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A Wind Erosion Model To Predict Average Soil Loss For Single Events

By

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ABSTRACT

A WIND EROSION MODEL TO PREDICT AVERAGE SOIL LOSS FOR SINGLE EVENTS.

By

William A. Presson

A model to predict average soil loss for single events was developed. The model is based upon Gregory's equation for soil flux across an eroding field. Input data necessary for use of the equation are modeled through a Michigan wind erosion season (December - June).

Residue decomposition is modeled using a residue decay equation with the appropriate parameters. Crop cover is limited to corn. The CERES model for corn development and corn growth data from Michigan are used to model canopy development. Data from Bay City, Michigan for the 1984-85 wind erosion season is used for model verification. Results are favorable but not conclusive, due to insufficient data.

Approved: ______________________
Major Professor

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Department Chairman

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I. Introduction

The modeling of wind erosion, due to its immense complexity, is still in an infancy stage. Until recently, the only tool available to predict wind erosion to any extent was the Wind Erosion Equation developed at the USDA, ARS wind erosion laboratory at Manhattan Kansas. The Wind Erosion Equation (WEE) predicts potential soil loss on an annual basis. Potential soil loss on an annual basis is used to provide criteria for the implementation of practices to reduce annual soil losses. However, the WEE does nothing to predict soil loss over a particular wind event. To model soil loss over the duration of a wind event an expression for mass flow per unit time must be incorporated. Two approaches have been proposed, Cole (1984) and Gregory (1984a). Cole and Gregory both agree that a mass flux can be incorporated in a wind erosion prediction equation. Gregory's prediction equation was chosen for modeling use due to its simplicity and because it has been verified with experimental data (Gregory, 1984a; Pfost, McCarty, and Gregory, 1985).

Predicting soil movement with any mass flux equation is only the start of a wind erosion model. Various other contributing factors must be accounted for and quantified. Some of these factors include: 1) moisture conditions; 2) wind velocity profiles; 3) cover (both organic residue and green plant); and 4) field features and orientation. Each of these factors present a unique difficulty in modeling. Additional models and equations must be used to predict unknown factors. Some of these models are:

1) CERES model for corn development (Jones, 1985)
2) Swinbanks equation for predicting wind velocity profiles (Swinbank, 1964)
3) Gregory's equation for residue decay (Gregory et al., 1985)
4) Gregory's equation for residue mass to cover conversion (Gregory, 1982)
5) Cole's expression for field length on a rectangular field (Cole, Lyle, and Hagan, 1983)

One advantage of an event prediction model is the possible addition of wind storm probability to obtain a yearly potential soil loss model. In Michigan, the Wind Erosion Equation has not proven to be adequate (Sampson, 1984; Quissenberry, 1985)*. In the future, if event modeling can be made reliable, this approach may provide an alternative to the WEE for areas with climate variability and vegetation similar to that experienced in Michigan.

The objective of this study is to develop an event based model that incorporates and models the essential factors necessary to estimate soil movement caused by a single wind erosion event.

* - personal communication

II. Literature Review

A. Summary of wind erosion research

1. The Process of Wind Erosion

The process by which soil moves is characterized by three steps: a) Initiation of soil movement; b) Soil transport; c) Sorting and deposition (Malina, 1941 as referenced by Chepil, 1945b).

a. Intiation of Soil Movement

Particle movement will occur when the pressure of the wind exceeds the gravitational and/or cohesive forces holding the particle in place (Chepil, 1959). The wind speed required to exceed the gravitational force and initiate soil particle movement is called the threshold velocity. The threshold velocity varies according to soil, crop and environmental conditions (Chepil, 1945b; Gillette, 1978).

A fluid, e.g. wind in motion, exerts three types of pressures on a particle (Chepil, 1959; Chepil and Woodruff, 1963). These pressures are as follows:

1) Velocity or impact pressure - a positive pressure exerted on the windward side of the particle, a function of wind speed.

2) Viscosity pressure - a negative pressure on the leeward side of the particle, a function of air density, velocity, and viscosity.

3) Static, isotopic, or internal pressure - a negative pressure on the top of the particle, a function of the velocity differences between the top and bottom surfaces.

The static pressure can be explained by the Bernoulli effect which causes an upward lift on the particle (Chepil, 1945a). The sum of the impact and viscosity pressures are called drag. Thus, the forces acting on a particle during initial particle movement are lift, drag, and gravity. The threshold drag and lift required to initiate particle movement are functions of particle diameter, shape, density, closeness of packing and the angle of repose of the particle with respect to the average drag of the wind (Chepil, 1959; Chepil and Woodruff, 1963).

b. Soil transport

After the initiation of particle movement, the particle is transported in one of three types of soil transportation. They are as follows (Chepil, 1945a; Lyles, 1977):

1) Saltation - soil particles move in a series of short jumps. Approximately 50-80 percent of soil movement is transported this way (Chepil and Milne, 1939 as referenced by Stone, 1980; Lyles, 1977).

2) Suspension - soil particles become airborne after movement is initiated by saltating particles (Hsieh and Wildung, 1969; Gillette and Walker, 1977; Lyles, 1977).

3) Surface Creep - soil particles roll or slide across the surface (Peterson, 1986).

The type of transport is largely a function of particle size. A general guidline can be seen in table 1.

TABLE 1

Particle Size Range verses Type Of Transport (Chepil, 1945a).

Particle size	Type of Transport
< 0.1 mm	Suspension
0.1 - 0.5 mm	Saltation
0.5 - 1.0 mm	Surface creep

c. Sorting and deposition

Sorting and deposition is the final process of wind erosion (Malina, 1941). The varying mobility of particles results in the sorting of soil particles across a field (Chepil and Woodruff, 1963). Deposition of soil particles takes place when the gravitational force exceeds the wind's force on the particle (Chepil and Milne, 1941b as referenced by Stone, 1980). This so called "fanning mill" process causes the field to become progressively coarser in texture with time (Chepil, 1946; Zingg and Chepil, 1950), a phenomenon which can make the remaing soil more erodible (Zingg and Chepil, 1950).

2. Factors affecting wind erosion

The primary factors affecting wind erosion for a given field are: soil cloddiness, surface roughness, wind, soil moisture, field length, and vegetative cover (Woodruff et al., 1977). Of the above, Woodruff and Chepil (1956) attributed up to 75 percent of wind erosion variability to soil cloddiness, surface roughness, and vegetative cover with soil cloddiness being the most significant of the three factors. Soil cloddiness absorbs the wind's drag thus sheltering more erodable particles (Chepil and Woodruff, 1963; Woodruff et al, 1977) and therefore, it can be considered as cover (Fryrear, 1983; Gregory, 1984b). Surface roughness also reduces wind erosion by absorbing drag (Lyles, 1977). However, there is an optimum ridge height beyond which surface roughness looses its' effectiveness because greater erosion can occur off the crests (Chepil and Milne 1941a). The optimum ridge height is from 3 to 7.5 cm (2 to 5 inches) (Woodruff et al, 1977).

Vegetation and vegetative residue have two effects on wind erosion 1) absorbing wind drag (Zingg, 1951; Lyles, 1977; Skidmore and Hagan, 1977) and 2) entrapping soil particles (Chepil, 1944 as referenced by Stone, 1980).

The intensity of wind erosion varies by the cube of wind velocity and inversely by the square of effective precipitation (Chepil, Siddoway, and Armbrust, 1963). Moisture has a two fold effect on wind erosion. Moisture in the air reduces its density and therefore reduces the wind's erosive force (Chepil, 1945c). Moisture in the soil produces water films that create cohesive forces which resist erosive winds (Chepil, 1956).

The last primary affect is field length. Increasing field length allows increased soil particle interaction which produces more particle movement.

c. Wind erosion control

Woodruff and Siddoway (1973 as referenced by Stone, 1980) state that wind erosion is caused by "... a strong turbulent wind blowing across an unprotected soil surface that is smooth, bare, dry, and finely granulated". The control therefore is the manipulation of the factors discussed in the previous section. These manipualtions are (Woodruff et al., 1977):

1) Promoting a cloddy soil surface.

2) Ridging the soil surface perpendicular to the direction of the prevailing wind.

3) Reducing field length with barriers or crop strips oriented perpendicualr to the direction of the prevailing wind.

4) Establishing and maintaining a cover of vegetation or vegetative residue.

Soil clods are formed during tillage and are a function of soil texture, density, and moisture (Lyles and Woodruff, 1961). Generally if the soil surface is covered with at least two-thirds of particles and clods greater than 0.84 mm in diameter, adequate cover is provided for most winds (Woodruff and Siddoway, 1973 as referenced by Stone, 1980). Ridging the soil surface can provide protection from wind erosion if the soil texture is suitable to resist abrasion (Chepil and Woodruff, 1963).

Barriers or crop strips can be constructed at right angles to the prevailing winds (Chepil and Woodruff, 1963). The barriers or crop strips exert a drag and reduce the erosive force of the wind. The effective distance from the barrier for wind erosion protection is about 10 times its height (Woodruff, 1956). The barrier or crop strip also reduces avalanching by entraping saltating particles (Chepil and Milne, 1941b as referenced by Stone, 1980). Crops and crop residues raise the zero velocity level of the wind (Chepil and Woodruff, 1963), decrease wind velocity at the surface, and entrap eroding particles (Chepil, 1944 as referenced by Stone, 1980). Minimum tillage practices that maintain crop residue while increasing water infiltration and storage can reduce wind erosion (Fenster and Wicks, 1977).

For an indepth review of literature on Wind Erosion Research see Stone (1980).

B. The wind velocity profile

The wind velocity profile first used in wind erosion research was adapted from Von Karman's expression for fluid flow in pipes. The equation is as follows:

$$\frac{u}{u*} = \frac{1}{K_0} \ln \frac{z}{K} + C \qquad (1)$$

where:

u = velocity at height z

$u* = (t/p)^{1/2}$

z = height above a surface

C = constant

K_0 = constant, Von Karman constant

K = height of surface roughness

t = shear stress at the boundary

p = fluid density

Prandtl suggested that equation (2) could be extended to the atmosphere (Brunt, 1944 as referenced by Zingg and

Chepil, 1950). Nikuradse conducted experiments and determined the constants to be K_0=0.4 and C=8.5 (Zingg and Chepil, 1950). Substituting these constants and converting equation (2) to logarithmic base 10 yields the following equation.

$$\frac{u}{u*} = 5.75 \log \frac{z}{K} + 8.5 \qquad (2)$$

To simplify the equation further, setting k=K/30 will satisfy the equation so that the constant 8.5 can be eliminated (Zingg and Chepil, 1950). The equation then has the following form:

$$u = 5.75\ u* \log \frac{z}{k} \qquad (3)$$

This equation with several modifications was used by Bagnold and Chepil (Zingg and Chepil, 1950). The equation used for more recent wind erosion work today is the following:

$$u(z) = \frac{u*}{K} \ln \left[\frac{z-d}{z_0}\right] \qquad (4)$$

Where:

u(z)= velocity as a function of height (z)

K = Von Karman constant, 0.4

d = effective surface roughness height

z_0 = roughness parameter

Equation (4) (Schwab et al., 1981) assumes neutral atmospheric conditions. This assumption is probabaly not the case for most wind erosion events. Harrington (1965) concludes that the most appropriate expression for the wind profile near the ground is Swinbank's expression (Swinbank, 1964). The equation is as follows:

$$u(z) = \frac{u*}{K} \ln\left[\frac{\exp((z-d)/L) - 1}{\exp(z_0/L) - 1}\right] \quad (5)$$

Where:

$$L = \frac{-u*3}{(kgH/\rho C_p)}, m \quad (6)$$

g = acceleration of gravity, m s^{-2}

H = sensible surface heat flux, J m^{-2} s^{-1}

ρ = ambient air density, g m^{-3}

C_p= specific heat of air, J g^{-1} $^oK^{-1}$

The effective surface roughness height (d) and the roughness parameter (z_0) can be related to crop height (h) by the following equations where the units are in meters.

log d = log h - 0.15 (Stanhill, 1969) (7)

log z_0= log h - 0.09 (Tanner and Pelton, 1960) (8)

For a more indepth review of literature regarding wind velocity profiles see Harrington (1965).

C. Modeling soil erosion by wind

1. The wind erosion equation

The WEE was developed from work performed and data taken in the Great Plains (Chepil and Woodruff, 1954; 1959; Chepil, 1960). The WEE estimates potential soil loss on an annual basis for a given agricultural field. The equation is as follows (Woodruff and Siddoway, 1965):

$$E = f(I , K , C , L , V) \tag{9}$$

where:

E = potential average soil loss, Tons acre^{-1} year^{-1*}

I = soil erodibility index, Tons acre^{-1} year^{-1*}

K = soil ridge roughness factor,

C = climatic factor,

L = field length along the prevailing wind direction, feet

V = equivelent of quantity of vegatative cover, lbs acre^{-1*}

Use of the WEE, due to it's complexity, (Chepil and Woodruff, 1963) requires look up charts and tables and graphical solution techniques. A computer program was developed by Skidmore, Fisher, and Woodruff (1970) to solve

* note the WEE is not used with SI units

the WEE. The computer program was of little help however for use in the field. The Soil Conservation Service, the Agricultural Research Service and the Graphics Calculator Company developed a slide rule to improve ease of use of the WEE (Posselius, 1983). Posselius developed a program for use on a Hewlett Packard 41 CV handheld calculator. For further background regarding the WEE see Stone (1980). For further information regarding the equation's use in Michigan refer to Quisenberry (1984).

2. Gregory's wind erosion equation

An alternative to the Wind erosion Equation's yearly average soil loss is Gregory's wind erosion equation for single events (Gregory, 1984a). Pfost, McCarty, and Gregory (1985) applied the equation with further modifications. The equation is as follows:

$$M_S = C\ S\ V\ (V^2 - V_{C2}^2)[1 - \exp(-Z\ A\ L\ K/V)] \qquad (10)$$

where:

M_S= mass flux per unit width of blowing soil, $Kgm^{-1}\ s^{-1}$

C = 0.0000244 $Kg\ s^2\ m^{-4}$

S = Relative soil detachment factor (a function of crop canopy, residue, and soil roughness), calculated by equation (13)

V = Wind velocity, $m\ s^{-1}$ (at 15.2 meters above the surface)

V_c= critical threshold velocity required to initiate erosion of dry soil, assumed to be 13.0 m/s @ 15.2 m height (equivelent to 6.7 m/s @ 0.15 m height (Fryrear and Downes, 1975))

Z = 0.003 ha t^{-1} s^{-1}

A = a dimensionless soil abrasion adjustment factor

$$= 0.77\ [1-\exp(-0.072\ \exp(4.67\ Z\ L\ K/V))] + 0.23 \qquad (11)$$

L = unprotected length of field in direction of wind, m

$$= L_f - [17(V_c)/V]\ H \qquad (12)$$

L_f= length of field in direction of wind, m

H = heigth of windbreak (on windward side of field), m

K = soil erodibility, t/ha (from table 2)

The relative soil detachment factor (S) was developed by Gregory (1984b) for water erosion as well as wind erosion. For use in the above equation (S) can be calculated from the following equation:

$$S = \frac{(1-F_c)\ (1-F_r)}{\left[\frac{F_c h_c}{h_s} + (1-F_c)\frac{F_r h_r}{h_s} + (1-F_c)\ (1-F_r)\right]^2} \qquad (13)$$

where:

S = relative soil detachment (S=1 for a smooth, bare soil)

F_c= fraction of canopy cover due to a growing crop

F_r= fraction of cover due to residue or stable soil clods (can be predicted by equation 19, or see Table 3 for typical values)

h_c= height of canopy, mm (or same units as h_s or h_r)

h_s= height of soil roughness, mm

h_r= height of residue, mm

Table 2

Soil Erodibility values For Various Textural Classes Of Dry, Bare Soil (Chepil, 1957).

Soil Class (Textural)	Soil Erodibility K, t/ha*	Soil Erodibility I, ton/ac
Sand	370	165
Loamy Sand	220	98
Sandy Loam	40	18
Loam	16	7
Silt Loam	13	6
Clay Loam	11	5
Silty Clay Loam	9	4
Silty Clay	27	12
Clay (subject to granulation)	52	23

*K = 2.24 times I.

Table 3

Fraction of Cover Produced by Various Amounts of Crop Residues
(Pfost, McCarty, and Gregory 1985)

	Residue Amount (Kg/ha)									
	200	600	1000	1500	2000	3000	4000	5000	6000	8000
CROP	Fraction OF Residue Or Plant Cover									
CORN	0.08	0.21	0.33	0.45	0.55	0.70	0.80	0.86	0.91	0.96
COTTON STEMS	0.02	0.06	0.10	0.14	0.18	0.26	0.33	0.39	0.45	0.55
SOYBEAN	0.13	0.34	0.50	0.65	0.75	0.88	0.94	0.97	0.99	1.00
SOYBEAN STEMS	0.04	0.11	0.18	0.26	0.33	0.45	0.55	0.63	0.70	0.80
SUNFLOWER	0.04	0.11	0.18	0.26	0.33	0.45	0.55	0.63	0.70	0.80
WHEAT	0.10	0.26	0.39	0.53	0.63	0.78	0.86	0.92	0.95	0.98

D. Modeling residue losses

1. Modeling residue decay

Predicting residue cover is essential to the modeling of wind erosion events. At any time during the wind erosion season, residue cover must be known or predicted within reasonable tolerances. The first attempts at modeling residue decay assumed that decay follows a first order reaction with time. The equations that were developed then have exponential forms (Parnas, 1975; Hunt, 1977; Gilmour, 1977; Reddy, Khaleel, and Overcash, 1980).

Gilmour, Broadbent, and Beck (1977) and Hunt (1977) used first order kinetics to describe residue decay in two to three different stages depending on ease of decomposition. The equation is as follows:

$$-dC_i/dt = k_i C_i \quad (14)$$

where: C = organic carbon substrate

k_i = first order rate constant at phase (i)

i = phases I, II, and III

and by integrating equation (14).

$$C_{ti} = C_i \exp(-k_i t) \quad (15)$$

where: C_{ti} = remaining organic substrate at time (t), at phase (i)

C_i = initial organic substrate at phase (i)

k_i = first order rate constant at phase (i)

t = time

Three difficulties arise from these equations: 1) two or three phases of decomposition must be considered; 2) the first order rate constant varies over time; and 3) an exponential relationship requires infinite time to reach total decay. Reddy, Khaleel, and Overrcash (1980) developed procedures to modify equation (15), but these modifications require data not easily measured or estimated. Gregory et.al. (1985) derived a simplified model that could be used with easily measured or estimated data. The model is derived from five basic concepts. They are as follows:

1) A simple model should model the integrated effects of all microorganisms at work in residue decomposition.
2) As temperature increases above zero degrees celcius, residue decay increases also.
3) The residue decay rate is inversely proportional to the carbon to nitrogen ratio (C/N) of the undecayed part of the residue at harvest time.
4) Residue moisture level affects the rate of residue decay.
5) Decay occurs on the surface of the residue and therefore depends on the surface area of the residue.

The model is as follows:

$$M = M_0(1-ut/R_0)^2 \qquad (16)$$

where: M = Mass at time (t), Kg

M_O = Mass at time (t=0), Kg

u = constant

R_O = radius of one stem, mm

t = a weighted time variable adjusted for temperature, moisture, and intial C/N ratio.

$= TtA_m/(C/N)$ (17)

T = temperature, (degrees Celcius above zero)

t = time, days

C/N= intial C/N ratio

A_m = moisture index, mm

summation of (Ii/i) for i=1-5 (18)

I = depth of a rainfall on a given day,mm

i = the numbered day, with the present day being 1, the previous day 2, ect.

All of the above parameters can be easily measured or estimated except for the values u and R_O. These values were determined experimentally as one variable u/R_O for various crops (Gregory et al., 1985; Ghidey et al., 1985). Recommended values are listed in table 4. The C/N ratio can be estimated with data, reported by Ghidey et al.(1985), table 5. The moisture index is not allowed to exceed the index based on the average potential evaporation rate. Therefore A_m is not allowed to exceed 10 mm (see Gregory et.al. (1985) for a more indepth explanation).

Table 4

Recommended values for u/R_0 for use in Gregory's residue decay equation (Gregory et al., 1985).

Crop	u/R_0
wheat	0.00210
corn	0.00118
sunflower	0.00119
soybeans	0.00137

Table 5

Recommended Carbon Nitrogen ratios for Gregory's residue decay equation (Ghidey et al., 1985).

Crop	C/N
wheat	108
corn	57
sunflowers	40
soybeans	30

2. Residue mass to cover relationship

Modeling residue decay has been performed in terms of mass. Mass of residue however is not the input parameter needed for Gregory's wind erosion equation. A residue cover i.e. decimal fraction of cover, input is necessary. Sloneker and Moldenhauer (1977) and Wischmeier and Smith (1978) related the fraction of the surface covered to the mass of dry material on the surface. Gregory (1982) derived an equation to directly predict soil cover from the mass of dry material on the surface. The equation was verified using reported data of Gregory (1982) as well as Sloneker and Moldenhauer (1977) and Wischmeier and Smith (1978). The eqution has the following form:

$$F_c=1-e^{-AmM} \qquad (19)$$

Where: F_c=fraction of soil covered, decimal

Am=crop dependant constant, ha/Kg

M =Mass of residue per unit area, Kg/ha

Recommended values for Am are listed in Table 6.

Table 6

Recommended values for Am constant in Gregory's residue mass to cover conversion equation (Gregory, 1982).

Residue	Am(ha/Kg)
Soybean	0.0004-0.0007
wheat	0.0005
corn	0.0004
sunflower	0.0002
soybean stems	0.0002
cotton stems	0.0001

3. Residue losses due to tillage

Fenster et al. (1965) observed residue reduction from individual passes of implements over stubble mulch systems. Fenster et al. (1965) measured reductions of up to 45% of residue mass with primary tillage and gains of up to 4% residue mass with secondary tillage. Researchers since then e.g. Anderson (1968), Sloaneker and Moldenhauer (1977) and Colvin, Laflen, and Erbach (1980), have reported residue reductions from tillage, but none have tried to model residue reduction caused by tillage. Gregory et al. (1982) derived an equation to predict residue reduction by tillage. This equation is as follows:

$$t=(1-\frac{W_B}{W_D})\,e^{-(1-F_S+F_SW_B/W_T)(M_U/M_T)(BD)Kd} \qquad (20)$$

Where: t =ratio of the new fraction of cover to the old fraction of cover,

W_B/W_D=ratio of tool width to width disturbed,

W_B/W_T=ratio of tool width to width tilled,

M_U/M_T=ratio of mass of soil moved above untilled top of soil to total (M_T) moved by the tool,

d =effective or average depth of tillage, cm

F_S =fraction of stable residue cover,

BD =dry bulk density, g cm^{-3}

K =clod size coefficient,(area/mass)

Koohestani and Gregory (1985) further developed the input parameters for the above equation. Residue reduction by tillage is quantified in table 7 for use in Michigan for corn (Quisenberry, 1981).

Table 7

Typical percentages of residue left for various tillage sequences for corn in Michigan (Quisenberry, 1981).

System	Residue remaining
moldboard plow-offset disk-planter	0%
offset disk-planter	25%
chisel plow (twisted shovel)-planter	50%
chisel plow (straight shovel)-planter	65%
till planter with cultivator	80%
no till planter with cultivator	100%

III. Model Development

The model is designed to follow as reasonably as possible the development of the conditions preceeding a wind erosion event. The model then evaluates the average mass loss during the event. The assumptions used for the model are as follows: 1) Event basis analysis ; 2) Dry soil conditions; 3) Short duration wind events; 4) Rectangular fields;5) Homogeneous soil texture for the field; and 6) No soil particle input from outside the field boundry. The input and output variables are outlined in figures 1 and 2 (pages 31-32). Basic model flow is illustrated in figure 3 (page 33). These were the basic areas recognized as being important in a wind erosion model. The actual flow of the model is illustrated in figures 4 and 5 (pp.34-35). The main features accounted for in the model are as follows:

1) Residue breakdown
2) Field orientation and layout
3) Crop development (corn)
4) Average mass movement per unit area determination
5) Average mass loss per unit area determination

1. Residue breakdown

Residue cover is a major variable of interest in Gregory's Wind Erosion Equation and therefore must be known within a reasonable tolerence. In Michigan, on the plots used for data collection, the usual tillage sequence is fall plow (chisel or moldboard), spring secondary tillage (disking or combination implement) and planting. Initial residue input into the model is after fall tillage and is inputted as a decimal fraction of cover. Residue decay is then modeled throughout the fall up until the desired wind event calculation. Equation (16) section D, is used to evaluate residue decay in five day increments (Gregory et.al., 1985). Average monthly temperatures and rain amounts are used through the decay period. The residue decay equation requires an input of mass per unit area. Therefore equation (19) is used to make this conversion. This conversion is required intially, as well as for the residue cover input parameter in Gregory's Wind Erosion Equation (10). If an event occurs after planting, residue loss due to tillage is determined by a factor taken from table 7.

2. Field orientation and layout

Field orientation is important to determine the unprotected field length in the direction of the wind. The model is set up to handle a rectangular field that has all sides either parallel or perpendicular to the compass directions, i.e., north, south, east and west. Windbreak heights are inputted for each side of the field. To calculate the effective length of field in the direction of the wind, Cole, Lyle, and Hagan (1983) proposed an expression used in the model. The equation is as follows:

$$L_f = \frac{l\ w}{w/\cos\beta/+l/\sin\beta/} \tag{21}$$

Where:

L_f = effective field length, m

l = length of field, m

w = width of field, m

ß = angle between wind direction and east-west axis of the field, degrees

The effective field length (L_f) is substituted for the field length (L_f) input parameter for equation (12). The effective field length is also used to convert mass flux per unit width to average mass rate per unit area.

3. Crop development

Corn is the only crop for which the model is designed at this stage of development. For corn, two crop parameters are neccesary if an event occurs after plant emergence. The two parameters are crop canopy cover and crop canopy height. Both of these parameters exhibit a linear relationship with sum of degree days (8^{o}C base for degree day). To predict crop canopy cover, the Ceres corn growth model (Jones, 1985) was used to predict leaf area index development. The leaf area index then was converted to crop canopy cover using sorghum data from Richie and Burnett (1971). The differences between the leaf area index verses the canopy cover relationship between corn and sorghum were considered negligable for this type of estimate (Richie, 1985)*. Crop canopy height is estimated with corn growth data taken from southern Michigan during the same period and related to the sum of degree days.

