYME) which was expressed as:

$$K = -0.146 + 0.33A - 0.0058B + 0.225C + 0.0019D - 0.0035E \qquad (2.17)$$

$$(R^2 = 0.89)$$

where: K, A, B, C, D and E are as previously defined in YME.

The measured K factor and the soil property values used in developing the modified multiple regression are listed in Pauls (1987) Appendix B.

Some other equations have been proposed for estimating K values. The Australian soil erodibility index which is made up of soil detachability and water transmission components was proposed by the New South Wales (Australia) Soil Conservation Service (Charman 1978). The equation for calculating the index was expressed as:

$$K = \frac{T\ S\ D\ \text{(soil detachability component)}}{(I\ K\ C\ )^{0.5}\text{(water transmission component)}} \quad (2.18)$$

where:
K = soil erodibility index
T = soil texture
S = soil structure
D = soil aggregate stability
I = square root of the infiltration rate
K = horizontal permeability
C = water holding capacity

Bruce-Okine and Lal (1975) proposed a procedure for using a modified raindrop technique for estimating soil erodibility values for two tropical soils in Western Nigeria. The technique depends on aggregate stability and is expected to be simple with a potential usefulness in tropical regions. Lindsay and Gumbs (1982) evaluated K values for four tropical soils using the USLE Nomograph, the Australian Erodibility Index and the Modified Raindrop Technique. The USLE Nomograph correctly predicted K values of all four soils; the Australian Index for two soils; and the Raindrop Technique was found not to be a suitable method.

The USLE Nomograph does not account for soils with organic matter content above 4%. Wischmeier et al. (1971) reported that whether or how much the estimated K values change when organic matter content exceed 4% was not determined. The USLE Nomograph treats soils with organic matter content greater than 4% as 4% (Steele 1979), and the K values for these soils have, therefore, been overestimated. Most Manitoba soils have organic matter content above 4%, and it is generally believed that the USLE nomograph is overestimating the K values under Manitoba conditions. Arnoldus (1977) modified the USLE Nomograph to determine K factor vales for soils with organic matter levels above six percent for Morocco.

Studies have shown that a universally applicable prediction equation for K values may not exist. Within the limits of the definition, accurate K-value estimates are best obtained from direct measurements on natural runoff plots if a sufficiently long observation period is used and unit plot conditions are met (Romkens 1985). Current evaluation techniques for the estimated K values are based on a statistical relationship between K factor and a series of soil physical properties, antecedent soil conditions and weather patterns. Complexity of the erosion process precludes any simple calculation of K factor, but some variability in K value measurements can be significantly reduced by estimating the effect of variation in soil surface mulch and crop canopy cover, antecedent soil moisture content and soil surface roughess (Romkens 1985).

2.4.3 Slope-Length (L) Factor

The L factor is the horizontal distance downslope from the point where overland flow originates to where runoff water enters a defined waterway or where slope decreases and sedimentation begins. L factor is the ratio of soil loss from field slope to that from a 22.13 m long slope on the same soil type and slope gradient. Soil erosion was indicated to be proportional to slope length raised to a power (Lp)m, where m is an exponent with a value ranging from 0.2 to 0.5. Lp represents plot length in meters and m represents values that have been revised through the years (Mutchler and Greer 1980; Smith and Wischmeier 1962; Wischmeier 1959; and Zingg, 1940).

Wischmeier and Smith (1978) provided m values for different slope gradients as follows:

Slope Gradient	Value of m
<1.0%	0.2
1.0 - 3.0%	0.3
3.5 - 4.5%	0.4
>5.0%	0.5

2.4.4 Slope-Gradient (S) Factor

The S factor is the ratio of soil loss from the field slope gradient to that from a 9% slope. Zingg (1940) concluded that soil loss varies as the 1.49 power of the percent slope. Wischmeier and Smith (1957) determined that soil loss correlated with a parabolic description of the effect of slope steepness. This was normalized to a standard plot of nine percent and resulted in a description of slope gradient factor as:

$$S = \frac{0.43 + 0.30s + 0.043s^2}{6.613} \qquad (2.19)$$

where: S = slope gradient factor

s = slope angle (percent)

Balasubramanian and Sivanappan (1981) found that erosion rates, slope and rainfall were exponentially related on runoff plots of 0%, 2%, 3% and 4%. The fitted equation was expressed as:

$$E = 0.29\ R^{1.325}\ S^{1.514} \quad (n = 56\ ;\ R^2 = 0.9) \qquad (2.20)$$

where: E = soil loss in kg ha^{-1}

R = rainfall in mm

S = slope angle (percent)

The equation shows that soil loss increases significantly with the degree of slope and rainfall. Wischmeier(1959) observed a non-linear relationship between soil loss and slope.

2.4.5 Topographical (LS) Factor

The L and S factors are determined separately but can also be combined into a single topographical factor (LS) for USLE calculations. LS factor is the ratio of soil loss per unit area from the field slope to that from a 22.13 m length of 9% slope.

Soil loss would be expected to increase with respective increases in slope length and slope steepness as a result of increases in surface runoff volume and velocity. Also, while on a flat surface raindrops splash soil particles randomly in all directions, on a sloping surface more soil is splashed downslope than upslope. The proportion of the amount of soil splashed downslope increases as the slope steepens.

Wischmeier and Smith (1978) derived an equation and a nomograph for estimating the LS factor values. The derived equation was expressed as:

$$LS = [(x/22.13)^m] (0.065 + 0.045s + 0.0065s^2) \qquad (2.21)$$

where: LS = topographic factor

x = slope length (meters)

m = an exponent

s = slope angle (percent)

2.4.5.1 LS Factor Evaluation and Local Modification

The LS factor has been evaluated and modified for different geographical conditions. Mean slope steepness has been used for predicting soil loss on irregular slopes. Young and Mutchler (1968) reported soil loss to be most dependent on short slope length immediately above the measurement point. Except where slopes were uniform, average slope was found not to be an appropriate soil loss indicator. Onstad et al. (1967) developed a model for use with the USLE in predicting soil loss on concave slopes. Soil loss was shown to be greater on convex slopes than on similar lengthened uniform or concave slopes. Foster and Wischmeier (1974) and Wischmeier (1974) derived equations for evaluating LS values for irregular slopes, changes in soil types along a slope and changes in crop-management situations along a slope for slope segments of equal and unequal lengths.

2.4.6 Crop-Management (C) Factor

The C factor is the ratio of soil loss from a field with specified crop-management practices to that from fallow condition on which the K factor was evaluated. The factor is a dimensionless multiplier and its value is influenced by the vegetative crop growth stage, cropping sequence, crop type, population density, root growth, residue management, soil fertility, tillage practices, crop water use and other ephemeral changes from planting time to harvest (Wischmeier 1960). For different conservation tillage systems, surface roughness and crop residue cover are two major subfactors that determine C factor values (Wischmeier 1984). The C factor is the most important erosion controlling factor, since it represents the condition of soil surface and the vegetative cover at the time the potential for erosion exists (Renard and Foster 1983). The factor has the widest potential range in value in response to crop-management decisions (Wischmeier 1984). Wischmeier (1960) designated five different crop growth stages, based on relative uniform crop and residue cover changes as they occur through the growing season. Soil loss ratios for each growth stage under different crop-management practices and field patterns were determined by dividing measured soil losses from the cropped treatment by measured losses from a continuous fallow treatment. This was done under similar rainfall characteristics, soil type and topographical features. Wischmeier (1960) tabulated measured ratios and respective C factor values for different crop-management practices.

C factor value was determined using the equation:

C = The sum for all growth stages for: (2.22)

[(Soil loss Ratio for growth stage)(Annual EI fraction for growth stage)]

Wischmeier and Smith (1978) redefined the designated crop growth stages with changes in percentage of crop canopy cover due to related variations in ground surface protection afforded by specific crops during the growing season from seeding to harvest. Developed tables differentiated the C values between different crop-management practices with residue cover in place of crop yield. These tables represented most crop-management practices existing in the United States. Six crop-stage periods were separated as:

Period F	-	Rough fallow. Inverse ploughing to secondary tillage.
Period SB	-	Seedbed. Secondary tillage for seedbed to 10% canopy cover.
Period 1	-	Establishment. 10% - 50% canopy cover
Period 2	-	Development. 50% - 75% canopy cover
Period 3	-	Maturing crop. 75% canopy cover to crop harvest.
Period 4	-	Residue or stubble. Crop harvest to ploughing or new seeding.

To obtain the C value for each crop growth stage, the appropriate erosion index distribution curve is entered to obtain the percentage of annual erosion index value expected within each crop growth stage period. The crop growth stage C value multiplied by the corresponding value obtained from the erosion index distribution curve is the C value for that period. The sum of obtained crop stage C values for specific crop-management patterns provide the annual C value for specific crop-management systems.

2.4.6.1 C Factor Evaluation and Local Modification

Elwell and Stocking (1976) presented a crop cover and classification approach for conditions tested in Rhodesia (Zimbabwe). The results obtained included relationships of soil loss as a function of mean seasonal vegetative cover. Roose (1977) developed average annual C factor values for vegetative cover and cultural techniques for West Africa.

Estimated C factor values for standard crop-management systems have proven accurate in estimating soil loss, but changing crop-management practices related to special tillage practices and cover situations have necessitated the C factor evaluation for appropriate adjustment under specific crop-management systems. This requirement specifically applies to conservation tillage, insufficiently tested crop-management systems, rangeland and forest areas.

Van Doren et al. (1984) found a 45% increase in soil loss from a cropping sequence of soyabean to corn. Observed soil loss was shown to be higher than the 25% estimated with USLE, and was less than that observed in other research situations which indicated increases in soil loss from 43% - 700%. The USLE was also observed to estimate a 30% decrease in soil erosion for zero tillage as compared to conventional tillage, and other researchers observed decreases in erosion from 56% - 75%. Van Doren et al. (1984) reported a soil loss of 90% lower than that predicted by the USLE for zero tillage crop-management system.

Burwell and Kramer (1983) showed that measured soil losses compared to USLE predicted soil losses were 54% for conventional tillage and 63% for conservational tillage systems under corn on Central Missouri clay in a 24 year study. Jones et al. (1983) found the USLE estimated soil loss to be double that observed in a six year watershed runoff study. Consequently they suggested that the possible causes of error could be due to an insufficient length of the study period and too high C factor values. Wendt and Burwell (1985) concluded that annual C factor values found in the USLE Handbooks were too high for conventional, minimum and zero tillage systems under corn. Dissmeyer and Foster (1981) described new procedures which were recommended to replace C factor values in the USLE Handbooks for woodlands.

2.4.7 Conservation Practice (P) Factor

The P factor is the ratio of soil loss from a specific soil conservation practice to that from soil loss obtained using an upslope-downslope cultivation practice. Conservation practices included in this factor are contouring, contour strip-cropping and terracing. Crop-management practices relating to conservation tillage, crop rotation, fertility treatments and retention of crop residues also contribute to P factor. Wischmeier and Smith (1978) recommended P factor values for three major mechanical soil conservation practices.

2.4.7.1 P Factor Evaluation and Local Modification

The P factor has been evaluated and modified for different crop-management systems. Williamson and Kingsley (1974) found a 51%-82% decrease in soil loss when switching from up and downslope tillage to contour tillage under corn and oats rotation in South Dakota. This observation compared well with the USLE estimated soil loss within the range of 50%-75%. Foster and Highfill (1983) proposed P subfactors to account for interterrace deposition (Pc) for soil conservation planning which would account for soil losses on each terrace, and (Py) for sediment yields which would calculate losses from the whole field.

2.5 USLE APPLICATIONS, LIMITATIONS, EVALUATIONS AND MODIFICATIONS

2.5.1 Applications and Limitations

Reduction of erosion rates to tolerable limits depends on properly planned crop-management practices. The USLE was developed to predict long-term average soil losses from specified field areas with specific crop-management systems (Wischmeier and Smith 1978). The equation has been used primarily to inventory erosion under existing field conditions and to guide in the development and application of relevant soil conservation plans (Foster 1982). The USLE predicts soil losses from sheet and rill erosion but does not apply to gully and streambank erosion. Also, the equation does not account for sediment deposited in the same field or watershed or that which ends up in a river or stream. The range of the USLE application is limited by the availability of representative local factor values, since the available tables and nomographs for calculating factor values are only directly applicable to the United States (Wischmeier et al. 1971; Wischmeir and Smith 1978). This situation stresses the need to evaluate the available USLE tables and nomographs for areas where rainfall, soil genesis and crop-management systems are different (Wischmeier 1984).

The equation was developed and tested on a comprehensive field data base assembled from experimental sites in the United States and is, therefore, widely regarded as reliable. It has been accepted as a standard tool for soil conservation planning (FAO 1965; Hudson 1981). The equation is used in obtaining tolerable soil loss (T) values by rearranging the factor combinations so that the L factor values required to reduce soil loss to the expected limit are calculated. Appropriate terrace spacings for reducing soil loss to tolerable levels can then be determined. The C value is estimated for suitable crop-management practice which, when combined with selected terrace spacing will provide the required tolerable soil loss value.

The USLE estimated A is replaced by a new symbol T and R and K factor values are considered as fixed for a specific field. Changeable factors are then grouped to determine appropriate crop-management alternatives for reducing existing soil loss to maximum T values. (Donahue et al. 1983, Wischmeier and Smith 1962). The USLE is rearranged and expressed as:

$$\frac{T}{R\ K} = LS\ C\ P \qquad (2.23)$$

where:

T = maximum soil loss torelance

R, K, (LS), C and P are as defined previously in USLE

The T/(R K) value is constant for a specific field and the required management alternatives for reducing erosion are obtained through the combinations of the adjusted factor values for LS, C and P. Possible conservation measures, for adjusting the management factors C and P are determined and their values obtained from the USLE tables (Wischmeier 1960). Maximum LS values for appropriate widths of terrace spacings are calculated for local conditions using:

$$LS = \frac{T}{R\ K\ C\ P} \qquad (2.24)$$

where:

LS = topographic factor value for terrace spacing

T = maximum tolerable soil loss

R, K, C, and P are as previously defined for USLE

The USLE cannot be used to estimate erosion from specific rainstorm events, since if applied this way it will provide an estimate of average soil loss expected from such a storm, which may be quite different from actual soil loss (Morgan 1986). Also, for the R and C factor values, the equation will estimate the average soil loss for numerous recurrences of this event on a given field and for a particular crop-stage period. The soil loss for any one of these events will vary tremendously in either direction from this average.

The equation is an empirical statistical equation whose factor variables are evaluated on the basis of the best percentage of explained variations. Therefore, refinements needed for short-run soil loss estimations were sacrificed for the purpose of conciseness and simplicity of the equation. Estimation of total watershed sediment yield limits is a specific cited example of misuse of the equation. The factor values for K, C and LS cannot be averaged for a complete complex watershed. For the equation to be applied with accuracy, the watershed must be subdivided into homogeneous individual units, and the deposition of some of the eroded soil sediment must be accounted for.

Inappropriate selection of the USLE factor values is a common source of error, especially when the basis for the factor selection is not specific. Application of C factor values over an entire corn field without considering the management practices will result in errors of estimated soil loss. Also, applying C and P factor values to slope lengths greater than those for which the factors can be applied with accuracy will also result to errors. Extrapolation of estimated soil loss beyond the range of available data from which the USLE was developed is inappropriate. Determination of slope length must take into consideration the situation that slope extends from origin of surface runoff to sediment deposition areas. Also, irregular slopes cannot be averaged but need to be computed separately. Estimation of soil loss may require addition of subfactors to annual R value so as to account for soil losses resulting from frozen soil and snow-melt in cooler climates. The equation estimates soil loss from sheet and rill erosion on slope segments associated to specific topographical factors, and does not take into consideration amounts of eroded sediment deposited on the same field. The data base for the equation, though extensive, is mainly restricted to the United States, specifically for 24 states east of the Rocky Mountains. The data base is further restricted to slopes where cultivation practices are permissible, which are normally 0 to 7°, and also to soils with low montmorillonite content (Young and Mutchler 1977).

In addition to these practical field limitations, there are other theoretical problems associated with the equation. Considerable interdependence exists between various factors, since rainfall influences R and C factors and terracing influences L and P factors. Other interactions between factors, such as the greater significance of slope steepness in areas of intense rainfall are not taken into consideration. Soil loss would be expected to increase with increase in slope steepness and slope length, due to respective increases in velocity and volume of surface runoff (Morgan 1986). The R value is based on studies of drop-size distributions of rain which may have limited applicability while surface runoff, an important factor to which soil loss is closely related, is omitted. To overcome this shortcoming, Foster et al. (1973) suggested the replacement of the R factor with an energy term, (W), which is a function of rainfall and runoff energy defined as :

$$W = 0.5\,R + 15\,Q\,q\,p^{0.33} \qquad (2.25)$$

where: R = rainfall erosivity factor
Q = storm runoff (m^3)
$q\,p$ = storm peak runoff rate ($m^3\ h^{-1}$)

Application of the USLE in many parts of the world has illustrated differences in the degree of accuracy. Soil erosion measurements by Hart (1984) in Utah State under different rangeland ecosystems with high organic matter levels showed that the USLE overestimated soil losses on steep slopes under dry conditions and underestimated soil loss under wet conditions. The observation suggested a significant effect of antecedent soil moisture on soil loss which will influence measured K factor values. The study indicated the need to modify the USLE before it can be applied on rangelands, taking into consideration the steep slopes, the residual plant roots, high organic matter levels and antecedent soil moisture content. Aldrich and Slaughter (1983) showed that soil loss estimated by the USLE on subarctic soils was 21% greater than that measured on annual basis, and up to 174% greater on an individual storm basis. This shows that the USLE overestimates soil losses on subarctic soils due to failure to take into consideration the inherent field conditions.

The USLE application has also involved soil loss estimation in watershed studies and in models for determining soil productivity losses resulting from erosion. Snell (1985) used the equation to determine soil erosion potential from high risk watersheds in Southern Ontario. Muessig et al. (1985) used homogeneous USLE factor values to estimate soil erosion potential for Minnesota State on 40 acre parcels of land, using field data from rainfall, soil survey and aerial photographs. Two models - CREAMS (USDA 1980) and EPIC (Williams et al. 1983) - have utilized the USLE in determining soil productivity losses resulting from persistent erosion.

The USLE application in estimating soil loss in Canada has been carried out without consideration of differences in local field conditions from those existing where the USLE was developed. Van Vliet et al. (1976) used the equation in estimating average annual soil loss on 13 agricultural watersheds in Southern Ontario. The study did not take into consideration soil losses resulting from the effects of freezing, thawing and snowmelt. The difficulty in using this method was that estimated soil losses were not equal to the sediment leaving the watershed, since the equation did not take into consideration the deposition of eroded sediment in the same field. Van Vliet and Wall (1979) carried out actual measurements of soil loss in Southern Ontario over a four to six year period and observed no significant differences from the USLE predicted soil losses. The effect of snowmelt and frozen soil on total soil loss was not considered in the study.

Stephen et al. (1985) used aerial photographs to estimate the USLE factor values in New Brunswick by using colour-infrared photographs to delineate homogeneous erosion mapping units, crop rotations and management practices. The study also depended on topographic maps for slope information and an improved soil erodibility map. He reported an accuracy of 88 ± 1-2% when the method was compared with field soil loss estimates obtained using the existing USLE factor values provided in the USLE Handbook. Wischmeier (1984) cautioned that for accurate application of the USLE in combination with interpretations from aerial photographs for large-scale soil loss estimation the complex watershed should be divided into subareas for which factor values can be easily identified. Therefore, using estimated watershed-average factor values of K, C and P with the average slope length and average gradient would be inaccurate, since the USLE was developed to estimate average annual soil losses from field-sized areas as a function of the way in which the various erosion controlling factors are combined.

de Jong et al. (1986) in New Brunswick found that potential soil losses estimated using the ^{137}Cesium method correlated well with those estimated using the USLE. He observed that the USLE overestimated total soil losses in areas where deposition of eroded soil sediment was occurring with or without simultaneous erosion. Steele (1979) attempted to apply the USLE to two Manitoba regions using soil survey, climatic data and published reports. For soil organic matter levels above 4% the value of 4% was used when determining the K factor values using the USLE nomograph. Topographic factors were observed to account for most of the soil loss variation in the study area. The study did not consider the effect of snow-melt and frozen soil on soil loss. Therefore, calculated K factor values were overestimated by treating soil organic matter levels above 4% as 4%. Shaw (1981) experienced difficulties in using soil survey reports data for determining the USLE factor values and pointed out the need for the reports to include slope length, percent very fine sand and field permeability data, required for determining the K and L factor values.

2.5.2 Evaluations and Modifications

The accuracy in evaluating the USLE factor values as provided in the USLE tables and nomographs and estimated soil loss depends upon the degree of experimental replication and the length of the study period. R factor values as proposed by Newman (1970) were based on a 22 year weather cycle. The R value for a given year may be equal to or less than one half, or more than two times the 22 year average. Wischmeier (1976) observed that even 10 year averages can significantly bias results. Testing of the USLE indicated that 58 of 88 deviations greater than 1.0 ton/acre from the average annual soil losses resulted from use of data records less than one half of the 22 year rainfall cycle (Wischmeier 1972). Therefore, study period and degree of replication are important considerations in assessing the accuracy of the USLE factor values, and the estimated soil losses.

Measured K factor values can vary on a storm basis, due to antecedent soil surface conditions and the storm characteristics. The soil may be dry, wet, freshly cultivated or crusted, and wind direction and velocity during a rainstorm as well as time of high intensity rainfall may vary between storms and within storms. Pauls (1987) stated that the presence of an intermittent fragipan during a rainstorm may have a variable effect on observed soil losses.

Average C factor values may be affected by time in the growing season, crop growing conditions, variable surface residue cover, tillage practices and the variation in EI distribution. Wendt et al. (1986) measured the variability of soil loss on 40 clean tilled fallow plots located side by side for 25 rainfall events. The coefficient of variation for soil loss was found to be relatively constant at about 20% for the various rainstorms, excluding the small runoff events. Sampling errors were deemed small compared to possible total unexplained within-plot variability, due to spatial variation in infiltration, soil erodibility, furrow geometry and total number and breakdown rate of soil aggregates. The study showed that increasing the number of experimental replications decreased the size of the confidence limit interval significantly.

The USLE has been evaluated and modified in many parts of the world for the purpose of ensuring accuracy in estimated soil loss. Pauls (1987) evaluated the applicability of the USLE in Manitoba and found that the absence of appropriate fallow conditions and directly comparable crop-management systems created problems in comparing measured and estimated K and C factor values. The short duration of the study was a major limiting factor, since the measured R, K, and C factor values for individual storms showed extreme variability. The study stressed that many plot years of data will be needed for averaging the measured factor values before effective modification of the USLE for Manitoba conditions can be established.

Hudson (1961) modified the equation for Zimbabwe and Roose (1975) investigated the equation's applicability to the Ivory Coast, and concentrated on evaluating the C factor values. Bolline (1985) evaluated the equation's tables and nomographs in central Belgium and concluded that direct application of the equation may lead to large errors unless the values proposed for the United States are confirmed by experimental measurements. Singh et al. (1985) evaluated the application of the equation for India and found that specific values for some USLE factors are available that can be effectively used to assess soil loss under different crop-management conditions. Cooley and Williams (1985) evaluated the applicability of the USLE and modified the equation for Hawaii. They obtained data-based values for the crop-management factor which were somewhat lower than those available in the USLE tables. The equation has also been modified for other land management systems. Dissmeyer and Foster (1985) modified the USLE for forest land by developing a new procedure for assigning cover-management-factor values for forest land by extending the sub-factor value introduced by Wischmeier (1973 and 1975). The equation was not designed to estimate specific runoff and soil loss events or downslope deposition but can be applied in comparing potential long-term effects of alternate methods of managing rangeland areas and for identifying major sediment sources (Wischmeier 1984). The table of "C-factor values for permanent pasture, range and idle land" (Table 10 in Agriculture Handbook 537), can help make the equation more useful under rangeland conditions. More research is necessary for evaluating the factor values for the R, K and L under rangeland conditions.

The USLE, in its present form, does not take into consideration the effect of surface runoff on rainfall erosivity. Williams (1975) proposed a modified USLE (MUSLE) for estimating soil losses from watersheds. The MUSLE replaced the R factor with a runoff energy factor, $11.8\ (Qqp)^{0.56}$ for specific rainstorm events. The equation was expressed as:

$$Y = 11.8\ (Qqp)^{0.56}\ K\ LS\ C\ P \qquad (2.26)$$

where: Y = sediment yield in metric tons,
Q = runoff volume in m^3,
qp = peak runoff rate in $m^3\ s^{-1}$,
K, LS, C and P are as previously defined for the USLE.

Smith et al. (1984) tested the equation for the Southern Plains grasslands of the United States and found a good correlation between measured and estimated soil losses.

Modifications of the USLE in sediment yield estimation mainly involves extensions that attempt to apply the equation to specific watersheds. Different modifications have been proposed in this area. Modifications to improve the accuracy in estimating the various USLE factor values for specific fields have already been discussed in the section on the USLE factor components.

Renard et al. (1974) discussed special conditions of semi-arid rangelands of the south-west United States and applied the USLE to sediment yield estimates from small watersheds by describing sediment yield with the USLE (in metric form) expressed as:

$$A = (0.2242)\ (\ R\ K\ LS\ CP\ )\ Ec \qquad (2.27)$$

where: A = sediment yield ($kg\ ha^{-1}$)
Ec = the channel erosion factor

R, K, LS, C and P are as defined
previously in the USLE

The channel erosion term Ec is similar to a sediment delivery ratio used to estimate sediment yield at the outlet and was created because a sediment delivery ratio is considered to be less than one. For some of the watersheds studied, the Ec term was larger than unity, since the quantities of sediment produced from channel bed and banks erosion were larger, making the sediment yield greater than the total upland field soil loss (Kirkby and Morgan, 1980).

Williams and Bendt (1976) modified the USLE for predicting sediment yield from watersheds and expressed the equation as:

$$Y = 11800\ (Qqp)^{0.56}\ K\ C\ LS\ P \qquad (2.28)$$

where: Y = sediment yield from an individual storm (kg)

Q = storm runoff volume (m^3)

qp = peak runoff rate($m^3\ s^{-1}$)

K, LS, C and P factors are as defined previously
in the USLE.

Williams (1975) obtained the coefficients from fitting the equation to data from Texas and Nebraska in the United States. The equation did not consider a sediment delivery ratio as necessary, since the R factor was replaced by the runoff term as shown in the equation. Accuracy in applying the equation required the evaluation of the K, LS, C, and P values that were different from those originally proposed for the USLE (Williams and Bennet 1972)

Onstad et al. (1976) used a modification of the USLE (Foster et al. 1973) as a major component in a sediment yield model for small watersheds which was expressed as:

$$A = (0.2242)\ W\ K\ LS\ C\ P \qquad (2.29)$$

where: W = a hydrologic term

$W = a\ Rst + (1-a)\ 0.40\ Qqp^{0.33}$

A, K, LS, C and P are as defined previously in the USLE

where: Rst = storm rainfall factor (EI units of the USLE)

Q = runoff volume (m^3)

qp = peak runoff rate ($m^3\ h^{-1}$) and

a = a coefficient ($0 < a < 1$) that represents the relative importance of rainfall energy compared with runoff energy for detaching soil sediment

Onstad and Foster (1975) used a hydrologic term value of 0.5 in an earlier study. The two equations were developed as a result of the analysis to describe the source of soil loss with respect to interrill and rill areas.

Computerized geographical information systems have also been used with the USLE and a sediment delivery ratio to estimate potential sediment loading to streams from agricultural fields (Hession and Shanholtz, 1988). Necessary calculations for estimated potential sediment yields require information on crop-management, soil type, rainfall and topographical features. The USLE expressed with a delivery ratio is given as:

$$PSL = R\ K\ (LS)\ C\ P\ (DR) \qquad (2.30)$$

where: PSL = potential sediment loading (Mg/ha)

R, K, LS, C and P are as defined previously in the USLE

(DR) = sediment delivery ratio

Delivery ratio is used to estimate the amount of eroded sediment that finally reaches a stream. The ratio is calculated from topography (relief and slope), watershed, waterbody, and landuse data maps according to the expression:

$$DR = 10(r/L) \qquad (2.31)$$

where: DR = sediment delivery ratio

r = relief, which is the difference in elevation between an agricultural land and associated stream

L = slope length

Maximum (r/L) value obtained is used in the equation for the necessary calculations.

These modifications are extensions of the USLE range of application and were developed to estimate total watershed sediment yields. Modifications are preliminary and are limited in a geographical oriented base, since only limited data verification has been accomplished (Kirkby and Morgan 1980).

Erosion rate at a given point varies nonuniformly with distance along the flow path on a uniform landscape profile. The USLE estimates average soil loss from a slope with full eroding length and uniform steepness. However, it can be modified to calculate erosion at any point on the landscape experiencing net erosion so as to give the best estimate of average annual soil loss for a given nonuniform landscape profile, excluding that part of the profile experiencing net deposition (Griffin et al. 1988). The modified form of the equation for this purpose is expressed as:

$$D = (m + 1)\ R\ K\ (x/lu)^{m}\ S\ C\ P \qquad (2.32)$$

where: D = erosion rate at the given point

x = distance of the given point from the origin of the landscape profile

lu = length of the USLE unit plot (22.13 m)

m = USLE slope length exponent

R, K, S, C and P are as defined previously in the USLE.

The USLE factor values for R, K, S, C and P are as defined for the point (x), and in particular, S is a function of (x), since slope steepness typically varies along the landscape profile.

2.6 THE USLE AND THE FUTURE OF SOIL EROSION MODELLING

The USLE has been mainly applied in erosion modelling and soil conservation planning from the time it was developed (Wischmeier and Smith 1978). The success of the equation has been due to its simplicity, which makes it easy for even non-technical staff in the field advisory and extension services to apply.

A soil loss estimation model coded SLESMA (Soil Loss Estimator for Southern Africa) has also been developed (Elwell 1981). The model is considered to be suited particularly to countries that are unable to support extensive soil erosion research programs which urgently require a decision making aid to combat erosion. The model predicts mean annual soil erosion losses arising from sheet erosion on the area of arable land between two adjacent contour ridges. The method of soil loss estimation differs in concept from the USLE where cropping and tillage are treated as integral parts of the C factor, while the SLESMA model treats them as separate factors. The model divides the soil erosion system into four influencing factors, treating each factor separately. The factors considered in the system are climate, soil, tillage and topography.

The USLE has also been used by researchers in estimating potential hillslope soil loss rates, but as a research tool it has limitations (Morgan 1986). The reason is because the USLE views erosion as a multiplicative function of the various erosion controlling factors as they occur in various land management systems. The assumption is that each factor has equal weight, and that there are no interactions between the various factors and also, that erosion is linearly related to them. The USLE has been observed to be more complex than this and the soil erosion process cannot be effectively represented by taking the values of the various factors and multiplying them together, since the differences in the magnitudes and ranges of the factor values prevent equal weighting. Also, the equation used to determine the values for the slope steepness factor, for example, is non-linear in form.

The increasing recognition of the limitations of the USLE has resulted in a move toward more research aimed at modifying or replacing the equation with a more efficient model. Meyer and Wischmeier (1969) laid the foundation for a new generation of soil erosion models by calling for a return to the fundamental approach proposed by Ellison (1947). The approach considered erosion as a process resulting from the detachment of soil particles from the surface soil mass and the subsequent transportation of the eroded sediment from the place of detachment. Therefore, the soil erosion process is viewed as a complex process that has not been sufficiently and descriptively simulated by the existing empirical equations. The Meyer-Wischmeier (1969) scheme provides for the effects of the raindrop splash impact and surface runoff as agents of soil sediment detachment and transportation.

The proposed mathematical model of the erosion-sedimentation system is expected to take into consideration the relative individual contributions of four erosion controlling subprocesses and describes soil movement at all locations along a hillslope. The erosion controlling subprocesses considered are those related to sediment detachment and transportation capacity due to both rainfall and surface runoff. The parameters for which mathematical relationships are needed are in terms that can be quantitatively measured. These include the detachment potentials and transport capacities of rainfall and surface runoff, including expressions of the surface soil mass susceptibility to detachment and transport. The model is expected to be broadened to include pertinent field site parameters in their time-dependent forms. These are rainfall intensity, infiltration rate, rill geometry as it affects the hydraulics of the surface runoff, the time required for the sediment and the surface runoff to move downslope and the manner in which some of the soil properties that affect detachment and transport of sediment change with time.

There are other essential erosion controlling field parameters to be considered in the expanded erosion model:

1. Seepage and other subsurface flows as they affect soil erosion.
2. Vegetation and crop residue cover as they affect the erosive potential of rainfall and surface runoff.
3. Tillage practices, freezing and thawing as they influence soil susceptibility to detachment and transport.
4. Land topography and surface microtopography as they affect soil moisture storage.
5. Overland flow, exposure to rainfall, and surface-water depth as it affects sediment detachment and transport.
6. Accumulation of excess detached sediment available for transport during subsequent periods of greater capacity and additional interrelationships among the subprocesses.

The proposed mathematical erosion model will be expected to provide a comprehensive expression of the soil physical, mechanical and chemical processes contributing to the soil erosion and sedimentation process. More reliable predictions of locations of excess soil erosion rates and deposition areas within a watershed are expected to become available. Relative importance of various components of the soil erosion process are expected to be evaluated as a basis for selecting the most effective method for erosion reduction in the total watershed.

Foster et al. (1981) developed a model for a field-sized area to evaluate sediment yields under various crop-management practices. The model incorporated fundamental principles of erosion deposition and sediment transport, and provides a tool for evaluating field sediment yields on a storm-by-storm basis for control of erosion and sediment yields from agricultural fields. The need to consider sediment detachment and transport processes on a storm-by-storm basis limits the accuracy of the USLE. Williams (1975) modified the USLE model on a field sized basis, and incorporated fundamental erosion-sediment transport relationships for use in evaluating best crop-management practices for effective control of erosion and sediment yields. The model procedure takes into consideration the soil erosion parameter changes along the overland flow profile and along waterways so as to represent both spatial variability and the variations that occur from storm to storm.

