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CONSERVATION TILLAGE: IMPACT ON AGRICULTURAL HYDROLOGY AND WATER QUALITY IN THE SAGINAW BAY DRAINAGE BASIN

by

Arthur J. Gold

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ABSTRACT

CONSERVATION TILLAGE: IMPACT ON AGRICULTURAL HYDROLOGY AND WATER QUALITY IN THE SAGINAW BAY DRAINAGE BASIN

by

Arthur J. Gold

Water borne edge-of-field losses of sediment and nutrients from conservation (chisel plow) and conventional (moldboard plow) tillage sites were investigated. A field scale monitoring program was undertaken for 20 months, from March 1, 1981 to October 1, 1982 on adjacent plots. Flow from overland runoff and subsurface tile discharge was recorded and nutrient and sediment analysis performed. Precipitation characteristics, residue cover, crop stage, and antecedent soil moisture were analyzed to determine the conditions that generated substantial water borne losses from one or both of the study fields. Longterm weather records were then evaluated to find the likelihood of occurrence of those conditions that appeared to generate runoff and erosion.

Eleven hydrologic events (tile and/or overland flow) occurred during the sampling period; two resulted from snowmelt and nine from precipitation. The combined volume of overland and tile flow from the two fields was almost identical for the study period, but the conservation tillage field had significantly more subsurface tile flow than the conventionally tilled field. Subsurface tile flow on both fields had significantly lower concentrations of phosphorus, sediment, and total kjeldahl nitrogen than overland flow. Nitrate nitrogen concentrations were higher in tile flow than overland flow.

The conventionally tilled field lost substantially more sediment, phosphorus and total kjeldahl nitrogen than the conservation field. A large portion of the nitrogen and phosphorus lost from both tillage systems was in a soluble form. Sediment loss from both fields was low; snowmelt runoff generated the largest quantity of sediment on both fields. A single intense storm that occurred on emerging field beans accounted for much of the difference in sediment and phosphorus losses from the two tillage systems.

Based on longterm weather records, conservation tillage practices will cause a larger reduction of phosphorus and sediment losses on sites planted to field beans than corn. Erosive events are not expected from November through May and water borne losses can be reduced by any management practice that diminishes overland flow.

To Marion

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NOMENCLATURE

AMC = Soil antecedent moisture content

C = Crop management factor

ET = Actual evapotranspiration for a given crop species and stage

ETo = Reference evapotranspiration

K = Crop coefficient (ET/ETo)

N = Nitrogen

P = Phosphorus

P(B)= Probability of B

P(A1B) = Conditional probability of A given B

P(A,B) = Probability of the intersection of A and B

R = Rainfall erosion index (MT-m/(ha-hr))*

Rs = Snowmelt erosion index (MT-m/(ha-hr))*

S = 24 hour storm greater than or equal to 12.7 mm

SL = 24 hour storm greater than or equal to 25.4 mm and less than 50.8 or 60.0 mm during the dormant or growing season, respectively.

SLL = 24 hour storm greater than SL

SM = 24 hour storm greater than or equal to 12.7 mm and less than 25.4 mm

T = Return period (years)

TKN = Total kjeldahl nitrogen

X = Excessive rate storm

*Published units (Wischmeier and Smith, 1978) incorrectly representing (Kinetic Energy/Volume) x Intensity. Accepted British units are: $(\text{ft}\cdot\text{lb}/\text{acre}\cdot\text{in}) \times (\text{in}/\text{hr}) = \frac{\text{ft}\cdot\text{lb}}{\text{acre}\cdot\text{hr}}$

A more accurate metric conversion would be: $(\text{Joules}/\text{ha}\cdot\text{cm}) \times (\text{cm}/\text{hr}) = \frac{\text{Joules}}{\text{ha}\cdot\text{hr}}$. The published units were utilized to facilitate comparison with other studies.

CHAPTER 1

INTRODUCTION

1.1 Background

Croplands have been cited as a major source of pollution to the Laurentian Great Lakes (PLUARG, 1978). Fertilizers and pesticides that promote large and consistent crop yields can become contaminants if they enter the ground or surface waters. Of the many sources of nonpoint pollution row crops planted on fine textured soils have been credited with contributing the greatest amounts of phosphorus and sediment to the Great Lakes per unit area.

Since 1978 considerable national and international attention has focused on measures to reduce agricultural pollution to the Saginaw Bay of Lake Huron. The water quality of the Saginaw Bay is among the worst in the Great Lakes, comparable to the western basin of Lake Erie and the Green Bay of Lake Michigan. Within the inner Bay the influx of contaminants from the drainage basin has degraded its value for recreation and water supply purposes. In 1978 the International Reference Group on Great Lakes Pollution from Land Use Activities (PLUARG, 1978) recommended that all potential nonpoint source problems related to agricultural practices be considered and economically viable plans to abate pollution be explored.

In response to this recommendation the East Central Michigan Planning and Development Region, under the sponsorship of the United States Enivornmental Protection Agency (EPA), began a study of conservation tillage as a pollution control practice in the drainage basin of the southeast Saginaw Bay (hereafter known as the study region). The moldboard plow was the conventional tillage implement in the region and left the soil exposed to wind and water losses from fall tillage until the establishment of a crop canopy in early summer. Conservation tillage systems rely on crop residues to reduce soil and water losses.

The focus of the study documented in this dissertation was to compare the discharge of water borne substances to a receiving ditch or water body (edge-of-field losses) from conservation and conventionally tilled fields. Field monitoring was carried out from March 1, 1981-October 1, 1982. The results of the study will be utilized by the USEPA to model the changes expected in the water quality of the southeast Saginaw Bay if conservation tillage is widely adopted in the drainage basin. Additional studies on the economic feasibility of conservation tillage (Muhtar, 1982) and windborne edge-of-field losses (Merva and Peterson, 1983) were undertaken to evaluate all pertinant aspects of conservation tillage as a best managment practice.

Prior to this study research had been conducted on conservation tillage in the agricultural lands which drain into Lake Erie. The conclusions of studies in Indiana (Lake and Morrison, 1977) and Ohio (Honey Creek, 1980) indicated that conservation tillage systems could be expected to reduce water borne losses of sediment and phosphorus from croplands. Although these studies were located within 300 km of the Saginaw Bay region several distinct differences exist between the areas that warrant a fresh investigation of the feasibility of conservation tillage as a best management practice in the study region.

Conservation tillage has been shown to be very effective in reducing soil detachment and sediment loss. In areas where large annual losses of sediment occur, curtailing erosion can also be expected to significantly reduce losses of nutrients and other fresh water contaminants. Water borne erosion losses in the study region however, are expected to be relatively minor. The land is flat, the soils have good cohesiveness, and the annual rainfall erosivity, the driving force for soil detachment and transport, is among the lowest that occurs in the United States east of the Mississippi River. The rainfall erosivity in the study region is less than one-half that expected on the Lake Erie drainage basin where conservation tillage was previously studied. With lower erosion losses expected nutrient transport needs to be evaluated to determine the extent of pollution abatement from conservation tillage.

Phosphorus is considered the major water quality contaminant to the Saginaw Bay (PLUARG, 1978). In the last two decades the quantity of available P in the agricultural soils of the study region has increased by nearly five fold as a result of intense fertilization. Both the quantity and form (soluble or sediment bound) of the phosphorus transported from the cropland of the regions should be investigated in light of this unusually rapid increase in soil phosphorus levels.

Overland runoff can transport substantial quantities of sediment and nutrients from croplands. Practices that increase infiltration can be expected to diminish overland flow. A unique feature of the study region is that virtually all of the prime farmland has improved infiltration as a result of subsurface tile drainage. To gain a full perspective on the influence of conservation tillage as a best management practice an evaluation of both the surface and subsurface discharge waters should be undertaken.

The results of this study are not only intended to evaluate conservation tillage as a management practice, but also to determine the conditions that may result in significant losses of freshwater contaminants from conventionally tilled systems. Once these conditions are identified, management practices can be utilized or developed that are specifically tailored to reduce losses in the drainage basin of the southeast Saginaw Bay. This study is viewed as the first step to enable planners and management personnel to select and encourage effective pollution abatement programs for croplands in the study region.

1.2 Objectives

The overall objective of the study was to investigate the water borne losses of sediment and nutrients from conservation and conventionally tilled croplands in the southeast Saginaw Bay drainage basin. The specific objectives of the study were:

1. To compare the climatic and physical features of the study region to other areas where conservation tillage has been used to reduce edge-of-field losses from croplands.

2. To monitor and quantify the losses of sediment and nutrients in subsurface and surface flow from conservation and conventionally tilled croplands.

3. To determine the combinations of crop stage, soil conditions, and storm characteristics that generated substantial water borne losses from the croplands of the study region.

4. To identify the conditions that resulted in a substantial reduction of sediment or nutrient losses from conservation tilled sites compared to conventionally tilled sites.

5. To determine the longterm probability of events that may generate water borne losses from one or both of the tillage systems studied.

CHAPTER 2

LITERATURE REVIEW

2.1 Freshwater Contaminants from Croplands

Drainage from agricultural croplands has been found to carry varying amounts of freshwater contaminants depending on soil characteristics, tillage practices, canopy cover, fertilization methods, rainfall patterns, and field morphology. Sediment is the most visible pollutant from croplands. However, many of the nutrients, herbicides, and pesticides employed for modern agriculture can influence freshwater quality. The discharge of these substances from croplands to a receiving water body is commonly referred to as edge-of-field losses (Frere, 1976).

Nutrient losses from agricultural croplands can cause serious degradation of surface waters. Most soils lack the necessary quantities of nitrogen, phosphorus, and potassium to generate high yields desired by modern farmers. Accordingly, these elements are added to agricultural croplands each year by chemical fertilization or by animal manures. Frere(1976) estimated that 2.6 million tons of phosphorus and 7.8 million tons of nitrogen are added to agricultural croplands each year in the United States. Limnological studies have shown that phosphorus and nitrogen are the limiting nutrients to plant growth in most aquatic systems (Vallentyne, 1974). Additional inputs of these nutrients whether from sewage, detergent, rainfall, or agricultural runoff can degrade surface waters through cultural eutrophication.

Eutrophication is an aquatic process caused by an increased level of plant nutrients. Photosynthesis and plant growth accelerate, turbidity increases, species composition alter and reduced levels of dissolved oxygen may occur in bottom waters (Wetzel, 1975). Algal growth resulting from eutrophication can degrade drinking supplies by increasing treatment costs and affecting taste and odor (Borchardt, 1970).

Although every aquatic system may respond differently to nutrient inputs, preliminary work done by Sawyer (1947) indicated that aquatic plant growth will be accelerated by nitrogen concentrations of 0.30 mg/l and ortho phosphorus levels exceeeding 0.01 mg/l. Later studies (Shannon and Brezonik, 1972; Vollenweider, 1971) found that the critical concentrations of phosphorus and nitrogen will depend on the buffering capacity of the receiving water, the trophic status, and the morphology of the water body. Many aquatic systems will not change at the concentrations cited by Sawyers (1947) while others would be expected to alter dramatically from inputs at even lower concentrations

To obtain reasonable standards for management, concentration of nutrients coming off of croplands must be compared to "natural" nonpoint sources rather than to studies of algal and aquatic plant requirements. Nutrient concentration from nonpopulated forested areas and from precipitation often exceed the critical levels cited by Sawyer. Background concentrations of total phosphorus and nitrate nitrogen in the Great Lakes region have been estimated at 0.02-0.10 mg/l and 0.2-0.5 mg/l respectively (McElroy et al., 1976). Rainwater sampled for 18 years in northern Ohio was found to have mean concentrations of 0.5 mg/l total phosphorus and 2.2 mg/l nitrate nitrogen (Schwab et al., 1980).

In a 6 month study in the Saginaw Bay region of Michigan rainwater had mean concentrations of 0.18 mg/l orthophosphate and 0.64 mg/l nitrate nitrogen (Richardson and Merva, 1976).

Nutrient concentrations in runoff from croplands can vary widely. Concentrations of orthophosphate and nitrate nitrogen found in studies of overland runoff ranged between 0.005-0.950 mg/l and 1.0-28.0 mg/l respectively (Harms et al., 1974; Johnson et al., 1979; McDowell and McGregor, 1980; Baker and Laflen, 1982; Schwab et al., 1980; Logan and Adams, 1981). Holt et al. (1976) in a review of research concerning subsurface water quality from croplands found that yearly flow weighted mean concentrations of ortho phosphate and nitrate nitrogen ranged from 0.001-0.52 mg/l and from 1.0-33.0 mg/l respectively.

Based on the range of concentrations found in runoff from agricultural croplands, all agricultural regions can not be veiwed as sources of nutrient contamination to surface waters. Specific combinations of surface water characteristics, proximity, and cropland management can result in either non degrading situations or situations where agricultural runoff can lead to cultural eutrophication.

2.2 Sediment Loss From Agricultural Cropland

Sediment is the largest pollutant by volume from agricultural croplands. Half of all sediment in the United States is the result of erosion of agricultural lands (Wischmeier, 1976). Annual soil loss from agricultural croplands range from 2.2 Mg/ha to greater than 220 Mg/ha; however,only 20% of the 179 million hectares of cropland lose more than 17 Mg/ha per year.

Sediment that enters freshwater can alter aquatic communities, increase turbidity and clog waterways. Reduction in channel capacity and reservoir storage can result in increased flooding. In the 1940's a survey showed that more than 33% of the midwest's water supply reservoirs would become unusable by the year 2000 due to sedimentation (Beasley, 1972). Removing sediment from waterways is an expensive burden costing the United States 250 million dollars a year (ASCE, 1977).

Sediment in waterways affects light penetration, decreases photosynthesis, and can ruin spawning grounds for fish. No standard exists for tolerable concentrations of sediment losses. On agricultural croplands the magnitude and intensity of the sediment losses are not constant but vary with field conditions and storm events. The impact of sediment losses is affected by a field's proximity to surface water. It has been suggested (Skaggs et al., 1982) that sediment control is more critical on agricultural croplands near coastlines, lakes,and rivers where the delivery ratio is relatively high. The EPA recommended standard of 800 mg/l (U.S. EPA, 1973) might serve as a target for croplands directly outletting to a waterbody. This is equivalent to a yearly soil loss of 1.2 Mg/ha for a region with 15 cm of runoff, well below the tolerance limits for most Michigan soils currently set by the United States Soil Conservation Service (6-11 Mg/ha) (USDA/SCS, 1981).

2.3 Pesticide Losses From Agricultural Croplands

Losses of pesticides from agricultural cropland can not be treated in a singular fashion because of the variations that occur between the different chemicals in solubility, degradation time, adsorbtivity, and application methods and timing. Pesticide hazard is usually classified by the LC 50 of the pesticide, i.e. the concentration that proved to be lethal to 50% of a test species in a bioassay. The bioaccumulation factor is another parameter commonly used to evaluate potential hazard. The International Reference Group on Great Lakes Pollution (PLUARG, 1978) did not find serious surface water degradation or biological contamination from agricultural pesticides in the Great Lakes.

The highest concentrations of substances moderately or weakly adsorbed to sediment have been found in runoff events occurring close to the time of application (Smith et al., 1974). Triplett et al. (1978) found that atrazine, a moderately adsorbed substance was present in runoff occurring soon after application. Concentrations declined rapidly in later runoff events. Other researchers cited by Triplett have found that the majority of the annual pesticide loss occurred in the first one or two runoff events after application.

2.4 Sediment as a Transport Agent

Water borne substances leave a field either in solution, adsorbed on sediment particles, or as solids. Soluble nutrients and pesticides move more rapidly from a field than do solids and soil borne substances which are subject to the processes of erosion and sedimentation. Edge-of-field losses of constituents strongly adsorbed to soil particles can be minimized by controlling sediment losses. Limiting losses of soluble constituents requires other management stategies.

Water borne pollutants have been classified by their relative concentrations in water or on soil particles by an adsorptive partition coefficient, Ks (Steenhuis and Walter, 1979). Ks is the ratio of the concentration of the substance adsorbed vs. the concentration in solution. Substances with high Ks (1000) such as organic nitrogen, ammonium nitrogen, solid phase phosphorus, and toxaphene will move with the soil. Atrazine and soluble inorganic phosphorus have Ks values near five and are considered moderately adsorbed pollutants, while nitrate nitrogen has a very low Ks (0.05) and is highly soluble.

A study carried out by Stoltenberg and White(1953) found that eroded material contained twice the concentrations of nitrogen and phosphorus compared to the soil from which it originated. The eroded material contained considerably more clay and organic matter which have greater cation exchange capacity than coarser particles and hold a high proportion of the nutrients found in the soil. The magnitude of the nutrient increase found in sediment carried from the field has been quantified by an enrichment factor, which is the ratio of the concentration of the constituent in the sediment to the concentration of the same constituent in the soil. Stoltenberg and White found that enrichment was due to differences in transport and suspension among sediments. The lighter clay and organic matter particles were not as subject to redepositon by the runoff water. Once suspended these particles with their adsorbed substances left the field more readily than larger heavier particles.

Massey et al. (1952) found enrichment ratios to vary inversely to sediment concentration and net sediment loss. Walter et al. (1979) have concluded that the enrichment ratio for clay and organic matter increases with an increase in soil detachment by raindrop splash relative to detachment by flow. The authors suggest that as transport energy decreases, the enrichment ratios increase as the lighter particles comprise a larger porportion of the sediment.

The water quality impact of nutrients and pesticides lost from agricultural croplands must be assessed in terms of the availability of a substance to the aquatic system. Whereas soluble substances are considered to be readily available to algae and other aquatic organisms (Lee, 1978) only a portion of substances associated with the sediment readily influence the aquatic community. In the case of phosphorus Huellt (1979) found that only 20-40% of the phosphorus associated with sediment was available to algae. DePinto et al. (1981) in a bioassay study of sediment from Great Lakes tributaries concluded that 21.8% of the total particulate phosphorus was available to a common species of green algae.

When soil loss is high, most of the phosphorus and nitrogen leaving a field is strongly associated with the sediment. Lake and Morrison(1977) reported that 90% of all phosphorus lost from the Black Creek agricultural watershed was attached to soil particles. Johnson et al. (1979) found that sediment carried 80-99% of the total phosphorus and most of the nitrogen lost from steep erodible watersheds. Erosion losses in the study were quite high (31 Mg/ha). Sediment bound phosphorus constituted 90% of the total losses from two watersheds in Michigan with moderate erosion rates (Ellis and Erickson, 1977).

2.5 Conservation Tillage for Pollution Control

Controlling erosion losses from agricultural croplands will prevent many agricultural contaminants from reaching surface waters. The trends in American agriculture since World War II have been towards larger field size, extensive monoculture and larger equipment. Terraces, once a popular conservation practice have been found to increase the time required to till, plant and harvest crops, detrimental features in an era of rising labor costs (Spomer et al. 1976). Various conservation practices are being regularly evaluated to study both their effectiveness and compatibility with modern agriculture (Lake and Morrison, 1977; Siemens and Oschwald, 1978; Phillips and Young, 1973).

In the last decade conservation tillage has emerged as an agronomic practice to control water pollution from croplands. Conservation tillage systems rely on surface crop residues to reduce soil and water losses. Conservation tillage is now widely used in place of or in conjunction with traditional sheet erosion control practices. Wischmeier (1976) felt that residue management was one of the major tools for erosion control and an area which required futher research.

Conservation tillage practices range from no till where planting occurs in the undisturbed residue of the previous crop to modified fall tillage practices such as chisel plowing, discing, or ridge planting, where a portion of the residue is buried, leaving residue on 20-80% of the ground surface. Conservation tillage can effectively reduce sediment loss when no canopy exists and erosion hazard is considered the greatest (October-July). Conservation tillage practices have been designed for use on most row crops and have been adapted to modern farming. Currently one quarter of the nation's croplands are using some form of minimum or conservation tillage (Sterba, 1982). Conservation tillage practices can influence overland runoff and are very effective in reducing sediment loss from croplands.

2.6 Sedimentation Processes

The mechanisms involved in erosion and sediment loss from croplands have received considerable research (Wischmeier and Smith, 1958; Harrold, 1947; Foster and Meyer, 1977; Beasley, 1972). Sediment loss from a field is generated through a process which includes soil detachment, transport, and deposition. Factors affecting any of these processes will influence the character and quantity of sediment loss.

Predictive models have been developed to estimate soil erosion losses from cropland. The model accepted for use by the U.S. Soil Conservation Service is known as the Universal Soil Loss Equation (USLE) (Wischmeier, 1976). In the equation:

$$A=RKLSCP \quad (1)$$

where

A=Soil Loss (kg/ha/year)

R=Rainfall erosivity Factor (MT-m/(ha-hr))

K=Soil Texture Factor

LS=Topographic Factor

C= Crop management Factor

P= Support practice Factor

The Universal Soil Loss Equation was intended to predict average soil losses over extended periods given a set of management practices and a specific rotation. The model can not account for yearly differences in antecendent soil moisture conditions, soil crusting, or other factors which influence runoff and sediment transport. When used for single precipitation events the USLE may predict soil loss based upon storm characteristics although no surface runoff left the watershed. Several models have recently been developed that include runoff characteristics along with rainfall characteristics to compute sediment loss (Williams and Berndt, 1977; Onstad and Foster, 1975).

Soil detachment is caused by either raindrop impact or flowing water. On upland sites without developed rills or gullies, raindrop impact is the primary source of soil detachment. Meyer and Wischmeier (1969) using laboratory experiments of simulated rain with uniform drop size suggested that interrill soil detachment is proportional to the square of the rainfall intensity. High intensity storms will have higher potential to detach soil than low intensity storms if the volumes of precipitation are equal. The United States Weather Service has recorded intense rainstorms that meet the classification of an excessive rate storm. Excessive rate storms are defined as storms of depth (mm) equal to or exceeding the quantity (5 + 0.25t) where t is the storm duration in minutes (Schwab, et al., 1981). Wischmeier (1959) described the total erosive power of a rainstorm as the product of the kinetic energy of the rainstorm times its maximum thirty minute intensity. This product known as the rainfall erosion index (R) has been computed for selected points throughout the United States (Wischmeier and Smith, 1978).

Crop canopy or residue cover can intercept raindrops and shield soil aggregates from impact and possible detachment. Intense storms which occur during periods with canopy or residue cover will generate substantially less erosion than storms occurring during periods without cover. Greer et al. (1976) in a six year study in Mississippi found that rainfall intensity and crop stage were the major factors that produced runoff and erosion from croplands. Excessive rate storms accounted for 55% of the the runoff and 77% of the soil loss during the study period. Only 37% of all the rainfall events were intense enough to be considered excessive rate storms.

Excessive rate storms had the greatest impact on sediment loss when the soil was unprotected following seedbed preparation. During this annual two month period, excessive rate rainstorms generated 50% of the sediment loss while comprising only 6% of the total rainfall of the period. This contrasts with the results obtained during the period of crop growth and harvest when a 70-100% crop canopy covered the soil. Although excessive rate storms accounted for 31% of the rainfall in these periods they produced only 25% of the total soil loss from these periods.

In a three season study of edge-of-field losses conducted in Michigan (Ellis,et al., 1978) it was found that the majority of the sediment and total phosphorus lost during the study period occurred with one intense rainstorm on partially frozen soil. The Black Creek, Indiana investigation of agricultural water quality (Lake and Morrison, 1977) concluded that the transport of sediment and nutrients was strongly associated with the large storm events of the year. Spomer et al. (1976) found that a few large storms produced most of the sediment lost from croplands in western Iowa over a ten year period.

In the Iowa study 92% of the annual sediment yield occurred in May and June during seedbed preparation and crop establishment. During this period 30% of the annual rainfall occurred comprising 45% of the annual rainfall erosivity (R). The mollifying effect of canopy cover on erosion losses was demonstrated during one season when rainfall erosivity was 321 units compared to the average annual erosivity of 160 units. Annual sediment loss for that year however instead of increasing dramatically, fell far below the average of the study. Upon close examination the authors concluded that distribution of the erosive storms accounted for this discrepency. Of the total erosivity that occurred during that year, 71% occurred during August and September when a substantial crop cover shielded the soil from direct raindrop impact.

The distribution of excessive rate rainstorms was shown to dramatically alter sediment loss from croplands in New York (Free and Bay, 1969). Studies of erosion were undertaken on the same plots from 1939-1948 and from 1956-1964. In the first period tillage was performed by a moldboard plow on the contour. In the second period the moldboard plow was used up and down the 16% slope. The authors expected erosion from the later study to be double that of the first period due to the effect of row direction. However only one-sixth of the soil lost during the first period came off the plots during the second eleven years of study. Annual rainfall erosivity was similar during the periods (74 EI units), but the distribution of the intense rainstorms was very different. In the first period 65% of the total precipitation from March through June was associated with excessive rate storms. This compares to 13% for the same months during the second 11 year period. The authors concluded that the lower average annual erosion that resulted from the second study occurred because most of the rainfall erosivity came after a full canopy was developed.

In a watershed study in Watkinsville, Georgia (Walters, et al., 1979) the ten largest storm events generated 95% of the sediment lost over a three year period. The presence of a canopy cover reduced sediment loss by 60% for storms of equal magnitude and intensity that generated similar runoff quantities.

Crop canopy intercepts a proportion of the raindrops that fall on cropland. While some of the intercepted precipitation is evaporated or reaches the soil by stemflow, in large intense storms much of the intercepted water reforms into drops which may be larger than the original raindrop size. The height of the canopy limits the velocity these drops obtain before striking the ground. Ghadiri and Payne (1977) have shown soil splash and detachment to be a function of drop diameter times the velocity squared.

Wischmeier and Smith (1978) have computed the ratio of the rainfall erosivity (R) striking soil protected by canopy cover to the rainfall erosivity impacting fallow ground. This ratio is known as the Crop Management Factor (C) in the USLE. They used both crop height and cover density in their calculations. Soil protected by a full crop canopy can be expected to receive between 0.4 and 0.2 of the rainfall erosivity that strikes bare soil.

Residue cover is more effective at reducing raindrop energy impacting the soil surface than is crop cover (Wischmeier and Smith, 1978). Droplets intercepted by surface residue do not regain any appreciable fall velocities. The role of surface cover in dissipating raindrop energy and soil detachment extends beyond the soil surface directly covered by the residue. Foster (1982) using data derived from an unpublished Master's thesis by Lattenzi (1973) concluded that surface residue cover increases the hydraulic roughness of the flow surface and thereby increases the flow depth of surface runoff. Mutchler and Young (1975) suggested that a water depth of 6 mm. essentially eliminated detachment by raindrop impact and depths up to 6 mm. were capable of reducing detachment. The surface roughness provided by conservation tillage can be expected to limit detachment on a larger surface area than is covered by the residue. Wischmeier and Smith (1978) computed the "C" factor for mulch at various levels of cover. When no crop canopy is over the soil surface, soil covered by mulch at 20%,40%,and 60% cover will receive 0.65,0.35, and 0.25 respectively of the rainfall erosivity striking bare ground.

2.7 Sediment Transport

The hydrologic processes of rainfall and runoff generate erosion and sedimentation. Factors that affect either rainfall or runoff directly affect erosion and sediment transport. Any complete analysis of erosion and sediment yield from croplands must consider hydrology and runoff.

Hydrologic factors that influence runoff volumes and velocities, such as surface porosity, soil antecedent moisture content, and surface roughness will alter sediment and nutrient losses from farmlands. Meyer et al. (1970) employed rainfall simulators to examine the influence of mulch rates on sediment losses. It was found that relatively light residue cover of 0.56 Mg/ha and 34% cover reduced erosion by one half on steep slopes compared to conventionally clean-tilled treatments. A significant decrease in runoff velocities on the mulched plot was cited as the major cause of the observed difference. It was noted that the mulch straw lying across the slope collected soil about it and acted as a series of reservoirs slowing the runoff thereby reducing its carrying capacity for sediment.

Romkens and Mannering (1973) monitored runoff from five levels of residue with a rainfall simulator. Slopes ranged from 8-12%. Chisel plowed plots with 38% cover after planting significantly reduced erosion losses. Runoff velocities were slower and sediment was trapped by both tillage ridges and corn residue. The authors noted that the sediment resulting from plots with residue had higher proportions of colloidal particles and higher nitrogen and phosphorus concentrations. The sediment was more enriched as a result of the reduced velocities of the runoff.

Neibling and Foster(1977) compared runoff velocities from several types of residues at different levels of cover to velocities from bare, fallow, unrilled soil. Runoff velocities decreased with increasing levels of residue cover. Partially incorporated corn stalk residue at 2 Mg/ha, 4 Mg/ha, and 5 Mg/ha levels of cover decreased runoff velocities 10, 30, and 40% respectively, compared to bare soil.

During storm events, overland flow can not occur until the precipitation rate exceeds the infiltration rate of a soil. However, intense storms on bare soil can alter the porosity of the surface soil markedly decreasing its initial and final infiltration rates. If infiltration declines, runoff and sediment transport can be expected to increase.

