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SUSCEPTIBILITY OF SOME MICHIGAN SOILS
TO WIND EROSION

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SUSCEPTIBILITY OF SOME MICHIGAN SOILS
TO WIND EROSION

By

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ABSTRACT

SUSCEPTIBILITY OF SOME MICHIGAN SOILS TO WIND EROSION

By

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The wind erodibility of some Michigan soils was studied. Susceptibility to wind erosion was related to Wind Erodibility Groups, particle size distribution, organic matter and calcium carbonate. Forty sites comprising seven surface soil textures were sampled. An alternate version of Chepil's rotary sieve was developed.

For each texture, the measured percentage of dry fractions >0.84 mm was larger than the percentage assigned to the Wind Erodibility Group of that texture. Over the ranges studied, organic matter and calcium carbonate by themselves did not have a significant affect on wind erodibility.

It was shown for the first time that the effects of clay, silt and sand on wind erodibility are the same in Western Canada, the Great Plains and in Michigan - three widely different geographical regions of North America. On the basis of polynomial regression, soil with the greatest resistance to wind erosion was found to be medium textured, with 24-30 percent clay, 30-40 percent silt and 31-45 percent sand. These percentages agree well with the optimum percentages for Western Canada and Great Plains soils. This commonality of data indicates the alternate sieve is a valid method for determining wind erodibility of soils.

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INTRODUCTION

Wind erosion is the disintegration and movement of soil material by wind (Chepil, 1944). It occurs when forces holding soil particles in place are overcome by forces tending to move the soil particles (Chepil, 1959a). This movement takes place when soils susceptible to soil blowing are devegetated through construction, overgrazing or cultivation (Kimberlien et al., 1977).

The "dust bowl" of the 1930's is a frequently mentioned example of wind erosion on a large scale (Chepil and Woodruff, 1963; Kimberlien et al., 1977; Woodruff, 1975). Serious wind erosion did, however, occur before the 1930's (Call, 1936) and has occurred since (Soil Conservation Service, 1980). The United States Soil Conservation Service reports that wind erosion in the 10 state Plains area has damaged an estimated 3.1 million acres from the period of November 1979 to February 1980. This is an increase from the 1.5 million acres reported damaged during the same period the previous year. This increase was attributed to low summer and fall precipitation and a lack of winter snow cover.

Of the 322 million acres of soil susceptible to wind erosion nationwide (Kimberlien et al., 1977), 1,500,000 are located in Southern Michigan, and encompass both mineral and organic soils (Drullinger and Schmidt, 1968). Crops grown on the mineral soils include beans, potatoes, corn, tomatoes and sugarbeets. High value truck crops such as onions, carrots, celery, radishes, and head lettuce are grown on the organics. Many of these crops are sensitive to the abrasive action of windblown soil particles.

Wind erosion has social, environmental and economic affects. Dust storms contribute to environmental degredation for they probably add more particulate matter to the atmosphere than all other sources combined (Kimberlien et al., 1977). The visibility reduction resulting from suspended dust has been responsible for multiple car crashes, with accompanying death and injury (Hagen and Skidmore, 1977). Particulate matter in the air slows or halts air traffic, clogs machinery, is deposited in buildings and causes respiratory problems.

Wind erosion also affects the agricultural community. Many crops are sensitive to the abrasive action of windblown soil particles (Skidmore, 1966; Armbrust, 1968; Fryrear and Downes, 1975). Partial or even total loss may result. Market value may be lowered as surface lesions facilitate insect damage (Skidmore and Siddoway, 1978). In rural areas where wind erosion is a problem, roads and fences may be buried, and irrigation ditches filled (Woodruff, 1975). Wind erosion also affects soil productivity and water holding capacity. Organic matter, clay and silt are the most valuable portions of the soil from a productivity standpoint. These are also the parts of the topsoil most readily removed by the wind. The water holding capacity of the soil decreases over time, for coarser soil fractions are untouched by the action of the wind (Daniel, 1936; Daniel and Langham, 1936; Lyles, 1975, 1977).

Conditions in the Great Plains in the 1930's provided the impetus for wind erosion research. The causes and effects of wind erosion, the erosion process, and the control of soil blowing have been intensively studied (Woodruff, 1975). Investigations into the control of wind erosion have yielded the following principles of effective wind erosion control (Woodruff et al., 1977):

1. Promote an aggregated or cloddy condition of the soil surface. Clods must be large enough to resist the force of the wind.
2. Roughen the soil surface to reduce wind velocity and trap eroding soil particles.
3. Establish barriers or crop strips to reduce field length along the direction of the prevailing wind.
4. Keep the soil surface vegetated.

These precepts of wind erosion control are reflected in a wind erosion equation, developed by W. S. Chepil and his associates. Users of the equation include researchers and soil conservationists. The equation serves two purposes (Woodruff and Siddoway, 1965). It is used to estimate the average potential soil loss in Tons/Acre/Year that may occur from a given area. The equation is also used to arrive at an approximate sequence of management practices necessary to reduce wind erosion losses to an acceptable level. The present form of the equation is (Woodruff and Siddoway, 1965):

$$E = f(I', K', C', L', V)$$

where:

E = average potential soil loss in Tons/Acre/Year

I' = soil erodibility index (knoll present) in Tons/Acre/Year

K' = soil ridge roughness factor

C' = climatic factor

L' = field length along prevailing wind direction in feet

V = equivalent quantity of vegetative cover in equivalent lbs/acre

The soil erodibility index I' is determined from the percentage of dry fractions >0.84 mm in diameter. Since aggregation >0.84 mm in diameter varies inversely with wind erosion, I' decreases as the percentage of such dry aggregates increases (Chepil, 1958). The dry aggregate state of a soil, and hence its erodibility index, is determined using a standard dry sieving procedure (Chepil, 1952). This sieving has been performed for many soils of the Great Plains, where the research has been conducted (Chepil, 1959b, 1960). Two basic tables were then generated from this data (Woodruff and Siddoway, 1965; Gillette, 1978a). One related percent dry aggregation >0.84mm in diameter to I (without knoll). The other related surface soil texture to average values of percent dry aggregation and I. The Agricultural Research Service of the USDA is the agency that assigned soil textural classes into Wind Erodibility Groups (WEG's) (Gillette, 1978a). The I values in Tons/Acre/Year assigned to WEG's are used by the Soil Conservation Service in planning wind erosion control programs (Hayes, 1972).

Due to a lack of dry sieving data, WEG's are used outside the Plains area, where they were developed. Michigan is one of the states for which no sieving data is available (Quisenberry, personal communication). Michigan soil conservationists are using WEG's to assist farmers in planning wind erosion control programs. The objectives of this research are to:

1. Inventory the I' values of selected surface soil textures of Michigan soils.
2. Relate the percent dry aggregates >0.84 mm in diameter to percentages of sand, silt, clay, organic carbon and $CaCO_3$.

LITERATURE REVIEW

Scientific interest in wind erosion dates to the late 19th and early 20th centuries. In 1894, the University of Wisconsin published a bulletin concerning the wind erosion problems on coarse-textured Wisconsin soil (King, 1894). The United States government officially recognized wind erosion as a problem in 1911, when the U. S. Department of Agriculture published The Movement of Soil by Wind by E. E. Free and its accompanying Bibliography of Eolian Geology by S. C. Stuntz and E. E. Free. This detailed bulletin and its extensive bibliography still did not inspire research activity (Woodruff, 1975). That inspiration came from the diastrous effect of the dust bowl of the 1930's.

Wind erosion research has dealt with the process of wind erosion, the factors influencing wind erosion, the control of wind erosion, and the development of the wind erosion equation.

Airflow Near the Ground

Knowledge of wind characteristics near the ground is important in the discussion of wind erosion. The air flow involved in wind erosion is always turbulent, characterized by multidirectional eddy flow (Chepil and Woodruff, 1963). The transporting power of the wind changes with eddy flow. For this reason eddies are more important than average wind velocity in the wind erosion process.

The pattern of windspeed with height above the ground is the wind speed profile (Rosenberg, 1974). The change in velocity per unit of height is the velocity gradient (Chepil, 1961). No matter what the gradient is, wind speed increases with height in an exponential manner (Chepil and Woodruff, 1963). Over a surface roughened, for example, by a crop or soil clods, wind speed at any height, Z, above the roughness elements is described by the equation (Skidmore and Siddoway, 1978):

$$\mu = \frac{\mu^*}{k} \ln\left(\frac{Z-Zd}{Zo}\right) \quad (1)$$

where:

μ = wind speed at height Z

μ^* = friction velocity

k = Von Karman's constant (.4)

Zd = displacement height

Zo = roughness parameter

The factor Zd, the displacement height, is introduced for wind flow over a rough surface (Rosenberg, 1974). It is also known as the effective roughness height (Lyles, 1977) and as the zero displacement height (Chepil and Woodruff, 1963). It is the average height of the roughness elements and varies directly with the height of the elements. It separates the fast moving "free air" above the roughness elements, from the slow moving "restricted flow" below the roughness elements (Chepil and Woodruff, 1963).

Figure 1 illustrates the interrelationships between Zd, Zo, the roughness elements and the ground surface. The hatched area of Figure 1 represents the roughness elements.