Morgan et al. (1984) developed a model for predicting annual soil loss from field-sized areas on hillslopes, which comprised a water phase and a sediment phase. Sediment phase considered erosion to be a function of detachment of soil particles by raindrop-splash effect and sediment transport by surface runoff. The water phase uses annual rainfall to determine the rainfall energy for sediment detachment and the volume of surface runoff available for sediment transport. The model incorporates data from geomorphologists and agricultural engineers into a model which, although empirical in nature, has a stronger physical base than the USLE or the Chemical Runoff and Erosion from Agricultural Management Systems(CREAMS) model. The model was developed with the specific objective of determining to what extent existing work could be combined in a simple format to estimate annual soil loss from field areas on a hillslope, and gives realistic estimates over a wide range of field conditions.

The USLE has served its purpose well in predicting mean annual soil losses from different fields and watersheds under specific land management practices. Therefore, the need for a greater resolution provided by more complex models may not be necessary, since knowing how much soil is lost during a specific rainstorm may not be as important as knowing whether the estimated annual soil loss exceeds a particular threshold or tolerance level (Morgan 1986). The emphasis on research developing more sophisticated storm models or daily simulation models will mean losing the simplicity of the USLE, since with models like that of Foster et al. (1981) it may be difficult to determine the factor or a number of factors that may have contributed significantly to the estimated soil loss. The models are also not suitable for field use by soil conservation workers, since large data inputs are needed along with the necessary computer facilities for data analysis. Therefore, the USLE still remains as the most suitable soil conservation tool in estimating soil losses under specific crop-management practices for ensuring effective soil conservation planning. Foster et al. (1987) described the USLE as "the world standard for an equation to estimate sheet and rill erosion", saying that "no other current equation or procedure for estimating erosion approaches, as a whole, the USLE in ease of application, breadth of application, and accuracy."

2.7 FIELD EXPERIMENTS FOR MEASURING SOIL LOSS

Field data on soil erosion and its controlling factors are collected on selected experimental sites with appropriate crop-management treatments. Experiments are carried out either in permanent research stations or may be designed to assess erosion at a number of temporarily selected sample sites distributed over a large area. Data collection from permanent experimental sites is done on bounded runoff plots of known specific area, slope steepness, slope length and soil type with different crop-management treatments. Soil loss and surface runoff measurements are done for different crop-management treatments and rainstorm events. Mitchell and Bubnezer (1980) suggested three specifications for field experimental plot establishment and field equipment needed for surface runoff and soil loss measurements. These are: 1) the designated plot boundaries should be well defined, with sample collection equipment for concentrating runoff and sediment samples, 2) the conveyance equipment for carrying runoff to a sampling unit and a sampling unit for splitting the runoff and sediment to manageable quantities should be included, 3) the storage tanks for the sampled surface runoff and sediment should have a sufficient storage capacity for containing samples from the expected highest possible rainstorm event so as to avoid undersampling problems.

2.7.1 Experimental Plot Design

Plot dimensions for a standard erosion plot are 22.13 m long (up and down slope) and 4.6 m wide, established on a 9% average slope gradient. Standard plots were used in obtaining most of the 10,000 plot years of soil loss data used in developing the USLE (Wischmeier 1984). Using these as bases for K, L and S minimized potential errors in adjusting the data to a common base. Plot edges were made of sheet metal, wood or any suitable material which is stable, does not leak and is not susceptible to rust. Many different devices, including soil mounds, sheet metal strips and wooden planks are used to isolate experimental plots from the surrounding area. Hudson (1957) pointed out that these materials are expensive and some are highly susceptible to deterioration with time and thus proposed the use of flat asbestos cement planks, set on edge and supported by round pegs. Border depth below and height above ground should be sufficient to prevent water movement, vegetative growth and rodent tunneling across them (Dendy et al. 1979). Commonly used depths and heights are 5 to 30 cm and 7 to 25 cm, respectively (Pauls 1987).

Bounded plots probably give the most reliable data on soil loss per unit area, but there are several sources of error involved with their use (Hudson 1957). These include silting of the collecting troughs and pipes leading to the tanks, inadequate covering of the troughs against rainfall, and the maintenance of a constant level between the soil surface and the sill or lip of the trough. Other related problems are that surface runoff may collect along the boundaries of the plot and form rills which would not otherwise develop and the plot itself is also a partial closed system being cutoff from the input of sediment and water from upslope.

2.7.2 Surface Runoff and Sediment Sampling System

Runoff and sediment collecting equipment located at the lower end of the plot usually consist of a sheet metal trough buried in the soil to a depth that will permit surface runoff to flow over the front lip unimpeded into the trough. Dendy et al. (1979) recommended that troughs be wide enough for easy cleaning (20 to 25 cm) and be sloped to the middle at a 5% slope. For wider plots (i.e. 6 to 10 m), the suggested requirement was that runoff and sediment should be concentrated by appropriately positioned plot borders before entering the collectors. Hudson (1957) reported that the troughs should remain covered during rainfall events as significant errors could arise during light rainstorms. For large plots or where runoff volumes are very high, the overflow from a first collecting tank is passed through a divisor which splits the flow into equal parts and passes one part as a sample into a second collecting tank. Runoff and sediment conveyance equipment often used is a variable length pipe or rectangular channel, connecting the collector to a sampling unit. The conveyor is expected to have sufficient slope for good drainage (Parsons et al. 1954). The channel for collecting the sediment should match the plot width if a flume is included in the design.

The collected surface runoff and sediment mixture is measured and then sampled for further laboratory analysis. Slot-type samplers are used in larger plots since sample volumes are reduced to manageable quantities, and are, therefore, most preferred. Geib (1933) proposed multislot divisors, which subsample the surface runoff and sediment by causing them to pass through five to 15 rectangular slots where only one slot passes the sampled aliquot to another collection tank. This method subdivides the sample, and sludge tanks are used for collecting the sampled sediment. These are located between the conveyance channel and the divisor, and one to three sample collection tanks after the divisor. Flow-rate information is obtained through measurements using flumes located on the conveyance channel. Runoff volume and sediment losses are determined through water depth measurements and subsampling of the solution while mixing at the same time.

The Coshocton Sampling System which is a continuous sampling slot type device was developed by W.H. Pomerene in the mid-1940's (Parsons 1954). The system consists of a small H flume which discharges surface runoff and sediment over a slightly inclined finned wheel, causing it to rotate. The wheel has an elevated sampling slot which extracts an aliquot as the wheel rotates through the runoff discharge, once per revolution. The subsample is passed through the base of the wheel into storage tanks, and the runoff volume and sediment losses are determined in a similar fashion as described for multislot divisors. Total sample obtained for a specific rainstorm may be 1/3%, 1/2% or 1% of the total runoff and sediment, depending on the model of the system used. Sampling error increases significantly as the runoff discharge rate increases over 80% percent of the total flume capacity (Parsons 1954). Mutchler (1963) observed that for design purposes of all fractional hectare surface runoff measuring systems, the assumption is that the maximum surface runoff rate is equal to the maximum five minute rainfall rate and sample storage space is equal to the aliquot portion of the maximum 48 hours runoff event that could possibly occur.

There are other methods that have been designed to sample surface runoff from small watersheds. Dendy (1973) developed a system whereby a traversing slot moved back and forth through the nape of a Parshall flume. The fraction of the flow extracted is further reduced by sample splitters and the system was effective for computing sediment concentration but poor for determining total sediment or runoff volumes, since the fraction of flow extracted decreased as the runoff discharge increased. For remote watersheds or when flashiness of surface runoff is involved or when good concentration graphs are required, automatic pumping samplers are used. The most widely used modified Chickasha method is an example of a sediment sampler, which is able to sample 28 pint bottles in 12 hours (Allen et al. 1976; Miller et al. 1969). The pump is activated by an increase of stream depth and fills each bottle at a preset time interval.

2.7.3 Rainfall Total and Intensity Measurement

Rainfall is measured with both standard and tipping bucket recording rain gauges installed adjacent to the plots, so that the measured surface runoff and soil loss can be related to the rainfall total and intensity for specific rainstorms (Morgan 1979).

2.7.4 Crop and Residue Cover Measurement

The soil erosion process is affected by the fraction of the soil surface that is protected by crop and residue cover (Laflen et al. 1978, Laflen et al. 1981, and Wischmeier and Smith 1978). Methods used in measuring the crop and residue cover are expected to provide a good estimate of the average cover on a field with a reasonable number of measurements. Wischmeier and Smith (1978), used a point-line method which was composed of a 5.0 m rope with 10 evenly spaced markings. Presence or absence of residue or plant part immediately below each marking was recorded. The method sampled 20 times per sample point and was replicated five times per plot. When the crop had grown to about 15.0 cm in height a horizontal bar with 20 evenly spaced markings supported on a stand above the crop canopy was used. Sighting down from each marking established the presence or absence of a plant part. Five replicate measurements were made on each treatment from which percent cover was calculated. Crop and mulch cover measurements are done throughout the growing season for obtaining appropriate crop cover changes for which C factor values are calculated.

2.7.5 Antecedent Soil Moisture Measurement and Tillage

Antecedent soil moisture is known to influence the initiation and generation of surface runoff. Moisture measurements are done throughout the growing season using the gravimetric method. Variability in K value measurements can be reduced by estimating the effect of variation in antecedent soil moisture content and soil surface roughness (Romkens 1985). Several observations regarding type, manner and frequency of tillage of erosion plots are also made as they relate to soil surface roughness due to cultivation. The manner and frequency of tillage will influence infiltration rates, ponding, time of initiation of surface runoff and velocity and subsequent soil loss. Therefore, time of cultivation will influence the variability of K and C value measurements.

Chapter III

MATERIALS AND METHODS

The purpose of this study was to develop a comprehensive data base on field soil loss due to natural rainfall under different soil types and crop-management practices. The data base was to be used in evaluating the USLE K and C factors under Manitoba agricultural and climatic conditions. Field experiments were established on selected field sites with different soil types and crop-management treatments so as to quantify the surface runoff and sediment production from the various treatments under different rainstorm events. The erosion controlling factors taken into consideration included rainfall total and intensity, surface runoff peak volume and flow rates, soil physical properties, crop residue and canopy cover, antecedent soil moisture, crop-management practices, farm operations (cultivation) and topographical features.

3.1 EXPERIMENTAL SITE LOCATIONS AND DESCRIPTIONS

Four field experimental sites were selected on the basis of the distribution of the major soil types and the required uniform slopes. The first two sites were established in the escarpment and Agassiz beach landscape areas of South and Central Manitoba. The first site was established in the summer of 1984, located in the escarpment near Miami (legal description, NE 2-5-7W) on a Gretna clay soil, developed on Cretaceous clay overwash or outwash of weathered shale clay derived from escarpment ravines (Ellis and Shafer 1943). The site has a southerly exposure and a recent continuous cropping history. The second site was established in the spring of 1985, on the Agassiz beach landscape near Roseisle (legal description, NW 18-6-7W) on a well drained Leary sandy loam underlaid by sandy material (Ellis and Shafer 1943). The site has a westerly exposure and a cropping history of a wheat-wheat-summerfallow rotation.

The third site was established in the summer of 1986, in South-Western Manitoba, located near Boissevain (legal description, SW of SE 2-3-21W), in the Whitewater Lake basin on a Ryerson sandy clay loam soil, developed on deep strongly calcareous medium to moderately fine textured glacial till with coarse fragments composed of shale, limestones and granitic rocks (Eilers et al. 1978). The site has an easterly exposure with a cropping history of wheat-canola-fallow rotation. The fourth site was established in the spring of 1987 in Western Manitoba, located near Brandon (legal description, SW 29-8-19) in the glacial lake Souris and the Brandon glacial lake basins on well drained medium textured Carroll clay loam soil, developed on lacustrine sediment deposits, underlain at varying depths by a substrate of glacial till (Ehrlich et al. 1956). The site has a south-westerly exposure with a cropping history of wheat-canola-fallow rotation. The distribution and location of the various selected experimental sites is as shown in the map attached (Figure 2).

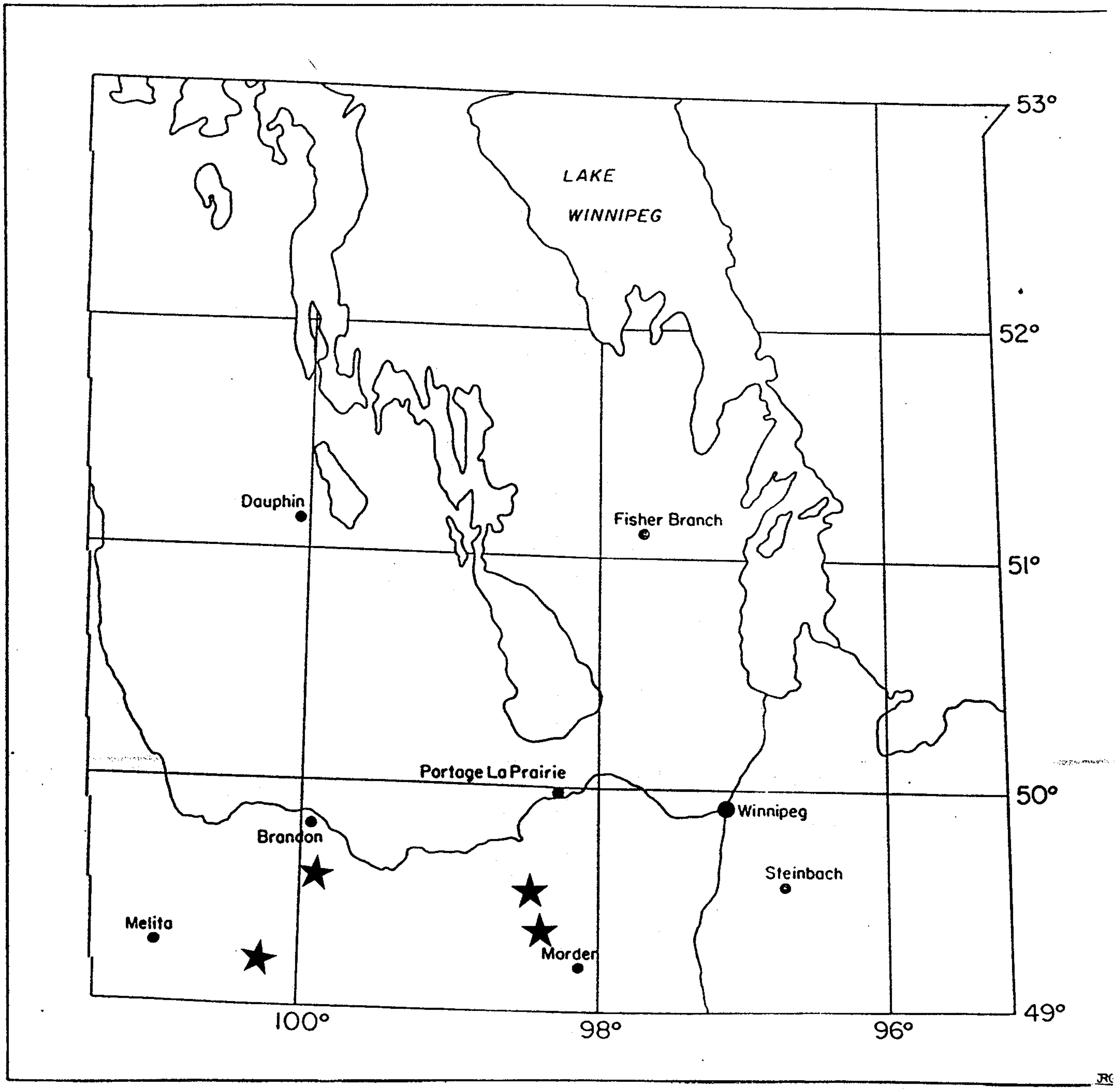


Figure 2: Location of the Field Experimental Sites

3.2 EXPERIMENTAL PLOT DESIGN AND CROP-MANAGEMENT TREATMENTS

Experimental plot dimensions were 22.13 m (up and down slope) and 4.6 m wide, established on a uniform 9% slope. These dimensions were chosen to conform to the standard plot dimensions used during the USLE development, so that the field data collected could be easily compared with the data used during the USLE development. The standard plot was as described above and was tilled up and down slope under a continuous fallow for at least two years (Wischmeier and Smith 1978).

Five continuous crop-management treatments: 1) summerfallow, 2) conventional tillage wheat, 3) minimum tillage wheat, 4) conventional tillage corn, and 5) alfalfa, were selected for the experiments. For the Gretna clay and Leary sandy loam sites, the minimum tillage wheat treatment was not included. The crop cultivars used were Rambler alfalfa (Medicago sativa), Benito wheat (Triticum aestivum) and Pioneer 3995 corn (Zea mays L.). The crop cultivars selected were among the most commonly grown crop species in Manitoba. Seeding and fertilizing operations were done according to the guidelines outlined in "Field Crop Recommendations for Manitoba". For weed control, Embutox E, Hoegrass II, and Aatrex Plus were used on the alfalfa, wheat and corn plots, respectively. Round Up was used for spot spraying against resistant weeds in and around the plots.

Field measurements for Gretna clay and Leary sandy loam sites were done during the 1986 and 1987 growing seasons. Field measurements for Ryerson sandy clay loam and Carroll clay loam sites were done during the 1987 growing seasons only.

3.3 EXPERIMENTAL FIELD OPERATIONS

Details for the various field operations undertaken for the establishment and maintenance of the crop-management treatments are provided in Tables 1, 2, 3, 4, 5 and 6. For the establishment of the alfalfa plot, the alfalfa was underseeded to wheat during the establishment year. Seed was broadcast on the prepared seedbed and harrowed twice. Wheat was drill seeded on both conventional and minimum tillage treatments and the corn was hand planted. Row spacings for wheat and corn were 18 cm and 91 cm, respectively. Corn plots were cultivated three times during the growing season. Summerfallow plots were cultivated every three to five weeks so as to keep them weed free and to prevent crust formation. This was done with a 2.3 m cultivator equipped with 16 shovels (15 cm wide). Wheat and corn plots were tilled once before seeding and once after harvest. Corn plots were also row cultivated twice during the growing season. All the tillage and cultivation operations were done up and down the slope in order to eliminate the soil conservation practice (P) factor effect.

The crops were harvested at maturity to determine dry matter and seed yields. Yield was compared to the average crop yields expected in the farmers' fields in the study area for the selected crops. Wheat was harvested at maturity for dry matter and seed yield, and corn at 65% whole plant moisture for total dry matter yield. The stubble remaining after harvest was 10-12 cm for wheat and 5-10 cm for corn, and all the plant residues were removed after harvest. Plant samples were taken from three one-half square meter quadrats located randomly, on both alfalfa and wheat plots, along the upper, mid and lower slopes. For corn the sampling was done along randomly selected rows on upper, mid and lower slopes within specific row lengths of 1.0 m. Corn and alfalfa samples were oven dried to constant weight at 80°C. Wheat samples were dried at room temperature amd threshed to determine both dry matter and seed yields.

3.4 FIELD DATA MEASUREMENTS

3.4.1 Crop and Residue Cover Measurements

Percentage residue and crop cover measurements were done throughout the growing season for corn, wheat and alfalfa. The method used was the point-line method used by Wischmeier and Smith (1978) as modified by Pauls (1987). During spring, measurements were done by stretching a 5.0 m rope with ten evenly spaced markings diagonally across the plot. The presence or the absence of residue or plant part immediately below each mark was recorded for 20 markings per sampling point, with the rope stretched diagonally along the right and left side of the sampling point. When the crop had grown to above 15 cm in height, the point-line method was used. This comprised of a horizontal bar with 20 evenly spaced markings supported on two stands above the crop canopy. Measurements were made by sighting down from each marking for the presence or absence of a plant part. These measurements were done on a weekly basis for five replicates on each treatment. The data obtained were used in calculating the percent crop cover changes through the growing season for separating different crop stage periods.

Crop stage periods defined by Wischmeier and Smith (1978) were modified to account for the presence of a winter period and the absence of turn plough tillage. The comparative system is given in Table 7.

TABLE 1

Field Operations for Gretna Clay Site in 1986

Treatment	Date	Operation (Rate)	Equipment used (Size)
Wheat	May 15	cultivation	cultivator (2.3 m)
	May 15	broadcast 34-0-0 (.27 t ha^{-1})	hand spreader
	May 15	band 11-51-0 (.08 t ha^{-1})	press drill (1.5 m)
	May 22	seed wheat (.1 t ha^{-1})	press drill
	May 22	harrow	harrows
	July 2	spray Hoe-grass II (3.5 L ha^{-1})	bicycle sprayer (15.0 L)
	Sept. 12	harvest (residues removed)	sickle mower (.9 m) rake
	Sept. 15	deep tillage	
Corn	May 15	cultivation	cultivator
	May 15	band 11-51-0 (.08 t ha^{-1})	press drill
	May 15	band 34-0-0 (.27 t ha^{-1})	jab planter
	May 22	harrow	harrows
	May 22	seed corn (75,000 plants ha^{-1})	jab planter
	June 2	spray Aatrex Plus (5.0 L ha^{-1})	bicycle sprayer
	June 3	topdress 34-0-0 (.27 t ha^{-1})	hand spreader
	June 24	row cultivation	cultivator
	July 24	row cultivation	cultivator
	Sept. 12	harvest (residues removed)	sickle mower-rake
	Sept. 15	deep tillage	cultivator
Alfalfa	June 25	broadcast 11-55-0 (.08 kg ha^{-1})	hand spreader
	June 25	harvest (residues removed)	sickle mower-rake
	Aug. 11	harvest (residues removed)	sickle mower-rake
Fallow	May 15	cultivation	cultivator
	June 24	cultivation	cultivator
	July 24	cultivation	cultivator
	Aug. 25	cultivation	cultivator
	Sept. 15	deep tillage	cultivator

TABLE 2

Field Operations for Leary Sandy Loam Site in 1986

Treatment	Date	Operations (Rate)	Equipment (Size)
Wheat	May 15	cultivation	cultivator
	May 15	broadcast 34-0-0 (.08 t ha^{-1})	hand spreader
	May 15	band 11-51-0 (.27 t ha^{-1})	press drill
	May 15	harrow	harrows
	May 22	seed wheat (.1 t ha^{-1})	press drill
	May 22	harrow	harrows
	June 2	spray Hoe-grass II (3.5 L ha^{-1})	bicycle sprayer
	Sept. 12	harvest (residues removed)	sickle mower-rake
	Sept. 15	deep tillage	cultivator
Corn	May 15	cultivation	cultivator
	May 15	band 11-51-0 (.08 t ha^{-1})	press drill
	May 15	band 34-0-0 (.27 t ha^{-1})	jab seeder
	May 15	harrow	harrows
	May 22	seed corn (75,000 plants ha^{-1})	jab seeder
	May 22	harrow	harrows
	June 11	reseed corn	jab seeder
	June 2	spray Aatrex Plus (5.0 L ha^{-1})	bicycle sprayer
	June 24	row cultivation	cultivator
	July 24	row cultivation	cultivator
	Sept. 12	harvest (residues removed)	sickle mower-rake
	Sept. 15	deep tillage	cultivator
Alfalfa	June 11	weeded	hand
	June 11	broadcast 11-55-0 (.12 t ha^{-1})	hand spreader
	June 24	biomass sampling	quadrat (.25 m^2)
	June 25	harvest (residues removed)	sickle mower-rake
	Aug. 11	harvest (residues removed)	
Fallow	May 15	cultivation	cultivator
	June 24	cultivation	cultivator
	July 24	cultivation	cultivator
	Aug. 25	cultivation	cultivator
	Sept. 15	deep tillage	cultivator

TABLE 3

Field Operations for Gretna Clay Site in 1987

Treatments	Date	Operations (Rate)	Equipment (Size)
Wheat	May 8	cultivation	cultivator
	May 8	band 11-55-0 (.08 t ha^{-1})	press drill
	May 8	broadcast 34-0-0 (.21 t ha^{-1})	hand spreader
	May 8	seed wheat (.1 t ha^{-1})	press drill
	June 9	spray Hoe-grass II(3.5 L ha^{-1})	bicycle sprayer
	Aug. 4	weeded	hand rouging
	Aug. 25	harvest (residue removed)	sickle mower-rake
	Sept. 14	deep tillage	cultivator
Corn	May 8	cultivation	cultivator
	May 8	band 11-55-0 (.08 t ha^{-1})	press drill
	May 8	seed corn (75,000 plants ha^{-1})	jab planter
	May 8	harrow	harrows
	June 6	spray Aatrex Plus (5.0 L ha^{-1})	bicycle sprayer
	June 17	row cultivation	cultivator
	July 7	row cultivation	cultivator
	Aug. 25	harvest (residue removed)	sickle mower-rake
	Sept. 14	deep tillage	cultivator
Alfalfa	May 8	broadcast 11-55-0 (.12 t ha^{-1})	hand spreader
	June 9	harvest (residue removed)	sickle mower-rake
Fallow	May 8	cultivation	cultivator
	June 17	cultivation	cultivator
	July 7	cultivation	cultivator
	Aug. 12	cultivation	cultivator
	Sept. 1	cultivation	cultivator
	Sept. 14	deep tillage	cultivator

TABLE 4

Field Operations for Leary Sandy Loam Site in 1987

Treatment	Date	Operations (Rate)	Equipment (Size)
Wheat	May 8	cultivation	cultivator (2.3 m)
	May 8	broadcast 34-0-0 (.27 t ha^{-1})	hand spreader
	May 8	band 11-55-0 (.08 t ha^{-1})	press drill
	May 8	harrow	harrows
	May 8	seeding wheat (.1 t ha^{-1})	press drill
	June 6	spray Hoe-grass II (3.5 L ha^{-1})	bicycle sprayer
	Aug. 4	weeded	hand rouging
	Aug. 25	harvest (residue removed)	sickle mower-rake
	Sept. 14	deep tillage	cultivator
Corn	May 8	cultivation	cultivator
	May 8	band 11-55-0 (.08 t ha^{-1})	press drill
	May 8	seed corn (75,000 plants ha^{-1})	jab planter
	June 6	spray Aatrex Plus (3.25 L ha^{-1})	bicycle sprayer
	June 17	row cultivation	cultivator
	July 7	row cultivation	cultivator
	Aug. 25	harvest (residues removed)	sickle mower-rake
	Sep. 14	deep tillage	cultivator
Alfalfa	May 8	broadcast 11-55-0 (.12 t ha^{-1})	hand spreader
	June 6	harvest (residues removed)	sickle mower-rake
Fallow	May 8	cultivation	cultivator
	June 17	cultivation	cultivator
	July 7	cultivation	cultivator
	Aug. 12	cultivation	cultivator
	Sept. 1	cultivation	cultivator
	Sep. 14	deep tillage	cultivator

TABLE 5

Field Operations for Ryerson Sandy Clay Loam Site in 1987

Treatments	Date	Operations (Rate)	Equipment (Size)
Wheat (Conventional Tillage)	May 11	cultivation	cultivator
	May 11	broadcast 34-0-0 (.27 t ha^{-1})	hand spreader
	May 11	band 11-55-0 (.08 t ha^{-1})	press drill
	May 11	seed wheat (.1 t ha^{-1})	press drill
	June 5	spray Hoe-grass II(3.5 L ha^{-1})	bicycle sprayer
	Aug. 4	weeded	hand rouging
	Aug. 26	harvest (residue removed)	sickle mower-rake
	Sept. 14	deep tillage	
Wheat (Minimum Tillage)	May 11	cultivation	cultivator
	May 11	broadcast 34-0-0 (.27 t ha^{-1})	hand spreader
	May 11	band 11-55-0 (.08 t ha^{-1})	press drill
	May 11	seed wheat (.1 t ha^{-1})	press drill
	June 5	spray Hoe-grass II(1.1 L ha^{-1})	bicycle sprayer
	Aug. 4	weeded	hand rouging
	Aug. 26	harvest (residue removed)	sickle mower-rake
Corn	May 11	cultivation	cultivator
	May 11	band 11-55-0 (.08 t ha^{-1})	press drill
	May 11	harrow	harrows
	May 11	seeding (75,000 plants ha^{-1})	jab planter
	June 5	spray Aatrex plus (3.5 L ha^{-1})	bicycle sprayer
	June 18	row cultivation	cultivator
	July 8	row cultivation	cultivator
	Aug. 4	weeded	hand rouging
	Sept. 29	harvest (residue removed)	sickle mower-rake
	Sept. 29	deep tillage	cultivator
Alfalfa	May 11	weeded	hand rouging
	May 11	broadcast 34-0-0 (.08 t ha^{-1})	hand spreader
	June 6	harvest (residues removed)	sickle mower
Fallow	May 11	cultivation	cultivator
	June 18	cultivation	cultivator
	July 8	cultivation	cultivator
	Aug. 13	cultivation	cultivator
	Sept. 2	cultivation	cultivator
	Sept. 29	deep tillage	cultivator

TABLE 6

Field Operations for Carroll Clay Loam Site in 1987

Treatment	Date	Operations (Rate)	Equipment (size)
Wheat (Conventional Tillage)	May 12	cultivation	cultivator
	May 12	band 11-55-0 (.08 t ha^{-1})	press drill
	May 12	harrow	harrow
	May 12	seed wheat (.1 t ha^{-1})	press drill
	June 5	spray Hoe-grass II (3.5 L ha^{-1})	bicycle sprayer
	July 8	weeded	hand rouging
	Aug. 26	harvest (residue removed)	sickle mower
	Sept. 15	deep tillage	cultivator
Wheat (Minimum Tillage)	May 12	cultivation	cultivator
	May 12	band 11-55-0 (.08 t ha^{-1})	press drill
	May 12	harrow	harrow
	May 12	seed wheat (.1 t ha^{-1})	press drill
	June 5	spray Hoe-grass II (3.5 L ha^{-1})	bicycle sprayer
	July 8	weeded	hand rouging
	Aug. 26	harvest (residues removed)	sickle mower-rake
Corn	May 12	cultivation	cultivator
	May 12	band 11-55-0 (.08 t ha^{-1})	press drill
	May 12	harrow	harrows
	May 12	seed corn (75,000 plants ha^{-1})	jab seeder
	June 5	spray Aaltrex plus(3.25 L ha^{-1})	bicycle sprayer
	June 18	row cultivation	cultivator
	July 8	row cultivation	cultivator
	Sept. 29	harvest (residues removed)	sickle mower-rake
	Sept. 29	deep tillage	cultivator
Alfalfa (Estab.)	May 12	cultivation	cultivator
	May 12	seed wheat (.05 t ha^{-1})	press drill
	May 12	band 11-55-0 (.08 t ha^{-1})	press drill
	May 12	seed alfalfa (10 kg ha^{-1})	hand spreader
	May 12	harrow	harrows
	June 5	spray Embutox E (3.0 L ha^{-1})	bicycle sprayer
	Aug. 2	weeded	hand rouging
	Aug. 21	wheat harvested	sickle mower
Fallow	May 12	cultivation	cultivator
	June 18	cultivation	cultivator
	July 8	cultivation	cultivator
	Aug. 13	cultivation	cultivator
	Sept. 2	cultivation	cultivator
	Sept. 29	deep tillage	cultivator

TABLE 7

Comparative System for Modified Crop Growth Stage Periods

Wischmeier and Smith (1960)	Modified System
Period F (rough fallow)-Ploughing to secondary tillage.	Period W (Winter)-last fall tillage to spring tillage.
Period SB (Seedbed)-secondary tillage until the crop has developed 10% canopy cover.	Period SB (Seedbed) -first spring tillage until the crop has developed 10% canopy cover.
Period 1. (Establishment) -end of SB until the crop has developed 50% canopy cover.	Period 1. (Establishment) -end of SB until the crop has developed 50% canopy cover.
Period 2. (Development) -end of period 1 until canopy cover reaches 75%.	Period 2. (Development) -end of period 1 until canopy cover reaches 75%.
Period 3. (Maturing Crop) -end of period 2 until harvest.	Period 3. (Maturing Crop) -end of period 2 until crop harvest.
Period 4. (Residue or Stubble) -harvest to ploughing or new seeding.	Period 4.(Residue or Stubble) -harvest to fall tillage.