Ellison (1947) found that raindrops on bare soil broke up soil aggregates and displaced soil particles in the raindrop splash. The displaced particles caused surface puddling to occur. Certain clay soils tested lost up to 90% of their infiltrative capacity within several minutes of rainfall inception due to surface sealing from soil splash.

Duley (1939) made detailed studies of the effect of crop residue on soil infiltration. He found that soils mulched with 5 Mg/ha of wheat straw had significantly more infiltration than bare plots. All plots tested had high initial infiltration rates; however,the infiltration rate remained high on the mulched plots while falling rapidly on the unmulched plots. Microphotographs of the surface soils showed that a compacted crust approximately three millimeters thick had formed on the bare soil as a result of raindrop impact and movement of soil fines. Much less surface compaction was found on the mulched soils.

Mannering et al. (1966) using a rainfall simulator found that 6 Mg/ha (95% cover) of dry hay on corn ground doubled the total infiltration compared to conventional clean tillage treatments. Soil loss on the mulched field was essentially eliminated. In a three season study of three tillage practices on steep slopes Johnson et al. (1979) found that the ridge plant system with 59% residue cover reduced runoff by 60% and erosion by 90% compared to losses from moldboard plowed systems. Chisel plowed plots had a significant reduction in runoff and erosion compared to moldboard plowed plots in Illinois (Siemens and Oschwld, 1978). Increased surface roughness produced by the chisel plow provided additional storage areas for the runoff to settle and infiltrate.

Crop residues will decrease runoff quantity as long as permeable soils have available moisture holding capacity. Rainfall simulation studies (Johnson and Moldenhauer, 1979; Meyer et al., 1970) showed significant differences in runoff and infiltration between conservation tillage and conventional tillage only for their initial tests when the soil was dry or at field capacity. Follow up tests within the next 24 hours on partially saturated soil did not demonstrate runoff differences between tillage systems.

Logan and Adams (1981), in a review of published and unpublished data, concluded that surface residue will decrease overland runoff on permeable soils with good internal drainage. On soils with low infiltration rates and poor internal drainage surface residue has little influence on runoff quantity and may increase runoff. The observed increase in runoff on poorly drained soils was attributed to the insulating properties of residue, which slowed soil evaporation elevating soil moisture level compared to fallow ground.

The capacity of the soil to store water during a precipitation event can directly influence runoff and losses of both soluble and particulate materials. Thomas et al. (1981), in an examination of infiltration processes, found that the antecedent moisture condition of a soil dramatically affected the quantity of rainfall excess regardless of rainfall pattern. Mockus (1972) in his model of runoff from small watersheds gave considerable weight to the influence of antecedent moisture conditions on runoff volume and rate. Under dry conditions all the precipitation from an intense storm may infiltrate into the soil generating no overland flow.

A portion of the seasonal variation in sediment loss that has been observed in the literature can be attributed to the changes in soil moisture that occur throughout the year. In a study of overland runoff conducted on a somewhat poorly drained loam soil, Aull (1979) found that during the six week period folowing initial snowmelt (March 3, 1979) storms of very low maximum 30 minute intensities (less than 1 mm/hr) generated considerable runoff and sediment loss. The site did not have subsurface drainage tile and after thawing remained near saturation until mid April.

Subsurface drainage has been proposed as a method to reduce overland flow and associated sediment and nutrient losses on poorly drained soils (Skaggs, et al., 1982).

Schwab et al. (1980) have concluded that tile drainage has been found to reduce the volume and peak flow rate of overland runoff. Reducing volume and peak flow should have a noticable effect on the quantity of material transported off the field by overland flow. Reducing runoff volumes will limit losses of soluble nutrients, while curtailing peak flow rates should reduce the sediment carrying capacity of the runoff water.

Tile drainage water can be expected to carry lower concentrations of sediment than overland runoff. Most of the sediment carried in surface water is filtered out by the soil medium before it reaches the tile. Schwab et al. (1980) conducted a longterm field investigation to study sediment loss from tiled and untiled plots. Mean flow weighted concentrations of sediment in subsurface drainage were 50-90% lower than in surface flow. Skaggs et al. (1982) used a simulation model to investigate the influence of tile drainage on sediment loss. For the sites modelled losses were calculated at 9 Mg/ha for untiled conditions and 0.9 Mg/ha per year when subsurface tile was added.

Bengtson et al. (1982) compared the nutrient and sediment losses from both tiled and untiled plots on alluvial soils in Louisiana. Soil loss on all plots was relatively small (less than 2 Mg/ha per year); however, tiled plots reduced sediment loss by 17%. The greatest reduction in sediment loss due to subsurface drainage occurred during the winter when water tables were high and evapotranspiration low. During these periods, surface runoff was reduced by 34% and soil loss by 43%. Annual losses of phosphorus were reduced by 32% on the tiled plots.

Logan and Schwab (1976) monitored sediment losses in tile effluent on three watersheds in Ohio. On all sites yearly losses were less than 0.9 Mg/ha. Sediment concentrations did appear to be influence by surface hydrology. During several precipitation events, concentrations as high as 2,700 mg/l were observed. The elevated concentrations are thought to be the result of soil fines flowing directly into the tile through cracks in the soil.

Management practices that increase infiltration may affect both the quantity and quality of subsurface tile flow. Holt et al. (1973) suggested that tillage practices that increase soil porosity and infiltration may result in greater movement of nutrients and sediment into subsurface tile. Bengtson et al. (1982) found that sediment loss from subsurface tile flow was significantly higher on plots that were chisel plowed (1.4 Mg/ha) than on plots with a grass cover (0.4 Mg/ha). The authors concluded that chiseling contributed to an increase in soil loss from subsurface drainage.

2.8 The Movement of Soluble Nutrients

When soil loss is low, the soluble fraction of nutrients in runoff increases. Soluble phophorus comprised the largest fraction of total phosphorus lost from 33 plots in Missouri (Smith et al. 1974). The study was conducted on claypan soils with 3% slope. Sediment losses were slight (less than 1.5 Mg/ha per year).

Harms et al. (1974) in a two year study of nutrients and sediment losses in South Dakota found that the sediment bound fraction of phosphorus and nitrogen constituted 69% and 42% of the total lost from rainfall events. Rainfall runoff carried high concentrations of sediment. In snowmelt runoff which was essentially free of sediment, only 23% and 11% of the total phosphorus and nitrogen lost from the fields was sediment bound. For the entire study, all of the nitrate, 69% of total kjeldahl nitrogen and 27% of the phosphorus were independent of any sediment. Most of the runoff was from snowmelt (68%) and total sediment losses were low (less than 1.1 Mg/ha per year). The authors concluded that traditional soil and water conservation practices that limit rainfall runoff and erosion would not limit all the nutrients in agricultural drainage waters. However it was suggested that phosphorus losses could be curtailed by erosion control.

Runoff from snowmelt may have higher proportions of soluble nutrients than rainfall events. Ellis and Erickson (1977) found that soluble phosphorus constituted 25% of the total phosphorus in snowmelt compared to 7% of the total lost during rainstorm events. Nitrogen in snowmelt was predominantly lost as soluble nitrate and ammonium; whereas, during rainfall events 82-94% of the total nitrogen loss was in the sediment phase. The authors attributed the higher levels of soluble nutrients in snowmelt to the nutrient content of the snow that fell on the fields.

Concentrations of soluble nutrients may be relatively high in runoff coming from conservation tilled croplands. Plant material can release soluble phosphorus and soluble nitrogen when subjected to desiccation, freezing, thawing and drying. Timmons et al. (1975)

investigated the effect of changing environmental conditions on the extent of soluble nutrient release from crop residue. In laboratory analysis grain, straw, and forage crops were periodically frozen, dried, and subjected to leaching. Substantial quantities of soluble phosphate and nitrate were released to the leachate. Holt et al. (1973) reported that snowmelt from alfalfa land had concentrations and losses of soluble phosphorus two to four times greater than snowmelt from fallow land or moldboard plowed corn. Harms et al. (1974) found more soluble nutrients coming from noncultivated sites with forage or grain than from tilled sites.

Rainfall simulation tests have been used to evaluate movement of soluble nutrients from various tillage systems. Siemens and Oschwald (1978) in a study of seven tillage systems found that losses of soluble phosphorus and soluble nitrogen were not reduced significantly by conservation tillage. Johnson et al. (1979) in a study of nutrient and sediment losses from three different tillage systmes found that soluble concentrations in runoff increased with increased residue cover. Although conservation tillage reduced runoff and erosion compared to conventional tillage the higher concentration of soluble phosphorus in the runoff minimized differences in net phosphorus losses from the tillage systems. Most of the nitrogen lost from all three sites was in the form of total kjeldahl nitrogen and controlling sediment appeared to control nitrogen losses.

McDowell and McGregor (1980) also found that no till treatments reduced soil loss while increasing soluble phosphorus losses. The authors cited several reasons for this phenomena:

1) insufficient sediment in runoff to sorb phosphorus from

solution;

2) release of phosphorus from crop residues;

and 3) decreased fertilizer incorporation

The mean flow weighted concentration of soluble phosphorus was 0.4 mg/l from the no till plots vs. 0.02 mg/l from the conventionally clean tilled plots. Both treatments received the same amount of phosphorus fertilizer. Barisas et al. (1978) did not find nitrate nitrogen concentrations to be significantly correlated with residue cover. Soluble phosphorus concentrations did correlate significantly with residue cover. The authors concluded that conservation tillage was ineffective in reducing soluble nutrient losses in overland flow.

Baker and Johnson (1982) observed greater concentration of soluble phosphorus and nitrate nitrogen in runoff from plots with 1.6 Mg/ha of corn residue than in runoff from conventionally tilled plots. However the conservation tillage plots lost less than one half of the quantity (kg/ha) of the soluble phosphourus and soluble nitrogen compared to the conventional plots. This difference was the result of increased infiltration and storage on the conservation tilled plots. The tests were performed on a well drained sandy loam soil and the magnitude of the runoff from the conventional plots was 3.3 times that of the conservation tillage plots, offsetting the higher concentrations in the flow. Since elevated concentrations of soluble phosphorus and nitrogen appear to be a likely phenomena associated with conservation tillage, net losses of these nutrients can only be acheived in situations where runoff from conservation is considerably less than from conventional tillage.

Tile drainage has been found to have different water quality characteristics than overland flow. Subsurface tile drainage was monitored during the water quality study at Black Creek, Indiana (Lake and Morrison, 1977). Flow weighted mean concentrations of sediment, soluble phosphorus, and particulate phosphorus were much lower in tile drainage water than in overland flow. Concentrations of nitrate nitrogen were higher in tile flow than overland flow. The study concluded that best management practices that allow more water into tile drainage systems will significantly reduce sediment and phosphorus losses. Losses of nitrate nitrogen may be expected to increase.

In a study of agricultural subsurface drainage water from farms in Michigan, Erickson and Ellis (1970) concluded that tile drainage carried low concentrations of soluble phosphorus. Measured concentrations of ortho phosphorus ranged from less than 0.05 mg/l to 0.30 mg/l. Nitrate nitrogen losses were considerably higher, but the maximum concentration observed was 11.1 mg/l, just above the Public Health drinking water standard of 10 mg/l. Of the nitrogen and phosphorus applied as fertilizer to the farmlands 14% and 0.3% respectively left the fields via tile drainage.

Gianelli (1971) found nitrate nitrogen to be the dominant nutrient in tile drainage in the San Joaquin valley of California. Average concentration of nitrate nitrogen was 19.3 mg/l while average concentrations of total kjehldahl nitrogen and ammonium nitrogen were less than 1 mg/l. Ortho phosphorus concentrations averaged 0.09 mg/l.

Baker et al. (1975) sampled agricultural tile flow for four years in Iowa. Concentrations of phosphorus were very low. Ortho phosphorus ranged from 0.001 to 0.038 mg/l and total phosphorus from 0.007 to 0.182

mg/l. The authors considered these concentrations typical of tile drainage. Tests of the subsoil indicated that it had low levels of phosphorus and was capable of adsorbing phosphorus from the surface water percolating to the subsurface tile.

In the Iowa study nitrate nitrogen concentrations ranged from 2.3-44.2 mg/l. The flow weighted mean concentration was 21 mg/l. Sites with subsurface drainage can be expected to lose more nitrate nitrogen than undrained sites. Denitrification, the principal process of nitrate removal requires anaeraobic conditions in the presence of a carbon source. On sites with artificial drainage saturated anaerobic conditions in the carbon rich top soil are not maintained for extended periods and denitrification is minimized.

2.9 Simulation Models of edge-of-field Losses from Croplands

The increasing use of high speed computers has permitted the creation of complex simulation models to evaluate the influence of conservation practices on edge-of-field losses. A detailed review of sediment yield models was conducted by Foster (1982). Frere et al., (1982) have reviewed the various models that predict nutrient losses from agricultural lands. The models require field based calibration and are limited by the availability of precise hydrologic inputs. Storm characteristics are approximated with available precipitation data; however, the long term records of the National Weather Service (NOAA) are limited to daily increments for most locations. Hourly records, where available, still do not generate sufficient information on the brief intense storms that may generate overland flow or cause soil crusting. None of the models surveyed in the literature account for the influence of tile drainage on water quality.

2.10 Monitoring Approaches

Field studies monitoring runoff during periods of precipitation and runoff are the traditional approach for evaluating specific soil and water conservation practices. Studies are conducted both on small plots with numerous replications for statistical validity as well as on larger production scale areas. It has been suggested that small plots generate more sediment loss per unit area than field scale plots (Harms et al. 1974; McGregor and Greer,1972). Runoff from small plots may consist of a disproportionate quantity of sediment from soil splash. Deposition processes common in larger watersheds are often absent on short narrow plots.

Large production scale field studies require a long term committment to fixed experimental practices. Limited financial and land resources often restrict large field studies to side by side plot comparisons. While this permits evaluation of actual production scale practices, it eliminates the replications necessary for stringent statistical tests.

The conclusions drawn from a field study are extremely biased by the weather patterns that occurred while the monitoring apparatus was functional. Many field studies reported in the literature are based on two to four years of monitoring (Von Stryk and Bolton, 1977; Smith et al., 1974; Lake and Morrison, 1977; Ellis et al. 1979). However, Chow (1964) concluded that twenty years of records are required to produce a fair approximation of hydrologic patterns in a region.

To circumvent the uncertainty of weather driven studies, artificial rainfall simulators (rainulators) have been employed (Meyer, 1960). The simulators allow rapid data collection and excellent replication of raindrop size and intensity. Small plot rainulators (1 m x 1 m) have been used to study soil splash and detachment, while larger rainulators in conjunction with introduced runoff attempt to simulate large field conditions of runoff and erosion (Swanson and Dedrick, 1966).

The rainfall simulators are an excellent means for comparing the effect of various conservation treatments under a given set of conditions. Rainfall simulators are particularly useful for depicting "worst case" scenarios of high volume, high intensity storms. The studies need to be planned and analyzed in conjunction with long term weather records to insure that runoff producing scenarios of weather, soil moisture, and crop stage typical of the study region are simulated (Meyer, 1960).

CHAPTER 3

METHODS: FIELD INVESTIGATION

3.1 Site Selection

The United States EPA was interested in the water quality resulting from typical production scale agricultural practices. No large rainulators were available for the project. Funding and time constraints limited the amount of field work and construction that could be undertaken so a rigorous selection process was carried out to find a large field that could be used for a side by side plot comparison study. Because most of the prime farmland in the study region was tiled, it was decided to find a site where both overland runoff and subsurface tile flow could be monitored.

The predominant soil series in the study region are classified in Michigan Soil Association 20 and 21 (Whiteside et al., 1968). The soils of these associations were developed under poor natural drainage conditions from loam, clay loam, or silty clay loam parent material. The principle hazards to crop production are naturally poor drainage. When subsurface tile is utilized to improve drainage, these soils become some of the most productive agricultural sites in the state of Michigan.

The topography of most of the study region is nearly level with 0-1% slopes. The flat landscape is broken by narrow sand ridges with slopes of 1-3% intermittently located on the heavier soils. Agricultural land with slopes as great a 4-5% do exist on silty, highly erodible soils within the region of study. Conservation tillage practices could be expected to demonstrate dramatic reductions in sediment loss from such sites. However, since 90% of the region of study is located on flat, poorly drained, fine-textured soils, site selection was limited to these conditions.

Conservation tillage relies on crop residues to provide cover for the soil surface and thereby minimize erosion losses. Of the predominant crops grown in the region - corn, navy beans, and sugar beets - only corn provides a substantial residue cover following conservation tillage. To monitor the influence of conservation tillage during 1981 and 1982, site selection was restricted to fields that would be planted to corn during 1980 and 1981.

Site selection was limited to fields that could be hydrologically isolated from surrounding surface and subsurface drainage. The study site required a natural configuration that could provide a means to measure flow as it exited the fields. Unobstructed discharge of surface and subsurface water was required during all runoff events to insure accurate flow measurement and prevent contamination or artificial ponding and settling of suspended material.

The monitoring project was conceived as a year round project, gathering samples from any snowmelt or precipitation event. Aull (1980) discussed the special problems associated with field monitoring in cold and wet conditions. Based upon Aull's experiences site selection concentrated on locations that could be easily accessed by motorized vehicles in order to enhance maintenance and sample transport and fields where 110 V A.C. electric service would be available to winterize samplers during freezing weather.

Potential study sites were suggested by the Tuscola County Soil Conservation Service, the Tuscola County Cooperative Extension Service, the Tuscola County Agricultural Stabilization and Conservation Service, and Jerald Lemunyon, area Agronomist of the USDA/SCS. The most common reason for site disqualification was crop rotation. Area farmers strictly adhered to a given rotation and were not willing to follow a pattern conducive to the study. Twelve sites were closely evaluated for soil type, tile drainage and overland flow patterns before the final selection occurred.

3.2 Site Description

The site selected was on a field belonging to Richard Starkey, located 2 kilometers west of the town of Fairgrove, immediately south of Fairgrove Road. The legal description of the site was: W 1/2 of the E 1/2 of the NW 1/4 of Section 19, Fairgrove Township, Tuscola County, Michigan (Figure 1). The field drained into the Spohn County Drain which flowed to Saginaw Bay via the Northwest County Drain. The study site is located approximately 12 kilometers from the Saginaw Bay.

A detailed topographic survey of the field was undertaken on November 10, 1980 (Figure 2). The field slopes to the northwest at an 0.8% slope. A deep sand ridge created a natural hydrologic divide on the southern boundary and a roadside ditch on the northern border receives all the drainage from the field. The field was evenly graded and had no visible potholes or depressions that could pond runoff. The field was approximately 200 meters wide and 425 meters long.

A subsurface tile system ran parallel to the prevailing slope and drained only the study site. A separate system drained the land

Figure 1

Study Site Location

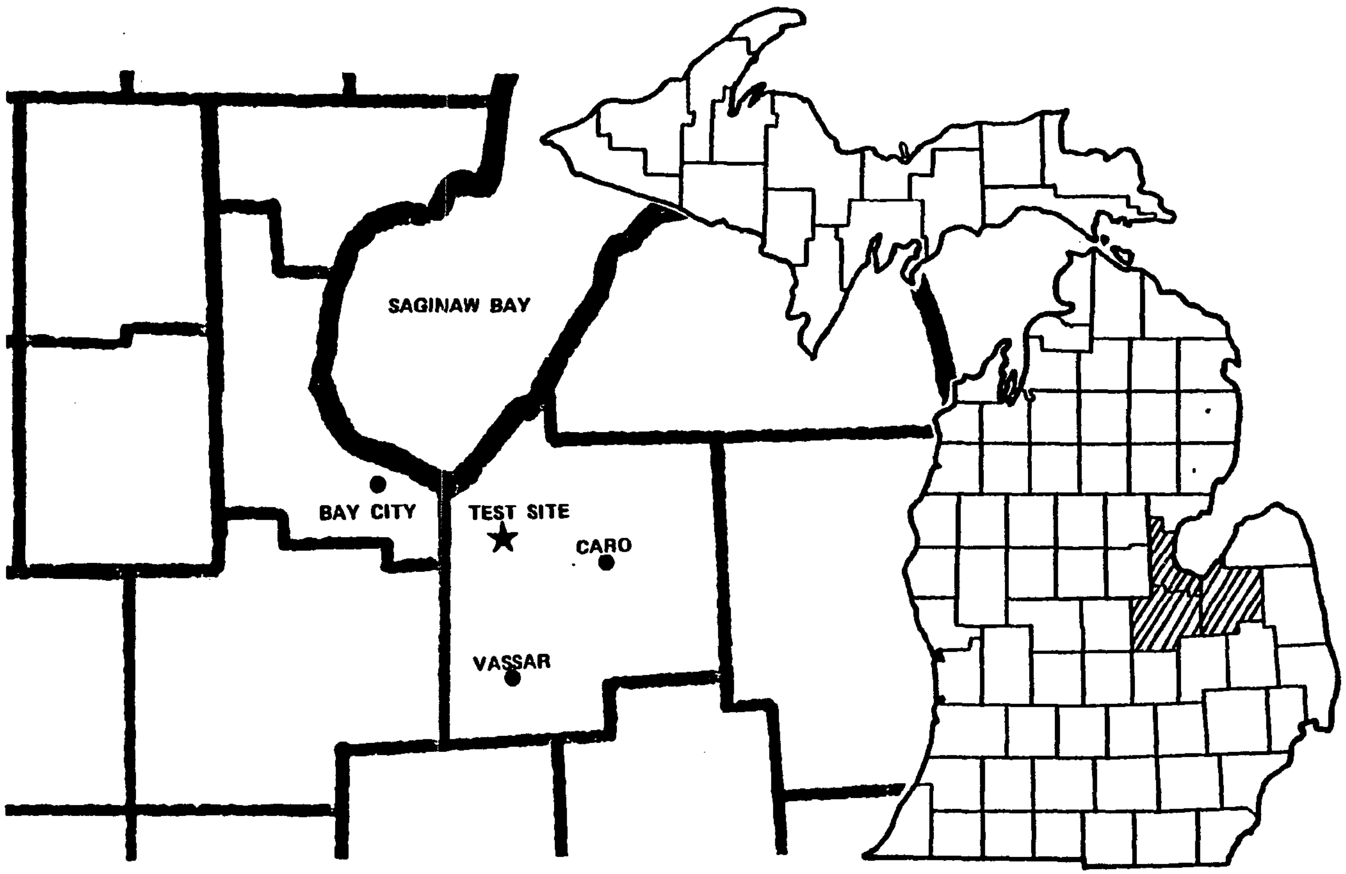
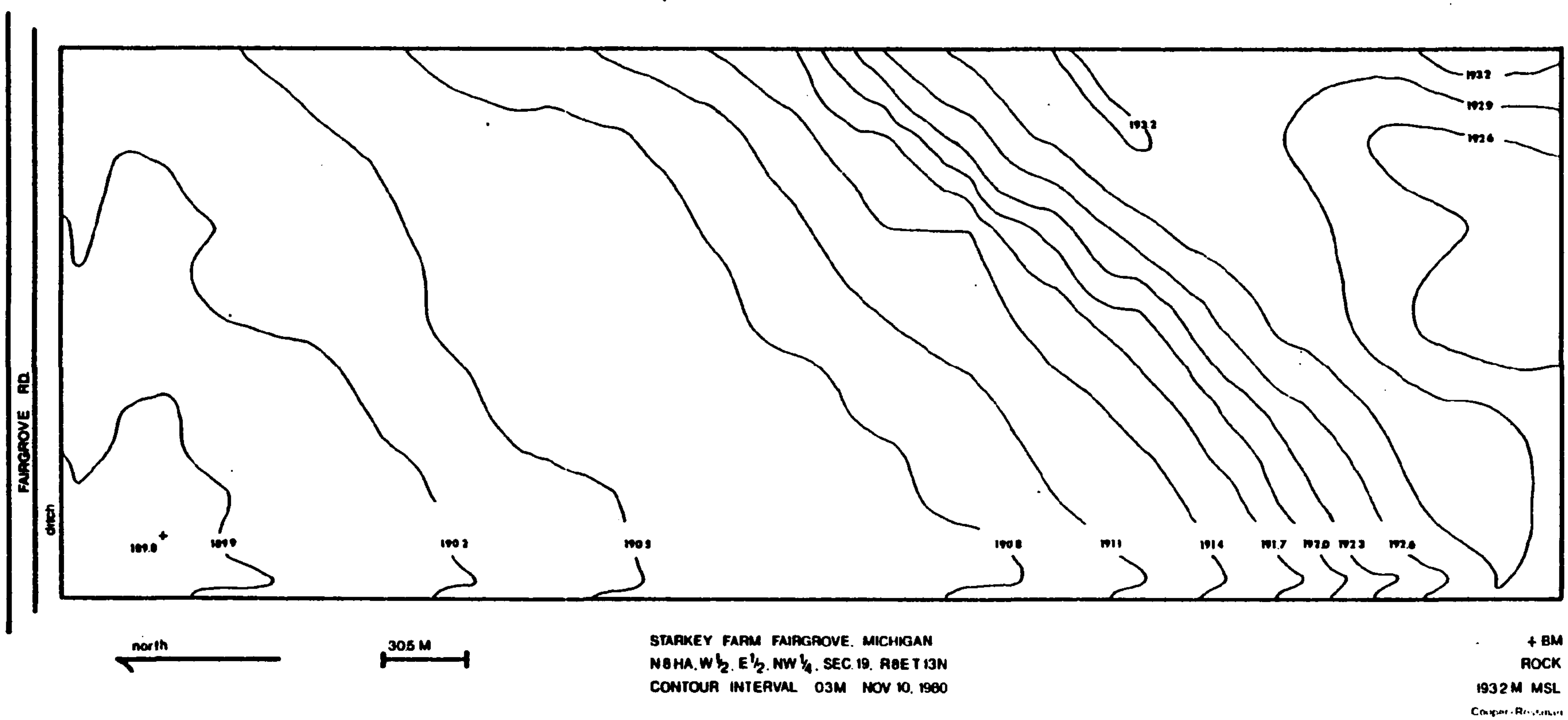


Figure 2
Topographic Survey: Original Site



adjacent to the plots. Tile were spaced at approximately 20 meter intervals and were found at a depth of 0.7 meters at the lower end of field. Based on farm records and field probings, the drainage network was found to follow a gridiron pattern. The system was installed during the 1950's with 10 cm clay laterals. The tile main paralleled the roadside ditch and exited at the northwest corner of the site. The sand ridge at the upper boundary of the plots intercepted any susbsurface flow from beyond the plot borders and transported it to a nearby gravel pit.

Overland flow was directed to a single area on the northwest corner of the site. During the site selection process this area showed evidence of surface flooding and crop stunting due to excessive wetness. Free outflow from the field was obstructed by a small berm along the northern field border created from ditch spoils.

The field had been farmed uniformly and had been planted to corn during the 1978, 1979 and 1980 growing seasons. The site produced corn yields of aapproximately 7.7 MT/ha. The only primary tillage tool used on the field had been a moldboard plow.

Soil on the site was mapped as a Londo loam complex, a fine textured poorly drained soil. Londo loam is classified in Michigan soil management group 21 as are most of the soils in the region of study. The soil was an alfisol with a loam surface horizon overlying a clay loam argillic horizon. It was officially classified as an aeric glossaqualf, fine-loamy, mixed mesic soil.

Drainage from the field discharged into a county ditch approximately two meters deep. Previous to the projects inception the ditch had not been cleaned since the late 1940's. The ditch was choked with cattails and had accumulated approximately 0.3 m of silt. Tile were still above the existing ditch bottom however. Slope on the ditch was 0.3% for 0.6 km before the ditch joined with a deeper N-S drain with a 0.7% slope and crossed under Fairgrove Road.

3.3 Field Modifications

The selected site was modified to create two hydrologically isolated plots, each approximately 100 m wide, extending south 400-450 m to the sand ridge. Field dimensions are given in Table 1.