4. Average mass movement per unit area per event calculation

Gregory's Wind Erosion equation predicts a mass flux per unit width per second (pg. 13, eq. 10). To obtain the mass movement per second over the field, the following equation can be used.

$$Mi = \int_{0}^{L_f} Ms(L)\ W\ dL \qquad (22)$$

where:

M_i - mass movement per second over the field, Kg s^{-1}

M_s - mass flux per unit width, Kg $m^{-1}s^{-1}$

L_f - length of field in the direction of the wind, m

* Personal Communication

d_L - differential length along the field, m

W - field width, m

The model approximates equation (22) by evaluating the mass flux per unit width at increments of 3 meters along the windward side of the field until the mass flux reaches its' maximum. The mass fluxes are then averaged over the region and weighted with the remaining maximum flux across the rest of the field. The resulting weighted mass flux per unit area width M_{sw} is then substituted back into equation (22). Evaluating equation 22 and dividing by the area, the mass flux per unit area is found. To find the mass movement per unit area per event, integration over the duration of the event can be performed. Equation (23) is the resulting equation.

$$M = \int_0^t [[\int_0^{L_f} (W\ Msw)dL]/\ Lf\ W]\ dt \qquad (23)$$

where:

M - total mass movement per unit area, Kg m^{-2}

M_{sw}- weighted mass flux over the field, Kg $s^{-1}m^{-1}$

t - time, s

dt - differential time increment, s

5. Average soil loss per unit area

Total soil movement does not by itself determine soil loss from a field. A soil particle is not considerd lost until is passes across the field boundry. Therefore, given a set of parameters that will produce wind erosion and assumimg the field is sufficiently large so that the maximum mass flux is reached, the amount of erosion is a function of the field leeward boundary exposure for short duration wind events. The equation used to calculate average soil loss per unit area is as follows:

$$M_a = M_s * d / L_f \qquad (24)$$

where

M_a - average soil loss per unit area, Kg m^{-2}

M_s - mass flux at distance Lf, Kg $s^{-1}m^{-1}$

L_f - length of field in the direction of the wind, m

d - duration of the event, s

Input and Output Parameters

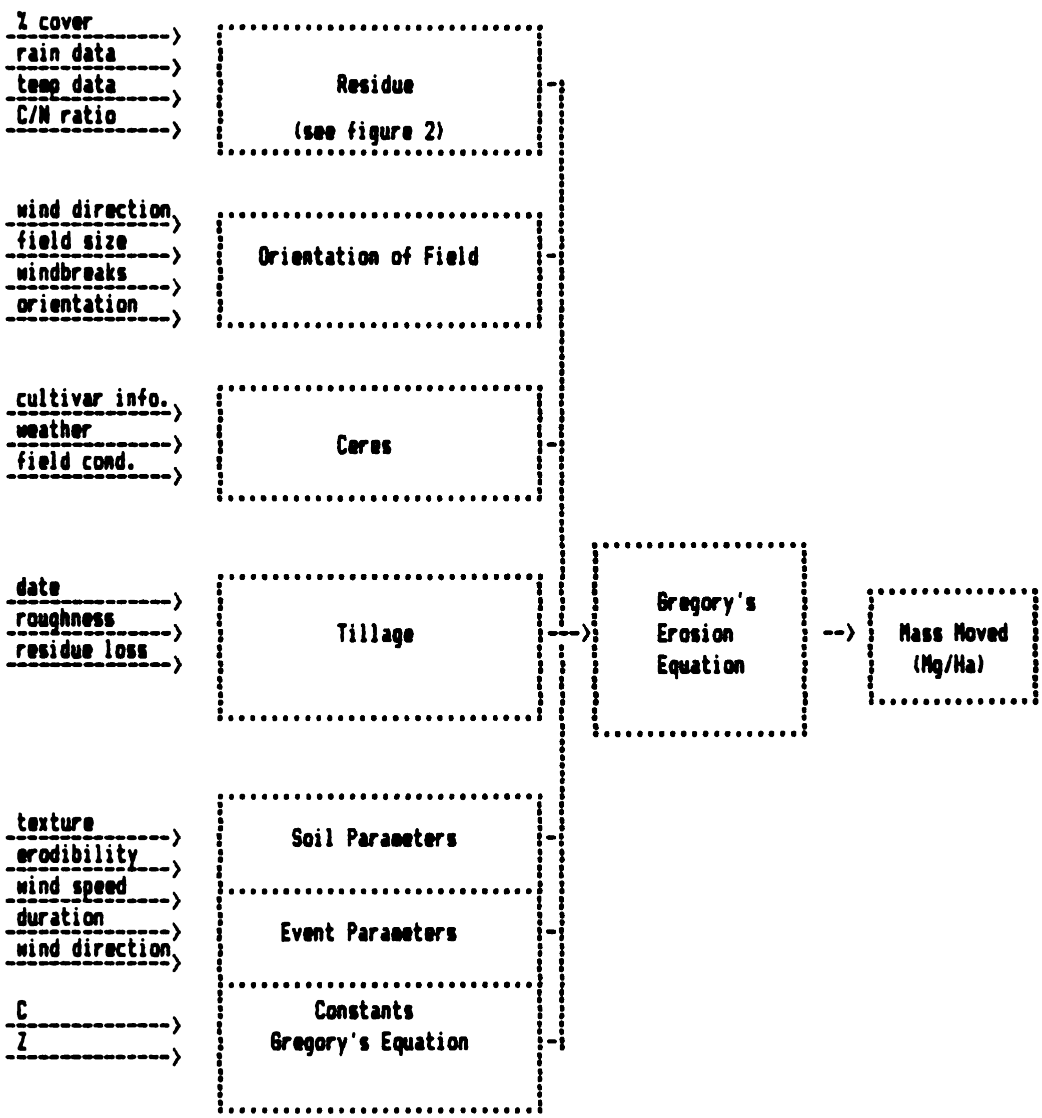

Figure 1

Residue

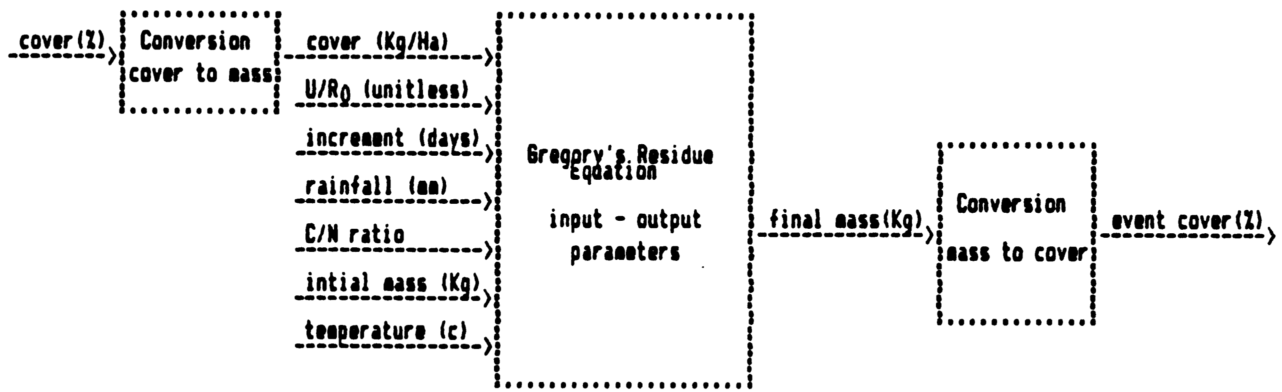

Figure 2

Model Parameters Through An Erosion Season

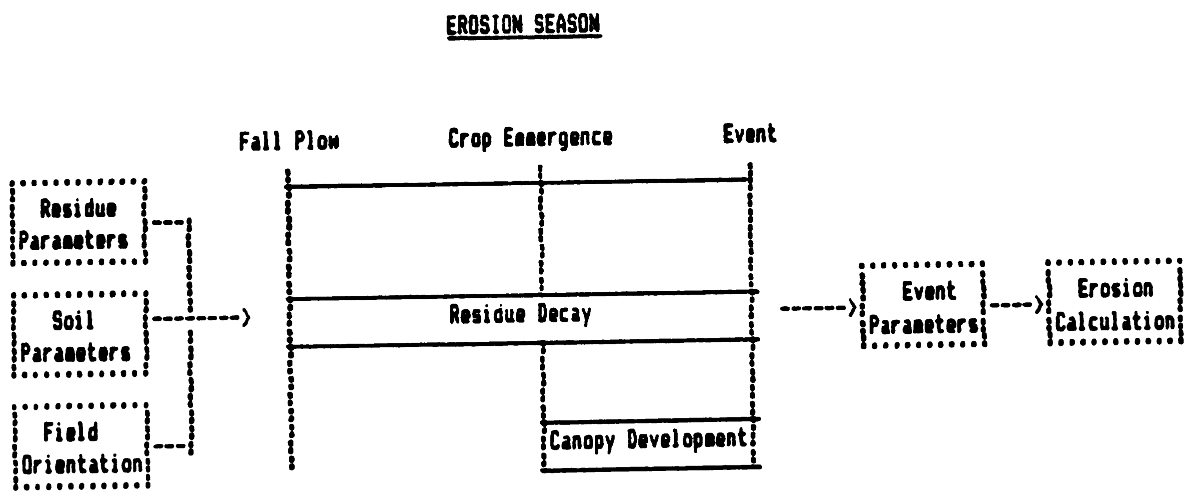

Figure 3

Erosion Modeling Flow Chart

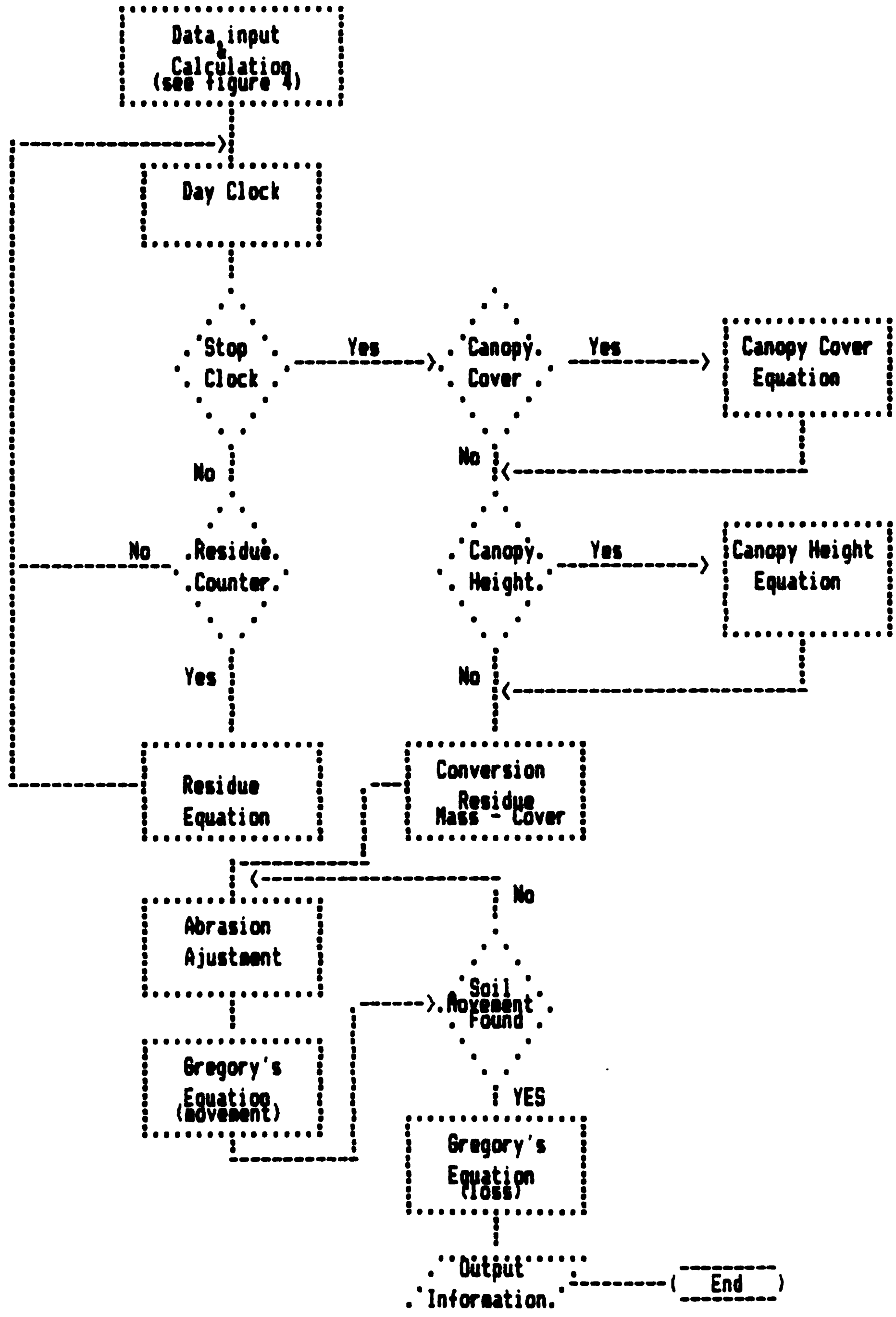

Figure 4

Data Input and Calculation

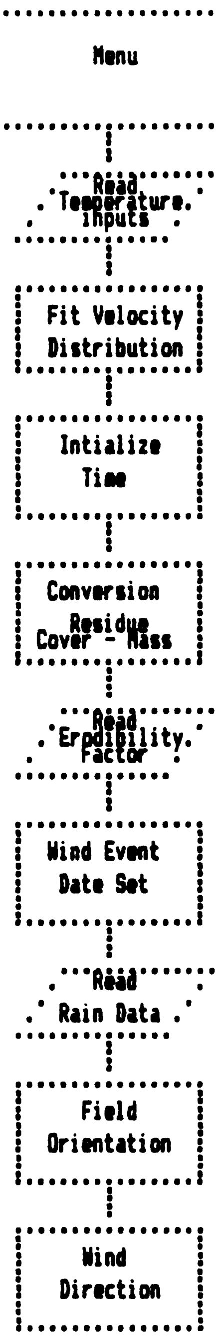

Figure 5

IV. Model Sensitivity

A model sensitivity analysis was performed for the major parameters which determine average soil loss rates per unit area. Figures 6 - 17 show the effect of individual parameters on average soil loss per unit area for a given set of parameters. Table 8 gives a detailed list of the data set used to develop the sensitivity relationships. Temperature and rainfall data that were used are the same as in Appendix A.

Some major features that can be clearly seen in these plots are as follows:

1) Figures 6 and 16 show a flat portion on their curves. The flat portion results from the fact that a bare soil's cover is equal to the percent of non-erodible particles in the soil. A non-erodible particle is defined as any particle that will not pass through a 0.84 mm screen. Therefore, it is unlikely that a soil is ever completely void of any cover. The soil's non-erodible fraction does not allow the curves to approch their limits and a flat portion on the curve results.

2) Figure 14 appears to have a change of slope in the mid region of the curve. The curve shown is actually composed of two separate curves. The right side of the curve is a function of the non-erodible fraction. The left side of the curve is a function of residue cover since the model does not consider the non-erodible fraction as cover

unless it is greater than residue cover.

3) Figure 8 may appear intially to be opposite of that expected. However, soil loss is a function of the leeward field exposure (pg. 30, section 5) and, therefore, the relationship shown is correct. A large field will have more soil movement than a small field, but the loss of soil may be greater on the smaller field. Soil loss has not taken place until the soil actually passes across the field's edge which, for short duration wind events is a function of the leeward field exposure.

4) Figure 17 indicates that as field roughness increases, so does average mass loss per hectare. Two relationships are expected from published literature on field roughness verses soil movement. The first occurs when the field surface roughness deviates from a smooth surface. The increase in soil roughness imparts greater drag on the wind, thus reducing the wind velocity and in turn reducing soil movement. The second relationship, was observed by Chepil and Milne (1941a). Soil movement will increase if soil roughness becomes to great. Erosion will occur off the crests of the ridges. Therefore, the curve should consist of a negative slope until the optimum ridge height is reached and then a positive slope should occur therafter. The curve in figure 17 lacks the intial negative slope and presents an unresolved problem within the model.

Table 8

Intialized Parameters For Sensitivity Test

1.	January Temperature (c)	-8.4
2.	February Temperature (c)	-5.5
3.	March Temperature (c)	2.7
4.	April Temperature (c)	11.4
5.	May Temperature (c)	16.1
6.	June Temperature (c)	11.0
7.	July Temperature (c)	17.0
8.	August Temperature (c)	19.0
9.	September Temperature (c)	16.0
10.	October Temperature (c)	12.0
11.	November Temperature (c)	8.0
12.	December Temperature (c)	-1.5
13.	Fall residue Cover (decimal)	0.38
14.	Residue Increment (days)	5
15.	u/r0 Ratio	0.0018
16.	C:N Ratio	57
17.	Intial Tillage Date	111584
18.	Event Date	051685
19.	Event Hour	14
20.	North Field Length (m)	795
21.	East Field Length (m)	346
22.	Wind Direction (deg)	197
23.	Residue Height (cm)	5
24.	Residue Constant	4.51685E-4
25.	Windbreak North (m)	0
26.	Windbreak East (m)	0
27.	Windbreak South (m)	0
28.	Windbreak West (m)	0
29.	Event Duration (min)	150
30.	Critical Velocity (m/s)	13.0
31.	Wind Velocity (m/s)	17.0
32.	Velocity Height (m)	15.2
33.	Planting Date	050585
34.	Emergence Date	051685
35.	Non-erodible Fraction(%)	8
36.	Crusting Factor	0.17
37.	Factor Spring Tillage (residue)	0.30
38.	Spring Tillage Date	051085
39.	Field Roughness (cm)	2
40.	Days to Germinate (days)	10