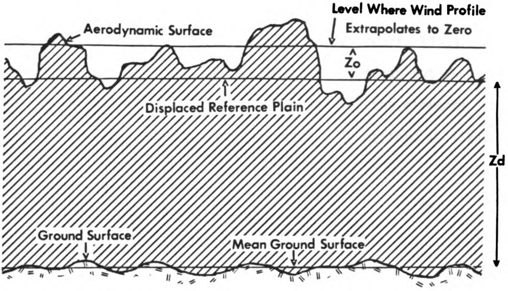

Fig. 1 Diagrammatic representation of the relative position of the ground and vegetative roughness elements above the ground. (After Chepil and Woodruff, 1963; and Skidmore and Siddoway, 1978).

As seen in Figure 1, the wind speed above a rough surface ideally extrapolates to zero at some point below the tops of the roughness elements (Chepil and Woodruff, 1963; Rosenberg, 1974; Skidmore and Siddoway, 1978). Wind speed is zero at height Zd + Zo if the surface is impervious. Over a porous surface, such as that covered by vegetation, the velocity at Zd + Zo is somewhat greater than zero. The porous nature of the roughness elements permits some air movement (Chepil and Woodruff, 1963; Skidmore and Siddoway, 1978). The protective nature of vegetation or other roughness is clear, however. The distance Zd increases with height of roughness elements so if the erodible soil is located below Zd, no erosion should occur (Skidmore and Siddoway, 1978). Zo, which Chepil and Woodruff (1963) called _k_ is the height above the displaced reference plane where the wind velocity is zero. It may be thought of as an index of _aerodynamic_ surface roughness for the value of Zo increases as the roughness of the aerodynamic surface increases (Chepil and Woodruff, 1963). Zo is not related to the height of the roughness elements but to variability in height, flexibility and density of the elements.

The friction velocity μ^* of Equation 2 is defined as (Skidmore and Hagen, 1977):

$$\mu^* = (T/\rho)^{\frac{1}{2}} \qquad (2)$$

where

T = surface drag

ρ = density of air

Friction velocity is the same as Chepil's drag velocity V* (Chepil and Milne, 1941a). It is considered by many workers (Chepil and Milne, 1941a; Lyles, 1977; Skidmore and Hagen, 1977) to be an index of the capacity of the wind to erode. This is because part of the momentum of wind flowing over a surface is transferred to that surface (Skidmore and Hagen, 1977). This transfer of momentum causes the shearing stress, T, on the surface. A soil particle becomes more susceptible to movement by wind as the stress on it increases.

The Process of Wind Erosion

The process by which a particle susceptible to wind erosion is actually moved consists of three parts: 1. Initiation of soil movement 2. Transportation and 3. Sorting and Deposition (Chepil, 1945b).

Initiation of Soil Movement

Movement begins when the pressure of the wind on the soil particles overcomes the force of gravity holding them in place (Chepil, 1959a). The wind speed required to overcome gravity and initiate movement is the threshold velocity. It varies according to soil, crop and other environmental conditions (Chepil, 1945b; Gillette, 1978b).

A fluid in motion, e.g. wind, exerts three types of pressures on a particle (Chepil, 1959a). The first type is velocity or impact pressure. This is a positive pressure exerted on that part of the particle facing into the wind. It is due to the impact of the wind on the particle. The second type is called viscosity pressure. It is a negative pressure on the lee side of the grain. Magnitude of the viscosity pressure depends on the density, velocity and viscosity of the wind. The third type of pressure is called static, isotropic or internal pressure. This is a pressure on the top of the particle which is negative when compared to the pressure on the bottom of the particle. The pressure difference is caused by the Bernoulli effect. According to the Bernoulli law, pressure on a surface is reduced when a fluid flowing over that surface is increased in velocity. The wind speed at the top of a soil particle is generally higher than at the bottom of the particle. This pressure difference causes a lift on the particle, increasing its tendency to rise (Chepil, 1945a).

The sum of the impact and viscosity pressures exerted on a particle is called drag. Pressure differences between the top and bottom of the particle constitute a lift, while the force of gravity tends to counteract the lift (Chepil, 1961). The forces acting on a soil particle before movement is initiated include: drag, lift and gravity. The threshold drag and lift required to initiate soil movement are influenced by particle diameter, shape, density, closeness of packing and by the angle of repose of the particle with respect to the average drag level of the wind (Chepil, 1959a; Chepil and Woodruff, 1963).

Soil Transport

After the forces of lift and drag initiate soil movement, the second phase of the wind erosion process, soil transport,begins. There are three types of soil transportation: saltation, suspension and surface creep (Chepil, 1945a; Lyles, 1977). Of the three, saltation is the most common, for between 50 and 80 percent of the soil moved is transported in this way (Chepil and Milne, 1939; Lyles, 1977). The average size of the soil particles moved by each of the three forms increases from suspension, through saltation, to surface creep (Lyles, 1977). The proportion of soil moved by the three forms varies with texture (Stallings, 1957). In general, coarse textured soils move by saltation and surface creep, while fine textured soils move mainly by saltation and suspension.

Soil particles airborne due to the effects of lift and drag move in saltation (Chepil and Woodruff, 1963). Saltation is a series of short jumps by which a particle moves across the soil surface. When the effects of lift and drag initiate movement, soil particles leap into the air at an angle ranging from 75 to 90 degrees (Chepil, 1945a). The height of rise varies directly with the initial velocity of rise from the ground and with the velocity gradient (Chepil, 1961). Saltating particles do not, however, rise more than a few feet above the ground. More than 90 percent stay below one foot. Chepil also found the almost vertical rise is followed by a straight line path of descent, striking the surface at an angle of 6-12^{o}. This straight-line descent path is due to the accelerating action of both wind and gravity (Chepil, 1945a; Bisal and Nielsen, 1962).

Chepil (1945b) also investigated the fate of particles in saltation when they hit the ground. Upon hitting the surface, the saltating particle either rebounds in another jump, or loses its kinetic energy, thereby becoming part of the soil mass on the ground. A particle in saltation can lose its kinetic energy by striking another particle when it impacts, thus setting the second particle in motion. During the course of a wind erosion episode, a given particle can move via saltation, come to rest, and have its movement reinitiated many times (Chepil and Woodruff, 1963). If the particle set in motion by the striking action of a saltating grain is in the correct size range, it too will move by saltation (Chepil, 1945a). Soil particles can, then, begin movement by saltation in one of two ways. The first is by the direct force of the wind, and the second is due to the impact of another saltating particle.

Chepil (1945 a, b) elucidated the basic relations between particle size and saltation. Soil grains moved by saltation range from 0.1 mm to 0.5 mm in diameter. Those from 0.1 mm to 0.15 mm in diameter are most susceptible to movement. Their threshold velocities are 8-9 mph at 6 inches (Chepil, 1945b).

Similarly, particles smaller than 0.1 mm and larger than 0.5 mm were found to be unaffected by the direct force of winds ordinarily encountered. For the small particles, this increase in the threshold velocity is due to both their cohesive nature and to their small size.

They are too small to protrude above the laminar layer of slow moving air that exists at the surface over which a wind flows. Soil particles larger than 0.5 mm in diameter do protrude above the laminar layer, but their larger diameters increase the threshold velocity necessary for initiation of soil movement (Chepil, 1945 a, b, c). Particles <0.1 mm and between 0.5 and 1 mm in diameter can, however, be set in motion by the impacts of saltating soil particles. The mode of transport, either suspension or surface creep, depends on particle size (Chepil, 1945a; Chepil and Woodruff, 1963).

The effects of saltating particles arise primarily from their role as abrasors (Chepil, 1946a; Armbrust, 1968; Gillette, 1977). Since particles moved by saltation are mainly sand their impacts produce a sand blasting effect (Chepil, 1945b, 1946 a, c; Gillette, 1977, 1978a). This abrasive action reduces crop yields, for it damages or kills the plants (Skidmore, 1966; Armbrust, 1968; Fryrear and Downes, 1975). Also subject to abrasion are non-erodible elements at the soil surface, such as clods and ridges. Pieces of these elements are broken off during abrasion, and are added to the erosive soil mass. The subsequent decrease in height or size of the elements increases their susceptibility to wind erosion (Chepil, 1946b).

For many years, scientists observed that during wind erosion episodes, more soil movement takes place to the leeward edge of fields (Free, 1911). Chepil (1946b) investigated the phenomena, and termed this increase in soil flow downwind <u>avalanching</u>. He found the rate of soil flow varied from the windward to the leeward edges of an eroding field. The rate of erosion was zero at the windward edge and under the cumulative abrasive influence of saltating soil particles, steadily increased downwind until the rate of soil flow reached the maximum a given wind could sustain. For any wind, Chepil (1959b) found the distance to maximum rate of soil movement was the same for a given soil. Since the rate of avalanching increases as a soil becomes more susceptible to wind erosion, the leeward distance to maximum flow decreases as soil erodibility increases (Woodruff et al., 1977).

There are then two general ways in which wind acts upon the soil (Chepil, 1946a). First, direct pressure of the wind moves particles susceptible to saltation, and second, the impacts of the saltating particles causes further soil movement. Since winds are much less erosive without saltation, wind erosion control should center on preventing its occurrence (Chepil, 1946a; Zingg and Chepil, 1950).