3.4.2 Surface Runoff and Soil Loss Measurements

Surface runoff and sediment sampling was done using a Coshocton Sampling System (Figure 3). Runoff and sediment flowed into a trough at the downslope end of each plot, and through a 15 cm high flume which directed runoff water onto a rotating Coshocton wheel. The sampling wheel was 30 cm in diameter and had on its surface an elevated slot along the radius of the wheel. Since the area of the slot was 1% of the surface area of the wheel, it sampled 1% of the total surface runoff and sediment per every revolution. The 1% subsamples were collected in a pan located directly beneath the sampling wheel. Sampling wheels at the

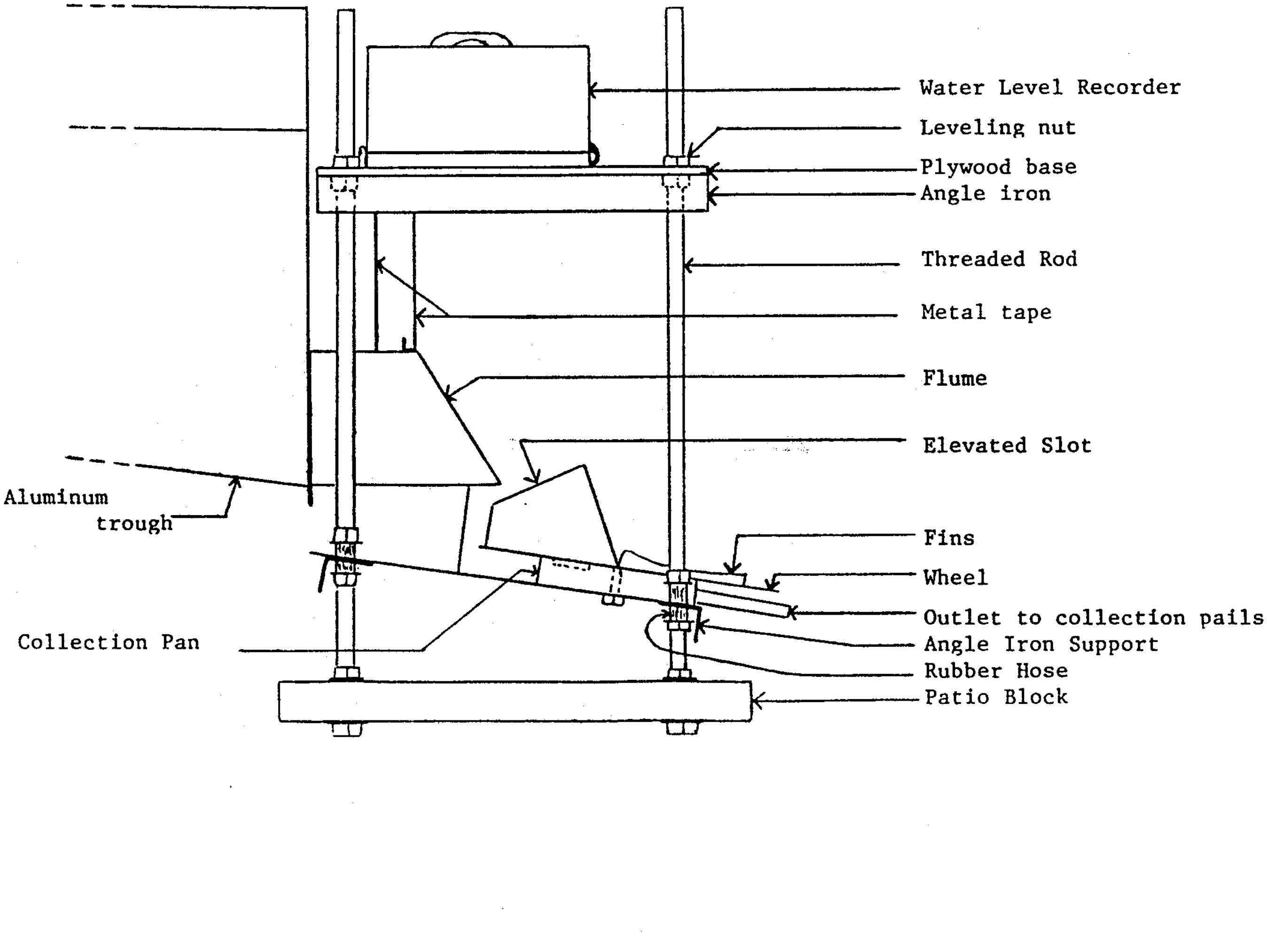


Figure 3: Side view of Coshocton Sampler, Water Level Recorder and Lower Trough end

Source, after Pauls (1987).

Gretna clay and Leary sandy loam sites were finned so that they were propelled by the runoff, and the wheels at the Ryerson sandy clay loam and Carroll clay loam sites were rotated by electric motors. The switch for operating the electric motors was activated by a float when about 6.25 mm of rainfall accumulated in a collection float chamber which was fed by a collecting funnel. Runoff and sediment sampled by the wheels were directed through tubing into removeable sample collection containers. Sample collection containers were exchanged after each rainstorm, and any soil deposited in the trough was collected. Collected samples were oven dried and weighed, and appropriate calculations were made to determine the total soil loss from various crop-treatments for specific rainstorm events.

Stilling wells, attached to the side of the flume, in which a float from a water level recorder was housed, made it possible for peak surface runoff volume and flow rates to be measured. The water level recorders and flumes were calibrated both in the laboratory and in the field. The readings obtained during the calibration included runoff flow rates in liters/second and the related number of divisions obtained on a runoff flow chart. Regression curves were prepared for different runoff recorders and were included in the computer programme used in calculating the surface runoff volume and flow rates. This was done by deriving the following equation for each water level recorder:

$$\mathrm{RATE} = b_0 + b_1(\mathrm{READ}) + b_2(\mathrm{READ})^2 \tag{3.1}$$

where: RATE = rate of discharge through the flume ($\mathrm{L\ s^{-1}}$)

READ = water level recorder reading (from chart)

b_0 = intercept for curve

b_1 and b_2 are regression coefficients for (READ)and $(\mathrm{READ})^2$, respectively.

An example of a typical calibration curve is provided in Figure 4. The surface runoff flow rates were correlated with total soil loss from each crop-management treatment for specific rainstorms.

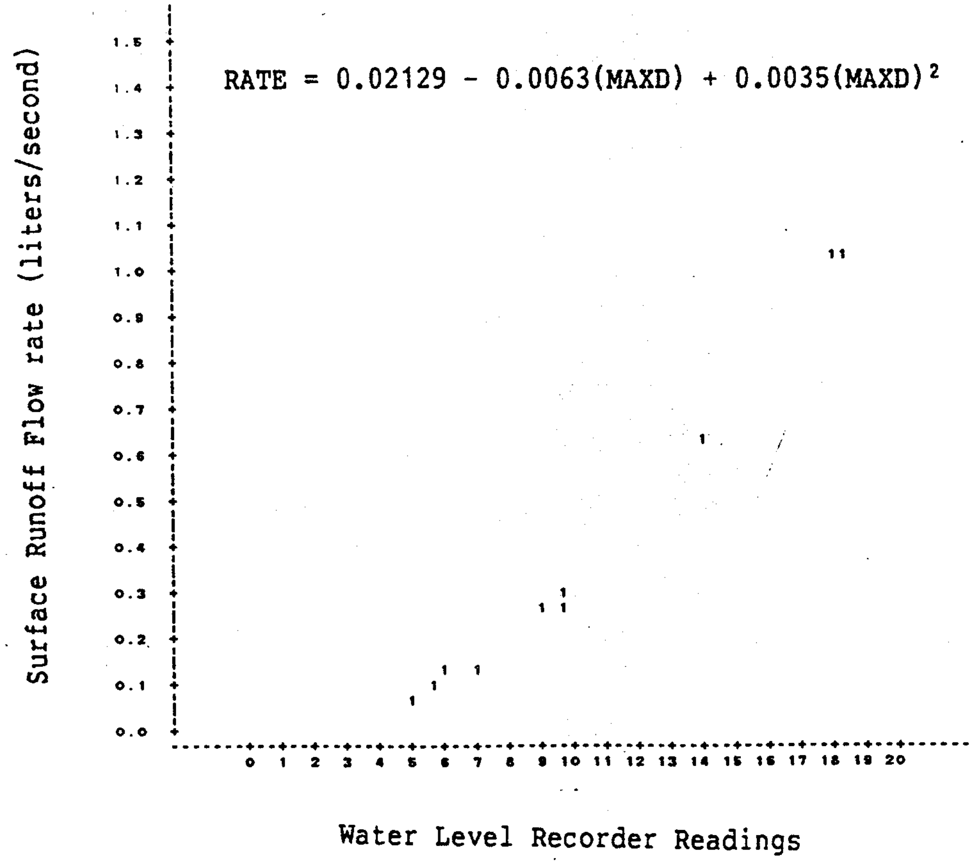


Figure 4: Calibration Curve for Surface Runoff Recorder (Carroll Clay Loam Minimum Tillage Wheat)

3.4.3 Rainfall Total and Intensity Measurements

Tipping bucket and standard rain gauges were installed a short distance from the plots at each site. Data on total amount and intensity of rainfall were extracted from the tipping bucket rainfall charts, and were used to calculate the rainfall erosivity (R) factor values. Total storm rainfall obtained was compared to that measured by the standard rain gauge. When a large difference occurred between the two readings, due to failure of the tipping bucket rain gauge measuring system, rainfall intensity data for this gauge from a nearby weather station was used. This problem was experienced only once for Gretna clay site in 1986.

R factor values for specific rainstorms were calculated based on the relationship between Kinetic Energy (KE) and rainfall intensity (I_{30}). To calculate R values required an analysis of drop-size distribution of rainfall. Laws and Parsons (1943) showed that drop-size characteristics vary with intensity of rainfall. Based on their work, Wischmeier and Smith (1958) developed the equation (in metric units):

$$KE = 11.87 + 8.73 \log_{10} I \qquad (3.2)$$

where: KE = kinetic energy ($J\ m^{-2}\ mm^{-1}$)

I = rainfall intensity ($mm\ h^{-1}$)

The equation was derived from equation 2.7 page 23, since the data was collected in metric units ($mm\ h^{-1}$, $t\ ha^{-1}$ and m) and the calculated R factor values were expected to be obtained in $MJ\ mm\ ha^{-1}\ h^{-1}$. The KE values were obtained for all rainstorms whose I values were equal or less than 76 $mm\ h^{-1}$ (Wischmeier and Smith 1978). The maximum KE value obtained for any rainstorm was given as 28.3 $MJ\ mm\ ha^{-1}\ h^{-1}$. Therefore, KE values for rainstorms with I values greater than 76 mm h^{-1} were regarded as 28.3 MJ mm ha^{-1} h^{-1}. To compute the KE of a rainstorm, the trace of the rainfall from the chart of a tipping bucket rain gauge was analyzed and the storm divided into small time increments of uniform intensity. For each time period, the KE of the rainstorm at that intensity was calculated from equation 3.2. This multiplied by the amount of rain received for each specific time period gave the KE for that period. The sum of the calculated KE values for all the time periods gave the total KE for a specific rainstorm.

The following example (Table 8) illustrates how KE values were calculated using the Wischmeier and Smith (1958) equation (equation 3.2).

TABLE 8

Sample Calculation of Rainfall Erosivity (R) for Gretna Clay Site, 1986

Time From Start (min)	Time Elapsed (mm)	Rainfall (mm)	Intensity (mm h^{-1})	Kinetic Energy (J m^{-2} mm^{-1})	Total Kinetic Energy (col. 3 x col. 5)
0 - 40	40	0.2	0.30	7.48	1.50
41 - 96	55	5.4	5.89	18.98	102.52
97 - 107	10	1.4	8.40	20.36	28.50
108 - 138	30	2.8	5.60	18.79	52.61
139 - 149	10	5.8	34.80	25.85	149.93
150 - 155	5	5.2	62.40	28.11	146.16
156 - 171	15	1.2	4.80	18.19	21.83
172 - 207	35	1.6	2.74	16.03	25.65
208 - 233	25	0.4	0.96	11.97	4.79
234 - 239	5	0.6	7.20	19.76	11.86
Total Storm		24.6			545.33

To calculate R values using Wischmeier index (I_{30}):

maximum 30-min rainfall = 5.8 mm + 5.2 mm + 1.2 mm
= 12.4 mm
maximum 30-min intensity = 12.4 x 2
= 24.8 mm h^{-1}
total kinetic energy = total of column 6
= 545.33 J m^{-2}
EI_{30} = 545.33 x 24.8
= 13,524.18 J m^{-2} mm h^{-1}
= 13,524.18 J m^{-2} mm h^{-1} x 10^{4} x 10^{-6}
= 135.24 MJ mm ha^{-1} h^{-1}

Wischmeier (1959) found that the measureable rainfall characteristics most closely related to soil loss were the total KE and the maximum 30 minute intensity (I_{30}) of a rainstorm. Therefore, total rainfall erosivity value was obtained as a product of total KE and the maximum I_{30} Sample data and the necessary calculations tabulated in Table 8 are for Gretna Clay rainstorm event for September 25, 1986.

3.4.4 Antecedent Soil Moisture Measurements

Antecedent soil moisture samples were taken from randomly spaced points on the upper, middle and lower slope positions of each plot at depths of 0.0-5.0 and 5.0-15.0 cm. The measurements were done on a weekly basis and the soil moisture content was determined in the laboratory using the gravimetric method. Average soil moisture content for each depth on each treatment was calculated and the data obtained was used to determine the influence of antecedent soil moisture on the measured soil losses.

3.4.5 Soil Physical Properties Measurements

Soil physical analysis was carried out so as to determine those properties which were used to estimate values of the soil erodibility K factor using the USLE Nomograph Equation (NE) and the Modified Young and Mutchler Equation (MYME). Nine soil samples were taken in a grid pattern across the plots on each site up to a 15 cm depth. The soil physical properties determined from each of these samples included particle size distribution, percent organic matter, aggregate index and dispersion ratio. Bulk density was determined separately using different samples, while the structure code, and permeability class, were estimated using soil survey data. Percent montmorillonite clay in the total soil was estimated using specific surfaces and soil texture analysis data. The analysis for different soil physical properties was carried out as follows:

3.4.5.1 Particle Size Analysis

Percent sand, silt and clay were determined using the standard pipette sampling method (Kilmer and Alexander 1949) for mechanical analysis. The components of the sand fraction were determined using sieves on a mechanical shaker. Particle size fractions were determined according to the Canadian Classification System (Canada Soil Survey Committee 1978).

3.4.5.2 Organic Matter Content

Percent organic matter content was determined using the Walkley-Black (1934) chromic acid oxidation method, based on the estimation of organic C. Organic C was oxidized with an excess of $K_2Cr_2O_7$ of known concentration in presence of conc. H_2SO_4 in mixture. An automatic titrator was used to back titrate excess $K_2Cr_2O_7$ with $FeSO_4$ and appropriate calculations were used to obtain the organic matter percentage values.

3.4.5.3 Aggregate Index

Two hundred grams of soil were sieved through 9.5 mm and 2.0 mm sieves for 15 minutes on a mechanical shaker. The weight of the 2.0 to 9.5 mm sample fraction was divided by the weight of the rest of the sample fraction to obtain the aggregate index ratio as:

$$AI = \frac{x}{200 - x} \tag{3.3}$$

where: AI = aggregate index ratio
x = the 2.0 to 9.5 mm sample fraction

3.4.5.4 Dispersion Ratio

The procedure described by Middleton (1930) was modified and used to determine the 50 micrometers suspension percentage (Pauls 1987). A 500 mL and 5.1 cm diameter acrylic cylinder was filled to a volume of 400 mL with distilled water at room temperature and an equivalent of 10 g of oven dry soil was added. The cylinder was stoppered and turned end over end for 20 cycles. The cylinder was then placed on a bench and sampled with a 10 mL automatic pippete at a depth of 10 cm after the appropriate settling time according to Stokes' Law for particles greater than 50 micrometers. The settling time was determined using the prevailing water temperature. In this case the water temperature was 21°C and the settling time used was 4 min 33 s. Percent silt and clay (<50 micrometers) was determined using the standard pipette sampling method (Kilmer and Alexander 1949).

Dispersion ratio was used as a measure of the aggregation of the sample and represented the percentage of particles smaller than 50 micrometers in the aggregated sample divided by the percentage of particles of the same size in the dispersed sample. The lower the ratio the greater is the percentage aggregation of silt and clay. The dispersion ratio was calculated using the formula:

$$\text{Dispersion Ratio} = \frac{\text{Suspension Percentage}}{(\%\text{ silt} + \%\text{ clay})} \tag{3.4}$$

3.4.5.5 Bulk Density

Field determination of bulk density was done using a 25 cm^3 core sampler. Collected soil core samples were oven dried and weighed. Four samples were collected on each sampling point at depths of 0.0 to 7.5 cm, and 7.5 to 15.0 cm in a grid pattern close to the four corners and along the middle of the experimental site (Figure 5).

Soil bulk density was calculated using the formula:

$$\text{Bulk Density} = \frac{\text{mass dry soil}}{\text{bulk volume soil}} \tag{3.5}$$

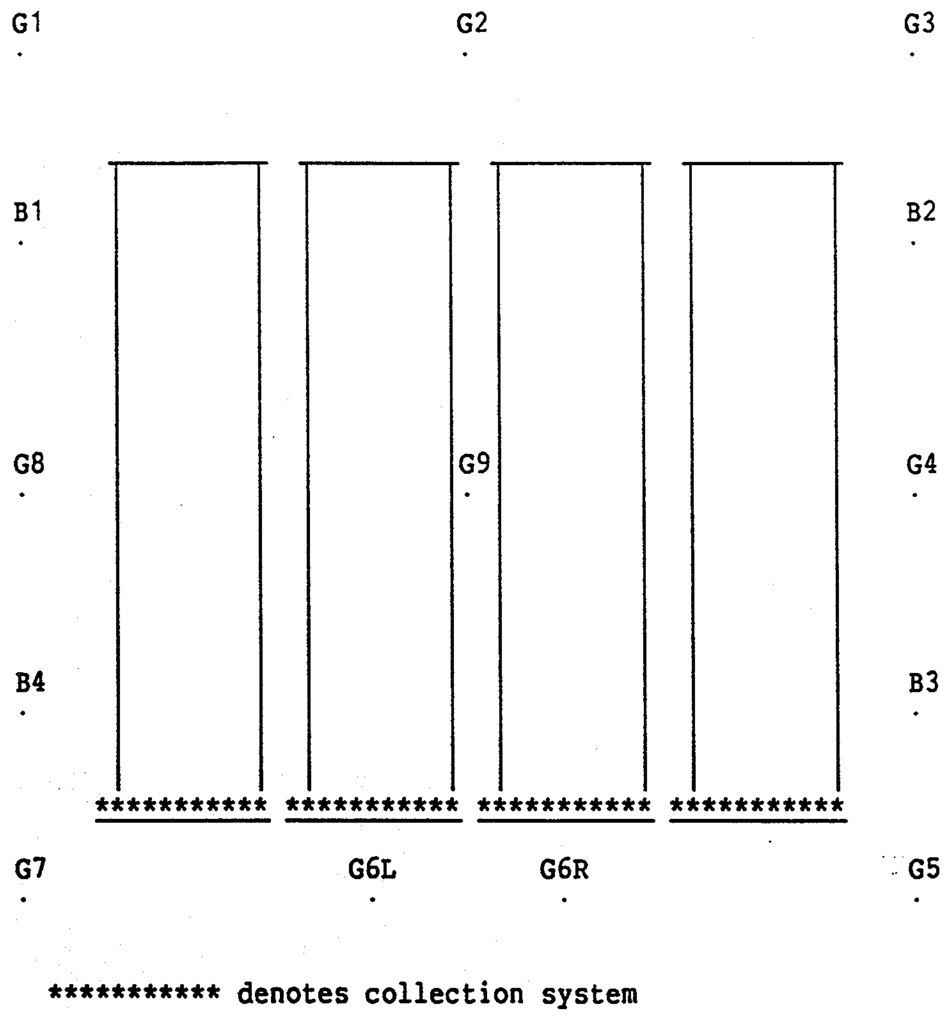


Figure 5: Experimental Site Diagram for Bulk Density Sampling Grid Pattern

Source, After Pauls (1987)

3.4.5.6 Structure and Permeability

Soil surface structure and profile permeability codes were estimated using the USLE nomograph (Wischmeier and Smith 1978), soil survey reports, field observations and consultation with soil surveyors (Langman, Manitoba Soil Survey 1988). Structure code was determined based on the classification:

1 - very fine granular
2 - fine granular
3 - coarse granular
4 - blocky, platy, or massive

Permeability class was determined based on the swelling potential, massive structure when wet and carbonation of aggregates of different soils. For dry clay soil no consideration was given to any large cracks that were likely to cause less soil loss due to high infiltration rates and trapping of surface runoff and sediment during the early part of a rainstorm. Different permeability classes were obtained as:

6 - very slow
5 - slow
4 - slow to moderate
3 - moderate
2 - moderate to rapid
1 - rapid

3.4.5.7 Percent Montmorillonite

Soils with a high montmorillonite clay content tend to be better aggregated than those in which other clay minerals predominate (Young and Mutchler 1977). Determination of percent montmorillonite in the clay fraction usually involves complex methods of x-ray diffraction, and specific surface area measurements. There are difficulties involved in carrying out the procedure, and the resulting value is an estimation with large confidence limits. Percent montmorillonite in clay fraction was estimated using estimated specific surface area measurements and soil texture analysis (Young and Onstad 1976), since this was the method used for estimating percent montmorillonite content in clay fraction when the Young and Mutchler Equation (YME) was being developed (Young and Mutchler 1977). The equation for the relationship used was expressed as:

$$SS = 0.116(S) + 0.185(Si) + 0.330(C) + 0.107(M)(C) \qquad (3.6)$$

$$(r^2 = 0.944), (n = 56),$$

$$(\text{standard error of estimate} = 16\ m^2\ g^{-1})$$

where: SS = specific surface area, $m^2\ g^{-1}$,

S = percent sand (>50 micrometers),

Si = percent silt (2 - 50 micrometers),

C = percent clay (<2 micrometers),

M = percent montmorillonite in clay fraction.

Specific surface area measurements were estimated using the organic matter content of soil and the -15 bar soil moisture content (Young and Onstad 1976). The -15 bar soil moisture content was measured using a pressure membrane apparatus. The Young and Onstad equation for the relationship used for estimating specific surface area was expressed as:

$$SS = -2.36 + 7.96(W) - 4.49(OM) \tag{3.7}$$

$(r^2 = 0.86)$, $(n = 67)$

(standard error of estimate = 8.43 $m^2\ g^{-1}$)

where: SS = specific surface of matrix soil ($m^2\ g^{-1}$)

W = percent soil moisture content by weight of matrix soil at -15 bar pore pressure

OM = percent organic matter

Using equation 3.6, the specific surface area of each soil was calculated. The value obtained was then substituted in equation 3.5 along with soil texture data and then solved for percent montmorillonite in clay fraction. The value obtained was then used to calculate the montmorillonite content as a percentage of total soil.

3.5 DATA ANALYSIS FOR THE MEASURED K AND C FACTOR VALUES

The field experimental conditions and the standard unit plots used eliminated some of the factor values in the USLE, simplifying the calculations for the measured K and C factor values. The LS factor was numerically equal to one under the standard experimental conditions, i.e. 22.3 m long and 4.6 m wide, established on the 9% uniform slope. The P factor was also numerically equal to one under the upslope-downslope cultivation practice used in the plots to eliminate the soil conservation effect. The C factor under the summerfallow conditions was also equal to one.

The USLE, after deleting the LS, P, and C factors, therefore, became:

$$A = R\,K \qquad (3.8)$$

where:

A = measured soil loss from summerfallow

R = measured rainfall erosivity

K = soil erodibility factor

The measured K ($t\ h\ MJ^{-1}\ mm^{-1}$) factor values were calculated as:

$$K = \frac{A\ (\text{Soil loss from summerfallow})}{R\ (\text{Rainfall erosivity})} \qquad (3.9)$$

$$= \frac{A\ (t\ ha^{-1})}{R\ (\ MJ\ mm\ ha^{-1}\ h^{-1})}$$

$$= \quad t\ h\ MJ^{-1}\ mm^{-1}\ \ (\text{dimensions})$$

The measured C (dimensionless) factor values (soil loss ratios) for different crop-management treatments were calculated as:

$$C = \frac{(\text{soil loss from cropped plot})}{(\text{soil loss from summerfallow plot})} \qquad (3.10)$$

The measured K values were calculated using total rainfall erosivity values and soil loss obtained for all rainstorms combined for each growing season. Wischmeier (1976) stated that "if USLE is applied to a specific rainstorm event it will estimate the average soil loss for numerous occurrences of that event on that field and in that crop stage period. The soil loss in any one of these events may differ widely from this average in either direction as influenced by antecedent field conditions." The measured K values were compared with the K values estimated using the USLE nomograph equation (NE) and the Modified Young and Mutchler Equation (MYME).

The NE as previously described in the literature review has the form:

$$100K = 2.1M^{1.14} (10^{-4}) (12-a) + 3.25(b-2) + 2.5(c-3) \qquad (3.11)$$

where: M = (percent silt + percent very fine sand) x (percent silt + percent sand)

a = percent organic matter

b = structure code (1 to 4)

c = profile permeability class (1 to 6)

The MYME as previously described in the literature review has the form:

$$K = -0.146 + 0.33A - 0.0058B + 0.225C + 0.0019D - 0.0035E \qquad (3.12)$$

$$(R^2 = 0.89)$$

where: K = soil erodibility index

A = aggregate index ratio

B = percent montmorillonite content in soil

C = soil bulk density ($g\ cm^{-3}$)

D = percent silt plus percent very fine sand

E = dispersion ratio (%)

Values for the crop-management factor (C) were represented by measured soil loss ratios calculated using total soil losses obtained for different crop growth stages for the cropped treatments and summerfallow. Soil loss ratios obtained for similar stages of development for different crop-management treatments were grouped for comparison. The measured soil loss ratios were compared with those obtained using the USLE soil loss ratios tables (Wischmeier and Smith 1978).

3.6 STUDY LIMITATIONS

The study experimental sites were scattered in a large area which made it difficult to complete data collection operation in one day. The collection of surface runoff and sediment samples was done after every rainstorm event that caused soil loss. This was to be done before the occurrence of the next rainstorm. The operation was done by a single sampling team. As the study area expands when more sites are established it may become necessary to operate with more than one field team. This will make it possible to complete the sampling on a real time basis.

Antecedent soil moisture data was collected on weekly basis and most rainstorms events occurred a few days after this was done. Therefore, the data obtained was not always representative of the actual soil moisture present immediately before the onset of the rainstorm. Actual soil moisture data can only be obtained by resident field teams. It may be necessary to consider this aspect so as to ensure accurate interpretation of the interaction between rainfall erosivity and antecedent soil moisture on soil loss. Also, moisture samples were weighed a few hours after collection and some moisture may have been lost before this was done. Therefore, arrangements should be sought to weigh these samples at the sampling site so as to prevent significant moisture losses before weighing.

The crop management treatments for the study were not replicated. This made it difficult to detect the variability of soil loss due to experimental error. The high initial cost of site installation made it impossible to replicate the treatments.

Defoliation of some of the crop-management treatments by wildlife prevented the expected crop stand development in some of the sites. Therefore, it may be necessary to fence the affected sites so as to prevent this problem in future.

Chapter IV

RESULTS AND DISCUSSION

The results discussed are for Gretna clay, Leary sandy loam, Ryerson sandy clay loam and Carroll clay loam soil types. Gretna clay and Leary sandy loam sites were sampled for the 1986 and the 1987 growing seasons. Ryerson sandy clay loam and Carroll clay loam sites were sampled for the 1987 growing season. Data collected from the four sites included total rainfall and duration, soil loss, surface runoff volume and peak flow rates, antecedent soil moisture, crop and mulch cover, crop biomass and grain yields, field operations and soil physical properties. Data analysis was done using computer programmes prepared for different data sets (Pauls 1987). Soil loss, surface runoff, and soil moisture data programmes were modified to include data analysis for the mimimum tillage treatment, added to Ryerson sandy clay loam and Carroll clay loam sites (Appendix M).

4.1 SOIL LOSS

The results for measured soil losses for different crop-management treatments are given in Tables 9, 10 and 11. Soil loss rates from various treatments were extremely variable among both treatments and soil types. Total soil losses for Gretna clay and Leary sandy loam soils for 1986 growing season exceeded the tolerable soil loss limit of 11.00 t ha^{-1} $year^{-1}$ for most of the treatments except the alfalfa treatment for

TABLE 9

Rainfall Characteristics, Antecedent Soil Moisture and Soil Losses for Gretna Clay

Date	Antecedent Soil Moisture at depth (cm) (% by weight)								Total Rainfall (mm)	Maximum 30 min Intensity (mm/h)	Rainfall Erosivity Factor (R)	Soil loss (t/ha) from			
	alfalfa		wheat		corn		fallow								
month, day	0-5	5-15	0-5	5-15	0-5	5-15	0-5	5-15				alfalfa	wheat	corn	fallow
1986 Growing Season															
5 6	-	-	-	-	-	-	-	-	55.2	16.7	392.31	12.18	44.55	37.81	62.08
6 20	17.3	17.2	23.4	24.0	21.7	22.9	20.8	22.3	21.6	14.4	142.62	0.03	0.12	0.15	0.10
7 3	17.1	17.0	22.3	22.3	21.0	23.7	22.3	22.5	27.0	19.0	254.01	0.06	4.82	7.41	5.78
7 10	17.8	16.5	22.8	24.4	23.7	25.7	24.0	24.9	22.0	3.9	28.94	0.08	2.85	3.37	1.67
9 25	11.1	12.6	10.8	14.6	10.6	16.8	17.6	20.3	24.6	12.4	135.24	0.01	0.05	0.00	0.00
9 29	25.0	21.3	24.6	18.3	24.3	18.6	28.1	21.7	13.0	4.0	16.23	0.00	0.20	0.01	0.01
Annual Total									163.4		969.35	12.36	52.59	48.75	69.64
1987 Growing Season															
7 3	12.4	14.8	17.0	17.5	13.7	21.0	26.4	22.7	13.0	7.6	18.66	-	0.06	0.04	0.09
7 10	13.9	13.4	15.6	16.7	18.8	20.3	19.6	23.6	55.8	31.4	392.23	0.01	0.21	0.04	0.11
7 20	28.5	26.7	33.3	26.9	31.7	24.8	32.3	27.0	42.2	10.3	77.33	0.01	0.08	0.04	3.78
7 24	28.1	27.9	26.1	19.0	27.9	28.1	28.3	28.3	13.2	10.0	26.73	-	0.05	0.05	1.73
8 14	15.8	18.5	18.1	22.7	19.4	21.2	22.9	22.9	73.8	80.0	1422.67	0.20	0.48	4.41	50.74
9 29	17.3	16.0	23.4	23.3	20.7	19.9	20.9	25.2	15.8	6.7	16.69	-	0.01	0.02	0.06
Annual total									213.8		1954.31	0.22	0.89	4.60	56.51

TABLE 10

Rainfall Characteristics, Antecedent Soil Moisture and Soil Losses for Leary Sandy Loam

Date month, day	Antecedent Soil Moisture at depth (cm) (% by weight)								Total Rainfall (mm)	Maximum 30 min Intensity (mm/h)	Rainfall Erosivity Factor R (R)	Soil loss (t/ha) from			
	alfalfa		wheat		corn		fallow					alfalfa	wheat	corn	fallow
	0-5	5-15	0-5	5-15	0-5	5-15	0-5	5-15							
1986 Growing Season															
4 30	-	-	-	-	-	-	-	-	19.0	2.4	13.77	0.01	0.00	0.01	0.00
5 6	-	-	-	-	-	-	-	-	54.2	10.87	214.00	8.10	10.65	7.87	7.37
6 14	5.9	6.4	8.2	15.9	9.9	15.8	8.0	13.0	42.4	18.00	326.15	0.15	0.47	1.68	0.62
6 20	10.4	10.8	9.8	12.2	10.2	13.1	9.2	12.8	21.2	14.40	140.70	0.12	8.74	8.94	8.88
7 3	13.8	14.5	8.9	11.6	14.0	14.9	8.9	13.3	12.0	12.00	83.15	0.01	3.80	0.76	0.25
7 10	7.3	8.7	6.1	8.0	9.8	11.9	9.2	11.7	58.0	5.00	99.25	0.01	1.73	0.68	0.33
9 25	7.5	6.7	7.7	8.5	9.0	9.5	8.8	11.2	24.2	5.20	49.58	0.01	1.05	2.38	0.22
9 29	13.0	11.9	11.8	12.7	12.4	12.3	15.5	13.1	19.3	2.40	14.83	-	0.06	-	0.02
Annual Total									250.3		941.43	8.41	26.49	22.32	17.69
1987 Growing Season															
5 21	6.4	6.9	9.0	14.3	11.4	13.1	9.8	12.7	27.4	3.1	12.62	-	0.07	0.08	0.03
6 24	5.5	5.1	5.6	6.6	9.1	12.2	9.5	13.1	22.4	11.2	44.90	-	0.04	0.05	0.07
7 3	7.9	8.2	8.5	8.2	10.0	10.9	10.1	12.2	18.8	10.3	38.13	-	0.06	0.04	0.05
7 10	6.4	5.8	6.9	6.9	10.8	9.4	10.0	11.8	16.0	8.0	21.02	0.00	0.01	0.01	0.01
7 20	9.8	9.1	9.4	10.6	11.6	11.6	11.4	12.4	51.4	14.4	140.30	-	0.01	0.03	0.03
8 14	11.7	6.5	12.1	8.4	13.1	7.8	12.9	10.6	96.8	48.3	1006.08	0.03	0.57	4.17	83.45
9 29	14.4.	6.9.	8.5	11.5	6.5	8.7	9.0	12.1	40.2	12.0	89.41	-	0.01	0.02	0.02
Annual Total									272.8		1352.36	0.03	0.77	4.41	83.66

TABLE 11

Rainfall Characteristics, Antecedent Soil Moisture and Soil Loss, for Ryerson Sandy Clay and Carroll Clay Loams

Date	Antecedent Soil Moisture at depth (cm) (% by weight)										Total Rainfall	Maximum 30 min Intensity	Rainfall Erosivity Factor	Soil loss (t/ha) from				
month,	alfalfa		conv. wheat		min. wheat		corn		fallow		(mm)	(mm/h)	(R)	alfalfa	conv. wheat	min. wheat	corn	fallow
day	0-5	5-15	0-5	5-15	0-5	5-15	0-5	5-15	0-5	5-15								
Ryerson Sandy Clay Loam, 1987																		
6 2	15.1	12.3	30.8	13.8	23.0	21.3	20.5	19.4	20.6	21.4	27.6	31.2	211.63	0.04	0.08	0.09	0.09	0.06
6 24	10.0	11.0	10.8	13.5	14.1	16.6	15.9	21.0	14.5	19.5	25.1	20.8	100.37	0.06	0.08	0.07	0.04	0.03
7 8	14.5	11.2	16.0	13.2	15.4	11.6	18.7	18.1	17.6	19.9	34.8	30.0	232.48	0.03	0.04	0.04	0.04	0.05
7 10	17.2	13.9	17.2	13.9	17.7	16.8	19.8	18.9	29.9	21.7	27.8	8.0	42.60	0.01	0.02	0.03	0.02	0.02
7 20	15.3	15.1	14.4	16.8	16.9	18.5	18.3	20.8	16.6	21.8	68.4	20.8	275.47	0.00	0.01	0.01	0.01	0.01
7 31	11.9	12.8	11.6	14.5	11.4	16.9	15.3	16.9	17.2	19.3	37.5	8.8	62.92	-	0.01	0.01	0.01	0.01
8 4	27.9	22.9	25.0	23.7	28.3	27.7	23.4	24.0	27.0	28.1	37.8	69.6	722.23	0.00	2.28	0.05	0.60	0.39
8 14	10.1	11.1	12.4	14.9	11.8	16.2	12.0	15.9	15.4	19.8	119.4	52.0	1429.01	0.15	0.79	0.97	12.27	14.73
Annual Total											378.4		3076.56	0.29	3.27	1.27	13.08	15.31
Carroll Clay Loam, 1987																		
6 3	23.5	26.4	22.3	25.0	22.2	26.0	21.7	23.0	22.5	27.5	18.6	22.8	95.74	0.01	0.02	0.03	0.02	0.02
7 14	13.0	15.9	16.3	15.4	12.4	15.3	17.1	22.0	19.1	25.2	22.0	13.2	56.57	0.01	0.01	0.01	0.01	0.01
7 20	31.3	22.4	31.5	21.9	30.1	20.2	36.3	26.6	34.6	29.2	84.0	10.0	155.85	0.02	0.01	0.02	0.02	0.03
7 31	12.5	17.8	13.9	17.9	15.4	18.7	15.6	22.1	18.2	26.5	29.0	9.3	52.70	0.01	0.00	0.01	0.01	0.01
8 12	16.7	18.5	13.6	15.8	14.4	15.5	18.1	23.3	19.7	27.6	35.6	27.2	227.10	0.09	0.08	0.06	0.55	0.22
8 14	24.5	17.3	25.2	18.0	25.0	21.0	24.0	23.2	25.2	27.4	126.6	24.6	715.22	0.04	0.43	0.21	0.12	0.32
Annual Total											315.8		1303.18	0.18	0.55	0.34	0.73	0.61

Leary sandy loam. Total soil loss for summerfallow treatment for Gretna clay, Leary sandy loam and Ryerson sandy clay loam for the 1987 growing season exceeded the tolerable soil loss limit. The soil loss variation sequence pattern among the treatments was expected to be: loss from summerfallow > loss from conventional tillage corn > loss from conventional tillage wheat > loss from minimum tillage wheat > loss from alfalfa. Soil loss from the summerfallow treatment did not conform to this pattern for most of the rainstorm events, since the losses from wheat and corn were often greater than those from summerfallow. This mainly occurred from rainstorms which were intermediate in erosivity, i.e. rainstorms in which the amount and intensity of rainfall were moderate. In these instances there may have been a reduction of surface runoff by high infiltration rates and ponding on the summerfallow plot. This could have been influenced by antecedent soil moisture content and soil surface roughness resulting from cultivation. Also, the reduced soil loss from summerfallow could have resulted from failure of surface runoff and sediment sampling system, possibly due to stuck bearings and sedimentation on the Coshocton wheel. Similar problems were observed by Pauls (1987).