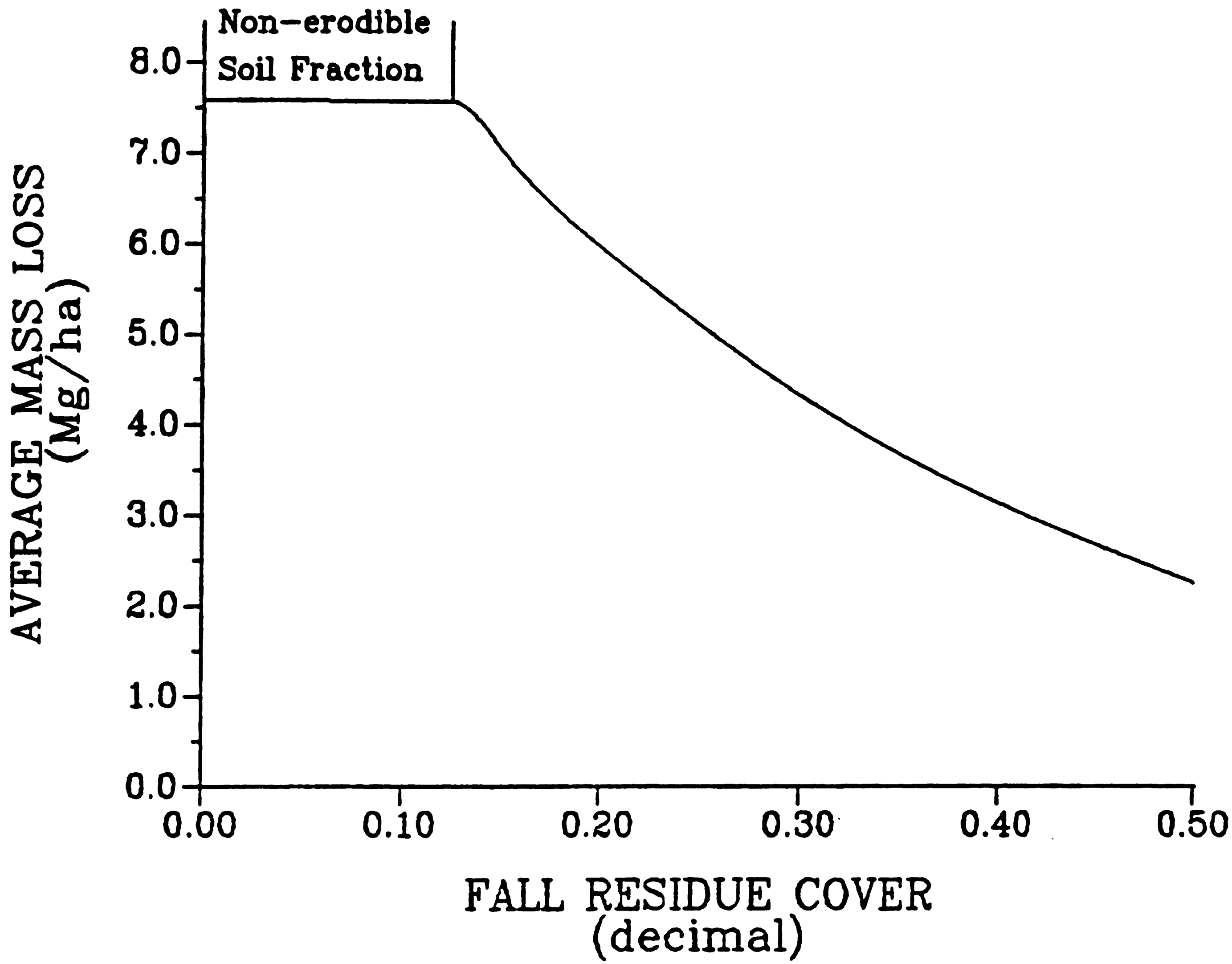

Figure 6 Sensitivity of Average Mass Loss to Fall Residue Cover

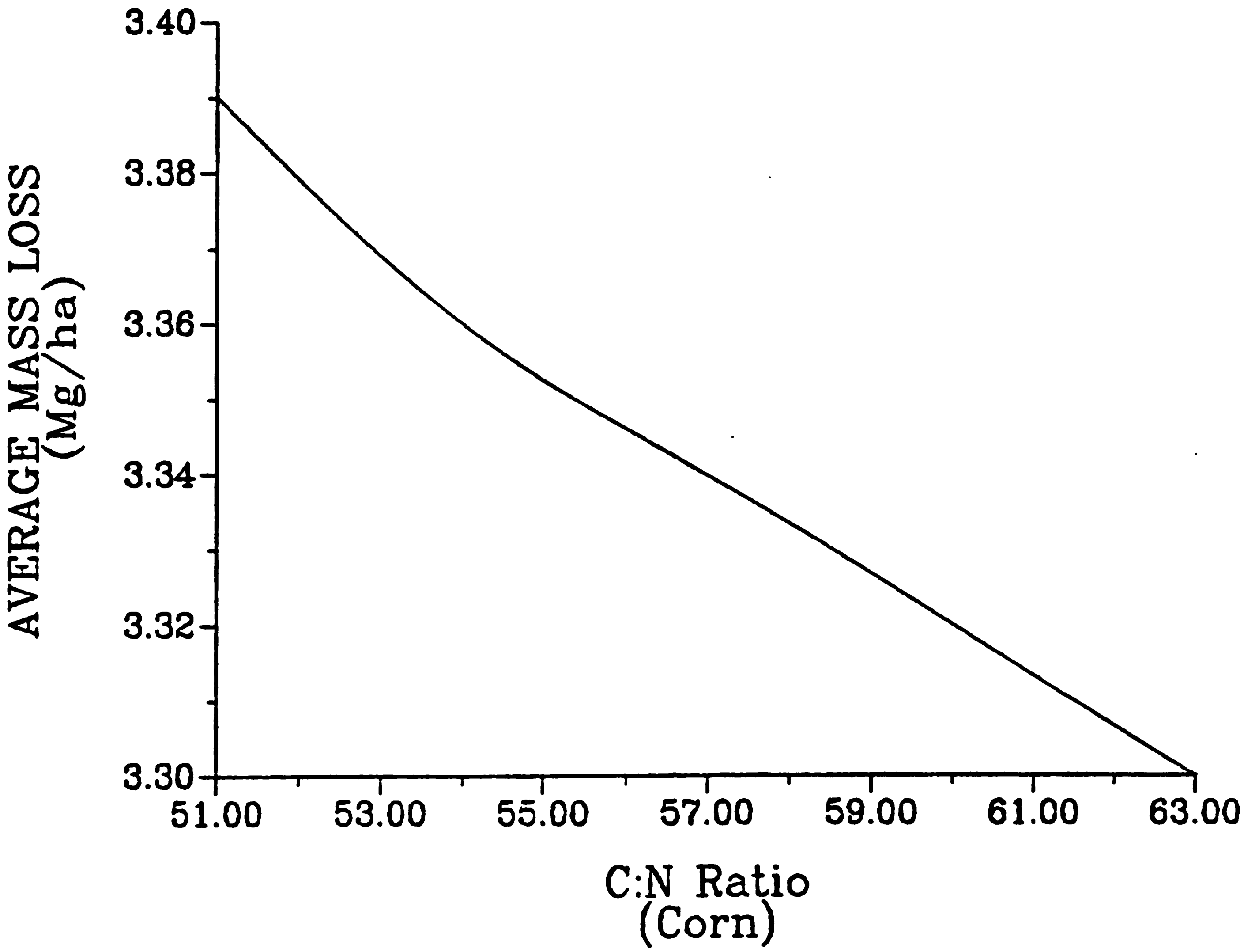

Figure 7 Sensitivity of Average Mass Loss to Intial C:N Ratio of Corn

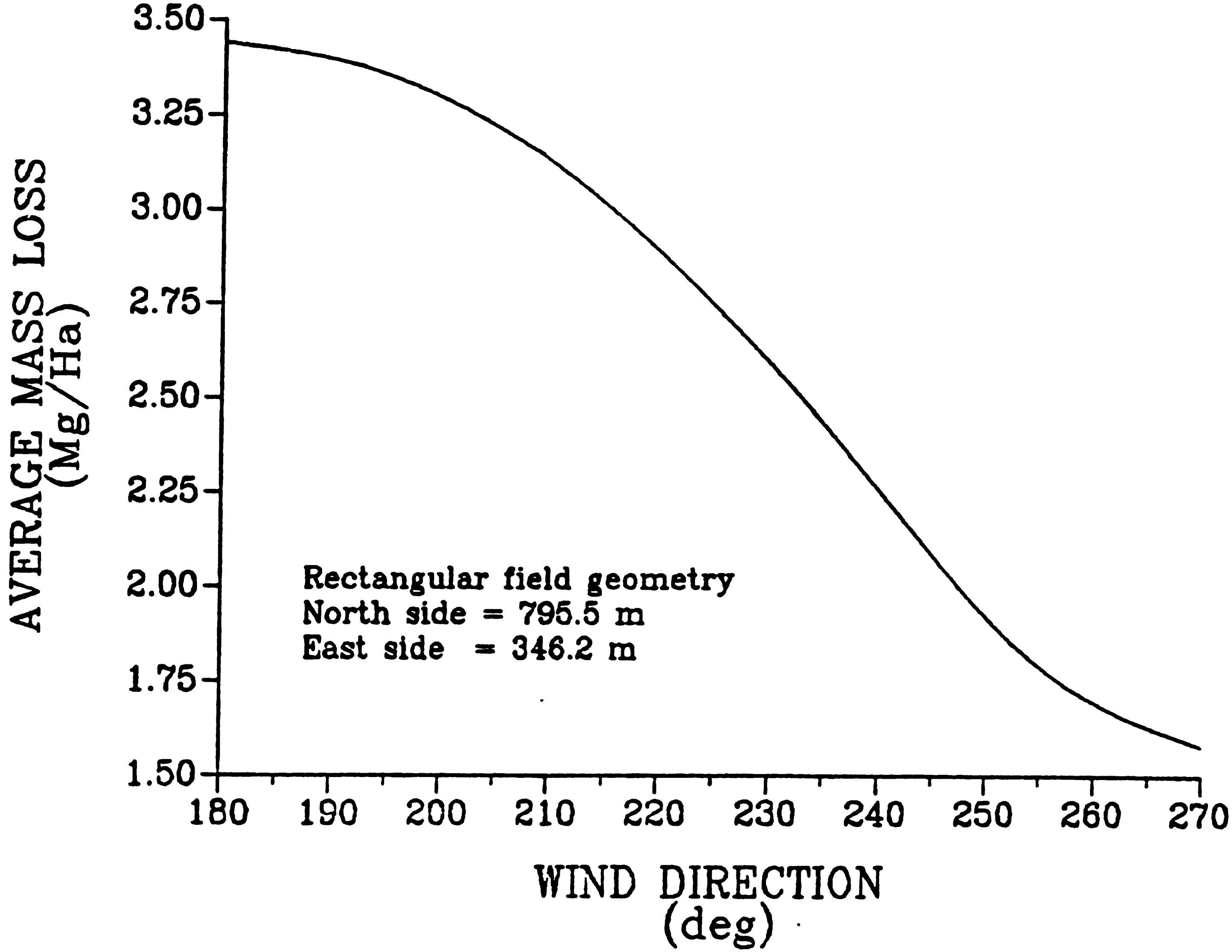

Figure 8 Sensitivity of Average Mass Loss to Wind Direction

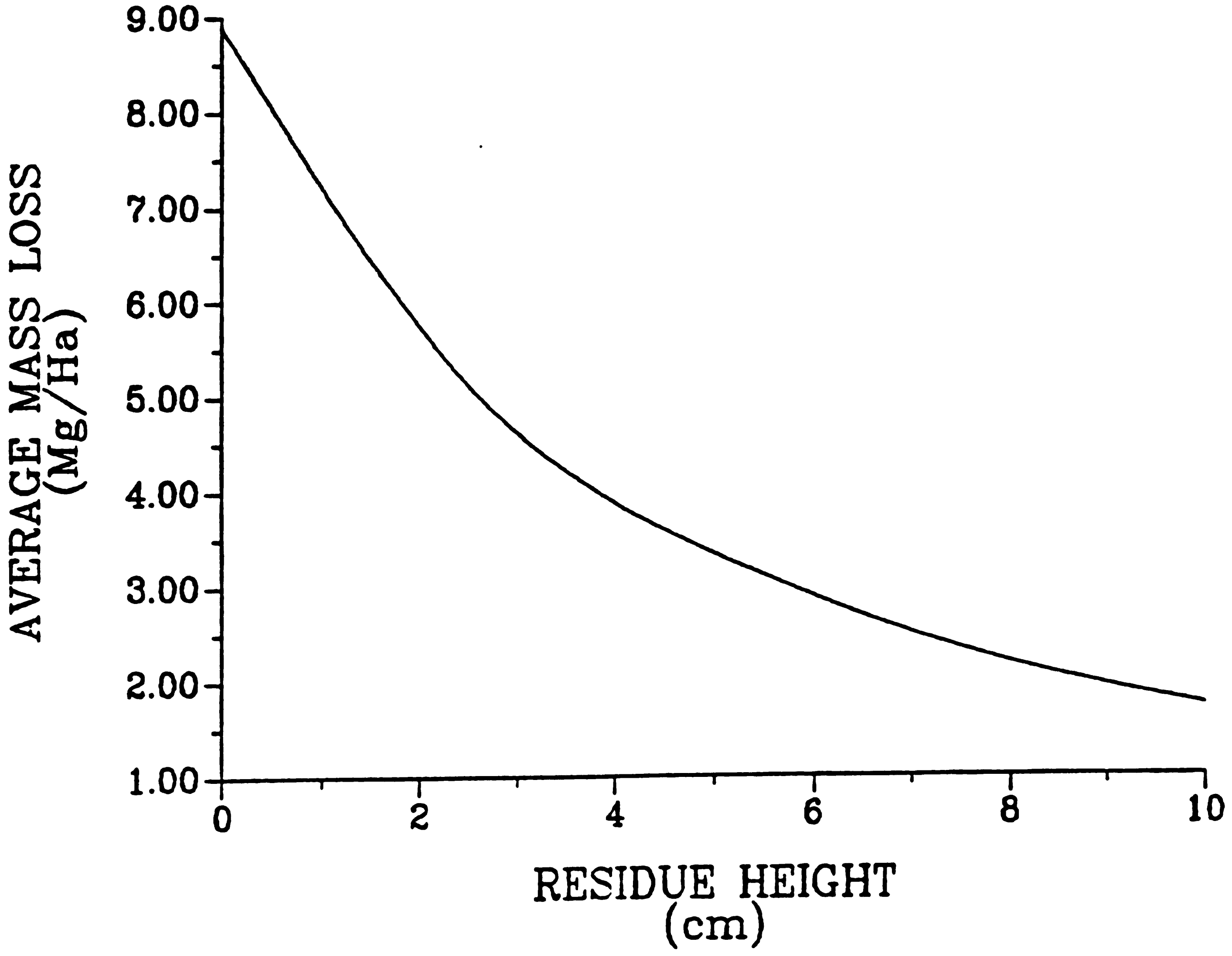

Figure 9 Sensitivity of Average Mass Loss to Residue Height

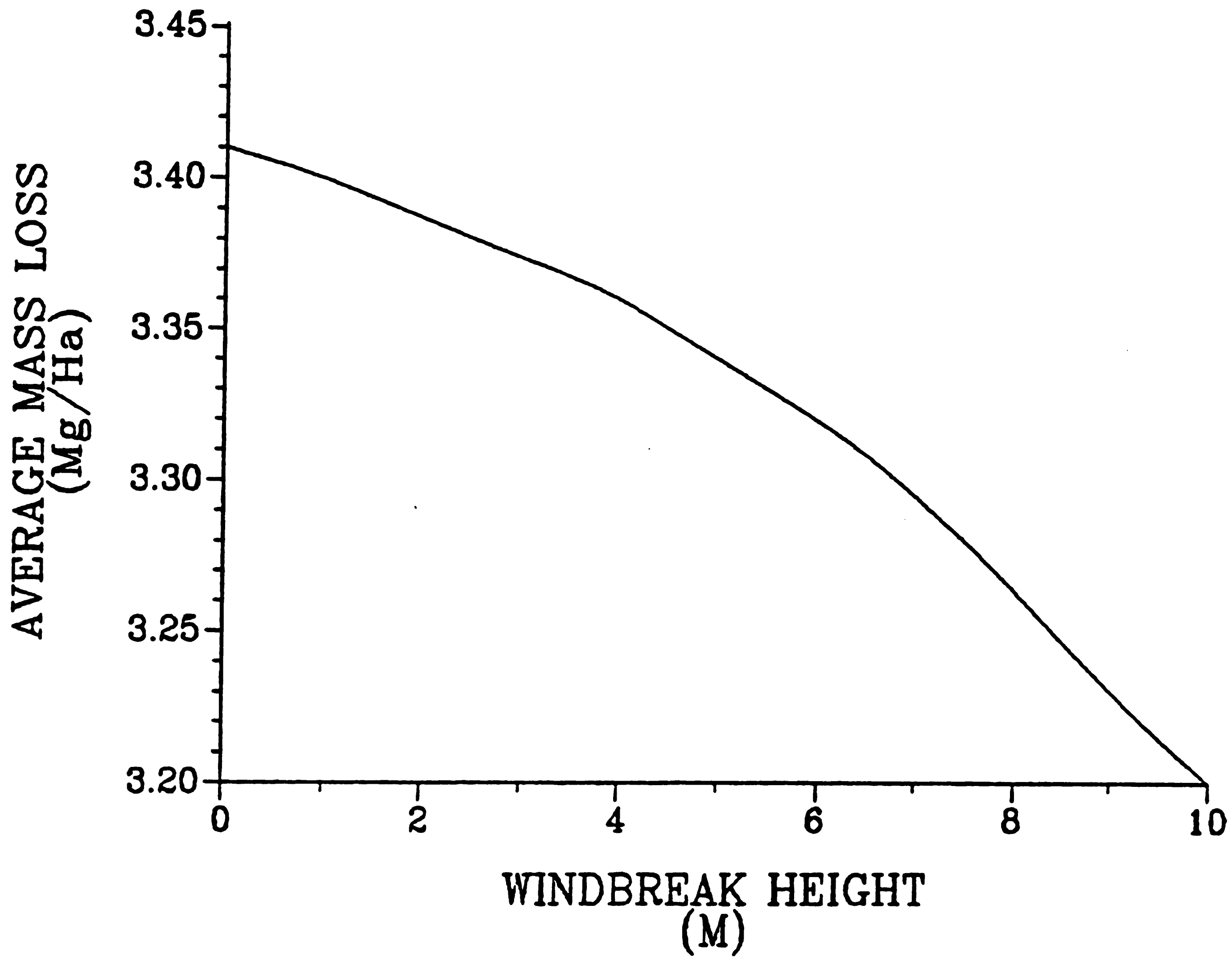

Figure 10 Sensitivity of Average Mass Loss to Windbreak Height

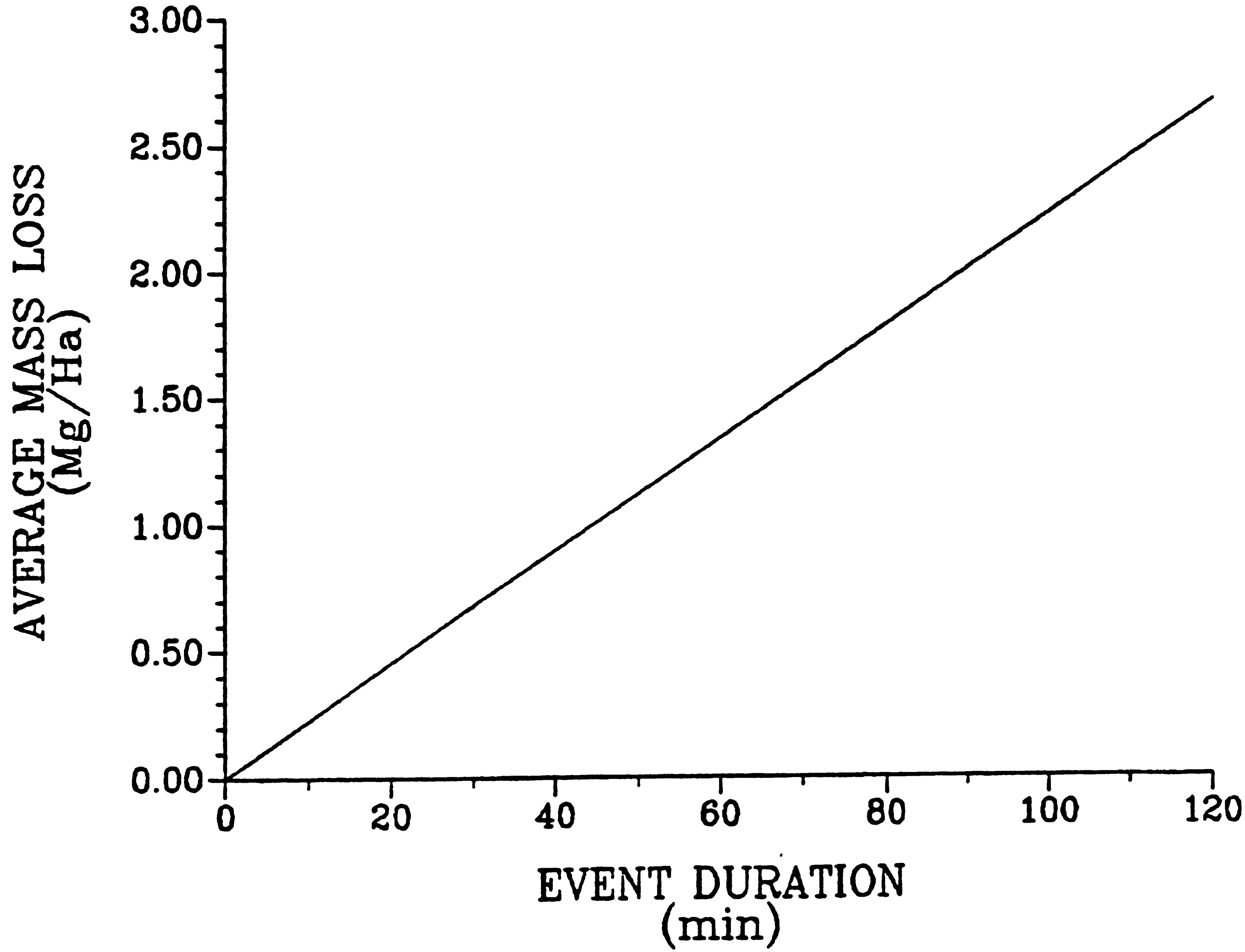

Figure 11 Sensitivity of Average Mass Loss to Event Duration

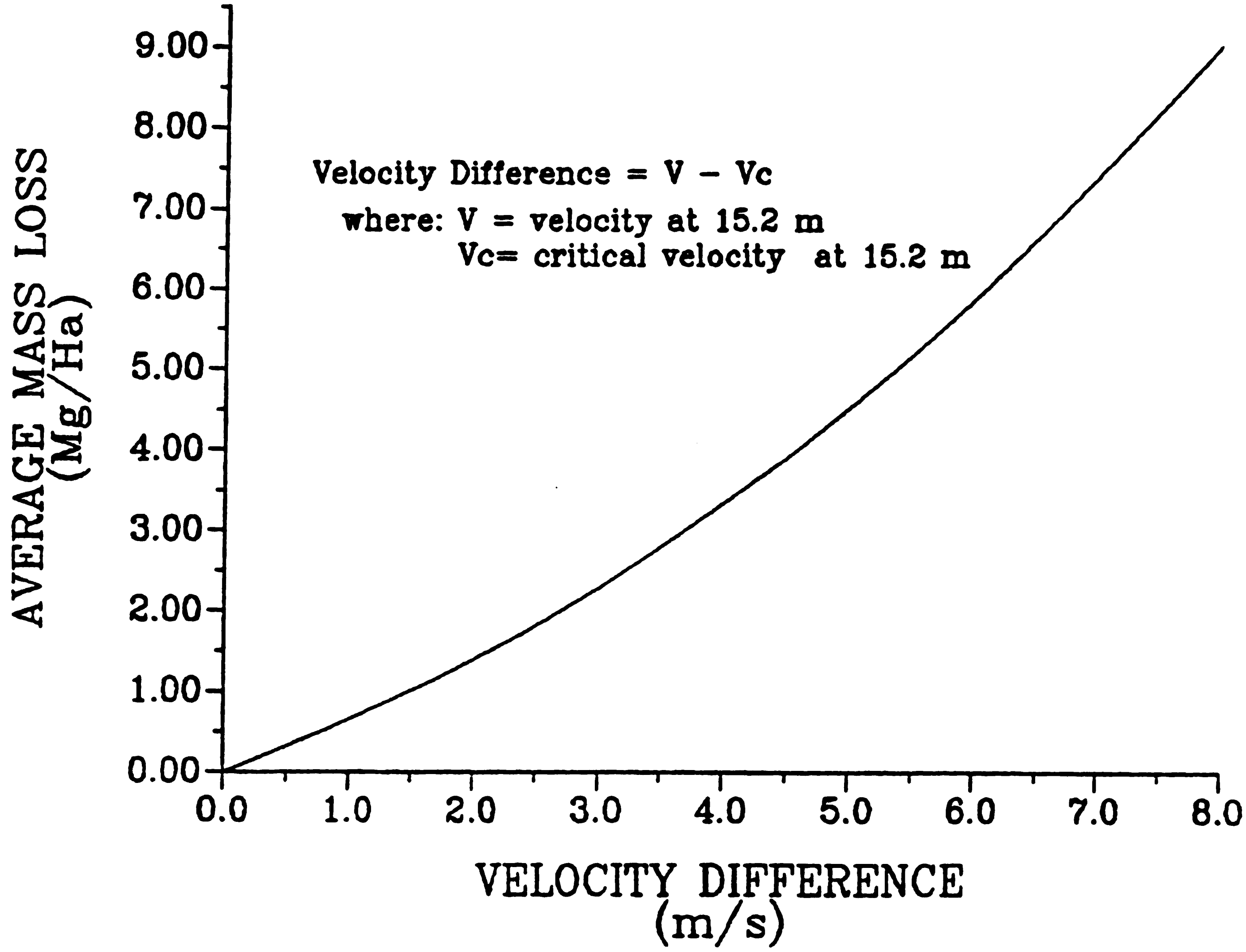

Figure 12 Sensitivity of Average Mass Loss to Velocity Difference

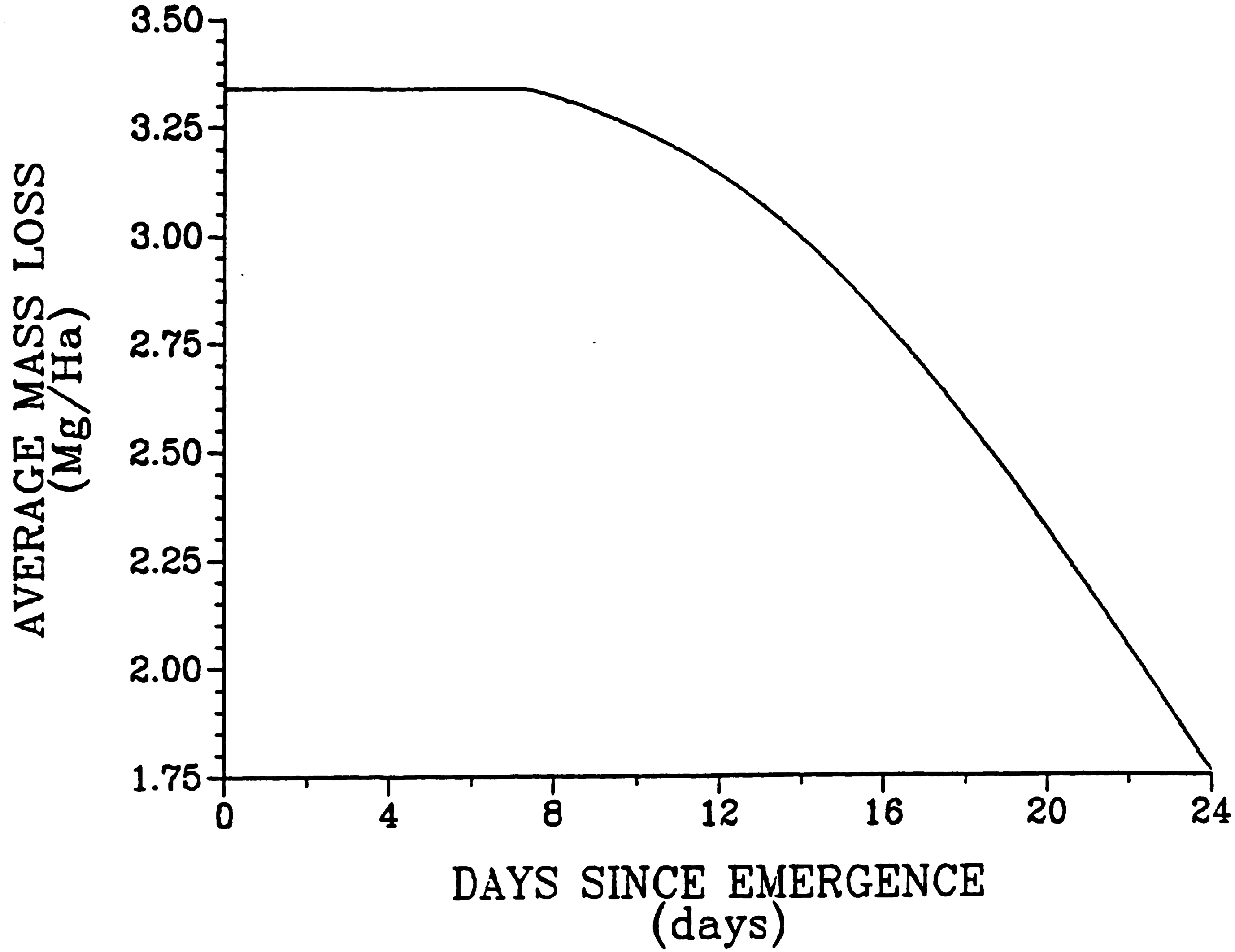

Figure 13 Sensitivity of Average Mass Loss to Days Since Emergence

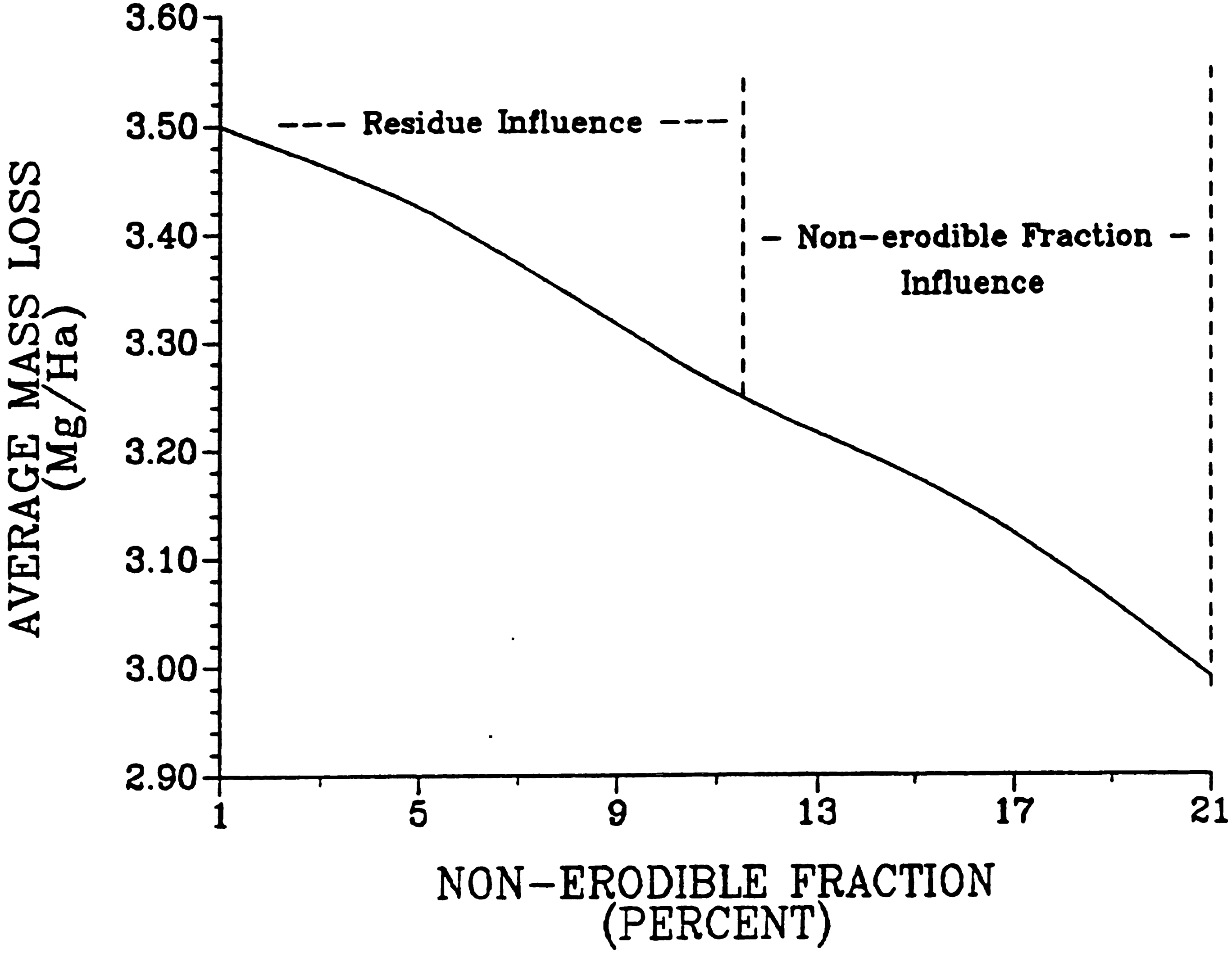

Figure 14 Sensitivity of Average Mass Loss to Non-Erodible Fraction

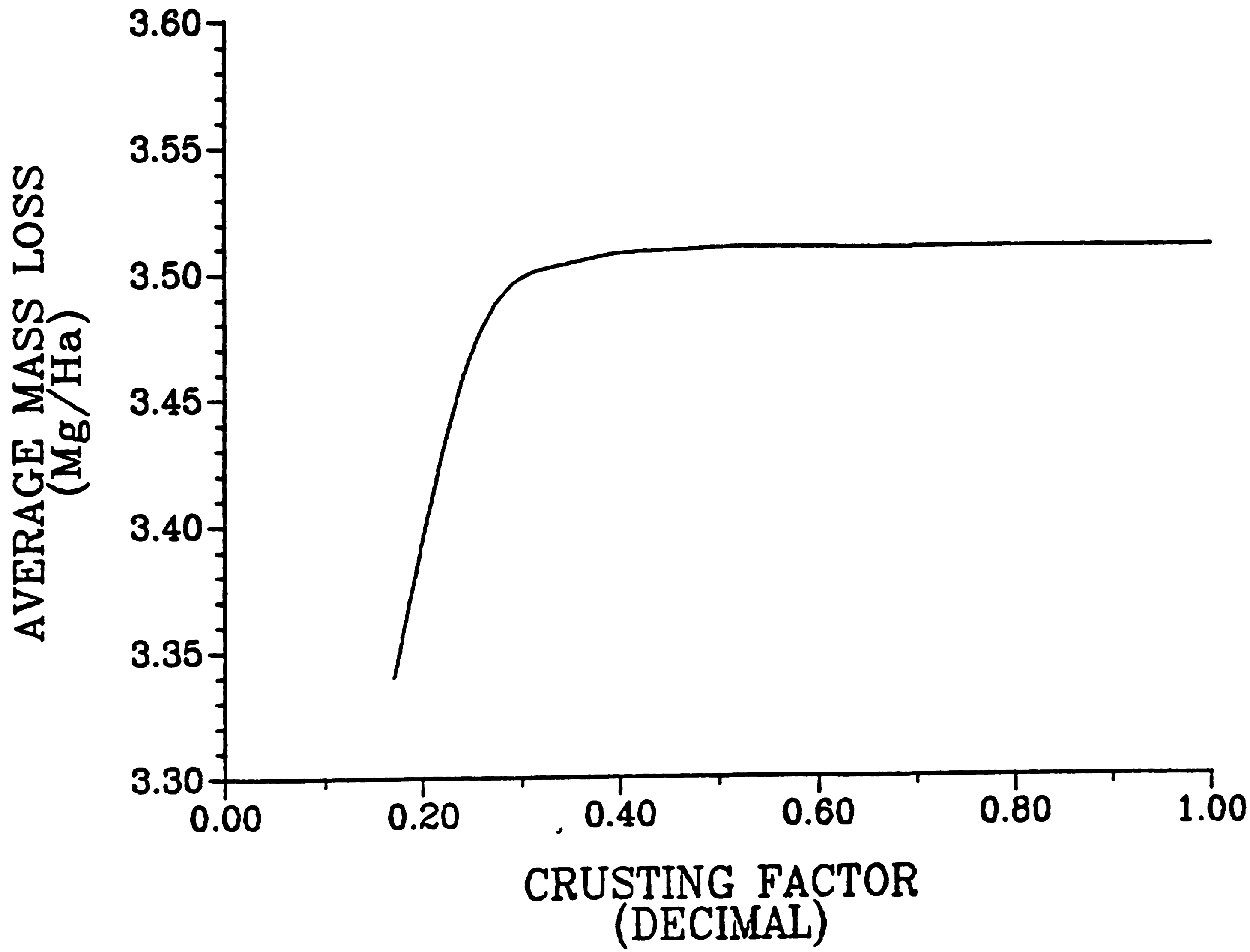

Figure 15 Sensitivity of Average Mass Loss to The Crusting Factor

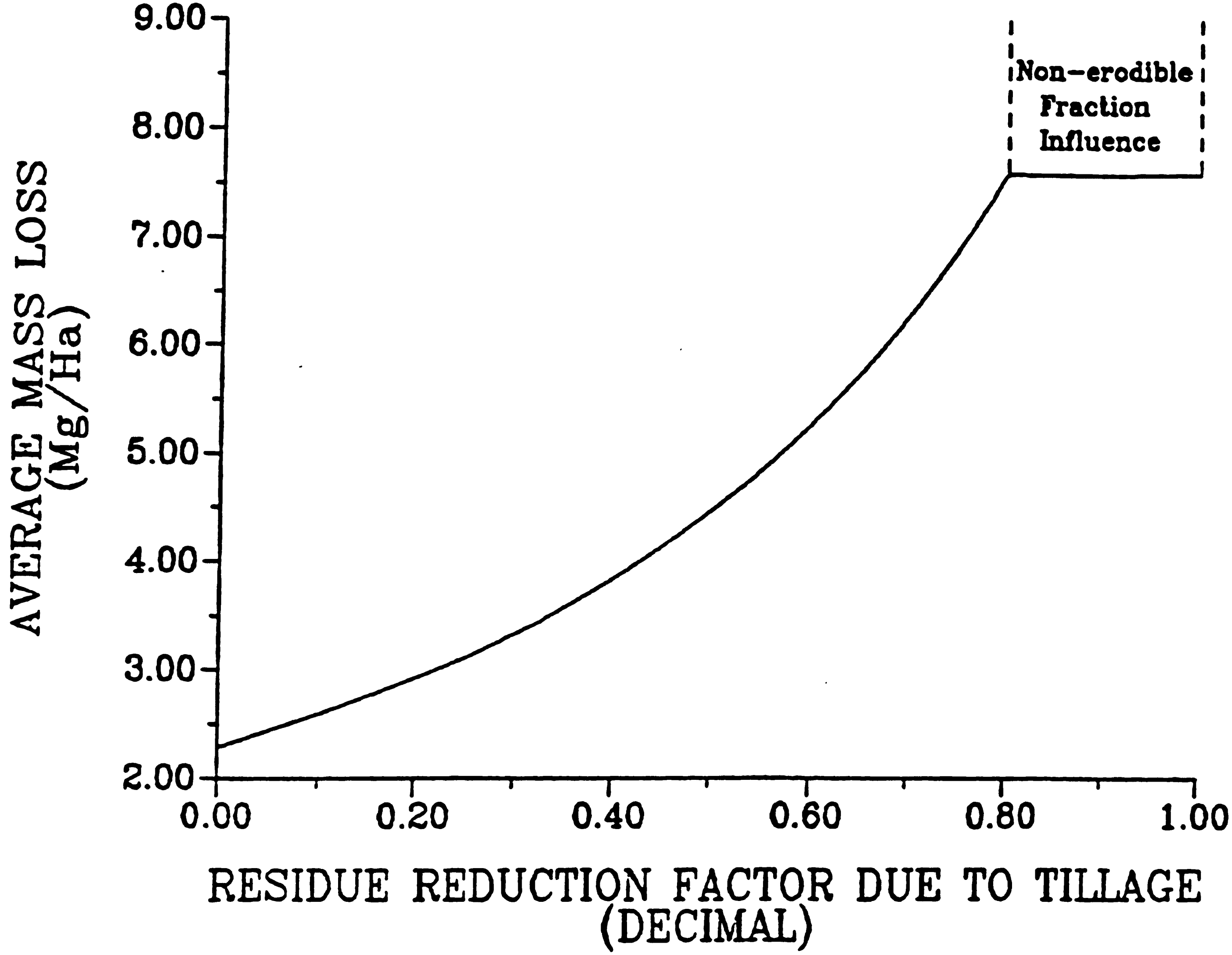

Figure 16 Sensitivity of Average Mass Loss to Residue Reduction Due to Tillage

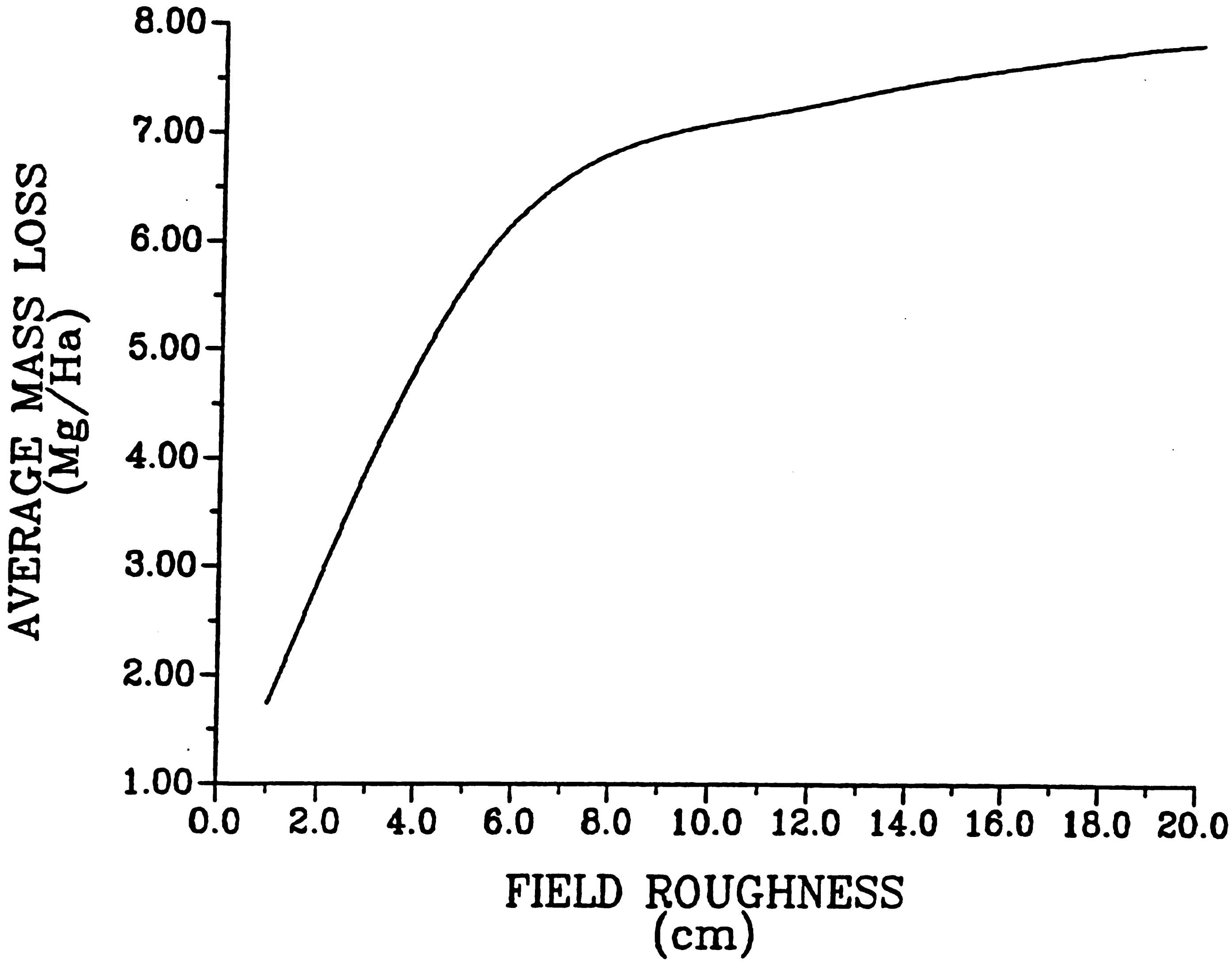

Figure 17 Sensitivity of Average Mass Loss to Field Roughness

V. Data Collection

Data collection was conducted for this study from December, 1984 to July 1985 and was funded by the Soil Conservation Service. The study was intiated to compare various tillage practices and tall wheatgrass strips for effective control of wind erosion. Data was collected in Bay County, Michigan where a diverse variety of agricultural crops are produced. Many of these crops produce little residue for wind erosion control. These crops include dry beans, sugar beets, and vegatable crops as well as the major state crops, corn, soybeans, and wheat. The county Soil Conservationist directed the supervision of a technician to maintain the samplers and weather station. Four sites were chosen for their tillage practice and/or the presence of tall wheatgrass strips, as well as their likely suceptibility to wind erosion. The four sites are as follows:

1. Satkowiak plot - crop (sugar beets)
   Moldboard plowed, loamy sand
2. Kipfmiller plot - crop (tomatoes)

   Moldboard plowed, tall wheatgrass strips, sand
3. Bleck plot - crop (half corn, half soybeans)
   Chisel plowed, sand

4. Wetters plot - crop (sugar beets)

Chisel plowed, tall wheatgrass strips,

sandy loam (ridges - loamy sand)

Modified Bagnold samplers (Merva and Peterson, 1983) were used for on site soil collection. Thirteen samplers were installed on the four sites. Two events were recorded during the sampling period. Due to a weather station malfunction the one event was not used for model verification.

The weather station was not erected on any of the sampler sites (approximately 3 miles from the plots) since the weather station was not portable enough to allow movement during spring tillage. AC power is also required during freezing weather to heat the instrument box and this was not available on any of the sample sites. The weather station is instrumented with two anemometers, a wind direction indicator, a temperature probe, a humidity sensor and a pyronometer. Data is logged on a Campbell Scientific CR-21 data logger and stored on cassette tapes. The tape is read through an interpretor box and stored on floppy disks. Two anemometers are required since threshold velocities are defined at low heights (30 cm or less). The two velocities at different heights allow a lognormal distribution to be fitted and extrapolated down to the defined threshold velocity height. Refer to appendix A for further information regarding the weather station. Appendix A also contains the data for the sampler sites and data used to verify the model.

VI. Experimental Verification Results

The model was adjusted to estimate the mass flux at a point. The sampler samples a 6.4 mm width of field. This, when compared to the width of the field can be considered a point estimate. Therefore, a point estimate is used to simulate the modified Bagnold sampler as it is used in the field. The data in Table 9 was used along with all the appropriate input data necessary for the model to simulate the wind event (all non-corn plots were bare except one, i.e. sugar beets, the crop cover was considerd to be that of corn). Table 10 lists the sampler collected mass, corrected mass, original model estimates, and the reduced K model estimates. Table 9 lists the input parameters that were changed from table 8 to run the model for each sampler. The model was modified to run through the event in 5 minute increments because the data was taken at that time increment. A modification (variable effective field length, constant wind direction) is also necessary to simultate the field as seen by the modified Bagnold sampler.