The second type of soil movement is suspension. In suspended flow (Chepil, 1945a; Chepil, 1946c; Lyles, 1977), particles smaller than approximately 0.1 mm are carried with the wind, and do not touch the ground. To suspend a particle, the wind must have an average upward velocity higher than the velocity of fall of the particle (Gillette, 1977). Suspension occurs after the impacts of saltating particles either throw fine particles into the wind, or "chip" small pieces of soil off larger clods or aggregates (Hsieh and Wildung, 1969; Gillette and Walker, 1972; Lyles, 1977). Using a wind tunnel, Chepil (1945a) subjected a layer of soil particles less than 0.05 mm in diameter to increasing wind velocities. Due to their cohesive nature and to the presence of the laminar layer, they were not moved, even by velocities of 37 mph at six inches. Coarser particles up to 0.5 mm in diameter were then mixed with the fine material. The threshold velocity was reduced, saltation of the coarse grains began, and their impacts caused the fine particles to rise in suspension.

The third form of soil movement by wind is called surface creep. Soil particles moved by surface creep range from approximately 0.5-1.0 mm in diameter (Chepil, 1945a; Lyles, 1977). Most particles moved, however, are smaller than 1.0 mm (Chepil, 1946c). Soil particles moving via surface creep roll and slide along the ground for they are too heavy to be lifted by the wind. Particles transported by surface creep derive their energy from the force of the wind and from the impact of saltating grains. Since surface creep is the slowest of the three modes of transportation, soil thus moved rarely leaves its field of origin. As such, it is not considered a loss to the area. Any crop damage caused by surface creep is that resulting from burial of the plants during deposition of soil particles moving by surface creep (Chepil, 1946c). A wind affected soil particle can be moved in one of three ways: by saltation, suspension or surface creep. The type of transport for a given particle depends primarily on size (Stallings, 1957).

Sorting and Deposition

The final stage of the wind erosion process is sorting and deposition (Malina, 1941). Sorting is the separation of eroded soil fractions into size classes based on their varying mobilities (Chepil and Woodruff, 1963). The size limits of these classes are not distinct, but "fade" gradually into one another (Chepil, 1946c). Deposition takes place when a reduction in velocity reduces the carrying power of the wind (Chepil and Milne, 1941b). Compared to large particles (Chepil, 1946c)smaller ones are moved by winds of lower velocity. In addition, the rate of movement of smaller particles is faster in comparison to coarse particles. This differential rate of movement causes coarse particles to be deposited in or near the eroding field, while fine particles settle out farther away (Chepil, 1946c). Particles carried in suspension may be deposited when it rains, or when the velocity of the wind lessens considerably (Chepil, 1945a). Small (<0.02 mm) particles may become permanent components of the atmosphere (Gillette, 1977).

The "fanning mill" action causes a field to become progressively coarser in texture with time (Chepil, 1946b; Zingg and Chepil, 1950). According to Zingg and Chepil (1950) this coarsening of texture may make the remaining soil more erodible. Those soil components deposited in the field are most susceptible to saltation and surface creep, thereby increasing the soils erodibility. The removal of clay and fine silt increases erodibility, for clay and silt help bind the soil particles into aggregates large enough to resist wind erosion. And finally, the coarser texture lowers the water holding capacity of the soil, which can reduce the soils protective vegetative cover (Zingg and Chepil, 1950).

Factors Affecting Wind Erosion

Soil Cloddiness

The primary factors affecting wind erosion from a given area are: soil cloddiness, surface roughness, wind, soil moisture, field length and vegetative cover (Woodruff et al., 1977). Up to 75 percent of the variability in wind erosion has been attributed to soil cloddiness, surface roughness and vegetative cover (Woodruff and Chepil, 1956). Of these three factors, soil cloddiness is the most important variable influencing the erodibility of an area (Chepil and Woodruff, 1956). Soil cloddiness is also known as secondary aggregation or dry soil structure (Chepil, 1953a).

Soil fractions large enough to reduce wind erosion act in two ways. They are not moved by the wind, and they shelter the more erodible fractions by absorbing part of the wind's drag (Chepil and Woodruff, 1963; Woodruff et al., 1977). For wind tunnel situations, soil movement ceased when the eroding surface became stabilized by non-erodible fractions (Chepil, 1941; 1945b; 1946a). As long as the wind blew, erosion continued indefinitely if the soil was composed of all erodible elements. Most cultivated soils are composed, however, of a mixture of erodible and non-erodible fractions. The rate of soil removal and the time needed for soil movement to cease varied with size and proportion of non-erodible aggregates (Chepil, 1941, 1950a). As the size of the non-erosive fraction decreased, the initial rate of soil removal increased, but the time necessary for erosion to stop decreased. Due to the greater surface area, the protective power of the aggregates increased as their size decreased. As the ratio of erodible to non-erodible aggregates increased, both the initial removal rate and the time until erosion cessation increased. Once the surface became stabilized by non-erodible clods, erosion resumed if there was any decrease in clod height (through abrasion), any increase in distance between clods or an increase in the wind velocity (Chepil, 1950a).

Surface Roughness

The ridges and furrows caused by tillage constitute the roughness of a field. A rough soil surface reduces wind erosion by absorbing part of the total wind drag (Lyles, 1977). The wind loses momentum because of the increased drag, velocity is reduced and the zero velocity level is raised (Plate, 1971; Skidmore and Siddoway, 1978). The non-erodible elements of ridges absorb the drag, while the erodible fractions are blown off the ridges. They are then deposited in the depressions, where the wind velocity is lower (Chepil, 1946a; Chepil and Woodruff, 1963). Particles moving by surface creep and saltation are trapped in a similar fashion, thereby reducing avalanching (Chepil and Milne, 1941a; Woodruff et al., 1977). The amount of drag absorbed, the extent of velocity reduction and the height to which the zero velocity level is raised all increase with height of ridges. However, ridge height should not be increased indiscriminately in hopes of greater reductions in wind erosion.

The positive effects of ridges are counterbalanced somewhat by their negative aspects. The increased drag absorbed by ridges causes greater erosion to occur off their crests (Chepil and Milne, 1941a). An increase in ridge height causes intense turbulence lee-ward of the ridges and greater stress on the soil located there (Lyles and Krauss, 1971). There is an optimum ridge height for wind erosion control. It ranges from 2 to 5 inches, depending on the soil (Wood-ruff et al., 1977).

The effect of vegetation and vegetative residue is similar to that of ridges (Chepil and Woodruff, 1963). Like ridges, vegetation traps eroding soil particles (King, 1894; Chepil, 1944). Living or dead vegetation also absorbs much of the total wind drag and raises the zero velocity level (Zingg, 1951; Lyles, 1977; Skidmore and Hagen, 1977).

The beneficial effects of vegetation, unlike ridges, increase uniformly with height. The taller the vegetation or residue, the higher the level of zero velocity (Chepil and Woodruff, 1963). A good example of this is the calm that prevails in a stand of tall corn on a windy day. Along the same line, it was found that standing residue is more effective in reducing erosion than flat residue (Chepil, 1944). On a weight basis, fine textured vegetation or residue such as that resulting from a small grain, is more effective than coarse textured vegetative cover (Chepil, 1944). However, small additions of coarse residue do give significant reductions in soil loss (Siddoway et al., 1965).

Wind and Soil Moisture

Wind and soil moisture also affect the amount of erosion occurring from an area. The intensity of wind erosion varies as the cube of wind velocity and inversely as the square of the effective precipitation (Chepil, Siddoway and Armbrust, 1963). The influence of water on erodibility has been ascribed to the cohesive qualities of adsorbed water films (Chepil, 1956).

Water also influences the erosive qualities of wind. When air increases in water content, water vapor replaces part of the air (Chepil, 1945c). Water vapor is lighter than air, so a wet wind is less dense than a dry one. A dry wind is more erosive than a wet one for the force of a wind varies directly with its density. A dry wind will also dry soil out, making the soil more susceptible to wind erosion.

Field Length

The final factor influencing wind erosion is field length. Avalanching makes a long field more susceptible to wind erosion, and adjoining fields may become one eroding unit (Chepil and Milne, 1941b; Chepil and Woodruff, 1963). Barriers such as crop strips or windbreaks are often used to decrease field length and help control erosion (Chepil, 1959b).

Wind Erosion Control

Since wind erosion is caused by "...a strong turbulent wind blowing across an unprotected soil surface that is smooth, bare, dry and finely granulated" (Woodruff and Siddoway, 1973) its control involves manipulation of the factors influencing wind erosion. The factors are: soil cloddiness, surface roughness, vegetative cover, field length, wind and soil moisture. This is accomplished by (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 perpendicular to the direction of the prevailing wind
4. Establishing and maintaining a cover of vegetation or vegetative residue.

Soil Cloddiness

Secondary aggregates are important in wind erosion control, for if large enough, they resist the force of the wind, and protect the more erosive aggregates and particles (Chepil, 1941). In general, the surface soil of a field will be protected against most winds if at least two-thirds of its dry fractions are >0.84 mm in diameter (Woodruff and Siddoway, 1973). The usefulness of clods in controlling wind erosion is, however, dependent on soil texture. Coarse-textured aggregates are more susceptible to the disintegrating effects of saltation, weathering and field traffic (Woodruff et al., 1977). Secondary aggregates are formed during tillage. Their size and strength depends on texture, moisture and soil density at time of tillage (Lyles and Woodruff, 1961).