For heavy rainstorms, soil losses from the summerfallow treatment were higher than those of all the cropped treatments. Also, the effect of crop cover on soil loss variability among different treatments adhered well to the expected pattern of soil loss sequence. The heavy rainstorm of August 14, 1987 provided a good example for this effect for Gretna clay, Leary sandy loam and Ryerson sandy clay loam soil types. The summerfallow treatment represented a soil surface condition of maximum susceptibility to erosion, due to the absence of a protective ground surface cover. Therefore, soil loss from this treatment was expected to be the highest among the various treatments.

There were cases where soil losses in the cropped treatments were high, due to poor crop stand development. This occurred during the 1986 growing season. For example, the wheat and corn plots were reseeded during the early growth stage for Leary sandy loam, due to poor germination. This resulted in irregular stand development for these treatments. Also, crop stand defoliation by wildlife for both treatments occurred during mid-seasons of 1986 and 1987 which reduced the degree of crop cover development. Soil surface trampling by hooved animals could have contributed to the soil detachment process by introducing loose soil. Also, channelized flow due to the effect of ridging along the corn rows resulting from cultivation could have contributed to high soil loss in the corn treatment. In 1986, soil loss for alfalfa treatment was exceptionally high for Gretna clay during the early part of the season when the rainstorm of May 6 occurred. This could have been due to incomplete stand development during this part of the season.

Soil losses for Ryerson sandy clay loam and Carroll clay loam sites were below the recommended tolerable loss, except for corn and summerfallow (Table 11, p. 105). In most cases the losses were higher for conventional tillage wheat treatment than for minimum tillage wheat treatment, indicating that minimum tillage reduces potential soil losses. There were cases when the losses for alfalfa and minimum tillage wheat were higher than would have been expected. This could have been due to severe disturbance of soil surface in these two treatments resulting from excavations by rodents. This introduced large volumes of loose surface soil which tended to magnify soil losses for these treatments. The alfalfa treatment for Carroll clay loam was established during the year the site became operative, with alfalfa being underseeded with wheat. The degree of ground cover was much lower than in a mature stand of alfalfa and could explain why soil losses from this treatment for the rainstorms of August 12 and 14 were similar to those of conventional tillage wheat. Also, soil losses from summerfallow for these two sites could have been modified by high amounts of mulch residues from the previous crop.

The results show that in a given year and site, most of the soil loss occurs in one or two rainstorms. For example, in 1986 on the Gretna clay, the storm of May 6 accounted for most of the annual soil loss. On the Leary sandy loam, the storms of May 6 and June 20 caused most of the soil loss for that year. In 1987, similar results were obtained from three of the four sites with the rainstorm of August 14. Therefore, these erosion events could be described as "catastrophic". The results show that a knowledge of "average" rather than individual rainstorm erosivity would be of little value in estimating soil losses. The results are further complicated by the fact that soil loss is not always proportional to the calculated rainfall erosivity. This may be an illustration of the view advanced by Wischmeier (1976) that the USLE estimates the average soil loss which may occur as a result of several similar rainstorms, but does not provide a reliable estimate of soil loss from an individual rainstorm. This variability might also be due to the effects of antecedent soil moisture and cultivation mentioned above. Finally, this variability may be an indication that the method of characterizing the erosivity of a storm as a product of its KE and maximum I_{30} may not be appropriate.

Differences in climatic and ground surface conditions existing among the four experimental sites made direct comparison of observed differences in soil erodibility potential of different soils difficult. The accuracy in evaluating differences in observed soil erodibility potential would be affected by the existing spatial differences in antecedent soil moisture, rainfall erosivity values, residual effects of mulch from the previous crop and possible failure of surface runoff and sediment sampling system for the summerfallow treatment in specific sites. Also, the surface runoff and soil loss sampling systems for the four experimental sites were not all the same. Gretna clay and Leary sandy loam sites were fitted with runoff propelled wheels. Ryerson sandy clay loam and Carroll clay loam sites were fitted with motorized wheels. However, Gretna clay summerfallow was indicated to be the most erodible among the four soil types, possibly because it had been sampled for the longest period and, therefore, free from the residual effects of mulch from the previous crop.

4.2 RAINFALL

Soil losses from different treatments were observed to vary with different rainstorm events (Tables 9-11, pp. 103-105). The differences in erosivity of rainstorms for which soil loss was sampled were separated as:

Low - 50 - 100 MJ mm ha^{-1} h^{-1}
Moderate - 100 - 400 MJ mm ha^{-1} h^{-1}

High - 400 - 1,000 MJ mm ha^{-1} h^{-1}

Rainstorm events for the 1986 growing season for Gretna clay and Leary sandy loam sites were mainly characterized by moderate rainstorms, i.e. less than 400 MJ mm ha^{-1} h^{-1}. Total rainfall erosivity values for that year were less than Wall et al.'s (1983) estimate of average annual erosivity value of 1,160 MJ mm ha^{-1} h^{-1} for Southern Manitoba. More highly erosive rainstorms occurred at all the four sites in the 1987 growing season. The annual cumulative erosivity values exceeded Wall et al.'s (1983) average annual estimate of erosivity value of 1,160 MJ mm ha^{-1} h^{-1} at all sites, exceeding 3,000 MJ mm ha^{-1} h^{-1} at the Ryerson sandy clay loam site. These results indicate the high potential for occurrence of highly erosive rainstorms in the study area, i.e. an average annual estimate of the rainfall erosivity factor value may not be very appropriate.

4.3 SURFACE RUNOFF

Soil loss during a rainstorm event is influenced by surface runoff occurrence. This mainly depends upon rainfall intensity and duration and the soil surface conditions that influence water infiltration rates and ponding. Results for surface runoff associated with rainstorm events for which soil loss occurred are provided in Tables 12-14. The generation of surface runoff was observed to be dependent upon rainfall intensity and duration and soil surface conditions. Rainstorm events of intermediate erosivity, i.e. rainstorms in which the amount and intensity of rainfall were moderate, caused negligible amounts or no surface runoff. In this case the runoff and sediment produced were not suffi-

TABLE 12

Summary of Surface Runoff Characteristics from Rainstorm Events for Gretna Clay

Date of Rainfall	Alfalfa		Wheat		Corn		Summerfallow	
	Max Flow Rate(L/S)	Tot Runoff Vol(L)	Max Flow Rate(L/S)	Tot Runoff Vol(L)	Max Flow Rate(L/S)	Tot Runoff Vol(L)	Max Flow Rate(L/S)	Tot Runoff Vol(L)
1986 Growing Season								
May 6	1.64	8372.2	1.15	8244.8	4.89	23491.5	1.80	12001.9
June 20	-	-	-	-	-	-	-	-
July 3	-	-	1.53	6536.4	1.78	5050.8	-	-
July 10	-	-	-	-	-	-	-	-
Sept.25	-	-	-	-	0.19	6467.1	-	-
Sept.29	-	-	-	-	-	-	-	-
1987 Growing Season								
July 3	-	-	0.10	2690.1	0.03	45.8	0.03	150.1
July 10	-	-	0.86	6068.0	0.15	9804.7	0.65	6635.9
July 20	-	-	0.07	1016.9	0.04	4129.5	0.47	5657.3
July 24	-	-	0.91	2591.6	0.31	3324.7	-	-
Aug. 14	0.04	42.1	0.18	1809.9	0.63	6000.0	4.05	8427.7
Sept.29	-	-	-	-	-	-	0.04	10.2

TABLE 13

Summary of Surface Runoff Characteristics from Rainstorm Events for Leary Sandy Soam

Date of Rainfall	Alfalfa Max Flow Rate(L/S)	 Tot Runoff Vol(L)	Wheat Max Flow Rate(L/S)	 Tot Runoff Vol(L)	Corn Max Flow Rate(L/S)	 Tot Runoff Vol(L)	Summerfallow Max Flow Rate(L/S)	 Tot Runoff Vol(L)
1986 Growing Season								
Apr. 30	-	-	-	-	-	-	-	-
May 6	2.06	23146.5	2.44	10920.7	2.49	7591.4	1.47	7810.3
June 14	1.39	3750.5	0.54	5209.4	1.49	8477.8	0.46	4980.3
June 20	2.53	15975.3	3.29	22977.1	3.09	14557.7	1.47	14670.4
July 3	1.06	11581.9	2.11	6203.2	1.16	3447.8	0.06	13.9
July 10	-	-	-	-	-	-	-	-
Sept.25	0.77	6620.8	4.43	5951.0	2.27	7548.9	0.65	5095.8
Sept.29	-	-	0.44	9124.8	0.43	7814.4	-	-
1987 Growing Season								
May 21	-	-	0.32	4959.0	0.04	1813.5	-	-
June 24	-	-	-	-	-	-	-	-
July 3	-	-	-	-	-	-	-	-
July 10	-	-	0.05	64.7	0.09	62.0	-	-
July 20	0.08	2731.0	0.04	688.5	-	-	-	-
Aug. 14	-	-	2.55	5670.7	2.96	12911.6	5.45	28561.0
Sept.29	0.07	205.0	0.03	509.0	0.08	445.2	0.05	3045.8

TABLE 14

Summary of Surface Runoff Characteristics from Rainstorm Events for Ryerson Sandy Clay and Carroll Clay Loams

Date	Alfalfa		Wheat (Con Till)		Corn		Summerfallow		Wheat (Min Till)	
of Rainfall	Max Flow Rate(L/S)	Tot Runoff Vol(L)	Max Flow Rate(L/S)	Tot Runoff Vol(L)	Max Flow Rate(L/S)	Tot Runoff Vol(L)	Max Flow Rate(L/S)	Tot Runoff Vol(L)	Max Flow Rate(L/S)	Tot Runoff Vol(L)
Ryerson Sandy Clay Loam, 1987										
June 2	0.04	2152.6	-	-	-	-	-	-	-	-
June 24	0.05	3210.7	0.05	97.3	0.03	363.2	0.05	89.8	0.06	1738.3
July 8	0.10	654.2	0.14	1076.0	0.03	1757.6	0.06	3877.5	0.06	3517.5
July 10	-	-	-	-	-	-	-	-	-	-
July 20	-	-	-	-	-	-	-	-	-	-
July 31	0.05	2560.4	1.09	10210.1	0.90	2657.5	0.29	3733.5	0.51	961.6
Aug. 4	-	-	-	-	-	-	-	-	-	-
Aug. 14	0.45	2671.9	3.48	33586.1	2.27	9942.4	10.66	25526.1	2.46	17301.0
Carroll Clay Loam, 1987										
June 3	-	-	-	-	-	-	-	-	-	-
July 11	0.26	2669.9	-	-	-	-	-	-	-	-
July 14	-	-	-	-	-	-	-	-	-	-
July 20	0.03	563.1	-	-	-	-	-	-	-	-
July 31	0.04	2204.8	-	-	0.10	6207.2	-	-	-	-
Aug. 12	-	-	0.22	1615.8	0.66	8865.1	0.52	12111.4	1.05	2817.5
Aug. 14	0.29	4800.6	0.32	3115.2	0.38	19505.7	0.26	9311.7	0.38	3967.5

cient to go past the sampling wheels and the eroded sediment was deposited in the troughs.

In 1986, Gretna clay soil generated no surface runoff for most of the rainstorms compared to Leary sandy loam soil. This was probably due to high infiltration rates resulting from the cracked soil surface of the Gretna clay soil when dry. This could have trapped large amounts of runoff and sediment during the early part of a rainstorm. Most of the rainstorms that occurred during the year were moderate rainstorms. The rainstorm which occurred on May 6 was the only rainstorm that resulted in surface runoff in summerfallow in 1986. This may have been due to high levels of antecedent soil moisture resulting from spring melt. The effect could have also been due to the slaked soil surface due to freezing and thawing. In 1987, Gretna clay soil generated surface runoff for most of the rainstorms compared to Leary sandy loam soil, probably due to higher levels of antecedent soil moisture for Gretna clay soil (Tables 12 and 13, pp. 111-112). The four soils generated large amounts of surface runoff for the heavy rainstorm of August 14 1987. Carroll clay loam soil recorded surface runoff with comparatively fewer rainstorms, probably because the rainfall erosivity values for the site were also comparatively low.

Foster et al. (1982) evaluated rainfall runoff erosivity factors for individual storms and concluded that annual rainfall erosivity indices that include surface runoff volume and flow rates would be more effective in estimating soil loss. The observation was that this would reduce overestimation of soil loss when surface runoff is negligible and reduce underestimation when runoff is high relative to rainfall intensity.

Deposition of eroded sediment will occur during a rainstorm when surface runoff is non-existent or negligible. The USLE does not predict soil loss accurately when deposition of eroded sediment is occuring in the same field, since it does not account for the deposited sediment (Wischmeier et al. 1971). Therefore, there is a need to relate observed soil loss to surface runoff volume and flow rates during specific rainstorms so as to ensure accurate estimation of soil loss.

The accuracy of the surface runoff recorder readings was observed to be influenced by: 1) evaporation of water from the stilling well, 2) mice disturbance which created meaningless curves on chart, 3) mechanical obstruction in pen movement which made it impossible for the pen to go back to zero after surface runoff flow ceased, and resulted to meaningless slopes on curve, 4) sedimentation in stilling well during heavy rainstorms which caused heavy soil losses that inactivated the runoff recorder, especially in summerfallow treatment. These problems could have affected the accuracy of the calculated runoff flow rates and total volumes for some of the rainstorms. Evaporation from stilling well and mice disturbance could have contributed to false readings on charts. Mechanical obstruction and sedimention of stilling well could have contributed to undermeasuring of surface runoff flow rates and total volumes.

4.4 SOIL LOSS FROM SUMMERFALLOW TREATMENT

Soil losses from summerfallow represent the soil erodibility characteristic of specific soils, since soil loss is not modified by surface residue or crop cover. The losses from this treatment were observed to be higher than those from other treatments, especially for heavy rainstorms (Tables 9-11, pp. 103-105). Therefore, erosion from the summerfallow treatment was used as a benchmark to estimate the soil erodibility potential and soil loss ratios for specific soils. Rainstorms of short duration and low intensity tended to cause low soil losses, probably due to high infiltration rates and ponding.

The dependence of soil loss from summerfallow upon rainfall erosivity is probably influenced by the degree of rainfall erosivity and soil surface conditions. During a rainstorm of a short duration and low intensity, the soil surface for this treatment allows for more rapid infiltration rate than permitted on the more compacted wheat and corn treatments. This condition is created by the periodical cultivation for the control of weeds and surface crust formation. During a heavy rainstorm, initial infiltration rate is also likely to be more rapid. The infiltration rate decreases as the moisture content of the soil surface increases until the soil gets saturated. At this stage, the amount of surface runoff and flow rate generated during a rainstorm reaches a maximum. Therefore, the lack of a protective crop residue or actively growing vegetation at this point becomes the most crucial factor in determining the susceptibility of soil to erosion. This shows that failure to recognize the effect of soil surface conditions on infiltration rate and ponding represents a deficiency in the accuracy of estimating soil loss with the USLE.

The rainstorm of May 6, 1986 caused higher soil loss for Gretna clay summerfallow than for Leary sandy loam (Tables 9 and 10, pp. 103-104). This was possibly due to the differences in infiltration rates between the two soils. Leary sandy loam soil has a higher infiltration rate than Gretna clay, and could have experienced less surface runoff than Gretna clay.

The rainstorm of August 14, 1987 had high erosivity for both Gretna clay and Leary sandy loam soils. Leary sandy loam summerfallow had a higher soil loss, although the rainstorm had a lower erosivity value. This was possibly due to failure of surface runoff and sediment sampling system for Gretna clay site. This could have possibly been caused by stuck bearings and sedimentation on the sampling wheel which could have slowed down the rate of rotation of the wheel during the rainstorm. Therefore, the total soil loss for Gretna clay summerfallow for this rainstorm was undersampled. The wheel bearing for the sampling wheel for this treatment was replaced after the rainstorm.

Ryerson sandy clay loam and Carroll clay loam sites had high erosivity values for the rainstorm of August 14, 1987 but with comparatively low soil losses. The soil losses could have been modified by the previous crop residues. Also, there could be a possibility that the low soil losses may have been due to failure of the surface runoff and sediment sampling system for these sites. There were cases when the motor failed to turn the wheel as a result of the breakage of the connection with the wheel and power failure. The necessary repairs were done after this observation.

4.4.1 Effect of Antecedent Soil Moisture

Antecedent soil moisture content influences infiltration rate, ponding and the amount of surface runoff and flow rate generated during a rainstorm. This will also determine the length of the period before the initiation of surface runoff after the beginning of the rainstorm. Wet soils would be expected to take a shorter time to become saturated before ponding and surface runoff discharge begins. The erosivity potential of specific rainstorms would consequently be affected by antecedent soil moisture levels. Effects of antecedent soil moisture on measured soil losses were observed in situations where soil losses for specific rainstorms were higher or lower than would be expected.

On the Gretna clay soil, a storm on June 20, 1986 with an erosivity value of 142.62 MJ mm ha^{-1} h^{-1} resulted in a soil loss from the summerfallow of 0.10 t ha^{-1}. A subsequent rainstorm on July 10, 1986 with an erosivity value of 28.94 MJ mm ha^{-1} h^{-1} resulted in a soil loss of 1.67 t ha^{-1}. The moisture contents for the upper layer on these two dates were 20.8 and 24.0%, respectively (Table 9, p. 103). Therefore, the higher soil moisture at the time of the second storm was probably responsible for the higher soil loss. Also, for the same soil a storm on July 10, 1987 with an erosivity of 392.23 MJ mm ha^{-1} h^{-1} resulted in a soil loss of 0.11 t ha^{-1} (Table 9, p. 103). Another storm on July 20, 1987 with an erosivity value of 77.33 MJ mm ha^{-1} h^{-1} resulted in soil loss of 3.78 t ha^{-1}. The moisture contents on these two dates were 19.6 and 32.3%, respectively. Therefore, the higher moisture content at the time of the second rainstorm was probably responsible for the higher soil loss. The amount of soil loss from summerfallow should be directly proportional to the rainfall erosivity. The higher soil moisture content prior to the rainstorm occurrence probably decreased the soil water infiltration rate with the result that there was more surface runoff and soil loss.

The effect of antecedent soil moisture on soil loss from a heavy rainstorm may not be very important. On Gretna clay, a rainstorm on August 14, 1987 with an erosivity of 1,422.67 MJ mm ha^{-1} h^{-1} resulted in a soil loss of 50.74 t ha^{-1}. Soil loss per unit erosivity was 0.036 t ha^{-1}. The soil moisture content in the upper layer was 22.9%. Thus, even though the moisture content was relatively low, soil loss per unit erosivity was relatively large. On Leary sandy loam, a storm which occurred on the same day with an erosivity value of 1,006.08 MJ mm ha^{-1} h^{-1} resulted in a soil loss of 83.45 t ha^{-1}. Soil loss per unit erosivity was 0.083 t ha^{-1}. The soil moisture content was 12.9% in the upper layer, again relatively low.

The results also indicated a soil moisture and crop interaction effect on soil erosion. On Gretna clay, a rainstorm on May 6, 1986 occurred with an erosivity value of 392.31 MJ mm ha^{-1} h^{-1} (Table 9, p. 103). A rainstorm occurring at this time of the year results in large soil losses from the summerfallow treatment relative to those from the cropped treatments. The rainstorm occurred at a time when the cropped treatments had not been established. Therefore, the soil surface was bare on all the plots but summerfallow recorded a soil loss of 62.08 t ha^{-1}. The soil loss was the highest among the plots for various crop-management treatment. The storm occurred during the spring of the year when there is usually a higher soil moisture content on summerfallow than would be expected on a field that was cropped the previous year.

Unfortunately, the soil moisture data for this period was not available to corroborate this observation.

The effect of antecedent soil moisture on the erosivity potential of different rainstorms is bound to have significant implications on measured K and C factor values, i.e. the measured factor values will vary with antecedent soil moisture levels present before a rainstorm occurrence. The lack of an antecedent soil moisture factor in the USLE would suggest that many of the soil loss estimates obtained with the equation may have large errors associated with them. Therefore, there is a need to modify the USLE so as to include the effect of antecedent soil moisture among the various erosion controlling factors integrated by the equation.

4.4.2 Effect of Cultivation

Time of cultivation, especially at different soil moisture regimes, contributes to surface roughness. This condition will influence infiltration rates and ponding during a rainstorm which will affect surface runoff volumes and flow rates. Cultivation will also enhance soil loss by making the surface soil more amenable to sediment detachment and transportation if a heavy rainstorm occurs immediately after cultivation is done. Frequency and manner of cultivation will also influence the soil surface roughness to an extent where it will significantly affect the hydraulics of the rainsplash effect and surface runoff through ponding. Therefore, the time of cultivation with respect to rainfall occurrence is important in accounting for soil losses.

Variability in soil loss for different crop-management treatments has been shown to be influenced by antecedent soil moisture. Time of cultivation and crop and residue cover changes occurring through the growing season will influence antecedent soil moisture levels. Cultivation will greatly reduce the surface runoff flow through high infiltration rates and ponding during the early stages of the rainstorm. Also, the accumulation of water on the soil surface through ponding is likely to reduce the rate of detachment of sediment through the raindrop splash effect by the interception of raindrops. Therefore, soil losses from light rainstorms of a short duration occurring immediately after cultivation will be modified more than those from heavy rainstorms. The benefits of a higher initial infiltration rate are short lived during a heavy rainstorm. In this case soil losses after cultivation would be expected to be larger because of the loosened condition of the soil surface.

On Leary sandy loam, a rainstorm occurred on September 25, 1986 with an erosivity value of 49.58 MJ mm ha^{-1} h^{-1} and caused soil losses of 0.22 t ha^{-1} from summerfallow and 2.38 t ha^{-1} from corn treatments. The summerfallow and corn plots had been cultivated on September 15, 1986 and July 24, 1986 respectively (Tables 2 and 10, pp. 78 and 104). The soil loss from summerfallow was possibly reduced through reduction of surface runoff due to high infiltration rates and ponding resulting from cultivation.

The above illustrates the effect of cultivation on soil loss resulting from low rainstorms. The effect on losses resulting from high rainstorms can be seen from the following example.

Gretna clay and Leary sandy loam summerfallow plots were cultivated on August 12, 1987 and rainstorms with erosivity values of 1,422.67 MJ mm $ha^{-1}h^{-1}$ and 1,006.08 MJ mm ha^{-1} h^{-1}, respectively, occurred on August 14, 1987 (Tables 3 p. 79, 4 p. 80, 9 p. 103 and 10 p. 104). Soil loss for Gretna clay summerfallow was 50.74 t ha^{-1}, and for Leary sandy loam summerfallow was 83.45 t ha^{-1}. The corn treatments for both sites were cultivated on July 7, 1987. Soil losses from the corn treatments for both sites were 4.41 t ha^{-1} for Gretna clay and 4.17 t ha^{-1} for Leary sandy loam, possibly because the soil surface condition for these treatments was more compacted. The magnitude of differences in soil loss between summerfallow and corn treatments for both sites was a good example of the effect of cultivation on soil loss due to heavy rainstorms. There was a possibility that the reduced soil loss from the corn treatment was also, greatly modified by the crop canopy cover.

These effects will have important implications on the measured K and C factor values. Therefore, there is a need for the USLE to take into consideration the effect of cultivation on potential soil losses so that more accurate estimates can be obtained.

4.5 SOIL PHYSICAL PROPERTIES

Soil physical properties and percent montmorillonite clay in total soil have been shown to influence the soil erodibility characteristics (Young and Mutchler 1977; Wischmeier et al. 1971; Romkens 1985). The soil physical properties data are provided in Appendix A, B, C and D. A summary of this data for estimating percent montmorillonite clay content in both the clay fraction and the total soil using estimated specific surfaces and soil texture data is provided in Table 15. A summary of this data for estimating the K values for different soil types using the NE and the MYME is provided in Table 16.

4.6 MEASURED AND ESTIMATED K FACTOR VALUES

The measured and estimated K factor values for different soil types are provided in Table 17. The measured values were calculated using data measurements of cumulative rainfall erosivity values and soil loss from summerfallow for a complete growing season. The soil loss was divided by the rainfall erosivity value to give measured K values for different soil types. The measured average K values for Gretna clay and Leary sandy loam were obtained by using cumulative rainfall erosivity values and soil loss from summerfallow for three years. The estimated values were obtained using the NE and MYME (See equations 3.11 and 3.12 page 99). The two equations depend on the soil physical properties data in estimating the K factor values. Estimated K values were obtained in Imperial units, since the equations were developed in these units. They were converted to SI units by multiplying with the conversion factor, 0.1317 (Foster et al. 1981) for ease of comparison with the measured values. The soil loss and rainfall erosivity data used in the calculations for measured K values are provided in Tables 9-11, pp. 103-105.

Annual variations in rainstorm frequencies and intensities, time of cultivation and different antecedent soil moisture contents have been shown to influence soil loss rates. This created a problem in the measured K value evaluations, due to related variations in soil loss rates for different rainfall erosivity values and antecedent soil surface con-

TABLE 15

Summary of Soil Physical Properties for Estimating Percent Montmorillonite Clay Content in Total Soil

Soil Type	Particle Size Analysis (%)			Organic Matter (%)	Moisture Content (-15 bar) (%)	Estimated Specific Surface $(m^2\ g^{-1}$	Montmorillonite Content	
	sand	silt	clay				% of Clay	% of Total soil
Gretna clay	23.0	28.6	50.4	4.3	20.6	142.6	21.9	11.0
Leary sandy loam	74.5	14.5	11.1	0.9	6.7	47.1	27.2	3.0
Ryerson sandy clay loam	57.2	19.4	22.9	5.8	14.8	89.8	29.4	6.7
Carroll clay loam	40.6	25.1	34.3	4.9	16.1	104.6	22.7	7.8

TABLE 16

Summary of Soil Physical Characteristics for Estimating K Values for Different Soil Types

Soil Type	silt + v. f. sand (%)	silt + sand (%)	Organic matter (%)	Structure Code	Permeability class	Aggregate Index	Montmorillonite (%)	Bulk Density (g cm^{-3})	Suspension Percentage	Dispersion Ratio (%)
Gretna clay	30.1	49.6	4.3	4	6	0.9	11.0	1.4	15.0	19.1
Leary sandy loam	25.2	88.2	0.3	4	2	0.1	3.0	1.5	3.2	13.0
Ryerson sandy clay loam	50.0	76.6	5.8	4	4	0.2	6.7	1.2	9.4	22.2
Carroll clay loam	60.6	65.7	4.9	4	4	0.4	7.8	1.3	11.2	19.3

TABLE 17

Measured and Estimated Soil Erodibility (K) Factor Values for Different Soils

Soil Type	Year	Cumulative Rainfall Erosivity (R)	Cumulative Soil Loss (Fallow) (t ha^{-1}) (A)	Soil Erodibility (K) Measured K = A/R	Soil Erodibility (K) Measured Average	Soil Erodibility (K) Estimated USLE(NE) ‡	Soil Erodibility (K) Estimated (MYME) †
Gretna Clay	1985	1275.2	2.8	0.002	0.031	0.027	0.052
	1986	969.2	69.6	0.072			
	1987	1954.3	56.5	0.029			
Leary Sandy Loam	1985	841.0	16.8	0.020	0.038	0.025	0.030
	1986	941.4	17.7	0.019			
	1987	1352.4	83.7	0.062			
Ryerson Sandy Clay Loam	1987	3076.6	15.3	0.005	0.005	0.039	0.025
Carroll Clay Loam	1987	1303.2	0.6	0.001	0.001	0.040	0.034

‡ USLE(NE) - Universal Soil Loss Equation (Nomograph Equation)
† MYME - Modified Young and Mutchler Equation

ditions. The procedure followed here calculated the measured K factor values on an average annual basis, using the cumulative annual rainfall erosivity and soil loss values from the summerfallow treatment. Table 17, p. 126, contains the measured and estimated K values for the various soil types. This included the measured K values obtained for the growing seasons for the years 1985 (Pauls 1987), 1986 and 1987. The measured K values for Gretna clay and Leary sandy loam soils for 1985, 1986 and 1987 were extremely variable. The average values for the three years were higher than those estimated from the NE and MYME. This could possibly show that the two equations underestimated the K values for these soils. The measured K values for Ryerson sandy clay loam and Carroll clay loam soils were extremly low compared to the estimated values, possibly due to the residual effects of mulch from the previous crop. These values were similar to the measured value for Gretna clay for 1985, i.e. the year of establishment of that site. The measured K value for Leary sandy loam for 1985 did not appear to have been much affected by the mulch residues of the previous crop (Table 17, p. 126). The measured values for Ryerson sandy clay loam and Carroll clay loam soils have to be determined over a number of years so as to eliminate the residual effects of the previous crop before they can be effectively compared with those obtained for Gretna clay and Leary sandy loam soils. The short period of data collection for determining the measured K factor values for these soils limited the accuracy of comparison with the NE and MYME estimated K factor values.

The NE estimated values for Gretna clay, Ryerson sandy clay loam and Carroll clay loam soils were possibly overestimated, since the soil organic matter content levels in these soils were higher than 4% which is the maximum organic matter content accounted for by the NE. The NE and MYME estimated K factor values for these two soils were not very different. The MYME estimated values were slightly lower than the NE estimated values, possibly because the MYME took into consideration the effect of soil aggregate index and percent montmorillonite in total soil on the estimated values.

4.6.1 Comparison of Measured and Estimated K Values

Specifications for summerfallow plot management requirements for the determination of measured soil loss ratios were expected to be similar to those applied for the determination of the measured K factor values (Wischmeier and Smith 1978). Management requirements were that summerfallow plots must be tilled and kept crop free for at least two years before sampling for soil loss. Also, they were to be cultivated and placed under conventional tillage corn seedbed condition each spring, and cultivated as needed to prevent surface crusting and weed growth. These specifications did not provide for a winter period for the experiments which, was an essential requirement for our study area.

Gretna clay and Leary sandy loam sites were both in the fourth year of fallow. Ryerson sandy clay loam was in the second year and Carroll clay loam was in the first year. Soil loss from summerfallow was, therefore, probably modified by the residual effects of incorporated residues from the previous crops, absence of spring ploughing and delay of cultivation due to excessive soil moisture conditions in our study area, especially for Gretna clay soil. The inability to provide the above specified summerfallow conditions in this study could have possibly modified the measured K values and reduced the degree of accuracy of comparison with the NE estimated values.

4.6.1.1 Gretna Clay Soil

The measured and estimated K factor values for this soil are provided in Table 17, p. 126. Field measurements for K factor values determination were done for the 1985, 1986 and 1987 growing seasons. The average measured K value for the three years was obtained as 0.031 and was higher than the NE estimated value of 0.027. This could possibly show that the NE underestimated the K value for this soil.

The measured value was not very different from that of 0.038 for Austin clay benchmark soil (Wischmeier and Smith 1977). The absence of data on the soil physical properties for Austin clay soil limited the accuracy of comparison of the NE estimated K factor value for Gretna clay soil with that of the benchmark soil. The measured K values obtained for 1985, 1986 and 1987 were observed to be extremely variable from year to year. This situation emphasized the need for these measurements to be repeated for a considerable period so that accurate average factor values can be obtained. The earlier field measurements of soil loss could have possibly been modified by the residual effects of mulch from the previous crop.