TABLE 1

Field Dimensions

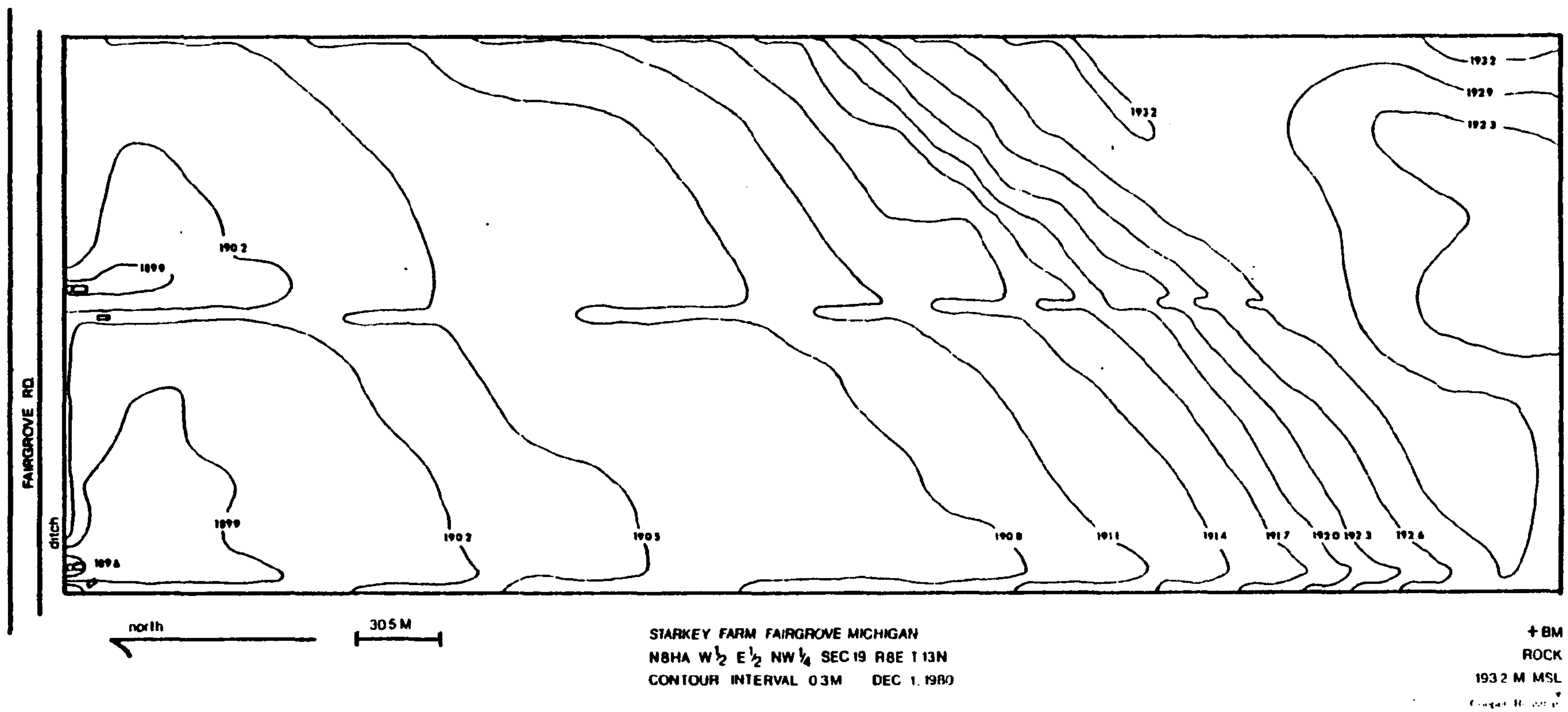
	Conservation Tillage Plot	Conventional Tillage Plot
Width (m)	98	98
Maximum Length (m)	488	412
Slope	0.7%	0.8%
Area (ha)	4.62	3.89

The configuration of the site required the creation of north-south berms on the eastern border of each plot (Fig. 3). To isolate subsurface flow the tile main was cut at the intersection of the two plots. An additional outlet was added at that location and received the subsurface flow from all the laterals draining the east plot. The original outlet thus drained only the laterals of the west plot. The cut main at the plot intersection was plugged with a plastic cap and set in concrete.

The receiving ditch was cleaned during November, 1980. The ditch proved suitable for carrying runoff from precipitation events. However

Figure 3

Topographic Survey: Modified Site



it did not provide a suitable outlet during snowmelt. In February, 1981 during the first snowmelt event monitored the ditch was completely filled with wind packed snow. No appreciable ditch flow occurred and the snowmelt runoff backed up and ponded on the plots for twenty hours. During the winter of 1982 the ditch again filled with wind packed snow. To avoid the outlet problems of the previous year a hydraulic backhoe was employed to remove the snow from the ditch before the snowmelt began. This action resulted in free outflow and a satisfactory outlet during the 1982 period of snowmelt runoff.

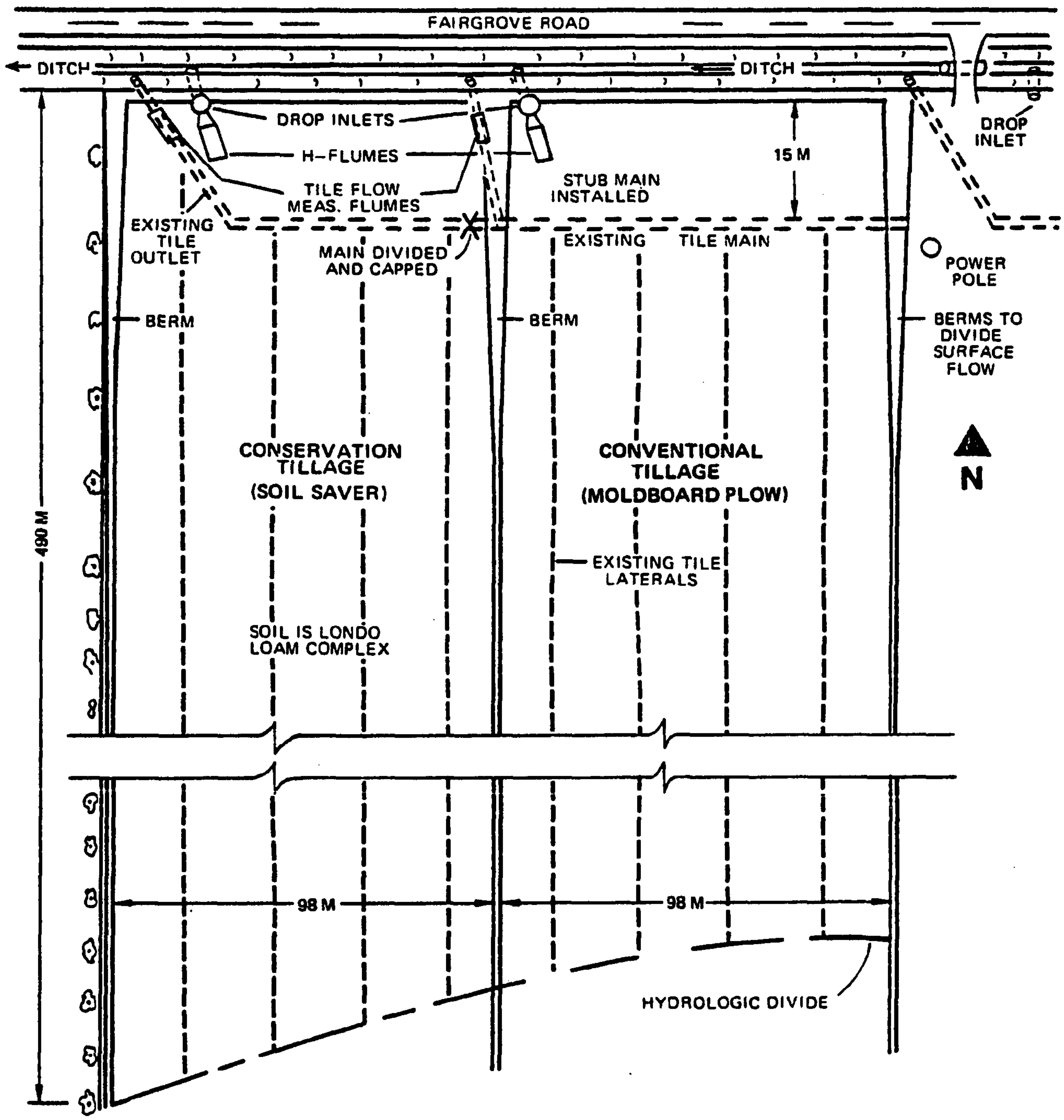
3.4 Monitoring Procedures

To compare edge-of-field losses from conservation and conventional tillage practices, measuring devices must be able to accomodate large infrequent runoff events as well as accurately measure the frequent low flows expected from flat tiled lands. An ideal setup would not create artificial ponding in the fields or backup in the subsurface tile. In addition any flow measurement device must be incorporated into designs that permit sampling of the drainage water before it leaves the field.

A sampling station to monitor overland flow was located in the northwest corner of each plot (Fig 4). The maximum design flow chosen to be measured at each overland flow station was set as the peak runoff resulting from a 10 year 24 hour storm. Based on a hydrologic frequency analysis (Section 7.2), a 10 year 24 hour storm in Tuscola County was expected to generate 70 mm of precipitation. Peak runoff was calculated using the Soil Conservation Service curve number method (Kent, 1973). Peak flow was calculated for conventional tillage since it can be

Figure 4

Field Monitoring Layout



expected to generate more runoff than conservation tillage. The weighted curve number chosen for the plots was 81 assuming row crops planted parallel to the slope on a site in good hydrologic condition. Given the flat slopes of the plots, peak runoff was predicted as 0.32 cu m/s.

Tiled agricultural cropland has been observed to have lower peak runoff rates than similar untiled sites. The Soil Conservation Service in the state of Michigan (Emeron Christenson, Assistant State Engineer) recommends that the hydrologic soil group be decreased one letter (from C to B for example) when calculating peak runoff on tiled fields. Recalculating the curve numbers for the plots using hydrologic soil group B rather than group C for tiled Londo loam yields a weighted curve number of 75 and a peak runoff rate of 0.25 cu m/s. The maximum flow to be measured by an overland flow device was therefore set in the range of 0.25 to 0.32 cu m/s.

Aull (1980) used a drop box 90 degree V notch weir to measure and sample overland flow. The device is accurate up to flow rates of 0.40 cu m/s (Grant, 1979) meeting the design flow criteria for the study sites. However, inaccuracies in flow measurement with a V notch weir are caused by changes in the velocity of the approaching water or partial submergence of the weir crest. In his study on runoff from a grassed buffer area Aull (1980) created a ponded region above the weir that reduced fluctuations in runoff velocities. The ponded area was intended to reduce sediment losses before the runoff left the field and would not be an acceptable phenomenon in a study investigating the edge of field losses of sediment and nutrients from tillage practices.

Runoff velocities from the plots were expected to vary widely based on storm and residue cover. Flumes do not require constant velocities to accurately measure flow. A 0.66 M fiberglass H flume manufactured and calibrated by PLASTI Fab Inc. of Tualatin, Oregon was therefore chosen as the overland flow measurement device for the study. Based on calibration tests performed by the manufacturer, accurate flow measurements are possible up to 0.31 cu m/s with this device.

The H flume was developed in the mid 1930's by the U.S. Soil Conservation Service to measure runoff from small agricultural watersheds. The design was intended to permit passage of debris without impeding accuracy (Brakensiek et al., 1979). Partial submergence does not significantly affect the calibrated stage discharge relationship of an H flume. Tests have shown that a submergence of 30% has less than a 1% effect on the calibration and a 50% submergence has less than a 3% effect. H flumes were used sucessfully in Michigan during the water quality monitoring project carried out by Ellis et al. (1978).

Flow into the H flumes must be non turbulent. A rectangular approach section was consturcted based on the recommendations of Grant (1979). The approach sections were fabricated from wolmanized 3/4 inch pressure treated plywood. The plywood rectangles were reinforced with five frames each having a 4 x 4 board on the bottom and 2 x 4 boards on the sides and top. The frames were glued and bolted together. Pressure treated lumber was utilized and additional weather proofing was applied. Each H flume was bolted to the approach boxes. A rubber gasket was added to insure a tight seal.

Since sampling was slated to occur during periods of snowmelt, special adaptations were made to the approach sections to prevent ice buildup. The floor of each approach section was grooved at eight inch intervals and construction grade heat tape was set in the grooves. The heat tapes were activated by a thermostat when ambient temperatures dropped below 3 degrees C. The interior floor and walls of the approach section was then lined with 20 gage stainless steel to create a smooth flow surface and to more evenly conduct the heat from the heat tapes.

Outflow from the H flumes was discharged into an upright 1.2 m corrugated metal pipe (CMP) that served as a drop inlet and sample collection area. The CMP was connected to the receiving ditch by a 38 cm plastic tile approximately 4 meters long. The top of each tile was set below the invert of the H flume and the tile was sloped to carry at least the peak design rate of 0.32 cu m/s by open channel flow. The bottom of the tile entrance was positioned at 0.3 m above the floor of each drop inlet creating a basin for sample collection. During runoff, water in the drop inlet was expected to be constantly mixed by the incoming discharge from the flumes. The design required that the drop inlets be pumped and cleaned after each event to insure that no residue or sediment remained to contaminate the results of the next event.

An area was excavated with a backhoe for the placement of each overland flow sampling station. The approach box and H flume were set on nominal 4 x 6 stringers attached to concrete piers. Approximately 0.2 m of gravel were placed under the approach boxes and a 10 cm drainage tile was set in the gravel to carry off excess moisture and avoid frost heave. The 1.2 m CMP drop inlet was set in concrete. The soil around the tile outlet was covered with 6 mil plastic and concrete creating a cutoff collar to prevent water from seeping around the tile and inducing soil piping.

After the approach box, flume, and drop inlet were installed, a small concrete pad was poured at the entrance to each approach box to minimize erosion of the soil that was disturbed during the construction process. Minor land grading was undertaken with a bulldozer on each plot to insure that the overland sampling stations were the lowest points on each field. Slopes on the concrete pad and approach boxes were set at 0.1% to eliminate ponding.

Samples of overland flow were obtained with Isco 1580 composite samplers. Aull (1980) used time activated discrete samplers to characterize edge-of-field losses. Daniels et al. (1979) compared the technical feasibility of using a flow proportional composite sample instead of discrete time based samples to determine losses of selected constituents during a runoff event. The authors found no significant difference between the sampling techniques and concluded that flow proportioned composite sampling would result in considerable reductions in analysis cost.

Isco bubbler flow meters were used to sense stage on the stilling wells connected to the H flumes. These flow meters were programmed at the factory to convert stage to flow and directly recorded total flow that occurred over a given period. The flow meters were electronically connected to the composite samplers and were able to initiate sampling whenever a predetermined quantity of flow had passed through the flume. The flow meters were always in operation and were able to automatically start the sampling process whenever a runoff event began. The flow meters were checked for accuracy at least once a week and recalibrated when necessary. All automatic signaling between the samplers and flow meters were checked at that time.

The composite samplers were usually set to draw 50 ml of sample for every 1.4 cu meters of runoff that passed through the H flumes. The sample containers could hold 19 liters and were capable of accomodating 380 samples representing 532 cubic meters of runoff from the plots at the standard setting. Runoff volume from a 10 year 24 hour storm is predicted at 1500 cu. meters (Mockus, 1972). During periods of intense runoff the sampling increment was increased. Samples were generally composited for 12-24 hours before being taken in for analysis.

A sampling station to monitor subsurface tile drainage was located in the tile outlet of each study plot. Several measurement devices were considered to monitor tile flow. A Palmer Bowles flume had been utilized on a project in Macomb County, Michigan (T.L. Loudon, unpublished data, MSU Agricultural Engineering Department) where pipe flow was relatively constant. It was expected that flow rates from agricultural tile would vary widely demanding a device that could be accurate over a wide range of flows. The primary disadvantages of Palmer Bowles flumes is that they have a relatively small useful range of flow and are not considered to have good resolution (Grant, 1979).

Tile flow measurements were obtained by using a 25 cm, 30 degree V notch flume designed by G.E. Merva (MSU Agricultural Engineering Department). The flume was constructed of plexiglass with a small sampling basin at the entrance (Fig. 5). Each flume was connected to a 20 cm plastic tile which received the entire subsurface drainage of each plot. A 20 cm CMP carried the outflow of the flume to the drainage ditch. The flumes were located approximately 0.8 meters below the ground surface and 6 meters from the outlet of each main. Stilling wells of PVC pipe were connected to the flumes for stage measurement.

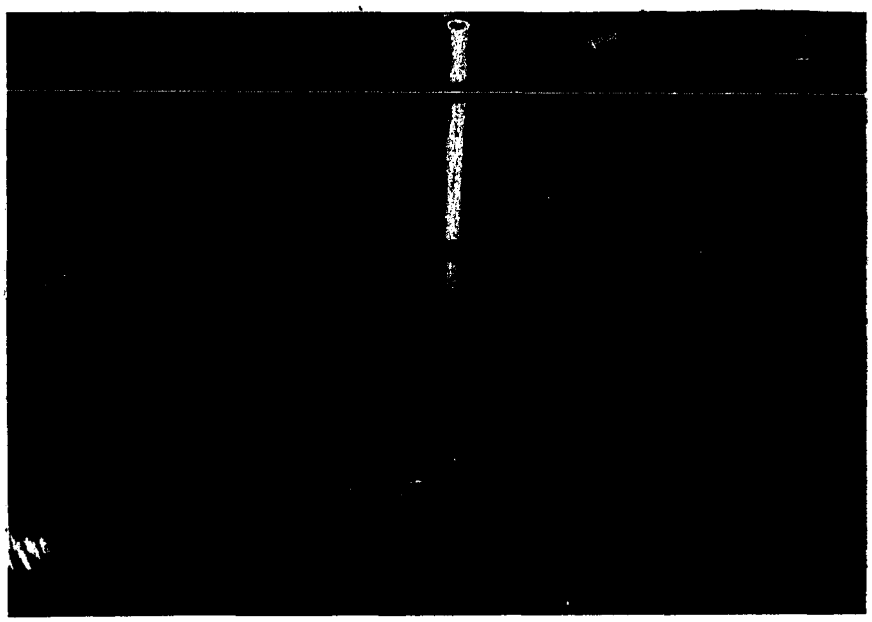
Figure 5

Tile Flow Measurement Device

30 Degree V Notch Flume

FRONTAL VIEW OF FLUME

LATERAL VIEW OF FLUME & APPROACH SECTION



FIELD PLACEMENT

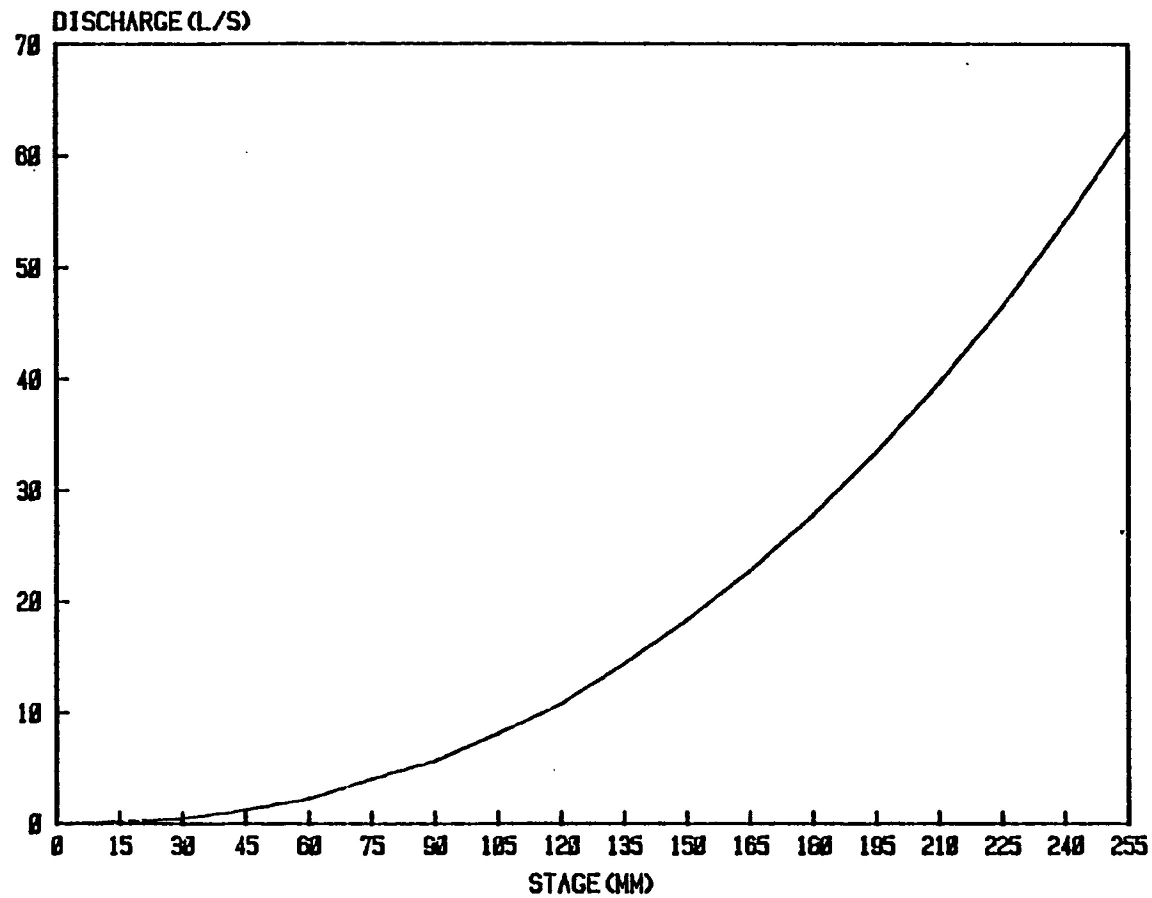
The 30 degree V notch flume was designed to measure flow from 0.0006 cu. m/s to 0.06 cu m/s, a range of 1:100. This was well in excess of the average daily design rate of 0.006 cu. m/s calculated by assuming a drainage coefficient of 12.5 mm/day and permits measurement during brief periods of peak tile flow. The calculated stage discharge relationships are presented in Figure 6.

Leopold Stevens type F stage recorders were used to measure stage on the V notch flumes. The meters were set to record the stage for 8 days on a single chart. A 1:1 gage scale was selected for the recorder permitting resolution to a stage of 0.003 m.

Tile water was sampled via surface risers placed upslope from the flumes. Flow meters were not available that could be used to create flow composited samples of tile flow. However, tile flow rates were expected to be more stable over time than typical overland runoff hydrographs. Whereas overland flow rates from agricultural croplands often display a "flashy" flow regime, the subsurface tile flow pattern is moderated by the infiltration and percolation rates of the soil. Isco time activated discrete samplers were therefore chosen as a suitable monitoring device. The samplers were manually activated in advance of an expected storm event. Sampling intervals ranged from 1/2 hour during peak flow periods to 2 hour intervals for base flow sampling. A maximum of 28 samples could be stored in the samplers. From the discrete samples a single flow weighted composite sample was manually created based on the tile hydrograph during the sampling period.

Figure 6

STAGE-DISCHARGE RELATIONSHIP
25 CM 30 DEGREE V NOTCH FLUME



3.5 Rainfall and Snowpack Measurement

A recording raingauge was installed on the study site April 15, 1981 to relate runoff characteristics with specific storm intensities and volumes. A Belfort 24 hour, 12 inch dual traverse univeral weighing rain gage was utilized. Charts were changed once a week if no major events occurred. Following any appreciable storm the chart was changed to avoid confusion in analysis.

All precipitation events greater than or equal to 12.7 mm were analyzed for the following characteristics from the recording rain gage:

1) maximum 30 minute intensity (mm/hr)
2) excessivive rate storm classification
3) depth (mm)
4) 5 day antecedent precipitation (mm)
5) rainfall erosion index (R)

Each storm was divided into successive increments of approximately uniform intensity permitting computation of the the rainfall erosion index, R. This is defined by Wischmeier and Smith (1978) as the product of the maximum 30 minute intensity (cm/hr) and the kinetic energy (E) of the rainfall divided by 100 (Mg-m/ha-hr). The kinetic energy per cm of rain was determined from the equation (Wischmeier and Smith, 1978):

$$E = 210 + 89. \times \log(I) \qquad (2)$$

where I = rainfall intensity (cm/hr)

Individual events were defined by separations of at least 6 hours without precipitation. As suggested by Wischmeier and Smith (1978) the maximum rainfall intensity used in computation of R was 76 mm/hr, since the terminal rainfall velocity and corresponding raindrop energy does not continue to increase above that intensity. In addition storm intensity analysis was restricted to events greater than or equal to 12.7 mm. The annual rainfall erosivity is not significantly altered when small storms are left out of the analysis (Schwab et al., 1981).

Crop cover and residue cover reduce the actual R that reaches the soil surface. The actual proportion of the rainfall erosion index that is considered to impact the soil surface is defined as the crop management factor (C). The "C" factor of the USLE was determined on both plots for each storm event. Pertinant crop stage and residue data was used in conjunction with the work of Wischmeier and Smith (1978) for the C factor determination .

All excessive rate storms with a magnitude greater than or equal to 12.7 mm were recorded. Excessive rate storms are defined by a depth (mm) greater than or equal to 5. + 0.25(t) for a given duration t (minutes).

Records of the snowpack were obtained just before the snowmelt period of each year of sampling. Cores 5 cm in diameter were taken at randomly selected points on each plot. The snow was melted and the average depth of water on each plot was computed. The west edge of the conservation tillage plot was bordered by a wooded fence row and a deep snow drift collected there each winter. The width, depth, and water equivalent of the drift was specifically measured each year.

The erosive forces of snowmelt runoff have not yet been satisfactorily modelled. Many of the widely used models that simulate edge of field losses from croplands neglect snowmelt erosion (Tubbs and Haith, 1977; Donigian et al. 1977). During snowmelt the soil profile is either partially frozen or saturated and puddling is common. Soil detachment and sediment transport responds to a different set of processes than occur during the snowfree periods of the year. Wischmeier and Smith (1978) developed a subfactor, Rs, to account for the erosive force of snowmelt. It is directly equivalent to the rainfall erosion index R. Rs is defined as 1.01 times the cumulative winter precipitation (cm of liquid water) that precedes a snowmelt runoff event. In calculating Rs winter precipitation was defined as that precipitation preceding snowmelt runoff which occurred during the contiguous period when a portion of the soil profile was presumed to be frozen. The inception of frozen soil was assumed to occur when the mean air temperature of the previous 20 days days was below freezing and no snow cover existed (Steenhuis, 1979).

3.6 Cold Weather Design

Aull (1980) found that considerable snowmelt runoff occurred during evening hours when temperatures dropped below freezing. To permit monitoring at these times a number of steps were taken. A plywood cover was placed over the stilling wells and a trouble light inserted to prevent them from freezing. Heat tape was wrapped around the intake lines of all the samplers. All heat tape utilized at the site was activated by a thermostat when temperatures dropped below 3 degrees C. The winterization scheme proved very reliable. No information was lost due to freezing conditions.

3.7 Residue Measurement

To effectively compare the results of this study with other investigations of conservation tillage it was necessary to quantify the extent of surface residue on the fields. Residue was measured at three different times during the year:

a) Following fall tillage (November)

b) Before spring planting (April)

c) Following planting and cultivation (June)

Both percent cover and gravimetric cover were measured. The percent of residue on the fields was determined with the line point sampling method (USDA, 1982). A measuring tape 15-30 meters long was placed on the ground diagonal to the rows. Crop residue fragments greater than 1 cm in length touching a tape mark at a predetermined interval were counted as cover. One hundred points were checked on each tape and percent cover was calculated directly. A minimum of six samples at random locations on each plot were used in the determination.

Estimates of gravimetric cover were obtained by collecting all the visible residue contained with a one square yard (0.8 sq m) frame. Between six and twelve samples were taken per plot. Samples were composited in sets of three, then air dried for at least two weeks before weighing. Following the estimation methods of the USDA-SCS the combined dry weight of residue in ounces was multiplied by 100 to determine the lbs/acre of residue cover. This bookkeeping method accounts for 99.2% of the actual lbs/acre on the field (USDA, 1982).

3.8 Agronomic Activity

A survey was conducted in the winter of 1980 to determine tillage methods commonly used on rowcrops in Tuscola County, Michigan (Muhtar, 1982). The survey found that a majority of farmers used a moldboard plow in the fall for primary tillage on corn ground. None of the 106 farmers that responded to the survey used no-till while 20% indicated that they used chisel plows and 9% used a disc tiller for primary tillage. Secondary tillage was performed with field cultivators by the majority of farmers using both moldboard and chisel plows.

Based on the results of the survey, the agronomic schedule depicted in Table 2 was followed to compare conventional to conservation tillage. All agronomic decisions were made in conjunction with the cooperating farmer, the Cooperative Extension Service, and the area agronomist of the USDA-SCS, Jerald LeMunyon. A chisel plow with twisted shanks was the primary fall tillage tool used on the conservation tillage site. Between 50-60% residue cover was expected to remain after tillage (Colvin et al., 1980). A moldboard plow was used for fall tillage on the conventional site. All other agronomic activities and inputs were identical on the conservation and conventional tilled fields; a common practice in the study region (Muhtar, 1982).

3.9 Water Quality Analysis

The water quality parameters chosen for analysis were intended to provide information regarding the affect of agricultural drainage on the cultural eutrophication of the Saginaw Bay. Annual loadings of nitrogen, phosphorus, and sediment to the Bay were necessary components

Table 2

Agronomic Activity

Date	Conservation Tillage	Conventional Tillage
November, 1980	Chisel plow (corn stubble) Anhydrous Ammonia applied	Moldboard plow (corn stubble) Anhydrous Ammonia applied
May 6, 1981	Field Cultivate Plant corn 1.4 kg/ha Atrazine 384 kg/ha 10-20-20 fertilizer Anhydrous Ammonia 168 kg/ha	Field Cultivate Plant corn 1.4 kg/ha Atrazine 384 kg/ha 10-20-20 fertilizer Anhydrous Ammonia 168 kg/ha
November, 1981	Harvest corn Chisel plow	Harvest corn Moldboard plow
June 1, 1982	Field Cultivate Plant Beans 308 kg/ha 10-20-20 fertilizer	Field Cultivate Plant Beans 308 kg/ha fertilizer
October 11, 1982	Harvest beans Chisel plow	Harvest beans Chisel plow

of a water quality model sponsored by the U.S. EPA. The field data gathered in this project were to be used as inputs and model calibration.