Ridges

The usefulness of ridges also depends on soil texture. Many times, the ridges of weakly granulated soils abrade too quickly to be of any real use in controlling erosion (Woodruff et al., 1977). Roughening the surface to control wind erosion can be useful if properly done on soils of suitable texture (Chepil and Woodruff, 1963). Tilling the soil surface to bring up moist, cloddy soil is an emergency control measure used when little or no vegetation protects the surface. This is called emergency tillage, and is done when erosion is either imminent or actively occurring (Woodruff et al., 1957).

Barriers

A more permanent set of control practices involves establishing barriers such as shelterbelts, snow fences and crop strips at right angles to the prevailing wind direction (Chepil and Woodruff, 1963). A given barrier has a drag, and by this drag it exerts a force upon the incident wind. In accordance with Newton's second law (Plate,

1971) the air loses momentum and its velocity is reduced. This decrease in velocity then decreases shear stress at the surface. The leeward extent of lowered velocity averages 20 to 30 times the height of the barrier (Woodruff, 1956), but in general, effective velocity reduction extends only 10 times the height of the obstruction (Woodruff, 1956). In addition to lowering velocity, barriers reduce avalanching by trapping saltating particles (Chepil and Milne, 1941b). The width of the "trap strip" effective in reducing erosion (Chepil, 1945a) varies with the density of the crop comprising the strip, and with the height of jump of the saltating particles.

<u>Vegetation</u>

The last of the four principles of wind erosion control is the establishment of vegetation or maintaining vegetative residues. They act as roughness elements by absorbing much of the total drag (Lyles et al., 1974). Crops and residues raise the zero velocity level of the wind (Chepil and Woodruff, 1963), decrease wind velocity at the surface, and trap eroding particles (Chepil, 1944). Like barriers and ridges, vegetation is more effective if it is oriented perpendicular to the prevailing wind direction (Siddoway, Chepil and Armbrust, 1965).

The importance of a vegetative cover in wind erosion control is illustrated by what happened in the Great Plains when the cultural practice of <u>summer fallow</u> was introduced. In summer fallow, the soil is kept bare of vegetation. This conserves water in the rooting zone, but also increases wind erosion (Fenster, 1975). Minimum tillage practices that maintain crop residue while increasing water infiltration and storage are now widely used (Fenster and Wicks, 1977). Other erosion control techniques using vegetation are: mulching, cover crops and establishment of permanent vegetation on marginal lands (Siddoway et al., 1965; Fenster and Wicks, 1977).

Wind Erosion Equation

A wind erosion equation integrating these principles of wind erosion control has been developed through work done in the Great Plains (Chepil and Woodruff, 1954; 1959; Chepil, 1960). It is used to estimate the potential for soil loss from a given agricultural field and to arrive at a sequence of management practices needed to reduce wind erosion to an acceptable level (Chepil and Woodruff, 1963). Five tons/acre/year is the maximum tolerable soil loss generally thought acceptable (Woodruff and Armbrust, 1968). The present form of the erosion equation is (Woodruff and Siddoway, 1965):

$$E = f(I', K', C', L', V) \tag{3}$$

where

E = potential average soil loss in T/Acre/Year

I' = soil erodibility index in Tons/acre/year

K' = soil ridge roughness factor

C' = climatic factor

L' = field length along the prevailing wind direction in feet

V = equivalent of quantity of vegetative cover in equivalent lb/Acre

The potential average soil loss, E, is expressed as a function of the 5 equivalent variables, for the complexity of the interrelationships between the variables prohibits a simple mathematical solution (Chepil and Woodruff, 1963). Because of this, charts and tables were developed to permit a graphical solution. The charts and tables were cumbersome, so researchers in Kansas developed a computer program to solve the equation. In the field, Soil Conservation Service personnel use a wind erosion equation "slide rule" that permits easy solution of the equation (Chepil and Woodruff, 1954, 1959; Woodruff and Siddoway, 1965; Skidmore et al., 1970). Following is a brief description of each variable and its role in the equation. The information is adapted from Woodruff and Siddoway (1965).

Description of the Variables

Soil Erodibility Index I'

I', the soil erodibility index in Tons/Acre/Annum, is the potential soil loss from a "wide, unsheltered isolated field, with a bare, smooth, non-crusted surface." The value of I' is dependent on the cloddiness of the soil, and increases as the percentage of dry fractions >0.84 mm in diameter increases. The percentage dry fractions >0.84 mm in diameter can be determined two ways. The preferred method is the standard dry sieving procedure (Chepil, 1952; 1962). Where the sieve is not available, the percentage is determined from a table relating Wind Erodibility Groups to an average percentage of dry factions >0.84 mm in diameter (Table 1) (Quisenberry, 1978). After the percentage of dry fractions >0.84 mm is determined for, or assigned to a soil, soil erodibility I in tons/acre is read from Table 2.

In the solution of the wind erosion equation, soil erodibility, I, is multiplied by knoll erodibility, Is, to give erodibility

TABLE 1

WIND ERODIBILITY GROUPS AND ASSOCIATED PERCENTAGES (from Hayes, 1972)

WEG	Soil Texture Class	% >0.84 mm
1	Very fine sand, fine sand, sand, coarse sand	1
2	Loamy very fine sand, loamy fine sand, loamy sand, loamy coarse sand, sapric organic materials	10
3	Very fine sandy loam, fine sandy loam, sandy loam, coarse sandy loam	25
4	Clay, silty clay, noncalcareous clay loam, and silty clay loam with > 35% clay	25
4L	Calcareous loam and silt loam, calcareous clay loam and silty clay loam with < 35% clay	25
5	Noncalcareous loam and silt loam with <20% clay, sandy clay loam, sandy clay, hemic organic materials	40
6	Noncalcareous loam and silt loam with >20% clay, noncalcareous clay loam with <35% clay	45
7	Silt, noncalcareous silty clay loam with <35% clay, fibric organic material	45
8	Soils not suitable for cultivation due to coarse fragments or wetness, wind erosion not a problem	-

Table 2

SOIL ERODIBILITY I FOR SOILS WITH DIFFERENT PERCENTAGES OF NONERODIBLE FRACTIONS AS DETERMINED BY STANDARD DRY SIEVING*
(from Woodruff and Siddoway, 1965)

Percentage of dry soil fractions >0.84 mm	Units									
	0	1	2	3	4	5	6	7	8	9
tens	tons/acre									
0	---	310	250	220	195	180	170	160	150	140
10	134	131	128	125	121	117	113	109	106	102
20	98	95	92	90	88	86	83	81	79	75
30	74	72	71	69	67	65	63	62	60	58
40	56	54	52	51	50	48	47	45	43	41
50	38	36	33	31	29	27	25	24	23	22
60	21	20	19	18	17	16	16	15	14	13
70	12	11	10	8	7	6	4	3	3	2
80	2	--	--	--	--	--	--	--	--	--

*For a fully crusted soil surface, regardless of soil texture, the erodibility I is, on the average, about 1/6 of that shown.

$E_1 = I \times Is = I'$. This accounts for the presence of a significant knoll. The value of Is depends on the slope of the knoll. For a flat field, the value of I_s is set at 1.0.

The soil erodibility values in Table 2 give the loss that would occur from a "wide, unsheltered, isolated field, with a bare, smooth, non-crusted surface," as if it were located at Garden City, Kansas during the severe wind erosion years of 1954, 1955 and 1956 (Woodruff and Siddoway, 1965). The other factors in the equation modify the I value to reflect local conditions of roughness, field length, vegetative cover and climate.

Soil Ridge Roughness Factor, K'

The soil ridge roughness factor is determined from Kr, a linear measurement of roughness elements of the soil, K' evaluates the effect of surface roughness other than that caused by vegetative residue or clods. A chart is used to determine K from Kr. The chart reflects the fact that the effectiveness of ridges in reducing wind erosion decreases as ridge height increases or decreases beyond certain limits (Woodruff et al., 1977). Erodibility $E_1 = I$ is then multiplied by K' to give Erodibility $E_2 = I' \times K'$.

Climatic Factor C'

The climatic factor C' is related to two subvariables, wind velocity V, and the P-E index of Thornthwaite. C' is given a value of 100 percent at Garden City, Kansas. Climatic conditions at other locations either increase or decrease its value. To account for local climatic conditions, erodibility $E_2 = I' \times K'$ is multiplied by C' to give erodibility $E_3 = I' \times K' \times C'$.

Field Length Along Prevailing
Wind Direction, L'

Avalanching makes L', the length of unsheltered field along the prevailing wind direction, an important consideration (Chepil, 1946b). L' is composed of two subfactors. They are D_f, the total distance along the prevailing wind direction, and D_b, the distance along the prevailing wind direction protected by a barrier. To evaluate the effect of L', the angle of deviation of the prevailing wind direction from normality to the field must be determined. In 1965, when the article was written, data on prevailing wind direction was available only for the Great Plains (Woodruff and Siddoway, 1965). This has now been expanded to include much of the United States (Skidmore and Woodruff, 1968).