The MYME estimated K factor value was obtained as 0.052 and was much higher than the measured and the NE estimated factor values. This could possibly show that the MYME is overestimating the K value for Gretna clay soil. The aggregate index (0.9) and the percent montmorrilonite in total soil (11.0%) for this soil were above those of all the test soils used to develop the MYME (Young and Mutchler 1977). The high K value for this soil obtained with MYNE could possibly show that the equation, in its present form, cannot be accurately applied in estimating K values for this soil. The soil physical property values for this soil which are considered by the MYME were outside the range of values used in developing the regression. Therefore, there is a need to modify the MYME so as to extend the range for the regression. This will make it more accurate in estimating K values for soils like Gretna clay soil.

4.6.1.2 Leary Sandy Loam Soil

The measured and estimated K factor values for this soil are provided in Table 17, p. 126. Field measurements for K factor values determination for this soil were done for the 1985, 1986 and 1987 growing seasons. The average measured K value for the three years was obtained as 0.038 and was higher than the NE estimated value of 0.025 and the MYME estimated value of 0.030. This could possibly show that the two equations are underestimating the K value for this soil. The NE estimated value was lower than the measured and the MYME estimated values. The measured K values for 1985, 1986 and 1987 were observed to be extremely variable from year to year. This situation emphasized the need for these measurements to be repeated for a considerable period so as to obtain average factor values that be accurately compared with the estimated values. The earlier field measurements of soil loss for the K factor values determination could have possibly been modified by the residual effects of mulch from the previous crop.

The NE estimated value of 0.025 was lower than that of 0.047 for the Cecil sandy loam benchmark soil (Wischmeier and Smith 1978). The absence of data on the soil physical properties for the Cecil sandy loam soil limited the accuracy of comparison between the NE estimated K values for Leary sandy loam and the benchmark soil.

The MYME estimated K value was obtained as 0.030 and was higher than the NE estimated value of 0.025. The soil had a low aggregate index (0.02) and a low montmorillonite clay content in total soil (3.0%) (Table 16, p. 125). This could explain why the estimated values for the two equations were not very different. The physical properties for this soil considered for estimating K factor values using the MYME were within the range of the regression. Therefore, the estimated K value was within the range of that of the four sandy loam test soils among the MYME test soils (Young and Mutchler 1977)

4.6.1.3 Ryerson Sandy Clay Loam Soil

The measured and estimated K values for this soil are provided in Table 17, p 126. The measured K value of 0.005 obtained for this soil was for the 1987 growing season. The measured value was extremely low compared to the NE estimated value of 0.039 and the MYME estimated value of 0.025. The soil losses from summerfallow for this soil were possibly modified by the mulch residues of the previous crop, since the experimental site was established and sampled in 1987. Therefore, the low measured K value could have been due to the residual effects of mulch from the previous crop. The soil losses for summerfallow were extremely low, although high rainfall erosivity values were measured for the site (Table 11, p. 105). The measured K value compares well to that of Gretna clay for 1985, showing that residual effects of the previous crop could have possibly modified the K value. Also, most of the soil loss obtained for this soil came from the rainstorm of August 14, 1987. The low soil loss from summerfallow could have also been due to a possible failure of the surface runoff and sediment sampling system. Therefore, there is a need to repeat the measurements for a considerable period so that average accurate measurements for the K values can be obtained.

The NE estimated K value for this soil of 0.039 was not very different from that of the Cecil sandy clay loam benchmark soil of 0.047 (Wischmeier and Smith 1978). The absence of soil physical properties data for the benchmark soil limited the accuracy of comparison between the NE estimated K value for the Ryerson sandy clay loam and the benchmark soil.

The MYME estimated K value was obtained as 0.025 (Table 17, p. 126) and was lower than the NE estimated value of 0.039. This was possibly due to the high aggregate index (0.24) and montmorillonite clay content (6.70%) for this soil which could have reduced the estimated K value (Table 16, p. 125). The soil had a high content of preferentially erodible particles (50.0%). The montmorillonite clay content in the total soil was higher than that of 12 of the 13 test soils used to derive the MYME (Young and Mutchler 1977). The aggregate index was lower than that of all test soils, possibly due to the mechanical shaking method used in determining the index. The dispersion ratio (22.2) and the suspension percentage (9.4%) were above those of all test soils. The organic matter content was high (5.8%) and above that of 11 test soils. The estimated K value was below that of two of the sandy clay loam soils among the 13 test soils, possibly due to the high montmorillonite clay content in this soil. Therefore, there is a need to modify the MYME for this soil, since some of the soil physical properties for this soil considered for the equation were outside the range of the regression. This could possibly show that the MYME estimated K value for this soil may not have been accurate.

4.6.1.4 Carroll Clay Loam Soil

The measured and estimated K factor values for this soil are provided in Table 17, p 126. The measured K value of 0.001 was obtained for this soil for the 1987 growing season. This was much lower than the NE estimated value of 0.040 and the MYME estimated value of 0.034. The value was extremely low, possibly because the soil losses from summerfallow were modified by the mulch residues of the previous crop. The site was established and sampled in 1987. Also, most of the soil loss obtained for this site came from the rainstorm of August 14, 1987. The site recorded a high rainfall erosivity value during the year (Table 11, p. 105). Therefore, there was a possibility that the low soil loss could have also, been due to failure of surface runoff and sediment sampling system. These possibilities could have contributed to the low measured K value for this soil. The measured value was below that obtained for Gretna clay soil for 1985. This shows that stable summerfallow conditions are necessary for determining the measured K value as recommended by Wischmeier and Smith (1978). The summerfallow would be expected to stabilize with time as the experiments continue. Therefore, there is a need to repeat these measurements for a considerable period so as to obtain accurate average measured factor values.

The NE estimated K value of 0.040 for this soil was not very different from that of the Cecil clay loam benchmark soil which was estimated as 0.034 (Wischmeier and Smith 1978). The absence of soil physical analysis data for the benchmark soil limited the accuracy of comparison between the NE estimated K value for this soil and the benchmark soil. The NE estimated K value could have been increased by the high proportion of highly erodible particle size of silt plus very fine sand (60.6%). The soil had the highest percentage of both particle sizes among the four soils studied (Table 16, p. 125).

From the MYME, a K value of 0.034 was estimated. The soil had an organic matter content (4.9%) above that of 11 of the 13 test soils and was well within the range of all the test soils (Young and Mutchler 1977). The aggregate index (0.35) was above that of two of test soils. The dispersion ratio (19.3) and the suspension percentage (11.2) were above those of all test soils (Table 16, p. 125). The estimated K value was below that of the clay loam soils among the test soil, possibly due to the high montmorillonite clay and organic matter content which were above those of the test clay loam soils. Therefore, there is a need to modify the MYME so as to improve the accuracy of the equation in estimating K values for soils like Carroll clay loam.

The results obtained for the estimated K values with NE and MYME for the Gretna clay, Ryerson sandy clay loam and Carroll clay soils have shown that there is a need to modify these equations for accurate application for most of Manitoba soils. This will require the availability of a more comprehensive field data base on soil loss measurements so that more accurate average measured factor values can be obtained.

4.7 CROP CANOPY AND MULCH COVER

4.7.1 Cover Changes

Soil loss from different treatments was observed to vary during specific rainstorm events (Tables 9-11, pp. 103-105). This was due to differences in ground surface cover density afforded by different crop-management treatments through the growing season. Mulch and crop cover changes were observed through the growing season and were also observed to vary from year to year. The cover differences were also observed among different crop-management treatments (Tables 18-23, pp. 137-142). Mulch and crop cover for all the sites were generally high and conformed well with the expected maximum cover for the various crop-management treatments. Crop residue cover measurements were done in all the sites. The grain residue cover in the plots was low. Poor germination, and reseeding affected the stand development for both corn and wheat in most of the sites. This resulted to lack of uniformity in the stand development for these treatments with differential growth patterns during the early growth stages. The problem was more serious in the Leary sandy loam site in 1986 and 1987, and Carroll clay loam site in 1987. Also, crop defoliation by wildlife at the Leary sandy loam site contributed to this problem during the 1986 and 1987 growing seasons. Reseeding had to be done for the wheat and alfalfa cropping treatments in the Gretna clay site for the 1986 growing season. Crop cover changes were generally observed to increase consistently in most of the sites up to crop maturity or time of cutting in alfalfa treatment. The measurements for both mulch and crop cover were started immediately after seeding and ended after crop harvest.

TABLE 18

Percent Crop and Residue Cover Measurements for Gretna Clay Site, 1986

Date of Cover Measurement	Corn	Wheat	Alfalfa
May 12	13 (Residue)	9 (Residue)	63
May 21	10	7	70
May 28	11	4	73
May 28	(Corn and Wheat seeded)		
June	1	0	39
June 11	1	2	58
July 16	22	85	71
July 23	41	85	74
July 30	43	88	84
Aug. 6	58	89	98
Aug. 13	54	88	100
Aug. 20	59	72	63
Aug. 27	52	60	61
Sep. 2	44	66	63
Sep. 9	42	64	43
Sep. 12	43	68	54
Sep. 12	(Corn and Wheat Harvested)		
Sep. 26	10 (Residue)	22 (Residue)	

TABLE 19

Percentage Crop and Residue Cover Measurements for Leary Sandy Loam Site, 1986

Date of Measurement	Corn	Wheat	Alfalfa
May 12	7 (Residue)	31 (Residue)	79
May 21	8	45	94
May 28	3	37	93
May 28	(Corn and Wheat Seeded)		
June 4	4	22	96
June 11	4	26	92
July 16	54	78	89
July 23	74	81	93
July 30	64	73	92
Aug. 6	69	76	93
Aug. 13	67	78	93
Aug. 20	57	65	84
Aug. 27	57	65	80
Sept. 2	49	56	81
Sept. 9	41	64	73
Sept. 12	41	70	64
Sept. 12	(Corn and Wheat Harvested)		
Sept. 26	9 (Residue)	28 (Residue)	67

TABLE 20

Percent Crop and Residue Cover Measurements for Gretna Clay Site, 1987

Date of Cover Measurements	Corn	Wheat	Alfalfa
May 8	(Corn and Wheat Seeded)		
May 19	6 (Residue)	20 (Residue)	77
May 26	18 (Residue)	38 (Residue)	57
June 2	15	63	72
June 9	14	62	62
June 17	15	79	83
June 24	21	69	85
July 3	37	57	55
July 7	31	71	81
July 15	47	65	86
July 21	51	76	86
July 29	61	59	96
Aug. 4	51	68	98
Aug. 8	51	63	97
Aug. 18	67	64	97
Aug. 25		(Wheat Harvested)	
Aug 25	60	53 (Residue)	93
Sept. 1	46	46 (Residue)	80
Sept. 8	47	-	65
Sept. 15	51	-	70
Sept. 22	51	-	84
Sept. 29	56	-	78
Oct. 5	(Corn Harvested)		
Oct. 5	4 (Residue)	-	86
Oct. 13	-	-	73

TABLE 21

Percentage Crop and Residue Cover Measurements for Leary Sandy Loam Site, 1987

Date of Measurement	Corn	Wheat	Alfalfa
May 8	(Corn and Wheat seeded)		
May 19	7 (Residue)	23 (Residue)	83
May 26	31	71	67
June 2	12	70	87
June 9	17	78	73
June 17	34	81	96
June 24	51	64	95
July 3	49	88	80
July 7	67	81	94
July 15	82	85	96
July 21	80	88	99
July 28	79	83	100
Aug. 4	75	84	100
Aug. 11	79	77	98
Aug. 18	63	77	98
Aug. 25		(Wheat Harvested)	
Aug. 25	72	47 (Residue)	99
Sept. 1	53	-	94
Sept. 8	56	-	88
Sept.14	55	-	81
Sept.22	60	-	97
Sept.29	58	-	96
Oct. 6	(Corn Harvested)		
Oct. 6	12 (Residue)	-	98
Oct. 13	-	-	80

TABLE 22

Percent Crop and Residue Cover Measurements for Ryerson Sandy Clay Loam Site 1987

Date of Cover Measurements	Corn	Wheat (Con. Till.)	Wheat (Min. Till.)	Alfalfa
May 11	(Corn and Wheat Seeded)			
May 19	13 (Residue)	30 (Residue)	55 (Residue)	85
May 27	45	58	79	58
June 3	33	28	23	58
June 10	22	56	80	99
June 16	25	73	80	93
June 25	36	74	59	95
July 2	38	55	62	80
July 8	34	64	74	79
July 14	58	71	72	91
July 22	54	75	71	92
July 29	62	76	73	98
Aug. 5	54	73	66	96
Aug. 11	65	74	66	96
Aug. 19	49	73	69	98
Aug. 26	-	(Wheat Harvested)		-
Aug. 26	52	49 (Residue)	38 (Residue)	98
Sept. 2	61	-	-	92
Sept. 8	50	-	-	89
Sept.15	41	-	-	80
Sept.22	50	-	-	87
Sept.29	52	-	-	89
Sept.29	(Corn Harvested)	-	-	-
Sept.29	8 (Residue)	-	-	86
Oct. 6	-	-	-	85
Oct. 20	-	-	-	89

TABLE 23

Percent Crop and Residue Cover Measurements for Carroll Clay Loam Site, 1987

Date of Measurements	Corn	Wheat (Con. Till.)	Wheat (Min. Till.)	Alfalfa and Wheat
May 12	(Corn and Wheat Seeded)			
May 20	18 (Residue)	21 (Residue)	26 (Residue)	26 (Residue)
May 27	59	60	54	62
June 3	53	63	58	62
June 10	54	70	65	72
June 16	42	73	70	79
June 25	52	67	64	63
July 2	55	79	77	88
July 7	45	67	59	55
July 14	49	76	68	77
July 22	39	60	71	80
July 29	59	79	76	81
Aug. 5	53	75	73	83
Aug. 12	56	76	69	84
Aug. 19	46	65	60	75
Aug. 26	-	(Wheat Harvested)	-	-
Aug. 26	52	47(Residue)	51(Residue)	87
Sept. 2	66	-	-	72
Sept. 8	55	-	-	75
Sept. 22	50	-	-	83
Sept. 29	(Corn Harvested)	-	-	-
Sept. 29	44 (Residue)	-	-	87
Oct. 6	6 (Residue)	-	-	85
Oct. 20	-	-	-	66
Oct. 27	-	-	-	85

4.7.2 Crop Biomass and Grain Yields

Final crop biomass and grain yields from the cropped treatments for the four experimental sites are provided in Table 24. The yields for all crops were generally high and were within the range of the expected average crop yields occurring in the study areas. This was an indication that the crop management system in the experimental plots was in conformity with that occurring in the farmers fields within the study area.

TABLE 24

Crop Biomass, Cover and Seed Yield for Different Sites for 1986 and 1987

Crop	Total Above Ground Dry Matter (t ha^{-1})	Seed Yield (t ha^{-1})	Maximum Ground Cover (%)	
			During Growing Season	After Harvest
Gretna Clay, 1986				
Corn	7.10	-	59	10
Wheat	10.60	4.44	89	22
Alfalfa	1.20	-	100	35
Gretna Clay, 1987				
Corn	6.75	-	67	4
Wheat	5.00	2.72	79	53
Alfalfa	1.94	-	98	86
Leary Sandy Loam, 1986				
Corn	2.29	-	69	9
Wheat	13.00	5.74	81	28
Alfalfa	3.94	-	96	67
Leary Sandy Loam, 1987				
Corn	7.69		82	12
Wheat	8.07	5.69	88	47
Alfalfa	2.43	-	100	73
Ryerson Sandy Clay Loam, 1987				
Corn	4.82	-	62	8
Wheat (Con. Till)	5.87	3.63	76	49
Wheat (Min. Till)	4.22	2.27	80	38
Alfalfa	1.44	-	99	79
Carroll Clay Loam, 1987				
Corn	3.27	-	66	6
Wheat (Con. Till.)	4.45	2.75	79	47
Wheat (Min. Till.)	6.95	4.47	77	51
Wheat (Alfalfa)	-	-	87	7

4.7.3 Soil Loss from Cropped Treatments

Soil loss variability from the cropped treatments was observed to depend on the degree of crop canopy protection of the soil surface cover afforded by different crops (Tables 9-11, pp. 103-105). This was mainly influenced by the crop type, the crop stand, and the status of the stand development. The crop cover was observed to vary greatly through the growing season and from year to year (Tables 18-23, pp. 137-142). Therefore, the effectiveness of crop cover in reducing potential soil losses depended mainly on the amount of rainfall erosivity occurring during the periods when the crop cover or management practice provided the least soil surface protection. Summerfallow generally lost the most soil and alfalfa lost the least. Generally, soil loss among the treatments varied in the order: summerfallow > corn > conventional tillage wheat > minimum tillage wheat > alfalfa. Summerfallow provided no protection on the soil surface from raindrop splash effect. Alfalfa's dense canopy cover provided the most effective protection among the treatments. Corn provided less canopy cover and wheat provided comparatively more cover. Minimum tillage wheat treatment lost less soil than conventional tillage wheat, i.e. reduced cultivation reduced soil loss in this treatment. For some rainstorms, the minimum tillage wheat treatment lost more soil than the conventional tillage wheat (Table 11, p. 105). This was mainly due to excavations by rodents in this treatment, which occurred at the Ryerson sandy clay loam site.

4.8 MEASURED AND ESTIMATED C FACTOR VALUES (SOIL LOSS RATIOS)

Measured and estimated C factor values are provided in Tables 25, 26 and 27. The C factor is the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled continuous fallow (Wischmeier and Smith 1978). Soil loss ratios would be expected to vary during the growing season with crop canopy and mulch cover, management practices and rainfall total and intensity. The factor is evaluated from soil loss ratios which vary during the growing season as influenced by many variables that are related to specific crop-management practices. These are crop canopy and residue cover, incorporated residues, tillage practices and rainfall cycles.

Soil loss rates were observed to vary with the degree of crop cover changes through the growing season. The cover values obtained were used in separating the six crop growth stages according to Wischmeier and Smith (1978), (Table 7, p. 83). Most of the crops reached the crop growth stages required for the soil loss ratio calculations, except for corn at the Leary sandy loam site for 1986 and Carroll clay loam site for 1987. Defoliation by wildlife at the Leary sandy loam site and low moisture conditions at the Carroll clay loam site affected the crop stand development (Tables 19, p. 138 and 23, p. 142). Soil loss ratios were calculated separately for each growth stage for each cropped treatment. Variability of soil loss in the summerfallow treatment affected the calculated values.

Calculated soil loss ratios were expected to be less than one, since the highest amount of soil loss was expected to occur in the summerfallow treatment. The calculated ratios were observed to be more than one for rainstorms events where summerfallow lost less soil than the cropped treatments due to the effect of antecedent soil moisture and time of cultivation as previously discussed (Tables 25-27). The cover for the alfalfa treatment remained consistently high after establishment until cutting was done when a slight decrease in cover was observed (Tables 18-22, pp. 137-141).

TABLE 25

Soil Loss Ratios for Gretna Clay Soil Rainstorm Events

Date of Rainfall	Rainfall Erosivity (R)	Calculated Soil Loss Ratios			Crop Stage Period (Estimated % Cover)			Estmated Soil Loss ‡ Ratios		
		Alfalfa	Wheat	Corn	Alfalfa	Wheat	Corn	Alfalfa	Wheat	Corn
1986 Growing Season										
May 6	392.31	0.20	0.72	0.61	-	-	-	-	-	-
June 20	142.62	0.30	1.20	1.50	2(75)	SB(7)	SB(10)	0.02	0.79	0.79
July 3	254.01	0.01	0.83	1.28	2(71)	3(85)	1(22)	0.02	0.33	0.62
10	28.01	0.05	1.71	2.02	2(71)	3(85)	1(22)	0.02	0.33	0.62
Sep. 25	135.24	-	-	-	-	-	-	-	-	-
29	16.23	0.00	20.00	1.00	2(54)	4(22)	4(10)	0.02	0.06	0.06
1987 Growing Season										
July 3	18.66	-	0.67	0.44	2(55)	2(57)	1(37)	0.02	0.42	0.62
10	392.23	0.09	1.91	0.36	3(81)	2(71)	1(31)	0.02	0.42	0.62
20	77.33	0.00	0.02	0.01	3(86)	3(76)	2(51)	0.02	0.33	0.42
24	26.73	-	0.03	0.03	3(91)	2(59)	2(61)	0.02	0.42	0.42
Aug. 14	1422.67	0.00	0.01	0.09	3(97)	2(64)	2(67)	0.02	0.42	0.42
Sep. 29	16.69	-	0.17	0.33	3(80)	4(46)	2(56)	0.02	0.06	0.42

‡ Obtained using soil loss ratios from Wischmeier and Smith (1978)

TABLE 26

Soil Loss Ratios for Leary Sandy Loam Soil Rainstorm Events

Date of Rainfall		Rainfall Erosivity (R)	Calculated Soil Loss Ratios			Crop Stage Period (Estimated % Cover)			Estmated Soil Loss ‡ Ratios		
			Alfalfa	Wheat	Corn	Alfalfa	Wheat	Corn	Alfalfa	Wheat	Corn
1986 Growing Season											
April	30	13.77	-	-	-						
May	6	214.77	1.10	1.45	1.07	3(79)	4(31)	4(7)	0.02	0.06	0.06
June	14	326.15	0.24	0.76	2.17	3(92)	1(26)	SB(4)	0.02	0.62	0.79
	20	140.70	0.01	0.98	1.01	3(89)	3(78)	2(54)	0.02	0.33	0.42
July	3	83.15	0.04	15.20	3.04	3(89)	3(78)	2(54)	0.02	0.33	0.42
	10	99.25	0.03	5.24	2.06	3(89)	3(78)	2(54)	0.02	0.33	0.42
Sep.	25	49.58	0.05	4.77	10.82	3(67)	4(28)	4(9)	0.02	0.06	0.06
	29	14.83	-	3.00	-	-	4(28)	-	-	0.06	-
1987 Growing Season											
May	21	12.62	-	2.33	2.67	3(83)	1(23)	4(7)	0.02	0.62	0.06
June	24	44.90	-	0.57	0.71	3(95)	2(64)	2(51)	0.02	0.42	0.42
July	3	38.13	-	1.20	0.80	3(80)	3(88)	1(49)	0.02	0.33	0.62
	10	21.02	0.00	1.00	1.00	3(94)	3(81)	3(67)	0.02	0.33	0.33
	20	140.30	-	0.33	1.00	3(99)	3(88)	3(80)	0.02	0.33	0.33
Aug.	14	1006.08	0.00	0.01	0.05	3(98)	3(77)	3(79)	0.02	0.33	0.33
Sep.	29	89.41	-	0.50	1.00	3(96)	4(47)	2(58)	0.02	0.06	0.42

‡ Obtained using soil loss ratios in Wischmeier and Smith (1978)

TABLE 27

Soil Loss Ratios for Ryerson Sandy Clay Loam and Carroll Clay Loam Soils Rainstorm Events

Date of Rainfall	Rainfall Erosivity (R)	Calculated Soil Loss Ratios				Crop Stage Period (Estimated % Cover)				Estmated Soil Loss ‡ Ratios			
		Alfalfa	Wheat (Con.)	Wheat (Min.)	Corn	Alfalfa	Wheat (Con.)	Wheat (Min.)	Corn	Alfalfa	Wheat (Con.)	Wheat (Min.)	Corn
Ryerson sandy clay loam, 1987													
June 2	211.63	0.67	1.33	1.50	1.50	2(58)	1(28)	1(23)	1(33)	0.02	0.62	0.62	0.62
24	100.37	2.00	1.33	2.33	1.33	3(95)	2(74)	2(59)	1(36)	0.02	0.42	0.42	0.62
July 8	232.48	0.60	0.80	0.80	0.80	3(79)	2(64)	2(74)	1(36)	0.02	0.42	0.42	0.62
10	42.60	0.50	1.00	1.50	1.00	3(91)	2(71)	2(72)	2(58)	0.02	0.42	0.42	0.42
20	275.47	0.00	1.00	1.00	1.00	3(92)	2(75)	2(71)	2(54)	0.02	0.42	0.42	0.42
31	62.92	-	1.00	1.00	1.00	3(98)	3(76)	2(73)	2(62)	0.02	0.33	0.42	0.42
Aug. 4	722.23	0.00	5.85	0.13	1.54	3(96)	2(73)	2(66)	2(54)	0.02	0.42	0.42	0.42
14	1429.01	0.01	0.05	0.07	0.83	3(96)	2(74)	2(66)	2(65)	0.02	0.42	0.42	0.42
Carroll Clay Loam, 1987													
June 3	95.74	-	1.00	1.50	1.00	2(62)	2(63)	2(58)	2(53)	-	0.42	0.42	0.42
July 14	56.57	-	1.00	1.00	1.00	3(77)	3(76)	2(68)	1(49)	-	0.33	0.42	0.62
20	155.85	-	0.33	0.67	0.67	3(80)	2(60)	2(71)	1(39)	-	0.42	0.42	0.62
31	52.70	-	1.00	1.00	1.00	3(81)	3(79)	3(76)	2(59)	-	0.33	0.33	0.42
Aug. 12	227.10	-	0.36	0.27	2.50	3(84)	3(76)	2(69)	2(56)	-	0.33	0.42	0.42
Aug. 14	715.22	-	1.34	0.66	0.38	2(75)	2(65)	2(60)	1(46)	-	0.42	0.42	0.62

‡ Obtained using soil loss ratios from Wischmeier and Smith (1978)

4.8.1 Average Measured C Factor Values

The average measured soil loss ratios for different crop-management treatments and growth stages are provided in Tables 28 and 29. The ratios were calculated for similar and different cropped treatments for specific growth stages. The ratios were observed to vary among different treatments and sites and from year to year. This was possibly due to the extreme variability of soil loss from summerfallow as influenced by the variability of rainfall erosivity and antecedent soil surface conditions. The results emphasize the need for repeated field measurements for these ratios so as to obtain accurate average measured factor values.

TABLE 28

Average Measured Soil Loss Ratios for Different Crop-management Treatments for Gretna and Leary Soils

Soil Type	Treatment	Measured Soil Loss Ratios (Growth Stage Periods)					
		W	SB	1	2	3	4
Gretna Clay Soil, 1986-1987							
1986 Growing Season							
	Alfalfa	-	-	-	0.12	-	-
	Con. Wheat	-	1.20	-	-	0.27	20.00
	Corn	-	1.50	1.65	-	-	1.00
1987 Growing Season							
	Alfalfa	-	-	-	-	0.09	-
	Con. Wheat	-	-	-	0.66	0.02	0.17
	Corn	-	-	0.4	0.12	-	-
Leary Sandy Loam Soil, 1986-1987							
1986 Growing Season							
	Alfalfa	-	-	-	-	0.25	-
	Con. Wheat	-	-	0.76	-	7.14	2.97
	Corn	-	2.76	-	2.04	-	11.89
1987 Growing Season							
	Alfalfa	-	-	-	-	0.00	-
	Con. Wheat	-	-	2.33	0.57	0.64	0.50
	Corn	-	-	0.80	0.86	0.68	2.67

TABLE 29

Average Measured Soil Loss Ratios for Different Crop-management Treatments for Ryerson and Carroll Soils

Soil Type	Treatment	Measured Soil Loss Ratios Growth Stage Periods F	SB	1	2	3	4
Ryerson Sandy Clay Loam, 1987							
	Alfalfa	-	-	-	0.67	0.78	-
	Con. Wheat	-	-	1.33	1.66	1.00	-
	Min. Wheat	-	-	1.50	0.96	-	-
	Corn	-	-	1.21	1.07	-	-
Carroll Clay Loam, 1987							
	Alfalfa	-	-	-	0.32	0.77	-
	Con. Wheat	-	-	-	0.89	0.79	-
	Min. Wheat	-	-	-	0.82	1.00	-
	Corn	-	-	0.68	1.50	-	-

4.8.2 Comparison of Measured and Estimated C Factor Values (Soil Loss Ratios)

The calculated and estimated soil loss ratios are provided in Tables 25-27. Crop cover changes were observed to have important effects on the calculated soil loss ratios, due to the effect of cover on soil loss. The ratios were observed to be extremely variable for similar growth stages among different treatments and from year to year (Tables 28 and 29). Crop stand development in most of the sites was generally good, except at the Leary sandy loam and the Carroll clay loam site where wildlife defoliation and low moisture levels during the early growth stage retarded the normal growth. Also, the alfalfa stand which was undersown with wheat was not fully established when sampling was started. Therefore, the cover measurements obtained were almost similar to those of the conventional and minimum tillage wheat treatments until just before the wheat was harvested when alfalfa growth became significant (Table 23, p. 142). The measured and estimated soil loss ratios for the alfalfa treatment for Carroll clay loam site were, therefore, omitted.

The calculated soil loss ratios for most rainstorms were observed to be greater than one. This situation occurred with less erosive rainstorms of low intensity and duration where soil losses from summerfallow were lower than those from cropped treatments, possibly due to the effect of low levels of antecedent soil moisture and surface roughness due to cultivation. More soil loss ratios greater than one were calculated for Gretna clay and Leary sandy loam sites for 1986 than for 1987, especially for corn and wheat treatments (Tables 25-26, pp. 148-149).

Generally high soil loss ratios were calculated for Ryerson sandy clay loam and Carroll clay loam sites, particularly for corn and wheat treatments (Table 27, p. 150). This was possibly due to the exceptionally low soil losses from summerfallow recorded for most of the rainstorms for these sites. The sampling wheels in these sites were motorized, and the problem of undersampling of surface runoff and sediment in summerfallow as compared to runoff propelled wheels should not have occurred. The differences observed between calculated soil loss ratios for conventional and minimum tillage wheat treatments were, generally, not great.

Estimated soil loss ratios for an established alfalfa crop stand for successive growth stages were given as 0.02 (Wischmeier and Smith 1978). This ratio was not very different from most of the measured values for the sites where the stand was fully established. Also, some of the measured values obtained for this treatment were below the estimated value.

The summerfallow treatment used in the determination of soil loss ratios was expected to be tilled and kept weed free for at least two years (Wischmeier and Smith 1978). The treatment was also expected to be cultivated and kept under conventional tillage corn seedbed condition each spring so as to prevent surface crusting and weed growth. Summerfallow for the four sites had been in operation for two years for Gretna clay, two years for Leary sandy loam, one year for Ryerson sandy clay loam and was newly established for Carroll clay loam. Summerfallow was sampled during the first year of plot establishment, and the measured soil loss ratios could have, therefore, been modified by the residual effects of mulch from the previous crop. Also, summerfallow could not be cultivated in spring, due to high soil moisture content resulting from spring melt. The effect of incorporated residues (Wischmeier and Smith 1978), absence of spring ploughing and time of summerfallow cultivation could have influenced the measured ratios. This situation created a problem in comparing the measured soil loss ratios with the estimated ratios as provided by Wischmeier and Smith (1978). Therefore, appropriate summerfallow conditions, where possible are necessary before accurate comparison of factor values can be obtained.

Differences existed between the crop-management systems used in this study and those with which the estimated C factor values were developed (Wischmeier and Smith 1978). This made the accuracy of direct comparison between the measured and estimated values difficult. Specified conditions for the standard experimental plot management as provided by Wischmeier and Smith (1978) could not be met for all the sites and treatments in this study. These were described in the tables of soil loss ratios (Wischmeier and Smith 1978, Tables 5, 5a and 5c). Also, these conditions did not allow for a winter period for the alfalfa crop-management treatment. Soil loss ratios given by Wischmeier and Smith (1978) were for one system of grain after grain with residue removed. In their example, the stubble was disked under as opposed to the method used in this study which included removal of stubble after harvest. Also, the reclassification of the crop growth-stage periods (Table 7, p. 83) for Periods, F and 4 made the comparison of factor values for these stages difficult.

Chapter V

SUMMARY AND CONCLUSION

Soil losses from different treatments and soil types were observed to be extremely variable as influenced by the degree of crop cover and rainfall erosivity. The losses occurring from different rainstorms were shown to be modified by antecedent soil moisture and cultivation. The effect was mainly dependent on rainfall intensity and duration and time of cultivation. These conditions were responsible for the observed high degree of variability in the measured K and C factor values. Therefore, there is a need to do long-term measurements of soil loss so that accurate average factor values can be obtained.

The results obtained have shown that antecedent soil moisture and time of cultivation have important effects on observed soil losses. Therefore, there is a need for the modification of the USLE so as to account for the effects of these field conditions in the estimated soil losses. A comprehensive field data base on antecedent soil moisture and soil surface roughness due to cultivation needs to be developed before this can be effectively done. Data on moisture content differences between antecedent soil moisture and moisture at soil saturation point are necessary. This will provide a better explanation of the effect of antecedent soil moisture on surface runoff occurrence and soil loss variability. The nature of soil surface roughness due to cultivation needs to be known and could appropriately be done on weekly basis.

Therefore, some qualitative surface roughness rating scheme needs to be developed for features like very coarse, coarse, very rough, rough, smooth etc. This will make it possible to monitor changes in soil surface roughness through the growing season. Also, microtopography survey could be done but this might be labour intensive and might also create problems of surface compaction due to increased human traffic in the summerfallow plots. This data would make it possible to account for the observed effects of antecedent soil moisture and cultivation on the erosivity potential of specific rainstorms more accurately.

The absence of appropriate summerfallow conditions and directly comparable crop-management treatments for the present study and those used when the USLE was developed made it difficult to obtain a direct comparison between the measured and estimated soil loss ratios. This was mainly due to the residual effects of mulch from the previous crop which tended to modify soil losses from summerfallow, especially for the new sites. Therefore, long-term measurements of soil loss are necessary so that accurate average C factor values can be obtained which can be effectively compared with the USLE estimated values.

The results obtained for the years 1985, 1986 and 1987 cannot be considered conclusive in achieving an effective evaluation of the USLE application in Manitoba, since this would require a sufficient long-term period of field data measurements before accurate factor evaluations can be achieved. The data base developed so far stresses the need for the continuation of the study for a number of years so that accurate average factor values can be obtained.