The reduced K model estimates were conducted because the soil erodibility values used were based upon an annual basis, while this model is based on an event. Therefore, a model run for all the collectors was made with the K value reduced by 90 percent. Figure 18 gives a graphical plot of the collected mass to the estimated mass. Figure 19 gives a graphical plot of the collected mass to the reduced mass from the reduction of the K values. A particle size analysis was performed on the plot soils and collected sampler masses. A sampler efficiency was estimated from this data (appendix A). The efficiency was determined to be approximately 80 percent. Therefore, Figures 20 and 21 show the results of both model runs with the corrected sampler masses. The data presented are only for the May 31, 1985 wind erosion event.

Table 9

Intialized Parameters For Field Runs

	Wetter	Satkowiak	Kipfmiller	Black	
				corn	bean
13. Fall Residue Cover	0.17	0	0	0.38	0.28
18. Event Date	053185	053185	053185	053185	053185
20. North Field Length (m)	375	387	371	795	795
21. East Field Length (m)	680	597	375	346	346
23. Residue Height (cm)	0	0	0	3.0	0
25. Windbreak North (m)	10.7	0	0	0	0
26. Windbreak East (m)	12.2	6.0	0	0	0
27. Windbreak South (m)	0	0	7.6	0	0
28. Windbreak West (m)	0	0	0	0	0
29. Event Duration (min)	5	5	5	5	5
30. Critical Velocity (m/s)	15.0	15.0	15.0	15.0	15.0
34. Emergence Date	----	051085	----	050585	----
35. Non-erodible Fraction(%)	1.4	8.1	4.6	3.0	3.0
36. Crusting Factor	0.7	0.7	0.7	0.7	0.7
37. Factor Spr. Till. (res.)	1.0	1.0	1.0	0.35	1.0
39. Field Roughness (cm)	2.0	2.0	2.0	3.0	3.0

note - all values not specified are the same as in table 8.
- Satkowiak plot was planted in sugar beets, the planting date was therefore manipulated until corn height was equal to sugar beet height.

Table 10

Collector and Model Estimate Data

(May 31, 1985 wind erosion event)

Collector#	Mass Collected (g)	Corrected Mass (g)	Original Model (g)	Reduced K Model (g)
1	1536.9	1844.3	1495.7	523.5
2	278.2	335.0	1517.7	535.8
3	935.5	1122.6	5505.6	3702.4
4	167.9	201.5	1124.4	718.5
5	850.9	1021.1	6474.4	1120.8
6	2465.1	2958.1	6543.2	1602.8
7	12.6	15.1	2039.0	147.5
8	566.7	680.0	3040.0	360.2
9	27.5	33.0	3248.5	510.9
10	45.8	55.0	2395.7	150.0
11	214.3	257.2	3229.0	369.3
12	90.7	108.8	3326.0	513.4
13	333.2	333.2	1124.2	718.5

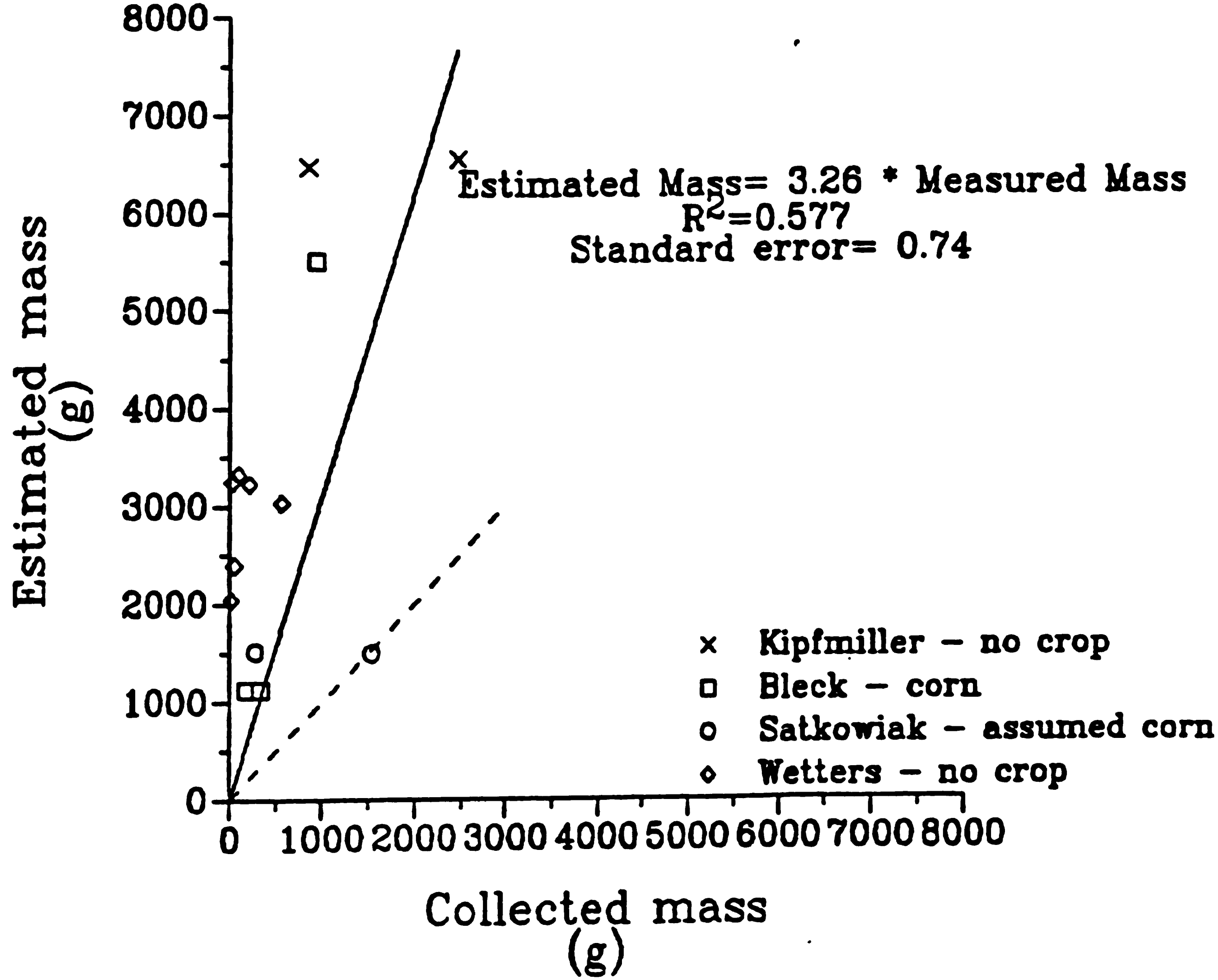

Figure 18 Collected Mass verses Estimated Mass for Original Model Run

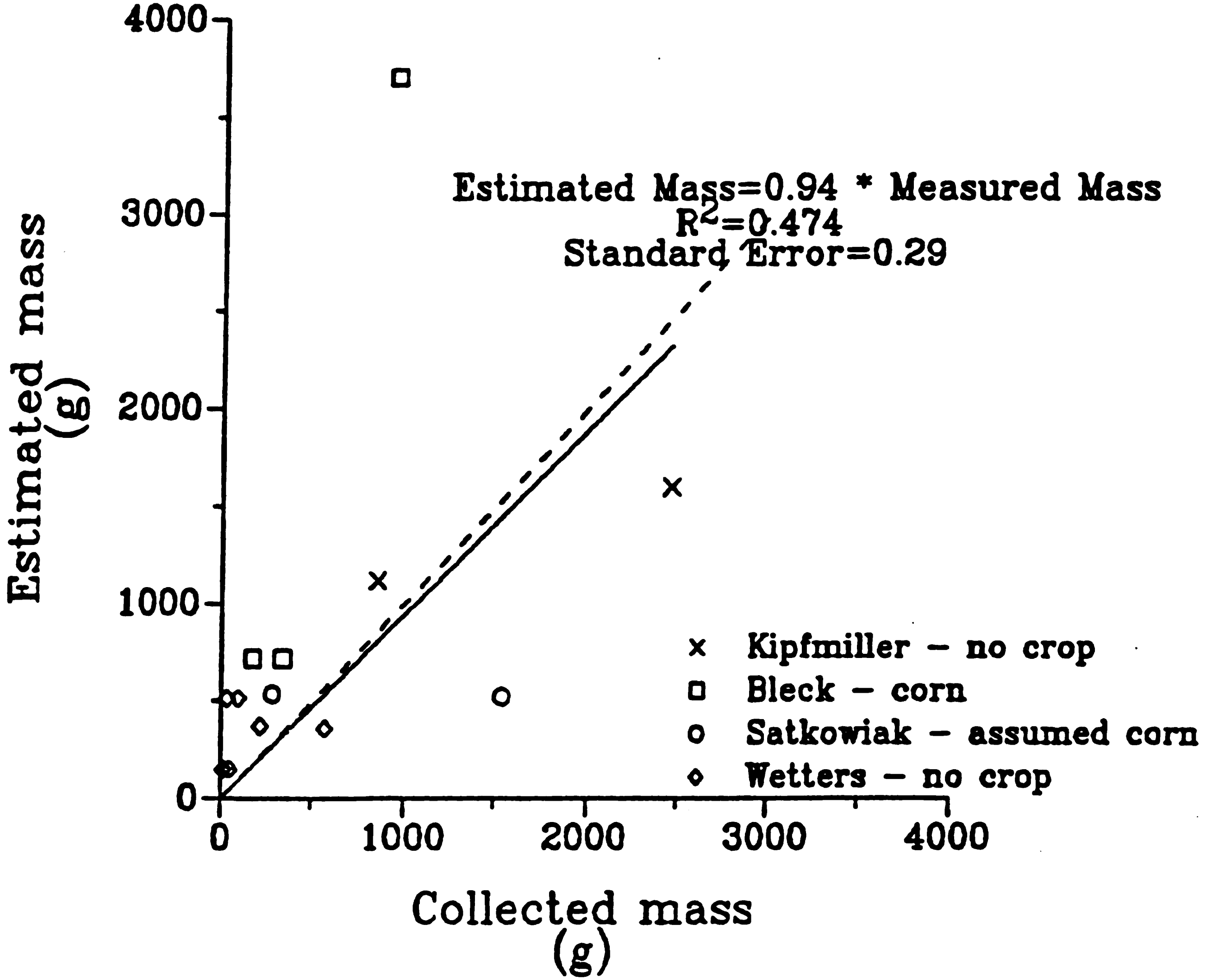

Figure 19 Collected Mass verses Estimated Mass For Reduced Erodibility Model

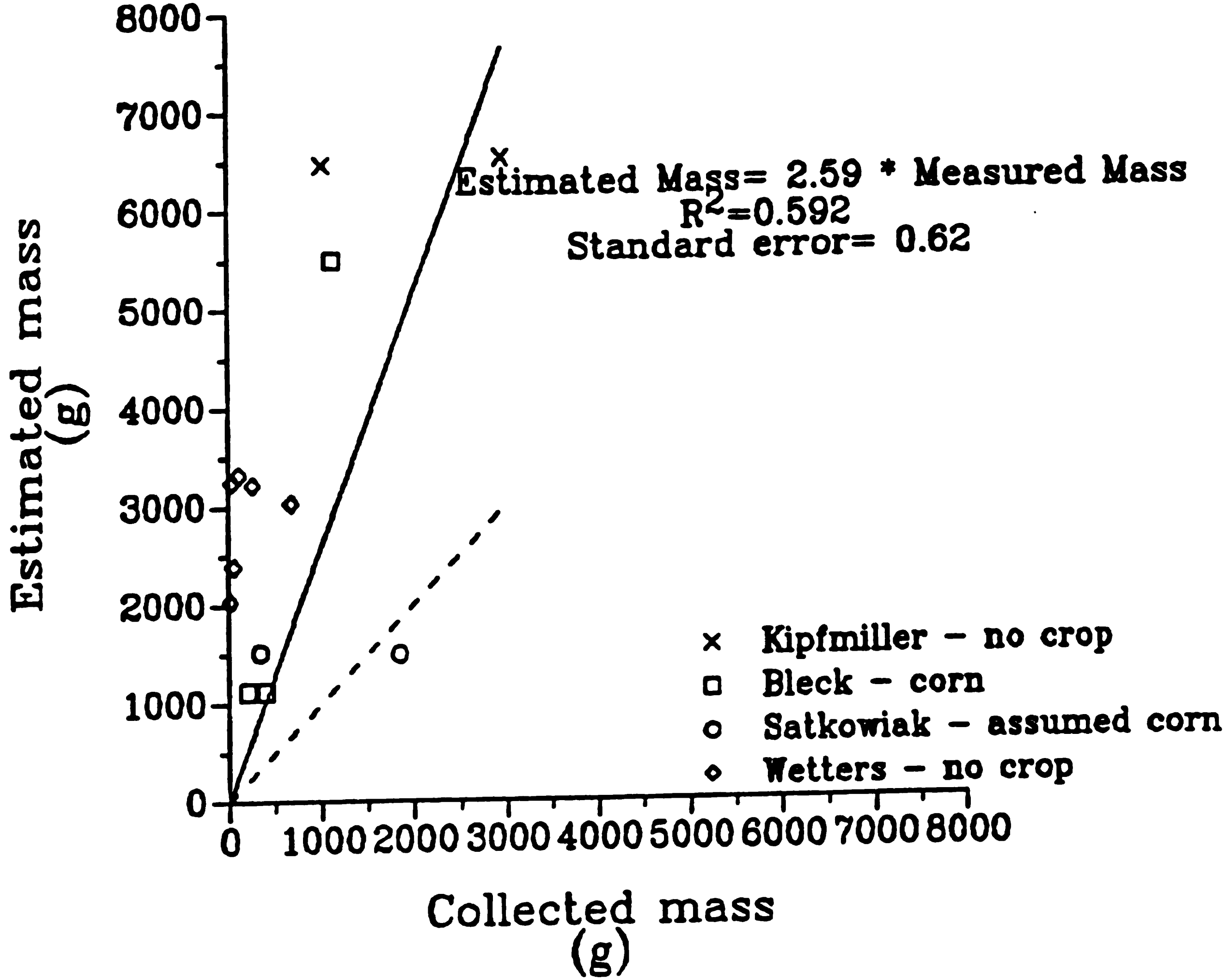

Figure 20 Collected Mass verses Estimated Mass for Original Model Run with Sampler Corrections

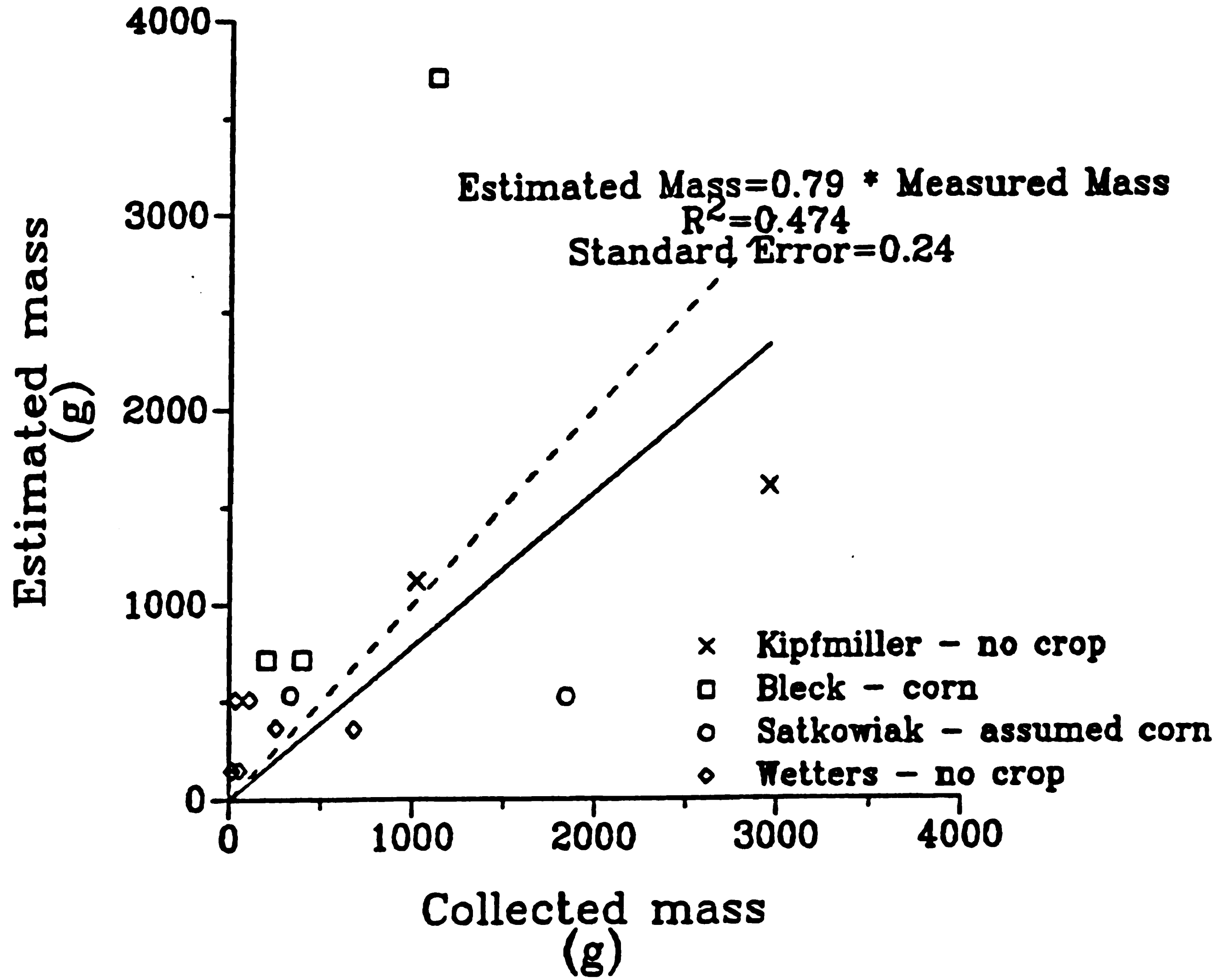

Figure 21 Collected Mass verses Estimated Mass For Reduced Erodibility Model With Sampler Corrections

VII. Discussion

In the developement of an event based model, one must consider the actual need and advantage of this research. The Wind Erosion Equation (WEE) has accomplished the need for an indicator of potential soil loss by wind for a agriculturally cultivated field. The WEE has supported the obvious fact that soil cover must be increased to decrease soil movement. The concern that has been raised with the WEE is, the equation is accurate quantitatively only in Kansas where it was developed. A more far reaching problem is that the WEE does not give any information as to the occurence of a single wind erosion event. Event based modeling provides the ability to estimate the soil movement off a particular field with a particular cover over a short duration of time, i.e. single wind event. The analysis however is much more complex and requires substantial computer use. The eventual advantage of this type of modeling will be the ability to include probablistic weather generators (wind speed, wind direction, temperature, and moisture). Weather generators will give the ability to estimate potential annual soil loss which the WEE has provided in the past while being able to predict soil movement for a single erosion event.