Samples were analyzed at Snell Environmental Group in Lansing, Michigan for the following parameters: Total phosphorus, soluble phosphorus, ortho phosphorus, nitrate nitrogen, ammonia nitrogen, total kjeldahl nitrogen, total suspended solids, and total volatile solids. Table 3 lists the analysis methods utilized.

The USEPA did not consider investigating herbicide and pesticide losses to be consistent with the projects goals. Sample analysis is costly and the International Joint Commission on Great Lakes Water Quality (PLUARG, 1978) concluded that herbicides and pesticides from agricultural runoff did not present water quality problems to the Saginaw Bay. However, as part of a cooperative agreement between the Pesticide Research Center and the Agricultural Engineering Department of Michigan State University, atrazine analysis was performed on samples collected during Spring, 1981. Atrazine is a common corn herbicide that has been frequently monitored in agricultural runoff. Atrazine concentrations were determined by extraction with hexane, evaporation, application of hydrosodium sulfate and analysis on a gas chromatograph (personal communication; R.A. Leavitt, MSU Pesticide Research Center).

Table 3

Water Quality
Sample Analysis

Parameter	Methods[1]
Total Phosphorus	EPA Method 365.2: Digestion with persulfate and sulfuric acid. Ascorbic acid colorimetric determination.
Soluble Phosphorus	Sample filtered before undergoing procedure described for total phosphorus analysis.
Ortho Phosphate	Sample filtered but not digested before ascorbic acid colorimetric determination.
Nitrate Nitrogen	EPA Method 353.3: Cadmium reduction method.
Ammonia Nitrogen	EPA Method 350.3: Electrometric determination with Orion specific ion electrode.
Total Kjeldahl Nitrogen	EPA Method 351.4: Digestion with sulfuric acid and potassium sulfate utilizing mercuric sulfate as a catalyst. Electrometric determination Orion ammonia ion electrode.
Total Suspended Solids	EPA Method 140.3: Gravimetric determination of known sample volume at 104 degrees C.
Total Volatile Solids	EPA Method 160.4: Gravimetric determination of a known sample volume at 550 degrees C.

[1]All methods refer to U.S. E.P.A., 1979

3.10 Soil Measurements

Selected physical and chemical characteristics of the surface and subsurface soil horizon of each plot were analyzed periodically during the course of the study. Samples were analyzed at the Michigan State University Soil Testing Laboratory for:

phosphorus	potassium
cation exchange capacity	pH
magnesium	calcium
organic matter content	texture

All surface samples (0-30 cm) sent to the testing lab were a composite of 20 samples taken at different locations in the field. Subsurface samples (30-70 cm) were each analyzed separately and average values of each parameter were then obtained for each plot.

Ten soil cores were obtained from the surface and subsurface horizons of each plot on June 6, 1981. These cores were used to develop the soil moisture characteristic curve (volumetric moisture content vs. matric potential) and to determine bulk density and porosity of the soil. Gravimetric measurements of the water content were made on samples placed on a pressure plate and subjected to pressures of 0.10, 0.33, 0.5, and 1.0 bars.

3.11 Statistical Model and Analysis

Traditional statistical comparison tests employed in agronomic plot studies are not capable of describing the degree of difference in the water borne edge of field losses from the two study plots. Data obtained from weather driven occurrences are the result of unique combinations of storm, soil, and crop characteristics. Sampling hydrologic events is not a controlled process that permits replicated observations of a specific process.

Paired comparison tests are often used to evaluate differences between treatments when conditions affecting the outcomes are not held constant. However paired comparison tests used in many plot studies are predicated on the assumption that the differences of each pair will be normally distributed. Weather generated hydrologic processes tend to be positively skewed with large variations expected in the magnitude of differences from each pair of hydrologic data. Infrequent storms of large magnitude may generate runoff, nutrients, and sediment orders of magnitude greater than the expected mean loss from a given event.

Aull (1980) utilized non-parametric statistics to quantify the differences in water borne edge-of-field losses resulting from two management practices. The null distribution of a non-parametric test statistic can be determined without regard to the shape of the underlying population distribution. The null hypothesis (Ho) of the Wilcoxon rank-sum test for comparing two treatments postulates that the population distributions of each treatment are identical. The alternate hypothesis postulates only that the distribution of one of the populations is shifted to the right or left of the other population.

Non-parametric statistics are a conservative approach for establishing population differences. If the null hypothesis is rejected with non-parametric tests and the population actually fits a specific probability distribution the null hypothesis would also be rejected with the appropriate parametric procedures. Parametric tests are generally more efficient and have shorter confidence intervals than non parametric methods. Cases arise,therefore, when the null hypothesis will not be rejected by non parametric tests but rejection will occur when parametric procedures are utilized.

A two step approach was used to compare the differences between the conservation tillage treatment and the conventional tillage treatment. All constituents monitored during runoff events were tested to determine if identical distributions occurred in the losses from each field as well as the concentrations found in surface and subsurface flow. The Wilcoxon signed rank non-parametric test for paired comparisons was chosen since it encompasses both the type and magnitude of the difference. The results from each event constituted a single data pair from a unique set of storm and soil conditions. If the null hypothesis was rejected at the 95% probability level, no further testing was performed.

The signed rank non-parametric test did not demonstrate significant differences in losses of sediment, total phosphorus, or TKN between the two tillage treatments. Over the course of the study the conventional field lost 2.7, 1.4, and 1.5 times the quantity of those respective constituents than was discharged from the conservation field. Tests based on an lognormal distribution were employed to gain further insight into the relative differences of these constituents.

The comparison of nitrate nitrogen losses from the two fields was complicated by the suspected contamination of a runoff sample from the conservation tillage field during Event 5 (Section 5.2). Instead of restricting the statistical analyses to the reported concentration of that sample a range of concentration was utilized. Non parametric tests were employed using a low estimate of 2.3 mg/l (equal to the concentration found in the overland flow from the conventional field during Event 5) as well as on the reported concentration of 29 mg/l.

Hydrologic occurrences are frequently modeled with lognormal or exponential distributions. These distribution patterns account for the infrequent occurrence of large events which cause the mean to lie to the right of the median. For sediment, total phosphorus, and TKN, differences in the mean loss of the logarithm of the loss/event for each tillage system were tested. A Students t test was used to compare the means from all eleven events and from the six largest events. However, tests based on a lognormal distribution did not result in significant differences in the losses of any of the constituents tested.

CHAPTER 4

METHODS: PREDICTING OVERLAND RUNOFF AND EROSIVE EVENTS

4.1 Overview

The interactions of storm volume, storm intensity, soil cover and antecedent soil moisture combine to produce the variety of runoff events that occur at a given location. Large precipitation events are often capable of generating overland runoff during periods when the antecedent soil moisture is at or below field capacity. Large precipitation events however, are generally uncommon occurrences at a given location. Storms of moderate depths that often occur on a yearly basis may not generate overland runoff unless antecedent soil moisture is above field capacity or the event is of particularly high intensity.

Overland runoff is the primary carrier of sediment and phosphorus from agricultural croplands. To gain insight into the likelihood of runoff and sediment loss occurring during periods of varying residue cover and crop development, the following analyses were performed:

1) The magnitude of 24 hour storm events of various return intervals was determined for monthly, seasonal, and yearly periods.

2) The probability of storms occurring at different antecedent moisture conditions during each monthly period from March 1 - October 31 was determined.

3) The probability of occurrence of excessive rate storms was found for each monthly period from March 1 to October 31.

4) The probability of excessive rate storms occurring at

different antecedent moisture conditions during various periods of the year was determined.

4.2 Storm Frequency Analysis

The Extreme Value Method (Chow, 1964) was utilized to determine the the magnitude of a 24 hour rainfall event to be expected at 2, 5, and 10 year recurrence intervals. This analysis also generated the probability of various magnitude storms occurring at different periods of the year. Rainfall magnitude was analyzed on a monthly, seasonal, and yearly basis. Chow (1964) concluded that homogenity of the data can be maintained if data are selected from a specific period of the year. For each period of interest, the extreme value series was obtained by selecting the maximum value of daily precipitation that occurred during each of 31 years of record. The data base used in the analysis consisted of 31 years of daily precipitation (1950-1980) recorded to the nearest 0.01 inch at the Caro State Hospital (U.S. Dept. of , Commerce, 1950-1980); the nearest NOAA weather station to the study plots. The data were provided on computerized files by the Michigan Department of Agriculture/ Division of Climatology (MDA/DC). Analysis was performed on precipitation that occurred from March 1 to October 31 to assure that snowfall events were not included in the analysis.

The general equation for hydrologic frequency analysis (Chow, 1964) was utilized:

$$x/xmean=1+Cv*K \quad (3)$$

where

x: variate of a random hydrologic series

xmean: arithmetic mean of the series

Cv: coefficient of variation

K: frequency factor

Equation (3) is applicable to many probability distributions used in hydrologic frequency analysis. A lognormal distribution was chosen to obtain the frequency factor (K) since the distribution is expected to be bounded by zero on the left, and positively skewed (Haan, 1979). In the lognormal distribution:

$$y = ymean + K*Sy \quad (4)$$

where

$y = \ln(x)$

ymean= arithmetic mean of the y values

Sy=standard deviation of transformed x values

K was obtained from Chow (1964) based on the transformed coeffient of variation and the desired return interval

$$T = 1/P(X.GE.x) \quad (5)$$

where

T=return interval

P=Probability

X=Randomly occurring storm

GE=greater than or equal

x=storm of a given magnitude

4.3 Antecedent Soil Moisture

The soil moisture content that exists at the inception of a precipitation event will influence the quantity and distribution of overland runoff and subsurface tile flow. Storms occurring when antecedent soil moisture is near saturation have a greater liklihood to generate overland flow and carry sediment from the study plots. Mockus (1969) used the 5 day antecedent rainfall (AMC) as an indicator of soil moisture. The runoff model he developed for the USDA/SCS utilizes three levels of antecedent precipitation to represent dry (AMC I), average (AMC II), and nearly saturated (AMC III) soil conditions. The AMC range for each level (I,II, or III) is lower during the dormant season than during the growing season. The transition occurs in one discrete step at the inception of the growing season. Mockus considered the AMC index to be a rough approximation of soil moisture since evapotranspiration and infiltration were not considered. The AMC index has been widely used however, and represents a well known basis for comparison with other regions.

To obtain the probability of occurrence of each level of the AMC index at various time periods and conditions, the 31 years of daily precipitation records for Caro Michigan were utilized (U.S. Dept. of Commerce, 1950-1980). A computer program was created to keep a constant tally of the previous 5 day precipitation. The AMC status of each day during the 31 years was classified by the criteria listed in Table 4.

Table 4

Classification of Antecedent Moisture Conditions (AMC)

(Numbers represent total PPT during previous 5 days)

	AMC I (mm)	AMC II (mm)	AMC III (mm)
dormant season	< 12.7	12.7-28.0	> 28.0
growing season	< 35.6	35.6-53.3	> 53.3

The growing season was defined differently for the two crops studied. Corn is planted approximately May 7 in the study region. Its growing season was defined to be from June 1 to September 30. Field beans, the other common crop, are planted approximately three weeks later than corn. The beans emerge rapidly however and their growing season was defined as the period from June 16 to September 30. The division between dormant and growing season was based on when evapotranspiration might begin to accelerate due to the growing crop.

The AMC status of each day was determined and then summed to generate the natural probability estimator for each AMC level. The natural estimator is defined as the:

Number of occurrences of a given AMC level/Number of total possible occurences.

Three separate monthly evaluations of AMC occurrences were performed:

1) P(AMC): The probability of each AMC condition occurring during each period, regardless of daily precipitation.

2) P((AMC)i¦SL): The conditional probability of having a given antecedent moisture level when daily precipitation (SL) was greater than or equal to 25.4 mm. and less than 50.8 mm during the dormant season or

60 mm during the growing season.

3) P((AMC)i¦SM): The conditional probability of a given AMC level given a precipitation event (SM) greater than or equal to 12.7 and less than 25.4 mm.

4.4 Estimates of Occurrence of Excessive Rate Storms

Excessive rate storms have been credited with generating much of the erosion and runoff from agricultural croplands. Longterm records of excessive rate storms do not exist for most of the weather stations in Michigan. No weather station within 50 km. of the sampling sites had records on the occurrence of excessive rate storms. The nearest weather station to the site with a record of excessive rate storms is the Flint, Michigan station approximately 70 km south of the site. The Flint station, however, has only 16 years of record, less than the 20 years of record considered as the minimum for a representative climatic sample by Van Te Chow (1964).

The most extensive record of excessive rate storms was found to be the Deer Sloan rain gage network located 140 km SSW of the study site in Ingham County, Michigan. Twenty-five years of continuous records of the magnitude and date of all excessive storms were available from the MDA/DC. The records from five of the 22 gages were selected for analysis. Gage selection was based on the following criteria:

1) A gage eligible for selection had to have had no history of problems with wind, leakage, obstructions, or machinery (Merva et al., 1971; Nurnberger, MDA/DC, personal communication).

2) The gages chosen were in the most northern portion of the network.

The gages selected for analysis were numbers 1, 3, 17, 18, and 19. These gages were located within a 6 x 2 km area.

All the excessive storms with a total depth greater than 12.7 mm were recorded from each gage. The average number of excessive rate storms of various depths occurring during the semimonthly periods from March 1 to October 31 was then computed. To the check the applicibility of the data set obtained from the Deer Sloan network to the study region, the data were compared graphically to the limited data available for Flint, Michigan (70 km south of the study region) and to data from Alpena, Michigan (130 km north of the study site). During the years 1958-1972, records of excessive rate storms were kept at all three stations permitting a comparison based on 15 years of data (U.S. Dept. of Commerce, 1958-1972). A similar distribution pattern of excessive rate storms occurred at all three locations (Figure 13).

The probability of occurrence of an excessive rate storm was estimated for each semimonthly and monthly period from March 1 to October 31. Since a computerized data base of all precipitation events had not been established for the Deer Sloan network, the number of excessive rate storms was compared to the total number of storms greater than 12.7 mm recorded at the East Lansing weather station for the same period of record. The East Lansing weather station is located approximately 15 kilometers from the gage network. The conditional probability of an excessive rate storm (X) occurring during any given period was computed as:

$$P(X|S) = \text{Number of excessive storms (1957-1981) per period} / \text{Total Storms (1957-1981) per period} \quad (6)$$

where

X= excessive rate storms greater than or equal to 12.7 mm.

S= all 24 hour storms greater than or equal to 12.7 mm.

The actual probability of an excessive storm occurring during any period was computed as:

$$P(X)=P(S) \times P(X|S) \tag{7}$$

where

P(S): was obtained from hydrologic frequency analysis (Section 4.2).

4.5 Occurrence of Excessive Rate Storms at Varying Levels of AMC

The amount of precipitation that occurred during the 5 day periods previous to an excessive rate storm in the Deer Sloan sample area was estimated from rainfall records obtained by the East Lansing weather station. If an excessive rate storm was recorded on a date when a comparable amount of precipitation did not occur in East Lansing, the record of the previous day and following day were checked to compensate for any errors due to the difference in the definition of a recording day. The conditional probability of a given AMC condition given that an excessive rate storm occurred was found from:

$P((AMC)i|X)=$ Total number of days of (AMC)i / Total number of days with excessive rate storms (8)

where

i=1,2, or 3.

The actual probability of an excessive rate storm occurring at a given AMC level was then defined as:

$$P(X,(AMC)i)= P(X) \times P((AMC)i|X) \tag{9}$$

4.6 Precipitation Excess

Crops can be expected to influence the daily soil moisture balance through evapotranspiration. Soil planted to an actively growing crop will lose considerably more moisture than fallow ground. As the soil moisture declines, both the storage capacity of the soil and the initial rate of infiltration can be expected to increase. Both of these conditions will reduce the likelihood of overland runoff during a precipitation event.

Sites planted to corn can be expected to lose more soil moisture as evapotranspiration during May and June than sites planted to field beans. The comparatively drier corn sites should generate different runoff patterns than the sites planted to field beans during this period.

To compare the relative influence of evapotranspiration from each crop on potential overland runoff the mean weekly precipitation excess was computed. The precipitation excess is defined as the expected mean weekly precipitation minus the predicted mean evapotranspiration from a given crop. Estimates of mean weekly precipitation (cm/week) have been developed for the study region based on 30 years of data from the Caro Weather Station (MDA/DC,Unpublished data).

The mean weekly evapotranspiration from corn and field beans was determined through a two step approach. Mean daily reference evapotranspiration (ETo) was calculated from a regression equation developed by Vitosh et al. (1980) for the East Central District of Michigan based on the Julian date. Mean daily evapotranspiration expected from each crop (ET) was then computed as:

$$ET = ETo \times Kc \quad (10)$$

where

Kc= a crop coeffecient derived from a separate regression equation for each crop based on the percentage of the growing season that has occurred by a given date. During the dormant season Kc was set at 0.15.

The growing season was defined as the period from emergence to maturity. In the study region corn is expected to have a 115 day growing season and to emerge on May 25th. Field beans have an 80 day growing season and emerge on approximately June 10th (Vitosh et al., 1980; unpublished data, Dwight Quisenberry, State Agronomist, USDA-SCS, East Lansing, Michigan).

CHAPTER 5

EVENT DESCRIPTIONS

5.1 Summary

Edge-of-field water borne losses from the study plots were monitored from February 1, 1981 until September 30, 1982. During the 20 months of study, eleven separate hydrologic runoff events were sampled. A hydrologic event was any period of continuous tile or overland discharge from either field. An event was defined to begin at the inception of flow and ended when measureable discharge ceased.

Each event was generated by specific hydrologic occurence; either precipitation or snowmelt. The runoff events varied in length from 24 hours to three weeks and the magnitude of the tile and surface flow ranged from 30 cubic meters of water (3mm) per hectare up to 710 cubic meters of water per hectare (71 mm). Table 5 lists the runoff events that occurred during the study period.

Table 5

Event Summary

February 1,1981-October 1,1982

Event	Date	Conservation System		Conventional System	
		Tile Flow	Overland Flow	Tile Flow	Overland Flow
*	2/16-2/22/81	*	*	*	*
1	4/9-4/10/81	Y	N	Y	N
2	4/28- 29/81	Y	N	Y	N
3	5/10- 12/81	Y	Y	Y	Y
4	9/3 - 5/81	Y	Y	Y	Y
5	9/26-29/81	Y	Y	Y	Y
6	9/30-10/2/81	Y	Y	Y	Y
7	3/11-14/82	Y	Y	N	Y
8	3/14-29/82	Y	N	Y	N
9	3/30-31/82	Y	N	Y	N
10	6/15-16/82	Y	N	Y	N
11	6/21-23/82	Y	N	Y	Y

Y: Occurrence
N: No occurrence
*: Sampling difficulty

The hydrologic characteristics of each event are given in Table 6. Table 7 summarizes the sediment losses, Table 8 the phosphorus losses and Table 9 the nitrogen losses that occurred in each of the 11 events. The flow weighted mean concentrations of the tile and overland flow from each tillage system are found in Table 10.

* Denotes Excessive Rate Storm

TABLE 6

EVENT SUMMARY: Hydrologic Characteristics

Date	Event	Tillage	PPT (MM)	Max. 30 Minute Intensity (MM/hr)	R MT-M/ (ha-cm)	Crop MGMT Factor (C)	RxC	Overland Flow (M^3/ha.)	Tile Flow (M^3ha.)	5 Day AMC MM	5 Day AMC Level
4/09/81	1	Conservation	24.0	7.6	3.5	0.31	1.1	0.	68.	0	AMC 1
		Conventional				0.44	1.5	0.	63.		
4/28/81	2	Conservation	22.7	16.5	6.1	0.31	1.9	0.0	32.	0	AMC 1
		Conventional				0.44	2.7	0.0	30		
5/10/81	3	Conservation	61.0	4.4	4.2	0.27	1.1	170.	277	1.3	AMC 1
		Conventional				0.54	2.3	220.	160.		
9/03/81	4	Conservation	51.4	11.4	10.0	0.13	1.3	73.	311.	71.1	AMC 3
		Conventional				0.20	2.0	129.	213		
9/26/81	5	Conservation	85.1	55.9*	121.0	0.13	15.7	560.	72	0	AMC 1
		Conventional				0.20	24.2	560.	149		
9/30/81	6	Conservation	48.3	7.6	5.7	0.13	0.7	130.	300.	85.1	AMC 3
		Conventional				0.20	1.1	185.	285		
3/11-13/82	7	Conservation	21.6	9.6	10.3	0.39		412.	63.	Snow-	AMC 3+
		Conventional				0.45		580.	0	Melt	
3/14-28/82	8	Conservation	Snow-	--	--	0.39	--	0.	278.	Snow-	AMC 3
		Conventional	Melt			0.45	--	0.	105.	Melt	
3/30/82	9	Conservation	23.5	27.9*	14.3	0.39	5.6	0.	181.	0	AMC 1
		Conventional				0.45	6.4	0.	158.		
6/15/82	10	Conservation	31.8	50.4*	41.4	0.27	11.2	0.	66.	0	AMC 1
		Conventional				0.68	28.1	0.	88.		
6/21/82	11	Conservation	19.0	28.7*	13.2	0.26	3.4	0.	86	52.5	AMC 3
		Conventional				0.67	8.8	54.	106		

Table 7

Event Summary: Sediment Losses

Date	Event	Tillage	Total Suspended Solids: Tile Flow (kg/ha)	Total Suspended Solids: Overland Flow (kg/ha)	Total Volatile Solids: Tile Flow (kg/ha)	Total Volatile Solids: Overland Flow (kg/ha)
4/9/81	1	Conservation	< 1.0	*	< 1.0	*
		Conventional	< 1.0	*	< 1.0	*
4/28/81	2	Conservation	< 1.0	*	< 1.0	*
		Conventional	< 1.0	*	< 1.0	*
5/10/81	3	Conservation	3.1	13.2	1.4	3.4
		Conventional	1.5	10.7	1.0	2.6
9/3/81	4	Conservation	5.7	12.7	< 1.0	1.2
		Conventional	2.8	9.7	< 1.0	1.8
9/26/81	5	Conservation	1.0	52.2	< 1.0	13.3
		Conventional	2.6	40.1	< 1.0	10.0
9/30/81	6	Conservation	6.7	22.8	**	**
		Conventional	9.0	29.7	**	**
3/11-13/82	7	Conservation	5	135.0	1.0	15.0
		Conventional	*	413.0	*	52.0
3/14-30/82	8	Conservation	22.1	*	5.6	*
		Conventional	7.6	*	< 1.0	*
3/30/82	9	Conservation	25.0	*	5.0	*
		Conventional	17.0	*	8.0	*
6/15/82	10	Conservation	5.3	*	< 1.0	*
		Conventional	8.1	*	2.9	*
6/21/82	11	Conservation	5.9	*	1.3	*
		Conventional	9.6	264.0	1.4	34.5

*: No flow occurred
<: Less than
**: Not measured

Table 8

Event Summary: Phosphorus Losses

Date	Event	Tillage	Total P Tile Flow (kg/ha)	Total P Overland Flow (kg/ha)	Soluble P Tile Flow (kg/ha)	Soluble P Overland Flow (kg/ha)	Ortho P Tile Flow (kg/ha)	Ortho P Overland Flow (kg/ha)
4/9/81	1	Conservation	0.004	*	< 0.001	*	< 0.001	*
		Conventional	0.003	*	< 0.001	*	< 0.001	*
4/28/81	2	Conservation	0.002	*	< 0.001	*	< 0.001	*
		Conventional	< 0.001	*	< 0.001	*	< 0.001	*
5/10/81	3	Conservation	0.083	0.142	0.067	0.090	0.051	0.064
		Conventional	0.044	0.208	0.027	0.163	0.026	0.147
9/3/81	4	Conservation	0.052	0.050	0.042	0.015	0.042	0.015
		Conventional	0.014	0.054	0.009	0.044	.009	0.037
9/26/81	5	Conservation	0.009	0.183	0.008	0.111	0.005	0.083
		Conventional	0.009	0.240	0.008	0.139	0.003	0.117
9/30/81	6	Conservation	0.046	0.033	0.039	0.020	0.032	0.016
		Conventional	0.032	0.063	0.023	0.044	0.016	0.037
3/11-13/82	7	Conservation	0.014	0.072	0.002	0.056	< .001	0.026
		Conventional	*	0.096	*	0.084	*	0.078
3/14-30/82	8	Conservation	0.029	*	0.003	*	< 0.001	*
		Conventional	0.012	*	0.004	*	< 0.001	*
3/30/82	9	Conservation	0.072	*	0.015	*	0.010	*
		Conventional	0.059	*	0.012	*	0.004	*
6/15/82	10	Conservation	0.009	*	0.002	*	< 0.001	*
		Conventional	0.013	*	0.003	*	0.002	*
6/21/82	11	Conservation	0.027	*	0.008	*	**	*
		Conventional	0.027	0.297	0.005	0.032	**	**

*: No flow occurred
<: Less than
**: No measurement taken

Table 9

Event Summary: Nitrogen Losses

Date	Event	Tillage	Nitrate - N Tile Flow (kg/ha)	Nitrate - N Overland Flow (kg/ha)	TKN Tile Flow (kg/ha)	TKN Overland Flow (kg/ha)
4/9/81	1	Conservation	1.3	*	< 0.1	*
		Conventional	1.2	*	< 0.1	*
4/28/81	2	Conservation	0.6	*	< 0.1	*
		Conventional	0.5	*	< 0.1	*
5/10/81	3	Conservation	3.9	2.0	< 0.1	0.5
		Conventional	3.2	4.2	< 0.1	0.90
9/3/81	4	Conservation	1.1	< 0.1	0.6	0.1
		Conventional	0.8	0.1	0.3	0.2
9/26/81	5	Conservation	0.3	?	< 0.1	0.9
		Conventional	0.4	1.3	0.1	0.8
9/30/81	6	Conservation	< 0.1	< 0.1	0.5	0.2
		Conventional	0.18	0.1	0.3	0.4
3/11-13/82	7	Conservation	0.2	0.7	< 0.1	0.8
		Conventional	*	1.8	*	2.0
3/14-30/82	8	Conservation	1.2	*	0.2	*
		Conventional	0.4	*	0.1	*
3/30/82	9	Conservation	1.0	*	0.3	*
		Conventional	0.5	*	0.3	*
6/15/82	10	Conservation	0.7	*	< 0.1	*
		Conventional	0.1	*	< 0.1	*
6/21/82	11	Conservation	0.7	*	< 0.1	*
		Conventional	0.9	1.5	< 0.1	0.8

*: No flow occurred; <: Less than

Table 10

Mean Concentration Per Event
(mg/l)

Total Phosphorus

Station	Event 1	2	3	4	5	6	7	8	9	10	11
CR	*	*	.83	0.68	0.33	0.25	0.17	*	*	*	*
CT	0.06	.06	.41	0.17	0.13	0.15	0.22	.10	.40	.14	0.31
MR	*	*	0.95	0.42	0.43	0.34	0.17	*	*	*	5.50
MT	0.05	.03	.28	0.07	0.06	0.11	*	.11	.37	.15	.25

Soluble Phosphorus

Station	Event 1	2	3	4	5	6[1]	7	8	9	10	11
CR	*	*	.53	.21	.20	.11	.14	*	*	*	*
CT	**	**	.33	.14	.11	.13	.03	.01	.08	.03	.09
MR	*	*	.74	.34	.25	.24	.14	*	*	*	.59
MT	**	**	.17	.04	.05	.08	*	.04	.08	.03	.05

[1]Soluble phosphorus content estimated based on ratio from Event 4 and Event 5 (average ratio used)

Ortho Phosphate

Station	Event 1	2	3	4	5	6[2]	7	8	9	10	11
CR	*	*	.38	.21	.15	.10	.06	0	0	*	*
CT	**	**	.24	.14	.07	.11	<.01	<.01	.06	<.01	**
MR	*	*	.67	.29	.21	.20	.13	0	0	*	**
MT	**	**	.16	.04	.02	.06	*	<.01	.03	.03	**

[2]Ortho phosphorus content estimated based on Op/Tp ratios in Event 4 and Event 5

CR: Conservation system overland runoff

CT: Conservation system tile runoff

MR: Conventional system (moldboard plow) overland runoff

MT: Conventional system tile runoff

*: No flow occurred

**: Not measured

Table 10 cont'd

Mean Concentration Per Event
(mg/l)

Total Suspended Solids

Station	1	2	3	4	5	6	7	8	9	10	11
	Event										
CR	*	*	78	133	93	175	328	*	*	*	*
CT	1.	9	15	18	14	22	79	79	138	80	69
MR	*	*	49	98	72	161	712	*	*	*	4900
MT	1.	3	9.	13	17	32	*	72	108	92	91

Total Volatile Solids

Station	1	2	3	4	5	6	7	8	9	10	11
	Event										
CR	*	*	20	16	24	**	36	*	*	*	*
CT	**	**	7.	2.	7	**	16	20	28	9	15
MR	*	*	12.	14	18	**	90	*	*	*	640
MT	**	**	6.	2.	3	**	*	7	51	33	13

Total Kjeldahl Nitrogen

Station	1	2	3	4	5	6	7	8	9	10	11
	Event										
CR	*	*	2.9	1.6	1.6	1.8	1.9	*	*	*	*
CT	< 0.01	< 0.01	0.1	2.0	0.1	1.7	0.8	0.7	1.5	< 0.2	0.5
MR	*	*	4.1	1.8	1.4	2.1	3.4	*	*	*	14.1
MT	< 0.01	< 0.01	0.1	1.2	0.9	1.1	*	1.1	2.1	0.2	0.5

Nitrate Nitrogen

Station	1	2	3	4	5	6	7	8	9	10	11
	Event										
CR	*	*	11.8	0.4	29.0	0.1	1.7	*	*	*	*
CT	19.4	17.9	19.5	3.6	3.9	0.3	2.7	4.3	5.8	2.0	8.1
MR	*	*	19.1	0.6	2.3	0.5	3.1	*	*	*	12.4
MT	19.0	17.9	20.0	3.8	2.9	0.6	*	3.7	3.0	8.1	8.1

CR: Conservation system overland runoff

CT: Conservation system tile runoff

MR: Conventional system (moldboard plow) overland runoff

MT: Conventional system tile runoff

*: No flow occurred

**: Not measured

5.2 Snowmelt: February 16-February 22,1981

The first runoff event was marred by the backup and failure of the receiving ditch, the Sphon drain. Although the ditch had been cleaned and deepened the preceding fall, it did not provide an outlet for the snowmelt runoff. Several factors accounted for this failure. During several intense snowstorms the ditch had filled with densely packed snow to a depth of approximately 2.5 meters. In addition, the ditch ran on an east west transect and the southern bank shielded the snow from the direct rays of the sun for most of the day. Consequently the snow in the ditch melted more slowly than the snow on the field and exhibited a low permeability to flowing water.