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Appendix A

PARTICLE SIZE ANALYSIS* FOR EACH GRID POSITION FOR RYERSON SANDY CLAY LOAM AND CARROLL CLAY LOAM SOILS

Grid No.	% Sand*					% Silt	% Clay
	v. coarse	coarse	medium	fine	v. fine		
Ryerson Sandy Clay Loam							
1	4.81	4.92	5.18	8.69	21.41	25.08	29.08
2	5.42	6.16	6.42	9.89	25.26	17.47	29.89
3	0.74	3.28	6.06	13.81	33.95	11.96	30.07
4	1.65	3.56	6.81	13.97	32.59	15.28	25.68
5	0.61	1.95	5.41	14.05	35.91	38.66	2.81
6	1.01	3.52	6.77	13.69	35.86	17.73	21.49
7	3.58	4.85	7.31	15.07	33.56	8.31	22.70
8	3.99	6.23	8.30	13.57	25.39	17.42	24.66
9	1.24	4.39	7.27	13.22	31.52	12.58	19.73
Carroll Clay Loam							
1	0.16	0.42	0.74	3.62	50.33	19.46	25.26
2	0.05	0.44	0.60	2.23	38.88	20.63	37.36
3	0.22	0.50	0.94	3.42	35.33	20.89	38.53
4	0.33	0.95	1.17	4.52	43.37	20.41	29.38
5	0.32	0.64	1.12	4.05	34.39	25.97	33.82
6	0.32	0.37	0.85	3.20	25.18	34.19	36.07
7	0.38	0.60	0.87	2.70	22.78	34.23	38.55
8	0.21	0.48	0.86	3.01	37.21	24.34	33.75
9	0.27	0.38	0.91	4.19	32.31	25.57	36.21

*Percent of soil excluding particles >2.0 mm

Appendix B

SOIL PHYSICAL PROPERTY VALUES FOR RYERSON SANDY CLAY LOAM AND CARROLL CLAY LOAM SOILS

Grid No.	Silt + v. f. sand (%)	Silt + Sand (%)	Organic Matter (%)	Structure Code	Permeability Class	Aggregate Index	Bulk Density (g/cm³)	Suspension percentage (%)	Dispersion Ratio (%)
Ryerson Sandy Clay Loam									
1	46.49	70.92	3.59	4	4	0.419	1.32	12.20	22.53
2	42.73	70.11	3.37	4	4	0.485	1.50	11.88	25.08
3	45.91	69.93	6.74	4	4	0.245	1.33	5.84	13.89
4	47.87	74.32	5.05	4	4	0.367	1.14	11.72	28.61
5	74.57	97.19	8.35	4	4	0.092	1.21	7.56	18.23
6	53.59	78.51	7.44	4	4	0.079	1.20	7.24	18.46
7	41.87	72.77	6.81	4	4	0.143	1.15	8.68	27.99
8	42.81	75.35	5.01	4	4	0.158	1.26	8.32	19.77
9	54.10	80.27	5.66	4	4	0.124	0.96	10.76	25.43
Carroll Clay Loam									
1	69.79	74.74	4.96	4	4	0.162	1.33	11.50	25.71
2	59.51	62.58	4.07	4	4	0.244	1.36	10.72	18.49
3	56.22	61.48	3.95	4	4	0.428	1.27	12.84	21.61
4	63.78	70.62	4.91	4	4	0.480	1.10	12.04	24.18
5	60.36	66.17	5.37	4	4	0.521	1.33	12.80	21.41
6	59.37	63.97	5.63	4	4	0.477	1.14	9.00	12.81
7	57.01	61.45	5.05	4	4	0.298	1.13	13.08	17.97
8	61.55	66.26	5.71	4	4	0.218	1.30	7.88	13.57
9	57.88	63.79	4.30	4	4	0.329	1.37	10.88	17.61

Appendix C

PARTICLE SIZE ANALYSIS* FOR EACH GRID POSITION FOR GRETNA CLAY AND LEARY SANDY LOAM SOILS

Grid No.	% Gravel	% Sand*					% Silt	% Clay
		v. coarse	coarse	medium	fine	v. fine		
Gretna Clay								
1	1.86	1.65	2.34	5.79	23.34	2.17	27.92	36.78
2	2.24	1.39	2.84	5.78	20.36	1.76	29.41	38.56
3	3.03	1.79	3.10	5.09	13.65	1.79	29.76	44.82
4	1.08	1.28	1.88	3.66	10.20	1.38	26.06	55.53
5	1.12	1.00	1.36	3.75	12.58	1.57	23.92	55.81
6	0.43	0.83	1.13	2.91	9.72	1.47	27.40	56.55
7	0.26	0.32	0.79	2.01	6.15	0.58	30.33	59.81
8	0.58	0.95	1.37	2.91	9.09	1.11	33.42	51.16
9	0.36	0.79	1.26	2.79	9.63	1.26	29.56	54.70
Leary Sandy Loam								
1	5.29	1.95	6.76	26.28	31.11	9.40	13.84	10.65
2	3.89	2.68	8.65	23.50	30.60	9.89	13.12	11.65
3	3.00	2.24	5.04	28.09	30.04	9.45	12.72	12.43
4	3.78	1.56	8.87	26.32	30.00	11.28	13.40	8.57
5	3.74	1.62	8.41	27.83	31.63	10.59	10.94	8.97
6	3.59	1.74	7.21	27.09	31.01	9.34	13.57	10.03
7	2.81	2.35	7.82	24.90	26.79	9.46	16.43	12.24
8	2.45	1.52	8.09	25.64	26.63	8.14	16.94	13.05
9	2.91	2.63	8.06	23.86	24.65	9.32	19.52	11.97

*Percentage of soil excluding particles >2.0 mm

Source, After Pauls (1987)

Appendix D

SOIL PHYSICAL PROPERTY VALUES FOR GRETNA CLAY AND LEARY SANDY LOAM SOILS

Grid No.	Silt + v. f. sand (%)	Silt + Sand (%)	Organic Matter (%)	Structure Code	Permeability Class	Aggregate Index	Bulk Density (g/cm^3)	Suspension percentage (%)	Dispersion Ratio (%)
Gretna Clay									
1	30.10	63.22	4.00	4	6	0.184	1.37	15.51	23.97
2	31.17	61.44	5.51	4	6	0.167	1.43	15.78	23.14
3	31.55	55.18	4.71	4	6	0.149	1.50	8.79	11.82
4	27.44	44.47	4.33	4	6	0.314	1.46	17.33	21.35
5	25.50	44.19	4.29	4	6	0.184	1.42	16.82	21.13
6	28.87	43.45	4.31	4	6	0.173	1.46	15.00	17.84
7	30.92	40.19	3.04	4	6	0.251	1.50	18.55	20.57
8	34.52	48.84	3.10	4	6	0.157	1.43	13.34	15.78
9	30.82	45.30	5.20	4	6	0.158	1.44	13.91	16.49
Leary Sandy Loam									
1	23.24	89.35	0.53	4	2	0.189	1.52	3.71	15.67
2	23.01	88.44	0.95	4	2	0.114	1.54	3.33	13.51
3	22.16	87.57	0.75	4	2	0.086	1.55	3.87	15.69
4	24.67	91.43	0.84	4	2	0.042	1.58	2.87	12.96
5	21.53	91.03	1.05	4	2	0.041	1.62	3.72	19.03
6	22.91	89.97	0.95	4	2	0.076	1.56	2.80	11.85
7	25.89	87.76	0.78	4	2	0.231	1.50	2.47	8.62
8	25.08	86.95	0.62	4	2	0.185	1.51	3.28	10.94
9	28.84	88.03	1.15	4	2	0.070	1.55	2.65	8.58

Source, after Pauls (1987).

Appendix E

DATE OF RAINFALL AND SOIL MOISTURE (% OF DRY MASS) FOR GRETNA CLAY SOIL, 1986

Date of Rainfall		Date of Sampling		Sampled Soil Layers (cm) and Percent Moisture Content							
				Corn		wheat		summerfallow		Alfalfa	
				0-5	5-15	0-5	5-15	0-5	5-15	0-5	5-15
5	06	5	21	24.23	26.59	25.60	53.49	23.01	25.01	17.79	25.95
			28	22.34	31.51	22.68	25.07	20.97	25.61	17.28	23.23
		6	04	19.59	22.96	22.30	24.77	17.67	22.58	16.23	17.31
			11	24.29	26.40	23.63	25.87	24.78	24.82	16.98	20.76
6	20		18	21.70	22.91	23.42	24.00	20.84	22.30	17.31	17.16
			25	24.04	26.02	24.78	24.03	22.02	22.81	20.66	19.72
7	03	7	02	21.03	23.69	22.30	22.34	22.31	22.51	17.08	16.97
7	10		09	23.74	25.69	22.79	24.42	23.99	24.91	17.75	16.52
			16	18.07	27.37	26.64	62.65	27.01	26.83	25.27	26.48
			23	23.31	25.94	26.49	27.63	29.24	25.97	28.02	23.75
			30	20.21	21.22	22.55	21.49	24.31	25.49	20.89	20.28
		8	06	21.14	21.89	19.41	19.03	24.16	26.79	17.50	19.51
			13	18.88	20.39	17.86	18.29	19.65	23.33	15.81	17.08
			20	15.90	21.71	16.90	18.22	19.69	23.54	13.93	15.29
			27	14.27	17.97	9.62	15.73	16.47	22.43	13.68	14.49
		9	02	15.82	17.08	13.66	14.20	20.41	20.73	11.64	12.77
			09	8.59	16.77	9.69	14.51	19.33	21.12	9.05	13.91
			12	6.95	16.97	9.58	14.87	13.11	18.89	9.09	14.05
9	25		19	10.59	16.80	10.80	14.64	17.63	20.30	11.10	12.63
9	29		26	24.32	18.62	24.61	18.29	28.08	21.70	24.96	21.27
		10	03	27.05	22.68	29.22	27.87	28.16	27.25	28.13	28.00
			10	22.47	22.89	19.37	24.28	22.73	23.92	22.93	25.02
			17	21.04	20.74	20.45	20.13	20.94	22.59	19.25	22.03
			24	19.21	20.79	19.15	20.92	21.59	24.83	19.23	20.64

Appendix F

DATE OF RAINFALL AND SOIL MOISTURE (% OF DRY MASS) FOR GRETNA CLAY SOIL, 1987

Date of Rainfall	Date of Sampling	Sampled Soil Layers (cm) and Percent Moisture Content							
		Corn		wheat		summerfallow		Alfalfa	
		0-5	5-15	0-5	5-15	0-5	5-15	0-5	5-15
	5 19	10.96	19.70	17.16	21.74	20.31	21.84	12.95	15.24
	26	22.29	18.20	25.90	16.47	25.54	21.72	25.05	15.15
	6 02	26.00	22.61	20.87	22.04	23.17	24.11	23.41	17.84
	09	20.25	21.80	13.66	18.10	21.24	22.44	11.19	14.23
	17	20.04	20.67	19.62	18.89	22.96	22.93	14.30	14.31
	24	13.68	21.01	17.04	17.50	6.35	22.68	12.41	14.81
7 03	7 03	14.36	19.83	14.55	18.05	13.23	21.49	15.47	14.47
7 10	07	18.80	20.33	15.55	16.74	19.62	23.62	13.87	13.50
7 20	15	31.65	24.84	33.30	26.88	32.32	27.03	29.49	26.69
7 24	21	27.92	28.05	26.13	18.95	28.31	28.25	28.10	27.87
	28	21.57	26.03	18.01	24.67	26.31	20.61	20.13	22.60
	8 04	19.38	21.15	18.11	22.67	22.85	22.91	15.76	18.47
8 14	11	-	-	-	-	-	-	-	-
	18	28.86	27.26	28.64	19.06	27.22	27.26	28.02	27.82
	25	25.19	25.63	17.62	26.24	14.76	24.77	17.50	37.12
	9 01	20.01	23.42	36.69	24.88	19.16	24.28	17.24	20.40
	08	17.97	13.90	21.36	23.23	19.59	21.47	0.00	17.07
	15	21.91	20.92	21.58	24.94	23.58	22.81	20.26	18.51
	22	20.69	19.92	23.41	23.34	20.87	25.22	17.32	16.04
9 29	29	26.46	21.81	27.87	25.05	25.31	22.94	24.32	19.53
	10 05	17.61	20.80	24.11	24.71	19.74	23.32	17.17	15.94
	13	17.12	19.51	22.56	24.28	18.76	22.79	11.80	16.41

Appendix G

DATE OF RAINFALL AND SOIL MOISTURE (% OF DRY MASS) FOR LEARY SANDY LOAM SOIL, 1986

Date of Rainfall	Date of Sampling	Sampled Soil Layers (cm) and Percent Moisture Content							
		Corn		wheat		summerfallow		Alfalfa	
		0-5	5-15	0-5	5-15	0-5	5-15	0-5	5-15
5 06	5 12	13.42	13.85	12.90	14.52	12.21	13.82	13.11	12.93
	21	10.13	13.91	10.18	15.78	10.07	14.06	17.42	11.41
	28	9.38	12.66	11.15	12.16	8.98	12.29	5.83	7.04
6 14	6 04	8.35	10.68	5.67	9.43	8.04	10.36	4.29	5.03
	11	9.86	15.78	8.23	15.87	8.40	13.04	5.93	6.38
6 20	18	10.16	13.05	9.77	12.20	9.21	12.82	10.35	10.75
	25	11.37	13.75	9.09	11.66	10.15	13.37	9.47	9.83
7 03	7 02	13.98	14.86	8.94	11.58	8.91	13.32	13.79	14.49
7 10	09	9.75	11.89	6.05	7.97	9.22	11.73	7.31	8.72
	16	11.77	14.51	10.33	12.64	10.82	13.54	11.32	11.92
	23	10.99	11.71	8.14	9.76	9.43	12.37	8.85	9.84
	30	10.70	11.16	10.22	10.12	8.96	11.51	11.28	9.40
	8 06	10.58	11.40	7.95	7.44	9.11	11.55	9.76	9.07
	13	9.04	12.20	6.50	7.17	10.02	13.10	6.08	6.59
	20	6.43	8.50	4.42	6.03	8.21	10.41	5.22	6.29
	27	6.23	7.89	5.37	5.69	8.13	11.24	5.51	5.80
	9 02	6.89	7.95	5.34	5.91	7.15	12.19	5.67	5.95
	09	7.56	7.62	6.65	6.66	7.41	10.76	5.81	5.86
	12	6.69	7.53	5.52	5.41	7.30	9.55	4.49	5.03
	19	8.98	9.45	7.74	8.51	8.77	11.20	7.54	6.66
9 25	26	12.36	12.26	11.77	12.69	15.50	13.06	12.98	11.92
9 29	10 03	12.05	13.35	12.92	17.17	14.21	15.29	13.12	12.67
	10	10.91	11.86	11.88	12.20	11.70	12.57	12.63	11.66
	17	9.02	11.64	8.42	9.78	9.66	11.46	9.81	11.05
	24	9.08	12.19	8.64	16.17	8.21	14.99	8.22	10.96

Appendix H

DATE OF RAINFALL AND SOIL MOISTURE (% OF DRY MASS) FOR LEARY SANDY LOAM SOIL, 1987

Date of Rainfall	Date of Sampling	Sampled Soil Layers (cm) and Percent Moisture Content							
		Corn		wheat		summerfallow		Alfalfa	
		0-5	5-15	0-5	5-15	0-5	5-15	0-5	5-15
5 21	5 19	11.38	13.13	8.96	14.34	9.78	12.70	6.42	6.86
	26	11.85	12.26	11.36	11.96	12.77	12.82	10.85	9.10
	6 02	10.30	12.47	8.96	12.02	10.42	13.27	7.62	6.36
	09	9.57	12.99	6.83	10.80	8.09	9.05	4.74	5.16
	17	9.11	12.17	5.64	6.63	9.54	13.08	5.51	5.12
6 24	24	10.04	10.86	8.45	8.11	10.13	12.17	7.93	8.16
7 03	7 03	9.80	10.75	8.41	8.53	10.52	11.91	8.14	6.62
10	07	10.80	9.41	6.90	6.85	10.02	11.81	6.35	5.81
20	15	11.55	11.60	9.36	10.59	11.42	12.37	9.80	9.12
	21	11.57	12.20	11.07	11.75	9.25	14.02	7.89	10.37
	28	7.10	8.60	5.25	7.31	8.62	11.82	6.44	7.59
	8 04	7.17	8.63	5.34	8.06	8.07	12.26	5.45	5.80
8 14	11	13.11	7.76	12.11	8.35	12.87	10.59	11.66	6.49
	25	11.26	11.10	6.62	10.25	9.55	12.37	6.30	8.25
	9 01	7.96	9.51	6.17	8.86	9.20	11.31	6.28	6.88
	08	6.11	8.49	7.28	9.74	5.46	12.37	1.78	3.74
	14	9.72	9.81	9.65	10.60	9.58	12.07	8.95	8.19
	22	6.45	8.72	8.51	11.49	8.98	12.13	14.40	6.90
9 29	29	11.99	12.05	13.09	13.54	12.66	14.85	13.09	11.27
	10 06	10.08	10.92	10.27	12.76	10.19	12.90	9.67	7.43
	13	9.60	15.79	9.26	17.43	7.86	11.66	7.81	7.41

Appendix I

DATE OF RAINFALL AND SOIL MOISTURE (% OF DRY MASS) FOR RYERSON SANDY CLAY LOAM SOIL, 1987

Date of Rainfall	Date of Sampling	Sampled Soil Layers (cm) and Percent Moisture Content									
		Corn		Wheat (Con. Till.)		Wheat (Min. Till.)		Summerfallow		Alfalfa	
		0-5	5-15	0-5	5-15	0-5	5-15	0-5	5-15	0-5	5-15
	5 19	16.80	15.94	13.67	18.19	18.06	17.69	18.26	19.97	12.70	14.92
	27	20.53	19.38	30.80	13.83	23.01	21.25	20.56	21.37	15.12	12.30
6 02	6 03	24.82	20.85	22.45	19.24	24.95	21.38	23.43	21.58	21.04	12.48
	10	14.36	20.03	13.45	11.61	14.07	17.49	15.60	21.04	9.84	11.72
	16	15.91	20.95	10.75	13.53	14.08	16.64	14.54	19.47	9.97	10.97
24	25	9.55	18.85	8.91	14.25	11.56	9.01	11.60	18.35	11.38	8.34
7 08	7 02	18.67	18.06	15.99	13.24	15.36	11.55	17.56	19.88	14.50	11.24
10	08	19.84	18.86	17.21	13.88	17.65	16.82	29.90	21.74	17.19	13.92
20	14	18.25	20.79	14.44	16.77	16.89	18.54	16.56	21.75	15.30	15.10
	22	23.43	23.99	24.95	23.71	28.26	27.69	27.01	28.05	27.85	22.93
31	29	15.30	16.91	11.60	14.46	11.37	16.87	17.22	19.31	11.92	12.81
8 04	8 05	20.02	20.40	16.41	19.57	10.90	20.10	15.72	24.26	15.36	16.28
14	11	12.02	15.92	12.43	14.85	11.76	16.21	15.42	19.82	10.13	11.07
	19	17.55	22.40	20.15	21.72	22.89	25.23	16.60	24.92	21.30	21.57
	26	16.09	20.22	18.06	20.60	19.93	23.80	17.37	23.50	16.74	18.45
	9 02	14.47	19.86	16.11	20.36	22.98	24.61	19.10	20.88	13.51	14.44
	08	10.21	15.63	14.82	17.67	17.15	22.62	16.83	21.46	11.50	11.98
	15	15.07	15.23	16.91	17.66	19.83	21.73	18.06	33.62	11.95	14.81
	22	14.21	15.86	16.85	17.54	21.99	21.53	16.52	22.48	18.53	12.30
	28	13.65	15.01	11.88	18.04	18.52	21.17	15.08	21.54	13.06	13.87
	10 06	9.67	12.66	11.37	15.83	14.44	18.16	15.08	17.94	7.05	10.19
	12	14.02	21.21	13.76	18.46	15.87	21.12	15.87	21.12	11.80	11.02
	20	10.90	15.00	12.96	16.88	16.87	19.93	14.49	20.57	11.15	11.81
	21	13.19	15.02	15.27	17.25	17.26	18.76	17.38	19.24	13.06	11.19

Appendix J

DATE OF RAINFALL AND SOIL MOISTURE (% OF DRY MASS) FOR CARROLL CLAY LOAM SOIL, 1987

Date of Rainfall		Date of Sampling		Sampled Soil Layers (cm) and Percent Moisture Content									
				Corn		Wheat (Con. Till.)		Wheat (Min. Till.)		Summerfallow		Alfalfa	
				0-5	5-15	0-5	5-15	0-5	5-15	0-5	5-15	0-5	5-15
		5	20	21.73	22.17	23.27	25.41	21.49	25.89	22.03	27.21	22.47	23.55
			27	21.70	22.95	22.30	24.98	22.16	26.01	22.45	27.46	23.54	26.36
6	03	6	03	25.06	24.49	24.01	24.42	24.42	23.17	24.84	24.74	23.77	23.02
			10	18.07	22.30	16.29	15.88	16.77	24.43	18.49	25.75	16.24	21.88
			16	19.82	23.03	15.41	17.25	15.52	15.53	15.41	17.20	14.41	17.59
			25	17.68	21.16	16.58	17.47	16.87	18.86	19.29	22.44	17.59	17.34
7	14	7	02	22.13	22.65	21.93	23.07	22.24	21.31	22.52	23.42	22.50	19.82
			08	17.13	21.95	16.26	15.42	12.36	15.29	19.12	25.22	12.97	15.91
			14	36.31	26.57	31.53	21.88	30.10	20.22	34.62	29.17	31.34	22.38
	20		22	27.46	28.00	26.68	24.70	26.84	27.50	27.42	30.50	26.69	24.94
	31		29	15.61	22.05	13.88	17.89	15.42	18.71	18.16	26.46	12.49	17.80
8	12	8	05	18.11	23.33	13.62	15.75	14.35	15.50	19.72	27.62	16.72	18.54
	14		12	24.00	23.21	25.24	18.02	25.02	20.97	25.18	27.42	24.48	17.25
			19	23.13	27.16	24.14	25.55	13.21	26.05	24.46	27.78	22.93	25.58
			25	20.90	21.05	20.16	23.55	17.69	22.35	22.65	29.90	19.37	22.12
		9	02	18.00	22.25	18.82	21.92	17.93	26.77	25.62	28.08	18.53	22.95
			08	15.98	20.91	15.08	19.09	11.95	19.29	25.70	28.24	14.22	18.08
			15	15.68	21.29	16.63	19.90	18.54	25.24	20.45	21.06	15.17	17.27
			22	21.57	20.91	33.98	24.92	23.17	23.87	24.96	26.70	22.50	22.40
			29	19.91	20.34	21.03	22.61	19.82	22.02	23.27	25.86	17.33	12.02
		10	06	15.07	18.49	19.31	20.50	16.68	17.96	19.67	22.31	13.01	25.17
			12	16.69	20.72	17.55	22.03	17.11	21.04	11.38	28.18	13.98	17.21
			20	16.94	21.12	16.69	18.92	16.72	20.64	19.98	24.78	13.69	14.96
			27	18.08	19.48	19.07	20.31	17.53	18.56	18.77	24.58	15.17	16.87

Appendix K

SOIL BULK DENSITY AND SOIL MOISTURE CONTENT AT TIME OF BULK DENSITY MEASUREMENT

Grid Position No.	Bulk Density ($Mg\ m^{-3}$) 0.0-7.5 (cm)	Bulk Density ($Mg\ m^{-3}$) 7.5-15.0 (cm)	Soil Moisture Content (%) 0.0-7.5 (cm)	Soil Moisture Content (%) 7.5-15.0 (cm)
Gretna Clay				
1	1.41	1.58	14.68	16.35
2	1.43	1.50	15.43	16.07
3	1.44	1.51	17.74	18.12
4	1.35	1.56	19.96	21.60
5	1.35	1.58	16.82	16.74
6	1.49	1.62	18.07	17.07
7	1.60	1.62	17.92	19.54
8	1.69	1.60	13.60	16.41
9	1.40	1.53	18.79	18.60
Mean Values	1.46	1.57	17.00	17.83
Leary Sandy Loam				
1	1.43	1.40	6.86	9.42
2	1.36	1.30	9.22	9.91
3	1.36	1.51	5.77	6.34
4	1.61	1.39	6.88	7.31
6	1.18	1.50	7.13	7.44
7	1.23	1.21	6.66	6.40
8	1.32	1.22	5.62	7.55
9	1.27	1.32	9.16	11.27
Mean Values	1.37	1.37	7.47	8.32

Appendix L

SOIL BULK DENSITY AND SOIL MOISTURE CONTENT AT TIME OF BULK DENSITY MEASUREMENT

Grid Position	Bulk Density (Mg m^{-3})		Soil Moisture Content (%)	
	0.0-7.5 (cm)	7.5-15.0 (cm)	0.0-7.5 (cm)	7.5-15 (cm)
Ryerson Sandy Clay Loam				
1	1.32	1.46	13.67	15.73
2	1.50	1.49	20.17	19.04
3	1.33	1.21	17.20	20.15
4	1.14	1.13	21.14	24.58
5	1.21	1.26	21.06	19.99
6	1.20	1.17	22.28	23.03
7	1.15	1.23	18.80	20.49
8	1.26	1.40	12.57	14.42
9	0.96	0.95	22.62	24.45
Mean Values	1.23	1.26	18.22	20.21
Carroll Caly Loam				
1	1.33	1.30	18.88	16.86
2	1.36	1.39	19.70	20.86
3	1.27	1.18	27.44	30.43
4	1.10	1.22	19.97	19.72
5	1.33	1.40	20.44	22.68
6	1.14	1.36	20.64	26.70
7	1.13	1.34	22.29	24.96
8	1.30	1.28	21.50	22.49
9	1.36	1.23	24.02	26.79
Mean Values	1.26	1.30	21.65	23.50

Appendix M

COMPUTER PROGRAMMES FOR DATA ANALYSIS

SOIL MOISTURE CONTENT DATA ANALYSIS PROGRAMME (PROG. 1)

```
//SOILLOSS  JOB ',,F=DDJ1'
//          EXEC WATFIV
//FT05F001  DD  *
$JOB  WATFIV
C
C      FILE NAME = MSWCPR
C  THIS PROGRAM CALCULATES THE SOIL WATER CONTENT FOR WATER EROSION SITES
C  USING THE FORMULA  W=(WET WEIGHT - DRY WEIGHT)/(DRY WEIGHT
C   - CONTAINER WEIGHT)*  100.  IT IS SPECIFICALLY WRITTEN
C  FOR USE WITH SMALL CONTAINERS, THE WEIGHTS OF WHICH ARE CONTAINED IN
C  FILE = 'SMALL', WHICH MUST BE SUBMITTED WITH THIS FILE.
C  TYPICAL SUBMIT COMMAND = SUB MSWCPR,SMALL,RSWCDA86.  FILE 'RSWCDA86
C  CONTAINS DATA FOR 0 - 5 CM AND 5-15 CM DEPTHS
C  IN THE FOLLOWING ORDER; CB,CM,CU,WB,WM,WU,SB,SM,SU,
C  AB,AM,AU.|
C
      DIMENSION N(5)
      REAL CNTWGH(300),
     *     SLWGH(24,3),WETIN,DRYIN,CAVG,WAVG,SAVG,AAVG
      INTEGER CT/0/,DTESV/0/,CNTNUM,DTEIN,LC/99/,IND
      DO 201 I = 1,264
  201 READ(5,101) CNTWGH(I)
  101 FORMAT(5X,F5.0)
      READ(5,66)  (N(M), M = 1,5)
   66 FORMAT(5A2)
150   CONTINUE
      READ (5,100,END=700)  DTEIN,CNTNUM,WETIN,DRYIN
100   FORMAT (I6,3X, I3, F6.2,F6.2)
      IF (CT .EQ. 0) GOTO 160
      CNTWGH(CT) = CNTWGH(CNTNUM)
      IF (DTEIN .NE. DTESV) GOTO 170
155   CONTINUE
      CT = CT + 1
C     IF (CT .NE. CNTNUM) GOTO 180
      SLWGH(CT,1)=WETIN
      SLWGH(CT,2)=DRYIN
      IF (CT .NE. 24) GOTO 150
      CT=0
      GOTO 500
160   CONTINUE
      IF (DTEIN .GT. DTESV) GOTO 190
      WRITE (6,50) DTESV,DTEIN
50    FORMAT ('-','*** DATE OUT OF ORDER. PREVIOUS ',I6,3X,
```

```
     *       ' CURRENT ',I6/'-')
       CT=0
       GOTO 150
170    CONTINUE
       WRITE (6,70) DTEIN
70     FORMAT ('-','*** UNEXPECTED NEW DATE ',I6 /'-')
       CT=0
       GOTO 150
180    CONTINUE
       WRITE (6,60) DTESV
60     FORMAT ('-','*** MISSING CONTAINER DATA FOR ',I6 /'-')
       CT=0
       GOTO 150
190    CONTINUE
       DTESV = DTEIN
       GOTO 155
500    CONTINUE
       IF (LC .GE. 48) GOTO 650
655    CONTINUE
       WRITE (6,15) DTEIN
15     FORMAT (/,'  ',I6)
       DO 660  IND = 1, 24
       SLWGH(IND,3)=((SLWGH(IND,1)-SLWGH(IND,2))/
     * (SLWGH(IND,2)-CNTWGH(IND)))*100.00
660    CONTINUE
      WRITE(6,21)
21    FORMAT(/,39X,'  0 - 5 CM')
       WRITE(6,20) SLWGH(5,3),SLWGH(11,3),SLWGH(17,3),SLWGH(23,3)
20     FORMAT ('   UPPER',11X,F6.2,9X,F6.2,9X,F6.2,9X,F6.2)
       WRITE(6,25) SLWGH(3,3),SLWGH(9,3),SLWGH(15,3),SLWGH(21,3)
25     FORMAT ('   MIDDLE',10X,F6.2,9X,F6.2,9X,F6.2,9X,F6.2)
       WRITE(6,30) SLWGH(1,3),SLWGH(7,3),SLWGH(13,3),SLWGH(19,3)
30     FORMAT ('   LOWER',11X,F6.2,9X,F6.2,9X,F6.2,9X,F6.2)
       CAVG=(SLWGH(1,3)+SLWGH(3,3)+SLWGH(5,3))/3.00
       WAVG=(SLWGH(7,3)+SLWGH(9,3)+SLWGH(11,3))/3.00
       SAVG=(SLWGH(13,3)+SLWGH(15,3)+SLWGH(17,3))/3.00
       AAVG=(SLWGH(19,3)+SLWGH(21,3)+SLWGH(23,3))/3.00
       WRITE(6,35) CAVG,WAVG,SAVG,AAVG
35     FORMAT (/,'   AVERAGE',9X,F6.2,9X,F6.2,9X,F6.2,9X,F6.2)
        WRITE(6,22)
   22 FORMAT(/,39X, '  5 - 15 CM')
       WRITE(6,20) SLWGH(6,3),SLWGH(12,3),SLWGH(18,3),SLWGH(24,3)
       WRITE(6,25) SLWGH(4,3),SLWGH(10,3),SLWGH(16,3),SLWGH(22,3)
       WRITE(6,30) SLWGH(2,3),SLWGH(8,3),SLWGH(14,3),SLWGH(20,3)
       CAVG=(SLWGH(2,3)+SLWGH(4,3)+SLWGH(6,3))/3.00
       WAVG=(SLWGH(8,3)+SLWGH(10,3)+SLWGH(12,3))/3.00
       SAVG=(SLWGH(14,3)+SLWGH(16,3)+SLWGH(18,3))/3.00
       AAVG=(SLWGH(20,3)+SLWGH(22,3)+SLWGH(24,3))/3.00
       WRITE(6,35) CAVG,WAVG,SAVG,AAVG
       LC = LC + 15
       GOTO 150
650    CONTINUE
       WRITE(6,1) (N(M), M= 1,5)
1      FORMAT ('1',27X,5A2,'SOIL  WATER  CONTENT')
       WRITE(6,5)
```

```
5       FORMAT ('0','  DATE',14X,'CORN',10X,'WHEAT',8X,
     *  'SMFALLOW',7X,'ALFALFA'/)
        LC=4
        GOTO 655
700     WRITE(6,40)
40      FORMAT ('-',32X,'END OF REPORT'/'1')
        STOP
        END
```