Df is determined using an alignment chart. The chart relates angle of deviation, and field width to Df. If a barrier is present, it is accounted for by multiplying its height by 10 to give Db. Db, subtracted from Ds, gives L'. There is no simple relationship between E and L', so a graph is used to determine $E_4 = I' \times K' \times C' \times f(L')$.

Equivalent Quantity of
Vegetative Cover V

Equivalent quantity of vegetative cover, V, is related to three subfactors: quantity of cover, R'; kind of cover S, and orientation of cover, Ko. R' is determined at the location in question using a standardized procedure (Cepil and Woodruff, 1954). Kind of cover, S, reflects the influence of cross sectional area of the vegetation, while orientation of cover, Ko, takes into account the effectiveness of standing vs. flat cover in reducing wind erosion.

As with field length, a graphical solution is necessary to evaluate $E_5 = E = I' \times K' \times C' \times f(L') \times f(V)$. One of three charts is used to determine V from R'. The choice of charts depends on the kind of cover. The value for V read from the chart reflects orientation, Ko. A final chart is used to arrive at $E_5 = E = I' \times K' \times C' \times f(L') \times f(V)$ in tons/acre/year.

Development of the Equation

Development of the wind erosion equation began when Chepil (1956b)determined there was a relationship between erosion and the size and proportion of dry clods in the soil. This study was the beginning of investigations into the I factor (Chepil and Woodruff, 1963).

The first wind erosion equation was developed to "estimate the relative susceptibility of field surfaces to erosion by wind, or conversely, to evaluate the effectiveness of crop residues and tillage practices in reducing erosion" (Chepil and Woodruff, 1954). The equation was developed from wind tunnel studies, and had the form:

$$X = 491.3 \frac{I}{(RK)^{0.835}} \tag{4}$$

where:

X = wind tunnel erodibility in Tons/Acre

I = soil erodibility index, based on percent dry fractions >0.84 mm in diameter

R = crop residue in lbs/acre

K = ridge roughness equivalent in inches

(Chepil and Woodruff, 1954)

The soil erodibility index I was a dimensionless expression of wind tunnel erodibility (Chepil and Woodruff, 1959). It was equal to X_2/X_1, where X_1 was the amount of erosion occurring under wind tunnel conditions from a soil with 60 percent of its clods >0.84 mm in diameter, and X_2 was the amount eroded from the same soil, in the same wind tunnel, when the percent of clods >0.84 mm in diameter is not 60. The size of 0.84 mm in diameter is the approximate dividing line between erodible and non-erodible soil fractions (Chepil and Woodruff, 1963).

To solve the equation, an alignment chart was used. The data needed to determine wind tunnel erodibility were the percentage dry fractions >0.84 mm, the amount of crop residue in lbs/acre, and the ridge roughness equivalent in inches. Since a wind tunnel must be used to determine K directly, K was estimated for general use from photographs of fields with known K values.

Through additional research, Chepil and Woodruff (1959) then revised this method to take the effect of the surface crust on erodibility into consideration. The constants of equation 4 were changed, from 491.3 and 0.835, to 400 and 1.26 respectively. They found the crust too fragile to be determined by dry sieving, so surface texture was used as an index of crusting.

Chepil and Woodruff (1959) felt they were justified in including a crusting parameter, for they found a crusted surface to be common on cultivated soils. In this revision, wind tunnel erodibility, X, was determined as before (Chepil and Woodruff, 1954), but with the alignment chart modified for the new constants. The wind tunnel erodibility was then multiplied by a factor, F, to give <u>natural erodibility</u>:

$$E = FX \tag{5}$$

where:

E = natural erodibility, defined as the relative erosion occurring under field conditions from a comparable series of winds

F = a factor, whose value depends on textural class of the surface soil

X = wind tunnel erodibility

(Chepil and Woodruff, 1959)

The value of the factor F increased as the soil crust became more fragile. This is shown in Table 3.

TABLE 3

FACTORS FOR CONVERSION OF WIND TUNNEL ERODIBILITY TO NATURAL ERODIBILITY ON A FIELD-SCALE BASIS (from Chepil and Woodruff, 1959)

Soil textural class	Factor F
Fine sand.	6
Loamy fine sand.	4
Fine sandy loam and clay	2
Loam, silt loam, clay loam, silty clay loam. .	1

Measurements of the rate of soil movement downwind at varying distances across eroding fields was the source of the data used in the next modification of the equation (Chepil, 1959b). This revision provided the method to evaluate the influence of: 1) deviation of the prevailing wind direction from normality to the field or to a barrier, 2) field length along the prevailing wind direction and 3) barriers. The revised method also helped the soil conservationist determine the width of field necessary to control wind erosion. At this time, the form of the wind erosion equation was:

$$E = IRKFBWD \qquad (6)$$

where

E = relative field erodibility

I = soil cloddiness factor

R = ridge roughness factor

K = soil abradibility factor (formally factor F)

B = wind barrier factor

W = width of field factor

D = wind direction factor

The solution of this equation involved determining natural erodibility as before (Chepil and Woodruff, 1959), and then using new graphs and alignment charts to arrive at relative field erodibility E.

Equations 4, 5 and 6 gave only a relative indication of erodibility (Chepil and Woodruff, 1954, 1959; Chepil, 1959b), so the next step in the development of the equation was to convert relative erodibility, E, to annual soil loss in Tons/Acre/Year (Chepil, 1960). To do this, a field study was conducted during the severe wind erosion seasons of 1954, 1955 and 1956. Sixty nine sites in western Kansas and eastern Colorado, mostly fields sown to winter wheat, were evaluated for soil loss due to wind erosion. Soil loss was measured for the wind erosion season for each of the three years. The wind erosion season was defined as beginning January 1st and extending through April. Chepil used two methods to estimate the average depth of soil removed.

1. Measuring the depth to which the wheat crowns were exposed, and
2. Measuring the difference in depth to the plow pan from the beginning of the wind erosion season to the end of the wind erosion season.

Average depth of soil removed was converted to seasonal loss in Tons/Acre, assuming 2,000,000 lbs. for an acre furrow slice 6 inches deep (Chepil, 1960). Soil loss per season, which was measurable on only 24 of the 69 sites, was then converted to annual soil loss. This was done using an analysis of the intensity and frequency of dust storms occurring at Garden City, Kansas during the years 1954, 1955 and 1956. Dust storm intensity was measured using the relationship of visibility to dust concentration determined by Chepil and Woodruff (1957).

On the basis of the data in Table 4, a conversion factor relating seasonal to annual soil loss was calculated. Seasonal soil loss from each plot was multiplied by the conversion factor (1.293) to convert to annual soil loss (Chepil, 1960).

TABLE 4

ESTIMATION OF ANNUAL FROM SEASONAL SOIL LOSS ON THE BASIS OF NUMBER AND INTENSITY OF DUST STORMS AT GARDEN CITY, KANSAS DURING 1954-56 (from Chepil, 1960)

	January 1 to April 30					
	Number of dust storms				Quantity of dust at 6 feet above ground	Total storms times dust concentration
Visibility	1954	1955	1956	Total		
miles					mg./cu. ft.	
0-0.5	5	9	1	15	5.0	75.0
0.5-1	2	1	2	5	1.2	6.0
1-3	13	3	2	18	0.5	9.0
Total	20	13	5	38		90.0
	Calendar year					
0-0.5	7	9	2	18	5.0	90.0
0.5-1	2	2	3	7	1.2	8.4
1-3	23	4	9	36	0.5	18.0
Total	32	15	14	61		116.4

Conversion factor from seasonal to annual soil loss therefore is 116.4/90.0 = 1.293.

After the relative erodibility for each plot was calculated (Chepil and Woodruff, 1959; Chepil, 1959b) annual soil loss in Tons/Acre was plotted against relative erodibility. The resulting curve was the tool wind erosion researchers needed to convert relative field erodibility to annual soil loss. However, Chepil (1960) wrote:

> In view of great inaccuracies in measuring relatively small annual soil losses from depth of soil removal, conversion of the relative field erodibility to annual soil loss based on the curve of . . . must be regarded only as highly approximate.

The next step in the development of the wind erosion equation was development of the climatic factor (Chepil et al., 1962). The climatic factor is a wind velocity-surface soil moisture parameter. For any area other than Garden City, Kansas, it is equal to

$$C = 100 \frac{V^3}{(P\text{-}E)^2} / 2.9 \qquad (7)$$

where:

C = climatic factor

V = mean annual wind velocity at 30 feet

P-E = potential evaporation index of Thornthwaite

2.4 = average value for C at Garden City, Kansas

Since 2.9 is the average value for C at Garden City, C is expressed as a percent of the climatic factor C at Garden City (Woodruff and Siddoway, 1965). Climatic factor C is directly related to the cube of wind velocity, and inversely related to the square of P-E, because the rate of soil movement also varies directly as the cube of velocity (Chepil and Milne, 1941a) and inversely as the square of effective moisture (Chepil, 1956). The P-E index was used instead of effective moisture, for data to determine effective moisture was not widely available (Chepil et al., 1962).