When overland runoff began to leave the two study plots it was unable to exit the fields since the snow in the ditch was effectively damming the outlets. Meltwater from the ditch and runoff waters from the plots backed up onto the fields and into the tile, contaminating the runoff waters and obscuring precise measurements of drainage volume. Flow was not accurately represented by stage height for overland or tile flow. Although samples were obtained they have not been used to calculate field losses.

5.3 Event 1: April 9-10,1981

On April 9, 1981 24.0 mm of precipitation fell on the study site generating subsurface tile flow from both fields. The recording rain gage had not yet been fully installed at the site, however, hourly rainfall records from the Vassar Weather Station (U.S. Dept. of

Commerce, 1981) located 16 km south of the study indicated that the storm was of low intensity and occurred over a 10 hour period. The maximum hourly precipitation associated with the storm recorded at Vassar was 8 mm/hr. The rainfall erosion index (R) of the storm was 3.5 MT-m/(ha-hr).

No agronomic activity had occurred on either plot since the fall tillage. Residue cover following fall tillage was 3500 kg/ha with 58% cover on the conservation tilled plot. The conventionally tilled plot had 300 kg/ha of residue with a 10% cover on the plot. Based on the findings of Wischmeier and Smith (1978), the crop management factor (C) was 0.31 for the conservation plot and 0.44 for the conventionally tilled plot.

Antecedent soil moisture at the inception of the precipitation event was AMC I since total precipitation during the 5 day period preceding the event was 8.5 mm, below the 12.7 mm considered the average condition for runoff events in the dormant season. No tile flow was occuring when the precipitation event began suggesting that the soil was at or below field capacity.

A total of 6.3 mm of water was discharged through the subsurface tile of the conventional field compared to 6.8 mm of water from the conservation field. No overland runoff occurred on either field. Actual losses of nutrients and sediment represented a small fraction of the total measured over the entire period. Concentrations were generally low with the exception of nitrate-nitrogen. Mean flow weighted concentrations of nitrate-N on both fields were approximately 19 mg/l, among the highest measured in tile waters during the study.

5.4 Event 2: April 28-29, 1981

A low intensity storm generated subsurface tile flow from both plots on April 28, 1981. A total of 22 mm of precipitation fell over a 13 hour period. The maximum 30 minute intensity was measured at 16.5 mm/hour, well below the 25 mm/hour intensity necessary for the event to be classified as an excessive rate storm. The rainfall erosion index of the storm was 6.1 MT-m/(ha-hr), nearly twice the "average" (3.9) rainfall erosivity that is expected to occur during the second part of April (Wischmeier and Smith, 1978).

No agronomic activity had occurred on either plot since fall tillage. The crop management factors (C) were essentially unchanged since the April 9th Event. The actual rainfall erosivity that impacted the ground surface (R-C) was 2.41 on the conventionally tilled field vs. 1.70 on the conservation plot.

During the 5 days preceding the event, no precipitation had occurred, placing the antecedent soil moisture condition into AMC I, below average runoff conditions. Subsurface flow from both plots was quite small; 3.0 mm from the conventional plot compared to 3.2 mm from the conservation field. This represented the smallest quantity of flow from any event during the entire sampling period. As in Event 1, actual nutrient and sediment losses were very small, but the mean flow weighted nitrate nitrogen concentrations in the tile flow from both fields were approximately 18 mg/l, more than twice the mean concentrations that occurred over the entire study period.

5.5 Event 3: May 10-12, 1981

An unusually large, low intensity storm generated overland runoff and subsurface tile flow from both study plots during May 10-12, 1981. Over a period of 31 hours 61 mm of precipitation occurred. The maximum volume that fell over a 24 hour period during the event was 50.2 mm. Based on hydrologic frequency analysis, this represents a 23 year return interval storm for the month of May.

The maximum 30 minute intensity of the storm was only 4.4 mm/hr the lowest value of any of the precipitation events which generated surface or subsurface flow. The rainfall erosion index (R) was found to be 4.2 MT-m/(ha-hr), the second lowest erosivity of the 11 events monitored. The surface conditions of both plots had been altered since the events of April. Secondary tillage (field cultivator), planting, and fertilization had concluded on May 6, 1981; four days before the event. Residue was measured to be 2200 kg/ha with 35% cover on the conservation field compared to 300 kg/ha with 3% cover on the conventional field. No crop growth emergence had occurred on either field. Based on crop and residue conditions, the crop management factors (C) were 0.54 for the conventional field vs 0.27 for the conservation field.

The antecedent moisture condition at the inception of the event was classified as AMC I, below the normal conditions for overland runoff. Only 1.3 mm of precipitation had occurred during the 5 days preceding the event. Of the 61 mm of precipitation, 22 mm left the conventional field as overland runoff compared to approximately 17 mm from the conservation plot. Subsurface drainage removed 16 mm on the conventional plot vs. 28 mm on the conservation plot. Technical difficulties with the Isco Bubbler flowmeter on the conservation plot prevented an accurate measurement of overland flow on that plot. The estimate of overland runoff was based on the curve number method (Mockus, 1973). The runoff volume on the conventional field was accurately modelled by a curve number of 78. Based on S.C.S recommendations for modelling fields with residue the curve number was reduced to 76 for the conservation field (USDA/SCS, 1981). The estimate of 17 mm is probably in excess of the actual quantity which left the field since the total drainage from the conventional field was 17% less than from the conservation field. During each of the four other events where both overland and subsurface flow occurred, the total water loss from each field was always within 12%. A slight overestimate of the surface runoff from the conservation field however, would not dramatically influence the total losses of any water borne constituent over the entire study period.

On both plots the May 10-11 event generated the lowest losses of suspended solids that resulted from the six events with overland flow. Suspended sediment losses were under 20 kg/ha from both fields. High levels of soluble nutrients however, were lost from both plots. The event discharged the largest quantity of soluble phosphorus lost from each plot during the study. A total of 0.19 kg/ha of soluble phosphorus came off the conventional field compared to 0.16 kg/ha from the conservation field. This represented 32% and 33% of all of the soluble phosphorus respectively,that was lost during the two seasons of study. Soluble phosphorus comprised 70% of the total phosphorus lost from the conservation field vs. 75% of the total phosphorus lost from the conventional field. Of the 62 kg/ha of phosphate fertilizer applied, 0.5% left each field as soluble phosphorus during this Event.

Losses of nitrate nitrogen were also high compared to the events monitored. Combined surface and subsurface losses totalled 7.4 kg/ha from the conventional field and 5.9 kg/ha from the conservation field. Nitrate-N losses accounted for 3-4% of the nitrogen fertilizer applied to each field. The quantity of nitrate-N lost from each plot was exceeded during only one Event, September 26, 1981, and that loss estimate is subject to question.

A mixture of 308 kg/ha of 10-20-20 fertilizer had been banded into the soil and an additional 168 kg/ha of anhydrous ammonium knifed into the soil four days preceding the event. Less than 0.5% of the applied phosphorus was lost as soluble P whereas 3-4% of the applied nitrogen was lost as nitrate nitrogen.

Atrazine had been applied at a rate of 1.4 kg/ha. During the runoff event, a total of 10.4% and 8.6% of the applied atrazine was discharged from the conventional and conservation fields. Atrazine concentrations in the overland flow ranged as high as 0.6 mg/l from the conventional site. The event represented a worst case scenario of a major rain immediately following application of the herbicide. All samples had concentrations well below the LC-50 concentration of 4.5 mg/l cited by Triplett et al. (1978) for the most sensitive fish species.

5.6 Event 4: September 3-5,1981

Surface and subsurface flow was generated on both plots by a large moderate intensity storm that occurred on September 3,1981. A total of 53 mm of precipitation fell over a 12 hour period. The maximum 30 minute intensity was 11.4 mm/hour. A storm of this magnitude in September is expected to have a return interval of 8 years based on hydrologic frequency analysis. The rainfall erosion index (R) was computed as 10.0 MT-m/(ha-hr) for the storm.

The corn crop was fully mature during this event and afforded a complete canopy cover over the soil. The crop management factor (C) for the conventional field was 0.20 vs. 0.13 for the conservation field. The canopy cover reduced the effective rainfall erosivity impacting on the soil surface (R-C) to 2.0 MT-m/(ha-hr) on the conventional field and 1.3 MT-m/(ha-hr) on the conservation field. These erosivity values are comparable to those which occurred during the low intensity event of May 10-11, 1981.

Antecedent soil moisture was in the AMC III category, above soil moisture levels associated with normal runoff conditions. A total of 71 mm of precipitation had occurred in the 5 days preceding the event. Low flow rates had been observed in the subsurface tile of both fields 48 hours before the event, indicative of the relatively high soil moisture levels.

Losses of suspended solids were quite low with total losses from each field were under 20 kg/ha. Losses of soluble nutrients were greater than sediment bound nutrients. Soluble P comprised 56% of the total P lost from the conservation field and 78% of the total phosphorus from the conventional field (Table 8). Of the nitrogen which left the fields, 64% was lost as soluble nitrate-N from the conventional field compared to 61% on the conservation field (Table 9). Compared to total losses from all 11 events over the two seasons of study, however, losses of soluble P and N from event 4 represented only 9% of the cumulative losses from the conventional field and 12% from the conservation field.

5.7 Event 5: September 26-29, 1981

On September 26, 1981 81 mm of precipitation fell on the study plots over a three hour period. The storm was very intense with a maximum 30 minute intensity of 56 mm/hr, well above the minimum of 25 mm/hr necessary to be classified as an excessive rate storm. The magnitude of the storm was exceptional. The storm's magnitude equalled the largest recorded storm during 1940-1980 at the Caro weather station. More rain fell in three hours than the average for the entire month of September in this region (U.S. Dept. of Commerce, 1971). The annual expected return period for a storm of this magnitude is 25 years.

The erosive force of the storm as estimated by the rainfall erosion index was 121 MT-m/(ha-hr), equivalent to the total average erosive force expected during the period from April 1 to November 30. The existing corn crop provided a total canopy cover and shielded the soil from direct raindrop impact. The effective erosive force impacting the soil surface measured by the rainfall erosion index (R-C in the USLE) (Wischmeier and Smith, 1978) was reduced to 24.2 MT-m/(ha-hr) on the conventional field and 15.7 MT-m/(ha-hr) on the conservation field.

Soil antecedent moisture was at AMC I when the event began. No precipitation had occurred during the 5 days previous to the event. An unusually large portion of the 81 mm of precipitation exited the fields via overland flow. On the conservation field 56 mm of overland runoff was recorded compared to 7.2 mm of subsurface tile flow. Overland flow from the conventional field was 56 mm and subsurface flow was 15 mm. Records of overland flow from the conventional site were disrupted by a malfunction of the Isco bubbler flow meter. The meter functioned correctly for part of the event and visual observation of stage on the H flume at 30 minute intervals were utilized to estimate total overland flow. From both plots 69% of the precipitation came off the fields as an overland runoff. This is nearly twice the proportion that occurred during any of the other 11 events.

During the runoff event the receiving ditch experienced some backup resulting in submerged tile outlets for 10 hours on the conventional field and 14 hours on the conservation field. Loss estimates for constitutients carried by subsurface flow during this event were for the period of free flow after the backup period. The total error incurred by ignoring the flow during the tile submergence is relatively minor, since most of the drainage was in the form of overland flow.

Considering the great erosive force of the storm, sediment losses were relatively small. Suspended sediment losses were 53 kg/ha on the conservation field compared to 43 kg/ha on the conventional field. The mean flow weighted concentration of suspended sediment from either field did not exceed 100 mg/l, well below the 800 mg/l standard recommended by the U.S. EPA.

Although mean flow weighted concentrations of most nutrients were not high relative to the other events, the large volume of water draining from the field generated comparatively high losses. For all 11 events, 21% of the total P and 25% of the soluble P came from the conventional field during this event. Losses from the conservation field accounted for 25% of the total P and 25% of the soluble P measured during the study period.

Nitrate nitrogen losses were substantial from each tillage system. A single composite sample of overland flow from the conservation tillage field was found to have unusually high concentrations (29 mg/l). Since all other nitrate measurements made during the month of September on both surface and subsurface flow did not exceed 5 mg/l and the TKN concentrations of the flow were within the normal range, contamination of the sample seems likely.

5.8 Event 6: September 30-October 2,1981

Overland and subsurface flow from both plots were generated by a 48 mm, low intensity storm on September 30, 1981. The maximum 30 minute intensity was 8.0 mm/hr. The storm magnitude has a six year return period for the month of September and a two year annual return interval. The rainfall erosion index (R) was computed to be 5.7 MT-m/(ha-hr) for the event.

The crop was at the same stage as it was during event 5 and the same crop management (C) factors were used. The expected erosive force impacting the soil surface (C-R) was 1.1 MT-m/(ha-hr) for the conventional field vs. 0.7 MT-m./(ha-hr) for the conservation field. These were the lowest values of any of the six events that generated overland flow.

When the event began, the soil antecedent moisture condition was in the AMC III category; 81 mm of precipitation had occurred four days earlier. Most of the flow from both fields was discharged through the subsurface tile. Low concentrations of nutrients and sediment were measured in both the overland and subsurface discharge waters. Losses of nutrients and sediment from the event were comparatively minor.

5.9 Event 7: March 11-March 14, 1982

All of the 1982 snow pack ran off the study fields during Event 7. Snow cores taken on March 6, 1982 indicated an average of 32.3 mm of liquid water equivalent on the conservation field compared to 30.8 mm the conventional field. On March 11, 1982 5.1 mm of rain fell, the temperature rose to 6 C and overland runoff began at each field. The snow cover on the conventional system melted quicker than the conservation system's snow pack. By the evening of March 12th, only 20-30% of the conventional field had either snow or slush compared to a 50-60% snow cover on the conservation system. The antecedent soil moisture was AMC III since the ground was partially frozen and saturated from melting snow. During the first 36 hours of snowmelt overland flow discharged 19.5 mm of water from the conventional field compared to 11.0 mm from the conservation system.

The receiving ditch proved to be a satisfactory outlet for snowmelt runoff. In preparation for snowmelt monitoring, on February 18, 1982 the ditch had been cleared of snow by a hydraulic backhoe, and was an excellent transport system throughout the spring season.

On March 13, 1982, 16 mm of rain fell on the fields, generating an additional 40 mm of overland flow from the conventional field and 30 mm from the conservation field. By March 14th, both systems were essentially free of snow or slush and overland flow ceased. Tile flow began from the conservation field on March 13th and drained 6 mm of water during the next 24 hours. No tile flow was generated from the conventional field during event 7.

The erosive forces of the runoff event were the result of 2 rainstorms and snowmelt runoff. The snowmelt erosion index (Rs) was 6.6

MT-m/(ha-hr). This estimate is based on the occurence of 6.45 cm of precipitation from December 14, 1981, when the soil began to freeze until the begining of event 7. The rainfall erosion index computed for the storms of March 11 and March 13 was 0.7 and 3.0, respectively, resulting in a total erosion index of 10.3 MT-m/(ha-hr) for the snowmelt event. Corn residue on the conservation field was 2300 kg/ha with 56% cover corresponding to a crop management C factor of 0.39. Residue cover on the conventional field was at 10% for a C factor of 0.45. The effective erosive force of the event was 4.0 for the conservation field compared to 4.6 for the conventional field.

Appreciable quantities of sediment left the fields. For the entire study, 50% of the suspended solids lost from the conventional system came from this single event compared to 45% from the conservation field. Snowmelt sediment losses from the conventional field were 413 kg/ha, nearly three times greater than the loss from the conservation field (135 kg/ha).

Losses of nutrients were comparatively low (Tables 8 and 9). Mean concentrations of total and ortho phosphorus in the overland flow were the lowest of the six overland flow events. For the total sampling period 8% of the total P and 14% of the soluble P came from the conventional field compared to 10% and 12% from the conservation field. Mean flow weighted nitrate nitrogen concentrations were well below 10 mg/l.

A high proportion of the nutrients lost in the runoff were in the soluble fraction. Soluble P losses comprised 67% of the total P lost from the conservation field and 88% of the total P from the conventional field. Nitrate nitrogen comprised roughly 50% of the total N lost from each field.

5.10 Event 8: March 14-March 30, 1982

During the period from March 14-30, 1982 no precipitation or overland runoff occurred. Tile flow occurred from both fields. The flow from each field displayed a diurnal pattern, rising during the afternoon and dropping each night. A snow drift in the conservation field melted during this period and comprised 25% of the total tile flow off that field. The drift was along a windbreak on the west boundary of the field and covered roughly 8% of the field with 25 to 35 cm of snow. The losses given in Tables 8 and 9 have been multiplied by a correction factor of 0.744 to eliminate the effects of the drift from the system comparisons.

Corrected runoff losses during Event 8 were 105 cu-m/ha from the conventional field and 278 cu-m/ha from the conservation field. Losses of all nutrients and sediment were small since mean flow weighted concentrations were low (Table 10). The proportion of soluble P in the tile flow was small. Only 10% of the total phosphorus lost from the conservation field was in the soluble phase. On the conventional field soluble P comprised 33% of the total P measured.

5.11 Event 9: March 30-April 1, 1982

An intense storm of 25.4 mm magnitude occurred on March 30, 1982 generated subsurface tile flow from both tillage plots. The maximum 30 minute intensity of the storm was 28 mm/hour meeting the criteria of an excessive rate storm. The rainfall erosion index computed for the storm was 14.3 Mt-m/(ha-hr). No agronomic activity had occurred since the fall tillage. The residue status and C factors were the same as existed in event 7, and 8. The effective erosivity impacting the soil surface (R-C) was 6.4 on the conventional site and 5.6 on the conservation site.

No rainfall had occurred during the 5 days preceding the event, placing the antecedent soil moisture status in AMC I, below normal runoff conditions. Subsurface tile runoff drained 18 mm of water from the conservation field and 16 mm from the conventional field. The subsurface drainage waters from both fields carried comparatively high concentrations of suspended solids and total phosphorus. However soluble phosphorus constituted only 20% of the total P loss from the conservation field and 22% from the conventional field. Actual losses (kg/ha) of all nutrients and sediment were minor compared to the entire study period.

5.12 Event 10: June 15-17, 1982

An intense excessive rate storm on June 15, 1982 generated subsurface tile flow on both fields. The storm's volume was 31.8 mm. Based on frequency analysis, a storm of that magnitude occurring during June is expected to have a 4 year recurrence interval. During one 15 minute interval, 24 mm of precipitation occurred. The maximum 30 minute intensity recorded was 50.8 mm/hr, well above the 25 mm/hr intensity that is the minimum standard of an excessive rate storm.

The erosive force of the storm was 55.2 MT-m/(ha-hr). Both fields had been planted to field beans 16 days previous to the event and were in the seedbed crop stage with small seedlings present. Residue on the conservation field was at 1700 kg/ha with 27% cover, giving it a crop management factor (C) of 0.27 (Wischmeir and Smith, 1978). The crop management factor on the conventional field was 0.68. The effective rainfall erosivity (C-R) impacting the soil surface was 28.1 on the conventional field vs 11.2 on the conservation field. This was the largest difference in the magnitude of erosivity (16.9) that occurred over the entire study. The conventional field received the highest direct impact from raindrops that occurred during the study period. Soil crusting may have developed as a result of the event. Considerable ponding occurred on the conventional field suggesting that decreased infiltration occurred. No puddles were observed on the conservation field.

No overland runoff occurred from either field. The antecedent soil moisture condition at the start of the precipitation event was AMC I, below normal runoff conditions. In the previous 5 days no precipitation had fallen.

Relatively insignificant losses of nutrients and sediment were generated by this event. The event generated less than 2% of the phosphorus, nitrogen, and sediment that was lost from either field over the course of study. Soluble P constituted 20% of the total P lost from each field.

5.13 Event 11: June 21-22, 1982

A brief high intensity storm that occurred when soil moisture conditions were near saturation, generated large differences in edge-of-field losses from the two study fields. The maximum 10 minute intensity of the storm was 75 mm/hour. Storm intensities equal to or greater than this intensity have been found to generate the maximum raindrop energy (Wischmeier and Smith, 1978). The storm met the criteria for an excessive rate 30 minute storm with a maximum 30 minute intensity of 28.7 mm/hour. The storm erosivity as measured with the rainfall erosion index (R) was 13.2. Less than a 10% canopy cover was provided by the field beans. No field work had occurred since Event 10 and residue cover was unchanged. The actual erosivity impacting the soil surface (R-C) was 8.8 Mt-m/(ha-hr) on the conventional field compared to 3.4 on the conservation field.

Tile flow occurred from both fields. Only the conventional field, however, had overland runoff. The overland flow carried extremely high concentrations of suspended solids, volatile solids, total phosphorus, and soluble phosphorus. The tile flows from both fields had nutrient and sediment concentrations within the range found in tile flows during the other ten events. Losses of nutrient and sediment from the conservation field constituted a small fraction of the total losses recorded from the field over the study period.

In contrast, the losses from the conventional field accounted for 28% of the total P and 33% of the suspended solids lost during the entire period. Overland runoff from this event was 5.4 mm, representing only 3.3% of the 166.1 mm of overland flow that occurred on that field during the two years of study. Hydrologically, it was the smallest overland runoff event to occur.

As a consequence of this single intense storm, the comparative losses of phosphorus and sediment from the conservation and conventional fields were markedly altered. Over all the previous 10 events losses of total phosphorus from the conventional field were 1.06 times greater than from the conservation field. Sediment losses from the conventional field were 1.8 times greater than from the conservation field. When the losses from Event 11 were added to the sum of the other events, the results demonstrate a substantial decrease in the losses of total P and sediment from the conservation field compared to the conventional field. For the entire study period the losses of total P and suspended solids are 1.4 and 2.6 times greater than the cumulative losses from the conservation field. Elevated concentrations of nitrate N were not found in the overland or tile flow from either field during event 11. The event did not measurably alter the comparative losses of nitrogen between the two fields.

A unique set of conditions combined to generate losses of sediment and P of such varying magnitude on the two fields. This was the only occurrence of an excessive storm when the soil antecedent moisture was high and no crop cover was present. Subsurface flow was occurring at low rates on each field when the precipitation event began. During the preceding 5 days 52.5 mm of precipitation had occurred slightly less than the 53.3 mm defined as AMC III for the growing season, however the event occurred early in the growing season when crop evapotranspiration was well below the rate expected in midseason.

Soil crusting on the conventional field may have partially accounted for the difference observed. While no measurements were taken on soil crusting, the intense storm of June 15, 1982 coupled with the high intensity precipitation of Event 11 may have effectively sealed the soil surface of the unprotected conventional field, reducing infiltration and promoting overland flow. The conservation field had 27% residue cover that should have maintained a permeable surface condition.

CHAPTER 6

ANALYSIS AND DISCUSSION: FIELD INVESTIGATION

6.1 Precipitation Analysis

The field data collected during the 20 month study period were strongly effected by the timing and magnitude of precipitation events. Although eleven hydrologic events were sampled, care must be used when attempting to draw long term conclusions from the data. The precipitation volume and rainfall erosivity that occurred during the study were compared to long term norms to check the variability of the 20 month storm patterns.

Table 11 compares the monthly precipitation quantity recorded at Caro Michigan during 1981 and 1982 to 30 years of record. During several months, precipitation was found to be dramatically different than the expected mean. March 1981 was unusually dry. Only 1.45 cm of precipitation fell compared to a 30 year mean of 5.33 cm. Based on gamma distributions, 95% of all years are expected to have more precipitation during March than occurred in 1981. No drainage occurred from either field. However, during March some form of drainage can usually be expected since the soil is often partially frozen and evapotranspiration is low. During March, 1982 for example, drainage occurred for approximately 19 days from each field.

The other major anomally occurred during September 1981 when precipitation was 11.54 cm above the mean. The 19.08 cm of precipitation recorded that September was larger than had been measured

Table 11

Comparison of Monthly Precipitation (PPT)
March 1, 1981 - October 31, 1982
To 30 Year Mean
Caro Weather Station, Caro, Michigan

Month	Mean	1981		1982	
	(cm)	PPT (cm)	% of years with more PPT	PPT(cm)	% of years with more PTT
March	5.33	1.45	>95%	6.43	>30%
April	6.38	10.19	<15%	4.45	>75%
May	6.48	7.54	<35%	4.17	>70%
June	7.84	6.38	>60%	12.12	<15%
July	7.42	7.82	<40%	4.67	>70%
August	7.52	13.54	<10%	8.38	<40%
September	7.54	19.08	<2%	7.01	>40%
October	5.84	8.30	<25%	1.85	>85%
November	5.77	3.58	>75%	----	----

in that month during the period 1950-1980 at the Caro Weather Station. Based on gamma distributions for the month of September the magnitude of precipitation during 1981 is expected to be exceeded in only 2% of all years (i.e. a 50 year return period). Considerable surface and subsurface flow occurred from both fields during September 1981 accounting for 48% of all the runoff that occurred from both the conservation and conventional fields over the entire 20 months of study. September is not usually expected to yield large runoff events in Michigan. Considerable evapotranspiration from mature crops is occurring and the soil is expected to have available moisture storage capacity. During 1982 no surface or subsurface flow exited either field throughout the month of September.

6.2 Soil Characteristics

The volumetric moisture content and bulk density of the surface and subsurface soils of both fields are given in Table 12.

Table 12

Soil Physical Properties

Parameter	CT Surface Mean	CT Surface S.D.	CT Subsurface Mean	CT Subsurface S.D.	MP Surface Mean	MP Surface S.D.	MP Subsurface Mean	MP Subsurface S.D.
Volumetric Moisture Content								
Saturation	0.42	0.02	0.39	0.01	0.42	0.01	0.38	0.01
0.10 Bar	0.34	0.01	0.27	0.01	0.32	0.02	0.28	0.01
0.33 Bar	0.31	0.01	0.27	0.01	0.31	0.02	0.26	0.01
0.50 Bar	0.30	0.01	0.27	0.01	0.30	0.02	0.26	0.01
1.00 Bar	0.30	0.01	0.26	0.01	0.29	0.02	0.25	0.01
Bulk Density (g/cu cm)	1.56	0.05	1.70	0.06	1.55	0.10	1.67	0.05

CT: Conservation Tillage Field
MP: Conventional Tillage Field

Using a Students t test, no significant difference at the 95% level was found in bulk density or volumetric moisture content measured in surface horizons of the two fields. The subsurface horizon of the conventional field had a significantally greater volumetric moisture content at 0.1 bars, while the conservation field had a significantly higher volumetric moisture content at 0.33, 0.5, and 1.0 bars. The water storage capacity of each field was considered equal and the average from all measurements was used for calculating the equivalent depth of water at a given tension.

The 70 cm of soil above the subsurface tile could hold approximately 6.6 cm of water between saturation and 0.1 bars, and an additional 1.0 cm between 0.1 and 0.33 bars. Since field capacity is considered to be between 0.1 and 0.33 bars of tension for a clay loam soil, the soil at field capacity could hold as much as 6-8 cm of water before saturation occurred.