SOIL MOSTURE DATA ANALYSIS PROGRAMME (PROG. 2)
(MODIFICATION OF PROG. 1 FOR MINIMUM TILLAGE WHEAT TREATMENT)

```
$ENTRY
//SOILLOSS  JOB ',,F=DDJ1'
//         EXEC WATFIV
//FT05F001  DD  *
$JOB  WATFIV
C
C      FILE NAME = MSWCPR87
C   THIS PROGRAM CALCULATES THE SOIL WATER CONTENT FOR WATER EROSION SITES
C   USING THE FORMULA  W=(WET WEIGHT - DRY WEIGHT)/(DRY WEIGHT
C    - CONTAINER WEIGHT)*  100.  IT IS SPECIFICALLY WRITTEN
C   FOR USE WITH SMALL CONTAINERS, THE WEIGHTS OF WHICH ARE CONTAINED IN
C    FILE = 'SMALL', WHICH MUST BE SUBMITTED WITH THIS FILE.
C    TYPICAL SUBMIT COMMAND = SUB MSWCPR,SMALL,HSWCDA87.  FILE 'HSWCDA87
C    CONTAINS DATA FOR 0 - 5 CM AND 5-15 CM DEPTHS
C   IN THE FOLLOWING ORDER; CB,CM,CU,WB,WM,WU,SB,SM,SU,
C   AB,AM,AU,ZB,ZM,ZU.|
C
        DIMENSION N(5)
       REAL CNTWGH(240),
     *      SLWGH(30,3),WETIN,DRYIN,CAVG,WAVG,SAVG,AAVG,ZAVG
       INTEGER CT/0/,DTESV/0/,CNTNUM,DTEIN,LC/99/,IND
       DO 201 I = 1,240
  201 READ(5,101) CNTWGH(I)
  101 FORMAT(5X,F5.0)
      READ(5,66)  (N(M), M = 1,5)
   66 FORMAT(5A2)
150    CONTINUE
       READ (5,100,END=700)  DTEIN,CNTNUM,WETIN,DRYIN
100    FORMAT (I6,3X, I3, F6.2,F6.2)
       IF (CT .EQ. 0) GOTO 160
       CNTWGH(CT) = CNTWGH(CNTNUM)
       IF (DTEIN .NE. DTESV) GOTO 170
155    CONTINUE
       CT = CT + 1
C      IF (CT .NE. CNTNUM) GOTO 180
       SLWGH(CT,1)=WETIN
       SLWGH(CT,2)=DRYIN
       IF (CT .NE. 30) GOTO 150
       CT=0
       GOTO 500
160    CONTINUE
       IF (DTEIN .GT. DTESV) GOTO 190
       WRITE (6,50) DTESV,DTEIN
50     FORMAT ('-','*** DATE OUT OF ORDER. PREVIOUS ',I6,3X,
     *         ' CURRENT ',I6/'-')
       CT=0
       GOTO 150
170    CONTINUE
       WRITE (6,70) DTEIN
70     FORMAT ('-','*** UNEXPECTED NEW DATE ',I6 /'-')
       CT=0
       GOTO 150
```

```
180     CONTINUE
        WRITE (6,60) DTESV
60      FORMAT ('-','*** MISSING CONTAINER DATA FOR ',I6 /'-')
        CT=0
        GOTO 150
190     CONTINUE
        DTESV = DTEIN
        GOTO 155
500     CONTINUE
        IF (LC .GE. 48) GOTO 650
655     CONTINUE
        WRITE (6,15) DTEIN
15      FORMAT (/,'  ',I6)
        DO 660  IND = 1, 30
        SLWGH(IND,3)=((SLWGH(IND,1)-SLWGH(IND,2))/
     *  (SLWGH(IND,2)-CNTWGH(IND)))*100.00
660     CONTINUE
       WRITE(6,21)
21     FORMAT(/,35X,'  0 - 5 CM')
       WRITE(6,20) SLWGH(5,3),SLWGH(11,3),SLWGH(17,3),SLWGH(23,3)
     *,SLWGH(29,3)
20     FORMAT ('   UPPER',2X,5(9X,F6.2))
       WRITE(6,25) SLWGH(3,3),SLWGH(9,3),SLWGH(15,3),SLWGH(21,3)
     *,SLWGH(27,3)
25     FORMAT ('   MIDDLE',1X,5(9X,F6.2))
       WRITE(6,30) SLWGH(1,3),SLWGH(7,3),SLWGH(13,3),SLWGH(19,3)
     *,SLWGH(25,3)
30     FORMAT ('   LOWER',2X,5(9X,F6.2))
        CAVG=(SLWGH(1,3)+SLWGH(3,3)+SLWGH(5,3))/3.00
        WAVG=(SLWGH(7,3)+SLWGH(9,3)+SLWGH(11,3))/3.00
        SAVG=(SLWGH(13,3)+SLWGH(15,3)+SLWGH(17,3))/3.00
        AAVG=(SLWGH(19,3)+SLWGH(21,3)+SLWGH(23,3))/3.00
        ZAVG=(SLWGH(25,3)+SLWGH(27,3)+SLWGH(29,3))/3.00
        WRITE(6,35) CAVG,WAVG,SAVG,AAVG,ZAVG
35      FORMAT (/,'   AVERAGE',5(9X,F6.2))
         WRITE(6,22)
   22 FORMAT(/,35X, '  5 - 15 CM')
       WRITE(6,20) SLWGH(6,3),SLWGH(12,3),SLWGH(18,3),SLWGH(24,3)
     *,SLWGH(30,3)
       WRITE(6,25) SLWGH(4,3),SLWGH(10,3),SLWGH(16,3),SLWGH(22,3)
     *,SLWGH(28,3)
       WRITE(6,30) SLWGH(2,3),SLWGH(8,3),SLWGH(14,3),SLWGH(20,3)
     *,SLWGH(26,3)
        CAVG=(SLWGH(2,3)+SLWGH(4,3)+SLWGH(6,3))/3.00
        WAVG=(SLWGH(8,3)+SLWGH(10,3)+SLWGH(12,3))/3.00
        SAVG=(SLWGH(14,3)+SLWGH(16,3)+SLWGH(18,3))/3.00
        AAVG=(SLWGH(20,3)+SLWGH(22,3)+SLWGH(24,3))/3.00
        ZAVG=(SLWGH(26,3)+SLWGH(28,3)+SLWGH(30,3))/3.00
        WRITE(6,35) CAVG,WAVG,SAVG,AAVG,ZAVG
        LC = LC + 15
        GOTO 150
650     CONTINUE
        WRITE(6,1) (N(M), M = 1,5)
1       FORMAT ('1',27X,5A2,'SOIL  WATER  CONTENT')
        WRITE(6,5)
```

```
5       FORMAT ('0','  DATE',14X,'CORN',10X,'WHEAT',8X,
      * 'SMFALLOW',7X,'ALFALFA',7X, 'MINIMUM'/)
        LC=4
        GOTO 655
700     WRITE(6,40)
40      FORMAT ('-',32X,'END OF REPORT'/'1')
        STOP
        END
$ENTRY
```

RAINFALL DATA ANALYSIS PROGRAMME

```
//GO.INPUT DD *
//SOILLOSS JOB ',,'
// EXEC PASCCG
//PASC.SYSIN DD *
PROGRAM RFSUMMPR(INPUT,OUTPUT);

   (*** THIS PROGRAM CALCULATES THE RAINFALL CHARACTERISTICS
        THE FIRST RECORD IN THE DATA FILE IS THE LOCATION
        CARD AND THE FIRST 8 CHARACTERS ARE TAKEN AS THE
        SITE NAME.
        THIS PROGRAM IS A SUMMARY VERSION, PRINTING THE TOTAL
        INTENSITIES AND RELEVANT TOTALS.
        THIS PROGRAM WAS WRITTEN BY JOY L. PAULS FOR USE
        IN THE SOIL EROSION RESEARCH PROJECT             ***)

CONST
   CLOCKHR = 24;
   MAXIPM = 5000;
   SITELEN = 8;
   MAXLINES = 60;

TYPE
   TIMEREC = RECORD
      HR : INTEGER;
      MIN : INTEGER;
   END;
   IPMARRAY = RECORD
      LAST : 0..MAXIPM;
      ARR : ARRAY [1..MAXIPM] OF REAL;
   END;

VAR
   LINECT,MINS,IND,DATEIN,DATESV:INTEGER;
   STTIME,ENDTIME:TIMEREC;
   SITE : STRING(SITELEN);
   CH : CHAR;
   AMTIN,INTENS,EPM,EPI,TOTAMT,TOTEPI:REAL;
   IPMTAB : IPMARRAY;

PROCEDURE HDGRTN(CONST SITE:STRING(SITELEN);
                 VAR LINECT,DATESV : INTEGER);

    (* PRINT THE HEADINGS *)

   BEGIN
   IF LINECT > 48 THEN
      BEGIN
      LINECT := 0;
      PAGE;
      WRITELN;  WRITELN;   WRITELN;
      END
   ELSE
      BEGIN
```

```
      WRITELN;  WRITELN;   WRITELN;
      END;
   WRITELN(' ':18,'SITE: ':6,SITE:SITELEN,' ':18,'DATE: ',DATESV:6);
   WRITELN;
   LINECT := LINECT + 4;
   END;
               (* END HEADING ROUTINE *)


FUNCTION MINCALC (OLDT,NEWT:TIMEREC):INTEGER;

   (* CALCULATE ELAPSED MINUTES FROM THE TWO GIVEN TIMES *)

   BEGIN
   IF NEWT.HR >=OLDT.HR THEN BEGIN
      IF NEWT.MIN >= OLDT.MIN THEN
         MINCALC := ((NEWT.HR - OLDT.HR)*60) + (NEWT.MIN - OLDT.MIN)
      ELSE
         MINCALC := (((NEWT.HR - OLDT.HR) - 1) * 60) +
                      ((60 - OLDT.MIN) + NEWT.MIN)
   END ELSE BEGIN
      IF NEWT.MIN >= OLDT.MIN THEN
         MINCALC := (((CLOCKHR - OLDT.HR) + NEWT.HR) * 60) +
                    (NEWT.MIN - OLDT.MIN)
      ELSE
         MINCALC := ((((CLOCKHR - OLDT.HR) + NEWT.HR) - 1) * 60) +
                     ((60 - OLDT.MIN) + NEWT.MIN)
   END;
   END;
                    (* END OF MINUTES CALCULATION *)


PROCEDURE INTPERMIN (VAR IPMTAB:IPMARRAY; MIN:INTEGER; AMT:REAL);

   (* THIS PROCEDURE INPUTS THE INTENSITY PER MINUTE FOR EACH *)
   (* MINUTE IN THE GIVEN INTERVAL, INTO THE IPM TABLE *)

   VAR
      I : INTEGER;
      IPMWK : REAL;

   BEGIN
   IPMWK := AMT / MIN;
   IF (IPMTAB.LAST + I) > MAXIPM THEN
      WRITELN('*** INTENSITY TABLE NEEDS SIZE INCREASE ***')
   ELSE BEGIN
      FOR I := 1 TO MIN DO
         IPMTAB.ARR[IPMTAB.LAST+I] := IPMWK;
      IPMTAB.LAST := IPMTAB.LAST + MIN;
      END;
   END;
              (* END INTENSITY TABLE INSERTION *)


FUNCTION  MAXINT (VAR IPMTAB:IPMARRAY):REAL;
```

```
          (* CALCULATE THE 30 MINUTE PERIOD OF MAXIMUM *)
           (* INTENSITY RAINFALL *)

VAR
   MAX,SUM:REAL;
   I : INTEGER;

   BEGIN
   WITH IPMTAB DO BEGIN
      IF LAST < 30 THEN
         BEGIN
         WRITELN('*** RAINFALL PERIOD OF INSUFFICIENT LENGTH *** - ',
                 LAST:3,' MINUTES');
         MAX := 0.0;
         FOR I := 1 TO LAST DO
            MAX := MAX + ARR[I];
         END    (* IF *)
      ELSE BEGIN
         MAX := 0.0;
         FOR I := 1 TO 30 DO
            MAX := MAX + ARR[I];
         I := 1;
         SUM := MAX;
         WHILE ((I + 30) <= LAST) DO
            BEGIN
            SUM := SUM - ARR[I] + ARR[I + 30];
            IF SUM > MAX THEN
               MAX := SUM;
            I := I + 1;
            END;   (* WHILE *)
         END;   (* ELSE *)
      MAXINT := MAX;
      END;   (* WITH *)
   END;

      (* END OF MAXIMUM INTENSITY CALCULATION *)


PROCEDURE DATEDATA(TOTEPI,TOTAMT:REAL);

   (* PRINT OUT DATA FOR RAINFALL AS PER DATE *)

   VAR
      MAXI30, MAXDBL, MAXMLT, TOTDIV : REAL;

   BEGIN
   WRITELN;
   WRITELN(' ':5,'TOTALS:',' ':14,'AMOUNT ',TOTAMT:5:1,' ':18,
          'KINETIC ENERGY ',TOTEPI:7:2);
   WRITELN;
   TOTDIV := TOTEPI/100.0;
   WRITELN(' ':5,'KINETIC ENERGY = ',TOTEPI:7:2,' /100 = ',
          TOTDIV:7:2,' MJ/ha');
   WRITELN;
```

```
   MAXI30 := MAXINT(IPMTAB);
   MAXDBL := MAXI30 * 2;
   WRITELN(' ':5,'MAX. RAIN IN 30 MINUTES = ',MAXI30:5:1,
          ' mm',' ':9,'I30 = ',MAXI30:5:1,' *2  = ',
          MAXDBL:5:1,' mm/hr');
   WRITELN;
   MAXMLT := TOTDIV * MAXDBL;
   WRITELN('     EI = ',TOTDIV:7:2,' * ',MAXDBL:5:1,
            ' = ',MAXMLT:7:2,' MJ mm/ha hr');
   LINECT := LINECT + 8;
   END;

   (** END OF DATE DATA PRINT AND CALCULATIONS *)


PROCEDURE DATECH(VAR TOTEPI,TOTAMT:REAL);

   (* CHANGE OF RAINFALL , PRINT AND RESET VALUES *)

   BEGIN
   DATEDATA(TOTEPI,TOTAMT);
   DATESV := DATEIN;
   STTIME := ENDTIME;
   READLN(DATEIN,ENDTIME.HR,ENDTIME.MIN,AMTIN);
   IPMTAB.LAST := 0;
   TOTAMT := 0.0;
   TOTEPI := 0.0;
   HDGRTN (SITE,LINECT,DATESV);
   END;

   (* END OF DATE OF RAINFALL CHANGE *)


BEGIN   (* MAINLINE *)
IF NOT EOF THEN
   BEGIN
   SITE := '';
   FOR IND := 1 TO SITELEN DO
      BEGIN
      READ(CH);
      SITE := SITE || STR(CH);
      END;   (* FOR *)
   READLN;
   READLN(DATEIN,STTIME.HR,STTIME.MIN,AMTIN);
   DATESV := DATEIN;
   HDGRTN(SITE,LINECT,DATESV);
   IPMTAB.LAST := 0;
   TOTEPI := 0.0;
   TOTAMT := 0.0;
   WHILE (NOT EOF) DO
      BEGIN
      READLN(DATEIN,ENDTIME.HR,ENDTIME.MIN,AMTIN);
      IF (DATEIN <> DATESV) THEN
         DATECH(TOTEPI,TOTAMT);
      IF (LINECT > MAXLINES) THEN
```

```
            HDGRTN(SITE,LINECT,DATESV);
         MINS := MINCALC(STTIME,ENDTIME);
         INTPERMIN(IPMTAB,MINS,AMTIN);
         TOTAMT := TOTAMT + AMTIN;
         INTENS := (AMTIN * 60) / MINS;
         IF AMTIN = 0.0 THEN
            EPM := 0.0
         ELSE
            IF INTENS > 76 THEN
               EPM := 28.87
            ELSE
               EPM := 12.13 + (8.9 * ((LN(INTENS))/(LN(10))));
         IF EPM < 0.0 THEN
            EPM := 0.0;
         EPI := AMTIN * EPM;
         TOTEPI := TOTEPI + EPI;
         STTIME := ENDTIME;
         END;   (* WHILE *)
      DATEDATA(TOTEPI,TOTAMT);
      PAGE;
      END;   (* IF *)
   END.
```

SOIL LOSS DATA ANALYSIS PROGRAMME (PROG. 1)

```
//GO.INPUT DD *
//SOILLOSS JOB ',,,,,','SOILLOSS'
/*TSO SOIL
// EXEC WATFIV
//GO.SYSIN DD *
$JOB   WATFIV   JOY
C THIS PROGRAM CALCULATES THE SOIL LOSS.  IT ACCEPTS A DATA
C FILE WHOSE FIRST RECORD CONTAINS THE NAME OF THE LOCATION
C OF THE RESEARCH PLOT IN THE FIRST 10 SPACES OF THE RECORD.
C THE FIRST FILE IT ACCEPTS - SLCONWTS - CONTAINS THE JAR WEIGHTS.  AT
C PRESENT THERE ARE 190 JARS IN THE FILE.  THIS IS HARD CODED
C INTO THE PROGRAM. PLEASE UPDATE AS NECESSARY.
C THE DATA FILE CONTAINS THE WEIGHT OF THE SOIL PLUS THE JAR.
C IT ALSO CONTAINS THE DATA, PLOT CODE, JAR NUMBER, WEIGHT,
C AND AN INDICATOR (0 OR 1) AS TO WHETHER THIS IS A 1% SAMPLE.
C
      INTEGER NUMJAR/190/,PGNUM/1/,LC/70/,DATEIN,DATESV,
     *       MULTIN,JARIN,IND,N
      LOGICAL  CIND/F/,SIND/F/,WIND/F/,AIND/F/,EOF/F/,EOW/F/
      REAL  JARWT(300), WGHTIN
       REAL*8  WEIGHT,WRK,STOT/0.0D0/,WTOT/0.0D0/,CTOT/0.0D0/,
     *        ATOT/0.0D0/,FINS/0.0D0/,FINW/0.0D0/,FINC/0.0D0/,
     *         FINA/0.0D0/
       CHARACTER  PLOTIN,PLOTSV,CROP*5,NAMEIN*10,CORN/'C'/,
     *          WHEAT/'W'/,ALFALF/'A'/,SMRFLL/'S'/
C
C   START PROGRAM
C
      EXECUTE INITWT
      READ(5,10,END=100) NAMEIN
      EXECUTE READCD
      IF (EOF) GO TO 100
      DATESV = DATEIN
      EXECUTE PLTSET
80    CONTINUE
      IF (DATEIN .NE. DATESV) THEN DO
        EXECUTE DATECH
        EXECUTE PLTSET
      ENDIF
      IF (PLOTSV .NE. PLOTIN) THEN DO
        EXECUTE PLTSET
      ENDIF
      WGHTIN = WGHTIN - (JARWT(JARIN))
      IF (MULTIN .EQ. 1) THEN DO
        WEIGHT = WGHTIN * 100.0D0
      ELSE DO
        WEIGHT = WGHTIN * 1.0D0
      ENDIF
      EXECUTE ADDPLT
      EXECUTE READCD
      IF (EOF) GO TO 90
      GO TO 80
90    CONTINUE
```

```
      EXECUTE DATECH
      EXECUTE FINTOT
100     CONTINUE
      STOP
10    FORMAT (A10)
C
C   INITIALIZE CONTAINER WEIGHTS TABLE
C
      REMOTE BLOCK INITWT
        DO 140 IND=1,NUMJAR,1
          JARWT(IND) = 0.0
140   CONTINUE
145   CONTINUE
        READ 150,JARIN,WGHTIN
          AT END
            EOW = .TRUE.
          END AT END
        IF (JARIN .EQ.000) THEN DO
          EOW = .TRUE.
        ELSE DO
          JARWT(JARIN) = WGHTIN
        ENDIF
        IF (.NOT. EOW) GO TO 145
150   FORMAT (I3,F6.2)
      END BLOCK
C
C READ INPUT DATA CARD
C
      REMOTE BLOCK READCD
      READ 678,PLACE
  678 FORMAT(A5)
      PRINT 679,PLACE
  679 FORMAT(1H1, 5X, A5)
        READ 120,DATEIN,PLOTIN,JARIN,WGHTIN,MULTIN
          AT END
          EOF = .TRUE.
          END AT END
120   FORMAT (I6,A1,I3,F6.2,I1)
      END BLOCK
C
C SET THE CORRECT PLOT INDICATOR ON, TO INDICATE ACTUAL DATA
C IS PRESENT FOR A PARTICULAR DATE FOR THAT CROP
C
      REMOTE BLOCK PLTSET
        PLOTSV = PLOTIN
        IF (PLOTIN .EQ. CORN) THEN DO
          CIND = .TRUE.
        ELSE DO
          IF (PLOTIN .EQ. WHEAT) THEN DO
            WIND = .TRUE.
          ELSE DO
            IF (PLOTIN .EQ. SMRFLL) THEN DO
              SIND = .TRUE.
            ELSE DO
              IF (PLOTIN .EQ. ALFALF) THEN DO
```

```
                AIND = .TRUE.
              ELSE DO
                PRINT 130,PLOTIN
              ENDIF
            ENDIF
          ENDIF
        ENDIF
130     FORMAT ('0','*** INVALID PLOT CODE ',A1)
      END BLOCK
C
C CHANGE IN DATE, PRINT OUT FOUR LINES OF DATA, ADD TO FINAL
C ACCUMULATORS, AND RESET ALL ACCUMULATEORS, INDICATORS AND
C SAVE AREAS.  CHECK FOR HEADINGS TO BE PRINTED. PRINT 'NEG'
C IF NO DATA HAS BEEN COLLECTED FOR A PLOT ON A PARTICULAR DATE.
C
      REMOTE BLOCK DATECH
        IF (LC .GT. 60) THEN DO
          EXECUTE HDGRTN
        ENDIF
        CROP = 'ALFA '
        IF (AIND) THEN DO
          WRK = ATOT * 0.0001D0
          PRINT 200, DATESV,CROP,ATOT,WRK
          FINA = FINA + ATOT
        ELSE DO
          PRINT 205,DATESV,CROP
        ENDIF
        CROP = 'WHEAT'
        IF (WIND) THEN DO
          WRK = WTOT * 0.0001D0
          PRINT 220,CROP,WTOT,WRK
          FINW = FINW + WTOT
        ELSE DO
          PRINT 210,CROP
        ENDIF
        CROP = 'CORN '
        IF (CIND) THEN DO
          WRK = CTOT * 0.0001D0
          PRINT 220,CROP,CTOT,WRK
          FINC = FINC + CTOT
        ELSE DO
          PRINT 210,CROP
        ENDIF
        CROP = 'SMFW '
        IF (SIND) THEN DO
          WRK = STOT * 0.0001D0
          PRINT 220,CROP,STOT,WRK
          FINS = FINS + STOT
        ELSE DO
          PRINT 210, CROP
        ENDIF
        ATOT = 0.0D0
        WTOT = 0.0D0
        CTOT = 0.0D0
        STOT = 0.0D0
```

```
          AIND = .FALSE.
          WIND = .FALSE.
          CIND = .FALSE.
          SIND = .FALSE.
          LC = LC + 5
          DATESV = DATEIN
 200    FORMAT('0',15X,I6,9X,A5,8X,F9.2,8X,F5.2)
 205    FORMAT('0',15X,I6,9X,A5,11X,'NEG.',11X,'NEG.')
 210    FORMAT (' ',30X,A5,11X,'NEG.',11X,'NEG.')
 220    FORMAT (' ',30X,A5,8X,F9.2,8X,F5.2)
        END BLOCK
C
C  HEADING ROUTINE
C
        REMOTE BLOCK HDGRTN
          PRINT 300,NAMEIN,PGNUM
          PRINT 310
          PRINT 320
          PRINT 325
          PRINT 330
          PRINT 335
          LC = 10
          PGNUM = PGNUM + 1
 300    FORMAT('1',27X,A10,' SOIL LOSS DATA',15X,'PAGE: ',I2)
 310    FORMAT(' ',27X,'-------------------------')
 320    FORMAT('-',45X,'S O I L  L O S S')
 325    FORMAT (' ',45X,'-----------------')
 330    FORMAT ('0',16X,'DATE',10X,'CROP',11X,'G/PLOT',10X,'T/HA')
 335    FORMAT (' ',16X,'----',10X,'----',11X,'------',10X,'----')
          END BLOCK
C
C ADD THE WEIGHT TO THE APPROPRIATE WEIGHT FOR PLOT ACCUMULATOR
C
        REMOTE BLOCK ADDPLT
          IF (PLOTSV .EQ. CORN) THEN DO
            CTOT = CTOT + WEIGHT
          ELSE DO
            IF (PLOTSV .EQ. WHEAT) THEN DO
              WTOT = WTOT + WEIGHT
            ELSE DO
              IF (PLOTSV .EQ. SMRFLL) THEN DO
                STOT = STOT + WEIGHT
              ELSE DO
                ATOT = ATOT + WEIGHT
              ENDIF
            ENDIF
          ENDIF
        END BLOCK
C
C PRINT THE FINAL TOTALS
C
        REMOTE BLOCK FINTOT
          WRK = FINA * 0.0001D0
          CROP = 'ALFA '
          PRINT 400,CROP,FINA,WRK
```

```
           WRK = FINW * 0.0001D0
           CROP = 'WHEAT'
           PRINT 410, CROP,FINW,WRK
           WRK = FINC * 0.0001D0
           CROP = 'CORN '
           PRINT 410,CROP,FINC,WRK
           WRK = FINS * 0.0001D0
           CROP = 'SMFW '
           PRINT 410,CROP,FINS,WRK
           PRINT 430
400     FORMAT('-',15X,'TOTAL',10X,A5,7X,F10.2,7X,F6.2)
410     FORMAT (' ',30X,A5,7X,F10.2,7X,F6.2)
430     FORMAT('-',31X,'* END OF PROCESSING *','/','1')
        END BLOCK
        END
```

SOIL LOSS DATA ANALYSIS PROGRAMME (PROG. 2)

```
$ENTRY
//SOILLOSS  JOB ',,'
//        EXEC WATFIV
//FT05F001  DD  *
$JOB
$NOEXT
C
C THIS PROGRAM CALCULATES THE SOIL LOSS.  IT ACCEPTS A DATA
C FILE WHOSE FIRST RECORD CONTAINS THE NAME OF THE LOCATION
C OF THE RESEARCH PLOT IN THE FIRST 10 SPACES OF THE RECORD.
C THE FIRST FILE IT ACCEPTS CONTAINS THE JAR WEIGHTS.  AT
C PRESENT THERE ARE 250 JARS IN THE FILE.  THIS IS HARD CODED
C INTO THE PROGRAM. PLEASE UPDATE AS NECESSARY.
C THE DATA FILE CONTAINS THE WEIGHT OF THE SOIL PLUS THE JAR.
C IT ALSO CONTAINS THE DATE, PLOT CODE, JAR NUMBER, WEIGHT,
C AND AN INDICATOR (0 OR 1) AS TO WHETHER THIS IS A 1% SAMPLE
C (IE. 1 = 1% SAMPLE, 0 = 100% SAMPLE).
C
      INTEGER NUMJAR/350/,PGNUM/1/,LC/70/,DATEIN,DATESV,
     *       MULTIN,JARIN,IND
      LOGICAL  CIND/F/,SIND/F/,WIND/F/,AIND/F/,ZIND/F/,EOF/F/,EOW/F/
      REAL  JARWT(350), WGHTIN
       REAL*8  WEIGHT,WRK,STOT/0.0D0/,WTOT/0.0D0/,CTOT/0.0D0/,
     *      ATOT/0.0D0/,ZTOT/0.0D0/,FINS/0.0D0/,FINW/0.0D0/,FINC/0.0D0/,
     *         FINA/0.0D0/,FINZ/0.0D0/
       CHARACTER  PLOTIN,PLOTSV,CROP*5,NAMEIN*10,CORN/'C'/,
     *          WHEAT/'W'/,ALFALF/'A'/,SMRFLL/'S'/,ZERO/'Z'/
C
C   START PROGRAM
C
      EXECUTE INITWT
      READ(5,10,END=100) NAMEIN
      EXECUTE READCD
      IF (EOF) GO TO 100
      DATESV = DATEIN
      EXECUTE PLTSET
80    CONTINUE
      IF (DATEIN .NE. DATESV) THEN DO
        EXECUTE DATECH
        EXECUTE PLTSET
      ENDIF
      IF (PLOTSV .NE. PLOTIN) THEN DO
        EXECUTE PLTSET
      ENDIF
      WGHTIN = WGHTIN - (JARWT(JARIN))
      IF (WGHTIN .LT. 0.0) THEN DO
            PRINT 85, DATEIN,JARIN,WGHTIN,PLOTIN,MULTIN
C       WGHTIN = 0.0
       END IF
 85   FORMAT(2X,'**',I6,' JAR = ',2X,I4,2X,'WT = ',F8.2,2X,A1,2X,I4)
      IF (MULTIN .EQ. 1) THEN DO
        WEIGHT = WGHTIN * 100.0D0
      ELSE DO
```

```
        WEIGHT = WGHTIN * 1.0D0
      ENDIF
      EXECUTE ADDPLT
      EXECUTE READCD
      IF (EOF) GO TO 90
      GO TO 80
90    CONTINUE
      EXECUTE DATECH
      EXECUTE FINTOT
100     CONTINUE
      STOP
10    FORMAT (A10)
C
C   INITIALIZE CONTAINER WEIGHTS TABLE
C
      REMOTE BLOCK INITWT
        DO 140 IND=1,NUMJAR,1
          JARWT(IND) = 0.0
140   CONTINUE
145   CONTINUE
        READ 150,JARIN,WGHTIN
          AT END
            EOW = .TRUE.
          END AT END
        IF (JARIN .EQ.000) THEN DO
          EOW = .TRUE.
        ELSE DO
          JARWT(JARIN) = WGHTIN
        ENDIF
        IF (.NOT. EOW) GO TO 145
150   FORMAT (I3,F6.2)
      END BLOCK
C
C READ INPUT DATA CARD
C
      REMOTE BLOCK READCD
        READ 120,DATEIN,PLOTIN,JARIN,WGHTIN,MULTIN
          AT END
          EOF = .TRUE.
          END AT END
120   FORMAT (I6,A1,I3,F7.2,I1)
      END BLOCK
C
C SET THE CORRECT PLOT INDICATOR ON, TO INDICATE ACTUAL DATA
C IS PRESENT FOR A PARTICULAR DATE FOR THAT CROP
C
      REMOTE BLOCK PLTSET
        PLOTSV = PLOTIN
        IF (PLOTIN .EQ. CORN) THEN DO
          CIND = .TRUE.
        ELSE DO
          IF (PLOTIN .EQ. WHEAT) THEN DO
            WIND = .TRUE.
          ELSE DO
            IF (PLOTIN .EQ. SMRFLL) THEN DO
```

```
            SIND = .TRUE.
          ELSE DO
            IF (PLOTIN .EQ. ALFALF) THEN DO
              AIND = .TRUE.
            ELSE DO
              IF(PLOTIN.EQ.ZERO) THEN DO
                 ZIND = .TRUE.
              ELSE DO
              PRINT 130,PLOTIN
              ENDIF
            ENDIF
          ENDIF
        ENDIF
      ENDIF
130   FORMAT ('0','*** INVALID PLOT CODE ',A1)
    END BLOCK
C
C CHANGE IN DATE, PRINT OUT FOUR LINES OF DATA, ADD TO FINAL
C ACCUMULATORS, AND RESET ALL ACCUMULATEORS, INDICATORS AND
C SAVE AREAS.  CHECK FOR HEADINGS TO BE PRINTED. PRINT 'NEG'
C IF NO DATA HAS BEEN COLLECTED FOR A PLOT ON A PARTICULAR DATE.
C
    REMOTE BLOCK DATECH
      IF (LC .GT. 60) THEN DO
        EXECUTE HDGRTN
      ENDIF
      CROP = 'ALFA '
      IF (AIND) THEN DO
        WRK = ATOT * 0.0001D0
        PRINT 200, DATESV,CROP,ATOT,WRK
        FINA = FINA + ATOT
      ELSE DO
        PRINT 205,DATESV,CROP
      ENDIF
      CROP = 'WHEAT'
      IF (WIND) THEN DO
        WRK = WTOT * 0.0001D0
        PRINT 220,CROP,WTOT,WRK
        FINW = FINW + WTOT
      ELSE DO
        PRINT 210,CROP
      ENDIF
      CROP = 'CORN '
      IF (CIND) THEN DO
        WRK = CTOT * 0.0001D0
        PRINT 220,CROP,CTOT,WRK
        FINC = FINC + CTOT
      ELSE DO
        PRINT 210,CROP
      ENDIF
      CROP = 'SMFW '
      IF (SIND) THEN DO
        WRK = STOT * 0.0001D0
        PRINT 220,CROP,STOT,WRK
        FINS = FINS + STOT
```

```
         ELSE DO
           PRINT 210, CROP
         ENDIF
         CROP = 'ZERO '
         IF (ZIND) THEN DO
           WRK = ZTOT * 0.0001D0
           PRINT 220,CROP,ZTOT,WRK
           FINZ = FINZ + ZTOT
         ELSE DO
           PRINT 210, CROP
         ENDIF
         ATOT = 0.0D0
         WTOT = 0.0D0
         CTOT = 0.0D0
         STOT = 0.0D0
         ZTOT = 0.0D0
         AIND = .FALSE.
         WIND = .FALSE.
         CIND = .FALSE.
         SIND = .FALSE.
         ZIND = .FALSE.
         LC = LC + 6
         DATESV = DATEIN
200    FORMAT('0',15X,I6,9X,A5,8X,F9.2,8X,F5.2)
205    FORMAT('0',15X,I6,9X,A5,11X,'NEG.',11X,'NEG.')
210    FORMAT (' ',30X,A5,11X,'NEG.',11X,'NEG.')
220    FORMAT (' ',30X,A5,8X,F9.2,8X,F5.2)
       END BLOCK
C
C  HEADING ROUTINE
C
       REMOTE BLOCK HDGRTN
         PRINT 300,NAMEIN,PGNUM
         PRINT 310
         PRINT 320
         PRINT 325
         PRINT 330
         PRINT 335
         LC = 10
         PGNUM = PGNUM + 1
300    FORMAT('1',27X,A10,' SOIL LOSS DATA',15X,'PAGE: ',I2)
310    FORMAT(' ',27X,'-------------------------')
320    FORMAT('-',45X,'S O I L  L O S S')
325    FORMAT (' ',45X,'------------------')
330    FORMAT ('0',16X,'DATE',10X,'CROP',11X,'G/PLOT',10X,'T/HA')
335    FORMAT (' ',16X,'----',10X,'----',11X,'------',10X,'----')
         END BLOCK
C
C ADD THE WEIGHT TO THE APPROPRIATE WEIGHT FOR PLOT ACCUMULATOR
C
       REMOTE BLOCK ADDPLT
         IF (PLOTSV .EQ. CORN) THEN DO
           CTOT = CTOT + WEIGHT
         ELSE DO
           IF (PLOTSV .EQ. WHEAT) THEN DO
```

```
              WTOT = WTOT + WEIGHT
            ELSE DO
              IF (PLOTSV .EQ. SMRFLL) THEN DO
                STOT = STOT + WEIGHT
              ELSE DO
                IF(PLOTSV.EQ.ZERO) THEN DO
                   ZTOT = ZTOT + WEIGHT
                ELSE DO
                ATOT = ATOT + WEIGHT
                ENDIF
              ENDIF
            ENDIF
          ENDIF
        END BLOCK
C
C PRINT THE FINAL TOTALS
C
        REMOTE BLOCK FINTOT
          WRK = FINA * 0.0001D0
          CROP = 'ALFA '
          PRINT 400,CROP,FINA,WRK
          WRK = FINW * 0.0001D0
          CROP = 'WHEAT'
          PRINT 410, CROP,FINW,WRK
          WRK = FINC * 0.0001D0
          CROP = 'CORN '
          PRINT 410,CROP,FINC,WRK
          WRK = FINS * 0.0001D0
          CROP = 'SMFW '
          PRINT 410,CROP,FINS,WRK
          WRK = FINZ * 0.0001D0
          CROP = 'ZERO '
          PRINT 410,CROP,FINZ,WRK
          PRINT 430
400     FORMAT('-',15X,'TOTAL',10X,A5,7X,F10.2,7X,F6.2)
410     FORMAT (' ',30X,A5,7X,F10.2,7X,F6.2)
430     FORMAT('-',31X,'* END OF PROCESSING *',/,'1')
        END BLOCK
        END
```