The assumptions that the model has been based upon are again listed below.

1. Event based model
2. Dry soil conditions
3. Rectangular field
4. Short duration wind events
5. Homogeneous soil texture
6. No particle flux onto the field

The first assumption has been discussed previously and assumption two will be discussed in depth later. The assumption of a rectangular field is important because of the limitation of the geometry being considerd in the model. The question that is raised here is, what is the length of the field as seen by the wind? In the event that the wind intersects the field at angles parallel or perpendicular to the windward field boundry then the effective field length is straight forward (i.e. the length or width of the field). A problem exists when the wind intersects the field boundry at any angle greater than zero or less than 90 degrees. It is possible that any two lines are drawn across the field in the direction of the wind will be of differing lengths. The subsequent problem becomes, what is the effective field width at differing wind directions? In the model, a elipse was fitted in the interior of the field and used as a boundry for determination of effective length of field (Cole, Lyles, and Hagen, 1983). Since the area of the field is constant regardless of wind direction, the effective field width is found by dividing the field area by the effective field length. There is no theoretical basis for using an elipse to define effective field length but for a lack of a better approach this method is used in the model.

Assumption four, short duration wind events, are important because if a wind event occurs long enough, the windward side of the field can become bare of erodible particles. This denuding of erodible particles would change the characteristic mass flux along the length of the field. In Michigan, wind events usually occur over time periods of less than 4 hours and of wind velocities slightly greater than the particle threshold velocity. Therefore, short duration wind events are considered a reasonable assumption for wind event modeling in the humid states such as Michigan.

Assumption five will be discussed in depth later in the discussion section. Assumption six, no particle flux onto the field is assumed so that the mass flux at the leeward boundry can be set equal to zero. Under actual field conditions this boundry condition is not always acceptable. A significant problem exists when two crops are grown on the same field or when fence rows do not provide enough cover to stop particle movement. The model however assumes one crop per field and that fence rows produce enough effective cover to eliminate particle flux onto the field.

Many factors contribute to the lack of completeness of this model. The following is a partial list:

1. Inability to model variable textural changes in a field.
2. Unreliability of soil erodibility values.
3. Problems in determing the wind profile for an event stemming from an inability to:
    a) estimate the roughness parameter (z_0)
    b) estimate the roughness height (d)
    c) estimate the duration of an event
    d) determine the effect of heat flux on the velocity profile
4. Uncertainty of the threshold velocity for a given soil texture and type.
5. Lack of a model to account for moisture and its effect on soil movement at the soil surface.
6. Lack of ability to quantify the effect of surface crusting on soil movement.

Another uncertainty is the data itself. The following is a list of some of the areas of concern when considering sampling data.

1. Sampler efficiency for saltation is not 100%
2. Low efficiency in sampling creep
3. No suspension sampling

Soil erodibility values were taken from Chepil (1957) and Skidmore and Woodruff (1968). Soil erodibility is defined as the potential soil loss in tons per acre per annum from a wide, unsheltered, isolated field with a bare, smooth, noncrusted surface (Woodruff and Siddoway, 1965). The values were originally determined on an annual basis and, therefore, are not applicable to event based modeling in their present form. High soil erodibility values seem to be the case when considering the original model results in table 10 (page 56). The Kipfmiller plot, samplers 5 and 6, have very similiar results. The Kipfmiller plot can be considered texturaly homogeneous. However, sampler 6 is down wind of sampler 5 and has approximately twice the unprotected field length. Both samplers would be expected to be collecting at a rate much less than the maximum flux rate for the field. This is verified by the sample results presented in table 10. Sampler 6 collected approximately 3 times more mass than sampler 5. In table 10, the fourth column gives the results for the model when the soil erodibility values were decreased by a factor of ten. Sampler 5 is approximately one third less. This is more in line with what is expected when the avalanching affect is considerd. One of the best features of Gregory's equation is the ability to estimate the increase of soil movement as one moves downwind in an eroding field.

Much of the variability in the field data taken can be explained by the non-homogeneous textural nature of the sampled plots. This presents a particularly difficult problem for modeling wind erosion in such states as Michigan where two or more textural groups are quite common in agricultural fields. The best example of this can be seen in the Wetter plot. Samplers 7-12 in table 10 (page 56) are on the Wetter plot. Samplers 7, 9, 10, and 12 are on a sandy loam while 8 and 11 are on loamy sand. From table 10, samples collected in 8 and 11 are from 5 to 50 times larger than the other samplers. While this is not all due to soil textural differences, a large amount of the difference can be attributed to textural non-homogeneity.

Correctly modeling the velocity profile appears to be the most important variable in a wind erosion model. Soil movement is a function of the cube of the wind velocity. The velocity determines another important parameter neccesary in event modeling soil movement, i.e. the duration of the erosion event. Several problems exist in the modeling of wind velocity profiles. In the past as well as presently, velocity profiles are modeled assuming neutral atmospheric conditons for wind erosion work (Hagan, 1986; Gregory, 1986)*. The assumption is that the turbulence is well enough established at winds high enough to cause wind erosion to negate the influence caused by heat flux from the soil surface. Negating the effect of heat flux was questioned in this study and an alternative method for determining the wind velocity profile, Swinbank (1964), was used to compare with the neutral velocity profile equation. Referring to Table 11 (page 67), it does appear that at the

* Personal communication

Table 11

Comparison of Neutral verses Heat flux

Fitted Velocity Distributions

		Height (m)			
Time	Data type	0.15	2.3	6.7	15.2
1635	WS	...	7.58	13.58	...
"	WSH	...	7.56	13.47	17.87
"	WSN	...	6.26	13.58	18.67
1720	WS	...	8.30	16.72	...
"	WSH	...	8.30	16.71	23.14
"	WSN	...	7.70	16.73	22.98
1920	WS	...	7.06	12.64	...
"	WSH	...	7.05	12.61	16.82
"	WSN	...	5.82	12.65	17.38

WS - weather station data

WSH - weather station data fit accounting for heat flux

WSN - weather station data fit using neutral conditions lower elevation (2.6m) heat flux does effect the profile. For that reason, heat flux effects were used to determine the wind velocity profile for input into the model. The lower elevation wind velocity is critical since threshold velocities are defined at heights of 30 cm or less.

Another difficulty arises in estimating the roughness parameter (z_0) and roughness height (d). These values have been determined empirically for well established crop covers (page 9) however, they are not well defined for bare soil surfaces or newly established vegetative covers. The importance of these parameters can be shown by the change in threshold velocities (Figure 22).

Determining the velocity profile directly determines the duration of the event. The event duration is the amount of time the wind exceeds the threshold velocity. Therefore, the velocity distribtion provides an estimate of the beginning and the end of the event. Referring Figure 23, the extent of this problem becomes more evident. Figure 23 shows that the wind velocity is not steady state and that the wind exhibits spikes of higher intensities. Figure 24 indicates further the unsteady wind velocity conditions by tracing the wind direction during a wind event. In this study it was determined that erosion occurs on the upper portion of these spikes. The problem of determining the event duration then becomes quite apparent. The estimated duration of the storm is much less, if small increment time measurements of the wind velocity are used, verses, using a

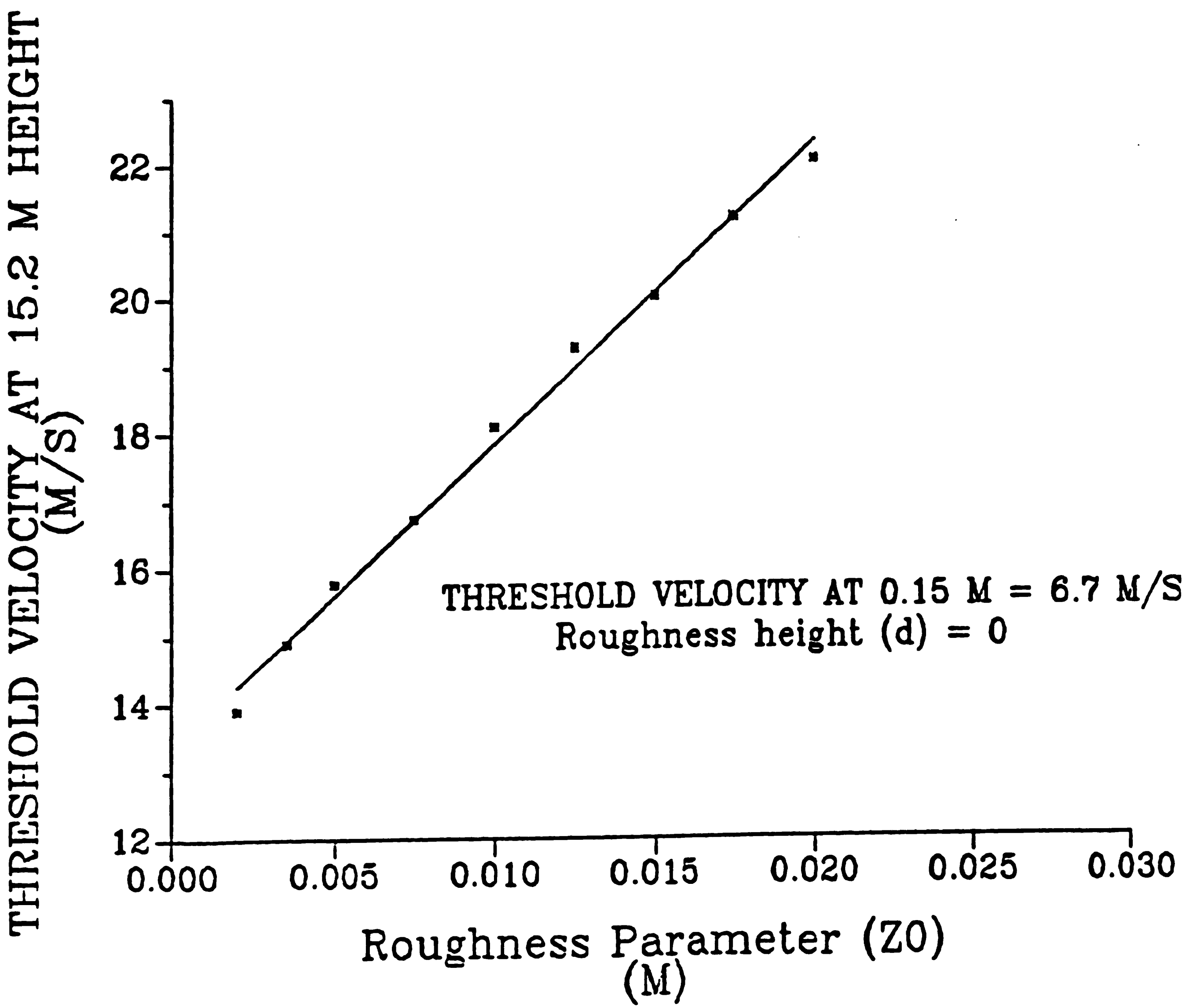

Figure 22 Roughness Parameter verses Threshold Velocity

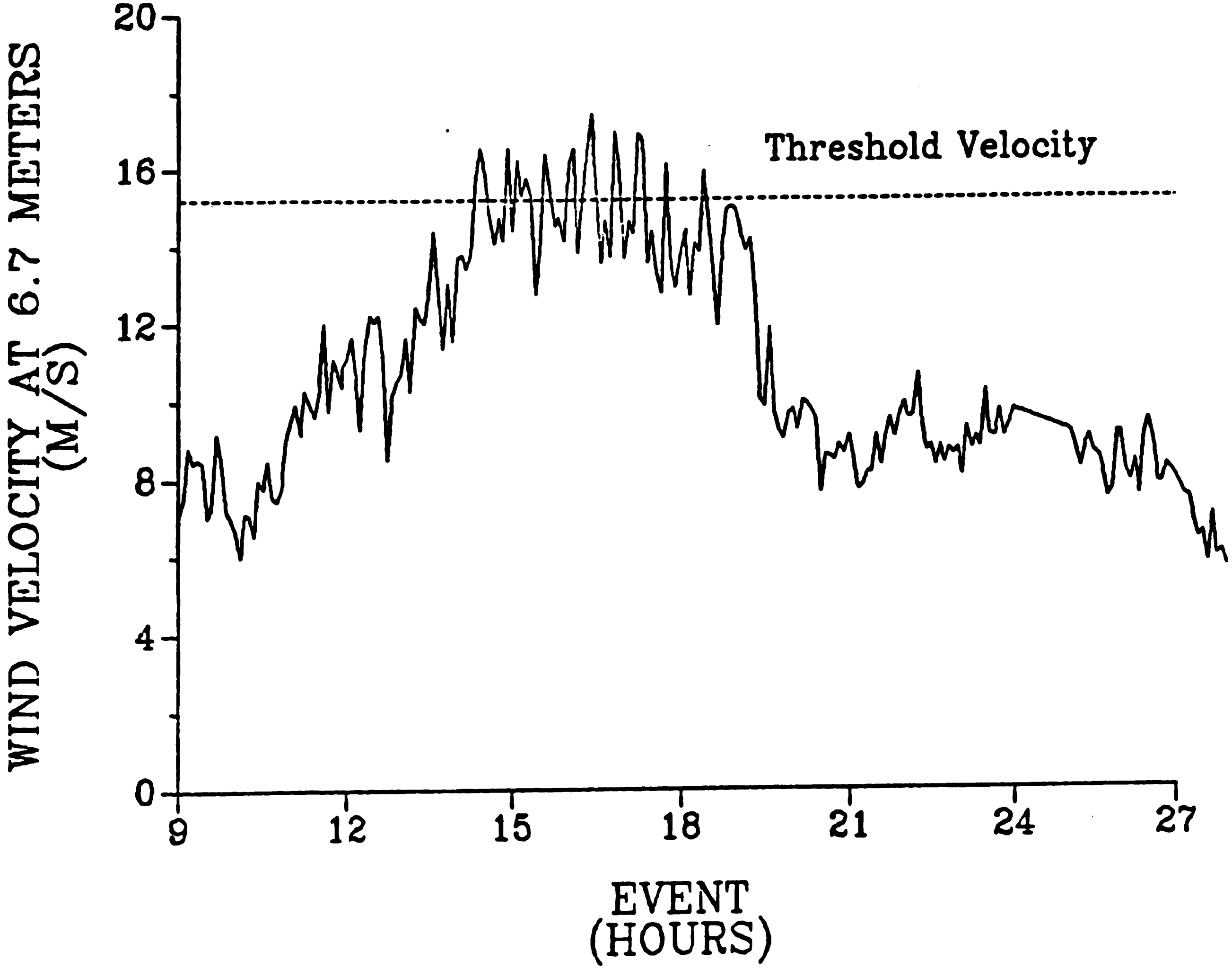

Figure 23 Wind velocity during 5/31/85 Wind Event

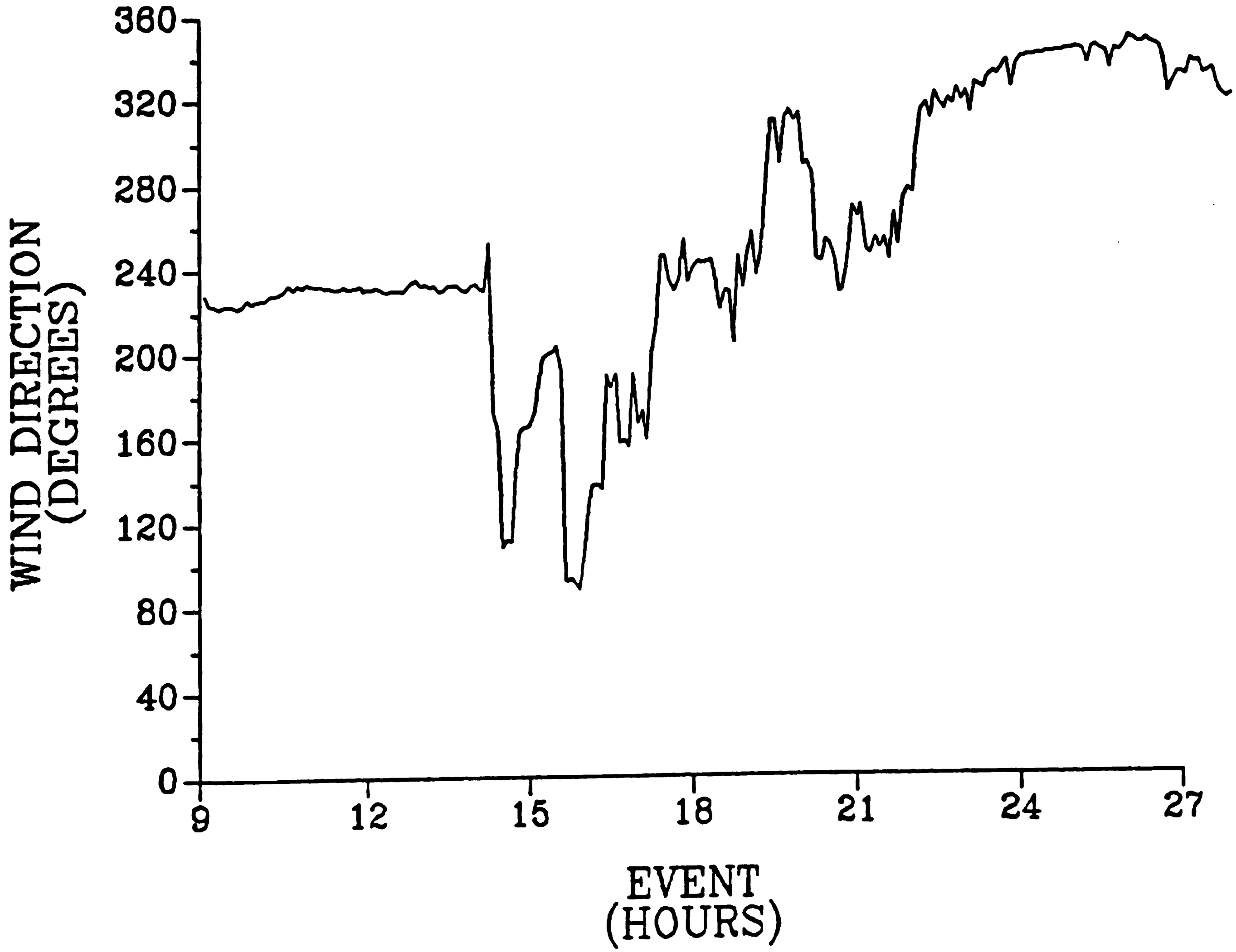

Figure 24 Wind direction during 5/31/85 Wind Event

larger estimated time increment average (Figure 27 data was taken at 10 second intervals and averaged over 5 minute increments for plotting).

Wind data reported across the United States does not include wind velocity at two different heights. Therefore, for general use of the model a generalized velocity profile must be developed for use in event based modeling. The generalized velocity profile would have to utilze the standard 6.7m (22 ft) height wind velocity, estimated parameters Z_0 and d, and some how account for the high intensity spikes referred to above. The duration then could also be reasonably estimated for a given wind storm.

Threshold velocities were considerd to be constant for the soils considerd in this study. There is no definitive data available for determining the threshold velocity for a given soil texture and type. Values that are availble are over wide ranges and take only soil texture into account. Other factors such as organic matter and moisture content are not considered. These missing factors cause large gaps in modeling wind blown soil movement. In many cases, a wind event will be preceeded by a rain storm in humid states such as Michigan. The influence of moisture upon soil movement has been noted by the soil conservationist and the technician working on the data gathering project. Due to the lack of information on soil moisture at the surface, no attempt was made in this model to account for the moisture effect on soil movement by wind and therefore dry soil conditions were assumed. Some data is available on soil movement verses moisture content relative to a limited number of soil textures. However, little work has been done to model soil moisture at the soil surface (approximately 1 cm depth). Soil moisture profiles have been observed in the literature but modeling attempts have not been successful.

During the spring months, in humid regions such as Michigan, many times a low pressure front will be followed by a high pressure front. The low pressure front will produce rain and the large pressure gradient between the fronts cause a wind event. With a high probability of rain storms proceeding wind events, crusting becomes increasingly more important as an input parameter for modeling wind erosion events in humid regions. The biggest problem occurs when a soil has been finely tilled for seed bed preparation and then receives an intense rainfall that seals the ground surface. How to quantify a particular crust's effect on erodibility has not been addressed adequately. Skidmore and Woodruff (1968), state that for a fully crusted soil, the soil erodibility values should be reduced to one-sixth of the table value regardless of soil texture. This is the only guideline at this point to estimate the effect of a crust on soil erodibility.

Observations over the course of the project tend to indicate that crusting may create the best cover for erosion. The crusting observed to give the best cover is not that resulting from a single rain storm on a recently tilled field, but rather from crust development over the course of the winter. This type of crusting seems to be markedly better in reducing erosion. The formation of this crust seems to be responsible for the small amount of erosion occuring before spring tillage. The period before spring tillage tends to be quite windy in Michigan but soil movement tends to be relatively minor when compared to after tillage events even on the most erodible and barest of fields.

To validate the model, adequate data must be available. The model is justified with only one documented wind event. This is not uncommon in wind erosion work since data is difficult and expensive to obtain. Due to the non-homogeneous soil conditions, noisy data is to be expected. However, noisy data creates poor regression fits with model prediction estimates. Noisy data will occur until non-homogeneous conditions can be reasonably modeled. Referring to Figures 18 and 19 (pages 57 and 58), the correlation coefficient value is very low due to the noise caused by non-homogeneous soil conditions. Many events are needed to adequately validate the wind erosion model until non-homogeneous soil conditions can be accounted for.

Uncertainty of the data also exists in the overall efficiency of the sampler used to collect data. The sampler is not designed to collect suspended particles and its efficiency for collecting creep is low . The total overall efficiency was determined to be approximately 80 percent (actual particle size groupings can be seen in appendix A). For these reasons, it is certain that field masses collected are lower than the actual amount moving in the field. Figures 20 and 21 (pages 59 and 60) show that accounting for the efficiency does improve collected verses estimated model results.

VIII. Conclusions

A wind erosion model to predict soil movement on an event basis has been developed. Many facets of wind erosion mechanics remain untouched for use in humid regions, however conclusions can be made from this model development.

1) No wind erosion model will be accurate until the velocity profile can be adequately modeled.

2) Heterogeneous soil conditions must be included in a wind erosion model to reduce data verses model standard error.

3) Surface soil moisture was observed to reduce soil movement, but no attempt was made in this model to account for it.

4) Soil erodibility as defined and used in the Wind Erosion Equation is not adequate for event based wind erosion modeling.

5) The crusting affect on soil erodibility is not defined well enough for event based wind erosion modeling.

6) The assumption of homogeneous soil conditions require a large data base to verify event based model development on heterogeneous soils.

IX. Recommendations

1) Wind velocity profile parameters need to be better defined for bare and spring field conditions.

2) The effect of heat flux off the soil surface should be further developed.

3) The addition of the effect of changing soil erodibility across the field needs to included in future event modeling attempts.

4) Modeling surface moisture and its affect on soil movement is badly needed for humid region wind erosion modeling.

5) The data base is very limited for proper model verification. In the future, more and better quality field data will be required.

6) The development of a weather generator would provide the link to make comparisons with the Wind Erosion Equation.