A summary of pertinant chemical analysis is given in Table 13. The organic matter of the surface horizon was tested on October 12, 1981 and found to be 4.4% on the conservation tillage field vs 4.7% on the conventional field. Using a paired comparison test, no significant differences were found between the surface horizons of the two fields in the quantities of phosphorus, calcium, magnesium or the cation exchange capacity. Based on samples obtained October 17, 1982 the subsurface horizon of both fields had significantly lower quantities of P than the surface horizons. The cation exchange capacity of the two horizons was not significantly different.

The available phosphorus content of the surface soil was very high with samples ranging from 83 - 148 kg/ha during the study period. For the 5 dates samples were taken, the mean quantity of available phosphorus was 120 kg/ha for the conventional field and 118 kg/ha for the conservation field. These quantities are above the level recommended for corn yields of 9.2 MT/ha. Yields on the site average 7.7 MT/ha; however, the cooperating farmer banded 70 kg/ha of P in 1981 and 61 kg/ha of P in 1982 well above the 28 kg/ha recommended based on the soil tests to enhance seedling growth (Warncke et al, 1976).

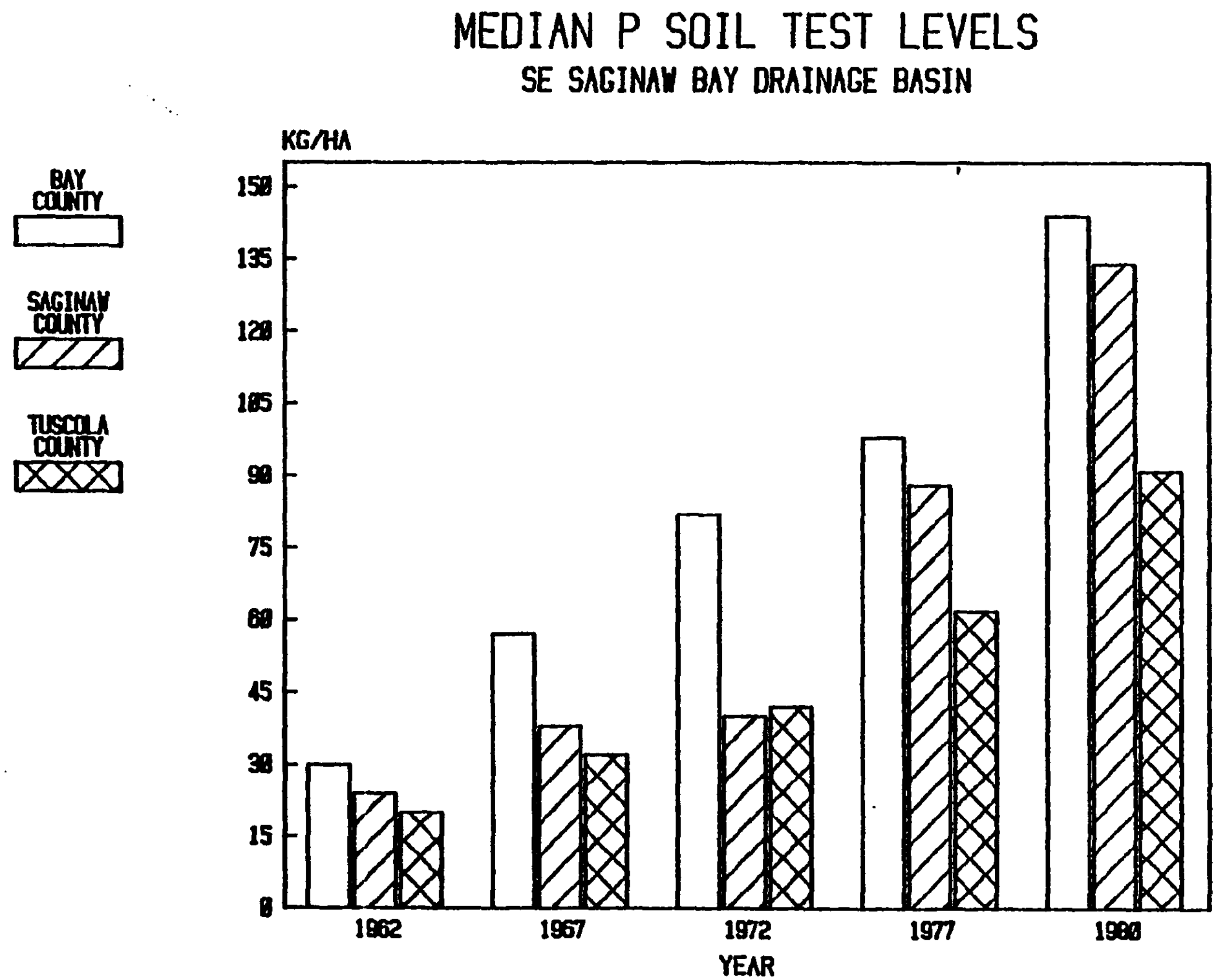
Heavy application of high phosphate fertilizer is a common agronomic practice in the study region and has resulted in a steady increase in soil phosphorus levels (Meints, unpublished data, MSU Soil Testing Service). Figure 7 depicts the median phosphorus soil test levels measured since 1962, for the counties which drain into the Southeast Saginaw Bay. Within the study region soil phosphorus levels

Table 13

Soil Chemical Analysis

Date	Site	CEC		P		K		CA		Mg		pH	
5/26/81	MP Surface	18		110		350		6300		940		7.3	
5/26/81	MP Surface	18		110		359		6400		970		7.4	
5/26/81	CT Surface	17		104		413		5900		860		6.9	
5/26/81	CT Surface	16		104		395		5774		830		6.9	
8/14/81	MP Surface	18		83				6230		940		7.2	
8/14/81	CT Surface	17		134				5870		940		7.2	
10/12/81	MP Surface	17		131				6100		810			
10/12/81	CT Surface	17		92				6230		830			
6/16/82	MP Surface	18		127		380		6400		890		7.1	
6/16/82	CT Surface	17		127		440		5870		820		6.7	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
10/17/82	MP(n=5) Surface	16	1	148	56	340	65	5600	170	860	65	7.0	.3
10/17/82	CT(n=5) Surface	16	1	134	17	413	40	5200	190	840	55	6.8	.4
10/17/82	MP(n=3) Subsurface	15	3	6	8	200	150	5500	1550	700	85	8.1	.3
10/17/82	CT(n=3) Subsurface	14.0	3.0	4	2	140	21	5100	1200	770	70	7.7	.4

Figure 7



MEDIAN P SOIL TEST LEVELS
SE SAGINAW BAY DRAINAGE BASIN
KG/HA
BAY COUNTY
SAGINAW COUNTY
TUSCOLA COUNTY
150
135
120
105
90
75
60
45
30
15
0
1962
1967
1972
1977
1980
YEAR

have risen 5 fold since 1962. Overland runoff from these soils may carry higher concentrations of soluble P compared to even one decade ago.

6.3 Antecedent Soil Moisture

As expected, antecdedent soil moisture appeared to influence the occurrence of overland runoff and tile flow from the study fields. Only the two largest storms during the period of study were capable of generating overland runoff when the antecedent soil moisture was at AMC I, below the normal moisture content for annual runoff events . In the four other events where overland flow occurred the antecedent soil moisture was at or near the saturation condition classified as AMC III (Mockus, 1971). The magnitude of those four storm events ranged from 19-51 mm. No overland flow resulted from twelve other storms of comparable magnitudes, that occurred when soil antecedent moisture conditions were at AMC I (Table 14). One large storm occurred in September 1981 that did not generate drainage from either field although the soil was at AMC II, the average condition for runoff events.

The degree of hydrologic response to a precipitation event was affected by the presence of an actively growing crop. Each of the six storms greater than 15 mm that occurred during the dormant season resulted in tile and/or overland flow from both fields. Evapotranspiration is low when no crop is present and soil moisture can be expected to remain near field capacity during much of the dormant period. A total of 15 storms greater than 15 mm fell during the 1981 and 1982 growing season that generated no overland or subsurface flow

Table 14

Precipitation Characteristics: Storms Generating No Edge of Field Flow

Date	PPT mm	i_{30max} mm/hr	R	Conv. C	Cons. C	Conv. RxC	Cons. RxC	Crop	Stage	5-Day AMC (mm)
6/15/81	16.3	59.7*	14.19	.43	.21	6.10	2.98	Corn	2	11.4mm 6/13 6.3mm 6/14
6/21-22/81	22.2	6.3	2.42	.37	.20	.90	.48	Corn	2	0.5mm 6/16
7/17/81	12.7	14.0	4.53	.20	.13	.91	.59	Corn	3;96	0
7/28/81	26.7	10.9	5.19	.20	.13	1.04	.67	Corn	3;96	0
8/7/81	36.1	38.3*	34.12	.20	.13	6.82	4.44	Corn	3;96	0
8/14-15/81	27.3	11.4	5.68	.20	.13	1.14	.74	Corn	3;96	3.3mm 8/13 2.5mm 8/12 1.3mm 8/10
8/28-29/81	25.4	23.4	12.16	.20	.13	2.43	1.58	Corn	3;96	0
8/29-30/81	13.3	11.8	3.04	.20	.13	.61	.40	Corn	3;96	25.4mm 8/28-8/29
9/1/81	59.1	39.2*	56.31	.20	.13	11.26	7.32	Corn	3;96	25.4mm 8/28-8/29 13.3mm 8/29-8/30
9/16-17/81	25.4	2.9	1.01	.20	.13	.20	.13	Corn	3;96	0
9/20-21/81	17.8	2.1	.56	.20	.13	.11	.073	Corn	3;96	25.4mm 9/16-9/17
11/20/81	14.0	6.5	1.56	.44	.31	.69	.48	Corn	F	1.3mm 11/19
11/26/81	25.4	19.8	10.22	.44	.31	4.50	3.17	Corn	F	0
5/31-6/1/82	17.8	6.3	2.01	.45	.39	.90	.78	Beans	F	0
6/9-10/82	14.6	16.2	5.01	.62	.30	3.11	1.50	Beans	SB	0
6/18-19/82	18.9	4.8	1.36	.67	.26	.91	.35	Beans	SB	31.7mm 6/15
7/17/82	14.0	15.3	4.30	.44	.24	1.89	1.03	Beans	2	1.3mm 7/16
7/27/82	15.2	8.2	2.54	.30	.23	.76	.58	Beans	3;80	0
8/8/82	16.3	13.1	4.20	.17	.15	.71	.63	Beans	3;96	0
8/20/82	12.7	25.4*	8.53	.17	.15	1.45	1.28	Beans	3;96	0
8/25-26/82	43.8	34.3*	33.38	.17	.15	5.67	5.01	Beans	3;96	0
9/27/82	19.0	5.8	1.94	.38	.39	.74	.76	Beans	4	12.2mm 9/22

*Indicates excessive rate storm

from either field. Antecedent soil moisture was below normal (AMC I) for 14 of these events and at AMC II for the additional event.

6.4 Rainfall Erosivity

The expected annual rainfall erosivity in the study region as evaluated by the rainfall erosion index is among the lowest that occurs in the eastern United States (Figure 8). Wischmeier and Smith (1978) consider the mean index of the study region to be 130 MT-m/(ha-hr). This compares to 260 MT-m/(ha-cm) at Black Creek, Indiana and 520 MT-m/(ha-hr) at Watkinsville, Georgia, two other locations where edge of field losses from conservation tillage have been monitored.

Although actual sediment losses during a given event at the study plots were the result of antecedent soil moisture, surface conditions, and precipitation characteristics, the rainfall erosion index impacting the soil surface is a good indicator of the potential for erosion to occur. Crop residue and canopy cover diminish the erosivity of a storm and are quantified by the crop management factor (C).

The product of the crop management factor (C) and the rainfall erosion index (R) is considered to be the actual erosivity impacting the soil surface. Table 15 summarizes the C factors on each field during the varying crop stages and levels of residue cover that occurred over the study period. The C factors on the conservation field ranged from 0.13 during the period of total corn canopy cover to 0.39 for the fallow period following fall tillage. The conventionally tilled field had higher C values throughout the study. The greatest C value was 0.69 and occurred during June, 1982 following the planting of field beans. At

Figure 8

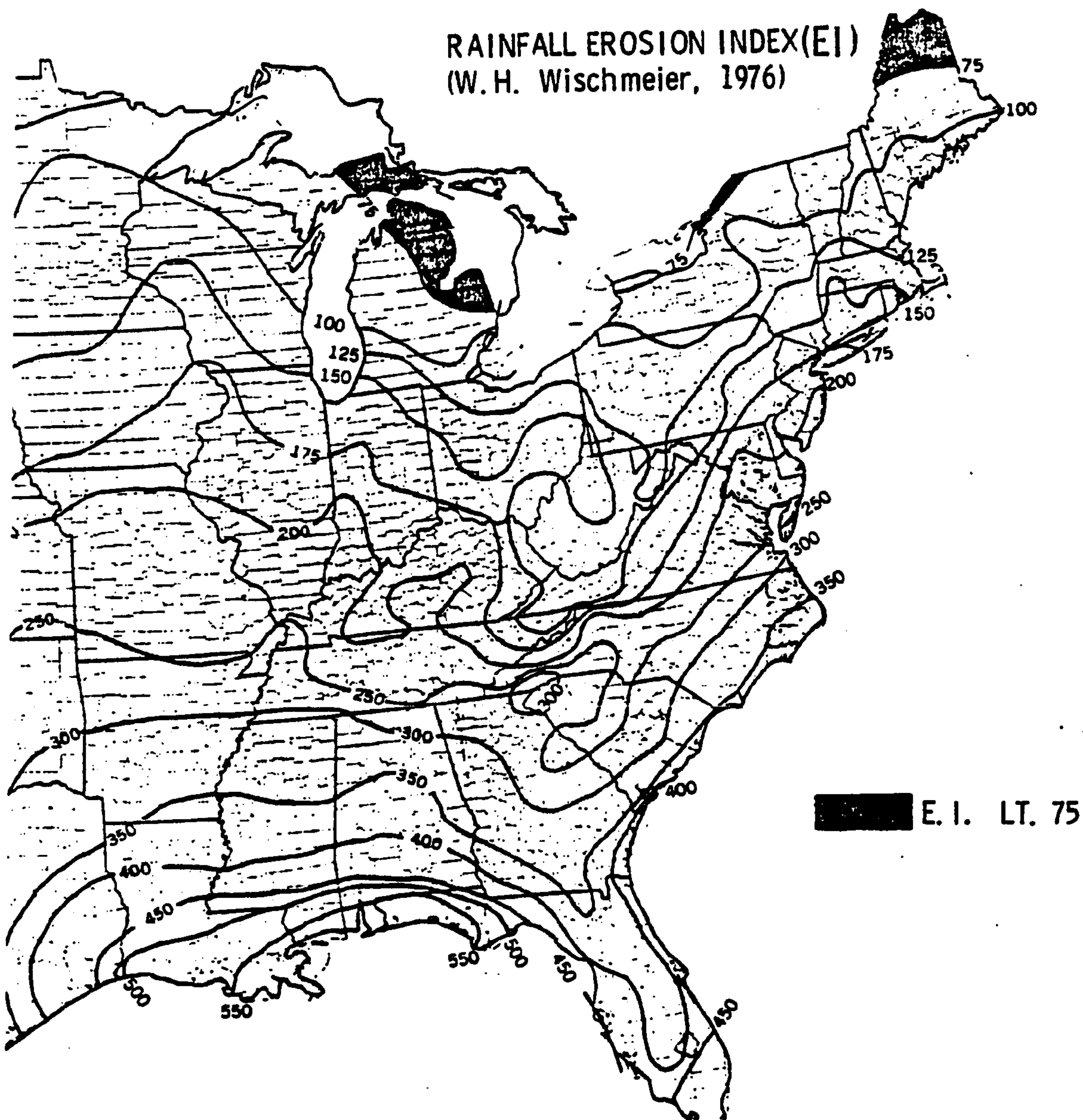

RAINFALL EROSION INDEX(EI)
(W.H. Wischmeier, 1976)
E. I. LT. 75
75
100
125
150
175
200
250
300
350
400
450
500
550

Table 15

Crop Stage, Crop Management Factor (C) and Residue Cover
Starky Farm, Tuscola County, Michigan

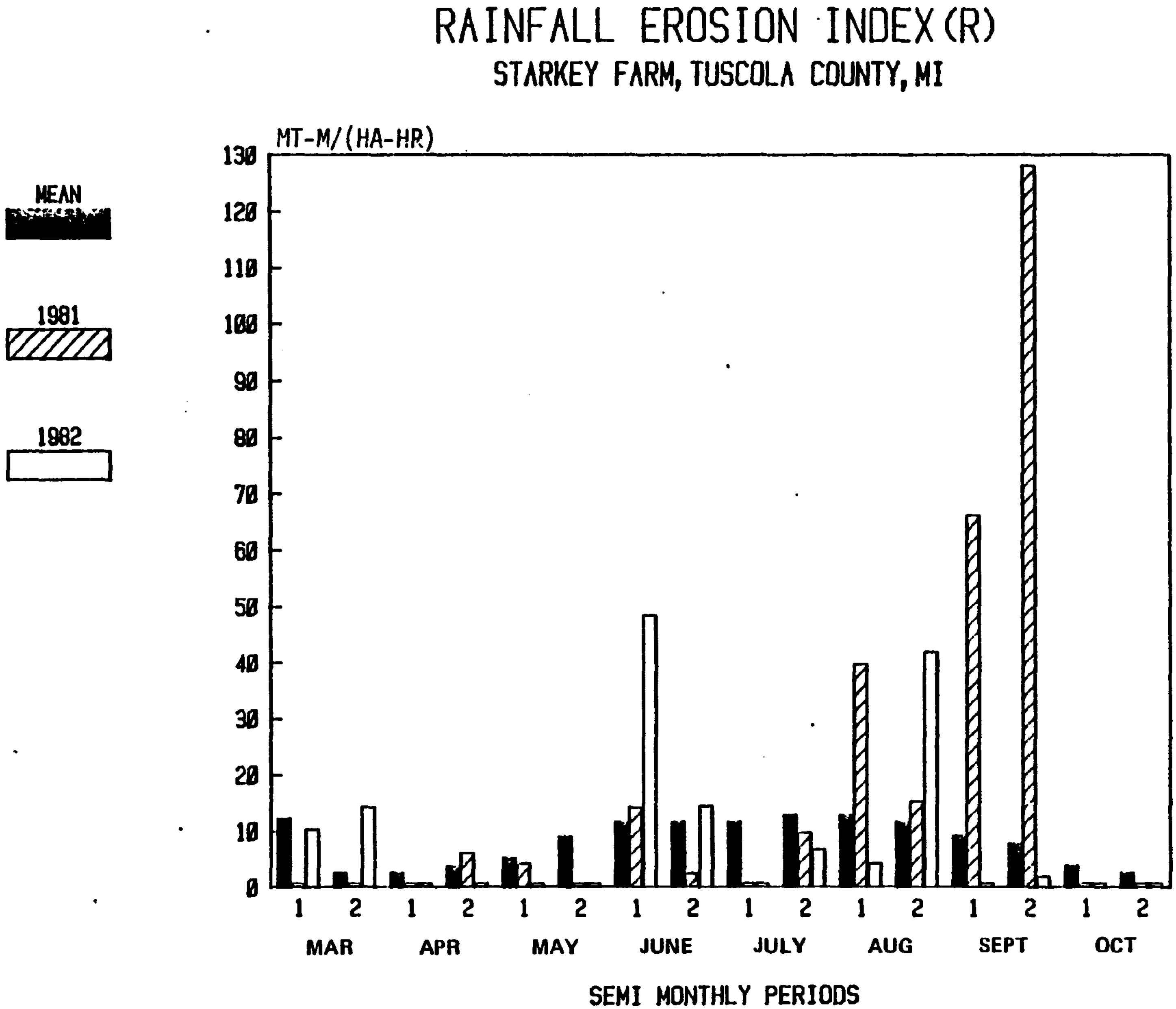
Date	Crop Stage	Residue Cover %	Residue Status kg/ha	C value At Midpoint of time interval	Residue Cover %	Residue Status kg/ha	C value at Midpoint of time interval
11/11/80-5/5/81	Corn F	58%	3500	0.31	10%	300	0.44
5/6-5/25/81	Corn SB	35%	2250	0.23	3%	300	0.65
5/26-6/15/81	Corn 1	35%	2250	0.215	3%	300	0.53
6/16/81-6/25/81	Corn 2	35%	2250	0.205	3%	300	0.38
6/25/81-7/1/81	Corn 3¦80	35%	2250	0.205	3%	300	0.32
7/2-7/9/81	Corn 3¦90	35%	2250	0.165	3%	300	0.26
7/10-11/1/81	Corn 3¦96	35%	2250	0.13	3%	300	0.20
11/2-11/10/81	Corn 4	>60%	>3500	0.31	3%	>3500	0.33
11/11/81-5/31/82	Corn F	56%	2300	0.39	10%	400	0.45
6/1-6/25/82	Beans SB	27%	1700	0.27	7%	400	0.69
6/26-7/15/82	Beans 1	27%	1700	0.25	7%	400	0.57
7/16-7/25/82	Beans 2	27%	1700	0.24	7%	400	0.38
7/26-7/31/82	Beans 3¦80	27%	1700	0.23	7%	400	0.29
8/1-8/7/82	Beans 3¦90	27%	1700	0.19	7%	400	0.20
8/8-9/25/82	Beans 3¦95	27%	1700	0.15	7%	400	0.17
9/26-10/8/82	Beans 4	27%	Not Obtained	0.39	7%	Not Obtained	0.38

Crop Stage Abbreviations: F: Fallow period; SB: Seed Bed; 1: 10% canopy cover; 2: 50% canopy cover; 3¦80: 80% canopy cover; 3¦90: 90% canopy cover; 3¦95: 95% canopy cover; 4: Harvest to Tillage this same period, the C factor on the conservation tilled field was only 0.27 due to the corn residue left by the fall chiseling. The potential erosivity resulting from a storm at this period was 2.5 times greater from the conventionally tilled field than the conservation tilled field.

Crop species strongly affected the maximum C factor of the conventional field during June. From June 15 through June 25, 1982 field beans were at the seedbed stage providing less than a 10% canopy cover over the soil for a C factor of 0.67. During the same period in 1981 the conventional field was planted to corn which provided a 50-80% canopy yielding a C value of 0.38. The potential raindrop erosivity on the conventionally tilled corn in mid June, 1981 was approximately one-half that which existed during the same period on the conventionally tilled field beans in 1982.

Figure 9 depicts the semimonthly magnitude of the rainfall erosion index (R) that occurred in 1981, 1982, as well as the long term expected value. The greatest variations from the projected norm occurred during September, 1981 and June, 1982. The storms of September, 1981 resulted in a greater rainfall erosion index (194) than is expected for the year (130 MT-m/(ha-hr)). For the 20 months of study 44% of the potential erosive force occurred during September, 1981. Sediment losses during that period were not as large as might be expected based on the storm erosivity. A mature corn canopy provided a total cover to the soil of both fields and intercepted most of the raindrop energy of the September, 1981 storms. The rainfall erosion index that actually impacted the soil surface during the month was 25.2 on the conservation field and 38.8 on the conventional field well below the 190 MT-m/(ha-hr)

Figure 9


RAINFALL EROSION INDEX (R)
STARKEY FARM, TUSCOLA COUNTY, MI
MT-M/(HA-HR)
MEAN
1981
1982
130
120
110
100
90
80
70
60
50
40
30
20
10
0
1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2
MAR APR MAY JUNE JULY AUG SEPT OCT
SEMI MONTHLY PERIODS

that would have fallen on fallow ground.

Figures 10 and 11 display the actual erosive force that impacted the soil surface (R x C) during 1981 and 1982. The greatest R x C recorded during the study occurred during June, 1982. The conventional field had been planted to field beans on May 31, 1982 and afforded almost no cover to the soil. The storms of June, 1982 generated only 8% of the total runoff from the conventional field during the entire study period. However, 34% of all the sediment and 29% of all the total phosphorus lost from the conventional field were discharged during June, 1982.

The rainfall erosion index impacting the soil of the conservation field during June, 1982 was 20.3 MT-m/(ha-hr) less than one half of the erosive force that impacted the conventional field. Sediment and total P losses were minimal. Based on the results of September, 1981 and June, 1982 ,it appears that soil cover provided by either residue or crop canopy is capable of reducing soil loss on the study site.

6.5 Comparison of Edge-of-Field Losses

The total edge-of-field losses measured from each study field during the 20 months of observation is summarized in Table 16. The results of the statistical comparison tests of runoff losses from the two fields are given in Table 17. Table 18 displays the outcome of the statistical tests comparing the concentrations of constituents monitored in the subsurface tile and overland flow from each field.

Figure 10

RAINFALL EROSION INDEX

IMPACTING SOIL SURFACE(C*R)

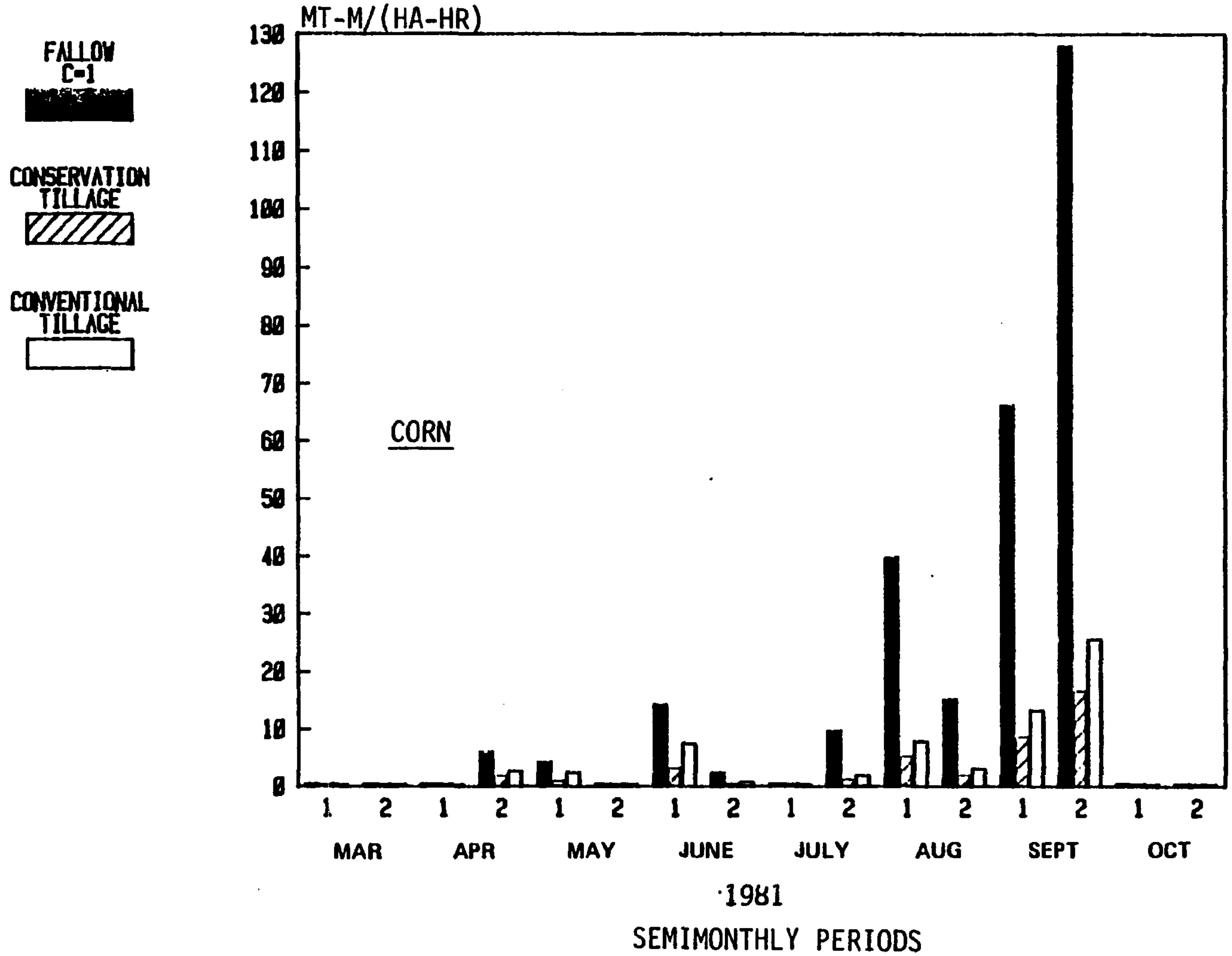
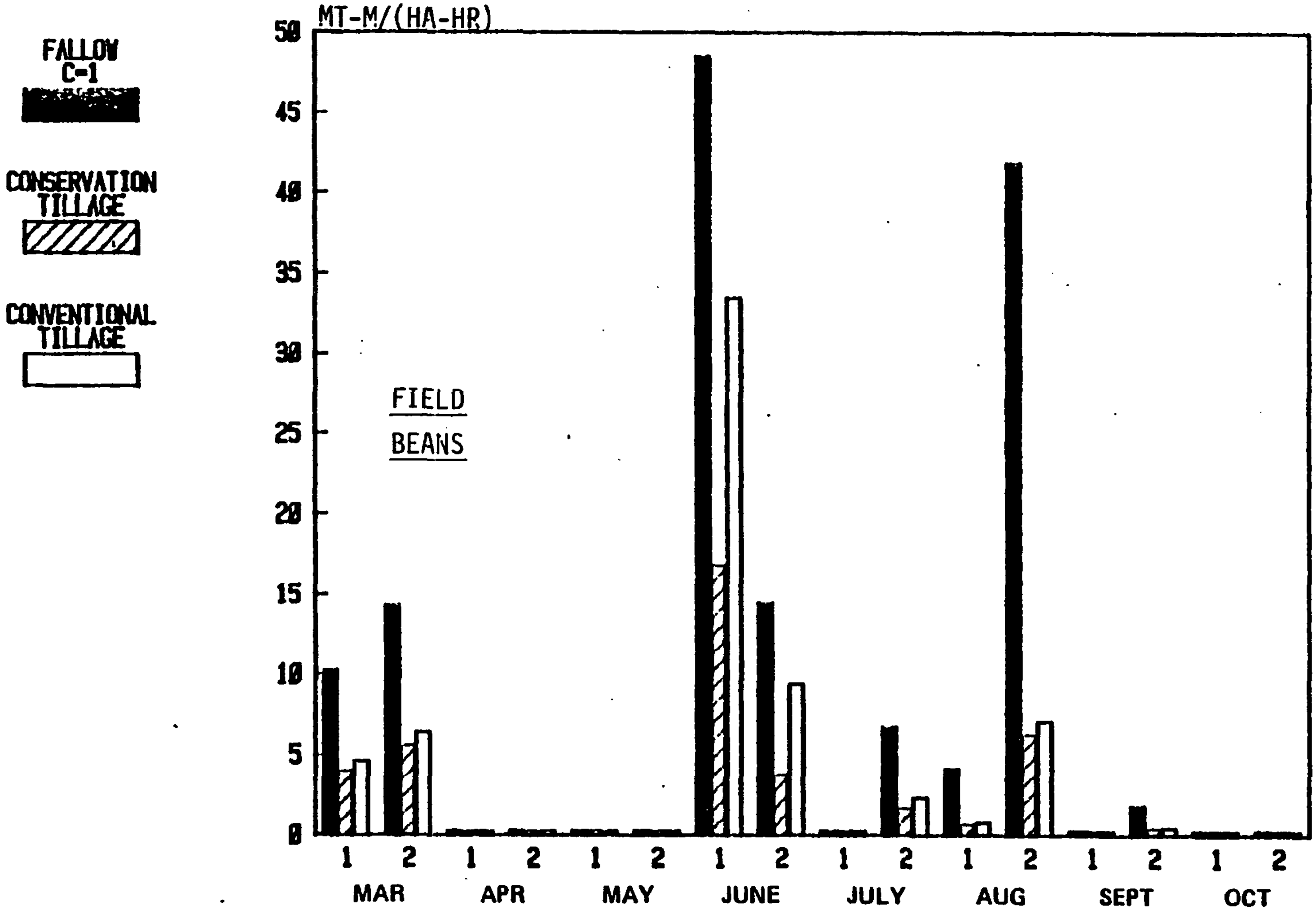


Figure 11

RAINFALL EROSION INDEX

IMPACTING SOIL SURFACE (C*R)



1982

SEMIMONTHLY PERIODS

Table 16

Edge of Field Losses
March 1, 1981-October 1, 1982 (kg/ha)

Conventional Tillage	Sediment	Total P	Soluble P	Ortho P	NO_3 N	TKN	Flow (M^3/ha)
Overland Flow	771.	0.958	0.506	0.416	7.5	5.0	1661.0
Tile Flow	57.	0.215	0.091	0.061	8.4	1.4	1367.0
Total From Field	828.	1.173	0.597	0.477	15.9	6.4	3028.