A new form of the equation was subsequently published. It reflected both the inclusion of the climatic factor, and the consolidation of barrier, wind direction and field lengths factors into the factor L - equivalent length of field (Chepil and Woodruff, 1963).

$$E = f\ (I,\ C,\ K,\ L,\ V) \quad (8)$$

where:

E = average annual soil loss in Tons/Acre/Year

I = soil erodibility

C = local wind erosion climatic factor

K = soil surface roughness

L = equivalent width of field

V = equivalent quantity of vegetative cover

In addition, the soil cloddiness factor I of equation 6, a relative value, (Chepil, 1959b) was changed to the soil erodibility I in Tons/Acre/Year of Equation 8. The field studies conducted by Chepil in 1954-1956 made this conversion possible (Chepil and Woodruff, 1963). Another change from equation 6 to equation 8 was in the soil abradibility factor F. It was discarded from equation 8, for surface crusts were thought to be too transient when considering erosion on an annual basis (Chepil and Woodruff, 1963).

Since the amount of wind erosion occurring from a knoll is higher than that for level terrain (Doughty and Staff, 1943 as cited by Chepil et al., 1964a) the I factor was modified accordingly in 1964. The isovelocity lines of wind flowing over knolls with slopes greater than 1.5 percent and lengths less than about 500 feet are compressed, with the amount of compression directly related to steepness of slope (Chepil et al., 1964; Woodruff and Siddoway, 1965).

Using an analysis based on this information, Chepil et al., computed the amount of erosion that would occur from the crest or from the slope of any significant knoll relative to the amount occurring from a level surface. With the relative soil loss from a level surface equal to 100 percent, the relative soil loss of a knoll crest or its slope, I_s, was shown to be greater than 100 percent (Chepil et al., 1964).

When a significant knoll is present in a field, the I factor, or potential soil loss in Tons/Acre/Annum for a flat surface, must be multiplied by I_s giving I , the soil erodibility index (Chepil et al., 1964; Woodruff and Siddoway, 1965). In their 1964 paper, Chepil et al., (1964) presented a chart whereby I_s could be determined if the windward knoll slope is known. This evaluation of the effects of slope on wind erosion was incorporated into the wind erosion equation, giving the form in present use:

$$E = f(I', K', C', L', V) \tag{3}$$

where the variables are defined as before (Woodruff and Siddoway, 1965). The final modification came in 1968; Woodruff and Armbrust published a paper in which they demonstrated the importance of monthly variations in wind velocity and soil moisture on wind erosion. They derived a monthly climatic factor using average monthly wind velocity in place of average annual wind velocity. Woodruff and Armbrust (1968) recommended use of the monthly climatic factor for accurate results. Values for the monthly climatic factor for most areas of the United States have been published (Skidmore and Woodruff, 1968).

The Non-erodible Fractions

I' is the most important of the five fractions comprising the wind erosion equation (Woodruff and Siddoway, 1965). For two soils under the same conditions of climate, roughness, vegetation and field length, the soil with the highest percentage of its dry structure and particles >0.84 mm in diameter is the least erodible. The parameter of percent >0.84 mm in diameter is then, a simple index of erodibility (Lyles and Woodruff, 1962).

The influence of soil structure on wind erosion arises from the sheltering effect of dry soil fractions large enough to resist the forces of the wind (Chepil, 1950b). The susceptibility of a soil to wind erosion therefore depends on the number and size distribution of the non-erodible fraction. However, the size and numbers of these structural units are influenced by their resistance to the forces of breakdown (Chepil, 1951). These disintegrating forces include tillage, weathering, abrasion and raindrop impact. Resistance to break down, or mechanical stability, is in turn affected by soil factors such as particle size distribution, calcium carbonate content, soil moisture, and microbial activity (Chepil, 1953b). Conditions at the time of aggregate and clod formation are also reflected in the characteristics of the non-erodible fraction (Lyles and Woodruff, 1962).

Nature of Dry Soil Structure

Chepil (1953a) described the nature of recently cultivated soil well when he wrote:

> Freshly cultivated soils are composed of a more or less loose mixture of particles and aggregates of widely varying dimensions.

> These may range from large clods several
> inches in diameter to particles of dust.

Since crusted soil is more common than the condition described above, Chepil (1953a) concentrated on characterizing the structure of a cultivated soil with a crust.

He found four types of structure present in a crusted cultivated soil. The mechanical stability of the four types varied in a definite manner. The four phases of dry structure arranged in order of decreasing structural stability are: (Chepil, 1953a)

1. primary aggregates (water-stable aggregates)
2. secondary aggregates (granules or clods)
3. surface crust
4. consolidated soil material between secondary aggregates

The primary aggregates consist of individual soil particles held together with water stable cements. They exhibit a high coherence and are very stable against weathering and abrasion (Chepil, 1953a, c). Primary aggregates are usually <1 mm in diameter, and most are of the size range easily moved by wind (Chepil and Woodruff, 1963). This is shown by the composition of drifts resulting from the deposition of saltating particles against an obstruction. The drifts are composed primarily of water stable aggregates and individual sand grains (Chepil, 1953a). Any primary aggregates in the soil body that are >0.84 mm in diameter will reduce erosion just as secondary aggregates of that same size class (Chepil, 1953c). Primary aggregates less than 0.02 mm in diameter will also reduce erosion. They are too small to protrude above the laminar layer, and their cohesiveness inhibits movement of larger particles.

Secondary aggregates are the second phase of dry soil structure. They are composed of both primary particles and primary aggregates held together with cements unstable in water (Chepil, 1953c). The cements consist of water dispersible particles <0.02 mm in diameter. Due to the nature of their cementation, secondary aggregates are unstable during wet sieving, and their quantity is determined using the dry sieving technique (Chepil, 1952; Chepil and Woodruff, 1963).

Secondary aggregates >0.84 mm in diameter are an important aspect of the dry soil structure. They comprise the greater part of the soil resistant to wind erosion (Chepil, 1953a). Primary particles such as gravel and coarse sand, and water stable agregates >0.84 mm in diameter make up the rest of the non-erodible fraction.

The third phase of dry soil structure is the surface crust. A crust is formed when the force of raindrops disintegrates surface aggregates. The soil disperses in the water, and forms the crust upon drying (Chepil and Woodruff, 1963). A major factor influencing crust formation is the amount of water dispersible fine silt in the soil (Chepil, 1953a). Silt disperses more readily in water then clay does, so medium textured soils with large amounts of silt form the thickest and most stable crusts (Chepil, 1953a; Chepil and Woodruff, 1963). A crusted soil is more resistant to wind erosion if no saltating particles abrade the crust. If a section of soil is not crusted, or if part of the crust is broken by mechanical means, saltation and subsequent abrasion can begin.

Consolidated material between secondary aggregates is the fourth type of dry structure. The erodibility of a soil decreases as the degree of consolidation increases (Chepil, 1953a). Consolidation occurs after wetting and drying, and this causes cementation between the secondary aggregates. The primary cause of consolidation was found to be the clay and silt dispersed during wetting. In general, silt is not considered an effective cement. It assumes more importance here though, because of its greater tendency to disperse in water (Chepil, 1953a; Chepil and Woodruff, 1963).

Factors Influencing the I Fraction

Although all phases of dry soil structure influence the erodibility of a soil, only that portion >0.84 mm in diameter, also known as the I fraction, is considered in assessing the susceptibility of a soil to wind erosion (Woodruff and Siddoway, 1965). This is because surface crusts and consolidated materials between secondary aggregates are too fragile to be sieved (Chepil, 1953a). The amount of water stable aggregates >0.84 mm in diameter is not used as an index of erodibility because Chepil (1953a) found their numbers too limited to be of any importance in reducing erosion. This work was with dryland soils. Since the I value of a soil is based on its percent dry fraction >0.84 mm in diameter, factors influencing both the amount and mechanical stability of that portion of the soil were considered.

In a soil, the amount and stability of the dry aggregates >0.84 mm in diameter depends primarily upon (Chepil, 1953b):

1. Particle size distribution
2. Organic amendments

3. Vegetation and vegetative residue
4. Microorganisms and the products of microbial decomposition
5. Free calcium carbonate
6. Weathering
7. Tillage

Particle Size Distribution

The influence of particle size distribution on erodibility was investigated by Chepil (1955a). When soils of only one textural constituent were analyzed for erodibility, sand was the most erodible, followed by clay, and then by silt, 0.005-0.01 mm in diameter. Mixtures of 95 percent sand and 5 percent of either silt or clay both had the same wind tunnel erodibility. For clay or silt contents above 5 percent, the silt produced more clods than clay, but they were of a softer nature. In general, erodibility decreased as the proportion of silt to sand increased.

The effect of clay was more variable. Erodibility decreased as clay increased, but only if the clay content was between 20 and 30 percent (Chepil, 1955a). In an earlier study, soils became more erosive as their clay contents increased above 40 percent (Chepil, 1953b). However, no mixture was more erosive than those containing >75 percent fine sand. It was concluded soil with 20-30 percent clay, 40-50 percent silt and 20-40 percent sand had the highest proportion of non-erodible clods.

These findings have been confirmed by others (Schmidt and Triplett, 1967; Anderson and committee, 1966). Clay was shown to increase aggregate size, particularly in soils low in organic matter (Hsieh and Wildung, 1969). Sands, fine sands, loamy fine sands, loamy sands and sandy loams are considered most erodible. They form unstable clods susceptible to abrasion and subsequent erosion (Anderson and committee, 1966). Loams, silt loams, clay loams and silty clay loams are considered most resistant to wind erosion. This is especially true if their silt ranges in size from 0.005 to 0.001 mm in diameter.