APPENDIX A

A. Data Used For Model Verification

1. Site description

The sites will be referred to by the owners name, they are as follows:

1) Wetter
2) Bleck
3) Satkowiak
4) Kipfmiller

Wetter plot:

Tillage practice - chisel plowed
Crop previous year - soy beans
Crop present year - sugar beets
Soil type - Tappan, Ridges - Wixom
Erosion structures - tall wheat grass strips
Residue previous year - 17 %
Residue present year - none
Acreage - 30
Samplers - single strip: 3 samplers 7,8,9
 - double strip; 3 samplers 10,11,12
Windbreak north side - 10.7 m
Windbreak south side - 0.0
Windbreak east side - 12.2 m
Windbreak west side - 0.0
Intial tillage date - 12/1/84
Residue heigth - 0.0
Non-erodible fraction - ridges: 1.4% low ground:23.1%

Bleck plot:

Tillage practice - chisel plowed
Crop previous year - corn(east side),beans(west side)
Crop present year - same
Soil type - Wixom
Erosion structures - none
Residue previous year - corn 38 %, beans 28 %
Residue present year - corn 22 %, beans 0 %
Acreage - 80
Samplers - corn residue: 2 samplers 4,13
 - bean residue: 1 sampler 3
Windbreak north side - 0.0

Windbreak south side - east end: 9.1 m west end:0.0m
Windbreak east side - north end:3.0m south end:9.1m
Windbreak west side - 0.0
Intial tillage date - 11/20/84
Non-erodible fraction - 2.95%

Satkowiak plot:

Tillage practice - moldboard plowed
Crop previous year - corn
Crop present year - sugar beets
Soil type - Posyville
Erosion structures - none
Residue previous year - none
Residue present year - none
Acreage -65
Samplers - 2 samplers: 1,2
Windbreak north side - 0.0 m
Windbreak south side - 0.0 m
Windbreak east side - north end: 0.0m south end: 6 m
Windbreak west side - 0.0 m
Intial tillage date - 11/20/84
Residue heigth - 0.0
Non-erodible fraction - 8.1%

Kipfmiller plot:

Tillage practices - moldboard plowed
Crop previous year - tomatoes
Crop present year - tomatoes
Soil type - Posyville
Erosion structures - tall wheat grass strips
Residue previous year - none
Residue present year - none
Acreage - 40 acres
Samplers - 2 samplers: 5,6
Windbreak north side - 0.0 m
Windbreak south side - 7.6 m
Windbreak east side - 0.0 m
Windbreak west side - 0.0 m
Intial tillage date - 11/20/84
Residue heigth - 0.0
Non-erodible fraction - 4.64%

note - fall residue measurement made 12/1/84
- spring residue measurement made 5/23/85

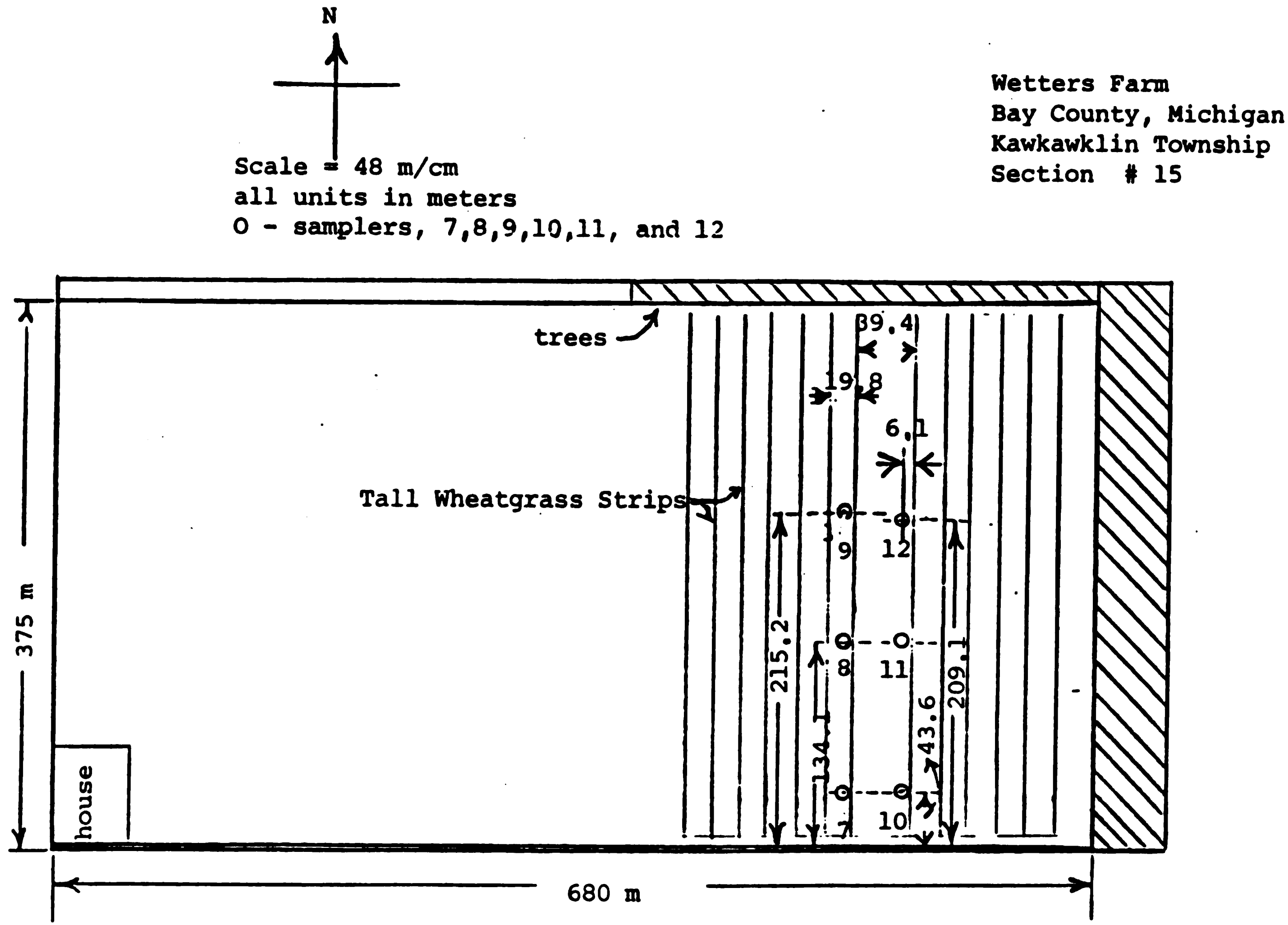

FIGURE 25 Diagram of Wetters Plot

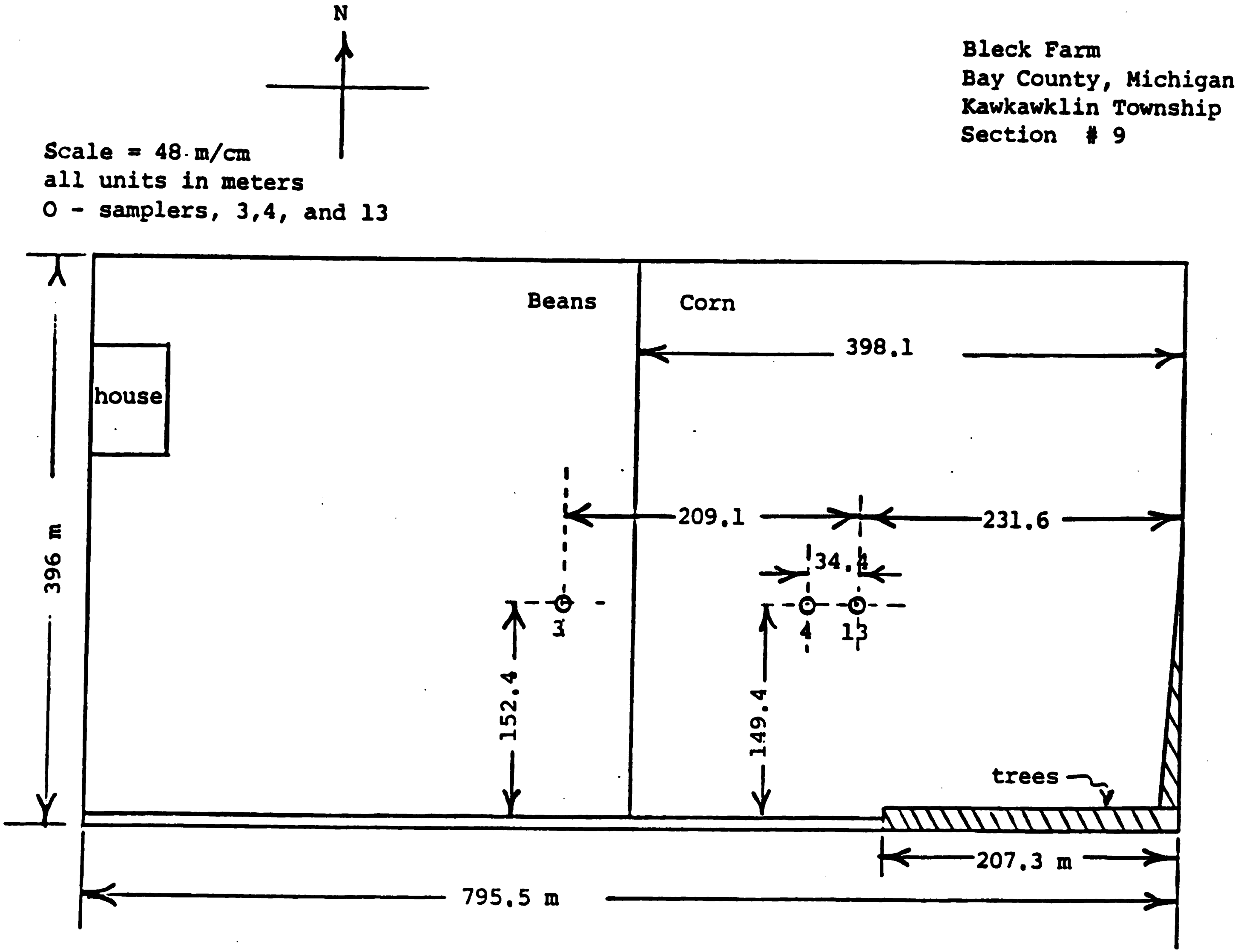

FIGURE 26 Diagram of Bleck Plot

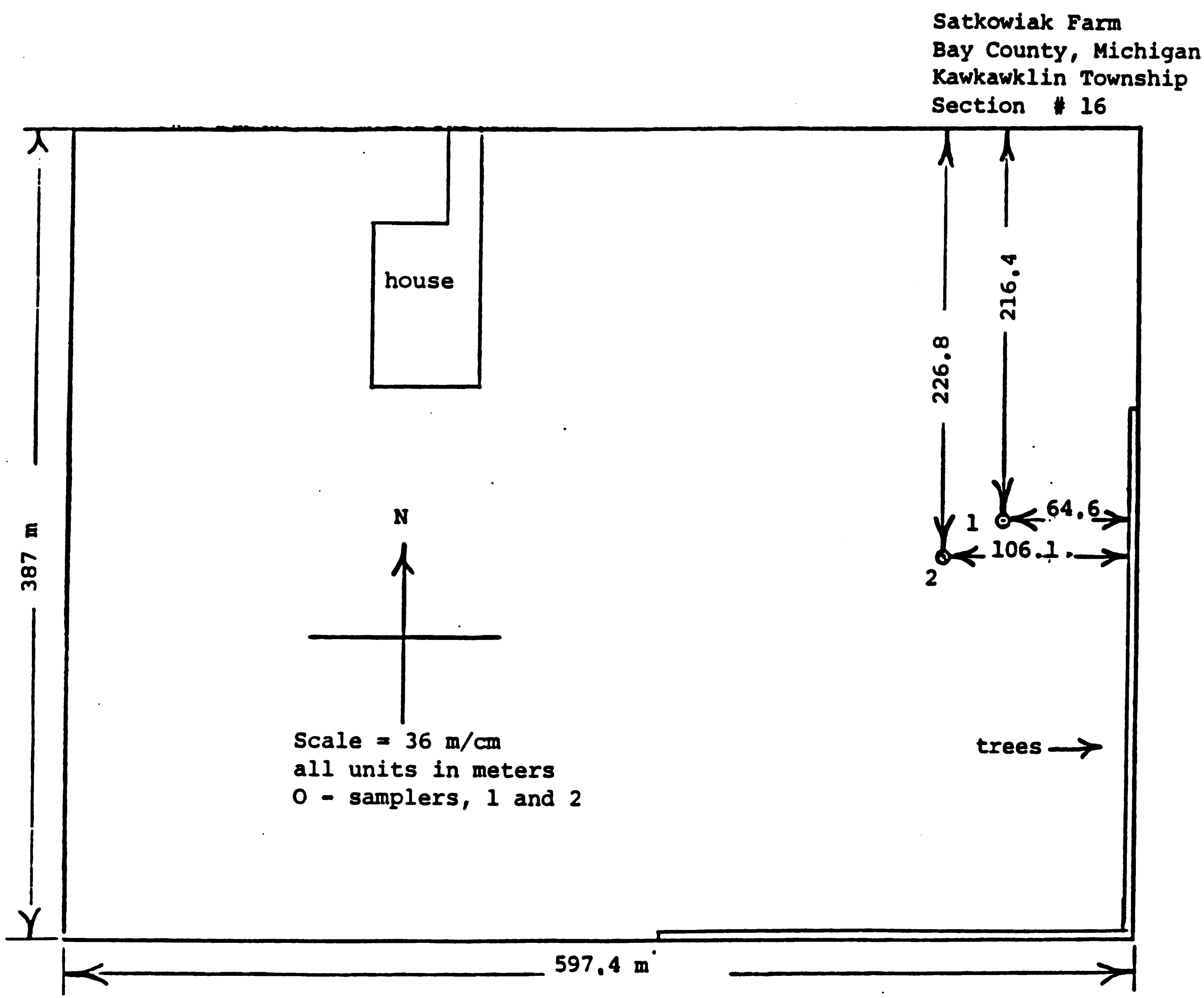

FIGURE 27 Diagram of Satkowiak Plot

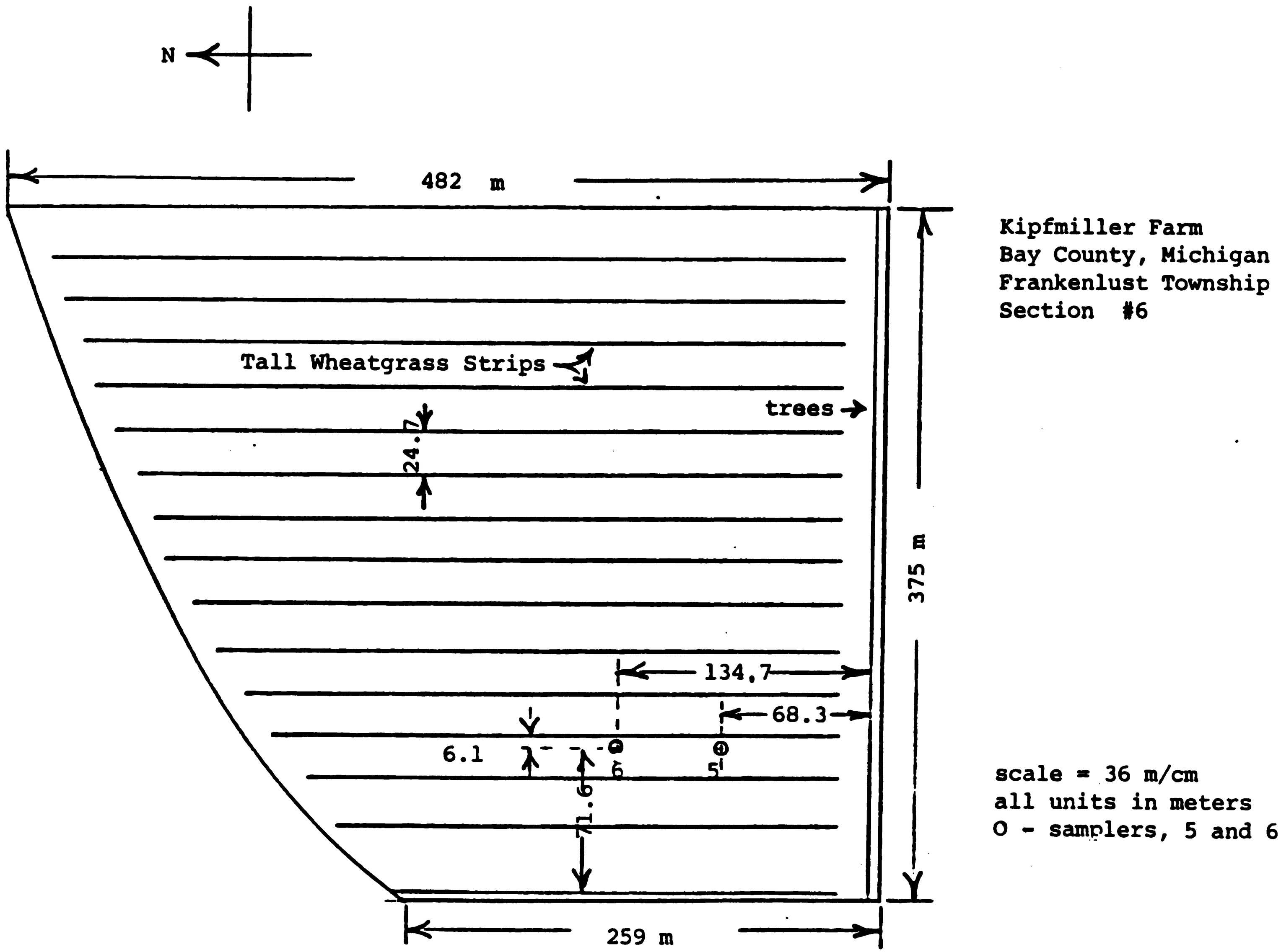

FIGURE 2 8 Diagram of Kipfmiller Plot

2. Soil movement data

5/18/85 - 5/20/85

Collector	Mass collected (dry weight,g)	Soil movement Mg/Ha(t/ac)
1	224.30	1.06 (0.39)
2	54.85	0.27 (0.10)
3	6.86	0.03 (0.01)
4	12.59	0.08 (0.03)
5	192.92	0.71 (0.26)
6	194.20	0.87 (0.32)
7	trace	----------
8	19.83	0.11 (0.04)
9	17.25	0.05 (0.02)
10	5.15	0.11 (0.04)
11	9.05	0.05 (0.02)
12	24.30	0.11 (0.04)
13	19.37	0.11 (0.04)

5/31/85

Collector	Mass collected (dry weight,g)	Soil movement Mg/Ha(t/ac)
1	1536.90	16.48 (6.05)
2	278.19	3.19 (1.17)
3	953.51	11.44 (4.20)
4	167.88	2.04 (0.75)
5	850.87	22.80 (8.37)
6	2465.12	33.48 (12.29)
7	12.60	0.52 (0.19)
8	566.73	4.66 (1.71)
9	27.53	0.26 (0.09)
10	45.78	1.93 (0.71)
11	214.29	2.91 (1.07)
12	90.71	0.79 (0.29)
13	333.24	4.09 (1.50)

3. Dry sieve analysis of samples
(Percent by size)

May 19th blow

Sieve size (mm)

Sample	<0.053	>0.053	>0.147	>0.589	>0.840	>1.168	>1.141
1	2.34	48.64	47.64	0.53	0.37	0.15	0.30
2	5.19	48.33	44.34	1.29	0.35	0.07	0.40
3	0.88	37.30	59.38	0.88	0.44	0.22	0.88
4	0.99	30.37	66.33	1.49	0.29	0.09	0.39
5	1.55	9.47	88.43	0.23	0.28	0.02	0
6	2.58	9.54	86.39	0.71	0.61	0.13	0
7	0	0	0	0	0	0	0
8	1.03	23.59	73.82	1.08	0.40	0.05	0
9	3.68	28.66	65.80	1.36	0.40	0	0.06
10	0	0	0	0	0	0	0
11	6.25	32.55	56.54	0.58	1.01	0.87	2.18
12	2.12	22.41	62.90	2.71	2.30	0.85	6.68
13	0.93	39.92	57.79	0.58	0.52	0.11	0.11

note - sampler #7 did not collect a measurable sample
- sample #10 was misplaced at the phosphorus testing lab

May 31st Blow

Sieve size (mm)

Sample	<0.053	>0.053	>0.147	>0.589	>0.840	>1.168	>1.141
1	0.79	27.03	71.51	0.40	0.22	0.02	0
2	1.61	27.95	68.44	0.94	0.80	0.23	0
3	1.61	38.87	59.12	0.30	0.05	0.02	0
4	3.25	40.48	55.06	0.26	0.36	0.57	0
5	2.33	11.68	85.16	0.46	0.29	0.05	0
6	0.95	3.75	93.48	1.34	0.41	0.02	0.02
7	8.67	41.49	42.54	3.72	2.83	0.48	.24
8	1.18	16.74	72.16	3.01	3.36	0.84	2.69
9	1.14	28.47	68.49	1.25	0.44	0.03	0.14
10	1.77	21.95	59.89	5.94	6.21	1.96	2.24
11	2.25	29.17	64.45	1.95	1.43	0.48	0.22
12	1.96	17.02	80.34	0.47	0.15	0.03	0
13	1.66	31.49	66.08	0.34	0.30	0.10	0

note - particles >0.84 mm are not susceptible to saltation,

Plot Soils

Soil	<0.053	>0.053	>0.147	>0.589	>0.840	>1.168	>1.141
1	1.51	28.97	66.23	1.84	0.74	0.16	0.51*
2	5.32	18.24	46.09	7.26	6.68	1.90	14.48*
3	4.14	30.18	54.52	2.97	2.77	0.71	4.66*
4	2.95	27.34	65.49	1.24	0.60	0.17	2.18*
5	3.62	6.96	81.57	3.17	1.63	0.36	2.65**

* - largest fraction consists largely of clods
** - largest fraction consists of gravel

Soil Type

Soil	Wind Erosion Group
1 - Wetter plot (light)	2
2 - Wetter plot (dark)	3
3 - Satkowiak plot	2
4 - Bleck plot	2
5 - Kipfmiller	2

4. Temperature data

Average monthly temperatures: for residue decay

Month	Temperature (C)
December	-1.5
January	-8.4
February	-5.5
March	2.7
April	11.4
May	16.1
June	11.0

Daily average temperature: for crop development

Date	Temperature (C)
051285	21.67
051385	19.72
051485	16.11
051585	21.92
051685	15.00
051785	13.61
051885	10.28
051985	15.00
052085	14.72
052185	13.06
052285	13.06
052385	15.28
052485	18.61
052585	21.39
052685	20.56
052785	14.44
052885	11.39
052985	13.61
053085	19.44
053185	20.83
060185	18.89
060285	20.00
060385	16.11
060485	15.28
060585	19.17
060685	15.28
060785	18.06
060885	22.78
060985	21.11
061085	16.39
061185	12.78
061285	10.00

061385	12.50
061485	14.72
061585	16.39
061685	14.44
061785	17.78
061885	15.00
061985	15.56
062085	15.56
062185	18.61
062285	20.56
062385	21.39
062485	17.78
062585	18.33
062685	17.50
062785	17.78
062885	18.06
062985	19.17
063085	20.83

5. Rain data

Date	Rain (mm)
120284	7.4
120384	1.3
120684	0.8
121284	15.7
121484	2.5
121984	1.0
122184	4.6
122384	3.8
122484	10.9
122684	5.3
122884	6.1
122984	15.2
123184	10.2
010185	11.9
010785	0.8
011085	1.5
011185	0.5
011485	0.8
011685	0.5
011785	4.3
011885	4.1
011985	5.3
012085	0.8
012185	2.5
012485	2.3
013185	1.0
020585	4.1

020685	1.5
020785	2.5
021085	0.3
021185	19.8
021285	13.5
021385	3.3
021485	5.3
021585	0.3
021685	0.5
021785	0.5
022285	1.0
022385	9.4
022485	8.6
030185	2.3
030485	51.3
031185	11.4
031285	2.5
031685	0.8
032385	7.6
032485	3.8
032785	9.4
032885	12.4
032985	1.5
040285	5.1
040385	0.5
040485	11.4
040585	32.5
040785	0.5
041085	0.3
041485	4.3
041785	1.8
041985	25.4
042485	11.2
042885	0.3
050585	3.3
051285	11.2
051585	17.3
051685	0.5
052085	0.3
052685	28.4
052885	7.1
053185	2.8
060985	12.2
061185	4.6
061285	1.0
061385	1.3
061585	7.6
061685	29.0
061785	2.0
062285	2.8

** - rain data through 7/1/85

6. Weather data

5/19/85 Blow

Column	Measurement	Units
1	time	Military
2	velocity (6.1 m)	m/s
3	average direction	degrees
4	temperature	celcius
5	relative humidity	percent

1	2	3	4	5
1450	10.29	250	26.7	34
1550	12.86	240	26.7	30
1653	12.35	250	26.1	29
1750	11.32	250	26.1	31
1854	10.29	250	25.6	32

** - national weather station data

5/31/85 Blow

Column	Measurement	Units
1	time	Military
2	velocity (6.7 m)	m/s
3	average direction	degrees
4	standard deviation of 3	degrees
5	velocity (2.3 m)	m/s
6	maximum direction	degrees
7	temperature	celcius
8	relative humidity	percent
9	solar radiation	Watts/m^2

1	2	3	4	5	6	7	8	9
0855	5.89	237.4	3.333	2.28	244.0	25.15	77.44	0.225
0900	7.01	234.5	2.586	3.16	241.0	24.78	77.45	0.132
0905	7.56	228.9	19.09	4.13	342.9	24.00	77.23	0.218
0910	8.79	223.9	3.945	5.02	236.4	23.20	72.13	0.329
0915	8.44	224.1	17.54	3.96	324.5	23.13	69.77	0.569
0920	8.46	222.7	3.609	4.19	230.7	23.48	68.76	0.583