Conservation Tillage	Sediment	Total P	Soluble P	Ortho P	NO^3 N	TKN	Flow (M^3/ha)
Overland Flow	232.	0.480	0.292	0.204	5.0-18.4*	2.5	1354
Tile Flow	80.	0.347	0.187	0.143	10.6	1.7	1659
Total From Field	313.	0.827	0.479	0.347	15.6-29.0*	4.2	3013

*Suspected contamination 9/26/81 accounted for 14.7 kg/ha of this quantity

Table 17

Field Comparison
Tests for Differences
Using Wilcoxon Signed Rank Comparison

	All Events (kg/ha)	6 Large Events (kg/ha)	Only Overland Flow kg/ha	Overland Flow Mean Flow Weighted Concentration	Tile Flow Concentrations
Total Flow/Event	0	0	*	-	-
Overland Flow					
Tile Flow	*	*	-	-	
Total P	0	0	*	0	**
Soluble P	*	*	*	*	**
Ortho P		*	*	*	**
NO_3-N	0	0	*	0	0
TKN	0	0	*	0	0
Sus. Solids	0	0	0	0	0
Total Volatile Solids	0	0	0	0	0
pH	-	-	-	0	0

0: No significant difference at 95% level

*: Conventional field significantly higher than conservation field

**: Conventional field significantly lower than conservation field

-: Not applicable

Table 18

Subsurface Tile vs Overland Flow
Tests for Difference
Using Wilcoxon Sign Rank Comparison Test

	Conservation Field	Conventional Field
Flow/Event (M^3/ha)	**	*
Total P (mg/l)	0 (94% level)	*
Soluble P (mg/l)	*	*
Ortho P (mg/l)	*	*
No_3 -N (mg/l)	0	**
TKN (mg/l)	*	*
Suspended Solids (mg/l)	*	*
Volatile Solids (mg/l)	*	*

0: No significant difference

*: Overland runoff significantly greater than subsurface tile

**: Overland runoff significantly less than subsurface tile

6.6 Hydrologic Losses

The sum total of subsurface and surface flow from each field was nearly identical. The conventional field discharged 30.3 cm of water during the 11 hydrologic events compared to 30.1 cm of discharge from the conservation field for the same period (Table 16). Using a non parametric paired comparison test, no significant difference was found in the total amount of water exiting the fields during a runoff event (Table 17). Conservation tillage was expected to reduce runoff velocity and increase infiltration into the subsurface tile. In the six events where both overland and tile flow occurred a significantly higher proportion of the total flow was lost as overland flow from the conventional field than from the conservation field.

The tile drainage systems of both fields were capable of quickly removing most of the gravitational water within four days of precipitation. In both 1981 and 1982 tile flow began within three days of snowmelt runoff and rapidly drained each plot to field capacity. During the six weeks following snowmelt in both years of the study, no overland flow was generated on either field by precipitation events, although several events of 20-24 mm magnitude occurred. These results contrast with the observations of Aull (1980) on untiled fields of similar slope and soil type near Williamston, Michigan. Aull found that in the six week period immediately following snowmelt, the soil remained saturated and overland runoff was generated by precipitation events of low intensity and magnitude.

6.7 Sediment Loss

Over the entire study period the conventional field discharged 826 kg/ha of sediment; 2.6 times the quantity (313 kg/ha) which left the conservation field (Table 16). The residue cover associated with conservation tillage is expected to have the largest relative impact on sediment losses during events of high erosivity before a crop canopy is present. These conditions occurred only twice during the 20 months of study and generated the greatest difference in sediment loss from the two fields.

Although the total quantity of sediment losses from the conventional field were considerably greater than what exited the conservation field, non-parametric paired comparison tests did not demonstrate a significant difference between the two fields (Table 17). The non-parametric analysis was not able to demonstrate significant differences between the two fields even when the analysis was constrained to the six largest events. These events constituted 96% of the total sediment lost from the conventional field and 83% of the losses from the conservation field. Losses from these six events on the conventional field were 3.1 times larger than the losses from the conservation field during the corresponding events.

Snowmelt runoff (Event 7) accounted for the largest magnitude of sediment from each field, representing 50% of the total losses from the conventional field (413 kg/ha) and 42% (140 kg/ha) of the losses from the conservation field (Table 7). The mean flow weighted concentration of suspended solids in snowmelt runoff from the conventional field was 712 mg/l, (Table 10) near the EPA recommended limit of 800 mg/l. The conservation field had flow weighted concentrations of 328 mg/l suggesting that the residue reduced soil detachment and transport during snowmelt.

Except for the losses that occurred from the field on June 21, 1982 (Event 11), runoff generated by precipitation resulted in very low sediment loss. The intense storm of Event 11 occurred during the period when the conservation field was providing the greatest amount of cover to the soil relative to the conventional field that occurred during the entire study. The flow weighted mean concentrations of suspended solids in overland flow from the conventional field was 4900 mg/l (Table 10) well in excess of the recommended EPA standard. This small runoff event constituted 33% (273 kg/ha) of all the sediment lost from that field during the entire study. The conservation tilled field experienced no overland flow during Event 11 and lost a total of 6 kg/ha of sediment (Table 7).

The increased infiltration into the subsurface tile that occurred on the conservation field contributed to the comparative reduction in sediment loss that was observed. Based on the Wilcoxon signed rank test (Table 18) tile flows from both fields had significantly lower flow weighted mean concentrations of suspended solids than overland flow. Any practice that reduced overland flow on the fields could be expected to reduce the net loss of sediment.

The magnitude of soil loss from both fields is within the standards set by the USDA-SCS (1980) to sustain long term agronomic yields. The maximum average annual rate of erosion that can occur without affecting crop productivity on the study field has been determined to be 11,000 kg/ha (Linsemeir, 1980). Over the two seasons of study the conventional field lost 7% of this quantity while the conservation field lost 3%.

From an agronomic perspective the magnitude of sediment loss from both fields appears to be very low.

6.8 Phosphorus Losses

Losses of total, soluble, and ortho phosphorus from the conventional field exceeded the losses of those constituents from the conservation field during the two seasons of study. Conservation tillage can reduce the magnitude of potentially large erosion events as well as increase infiltration of runoff waters into the subsurface tile waters. Sediment reduction and increased infiltration can both reduce losses of phosphorus. Using non parametric procedures significantly less soluble and ortho phosphorus was lost from the conservation field than from the conventional field (Table 17).

The greatest difference in total phosphorus losses resulted from event 11 when high concentrations of sediment were discharged by the conventional field. In this event 0.335 kg/ha of total phosphorus exited the conventional field compared to 0.027 kg/ha from the conservation field (Table 8). Sediment bound phosphorus constituted 89% of the total phosphorus lost from the conventional site during Event 11. Although the event contributed almost one third of all the total phosphorus from the conventional site during the study, the soluble phosphorus losses were not exceptional and represented only 6% of the total quantity discharged.

With the exception of Event 11 large phosphorus losses were not generally associated with sediment losses. Over the entire study period soluble phosphorus constituted 58% and 51% of the total phosphorus losses from the conservation and conventional fields, respectively. The high levels of available P measured in the surface soil may be responsible for the unusually high ratio of soluble P to sediment bound P observed. Considerable phosphorus moved off both fields during events 3 and 5 (Table 8) when sediment losses were minor (< 60 kg/ha) and flow weighted mean concentrations of suspended solids were less than 100 mg/l in both overland and tile flow.

Event 3, which occurred immediately after fertilization and planting resulted in the highest concentrations of soluble phosphorus that occurred on either field during the study. The flow weighted concentrations of soluble and total phosphorus that resulted from Event 5 were near the median levels for all 11 events, however,the unusually large flow volume of that event generated high phosphorus losses from both fields.

A strong trend was found to exist between soluble phosphorus concentrations in overland flow and the period of time that had passed since fertilization. Soluble phosphorus concentrations in overland flow were highest after planting and declined steadily with time. The phosphorus losses during snowmelt had lower concentrations of soluble phosphorus than almost all of the overland events that occurred during growing season (Table 10).

Practices which minimize overland flow after fertilization appear to be one approach to minimizing soluble phosphorus losses. Sediment control did not appreciably lower soluble phosphorus losses. Rather, the movement of drainage waters into the subsurface tile was the dominant factor in reducing phosphorus concentrations and losses on both fields.

Using the Wilcoxon signed rank test concentrations of soluble and ortho phosphorus in the tile flow on each field was significantly lower than the concentrations that occurred in the overland flow (Table 18). Total phosphorus concentrations in the tile flow of the conventional field were significantly lower than in the overland flow and significant differences at the 94% level were found between tile and overland flow concentrations on the conservation field.

The phosphorus concentrations observed in the tile drainage water may have resulted from the adsorption of soluble phosphorus by the subsurface soil. The study plots had consistently received large amounts of phosphate fertilizer, a common practice in Michigan, and had more than 110 kg/ha of available phosphorus in the surface layer (0-30 cm) of soil. In contrast the subsurface soils had less than 10 kg/ha of available phosphors and could be expected to adsorb large amounts of soluble phosphorus from the percolating water.

6.9 Nitrogen Losses

Most of the nitrogen which was discharged from both fields was in the form of soluble nitrate-N, representing 71% and 87% of the nitrogen losses from the conventional and conservation fields, respectively (Table 17). As expected, losses of nitrate-N were not associated with large sediment losses. With the exception of Event 5, where sample contamination was suspected, the greatest losses and highest concentrations of nitrate-N from both fields occurred during Event 3, which followed fertilization in May 1981 (Table 9). This event was the only instance were flow weighted mean concentrations in both overland and subsurface flow were above the Michigan Public Health standard of 10 mg/l (Table 10).

Subsurface tile flow on the conventional field had significantly higher concentrations of nitrate-N than overland flow, based on non parametric tests (Table 19). Concentrations of nitrate-N in the tile flow from the conservation field exceeded the concentrations in overland flow during four of the five events where surface and subsurface flow occurred together. Increasing infiltration to subsurface tile through conservation tillage practices may result in higher nitrate-N losses from conservation tilled fields than from conventionally tilled fields.

With the exception of Event 5 where contamination is suspected, differences in the flow weighted mean concentrations of nitrate nitrogen from the two tillage systems never exceeded 3.0 mg/l for any single event. Using both the upper and lower estimates of nitrate nitrogen concentrations in the conservation tillage runoff sample of Event 5, no significant difference was found in the nitrate N losses from the two fields with non parametric tests (Table 17). The variation in nitrate-N losses during all 11 events was much more uniform than the pattern exhibited by phosphorus and sediment losses. Concentrations ranged from 2.7-20.0 mg/l during the study (Table 10). Nitrate-N concentrations exceeded 10 mg/l, the drinking standard in Michigan, on both fields during the first three tile events in Spring, 1981. Two of those events occurred before planting and fertilization. Throughout the following 16 months the concentration in the tile never exceeded 7 mg/l. Anhydrous ammonia was applied to the soil in Fall, 1980 and may account for the elevated nitrate-N concentrations the following spring.

Losses of TKN were associated with fertilization as well as large sediment movement from the fields. During Event 3 which followed fertilization in 1981, sediment concentrations in the overland runoff waters of both fields were very low, but concentrations of TKN were among the highest measured during the study (Table 10). One hundred and sixty eight kg/ha of anhydrous ammonia was applied to both fields four days previous to the event and some of the ammonia may not have been strongly adsorbed to the soil when the event occurred. With the exception of the event just described the greatest concentrations of TKN were associated with large movements of sediment. This trend was especially pronounced during snowmelt runoff and the overland flow of June 21, 1982. No significant difference was found in the quantity of TKN lost from the two fields using non parametric tests. For the entire period of study, however, the conventional field lost 1.5 times more TKN than the conservation field.

The increased infiltration to the tile on the conservation field was a major cause of the lower TKN losses observed. Using non parametric tests the concentrations of TKN in subsurface flow was significantly lower than in overland flow from the conventional field. In 4 of the 5 events where overland runoff and tile flow occurred from the conservation field overland flow had higher concentrations of TKN than the tile drainage waters. Over the entire study the flow weighted mean concentrations of TKN in tile flow from the conventional and conservation fields were 1.04 and 1.05 mg/l vs concentrations of 2.97 and 1.88 mg/l in the overland flow of each field respectively.

Controlling losses of sediment laden water could be expected to reduce TKN losses. However, since nitrate-N is the principal source of nitrogen discharged from the fields, sediment control measures such as conservation tillage should not be expected to markedly lower nitrogen losses from croplands in the study region. Other control measures such as fertilizer management should be investigated if nitrogen losses become a serious concern in the Saginaw Bay drainage basin.

CHAPTER 7

ANALYSIS OF LONGTERM CLIMATIC CONDITIONS

7.1 Overview

Conservation tillage can be expected to have the greatest relative effect on water borne edge-of-field losses when no crop canopy is present. From fall tillage until crop cover is established the surface residue that remains following conservation tillage can reduce soil detachment and increase infiltration relative to conventionally tilled sites. During this period, large differences in edge of field losses from conservation and conventional tillage systems will most likely be generated by storms that cause overland runoff, particularly by high intensity storms that are capable of considerable sediment transport.

Controlling phosphorus losses from the croplands of the study region was one of the major motivations for testing conservation tillage as a best management practice. The results of the field monitoring program suggest that major losses of phosphorus and sediment are not always generated together. Precipitation events which do result in large movements of sediment may also discharge considerable phosphorus from a field. However overland flow events appear likely to carry substantial quantities of phosphorus regardless of their sediment load.

Conclusions drawn from the field results must be tempered by both the brevity of the study and an appreciation for the large variations inherent in weather driven processes. The appropriateness of conservation tillage as a nutrient control practice will depend on the longterm weather patterns that exist in the study region. If high intensity events capable of generating erosion are a typical phenomenon then conservation tillage can be expected to dramatically reduce sediment and phosphorus losses in the study regions. However, if most overland flow results from low intensity storms, practices that reduce soil detachment such as conservation tillage may not be the most appropriate management strategy. Instead, management practices that specifically improve infiltration should be considered.

To determine the comparative effectiveness of conservation tillage for reducing edge of field losses, an analysis of longterm weather patterns was performed. The analysis provides the probability of occurrence of specific conditions that may result in overland flow regardless of sediment load and the probability of occurrence of potentially erosive events. No attempt was made to specifically predict the actual losses associated with a given event.

The field results demonstrated that crop stage will influence the level of nutrient and sediment losses that result from a given hydrologic event. The analysis that follows considers the crop stage of field beans and corn for prediciting monthly frequencies of overland runoff and erosion. The results are intended to identify the periods during the year when runoff or erosion is likely on conventionally tilled ground. Specific management practices can then be tailored to create effective control practices for the conditions that would be most likely to produce the greatest edge of field losses.

7.2 Probability of Occurrence of Overland Flow Events

Storm magnitude and antecedent moisture were utilized to predict the monthly probability of overland flow in the study region. In the Soil Conservation Service model of runoff volume (Mockus, 1973) runoff is predicted whenever the volume of a precipitation event exceeds a quantity known as the "initial abstraction" (Ia). The initial abstraction represents the hydrologic losses resulting from interception, surface storage, and infiltration prior to runoff. The initial abstraction is based on the SCS runoff curve number for a given site, a function of soil type, antecedent soil moisture, and retention storage. Table 19 lists the minimum quantity of precipitation that is required by the model to generate overland flow at each antecedent moisture level.

Table 19

Precipitation Volume Required

to Generate Overland Flow (Curve Number: 75)

AMC	Precipitation (mm)
I	38.
II	17.
III	7.

When precipitation is exactly equal to the quantities listed in Table 19 only traces of overland flow are predicted. In the probability analysis of overland runoff events, precipitation volumes were selected that would generate a tangible runoff volume at each AMC level. For each antecedent moisture condition the precipitation magnitudes listed in Table 20 are expected to generate slightly less than a millimeter of runoff. The same precipitation depths for each AMC level are used during the growing season and dormant season for AMC II and AMC I, however, the results of the field study showed that in the summer growing season very large storms may not be capable of generating overland flow. The storm magnitude required to generate overland flow during AMC I conditions was set at a higher level in the summer than in the dormant season.

Table 20

Minimum Precipitation Required to Generate
Overland Flow of Measurable Magnitude

AMC	Precipitation (mm)
I	50.8 (dormant season)
I	60.0 (growing season)
II	25.4
III	12.7

For discussion purposes moderate magnitude storms (SM) are designated as precipitation events that will generate overland flow only at AMC III and range from 12.7-25.4 mm. Large storms (SL) are those events that will cause runofff if the soil moisture is at AMC II or AMC III. Storms that can result in overland flow at any soil moisture content are classified as extraordinary storm events (SLL).

From the hydrologic frequency analysis performed, Table 21 and Figure 12 depict the expected magnitude of 2, 5, and 10 year storms occurring during each month for March through October in the study region. The highest frequency for large storms occurs during the summer months, from June through September. The expected return period for extraordinary storms capable of producing overland flow at any antecedent soil moisture level (SLL) ranges from 67 years in March to 10 years during July and September.

Table 21

Hydrologic Frequency Analysis: 24 Hour Storm Predictions
Caro, Michigan Records 1950-1980
Based on Extreme Value Series, Log Normal Distribution

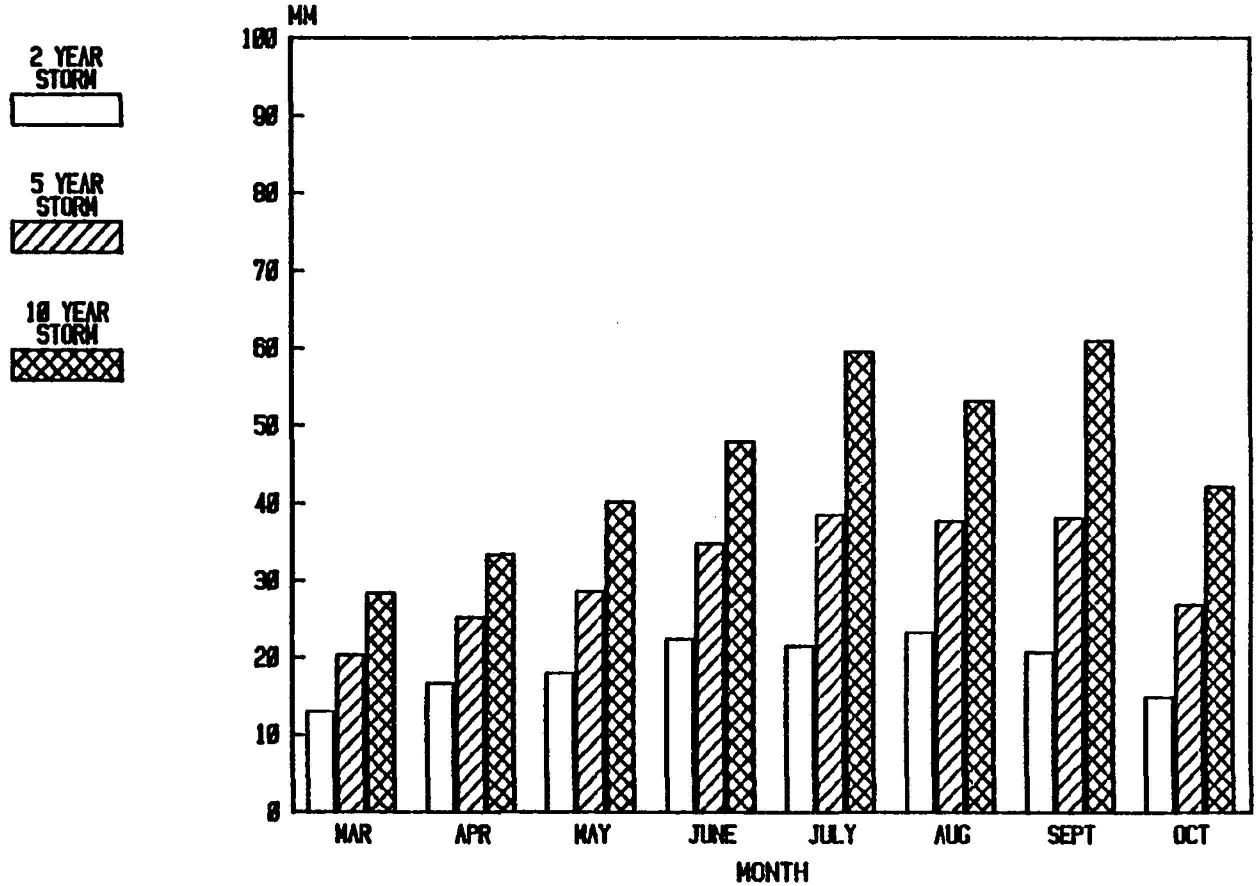
	(mm) Mean	(mm) Std Dev	Expected Magnitude (mm) T = 2	T = 5	T = 10	P(X ≥ 12.7mm)	P(X ≥ 25.4mm)
Annual	46.4	1.34	45.6	59.3	70.4	>.99	0.98
Seasonal:							
Spring (March-May)	24.5	1.36	24.1	31.5	37.8	0.99	0.44
Summer (June-Sept)	44.3	1.36	43.6	57.0	68.0	>.99	0.98
Monthly:							
March	13.7	1.65	13.0	20.3	28.4	0.56	0.13
April	17.4	1.59	16.7	25.2	33.4	0.75	0.20
May	18.9	1.69	18.0	28.6	40.2	0.74	0.30
June	23.6	1.63	22.4	34.8	47.9	0.90	0.42
July	23.1	1.91	21.5	38.5	59.5	0.82	0.42
August	24.6	1.70	23.3	37.6	53.1	0.89	0.45
September	22.3	1.99	20.7	38.1	60.9	0.79	0.40
October	16.1	1.93	14.9	26.8	42.1	0.60	0.24

T: Return period (years)

Figure 12

24 HOUR 2,5 AND 10 YEAR STORM

CARO, MICHIGAN



The expected return period of large magnitude storms (SL) ranged from 2.4 - 9.0 years. The month of June had the highest probability for large storms. March had the smallest probability (Table 22). For a large storm to generate overland flow, the antecedent soil moisture must be equal to or greater than normal conditions (AMC II or AMCIII). The conditional probability of AMC II or AMC III existing when a large storm occurred was greatest during May, April, and July representing 0.43, 0.38, and 0.27 of all the occurrences of large storms during those respective months. August had the lowest conditional probability of AMC II or AMC III occurring with large storms.

The probability of a large storm generating overland flow is represented by the intersection of the storm occurrence and AMC conditions greater than or equal to AMC II (Table 22). May was found to have the greatest probability of runoff events generated by large storms followed by June and July. During other times of the year overland flow resulting from large storms is restricted by the low frequency of those events or by the lack of sufficient soil moisture when an event occurs.

The probability of occurrence for storm of moderate magnitude (SM) was comparable during all the months of interest. The expected return period for a moderate storm ranged from 1.8 to 2.8 years (Table 23). The conditional probability of nearly saturated soil existing when a moderate storm occurred varied widely between months. May, April, and October had the greatest probabilities for saturated soil when a moderate magnitude storm occurred with conditional probabilities of 0.214, 0.150, and 0.147, respectively. From June through September the

Table 22

Probability of Large Storms
Occurring with AMC 2 or AMC 3

Month	P(SL)	P(AMC 2¦SL)	P(AMC 3¦SL)	P(SL x AMC ≥ 2)
March	0.115	0.000	0.200	0.023
April	0.177	0.250	0.125	0.066
May	0.254	0.285	0.143	0.109
June (corn)	0.376	0.111	0.111	0.083
June (beans)	0.42	0.111	0.111	0.083
July	0.322	0.091	0.182	0.088
August	0.385	0.050	0.000	0.019
September	0.300	0.136	0.045	0.054
October	0.182	0.076	0.076	0.028

P(SL): Probability of a large storm (SL) occurring in a given period

P(AMC(I)¦SL): Conditional probability of soil antecedent moisture condition 2 or 3 existing when a large storm occurs

P(SL x AMC ≥ 2): Probability of a large storm occurring when soil antecedent moisture is greater than or equal to AMC 2

$$P(SL \times AMC > 2) = P(SL) \times [P(AMC\ 2 | SL) + P(AMC\ 3 | SL)]$$

AMC 2: Average soil moisture conditions that produce runoff

AMC 3: Near saturated soil moisture (Mockus, 1971)

Table 23

Probability of Moderate Magnitude
Storms Occurring at High
Antecedent Moisture Conditions

Month	P(SM)	P(AMC 3¦SM)	P(SM x AMC 3)
March	0.43	0.028	0.012
April	0.55	0.150	0.083
May	0.44	0.214	0.094
June (corn)	0.48	0	0
June (beans)	0.48	0.050	0.24
July	0.40	0.053	0.021
August	0.44	0.024	0.011
September	0.39	0.034	0.013
October	0.36	0.147	0.053

P(SM): Probability of a 24 hour storm of moderate magnitude (SM) than is greater than or equal to 12.7 mm and less than 25.4 mm during a given period

P(AMC 3¦SM): Conditional probability that a high antededent soil moisture conditions exists when a moderate magnitude storm (SM) occurs

P(SM x AMC 3): Probability of a moderate magnitude storm occurring at high antecedent soil moisture conditions (AMC 3) conditional probability of having AMC III when a moderate storm occurred dropped to a range of 0.0 - 0.053. The consistent and relatively lower P(AMC 3|SM) found for the summer months contrasts with the pattern found for large storms where July had the second highest occurrence of AMC 3 when a large storm occurred. It appears that the 5 day antecedent precipitation pattern is dependent on storm magnitude during certain months and more precipitation can be expected before a large storm than in advance of a moderate magnitude storm.