Many of these effects have been attributed to the nature of the primary particles (Chepil, 1953b; Chepil and Woodruff, 1963; Hsieh and Wildung, 1969). Sand has little cohesiveness, so the clods that do form in sandy soils are more susceptible to disruption by mechanical forces. Clay and silt are viewed as aggregating agents for they exhibit the binding action important in aggregate formation. A model to explain the increase in mechanical stability seen with decreasing particle size was developed by Smalley (1970). He found mechanical stability directly related to tensile strength. Tensile strength in turn was inversely proportional to the cube of the particle diameter, and directly proportional to packing density and interparticle bond strength.

Vegetation and Residues, Organic Amendments and Microbial Activity

Vegetation and vegetative residue, organic amendments, and microorganisms and their decomposition products are interrelated in their effects on the I fraction. For this reason, these factors shall be discussed together. Vegetation and vegetative residue affect the I fraction in two direct ways. In an erosion situation, a vegetative cover reduces the number of particles in saltation (Chepil, 1957).

This decreases the amount of abrasion the I fraction is subjected to. A cover of vegetation or vegetative residue also decreases aggregate breakdown by absorbing the impact energy of raindrops (Stallings, 1957).

The decomposition of vegetative matter and organic amendments affects the I fraction, but in more tenuous ways(Chepil, 1955b). Qualitative observations in Canada indicated soils high in organic matter, with good "tilth," and with a high nutrient level were very susceptible to wind erosion. Experiments were started in the Great Plains in 1955 to investigate the relationship between erodibility and organic matter.

Varying amounts of straw were added to nine different Great Plains soils (Chepil, 1955b). Decomposition of the straw caused an initial increase in the percentages of both water stable and secondary aggregates >0.84 mm in diameter. This decreased wind tunnel erodibility. The effects were more pronounced as increasing amounts of organic matter were added. After the additions stopped, the beneficial effects disappeared in a year or two. Aggregates >0.84 mm in diameter then decreased in numbers, and the soils became more erodible. The soils stayed more erodible for 2 to 5 years, depending on the amounts of straw initially added. The effects lasted longer with greater quantities of straw. Based on this, Chepil recommended vegetative residue and organic amendments not be incorporated, but left on the surface. In this way, they would decompose more slowly, spreading out the initial benefits of decomposition over a longer period of time.

The findings of Chepil agree with those of soil microbiologists.

As microorganisms metabolize an energy source such as vegetative residue or organic amendments, they produce organic by-products. These organic materials act as soil cements and cause the initial increase in aggregation (Harris et al., 1966). When the residue or amendment is no longer available for metabolism, the organic binders causing the initial increase are used as energy sources and metabolized by soil microflora. After the initial binders are destroyed, they are replaced by secondary cements. The secondary cementing agents are more brittle, and are not as effective in maintaining large aggregates (Chepil and Woodruff, 1963).

Free Calcium Carbonate

The presence of free calcium carbonate is another soil property affecting the I fraction. The influence of differing amounts of $CaCO_3$ on some soils of the Central United States was studied by Chepil (1954a). Precipitated $CaCO_3$ was shaken in water with each of three textures: silt loam, fine sandy loam, and loamy fine sand. The soil-$CaCO_3$ mixture was then dried. Amounts of calcium carbonate added were 0, 1, 3 and 10 percent. The effect of $CaCO_3$ depended on soil texture. For silt loam and fine sandy loam, $CaCO_3$ increased soil erodibility by reducing both the proportion of the I fraction and the mechanical stability of the I fraction. Maximum increase in erodibility resulted from the addition of 3 percent $CaCO_3$. Loamy fine sand responded differently to the addition of $CaCO_3$. Calcium carbonate increased the proportion of its I fraction and increased the mechanical stability. The effects on all textures remained as long as there was lime in the soil.

Chepil and Woodruff (1963) explained the aggregating effect of $CaCO_3$ on loamy fine sand by equating its effect to silt. Silt increased the aggregation of sandy soils in a manner very similar to that of $CaCO_3$. In addition, the crystals of precipitated $CaCO_3$ are the size of silt when they are shaken in water. The decreases in non-erodible aggregates seen with silt loam and fine sandy loam was attributed to the flocculation phenomena.

Weathering

Another factor influencing the I fraction is not a soil property, but a process: weathering. Soil structural conditions are influenced by wind, by freezing and thawing, and by wetting and drying (Chepil and Woodruff, 1963; Gillette, 1977). The effect of wind blown abrasive particles has been discussed, but winds can also act alone, or in conjunction with rain to disintegrate aggregates. In Texas, the action of wind alone was shown to decrease clod size and increase erodibility (Gillette, 1977). The effects of wind velocity and the intensity and duration of rainfall were investigated by Lyles et al. (1969). For a given clod size and wind velocity, a 10 minute rain falling at the rate of 5.6 cm/hr was as disruptive as a 90 minute rain falling at a rate 1.6 cm/hr. When a rain was windblown, 66 percent more soil was lost from the clods. This was due to increasing drop size with increasing wind velocity.

The second type of weathering is wetting and drying. It can be either a disruptive or a consolidating process (Chepil, 1953a, b). Wetting and drying can cause cementation of soil between the secondary aggregates. This is from the shrinkage of water films associated with fine particles. The cementation increases the resistance of the soil to abrasion (Chepil, 1953a). The disruptive action of wetting is noticeable in fine textured soils, especially those with >40 percent clay (Chepil, 1953b; Chepil, 1954b). Air trapped in "dead end pores" during wetting can also break aggregates apart (Taylor and Ashcroft, 1972).

The third type of weathering is freezing and thawing. The expansion of soil water during the freezing process can cause aggregate breakdown (Chepil, 1954b). The effect of freezing water on soil structure was demonstrated over the course of two Kansan winters (Chepil, 1954b). One winter was moist, and the other was dry. Compared to the dry winter, frost action during the moist winter broke down more aggregates to a size <0.84 mm in diameter. This left the soil more susceptible to spring wind erosion. The differences in erodibility between the two winters was more noticeable on fine textured soils.

Although it has been agreed that freezing in the dry state does not change soil structure, there have been conflicting reports on the effects of moist winter time conditions (Chepil, 1954b; Bisal and Nielsen, 1964, 1967). Chepil (1954b) found freezing during a moist winter caused breakdown of the I fraction and increased erodibility in the spring. Others reported either a decrease in erodibility, or no change at all (Anderson and Wenhardt, 1966). Variations in the manner of soil drying have been used to explain these differences.

Experiments in Canada showed a soil can be dried in one of two ways (Bisal and Nielsen, 1964). It can be dried directly, without thawing, or it can be first thawed, and then dried. The first way is called sublimation. Sublimation occurs when a lack of snow cover exposes the soil surface to the drying air. A soil is left in a very erosive state when it is dried by sublimation. Use of trash to catch and hold snow has been recommended where sublimation is a problem. When a soil is dried the second way, the presence of water during drying has a cementing effect (Chepil, 1953a; Bisal and Nielsen, 1964). The final erodibility of a soil after it has been thawed and dried depends on texture. Clay loam and fine sandy loam decreased in erodibility after thawing and drying, while the erosiveness of clay increased.

Tillage

Tillage is the sixth factor affecting the I fraction. Its effect on soil structure can be either one of clod disintegration or clod formation. Excessive tillage can increase the erodibility of a soil by burying vegetation and destroying structure (Chepil and Woodruff, 1963; Woodruff et al., 1977). In Canada, eight summer fallow treatments were studied to assess changes in their erodibility over the winter and during the spring (Anderson and Wenhardt, 1966). Erodibility of the plots was determined three times: in the fall, before the first spring tillage, and later in spring, after tillage was complete. Erodibility decreased over the winter, but later increased due to spring tillage operations.

The number and characteristics of clods produced by tillage depend primarily on (Lyles and Woodruff, 1961; Woodruff and Siddoway, 1973):

1. Texture

2. Soil Moisture at Tillage

3. Type of Tillage Tool

Sands, fine sands, loamy sands, sandy loams and fine sandy loam, form clods only if they are cultivated while moist and wet (Anderson and committee, 1966). These clods are easily broken down by raindrops, and by freezing and thawing. Clay also forms secondary aggregates when cultivated. These are more resistant to raindrop impact, but are easily disintegrated by freezing and thawing. Those textures forming the greatest number of resistent clods are loams, silt loams, silty clay loams and clay loams.

Water content at tillage and type of tillage tool were studied to assess their effects on the I fraction of a silty clay loam (Lyles and Woodruff, 1962). The fewest large clods were formed when tillage was performed at an intermediate moisture content of 15 to 23 percent. This is the moisture content at which most tillage is done. Differences in clod size distribution due to differences in water content at tillage were obliterated very easily by rain.

The type of implement used also affected clod size distribution. The differences due to implements lasted longer than those due to water (Lyles and Woodruff, 1962). A moldboard plow produced more clods >0.84 mm in diameter than other a one way disk or surface sweep. The clods produced by the moldboard plow also had a higher mechanical stability. Differences in the I fraction due to kind of implement were not lost by rain, but were wiped out by weathering and the effects of subsequent tillage (Lyles and Woodruff, 1962).