SOIL LOSS DATA ANALYSIS PROGRAMME (PROG. 3)
(MODIFICATION OF PROG. 2 FOR MINIMUM TILLAGE WHEAT TREATMENT)

```
$ENTRY
//SOILLOSS  JOB ',,'
//         EXEC WATFIV
//FT05F001  DD  *
$JOB
$NOEXT
C*************************************************************
C*** PROGRAM CHANGES                                        **
C*** BRUCE BURNETT 02-09-88                                 **
C*************************************************************
C*** 1) CORRECTION OF NEGATIVE SOIL LOSS                    **
C***    THIS PROBLEM WAS DUE TO THE FACT THAT THE SOIL +    **
C***    JAR WT SUBTRACT THE JAR  WT WAS  NOT ALWAYS         **
C***    A POSITIVE VALUE DUE TO THE INVALID INPUT (USUALLY  **
C***    IMPROPER JAR NUMBERS OR BAD SOIL WTS.)              **
C***    FIX - AN IF THEN ELSE STRUCTURE WAS ADDED LINE 70   **
C***    TO PRINT A MESSAGE THAT NEGATIVE NUMBERS WERE       **
C***    ENCOUNTERED. A FLAG IS SET TO PRINT A WARNING AT    **
C***    THE END OF THE PROGRAM RUN                          **
C***    IT IS VERY IMPORTANT TO CORRECT THE DATA WHEN THIS  **
C***    MESSAGE IS PRINTED                                  **
C***                                                        **
C***    THE PROGRAM TAKES CORRECTIVE ACTION BY ZEROING THE  **
C***    NEGATIVE NUMBERS. THIS WILL LEAD TO ERROR IN THE    **
C***    SOIL LOSS CALCULATION. THE VALUE OF THE SOIL LOSS   **
C***    MAY BE VERY CLOSE TO THE ACTUAL VALUE BUT THIS CAN  **
C***    ONLY BE VERIFIED IF THE DATA IS CORRECTED           **
C*************************************************************
C
C
C
C THIS PROGRAM CALCULATES THE SOIL LOSS.  IT ACCEPTS A DATA
C FILE WHOSE FIRST RECORD CONTAINS THE NAME OF THE LOCATION
C OF THE RESEARCH PLOT IN THE FIRST 10 SPACES OF THE RECORD.
C THE FIRST FILE IT ACCEPTS CONTAINS THE JAR WEIGHTS.  AT
C PRESENT THERE ARE 250 JARS IN THE FILE.  THIS IS HARD CODED
C INTO THE PROGRAM. PLEASE UPDATE AS NECESSARY.
C THE DATA FILE CONTAINS THE WEIGHT OF THE SOIL PLUS THE JAR.
C IT ALSO CONTAINS THE DATE, PLOT CODE, JAR NUMBER, WEIGHT,
C AND AN INDICATOR (0 OR 1) AS TO WHETHER THIS IS A 1% SAMPLE
C (IE. 1 = 1% SAMPLE, 0 = 100% SAMPLE).
      INTEGER NUMJAR/350/,PGNUM/1/,LC/70/,DATEIN,DATESV,
     *       MULTIN,JARIN,IND
      LOGICAL  CIND/F/,SIND/F/,WIND/F/,AIND/F/,EOF/F/,EOW/F/
      LOGICAL WARNER
      REAL  JARWT(350), WGHTIN
       REAL*8  WEIGHT,WRK,STOT/0.0D0/,WTOT/0.0D0/,CTOT/0.0D0/,
     *        ATOT/0.0D0/,FINS/0.0D0/,FINW/0.0D0/,FINC/0.0D0/,
     *         FINA/0.0D0/
       CHARACTER  PLOTIN,PLOTSV,CROP*5,NAMEIN*10,CORN/'C'/,
     *          WHEAT/'W'/,ALFALF/'A'/,SMRFLL/'S'/
C
```

```
C   START PROGRAM
C
      WARNER = .FALSE.
      EXECUTE INITWT
      READ(5,10,END=100) NAMEIN
      EXECUTE READCD
      IF (EOF) GO TO 100
      DATESV = DATEIN
      EXECUTE PLTSET
80    CONTINUE
      IF (DATEIN .NE. DATESV) THEN DO
        EXECUTE DATECH
        EXECUTE PLTSET
      ENDIF
      IF (PLOTSV .NE. PLOTIN) THEN DO
        EXECUTE PLTSET
      ENDIF
      WGHTIN = WGHTIN - (JARWT(JARIN))
      IF (WGHTIN .LT. 0.0) THEN DO
            PRINT 85, DATEIN,JARIN,WGHTIN,PLOTIN,MULTIN
            WGHTIN = 0.0
            WARNER = .TRUE.
       END IF
 85   FORMAT(2X,'**',I6,' JAR = ',2X,I4,2X,'WT = ',F8.2,2X,A1,2X,I4)
      IF (MULTIN .EQ. 1) THEN DO
        WEIGHT = WGHTIN * 100.0D0
      ELSE DO
        WEIGHT = WGHTIN * 1.0D0
      ENDIF
      EXECUTE ADDPLT
      EXECUTE READCD
      IF (EOF) GO TO 90
      GO TO 80
90    CONTINUE
      EXECUTE DATECH
      EXECUTE FINTOT
      IF (WARNER) THEN DO
            PRINT 199
            PRINT 188
            PRINT 199
            END IF
 188  FORMAT (' WARNING -- INVALID SOIL LOSS VALUES CHECK DATA')
 199  FORMAT ('********************************************')
100     CONTINUE
      STOP
10    FORMAT (A10)
C
C   INITIALIZE CONTAINER WEIGHTS TABLE
C
      REMOTE BLOCK INITWT
        DO 140 IND=1,NUMJAR,1
          JARWT(IND) = 0.0
140   CONTINUE
145   CONTINUE
        READ 150,JARIN,WGHTIN
```

```
          AT END
            EOW = .TRUE.
          END AT END
        IF (JARIN .EQ.000) THEN DO
          EOW = .TRUE.
        ELSE DO
          JARWT(JARIN) = WGHTIN
        ENDIF
        IF (.NOT. EOW) GO TO 145
150   FORMAT (I3,F6.2)
      END BLOCK
C
C READ INPUT DATA CARD
C
      REMOTE BLOCK READCD
        READ 120,DATEIN,PLOTIN,JARIN,WGHTIN,MULTIN
          AT END
          EOF = .TRUE.
          END AT END
C       PRINT 121,DATEIN,PLOTIN,JARIN,WGHTIN,MULTIN
120   FORMAT (I6,A1,I3,F6.2,I1)
C121   FORMAT (I6,2X,A1,2X,I3,2X,F6.2,2X,I1)
      END BLOCK
C
C SET THE CORRECT PLOT INDICATOR ON, TO INDICATE ACTUAL DATA
C IS PRESENT FOR A PARTICULAR DATE FOR THAT CROP
C
      REMOTE BLOCK PLTSET
        PLOTSV = PLOTIN
        IF (PLOTIN .EQ. CORN) THEN DO
          CIND = .TRUE.
        ELSE DO
          IF (PLOTIN .EQ. WHEAT) THEN DO
            WIND = .TRUE.
          ELSE DO
            IF (PLOTIN .EQ. SMRFLL) THEN DO
              SIND = .TRUE.
            ELSE DO
              IF (PLOTIN .EQ. ALFALF) THEN DO
                AIND = .TRUE.
              ELSE DO
                PRINT 130,PLOTIN
              ENDIF
            ENDIF
          ENDIF
        ENDIF
130     FORMAT ('0','*** INVALID PLOT CODE ',A1)
      END BLOCK
C
C CHANGE IN DATE, PRINT OUT FOUR LINES OF DATA, ADD TO FINAL
C ACCUMULATORS, AND RESET ALL ACCUMULATEORS, INDICATORS AND
C SAVE AREAS.  CHECK FOR HEADINGS TO BE PRINTED. PRINT 'NEG'
C IF NO DATA HAS BEEN COLLECTED FOR A PLOT ON A PARTICULAR DATE.
C
      REMOTE BLOCK DATECH
```

```
          IF (LC .GT. 60) THEN DO
            EXECUTE HDGRTN
          ENDIF
          CROP = 'ALFA '
          IF (AIND) THEN DO
            WRK = ATOT * 0.0001D0
            PRINT 200, DATESV,CROP,ATOT,WRK
            FINA = FINA + ATOT
          ELSE DO
            PRINT 205,DATESV,CROP
          ENDIF
          CROP = 'WHEAT'
          IF (WIND) THEN DO
            WRK = WTOT * 0.0001D0
            PRINT 220,CROP,WTOT,WRK
            FINW = FINW + WTOT
          ELSE DO
            PRINT 210,CROP
          ENDIF
          CROP = 'CORN '
          IF (CIND) THEN DO
            WRK = CTOT * 0.0001D0
            PRINT 220,CROP,CTOT,WRK
            FINC = FINC + CTOT
          ELSE DO
            PRINT 210,CROP
          ENDIF
          CROP = 'SMFW '
          IF (SIND) THEN DO
            WRK = STOT * 0.0001D0
            PRINT 220,CROP,STOT,WRK
            FINS = FINS + STOT
          ELSE DO
            PRINT 210, CROP
          ENDIF
          ATOT = 0.0D0
          WTOT = 0.0D0
          CTOT = 0.0D0
          STOT = 0.0D0
          AIND = .FALSE.
          WIND = .FALSE.
          CIND = .FALSE.
          SIND = .FALSE.
          LC = LC + 5
          DATESV = DATEIN
200     FORMAT('0',15X,I6,9X,A5,8X,F12.2,5X,F6.2)
205     FORMAT('0',15X,I6,9X,A5,11X,'NEG.',11X,'NEG.')
210     FORMAT (' ',30X,A5,11X,'NEG.',11X,'NEG.')
220     FORMAT (' ',30X,A5,8X,F12.2,5X,F6.2)
        END BLOCK
C
C  HEADING ROUTINE
C
        REMOTE BLOCK HDGRTN
          PRINT 300,NAMEIN,PGNUM
```

```
          PRINT 310
          PRINT 320
          PRINT 325
          PRINT 330
          PRINT 335
          LC = 10
          PGNUM = PGNUM + 1
300     FORMAT('1',27X,A10,' SOIL LOSS DATA',15X,'PAGE: ',I2)
310     FORMAT(' ',27X,'------------------------')
320     FORMAT('-',45X,'S O I L   L O S S')
325     FORMAT (' ',45X,'-----------------')
330     FORMAT ('0',16X,'DATE',10X,'CROP',11X,'G/PLOT',10X,'T/HA')
335     FORMAT (' ',16X,'----',10X,'----',11X,'------',10X,'----')
          END BLOCK
C
C ADD THE WEIGHT TO THE APPROPRIATE WEIGHT FOR PLOT ACCUMULATOR
C
        REMOTE BLOCK ADDPLT
          IF (PLOTSV .EQ. CORN) THEN DO
            CTOT = CTOT + WEIGHT
          ELSE DO
            IF (PLOTSV .EQ. WHEAT) THEN DO
              WTOT = WTOT + WEIGHT
            ELSE DO
              IF (PLOTSV .EQ. SMRFLL) THEN DO
                STOT = STOT + WEIGHT
              ELSE DO
                ATOT = ATOT + WEIGHT
              ENDIF
            ENDIF
          ENDIF
        END BLOCK
C
C PRINT THE FINAL TOTALS
C
        REMOTE BLOCK FINTOT
          WRK = FINA * 0.0001D0
          CROP = 'ALFA '
          PRINT 400,CROP,FINA,WRK
          WRK = FINW * 0.0001D0
          CROP = 'WHEAT'
          PRINT 410, CROP,FINW,WRK
          WRK = FINC * 0.0001D0
          CROP = 'CORN '
          PRINT 410,CROP,FINC,WRK
          WRK = FINS * 0.0001D0
          CROP = 'SMFW '
          PRINT 410,CROP,FINS,WRK
          PRINT 430
400     FORMAT('-',15X,'TOTAL',10X,A5,7X,F10.2,7X,F6.2)
410     FORMAT (' ',30X,A5,7X,F10.2,7X,F6.2)
430     FORMAT('-',31X,'* END OF PROCESSING *',/,'1')
        END BLOCK
        END
$ENTRY
```

SURFACE RUNOFF FLOW DATA ANALYSIS PROGRAMME (WATPROG 1)

```
//SOILLOSS JOB ',,F=BDI1'
// EXEC PASCCG
//PASC.SYSIN DD *
PROGRAM WATLEVPROG(INPUT,OUTPUT);
   (*** THIS PROGRAM IS TO BE USED WITH THE MIAMI AND ROSEISLE
   SITES ONLY.
   THIS PROGRAM EVALUATES THE WATER LEVEL RECORDER DATA. IT
   EVALUATES THE MAXIMUM FLOW RATE BY PUTTING THE MAXIMUM NUMBER
   OF DIVISIONS FROM THE CHART THROUGH AN EQUATION BASED ON THE
   SPECIFIC PLOT.  IT ALSO CALCULATES THE TOTAL RUNOFF VOLUME, BY
   SUMMING THE VOLUMES FOR EACH 4 HOUR PERIOD AS GIVEN BY THE CHART.
   THE INPUT CONSISTS OF 2 TYPES OF INPUT RECORDS.  THE 1ST COLUMN
   CONTAINS A TYPE CODE.  A 1 CARD CONTAINS THE DATE, A PLOT CODE, AND
   THE MAXIMUM NUMBER OF DIVISIONS FOR THAT RAINFALL.  MULTIPLE NUMBER
   #2 CARDS FOLLOW EACH NUMBER 1 CARD.  EACH CONTAINS THE END DIVVAL  FOR
  A CONSTANT SLOPE ON THE GRAPH AND THEN THE TIME IN MINUTES OF THE
  CONSTANT SLOPE.  THE START DIV VAL IS TAKEN FROM THE PREVIOUS #2
   RECORD.  DATA IS PRINTED OUT WHEN THE
   DATE CHANGES FOR ALL 4 PLOT TYPES.  THE 1ST INPUT CARD CONTAINS THE
   SITE NAME IN THE 1ST 8 CHARACTERS.   ***)

CONST
   SITELEN = 8;
   MAXCON  = 99.9;
   SECCON  = 60;

VAR
   DATEIN,DATESV,LC,CODEIN,IND:INTEGER;
   PLOTCD,CH:CHAR;
   TOTA,TOTW,TOTC,TOTS,MAXA,MAXC,MAXW,MAXS,MAXD,STVAL:REAL;
   EDVAL:REAL;
   TIMEIN:INTEGER;
   SITE:STRING(SITELEN);

PROCEDURE HDGS(CONST SITE:STRING(SITELEN);
               VAR LC,DATESV:INTEGER);

          (* PRINT HEADINGS *)

   BEGIN
   PAGE;
   WRITELN(' ':36,SITE:SITELEN,' FLOW RATE DATA');
   WRITELN;
   WRITELN(' ':15,'ALFALFA',' ':15,'WHEAT',' ':16,'CORN',' ':17,
            'FALLOW');
   WRITELN(' ':8,'MAX FLOW  TOT RUNOFF',' ':2,
         'MAX FLOW  TOT RUNOFF',' ':2,'MAX FLOW  TOT RUNOFF',
         ' ':2,'MAX FLOW  TOT RUNOFF');
   WRITELN(' DATE  ','RATE(L/S)  VOL(L) ':19,' ':4,'RATE(L/S)',
         ' VOL(L) ','RATE(L/S)  VOL(L) ':22,
         'RATE(L/S)  VOL(L) ':23);
   WRITELN;
   LC := 7;
```

```
   END;
        (* END OF HEADING ROUTINE *)

PROCEDURE DATECH(VAR TOTA,TOTW,TOTC,TOTS,MAXA,MAXW,MAXC,MAXS:REAL;
                  VAR DATESV:INTEGER);

        (* PRINT OUT THE INFORMATION FOR THE DATE*)
        (* IF NO RECORDS PROCESSED FOR ANY ONE PLOT, THEN *)
        (* -99.9 WILL BE PRINTED ON THE OUTPUT *)

BEGIN
   IF LC > 60 THEN
      HDGS (SITE,LC,DATESV);
   IF TOTA = 0 THEN TOTA := -MAXCON;
   IF TOTW = 0 THEN TOTW := -MAXCON;
   IF TOTC = 0 THEN TOTC := -MAXCON;
   IF TOTS = 0 THEN TOTS := -MAXCON;
   WRITELN(' ',DATESV:6,' ':3,MAXA:6:2,' ':2,TOTA:7:1,' ':6,
      MAXW:6:2,' ':2,TOTW:7:1,' ':6,MAXC:6:2,' ':2,TOTC:7:1,
      ' ':6,MAXS:6:2,' ':2,TOTS:7:1);
   TOTA:=0;  TOTW:=0;   TOTC :=0;   TOTS:=0;
   MAXA:=-MAXCON;   MAXW:=-MAXCON;  MAXC:=-MAXCON;  MAXS:=-MAXCON;
   DATESV:=DATEIN;
   LC := LC +1;
   STVAL :=0;
   END;    (* END OF DATE CHANGE *)

PROCEDURE READRTN;

   (*  READ THE APPROPRIATE INPUT RECORD BASED ON THE TYPE CODE *)

   BEGIN
   READ(CODEIN);
   CASE CODEIN OF
      1:READLN(DATEIN,PLOTCD,MAXD);
      2:READLN(EDVAL,TIMEIN);
   END;  (* CASE *)
   END;        (* END OF READ PROCEDURE *)

PROCEDURE CALCMAX (MAXD:REAL);

   (* CALCULATE THE MAXIMUM FLOW RATE FOR THE PLOT, USING THE
     APPROPRIATE EQUATION *)

   BEGIN
   IF SITE = 'ROSEISLE' THEN
      BEGIN
      CASE PLOTCD OF
         'A':MAXA:=(0.1315 - 0.0537*(MAXD) + 0.0109*SQR(MAXD));
         'W':MAXW:=(0.0488 - 0.018*(MAXD) + 0.0053*SQR(MAXD));
         'C':MAXC:=(0.0542 - 0.0186*(MAXD) + 0.0052*SQR(MAXD));
         'S':MAXS:=(0.0454 - 0.0102*(MAXD) + 0.0047*SQR(MAXD));
      END    (* CASE *)
   END ELSE BEGIN
      CASE PLOTCD OF
```

```
          'A':MAXA:=(0.0128 + 0.0041*(MAXD) + 0.0035*SQR(MAXD));
          'W':MAXW:=((0.0024) + 0.011*(MAXD) + 0.0025*SQR(MAXD));
          'C':MAXC:=(0.0273 - 0.0054*(MAXD) + 0.0037*SQR(MAXD));
          'S':MAXS:=(0.0362 - 0.0098*(MAXD) + 0.0041*SQR(MAXD));
       END   (* CASE *)
    END   (* IF *)
    END;   (* PROCEDURE CALCULATE MAXIMUM *)

PROCEDURE SUMDIV (SVAL,EVAL:REAL; TM:INTEGER);

    (* SUM THE VOLUME FOR THE AVERAGE NUMBER OF DIVISIONS USING THE *)
    (* CORRECT EQUATION *)
  VAR
     SECS:INTEGER;
     AVG:REAL;

    BEGIN
    SECS := TM*SECCON;
    AVG:= (SVAL + EVAL)/2;
    IF SITE = 'ROSEISLE' THEN
       BEGIN
       CASE PLOTCD OF
          'A':TOTA:=TOTA + ((0.1315 - 0.0537*AVG +
          0.0109*SQR(AVG))*SECS);
          'W':TOTW:=TOTW + ((0.0488 - 0.018*AVG +
          0.0053*SQR(AVG))*SECS);
          'C':TOTC:=TOTC + ((0.0542 - 0.0186*AVG +
          0.0052*SQR(AVG))*SECS);
          'S':TOTS:=TOTS + ((0.0454 - 0.0102*AVG +
          0.0047*SQR(AVG))*SECS);
       END   (* CASE *)
    END ELSE BEGIN
       CASE PLOTCD OF
          'A':TOTA:=TOTA + ((0.0128 + 0.0041*AVG +
          0.0035*SQR(AVG))*SECS);
          'W':TOTW:=TOTW + (((0.0024) + 0.011*AVG +
          0.0025*SQR(AVG))*SECS);
          'C':TOTC:=TOTC + ((0.0273 - 0.0054*AVG +
          0.0037*SQR(AVG))*SECS);
          'S':TOTS:=TOTS + ((0.0362 - 0.0098*AVG +
          0.0041*SQR(AVG))*SECS);
       END   (* CASE *)
    END   (* IF *)
    END;   (* PROCEDURE SUM VOLUMES *)

BEGIN   (***********M A I N L I N E  *************)
LC := 65;
IF NOT EOF THEN
   BEGIN
   SITE := '';
   FOR IND:=1 TO SITELEN DO
      BEGIN
      READ(CH);
      SITE:=SITE||STR(CH);
      END;   (* FOR *)
```

```
   READLN;
   (* READ IN SITE NAME *)
   READRTN;   (* READ 1ST RECORD *)
   DATESV := DATEIN;
   STVAL := 0;
   MAXC := -MAXCON;   MAXA := -MAXCON;  MAXW:=-MAXCON; MAXS:=-MAXCON;
   TOTA:=0;  TOTW:=0;  TOTC:=0;  TOTS:=0;
          (* INITIALIZE ACCUMULATORS AND SAVES *)

   WHILE (NOT EOF) DO
      BEGIN
      IF DATEIN <> DATESV THEN
         DATECH(TOTA,TOTW,TOTC,TOTS,MAXA,MAXW,MAXC,MAXS,DATESV);
      CASE CODEIN OF
         1: BEGIN
              CALCMAX(MAXD);
              END;   (* CASE 1 *)
         2: BEGIN
              SUMDIV(STVAL,EDVAL,TIMEIN);
              STVAL:=EDVAL;
              END  (*  CASE 2 *)
         END;   (* CASE *)
      READRTN
      END;   (* WHILE *)
   DATECH(TOTA,TOTW,TOTC,TOTS,MAXA,MAXW,MAXC,MAXS,DATESV)
   END   (* IF *)
END.
//GO.INPUT DD *
```

SURFACE RUNOFF FLOW DATA ANALYSIS PROGRAMME (WATPROG 2)

(MODIFICATION OF WATPROG 1 FOR MINIMUM TILLAGE WHEAT TREATMENT)

```
//SOILLOSS JOB ',,F=BDI1'
// EXEC PASCCG
//PASC.SYSIN DD *
PROGRAM WATLEVPROG(INPUT,OUTPUT);
   (*** THIS PROGRAM IS THE SAME AS WATPROG BUT HAS BEEN MODIFIED
   TO BE USED WITH THE RYERSON, CARROLL AND NEWDALE SITES.
   THIS PROGRAM EVALUATES THE WATER LEVEL RECORDER DATA. IT
   EVALUATES THE MAXIMUM FLOW RATE BY PUTTING THE MAXIMUM NUMBER
   OF DIVISIONS FROM THE CHART THROUGH AN EQUATION BASED ON THE
   SPECIFIC PLOT.  IT ALSO CALCULATES THE TOTAL RUNOFF VOLUME, BY
   SUMMING THE VOLUMES FOR EACH 4 HOUR PERIOD AS GIVEN BY THE CHART.
   THE INPUT CONSISTS OF 2 TYPES OF INPUT RECORDS.  THE 1ST COLUMN
   CONTAINS A TYPE CODE.  A 1 CARD CONTAINS THE DATE, A PLOT CODE, AND
   THE MAXIMUM NUMBER OF DIVISIONS FOR THAT RAINFALL.  MULTIPLE NUMBER
   #2 CARDS FOLLOW EACH NUMBER 1 CARD.  EACH CONTAINS THE END DIVVAL  FOR
  A CONSTANT SLOPE ON THE GRAPH AND THEN THE TIME IN MINUTES OF THE
  CONSTANT SLOPE.  THE START DIV VAL IS TAKEN FROM THE PREVIOUS #2
   RECORD.  DATA IS PRINTED OUT WHEN THE
   DATE CHANGES FOR ALL 4 PLOT TYPES.  THE 1ST INPUT CARD CONTAINS THE
   SITE NAME IN THE 1ST 8 CHARACTERS.   ***)

CONST
   SITELEN = 8;
   MAXCON  = 99.9;
   SECCON  = 60;

VAR
   DATEIN,DATESV,LC,CODEIN,IND:INTEGER;
   PLOTCD,CH:CHAR;
   TOTA,TOTW,TOTC,TOTS,TOTZ,MAXA,MAXC,MAXW,MAXS,MAXZ,MAXD,STVAL:REAL;
   EDVAL:REAL;
   TIMEIN:INTEGER;
   SITE:STRING(SITELEN);

PROCEDURE HDGS(CONST SITE:STRING(SITELEN);
               VAR LC,DATESV:INTEGER);

          (* PRINT HEADINGS *)

   BEGIN
   PAGE;
   WRITELN(' ':36,SITE:SITELEN,' FLOW RATE DATA');
   WRITELN;
   WRITELN(' ':15,'ALFALFA',' ':15,'WHEAT',' ':16,'CORN',' ':17,
            'FALLOW',' ':17,'MIN-TILL');
   WRITELN(' ':7,'MAX FLOW  TOT RUNOFF',' ':2,'MAX FLOW ',
         'TOT RUNOFF',' ':2,'MAX FLOW TOT RUNOFF',' ':2,
         'MAX FLOW TOT RUNOFF',' ':2,'MAX FLOW TOT RUNOFF');
   WRITELN(' DATE  ','RATE(L/S)  VOL(L) ':18,' ':4,'RATE(L/S)',
         '     VOL(L) ','RATE(L/S)  VOL(L) ':20,
         'RATE(L/S)  VOL(L) ':21,'RATE(L/S)  VOL(L) ':22);
   WRITELN;
```

```
   LC := 7;
   END;
        (* END OF HEADING ROUTINE *)

PROCEDURE DATECH(VAR TOTA,TOTW,TOTC,TOTS,TOTZ,MAXA,MAXW,MAXC,MAXS,MAXZ:
                  REAL;VAR DATESV:INTEGER);

        (* PRINT OUT THE INFORMATION FOR THE DATE*)
        (* IF NO RECORDS PROCESSED FOR ANY ONE PLOT, THEN *)
        (* -99.9 WILL BE PRINTED ON THE OUTPUT *)

BEGIN
   IF LC > 60 THEN
      HDGS (SITE,LC,DATESV);
   IF TOTA = 0 THEN TOTA := -MAXCON;
   IF TOTW = 0 THEN TOTW := -MAXCON;
   IF TOTC = 0 THEN TOTC := -MAXCON;
   IF TOTS = 0 THEN TOTS := -MAXCON;
   IF TOTZ = 0 THEN TOTZ:= -MAXCON;
   WRITELN(' ',DATESV:6,' ':2,MAXA:6:2,' ':2,TOTA:7:1,' ':6,
      MAXW:6:2,' ':2,TOTW:7:1,' ':6,MAXC:6:2,' ':2,TOTC:7:1,
      ' ':5,MAXS:6:2,' ':2,TOTS:7:1,' ':6,MAXZ:6:2,' ':2,TOTZ:7:1);
   TOTA:=0;  TOTW:=0;   TOTC :=0;   TOTS:=0;  TOTZ:=0;
   MAXA:=-MAXCON;   MAXW:=-MAXCON;  MAXC:=-MAXCON;  MAXS:=-MAXCON;
   MAXZ:=-MAXCON;
   DATESV:=DATEIN;
   LC := LC +1;
   STVAL :=0;
   END;    (* END OF DATE CHANGE *)

PROCEDURE READRTN;

   (*  READ THE APPROPRIATE INPUT RECORD BASED ON THE TYPE CODE *)

   BEGIN
   READ(CODEIN);
   CASE CODEIN OF
      1:READLN(DATEIN,PLOTCD,MAXD);
      2:READLN(EDVAL,TIMEIN);
   END;  (* CASE *)
   END;       (* END OF READ PROCEDURE *)

PROCEDURE CALCMAX (MAXD:REAL);

   (* CALCULATE THE MAXIMUM FLOW RATE FOR THE PLOT, USING THE
     APPROPRIATE EQUATION *)

   BEGIN
   IF SITE = 'HAYFIELD' THEN
      BEGIN
      CASE PLOTCD OF
         'A':MAXA:=(0.02097+0.000649*(MAXD)+0.0042*SQR(MAXD));
         'W':MAXW:=(-0.00118+0.007486*(MAXD)+0.00407*SQR(MAXD));
         'C':MAXC:=(0.11307-0.02668*(MAXD)+0.00499*SQR(MAXD));
         'S':MAXS:=(0.05009+0.03867*(MAXD)+0.00154*SQR(MAXD));
```

```
         'Z':MAXZ:=(0.02129-00.0063*(MAXD)+0.00351*SQR(MAXD));
      END    (* CASE *)
   END ELSE BEGIN
      CASE PLOTCD OF
         'A':MAXA:=(0.04747-0.01447*(MAXD)+0.00562*SQR(MAXD));
         'W':MAXW:=(0.066650-0.0284615*(MAXD)+0.0068514*SQR(MAXD));
         'C':MAXC:=(0.01774-0.002841*(MAXD)+0.003722*SQR(MAXD));
         'S':MAXS:=(0.0539-0.01031*(MAXD)+0.00492*SQR(MAXD));
         'Z':MAXZ:=(0.10184-0.038036*(MAXD)+0.00728*SQR(MAXD));
      END   (* CASE *)
   END   (* IF *)
   END;   (* PROCEDURE CALCULATE MAXIMUM *)

PROCEDURE SUMDIV (SVAL,EVAL:REAL; TM:INTEGER);

   (* SUM THE VOLUME FOR THE AVERAGE NUMBER OF DIVISIONS USING THE *)
   (* CORRECT EQUATION *)
  VAR
     SECS:INTEGER;
     AVG:REAL;

   BEGIN
   SECS := TM*SECCON;
   AVG:= (SVAL + EVAL)/2;
   IF SITE = 'HAYFIELD' THEN
      BEGIN
      CASE PLOTCD OF
         'A':TOTA:=TOTA+((0.02097+0.000649*(AVG)+0.0042*SQR(AVG))*SECS);
         'W':TOTW:=TOTW+((-0.00118+0.007486*(AVG)+0.00407*SQR(AVG))
        * SECS);
         'C':TOTC:=TOTC+((0.11307-0.02668*(AVG)+0.00499*SQR(AVG))*SECS);
         'S':TOTS:=TOTS+((0.05009+0.03867*(AVG)+0.00154*SQR(AVG))
        * SECS);
         'Z':TOTZ:=TOTZ+((0.02129-0.0063*(AVG)+0.00351*SQR(AVG))
        * SECS);
      END   (* CASE *)
   END ELSE BEGIN
      CASE PLOTCD OF
         'A':TOTA:=TOTA+((0.04742-0.0145*(AVG)+0.00562*SQR(AVG))*SECS);
         'W':TOTW:=TOTW+(((0.0666)-0.0284615*(AVG)+0.0068514*SQR(AVG))
        * SECS);
         'C':TOTC:=TOTC+((0.017745-0.002842*(AVG)+0.003722*SQR(AVG))
        * SECS);
         'S':TOTS:=TOTS+((0.0539-0.01031*(AVG)+0.00449*SQR(AVG))*SECS);
         'Z':TOTZ:=TOTZ+((0.10184-0.038036*(AVG)+0.00728*SQR(AVG))*SECS);
      END   (* CASE *)
   END   (* IF *)
   END;   (* PROCEDURE SUM VOLUMES *)

BEGIN   (***********M A I N L I N E  *************)
LC := 65;
IF NOT EOF THEN
   BEGIN
   SITE := '';
   FOR IND:=1 TO SITELEN DO
```

```
      BEGIN
      READ(CH);
      SITE:=SITE||STR(CH);
      END;   (* FOR *)
   READLN;
   (* READ IN SITE NAME *)
   READRTN;   (* READ 1ST RECORD *)
   DATESV := DATEIN;
   STVAL := 0;
   MAXC:=-MAXCON;MAXA:=-MAXCON;MAXW:=-MAXCON;MAXS:=-MAXCON;
    MAXZ:=-MAXCON;TOTA:=0;TOTW:=0;TOTC:=0;TOTS:=0;TOTZ:=0;
        (* INITIALIZE ACCUMULATORS AND SAVES *)

   WHILE (NOT EOF) DO
      BEGIN
      IF DATEIN <> DATESV THEN
       DATECH(TOTA,TOTW,TOTC,TOTS,TOTZ,MAXA,MAXW,MAXC,MAXS,MAXZ,DATESV);
      CASE CODEIN OF
         1: BEGIN
              CALCMAX(MAXD);
              END;   (* CASE 1 *)
         2: BEGIN
              SUMDIV(STVAL,EDVAL,TIMEIN);
              STVAL:=EDVAL;
              END  (*  CASE 2 *)
         END;   (* CASE *)
      READRTN
      END;   (* WHILE *)
   DATECH(TOTA,TOTW,TOTC,TOTS,TOTZ,MAXA,MAXW,MAXC,MAXS,MAXZ,DATESV)
   END   (* IF *)
END.
//GO. INPU DD*
```