Table 24 gives the monthly probabilty of the occurrence of overland flow events. The analysis predicts that overland runoff events will have a 20 year return interval during the month of March. However, snowmelt often occurs during March causing extended periods of saturated soil conditions. Soil moisture predictions cannot therefore be based soley on 5 day antecedent precipitation during March. The overland runoff probabilities predicted for the month of March are certain to underestimate the actual conditions. No attempt was made to model the likelihood of runoff from snowmelt; however, during both both 1981 and 1982 minor storms in conjunction with snowmelt generated overland flow from both study sites.

May was found to have the greatest probability for an overland runoff event. The expected return period for overland flow during May was 4 years. Most of the events are expected to result from the occurrence of moderate or large magnitude storms when the soil moisture is above field capacity. Storms of extraordinary magnitude that can generate runoff during periods of low antecedent soil moisture account for approximately 18% of all the expected events in May. The runoff

Table 24

Probability of Overland Runoff Events

Month	P(SM x AMC 3)	P(SL x AMC ≥ 2)	P(SLL)	P(RO)
March	0.012	0.023	0.015	0.050
April	0.083	0.066	0.023	0.166
May	0.094	0.109	0.046	0.249
June (corn)	0.0	0.083	0.044	0.127
June (field beans)	0.024	0.083	0.062	0.169
July	0.021	0.088	0.098	0.207
August	0.011	0.019	0.065	0.095
September	0.013	0.054	0.100	0.167
October	0.053	0.028	0.058	0.139

P(SM x AMC 3): Probability of a 24 hour storm greater than or equal to 12.7 mm and less than 25.4 mm (SM) occurring during soil moisture condition AMC 3

P(SL x AMC ≥ 2): Probability of a 24 hour storm greater than 25.4 mm and less than SLL occurring at soil moisture greater than or equal to AMC 2

P(RO): Probability of a storm occurring that is likely to produce overland runoff

P(SLL): Probability of a 24 hour storm of extraordinary magnitude occurring. During dormant season SLL ≥ 50.8 mm. During the growing SLL ≥ 60 mm.

event of May 10, 1981 resulted from such an extraordinary storm when the soil was at AMC I. Runoff events in May can be expected to generate more nutrient losses from sites planted to corn than from sites in field beans. Corn is planted and fertilized during the first week of May, while field beans are not planted till June, and flow events that occur soon after fertilization appear to carry high concentrations of nutrients.

Most of the runoff that may occur during September is expected to result from very large storms. Precipitation events of extraordinary magnitude account for two thirds of all the runoff events during September. The large storms monitored in 1981, although unusual, are not to be considered as freak occurrences. However, since a mature crop canopy is present throughout most of September, sediment loss can be expected to be low from these storms regardless of storm intensity or the type of fall tillage employed.

During June, sites planted to field beans are expected to have a greater likelihood for overland flow than sites planted to corn. The field bean sites are dormant for the first portion of June and require less antecedent precipitation to generate saturated soil conditions and overland flow. During June, the frequency of overland runoff from corn sites is expected to be 0.127 compared to 0.169 for field beans. Events occurring immediately after field bean seeding may carry elevated nutrient concentrations as a results of recent fertilizer application.

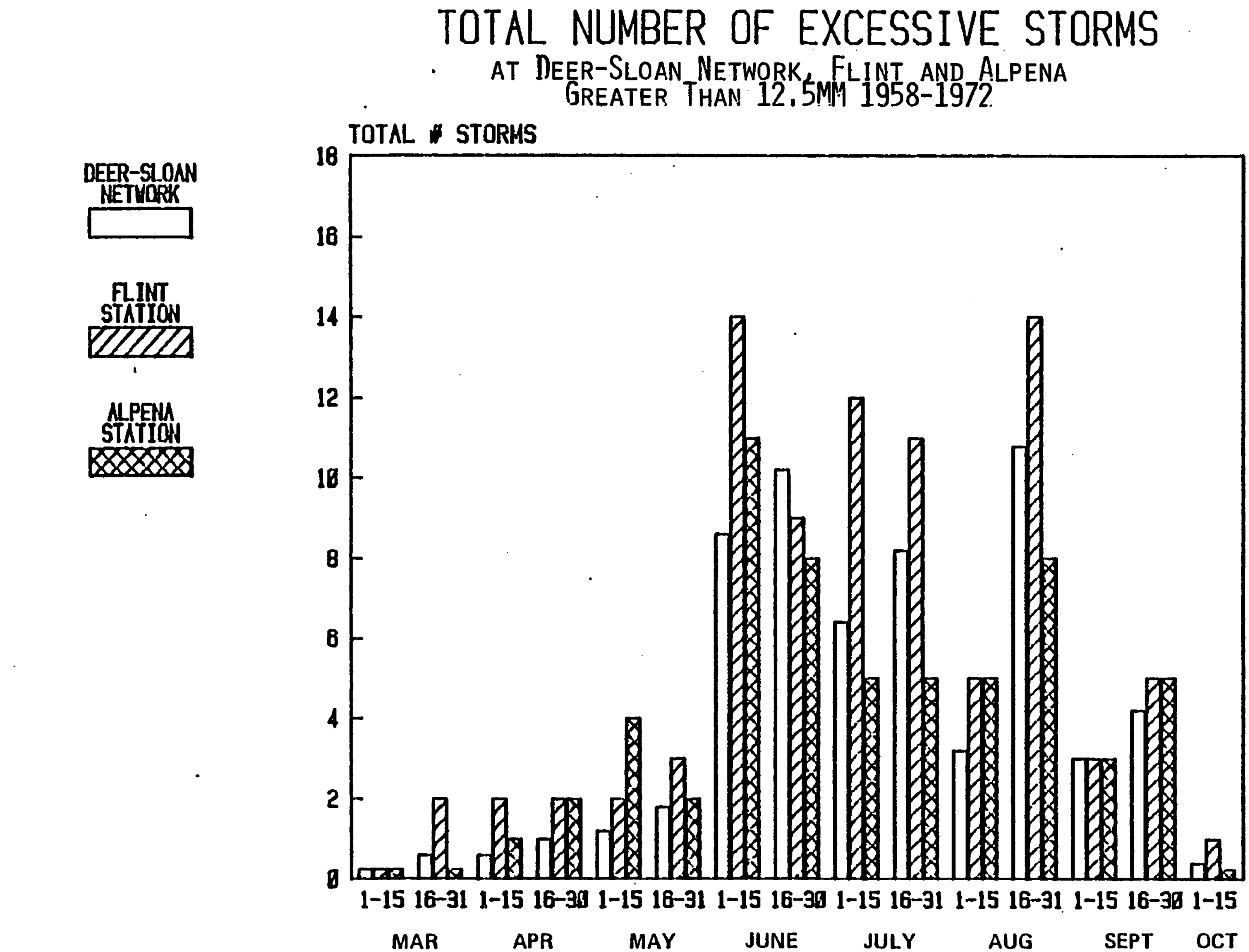
In the two years of monitoring no overland runoff events occurred during July. The probability analysis predicts that overland flow events during July will have a 5 year return period, the second highest frequency of occurrence for any month. One half of those events are expected to be generated by storms of extraordinary magnitude. Large storms occurring with high AMC account for almost all the rest of the runoff events. During the study the largest storm that occurred in July was 26.7 mm and fell when the soil was at AMC I.

7.3 Probability of Occurrence of Erosive Events

Erosive events are often generated by high intensity storms. Records of intense precipitation have been published by the National Climatic Center (formerly United States Weather Bureau) since 1895 (Schwab, et al, 1981). Storms are classified as excessive rate storms if the amount of rainfall in millimeters exceeds (5. + 0.25t) where t is the duration in minutes. The analysis of excessive rate storms was limited to storms with a minimum magnitude of 12.7 mm since smaller events are unlikely to cause discharge of overland flow from a field.

The distribution of excessive rate storms appears to be very similar at the Deer Sloan gage network of Ingham County, the Flint Weather Station, and the Alpena Weather Station. The total number of excessive rate storms that occurred during each semimonthly period from 1958-1972 at these locations are depicted in Figure 13. Excessive rate storms appear to be an infrequent phenomenon from March through May at all the recording stations. At each station a dramatic rise in the incidence of excessive rate storms occurs during June. The months of June-August experience four to five times the number of excessive rate storms that occur from March through May. The study region is located within the region spanned by these stations and is expected to have a similar semimonthly distribution pattern of excessive rate storms.

Figure 13


TOTAL NUMBER OF EXCESSIVE STORMS
AT DEER-SLOAN NETWORK, FLINT AND ALPENA
GREATER THAN 12.5MM 1958-1972
TOTAL # STORMS
DEER-SLOAN NETWORK
FLINT STATION
ALPENA STATION
0
2
4
6
8
10
12
14
16
18
1-15 16-31 1-15 16-30 1-15 16-31 1-15 16-30 1-15 16-31 1-15 16-31 1-15 16-30 1-15
MAR
APR
MAY
JUNE
JULY
AUG
SEPT
OCT

Excessive rate storms that occur before a crop canopy is established can generate considerable soil detachment and transport from a field. After July the crop canopy will dissipate most of the energy in a high intensity storm, thereby reducing the likelihood of an erosive event. The excessive rate storm of September 26, 1981 caused little sediment loss although its intensity and volume were of an extraordinary magnitude.

A high intensity storm that causes soil detachment will not generate edge of field losses unless overland runoff occurs. An analysis of the probable antecedent moisture conditions present when an excessive rate storm occurs is summarized in Table 25. Although high intensity storms can be expected to generate runoff at lower soil moisture levels than a low intensity storm of the same magnitude, Mockus (1973) does not consider storm intensity in his preditive model of runoff volume. The same minimum precipitation volumes at each AMC condition were used to compute the probability of overland flow regardless of storm intensity.

Table 26 gives the monthly probability of erosive events in the study region. Few high intensity storms occur in the period from November through May when cropland is in the fallow stage and has no protective crop canopy. Erosive events during this period should have a low probability of occurrence even on conventionally tilled sites. The analysis shows that virtually all of the overland flow events that occur during May are the result of low intensity storms and little sediment movement should be expected from any management practice. During

Table 25

A. Probability of a Large Excessive Rate Storm Occurring with Soil Antecednet Moisture Condition AMC 2 or AMC 3

Month	P(XL)	P(AMC 2¦XL)	P(AMC 3¦XL)	P(XL x AMC $\geq$ 2)
April	0.05	0.33	0	0.017
May	0.05	0	0	0
June*	0.23	0.1	0.2	0.069
July	0.20	0.33	0	0.067

B. Probability of a Moderate Magnitude Excessive Rate Storm Occurring with Soil Moisture Condition AMC 3

Month	P(XM)	P(AMC 3¦XM)	P(XM x AMC 3)
April	0.08	0.375	0.03
May	0.05	0.091	LT .01
June (corn)	0.20	0.083	0.017
June (beans)	0.20	0.125	0.025
July	0.14	0	0

XL: Excessive rate storm greater than of equal to 25.4 mm

XM: Excessive rate storm greater than or equal to 12.7 mm and less than 25.4 mm

*No difference found between field beans and corn

Table 26

Probability of Storms
Likely Generate Overland Flow and Erosion

Month	P(XM x AMC 3)	P(XL x AMC ≥ 2)	P(EE)
April	0.030	0.017	0.047
May	LT 0.01	0.0	LT 0.01
June (corn)	0.017	0.069	0.086
June (field beans)	0.025	0.069	0.094
July	0	0.067	0.067

EE: Precipitation event likely to generate erosion on fallow grond

April,the occurrence of overland flow from excessive rate storms is expected to have a 20 year return interval.

June was found to have the greatest likelihood for generating erosion and sediment loss. Based on antecedent moisture conditions, overland flow from excessive storms is more likely with field beans than with corn crops. The more mature corn crop will withdraw more soil moisture than field beans.

In the study region sites planted to corn are expected to have a 25% crop canopy on June 1 and a 50% cover by June 16. Sites planted to field beans have less than a 10% canopy cover during most of June. Figures 14 and 15 contrast the monthly probability of excessive rate storms to the Crop Management Factor (C) for conservation and conventionally tilled field beans and corn. Soil detachment from excessive rate storms should be minimized on corn sites by the crop canopy regardless of residue cover. Sites planted to field beans following corn should be expected to benefit from conservation tillage since the residue will protect the soil during the high intensity June storms. Conventionally tilled field bean sites can be expected to experience soil detachment and sediment movement much more frequently than conservation tillage sites during June.

Based on the analysis, the spring months are expected to have infrequent occurrences of erosive events. The analysis shows that excessive rate storms account for virtually none of the overland flow events that are expected during May, the month predicted to have the greatest frequency of overland flow. During April,the occurrence of overland flow from excessive rate storms is expected to have a 20 year

Figure 14

EXCESSIVE RATE STORM PROBABILITY
VS. CROP MANAGEMENT FACTOR (C)

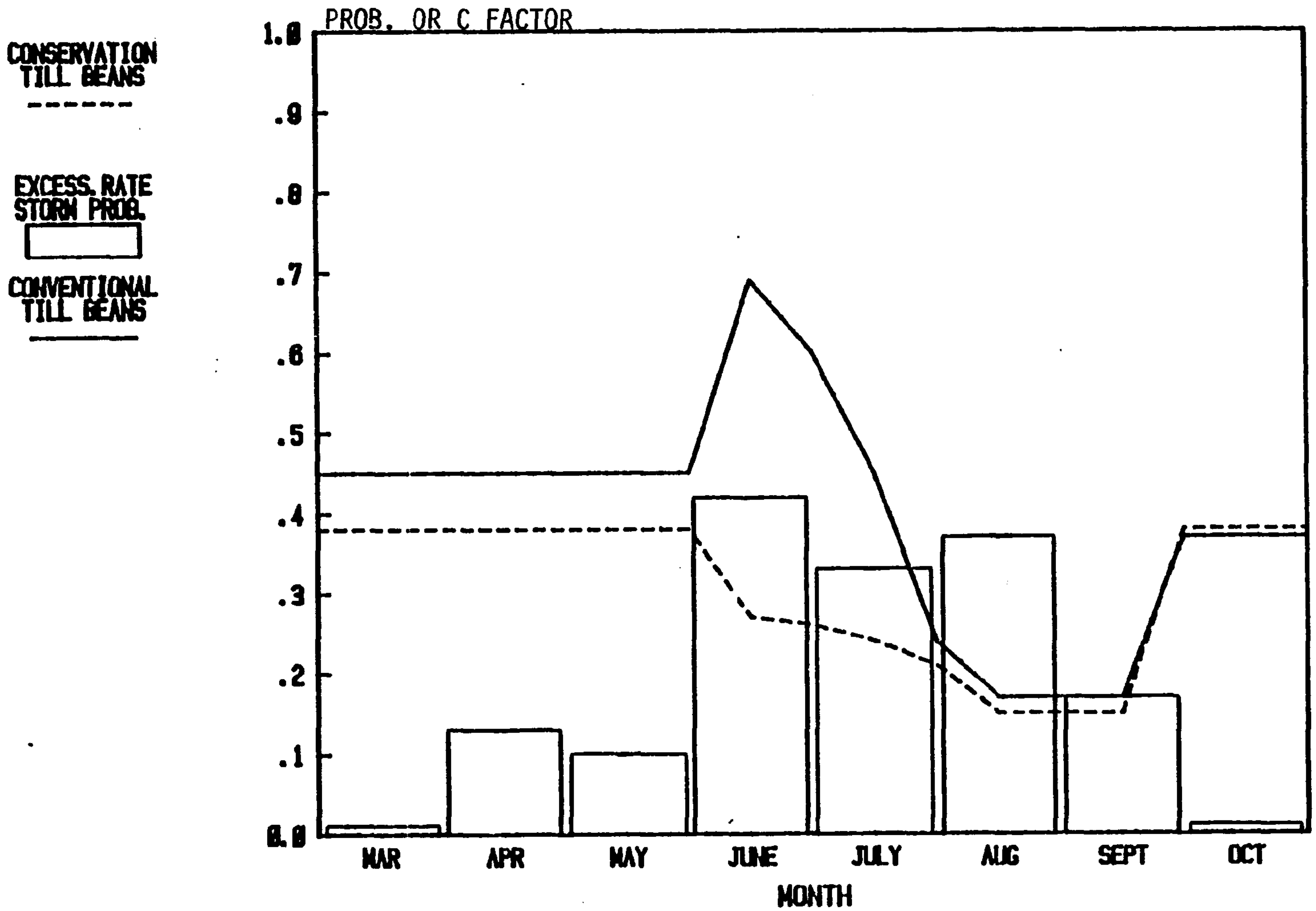
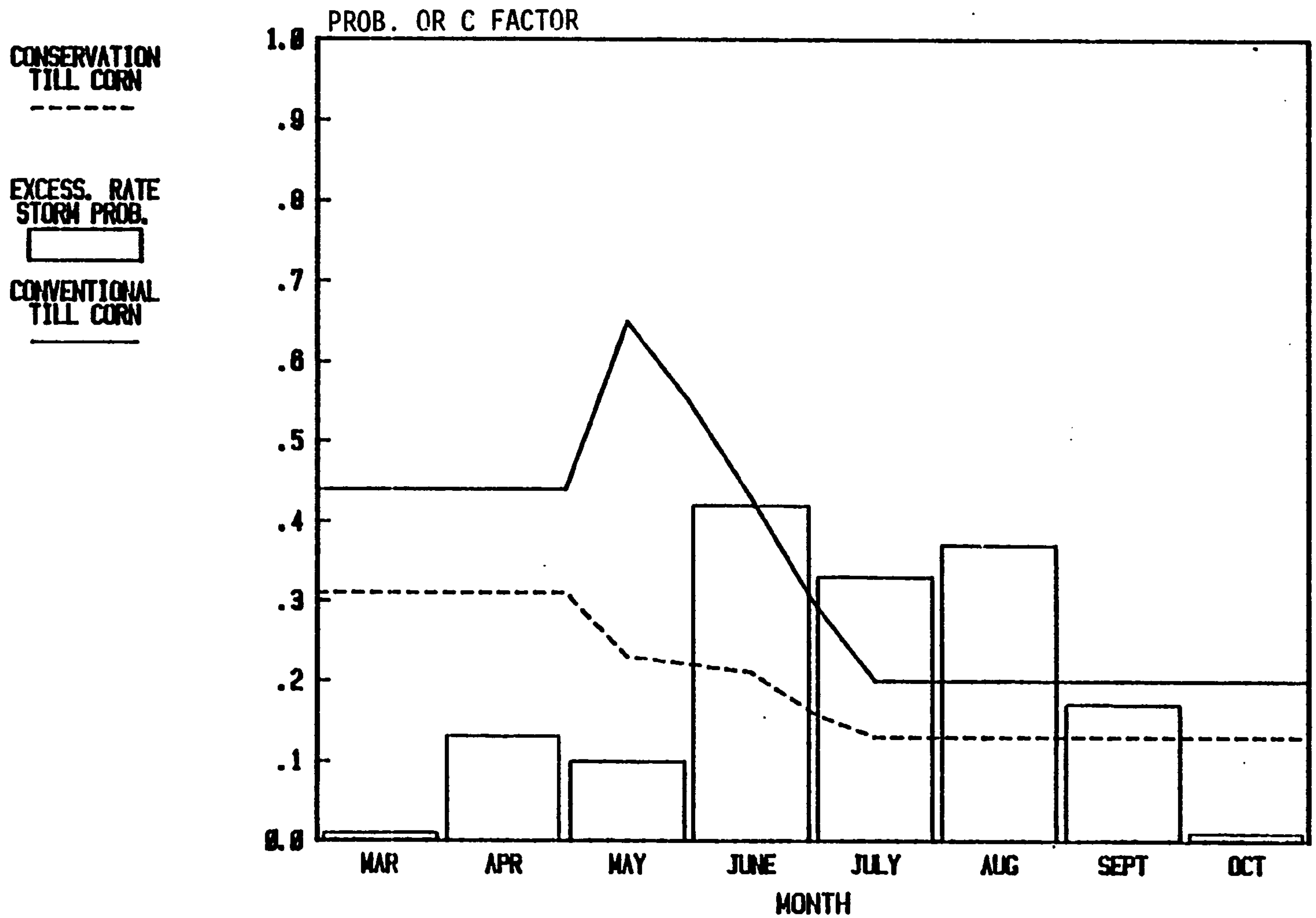


Figure 15

EXCESSIVE RATE STORM PROBABILITY
VS. CROP MANAGEMENT FACTOR (C)



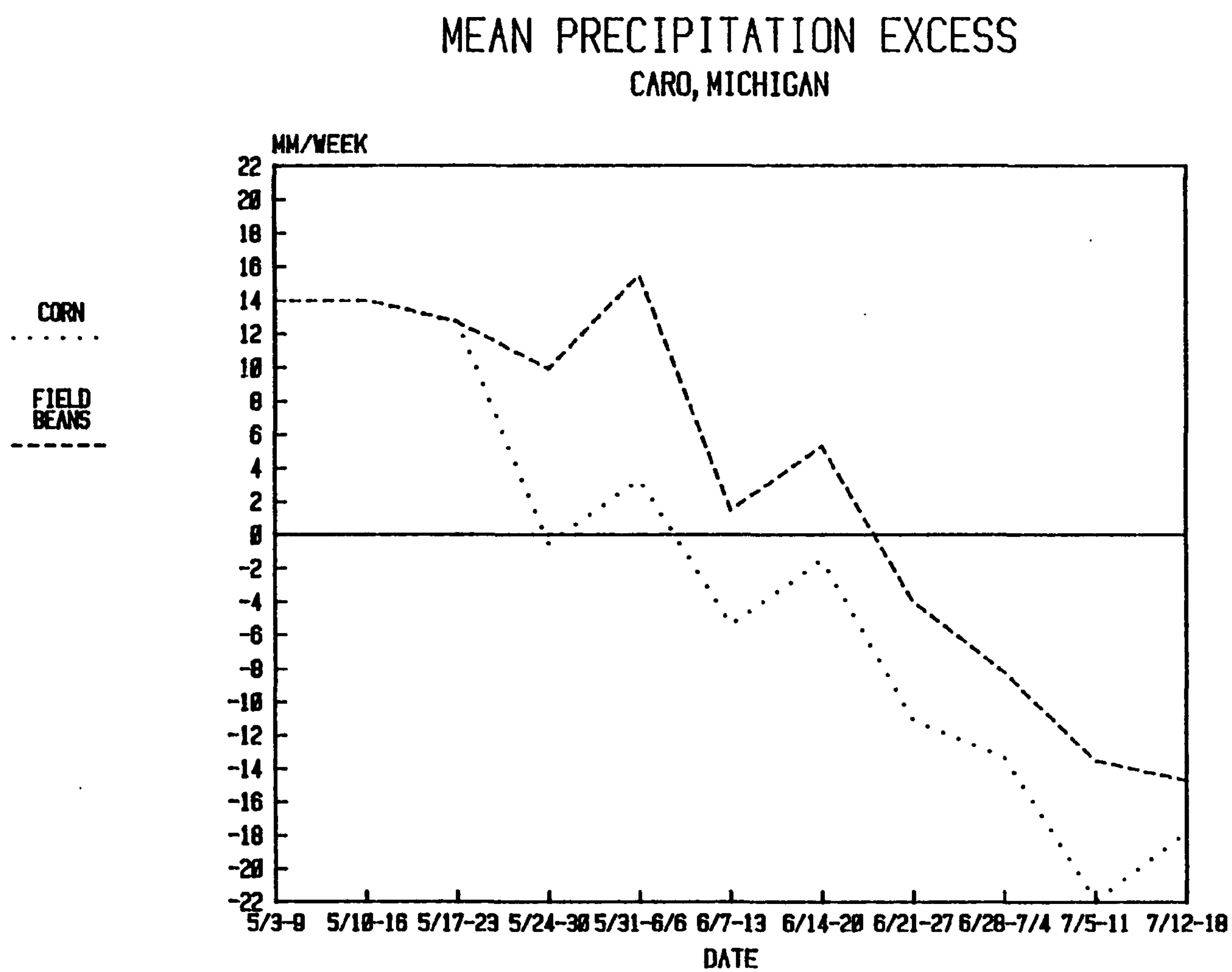
return period.

7.4 Precipitation Excess

Pronounced differences in soil moisture are expected to occur between corn and field bean sites that were not fully illuminated by the probability analysis of overland runoff and erosion events. The criteria employed for predicting antecedent soil moisture (Mockus, 1971) does not account for differences between crop stages. The influence of a transpiring crop on the soil moisture balance is modeled by one discrete change in the minimum 5 day precipitation of each AMC condition from the dormant to the growing season. Although the field beans emerge in mid June, the more mature corn can be expected to generate substantially more evapotranspiration during the latter part of June. Using the criteria of Mockus (1971) however, the two crops are not separated at this period since both are in their growing season.

Figure 16 displays the mean weekly precipitation excess (PPT-ET) expected during May and June on sites planted to field beans and corn. The earlier planting and emergence date of corn results in greater moisture use on corn sites than on sites planted to field beans. By the last week in May mean evapotranspiration is approximately equal to mean precipitation on soils supporting a corn crop. On field bean sites evapotranspiration remains low until approximately June 10 and mean weekly precipitation exceeds the expected moisture loss from evapotranspiration by 4-14 mm/week. Whereas corn sites can be expected to experience a precipitation deficit by the beginning of June, field bean sites are expected to have a precipitation excess until June 20.

Figure 16



MEAN PRECIPITATION EXCESS
CARO, MICHIGAN
MM/WEEK
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-22
CORN
FIELD BEANS
5/3-9
5/10-16
5/17-23
5/24-30
5/31-6/6
6/7-13
6/14-20
6/21-27
6/28-7/4
7/5-11
7/12-18
DATE

Based on the expected difference in the soil moisture balance during June for the two crops, a pronounced difference in runoff is expected than was predicted from the probability analysis. Given the relatively high frequency of excessive rate storms that occur during June, bean sites may be quite susceptible to overland flow and erosion during June. Providing cover on the field bean sites through conservation tillage should reduce the extent of the erosion losses that may occur during June.

CHAPTER 8

CONCLUSIONS

Field Monitoring

A large portion of the nitrogen and phosphorus lost from both tillage systems was in a soluble form. Soluble phosphorus constituted 51% of the the total phosphorus lost from the conventional field and 57% of the total phosphorus from the conservation field. Nitrate nitrogen accounted for approximately 75% of the nitrogen losses from both fields.

Sediment loss from both fields was low compared to other regions and may partially account for the relatively large proportion of soluble nutrients observed. Concentrations of suspended solids exceeded the EPA standard of 800 mg/l only once during the field monitoring. The greatest loss of sediment on both fields resulted from snowmelt runoff; however,nutrient concentrations in the snowmelt water was relatively low.

On both tillage systems overland flow had significantly higher concentrations of phosphorus, sediment, and total kjeldahl nitrogen than subsurface tile flow. Nitrate nitrogen however, was significantly higher in tile flow than overland runoff.

Soluble phosphorus concentrations in overland runoff were highest after planting and declined steadily with time.

Significantly more overland runoff occurred from the conventional system than from the conservation tillage system. The total flow (overland and tile) for the study period was almost identical for the two fields.

Over the entire study the conventionally tilled field lost substantially more sediment, phosphorus, and kjeldahl nitrogen than the conservation tillage field. Most of the additional losses observed from the conventionally tilled field resulted from an intense storm that occurred on emerging field beans. This was the only instance where a high intensity storm generated overland flow before a crop canopy was established.

Analysis of Long Term Weather Patterns

Erosive events have a low probability of occurrence from November through May regardless of surface residue cover. Overland flow events that result from low intensity storms can be regularly expected.

June was found to have the greatest frequency of erosive events. Conservation tillage practices can be expected to cause a greater reduction in edge of field losses from field beans than from corn sites during this period.

Management Recommendations

1) Management practices should be encouraged in the study region that enhance infiltration. Conservation tillage practices should be encouraged that provide protection to the soil and promote infiltration.

2) Subsurface tile drainage should be recognized as a best management practice to reduce phosphorus losses from the agricultural croplands of the Saginaw Bay drainage basin.

3) Conservation tillage should be particularly encouraged on sites that will be planted to field beans

Recommendations for Future Research

1) The field monitoring program should be continued to verify the trends observed during the first two years of study. Specific attention should be focused on snowmelt runoff and analysis of any hydrologic conditions that generate overland flow.

2) Additional field work should be encouraged to investigate the effect of fertilizer management on edge of field losses.

3) The results from the field monitoring program should be employed to test and calibrate computer based predictive models of edge of field losses. These models can then be employed to assess the longterm relative effectiveness of a variety of management practices in the study region.

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