1	2	3	4	5	6	7	8	9
0925	8.43	224.2	5.884	4.55	252.3	23.72	66.45	0.593
0930	7.04	224.4	2.909	3.49	230.5	24.05	65.44	0.615
0935	7.26	224.3	3.642	3.70	232.3	24.32	63.69	0.580
0940	9.12	222.6	2.043	4.66	228.1	24.26	61.23	0.565
0945	8.46	224.1	3.118	4.45	230.7	24.18	60.12	0.528
0950	7.20	226.5	2.855	3.89	231.3	23.97	59.36	0.463
0955	7.04	225.5	3.237	3.43	234.7	24.02	59.85	0.645
1000	6.72	226.1	3.451	3.09	231.9	24.47	60.27	0.672
1005	5.99	226.8	3.775	2.85	234.3	24.89	59.46	0.659
1010	7.12	226.4	4.702	3.72	235.8	25.30	58.61	0.701
1015	7.07	228.3	3.479	3.64	237.6	25.36	56.75	0.707
1020	6.56	228.8	3.914	3.17	236.8	25.61	57.74	0.710
1025	8.00	230.1	4.690	4.44	240.6	25.70	57.46	0.718
1030	7.77	231.1	3.460	4.30	240.0	25.78	57.35	0.736
1035	8.46	233.5	4.340	4.94	246.9	25.71	56.88	0.742
1040	7.54	231.6	4.117	4.13	238.6	25.81	57.94	0.751
1045	7.45	233.7	3.662	3.93	241.6	26.04	58.71	0.756
1050	7.76	231.8	3.442	3.95	238.6	26.25	59.37	0.704
1055	8.96	234.0	4.426	5.04	242.8	26.21	60.32	0.703
1100	9.45	232.5	3.782	5.41	239.4	25.89	61.49	0.618
1105	9.86	232.7	3.898	5.93	239.2	25.87	62.89	0.781
1110	9.12	233.1	2.791	5.53	238.2	26.07	62.87	0.611
1115	10.3	232.2	3.884	5.92	239.0	25.76	60.55	0.614
1120	9.94	231.9	4.392	5.57	241.0	25.51	60.25	0.532
1125	9.61	231.5	3.729	5.70	241.6	25.22	59.67	0.675
1130	10.3	231.5	3.979	6.38	238.4	25.41	59.72	0.810
1135	12.0	232.5	3.982	7.09	240.0	25.49	58.55	0.792
1140	9.70	231.7	4.293	5.68	241.4	25.67	59.54	0.799
1145	11.1	232.3	4.012	6.47	242.0	25.91	58.16	0.819
1155	10.4	233.0	3.682	6.35	238.8	25.91	56.50	0.783
1155	10.9	230.5	4.308	6.49	238.2	25.78	52.32	0.773
1200	11.1	231.2	4.319	6.30	237.4	25.54	48.53	0.784
1205	11.6	231.3	3.729	6.46	239.6	25.40	45.01	0.760
1210	10.6	232.1	2.885	6.51	239.8	25.26	43.46	0.732
1215	9.29	231.3	16.82	5.28	343.7	25.39	44.02	0.683
1220	11.3	230.1	3.818	6.74	240.0	25.35	41.61	0.736
1225	12.2	230.5	3.747	7.24	235.8	25.04	39.32	0.685
1230	12.0	231.0	3.757	7.00	242.0	24.82	39.79	0.653
1235	12.2	230.8	3.009	7.13	241.4	24.65	38.26	0.735
1240	11.0	229.9	3.738	6.71	238.0	24.58	38.98	0.686
1245	8.46	232.9	3.833	4.92	239.4	24.62	39.75	0.671
1250	10.1	235.1	3.852	5.95	241.2	24.77	39.15	0.700
1255	10.4	235.6	3.320	6.00	242.2	24.77	38.75	0.761
1300	10.7	233.0	3.304	6.37	241.4	24.82	37.79	0.769
1305	11.6	233.5	3.581	6.54	240.4	24.72	36.50	0.730
1310	10.3	232.1	4.525	6.27	243.0	24.72	37.38	0.583
1315	12.4	232.8	3.310	7.22	239.4	24.51	36.10	0.580
1320	12.1	230.2	2.674	6.53	236.4	24.36	36.68	0.475
1325	12.0	230.3	2.304	7.28	235.8	24.13	36.42	0.499
1330	13.0	232.6	3.345	7.13	243.2	24.03	36.22	0.468
1335	14.3	232.8	2.826	7.89	239.0	23.86	35.01	0.533
1340	12.7	232.8	3.949	7.63	242.6	23.86	35.57	0.499
1345	11.3	230.8	3.622	6.58	238.6	23.89	36.42	0.428

1	2	3	4	5	6	7	8	9
1350	13.0	230.0	4.247	7.25	242.4	23.93	36.14	0.500
1355	11.5	232.9	4.073	6.75	242.6	23.80	35.98	0.322
1400	13.6	233.4	14.69	7.38	321.7	23.70	35.67	0.405
1405	13.7	231.1	19.12	7.43	353.8	23.70	36.14	0.385
1410	13.4	229.6	6.400	6.98	239.4	23.74	36.69	0.383
1415	13.7	252.3	41.87	7.62	325.3	23.67	36.08	0.359
1420	15.8	171.4	49.11	8.22	359.7	23.67	35.60	0.354
1425	16.5	164.2	17.59	8.27	205.0	23.78	35.01	0.450
1430	15.9	108.3	7.070	8.25	133.4	23.79	35.29	0.398
1435	14.9	112.1	8.900	8.18	131.8	23.77	35.41	0.377
1440	14.1	110.9	16.02	8.00	194.3	23.62	36.16	0.335
1445	14.7	149.1	17.89	7.80	166.6	23.48	36.13	0.232
1450	14.1	163.3	17.90	7.72	305.1	23.20	36.59	0.187
1455	16.5	165.4	4.712	8.18	177.9	23.05	36.01	0.176
1500	14.4	165.6	4.452	7.70	172.9	22.95	36.48	0.177
1505	16.2	170.8	30.66	8.18	330.6	22.93	36.27	0.190
1510	15.3	184.7	21.66	7.95	202.4	22.82	36.49	0.194
1515	15.7	198.0	15.80	8.13	286.1	22.89	36.60	0.268
1520	15.2	199.7	6.245	8.08	214.1	22.95	36.92	0.257
1525	12.7	200.3	4.960	7.28	211.5	22.80	37.69	0.233
1530	13.8	203.1	16.81	7.60	307.5	22.68	38.51	0.190
1535	16.4	191.5	17.84	7.97	222.4	22.41	38.69	0.151
1540	15.4	92.9	31.94	8.25	317.4	22.40	38.73	0.216
1545	14.5	93.2	6.024	7.65	104.5	22.49	39.15	0.251
1550	14.7	92.5	17.32	7.82	169.0	22.43	39.60	0.237
1555	14.1	88.8	24.16	7.60	312.4	22.19	40.61	0.196
1600	16.1	104.8	46.51	8.15	245.1	22.06	41.01	0.258
1605	16.5	129.7	31.34	8.45	344.5	22.11	41.23	0.336
1610	13.8	138.0	24.90	7.68	336.0	22.17	41.95	0.298
1615	15.3	137.3	39.68	7.92	349.2	21.99	42.58	0.255
1620	16.4	135.6	56.15	8.22	348.6	21.57	43.36	0.196
1625	17.4	189.0	34.58	8.29	288.1	21.22	43.90	0.188
1630	15.4	183.2	8.740	8.24	206.2	21.15	44.64	0.232
1635	13.6	189.9	22.23	7.58	319.5	21.22	45.55	0.252
1640	14.6	157.6	46.47	7.86	336.0	21.08	46.42	0.217
1645	13.6	159.0	34.20	7.35	323.5	20.88	47.92	0.134
1650	16.9	155.5	55.48	8.13	355.7	20.39	49.29	0.092
1655	16.1	189.5	41.27	8.19	292.2	19.99	52.85	0.164
1700	13.6	166.4	50.68	7.39	329.4	19.93	54.64	0.192
1705	14.6	172.8	33.71	7.76	242.0	20.01	54.83	0.201
1710	14.3	159.1	29.63	7.81	282.7	19.90	55.02	0.119
1715	16.8	200.2	40.11	8.25	290.8	19.24	58.33	0.047
1720	16.7	213.1	19.49	8.30	244.7	17.60	70.89	0.064
1725	13.6	246.1	9.670	7.55	266.7	16.73	78.59	0.060
1730	14.7	246.0	11.48	7.58	293.2	16.26	80.80	0.095
1735	13.2	233.5	13.96	7.09	303.7	16.36	80.20	0.156
1740	12.8	229.2	19.67	6.84	300.3	16.57	78.78	0.092
1745	16.1	234.3	21.85	7.98	293.6	16.78	76.23	0.123
1750	13.4	253.4	34.67	7.61	326.1	16.95	75.01	0.155
1755	12.9	233.5	31.26	7.16	315.4	16.94	74.40	0.118
1800	13.8	240.1	27.78	7.36	300.1	16.99	72.56	0.174
1805	14.4	242.8	34.06	7.59	319.9	17.10	70.32	0.204
1810	12.7	242.1	34.77	7.05	312.2	17.02	69.65	0.114

1	2	3	4	5	6	7	8	9
1815	14.1	242.7	27.19	7.57	310.4	17.06	68.76	0.180
1820	13.8	243.6	31.72	7.60	329.2	17.16	67.35	0.182
1825	15.9	233.7	29.37	7.85	305.9	16.85	65.10	0.079
1830	14.8	220.5	29.08	7.68	299.2	16.58	65.33	0.060
1835	13.4	229.2	35.38	7.34	289.7	16.41	65.44	0.047
1840	11.9	228.6	43.27	6.89	318.3	16.24	65.50	0.039
1845	13.7	204.0	24.93	7.56	290.6	16.08	65.59	0.035
1850	14.9	245.3	35.76	7.93	320.9	15.96	65.49	0.031
1855	14.9	230.6	36.11	8.08	306.9	15.83	65.42	0.023
1900	14.9	246.8	38.15	7.66	314.6	15.70	65.78	0.014
1905	14.2	255.7	38.99	7.46	315.4	15.55	66.02	0.010
1910	13.8	235.8	37.91	7.64	323.7	15.39	66.08	0.007
1915	14.1	248.7	25.83	7.44	282.5	15.28	66.27	0.029
1920	12.6	282.0	34.55	7.06	325.1	15.34	66.07	0.076
1925	10.0	308.5	14.45	6.30	329.0	15.23	65.67	0.047
1930	9.78	308.3	26.96	5.91	329.4	15.04	65.53	0.036
1935	11.8	288.8	37.90	7.32	320.5	14.85	65.13	0.031
1940	9.70	310.0	28.75	5.82	333.2	14.69	65.23	0.022
1945	9.20	313.2	23.21	5.59	328.4	14.56	65.79	0.015
1950	8.96	308.8	29.71	5.23	329.0	14.54	65.86	0.010
1955	9.61	312.2	14.90	5.62	330.6	14.55	65.60	0.007
2000	9.70	287.9	41.05	5.73	325.5	14.55	65.62	0.004
2005	9.20	289.3	43.53	5.53	332.0	14.54	65.88	0.003
2010	9.94	284.0	37.00	5.85	327.4	14.55	65.86	0.001
2015	9.94	244.1	35.68	5.82	325.7	14.53	66.09	0.001
2020	9.61	242.3	36.42	5.85	314.6	14.47	66.36	0.001
2025	9.45	252.8	35.21	5.63	321.7	14.49	66.39	0
2030	7.63	250.6	34.88	4.03	316.4	14.45	66.95	0
2035	8.55	243.7	48.75	4.62	327.0	14.42	67.25	0
2040	8.46	228.0	36.60	4.95	308.8	14.45	67.04	0
2045	8.44	229.9	33.10	4.76	317.6	14.45	67.29	0
2050	8.79	243.8	38.29	4.87	319.7	14.50	67.26	0
2055	8.63	268.2	46.44	5.05	331.0	14.54	67.35	0
2100	9.04	263.8	48.42	5.69	330.2	14.59	67.20	0
2105	8.55	269.0	35.04	4.83	323.5	14.61	67.30	0
2110	7.73	248.0	32.86	4.49	327.4	14.63	67.42	0
2115	7.80	246.0	35.41	4.47	326.5	14.62	67.60	0
2120	8.13	253.0	35.75	4.38	324.3	14.63	67.62	0
2125	8.14	248.3	42.06	4.64	316.6	14.66	67.68	0
2130	9.04	253.4	38.05	5.11	320.1	14.69	67.57	0
2135	8.34	243.0	41.51	4.64	311.0	14.76	67.50	0
2140	9.12	264.9	40.45	5.49	337.3	14.78	67.57	0
2145	9.45	249.9	41.06	5.20	333.0	14.87	67.19	0
2150	8.96	271.8	40.50	5.48	328.2	14.89	67.36	0
2155	9.61	276.4	37.21	5.44	334.6	14.94	67.27	0
2200	9.86	274.6	31.64	5.67	342.1	14.97	67.21	0
2205	9.53	297.9	35.72	5.69	340.5	14.99	67.24	0
2210	9.53	313.3	33.49	5.68	346.2	14.99	67.18	0
2215	10.6	317.0	30.11	6.68	339.3	15.04	66.81	0
2220	9.29	309.1	35.67	5.52	341.3	15.05	66.68	0
2225	8.63	321.4	23.50	5.68	343.9	15.04	66.17	0
2230	8.79	316.8	23.89	5.47	338.7	15.01	65.97	0
2235	8.32	313.4	22.03	5.10	332.8	14.94	66.02	0

1	2	3	4	5	6	7	8	9
2240	8.79	318.9	25.39	5.12	340.9	14.93	65.45	0
2245	8.36	315.9	29.79	4.92	335.2	14.91	65.32	0
2250	8.71	323.8	20.15	5.34	341.7	14.87	65.30	0
2255	8.55	318.6	21.94	5.44	335.0	14.82	65.28	0
2300	8.71	322.5	30.30	5.51	341.9	14.78	65.36	0
2305	8.08	312.1	27.80	5.09	343.9	14.76	65.49	0
2310	9.20	326.4	19.55	5.50	334.8	14.67	65.50	0
2315	8.71	325.3	10.33	5.29	337.1	14.68	65.23	0
2320	8.96	323.9	20.33	5.20	342.9	14.65	65.37	0
2325	8.79	328.9	16.84	5.52	340.1	14.66	64.89	0
2330	10.2	331.8	4.425	6.30	339.1	14.68	64.36	0
2335	9.04	330.9	10.84	5.82	346.4	14.62	64.34	0
2340	8.96	334.6	12.84	6.12	343.3	14.59	64.28	0
2345	9.70	337.2	9.760	6.11	346.8	14.61	63.92	0
2350	9.04	324.6	29.95	5.55	345.1	14.55	64.08	0
2355	9.29	335.3	19.54	5.86	347.8	14.49	63.82	0
2400	9.70	338.8	18.74	5.80	349.2	14.37	63.92	0
0005	9.12	342.6	7.542	5.94	351.0	14.32	63.97	0
0010	8.63	341.7	5.179	5.14	349.2	14.32	63.98	0
0015	8.23	335.2	24.42	4.70	346.8	14.21	64.22	0
0020	8.71	342.8	14.98	5.21	351.4	14.06	64.22	0
0025	9.04	343.6	25.44	5.30	353.0	13.96	64.15	0
0030	8.55	341.4	16.07	5.40	349.8	13.86	64.28	0
0035	8.46	340.9	17.96	5.11	349.4	13.81	64.19	0
0040	8.19	332.9	25.15	4.44	347.2	13.68	64.59	0
0045	7.45	342.3	10.77	4.01	348.6	13.55	64.88	0
0050	7.67	340.6	15.63	4.20	350.0	13.44	65.13	0
0055	9.12	343.1	10.66	5.53	349.0	13.46	64.80	0
0100	9.12	347.3	3.718	5.52	353.2	13.54	64.40	0
0105	8.18	347.0	3.599	5.02	354.9	13.48	64.68	0
0110	7.86	345.2	3.804	4.50	352.4	13.42	64.93	0
0115	8.41	344.8	13.23	5.19	351.0	13.44	64.88	0
0120	7.54	346.6	3.108	4.28	351.2	13.41	65.20	0
0125	9.04	345.1	5.192	5.63	351.2	13.53	64.84	0
0130	9.45	344.5	3.347	5.54	350.0	13.66	64.40	0

7. Sampler Efficiency

Table 12 shows the results of field particle size verses sampler collected particle size efficiency. All the values seem resonable except for the greater than 0.589 mm particle size range. This particle size is in the top range for saltating particle sizes and this may indicate a sorting action occuring at the inlet of the sampler. However, overall, the efficiency can be estimated in the following manner. Estimate the total erosion mass to be distributed as 10% suspension, 80% saltation, and 10% creep. The particle size groups will be broken into <0.053 (suspension), >0.053-<0.840 (saltation), and >0.840 (creep). The following equation is used to estimate the overall efficiency of the Modified Bagnold sampler.

$$EFF = aX + bY + cZ \qquad (26)$$

where:

a = fraction of soil movement in suspension,

b = fraction of soil movement in saltation,

c = fraction of soil movement in creep,

X = effeciency of collector for suspension,

Y = efficiency of collector for saltation,

Z = efficiency of collector for creep,

Using the above equation results in an overall efficiency of 80 percent for the sampler.

Table 12

Particle efficiency of the Modified Bagnold Sampler

particle size ,mm	<0.053	>0.053	>0.147	>0.589	>0.840	>1.141	>1.168
% eff	54	128	101	37	38	55	6

* note - both recorded events were used, but the wetter plot data was not used because of the great differences in particle size across the field.

APPENDIX B

B. Procedures for Fitting The Wind Velocity Profile

The usual lognormal profile fit was not used in the model because the heat flux effect on the wind profile was considered substantial. Some solar radiation data was taken to estimate the heat flux off the test fields. The major unknown in any profile estimation for this study is the roughness parameter (z_0) and the roughness height (D). A major problem in the study was the lack of wind velocity data on the field test sites. This did not allow (Z_0+D) to be interpolated from the data for each test plot. To estimate these parameters an equation developed by Gregory (*1986) was used. The equation is as follows:

$$Z_0 = 0.13(H-D) \quad (25)$$

where:

Z_0 - roughness parameter, m

H - maximum field element height, m

D - roughness height, m

$$D = 0.7\ H \quad - \quad \text{for most crops} \quad (26)$$

$$D = 0.5\ H \quad - \quad \text{for field roughness} \quad (27)$$

The following procedure was used to fit the velocity distribution for model use.

* - Personal communication

1) Interpolate Z_0 (assuming D=0) from the velocity data.

2) Estimate the heat flux by multipling the total radiation by the albedo for the surface conditions.

3) Substitute in the above values and the velocity at 2.3 meters in equation (5) and solve for the shear velocity (U_*).

4) Using the estimated U_* solve for the velocity profile at the critical heights of 0.15, 2.3, 6.7, and 15.2 meters.

5) Estimate Z_0 and D with equations (25) - (27) for a test plot.

6) Add Z_0 and D to get the y - intercept for the test plot.

7) Take the velocity at 15.2 m found in step 4 and velocity equal to zero at the y - intercept. Substitute these into equation (4) and solve for U_*/k.

8) Using the data from steps 6 and 7 solve equation (4) at various heights to obtain the velocity distribution for the field plot.

Some profile fits from the May 31, 1985 wind event are shown in table 13.

Table 13

Fitted Wind Velocity Profiles (m/s)
(ZO= 0.002, D=0)

Time	Data type	Height (m) 0.15	2.3	6.7	15.2
1635	WS	...	7.58	13.58	...
"	WSH	...	7.56	13.47	17.87
"	WSN	...	6.26	13.58	18.67
"	F	8.63	14.09	16.23	17.87
1720	WS	...	8.30	16.72	...
"	WSH	...	8.30	16.71	23.14
"	WSN	...	7.70	16.73	22.98
"	F	11.18	18.25	21.02	23.14
1920	WS	...	7.06	12.64	...
"	WSH	...	7.05	12.61	16.82
"	WSN	...	5.82	12.65	17.38
"	F	8.12	13.26	15.27	16.82

WS - weather station data
WSH - weather station data fit accounting for heat flux
WSN - weather station data fit using neutral conditions
F - velocity profile for a field having the prescribed data, the previous fits are not a function of the z_0 and d values listed above.

APPENDIX C

C. Documentation And Source Code Of Model

1. Subroutines

Menu	- displays preset variables
Reset menu	- resets any varible from the menu
Print out	- variables from the menu are printed out
Intialize time	- intializes number of days in each month, extracts tillage date
Extract time	- extracts wind event time
Accumulate day	- accumulates time in days
Rain data	- reads in rain data from another file
Residue counter	- contains the residue equation
Rain date match	- matches rain events with residue equation
Residue conver	- converts residue cover to mass basis
Time stop	- matches wind event day to the clock
Orientation	- determines field length, given wind direction
Erosion Eq	- actual use of Gregory's equation
Wind direction	- determines the side for wind break inputs
Erod factor	- reads in an array for erodibility
Velocity dist	- sets a velocity variable
Canopy temp	- reads in temperature data to be entered
Sum degree day	- matches the day and sums degree days
Canopy cover	- determines LAI and crop cover
Crop height	- determines crop heigth by sum of degree days
Output	- intialized array varialbles

Output2	- program output
Extract tillage	- extracts tillage dates
Tillage date	- checks clock for tillage dates
Average mass	- used to find weighted mass flux Flux
Field Length	- determined field length in the direction of the wind
Length effect	- determines length of field to approach maximum flux rate

2. Variable list

A	- length of half of the north side
AE	- Soil abrasion adjustment factor
ALPHA	- angle between north and northeast corner
AM	- rain index coifficient for residue equation
A1E	- value check for AE
A1M	- intermediate value for AM
B	- lenth of half the east side
BETA	- angle between east and northeast corner
C	- constant
CHECK	- flag for loop with EVDAT$
CTDAT$	- cultivation date
DIR	- wind direction in radians
D0	- flag to end program
D1	- date days (intial tillage date)
D1$	- string d1
D2	- date set = to d1 used for flag
D3	- date days (wind event)
D3$	- string d3
D5	- date days (rain dates)
D5$	- string d5
D6	- date day for temperature, crop canopy
D6$	- date(string) day for temperature, crop canopy
D7	- pre-planting tillage date, day
d7$	- string D7
D8	- planting date, day
D8$	- string D8
D9	- cultivation date, day
D9$	- string D9
F	- counter
FC	- canopy cover
FR	- residue or clod cover

F1	- 1-FC
F2	- 1-FR
F3	- FR*HR/HS
F4	- FC*HC/HS
G	- counter
HC	- crop heigth
Hour	- hour of day
HS	- soil roughness heighth (cm)
HW	- wind break heighth (m)
I	- counter
ITDAT$	- string of V(17)
KE	- soil erodibility (Mg/ha)
LAI	- leaf area index
LE	- unprotected field length, (m)
LF	- length of field at the prescribed wind direction
LF	- length of field, direction of wind (m)
L1F	- length of field to reach A=1
L2F	- intermediate value of L1F
L3F	- length of field that is at A=1
M	- non-loop counter
MA	- total soil movement, Kg/ha/event
ME	- mass/area moved (Mg/ha)
MES	- exp(MIS)
MF	- mass of residue, interval value (Mg/Ha)
MIS	- value check on MS
MO(I)	- array of days in each month
MP	- weighted mass flux
MR	- mass of residue, intermediate value
MS	- mass flux / unit width of blowing soil(Kg/m.s)
MTS	- sum of fluxes across the field to L where A=1
M1	- date month (intial tillage date)
M1$	- string M1
M3	- date month (wind event)
M3$	- string M3
M5	- date month (rain dates)
M5$	- string M5
M6	- date month for temperature, crop canopy
M6$	- date(string) month for temperature, crop canopy
M7	- pre-planting tillage date, month
M7$	- string M7
M8	- planting date, month
M8$	- string M8
M9	- cultivation date, month
M9$	- string M9
PADAT$	- planting date string
PEDAT$	- emergence date string
PNUMBER	- number for variable changes in the menu
PP	- real number for SEPS
PTDAT$	- pre-planting tillage date
Q	- non-loop counter

RAIN(I)	- array of amounts of rain (mm)
RD	- half of LF
RESRED	- residue reduction due to tillage
RE$(I)	- array date of rain events
RN(I)	- array of amounts of rain, used for comparison
S	- relative soil detachment (dim)
SDD	- sum of degree days
SEPS	- number of 3 meter steps to A=1
SIDE	- variable for A or B for final calculation
TAU	- intermediat value in the residue equation
TD$(x)	- dates for temperatures, crop cover
THETA	- wind direction transformed,first quadrant
TH(X)	- average temperature for the day, crop canopy
VE	- wind velocity at 15.2 m (m/s)
V$(I)	- array of all menu variable discriptions
V(I)	- array of all menu values
W	- counter, sub canopy temp
X	- counter, sub sum degree days
YEAR	- date year (intial tillage date)
YEAR$	- string year
Y3	- date year (wind event date)
Y3$	- string date
Y5	- date year (rain dates)
Y5$	- string year
Y6	- date year for temperature. crop canopy
Y6$	- date(string) year for temperature, crop canopy
Y7	- pre-planting tillage date, year
Y7$	- string Y7
Y8	- planting date, year
Y8$	- string Y8
Y9	- cultivation date, year
y9$	- string Y9
Z	- counter in the main program
ZE	- constant (ha/Mg.s)

3. Input files

Temp data	- data: date, temp average(c)
Rain data2	- data: date, rain(mm)

4. Wind erosion program source code

```
100 REM ***** PROGRAM - MODEL WIND EROSION *********
105 REM 4/26/86
110 M=1:SDD=0:X=1:RESRED=1
120 DIM RE$(80),RAIN(80),M5(80),D5(80),Y5(80),RN(80),
KE(80),TH(55),TL(55)
130 DIM TD$(55),D6(55),M6(55),Y6(55)
140 GOSUB 440:REM SUB MENU
150 GOSUB 3010:REM SUB CANOPY COVER TEMP INPUT
170 GOSUB 2870:REM SUB VELOCITY DISTRIBUTION
180 GOSUB 1380:REM SUB INTIALIZE TIME
190 GOSUB 2220:REM SUB RESIDUE COVER TO MASS CONVERSION
200 GOSUB 2770:REM SUB ERODIBILITY FACTOR
205 GOSUB 5000:REM EXTRACT TIME, IMMERGENCE
210 GOSUB 1550:REM SUB EXTRACT TIME, WINDEVENT
220 GOSUB 4100:REM SUB RESIDUE REDUCTION DATE CHECK
230 GOSUB 1740:REM SUB RAIN DATA INPUT
240 GOSUB 2340:REM SUB ORIENTATION
250 GOSUB 2710:REM SUB WIND DIRECTION
255 GOSUB 7000:REM SUB FIELD LENGTH
260 FOR Z=1 TO 5
270 GOSUB 1640:REM SUB ACCUMULATE TIME (DAYS)
280 GOSUB 3170:REM SUB SUM OF DEGREE DAYS
290 GOSUB 4330:REM TILLAGE RESIDUE CHECK
300 GOSUB 2310:REM SUB STOP TIME
310 GOSUB 1920:REM SUB RESIDUE COUNTER
320 IF Z=5 THEN GOSUB 1990:REM SUB RESIDUE
330 IF DO=1 THEN GOTO 380
340 NEXT Z
350 PRINT M1,D1,YEAR
370 GOTO 260
380 GOSUB 3250:REM SUB CANOPY COVER:PRINT"GOSUB 3010"
390 GOSUB 3320:REM SUB CANOPY HEIGHT
400 GOSUB 2280:REM SUB RESIDUE CONVERSION MASS TO COVER
405 GOSUB 6500:REM SUB LENGTH EFFECT FOR ABRASION
410 GOSUB 6600:REM SUB AVERAGE MASS FLUX
415 CLOSE4
416 OPEN15,8,15:CLOSE15
418 OPEN4,4
420 GOSUB 3880:REM SUB OUTPUT 2
430 END
440 REM ******** SUB MENU ***********************************
***************
450 PRINT""
460 DIM V(50),V$(50)
470 DATA -8.4,-5.5,2.7,11.4,16.1,11.0,17.0,19.0,16.0,
12.0,8.0,-1.5
480 V(13)=0.38:V(15)=0.0018:V(14)=5:V(16)=57
490 FOR I=1 TO 12:READ V(I):NEXT
500 PRINT""
510 PRINT"******** RESIDUE INFORMATION**********"
```

```
520 PRINT" AVERAGE MONTHLY TEMPERATURE (CELCIUS)"
530 PRINT"1.  JANUARY   ";V(1):V$(1)="JAN TEMP"
540 PRINT"2.  FEBRUARY  ";V(2):V$(2)="FEB TEMP"
550 PRINT"3.  MARCH     ";V(3):V$(3)="MAR TEMP"
560 PRINT"4.  APRIL     ";V(4):V$(4)="APR TEMP"
570 PRINT"5.  MAY       ";V(5):V$(5)="MAY TEMP"
580 PRINT"6.  JUNE      ";V(6):V$(6)="JUN TEMP"
590 PRINT"7.  JULY      ";V(7):V$(7)="JUL TEMP"
610 PRINT"8.  AUGUST    ";V(8):V$(8)="AUG TEMP"
620 PRINT"9.  SEPTEMBER ";V(9):V$(9)="SEP TEMP"
630 PRINT"10. OCTOBER   ";V(10):V$(10)="OCT TEMP"
640 PRINT"11. NOVEMBER  ";V(11):V$(11)="NOV TEMP"
650 PRINT"12. DECEMBER  ";V(12):V$(12)="DEC TEMP"
660 PRINT"13. COVER RESIDUE       ";V(13):V$(13)="RES COVER"
670 PRINT"14. INCREMENT (DAYS) - ";V(14):V$(14)="RES INC"
680 PRINT"15. U/RO CONSTANT - ";V(15):V$(15)="U/RO CONST"
690 PRINT"16. INTIAL C/N  RATIO  - ";V(16):V$(16)="C/N
RATIO"
700 PRINT" "
710 INPUT"ENTER PARAMETER NUMBER TO BE CHANGED (0 TO
CONTINUE) ";PNUMBER
720 IF PNUMBER=0 THEN GOTO 740
730 GOSUB 1270:GOTO500
740 PRINT""
750 V(17)=111584:V(18)=051685:V(19)=14:V(20)=795.5:
V(21)=346.2:V( 22)=197.1
760 V(25)=10:V(26)=5:V(27)=5:V(28)=15:V(30)=13.0:
V(29)=150:V(31)= 17:V(32)=15.2
770 V(23)=5:V(24)=0.000451685:V(19)=14:V(20)=795.5:
V(21)=346.2:V( 22)=197.1
780 PRINT"17. INTIAL TILLAGE DATE";V(17):V$(17)="INTIAL
TILLAGE"
790 PRINT"18. DATE OF EVENT ";V(18):V$(18)="EVENT DATE"
800 PRINT"   (MONTH,DAY,YEAR) "
810 PRINT" "
820 PRINT"19. HOUR OF EVENT ";V(19):V$(19)="EVENT HOUR"
830 PRINT"20. FIELD LENGTH NORTH SIDE (M) ";V(20):V$(20)="
NORTH FIELD LENGTH"
840 PRINT"21. FIELD LENGTH EAST SIDE (M)
";V(21):V$(21)="EAST FIELD LENGTH"
850 PRINT"22. DIRECTION OF WIND (DEG) ";V(22):V$(22)="WIND
DIRECTION"
860 PRINT"23. COVER HEIGHT (CM) - ";V(23):V$(23)="RES
HEIGHT"
870 PRINT"24. RESIDUE CONVERSION CONSTANT(AM)
";V(24):V$(24)="RESIDUE CONSTANT"
880 PRINT"25. HEIGHT WINDBREAK NORTH SIDE(M)";V(25):V$(25)="
WINDBREAK NORTH"
890 PRINT"26. HEIGHT WINDBREAK EAST SIDE(M)";V(26):V$(26)="
WINDBREAK EAST"
900 PRINT"27. HEIGHT WINDBREAK SOUTH SIDE(M)";V(27):V$(27)="
WINDBREAK SOUTH"
910 PRINT" 28. HEIGHT WINDBREAK WEST SIDE(M)";V(28):V$(28)="
WINDBREAK WEST"
```

```
920 PRINT"29. DURATION OF EVENT (MIN)";V(29):V$(29)="EVENT
DURATION (MIN)"
930 PRINT"30. CRITICAL WIND VELOCITY (M/S)";V(30):V$(30)="
CRITICAL VELOCITY"
940 PRINT"31.  WIND VELOCITY (M/S)";V(31):V$(31)="WIND
VELOCITY"
950 PRINT"32. HEIGHT WIND VELOCITY TAKEN(M)";V(32):V$(32)="
VELOCITY HEIGHT"
960 INPUT"ENTER PARAMETER NUMBER TO BE CHANGED (0 TO
CONTINUE) ";PNUMBER
970 IF PNUMBER=0 THEN GOTO 990
980 GOSUB 1270:GOTO 780
990 PRINT""
1000 V(33)=50585:V(34)=51685:V(35)=8
1010 V(36)=0.17:V(37)=0.3:V(38)=51085:V(39)=2:V(40)=10
1020 PRINT"************** COVER PARAMETERS *******
1030 PRINT" "
1040 PRINT"33  PLANTING DATE ";V(33):V$(33)="PLANTING DATE "
1050 PRINT"34 IMERGENCE DATE";V(34):V$(34)="EMERGENCE DATE "
1060 PRINT"35. NON-ERODIBLE FRACTION (%) ";V(35):V$(35)="
NON-ERODIBLE FRACTION"
1070 PRINT"36. FACTOR FOR CRUSTING (0.17-1)";V(36):V$(36)="
FACTOR FOR CRUSTING"
1080 PRINT"37. FACTOR SPRING
TILLAGE(RESIDUE)";V(37):V$(37)=" FACTOR SPRING TIL"
1100 PRINT"38  SPRING TILLAGE DATE  ";V(38):V$(38)="SPRING
TILLAGE DATE "
1110 PRINT"39  FIELD ROUGHNESS(CM)";V(39):V$(39)="FIELD
ROUGHNESS "
1120 PRINT"40  DAYS TO GERMINATE ";V(40):V$(40)="DAYS TO
GERMINATE "
1130 PRINT" "
1140 INPUT"ENTER PARAMETER NUMBER TO BE CHANGED (0 TO
CONTINUE) ";PNUMBER
1150 IF PNUMBER=0 THEN GOTO 1180
1160 PRINT""
1170 GOSUB 1270:GOTO 1020
1180 PRINT""
1190 PRINT"TO PRINT OUT THE INPUT ARRAY ENTER (2)"
1200 INPUT"TO PRINT OUT VARIABLE LIST ENTER (1), TO CONTINUE
ENTER (0).";PNUMBER
1210 IF PNUMBER=1 THEN GOSUB 3420
1220 IF PNUMBER=2 THEN GOSUB 1310
1230 PRINT""
1250 RETURN
1260 REM **** RESET MENU - CF MENU ****
1270 PRINT V$(PNUMBER)" [ ";V(PNUMBER);" ]"
1280 INPUT" ? ";V(PNUMBER)
1290 PRINT""
1300 RETURN
1310 REM **** SUB TO PRINT OUT VARIABLE ARRAY]- CF MENUE***
1320 OPEN4,4
1330 FOR I=1 TO 50
1340 PRINT#4,I,V$(I),V(I)
```

```
1350 NEXT I
1360 CLOSE4
1370 RETURN
1380 REM ******* INTIALIZE TIME *******
1390 REM ------- SET MONTH --------
1400 DIM MO(12)
1410 DATA 31,29,31,30,31,30,31,31,30,31,30,31
1420 FOR I=1 TO 12
1430 READ MO(I)
1440 NEXT I
1450 REM ------- EXTRACT TIME - TILLAGE DATE---
1460 ITDAT$=STR$(V(17))
1470 M1$=LEFT$(ITDATE$,3)
1480 M1=VAL(M1$)
1490 D1$=MID$(ITDATE$,4,2)
1500 D1=VAL(D1$)
1510 D2=D1
1520 YEAR$=RIGHT$(ITDATE$,2)
1530 YEAR=VAL(YEAR$)
1540 RETURN
1550 REM **** SUB EXTRACT TIME - WIND EVENT ****
1560 EVDAT$=STR$(V(18))
1570 M3$=LEFT$(EVDAT$,2)
1580 M3=VAL(M3$)
1590 D3$=MID$(EVDAT$,3,2)
1600 D3=VAL(D3$)
1610 Y3$=RIGHT$(EVDAT$,2)
1620 Y3=VAL(Y3$)
1630 RETURN
1640 REM ****** ACCUMULATE TIME (DAYS) *******
1650 IF D1=MO(M1) THEN M1=M1+1:D1=0
1660 IF M1=13 THEN M1=1:YEAR=YEAR+1
1670 D1=D1+1
1680 RETURN
1690 REM *** ACCUMULATE TIME (HOURS) **
1700 IF D1>D2 THEN HOUR=1
1710 HOUR=HOUR+1
1720 D2=D1
1730 RETURN
1740 REM ********** SUB RAIN DATA *****
1750 OPEN 2,8,2,"0:RAIN DATA2,S,R"
1760 FOR F=1 TO 80
1780 INPUT#2,RE$(F),RAIN(F)
1800 CHECK=VAL(RE$(F))
1810 IF CHECK=-1 THEN GOTO 1900
1820 M5$=LEFT$(RE$(F),2)
1830 D5$=MID$(RE$(F),3,2)
1840 Y5$=RIGHT$(RE$(F),2)
1850 M5(F)=VAL(M5$)
1860 D5(F)=VAL(D5$)
1870 Y5(F)=VAL(Y5$)
1890 NEXT F
1900 CLOSE2
1910 RETURN
```

```
1920 REM ******** SUB RESIDUE COUNTER ****
1930 Q=6-M
1940 RN(Q)=0
1950 GOSUB 2170
1960 M=M+1
1970 IF M=6 THEN M=1
1980 RETURN
1990 REM ***** SUB  RESIDUE ****
2000 AM=0
2010 FOR Q=V(14) TO 1 STEP -1
2020 A1M=RN(Q)/Q
2030 AM=A1M+AM
2040 REM  PRINT"***AM= ";AM
2050 IF AM>10 THEN AM=10
2060 NEXT Q
2070 TAU=V(M1)*V(14)*AM/V(16)
2090 IF V(M1)<0 THEN TAU=0
2100 MF=((1-(V(15)*TAU))3)*MR*RESRED
2110 MR=MF
2150 RESRED=1
2160 RETURN
2170 REM **** SUB RAIN DATE MATCH - CF RESIDUE COUNTER ***
2180 FOR G=1 TO 80
2190 IF D5(G)=D1 AND M5(G)=M1 THEN RN(Q)=RAIN(G)
2200 NEXT G
2210 RETURN
2220 REM ***** SUB RESIDUE COVER TO MASS CONVERSION ****
2230 MR=LOG(1-V(13))/(-V(24))
2240 GOSUB 4100:REM SUB EXTRACT TIME, TILLLAGE
2250 REM MR- MG/HA
2260 REM TON/AC=0.4462*MG/HA
2270 RETURN
2280 REM ****** SUB RESIDUE CONVERSION MASS TO COVER
2290 V(13)=1-(EXP(-V(24)*MR))
2300 RETURN
2310 REM ***** SUB TIME STOP ********
2320 IF D1>=D3 AND M1=M3 THEN DO=1
2330 RETURN
2340 REM ****** SUB ORIENTATION *******
2350 A=V(20)/2:REM PRINT"A= ";A
2360 B=V(21)/2:REM PRINT"B= ";B
2370 DIR =V(22)*/180:REM PRINT DIR
2380 ALPHA=ATN(A/B):REM  PRINT"ALPHA= ";ALPHA
2390 BETA=/2-ALPHA:REM PRINT BETA
2410 IF DIR>=(/2+BETA) AND DIR<= THEN THETA=-DIR:SIDE=B
2420 IF DIR<=(+ALPHA) AND DIR>= THEN THETA=DIR-:SIDE=B
2430 IF DIR<=2* AND DIR=>((3*ALPHA)+(4*BETA)) THEN
THETA=2*-DIR:SIDE=B
2440 IF DIR>=ALPHA AND DIR=</2 THEN THETA=/2-DIR:SIDE=A
2450 IF DIR=</2+ALPHA AND DIR>=/2 THEN THETA=DIR-/2:SIDE=A
2460 IF DIR>=+ALPHA AND DIR=<1.5* THEN THETA=1.5*-DIR:SIDE=A
2470 IF DIR=>1.5* AND DIR=<2*-ALPHA THEN DIR=1.5*:SIDE=A
2485 LF=(V(20)*V(21))/((V(21)*ABS(COS(THETA)))+(V(20)*
ABS(SIN(THET A))))
```

```
2500 RETURN
2510 REM ******* SUB EROSION EQUATION ******
2520 ZE=0.003:REM HA/T.S
2525 HS=V(39)
2530 C=0.0000244:REM KG/S3/Ma
2532 IF J>1 THEN GOTO 2610
2535 V(23)=V(23)+V(39)
2536 HC=HC+V(39)
2540 F1=1-FC
2545 VP=V(35)/100
2550 IF V(13)>=VP THEN FR=V(13)
2555 IF V(13)<VP THEN FR=VP
2560 F2=1-FR
2570 F3=FR*V(23)/HS
2580 F4=FC*HC/HS:REM  PRINT"F4= ";F4
2590 S=(F1*F2)/((F4+(F1*F3)+(F1*F2))3)
2610 LE=L2F-(17*V(30)/VE)*HW*BDIR
2615 IF LE<0 THEN LE=0
2630 A1E=4.67*ZE*KE(V(35))*LE/VE
2640 IF A1E>LOG(1.7E38) THEN AE=1:GOTO2660
2650 AE=0.77*(1-EXP(-0.072*EXP(4.67*ZE*LE*KE(V(35))/VE)))
+0.23
2660 MIS=-ZE*AE*KE(V(35))*LE/VE
2670 IF MIS<LOG(1.7E-38) THEN MES=0:GOTO2680
2675 MES=EXP(MIS)
2680 MS=C*S*VE*(VE3-V(30)3)*(1-MES)
2700 RETURN
2710 REM ******* WIND DIRECTION *****
2720 IF DIR<=ALPHA OR DIR>=(3*/2+BETA) THEN
HW=V(25):BDIR=COS(BETA):GOTO 2760
2730 IF DIR<=(/2+BETA) THEN HW=V(26):BDIR=COS(ALPHA):
GOTO 2760
2740 IF DIR<=(+ALPHA) THEN HW=V(27):BDIR=COS(BETA):GOTO 2760
2750 IF DIR<=(3*/2+BETA) THEN HW=V(28):BDIR=COS(ALPHA)
2760 RETURN
2770 REM ***** SUB ERODIBILITY FACTOR ***********
2780 FOR I2=1 TO 80
2790 READ KE(I2)
2800 KE(I2)=KE(I2)*2.24*V(36)
2810 NEXT I2
2820 DATA
310,250,220,195,180,170,160,150,140,134,131,128,125,
121,117,1 13,109
2830 DATA
106,102,98,95,92,90,88,86,83,81,79,76,74,72,71,69,67,
65,63,62 ,60,58
2840 DATA
56,54,52,51,50,48,47,45,43,41,38,36,33,31,29,27,25,24,
23,22,2 1,20,19
2850 DATA 18,17,16,16,15,14,13,12,11,10,8,7,6,4,3,3,2,2
2860 RETURN
2870 REM ****** SUB VELOCITY DISTRIBUTION ***********
2880 VE=V(31):REM  *(LOG(15.2)/LOG(V(32)))
```

```
2960 IF VE<V(30) THEN PRINT"WIND VELOCITY TOO SMALL":GOTO
430
2970 RETURN
3010 REM #### SUB CANOPY COVER TEMP INPUT##
3020 OPEN6,8,6,"0:TEMP DATA,S,R"
3030 FOR W=1 TO 55
3040 REM PRINT"TEMP DATA"
3050 INPUT#6,TD$(W),TH(W)
3060 IF TH(W)=-1 THEN GOTO 3150
3070 M6$=LEFT$(TD$(W),2)
3080 D6$=MID$(TD$(W),3,2)
3090 Y6$=RIGHT$(TD$(W),2)
3100 M6(W)=VAL(M6$)
3110 D6(W)=VAL(D6$)
3120 Y6(W)=VAL(Y6$)
3140 NEXT W
3150 CLOSE6
3160 RETURN
3170 REM ####### SUB - SUM OF DEGREE DAYS ##########
3180 IF D1=(D8+1) AND M1=M8 THEN GOTO 3200
3185 IF X>1 THEN GOTO 3200
3190 GOTO3240
3200 SDD=SDD+(TH(X)-8):REM PRINT#4,"D1= ";D1,"M1= ";M1,"D8=
";D8,"M8= ";M8
3210 X=X+1
3240 RETURN
3250 REM ######## SUB CANOPY COVER ##########
3260 LAI=(0.00346*SDD)+(-0.225)
3270 FC=(33.252*LAI)+0.5078
3280 FC=FC/100
3290 IF LAI<0 THEN FC=0
3310 RETURN
3320 REM ####### SUB CROP HEIGHT ####
3330 HC=(0.0340*(SDD))+(-0.908):CO=HC
3340 RETURN
3420 REM ####### SUB OUTPUT########################
3430 OPEN4,4
3440 PRINT#4,"                              INTIALIZED PARAMETERS"
3450 PRINT#4," "
3460 PRINT#4," "
3470 PRINT#4,"1.  JANUARY TEMP (C)              ";V(1)
3480 PRINT#4,"2.  FEBRUARY TEMP (C)             ";V(2)
3490 PRINT#4,"3.  MARCH TEMP (C)                ";V(3)
3500 PRINT#4,"4.  APRIL TEMP (C)                ";V(4)
3510 PRINT#4,"5.  MAY TEMP (C)                  ";V(5)
3520 PRINT#4,"6.  JUNE TEMP (C)                 ";V(6)
3530 PRINT#4,"7.  JULY TEMP (C)                 ";V(7)
3540 PRINT#4,"8.  AUGUST TEMP (C)               ";V(8)
3550 PRINT#4,"9.  SEPTEMBER TEMP (C)            ";V(9)
3560 PRINT#4,"10. OCTOBER TEMP (C)              ";V(10)
3570 PRINT#4,"11. NOVEMBER TEMP (C)             ";V(11)
3580 PRINT#4,"12. DECEMBER TEMP (C)             ";V(12)
3590 PRINT#4,"13. RESIDUE COVER (%)             ";V(13)
3600 PRINT#4,"14. RESIDUE INCREMENT(DAYS)       ";V(14)
```

```
3610 PRINT#4,"15. U/RO RATIO                    ";V(15)
3620 PRINT#4,"16. C/N RATIO                     ";V(16)
3630 PRINT#4,"17. INTIAL TILLAGE DATE           ";V(17)
3640 PRINT#4,"18. EVENT DATE DATE               ";V(18)
3650 PRINT#4,"19. EVENT HOUR                    ";V(19)
3660 PRINT#4,"20. NORTH FIELD LENGTH (M)        ";V(20)
3670 PRINT#4,"21. EAST FIELD LENGTH (M)         ";V(21)
3680 PRINT#4,"22. WIND DIRECTION (DEG)          ";V(22)
3690 PRINT#4,"23. RESIDUE HEIGHT (CM)           ";V(23)
3700 PRINT#4,"24. RESIDUE CONSTANT              ";V(24)
3710 PRINT#4,"25. WINDBREAK NORTH (M)           ";V(25)
3720 PRINT#4,"26. WINDBREAK EAST (M)            ";V(26)
3730 PRINT#4,"27. WINDBREAK SOUTH (M)           ";V(27)
3740 PRINT#4,"28. WINDBREAK WEST (M)            ";V(28)
3750 PRINT#4,"29. EVENT DURATION (MIN)          ";V(29)
3760 PRINT#4,"30. CRITICAL VELOCITY (M/S)       ";V(30)
3770 PRINT#4,"31. WIND VELOCITY (M/S)           ";V(31)
3780 PRINT#4,"32. VELOCITY HEIGHT (M)           ";V(32)
3790 PRINT#4,"33. PLANTING DATE                 ";V(33)
3800 PRINT#4,"34. EMERGENCE DATE                ";V(34)
3810 PRINT#4,"35. NON-ERODIBLE FRACTION(%)      ";V(35)
3820 PRINT#4,"36. CRUSTING FACTOR               ";V(36)
3830 PRINT#4,"37. FACTOR SPRING TILLAGE  ";V(37)
3840 PRINT#4,"38. SPRING TILLAGE DATE ";V(38)
3842 PRINT#4,"39. FIELD ROUGHNESS  ";V(39)
3844 PRINT#4,"40. DAYS TO GERMINATE ";V(40)
3850 PRINT#4," "
3870 RETURN
3880 REM ******** SUB OUTPUT 2 **************
3900 PRINT#4,"                               OUTPUT PARAMETERS"
3910 PRINT#4," "
3920 PRINT#4," "
3930 PRINT#4,"13. RESIDUE COVER                 ";V(13)
3940 PRINT#4,"RESIDUE MASS (KG)                 ";MR;"
("; MR*2.205;" )"
3950 PRINT#4,"WIND FIELD LENGTH (M)             ";LF;"
(";LF*3.28;" )"
3960 PRINT#4,"CROP COVER                        ";FC
3970 PRINT#4,"CROP HEIGHT (CM)                  ";CO;"
(";CO/2.54;" )"
3980 PRINT#4,"LEAF AREA INDEX                   ";LAI
3990 PRINT#4,"SUM OF DEGREE DAYS                ";SDD;"
(";SDD*1.8+32;" )"
4000 PRINT#4,"RELATIVE SOIL DETACHMENT (S)  ";S
4010 PRINT#4,"UNPROTECTED LENGTH (M)            "LE;"
(";LE*3.281;" )"
4015 PRINT#4,"WIND BREAK HEIGHT (M)             ";HW;"
(";HW*3.281;" )"
4020 PRINT#4,"VELOCITY AT 15.2 M                ";VE;"
(";VE*2.237;" )"
4030 PRINT#4,"VELOCITY DIFFERENCE (M/S)         ";VE-V(30)
4040 PRINT#4,"SOIL ERODIBILITY (MG/HA)          ";KE(V(35));"
(";KE(V(35))/2.24;" )"
4045 PRINT#4,"SOIL ERODIBLE FRACTION            ";V(35)
```

```
4050 PRINT#4,"SOIL ABRASION ADJUST FACTOR  ";AE
4052 PRINT#4,"LENGTH OF WIND EVENT (MIN)   ";V(29)
4055 PRINT#4,"MIS                          ";MIS
4058 PRINT#4,"WEIGHTED MASS FLUX (KG/M.S)     ";MP;"
(";MP*.672;" )":REM LB/FT.S
4060 PRINT#4,"MASS FLUX (KG/M.S)           ";MS;"
(";MS*.672;" )":REM LB/FT.S
4065 PRINT#4,"MASS MOVEMENT PER EVENT (MG/HA)       ";MA;"
(";MA/2.2416;" )"
4070 PRINT#4,"MASS LOSS PER EVENT (MG/HA)       ";ME;"
(";ME/2.2416;" )"
4090 RETURN
4100 REM #### SUB EXTRACT TIME - TILLAGE RESIDUE REDUCTION
#########
4110 PTDAT$=STR$(V(38))
4140 M7$=LEFT$(PTDAT$,2)
4170 M7=VAL(M7$)
4200 D7$=MID$(PTDAT$,3,2)
4230 D7=VAL(D7$)
4260 Y7$=RIGHT$(PTDAT$,2)
4290 Y7=VAL(Y7$)
4320 RETURN
4330 REM ####### SUB TILLAGE DATE CHECK ######
4340 IF D1=D7 AND M1=M7 THEN RESRED=1-V(37)
4370 RETURN
5000 REM #######SUB EXTRACT TIME - EMERGENCE DATE
5110 PEDAT$=STR$(V(34))
5115 IF V(34)=0 THEN GOTO 6000
5140 M8$=LEFT$(PEDAT$,2)
5170 M8=VAL(M8$)
5200 D8$=MID$(PEDAT$,3,2)
5230 D8=VAL(D8$)
5260 Y8$=RIGHT$(PEDAT$,2)
5290 Y8=VAL(Y8$)
5295 PRINT"EMERGENCE DATE";M8;D8;Y8
5300 GOTO 6320
6000 REM PLANTING DATE TO TRIGGER PLANT DATE IF EMERGENCE
DATE NOT KNOWN
6110 PADAT$=STR$(V(33))
6140 M8$=LEFT$(PADAT$,2)
6170 M8=VAL(M8$)
6200 D8$=MID$(PADAT$,3,2)
6230 D8=VAL(D8$)
6260 Y8$=RIGHT$(PADAT$,2)
6290 Y8=VAL(Y8$)
6295 D8=D8+V(40)
6296 IF D8>MO(M8) THEN M8=M8+1
6297 IF D8>MO(M8) THEN D8=D8-MO(M8-1)
6320 RETURN
6500 REM ###### LENGTH EFFECT FOR ABRASION ####
6510 LE=352*VE/KE(V(35))
6520 L1F=LE+(17*V(30)/VE*HW):REM LF AT A=1
6530 PP=L1F/3:SEPS=INT(PP)
6540 RETURN
```

```
6600 REM ********* AVERAGE MASS FLUX **********
6630 MTS=0
6650 FOR J=1 TO SEPS
6660 L2F=3*J
6670 GOSUB 2510
6680 MTS=MS+MTS
6690 NEXT J
6700 MTS=MTS/SEPS
6710 L2F=LF
6720 GOSUB 2510
6730 L3F=LF-L1F
6740 MA=((MTS*L1F)+(MS*L3F))/LF:MP=MA
6742 MA=MA*600*V(29)
6750 ME=MS/LF*10*V(29)*60:REM MG/HA.EVENT
6780 RETURN
7000 REM ******* FIELD LENGTH ********
7010 A=V(20)/2:REM PRINT"V(20)= ";V(20),A
7020 B=V(21)/2:REM PRINT"V(21)= ";V(21),B
7030 DIR=((-V(22))*/180)+/2:REM PRINT"DIR= ";DIR
7040 RD=SQR(((A3)*(B3))/((A3*(SIN(DIR)3))+(B3*(COS(DIR)3))))
7050 LF=2*RD
7060 REM PRINT"LF= ";LF
7070 RETURN
```

APPENDIX D

D. List of Literature Cited

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* - denotes unrefereed reference or personal communication

APPENDIX E

E. Index of Authors