Tillage operations of the stubble mulch system of farming common in the Great Plains have also been studied (Woodruff et al., 1965).

Differences in the I fraction after initial and subsequent tillage were assessed. After initial tillage, the size and stability of secondary aggregates did vary with type of implement. The effects of subsequent tillage operations were quite variable, however. The investigators concluded they could make no statement concerning the effect of subsequent tillage on soil structure. Tillage is the last of the primary factors influencing the dry fraction >0.84 mm in diameter. The processes and soil properties discussed have both disrupting and consolidating tendencies.

Dry clod structure is a constantly changing facet of the soil (Bisal and Furguson, 1968). It can be influenced by particle size distribution, vegetation and vegetative residue, organic amendments, microorganisms and the products of decomposition, calcium carbonate, weathering and tillage. The dry fraction is in a continual state of flux, depending on the net effect of the aggregating and disintegrating forces acting upon it.

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METHODS AND MATERIALS

Analysis of a soil sample for susceptibility to wind erosion involves sieving the soil to determine the percentage of dry fraction >0.84 mm in diameter (Woodruff and Siddoway, 1965). This percentage must be known if the I factor for a soil can be determined with accuracy. The Agricultural Research Service of the U.S.D.A. has assigned I values to surface soil textures for use in areas where no sieving data is available (Gillette, 1978a). In Michigan, no soils had been sieved to determine the proportion of non-erodible dry fractions present. An inventory was then conducted to obtain a clearer picture of the wind erodibility of some Michigan soils.

Experimental Design

The erodibility of five surface textures was studied. They covered Wind Erodibility Groups 1, 2, 3, 4L, 5 and 6. Loam was subdivided according to specific soil properties. Textures were:

1. fine sand
2. loamy fine sand
3. loamy sand
4. sandy loam
5. loam
    a. with free $CaCO_3$
    b. without free $CaCO_3$
    c. >20% clay
    d. <20% clay

All sampling sites were located in Michigan, within an area south of a line extending from Bay to Oceana counties. Most of Michigan's agricultural activity is concentrated in the southern half of the lower peninsula (Michigan Department of Agriculture, 1980). For each texture and subdivision of loam, five sampling sites, each 25 m^2, were located within this area. Ten subsamples were collected at each site. Percent dry fraction >0.84 mm in diameter was determined for each of the ten subsamples. Five of the 10 subsamples were analyzed for particle size distribution and organic carbon. Calcareous loams were also analyzed for inorganic carbon.

The five sites of each texture were located as widely apart as possible across the sampling area, giving a good indication of the general erodibility of Michigan's soils. The relatively large number of subsamples were collected at each site to allow a better evaluation of the performance of the sieving method developed for use in the study. Where possible, the soils at the five sites for each texture were of the same soil type. This decreased variability from site to site. When the extent of a soil type was limited in the sampling area, several soil types of similar properties were combined to get five sites. The five sampling sites for a given soil type were ideally in five different counties, to achieve wide distribution. For some soil types, this was not possible, for they were concentrated in one part of the study area.

Textures Sampled

Four of the five textures sampled are sandy. Sandy soils are important because of their susceptibility to wind erosion (Woodruff et al., 1977). In Michigan, most of the wind erosion problems occur on sandy soils (Drullenger and Schmidt, 1968). Fine sands were sampled instead of medium coarse sands. The water holding capacity of soil increases as texture becomes finer, so fine sands were more likely to be cultivated (Taylor and Ashcroft, 1972). This was especially true in the sampling area for fine sands - Macomb, St. Clair and Wayne counties. Higher value crops in those urbanizing counties make cultivation of marginal soils profitable (Mokma, personal communication, 1979).

Loamy fine sand, loamy sand and sandy loam were sampled for several reasons. The increasing contents of silt and clay from coarser to finer provided a range of values, so the effect of particle size distribution could be studied. These textures also comprise a large portion of Michigan's erodible soils (Drullinger and Schmidt, 1968; Kimberlien et al., 1977). Their inclusion was necessary for a thorough overview of the erodibility of Michigan soil textures.

Loams were sampled because they are widespread throughout lower Michigan where many areas of economically important crops are grown (Drullinger and Schmidt, 1968). The economics are especially important in the "Thumb" area, an important sugar beet region of mainly loam soils. The abrasive action of wind blown soil particles has damaged valuable crops in the "Thumb" area (Dush, 1966; Drullinger, 1968). The Agricultural Research Service assigned loams to WEG's based on differences in clay content and on the presence or absence of $CaCO_3$ (Table 1). For this reason loams were subdivided to cover more WEG's.

Site Location and Soil Sampling

Preliminary Site Location

Sampling sites were located before field work could begin. A Soil Conservation Service computer printout was used to choose suitable soil types of wide distribution and large acreages. The printout listed Michigan soil types, gave the counties they were found in and the acreages in each county. Only those counties with a modern published soil survey were included in the printout.

After the decision was made to sample a particular soil type in a county, the soil maps of the county soil survey report were scanned for possible sampling sites. A potential sampling site had to be large enough to be located at sampling time, in cultivation when the aerial photograph for the base map was taken, and near a road for easy access. The sites were chosen on the basis of aerial photographs taken some time before the study was initiated. Changes in agriculture and land use could make a potential site unsuitable for sampling. Therefore, more than one site for a particular soil type was located in a county. The soil types sampled, the classification of each soil series, and the location of each sampling site are given in Table 5.

Morley loam and Miami loam were the two soil types sampled to assess the effects of clay contents >20 percent and <20 percent on wind erodibility. Both Miami and Morley have wide distributions in the sampling area, are cultivated, well drained and have a loam surface over clay loam subsoil (Soil Conservation Service, 1974, 1976). Morley parent material is finer than Miami parent material, presumably

TABLE 5

LOCATION AND CLASSIFICATION OF SOILS SAMPLED

Surface Texture	Soil Series	Classification	Location				Site No.
Fine Sand	Oakville	Mixed, mesic Typic Udipsamment	NE¼NW¼NE¼SE¼	Sec. 23	T4SR8E	Wayne Co.	1
			NE¼SE¼NE¼SE¼	Sec. 17	T4SR8E	Wayne Co.	2
			SE¼SW¼SW¼SW¼	Sec. 1	T3NR12E	Macomb Co.	3
			SE¼SW¼SE¼NW¼	Sec. 1	T3NR12E	Macomb Co.	4
	Fousseau	Sandy, mixed frigid Entic Haplorthod	SW¼SW¼NW¼SW¼	Sec. 24	T6NR15E	St. Clair Co.	5
Loamy Fine Sand	Tedrow	Mixed, mesic Aquic Udipsamment	SE¼SW¼SE¼	Sec. 29	T4SR8E	Wayne Co.	6
			SE¼SE¼NE¼SE¼	Sec. 17	T4SR8E	Wayne Co.	7
			SE¼SW¼NW¼NW¼	Sec. 36	T4SR7E	Washtenaw Co.	8
			NW¼NW¼NW¼NE¼	Sec. 24	T4SR7E	Washtenaw Co.	9
	Minoa	Coarse-loamy, mixed mesic Aquic Eutrochrept	NE¼SW¼NW¼SW¼	Sec. 9	T9NR6E	Genesee Co.	10
Loamy Sand	Selfridge	Loamy, mixed, mesic Aquic Eutrochrept	SW¼NW¼NW¼SE¼	Sec. 20	T4SR9E	Wayne Co.	11
			NE¼NE¼NE¼NW¼	Sec. 24	T10NR2W	Gratiot Co.	12
	Metea	Coarse-loamy mixed, mesic Arenic Hapludalf	SW¼NE¼NE¼SE¼	Sec. 23	T8NR7E	Genesee Co.	13
			SW¼SE¼NW¼SW¼	Sec. 32	T4NR3E	Livingston Co.	14
	Menominee	Sandy over loamy, mixed, frigid Alfic Haplorthod	NE¼NW¼NW¼SW¼	Sec. 32	T6NR14W	Ottawa Co.	15
Sandy Loam	Metamora	Fine-loamy, mixed, mesic Udollic Ochraqualf	SE¼SE¼SW¼SW¼	Sec. 33	T6NR7W	Ionia Co.	16
			SW¼SW¼SW¼NW¼	Sec. 2	T3SR8E	Wayne Co.	17
			NE¼NE¼NE¼SW¼	Sec. 18	T9NR7E	Genesee Co.	18
			NW¼NW¼SW¼NW¼	Sec. 21	T5NR14W	Ottawa Co.	19
			NE¼NE¼NW¼NE¼	Sec. 28	T3NR3E	Livingston Co.	20

TABLE 5 - continued

Surface Texture	Soil Series	Classification	Location				Site No.
Loam, 20% clay	Morley	Fine, illitic, mesic Typic Hapludalf	SW¼SW¼SE¼SE¼	Sec. 17	T7NR5W	Ionia Co.	21
			NE¼NE¼SE¼SW¼	Sec. 22	T3SR6E	Washtenaw Co.	22
			SE¼SE¼NE¼SW¼	Sec. 25	T5SR3E	Lenawee Co.	23
			SW¼SE¼SE¼SE¼	Sec. 32	T7NR9E	Lapeer Co.	24
			NW¼SW¼SW¼NW¼	Sec. 17	T5NR13W	Ottawa Co.	25
Loam, 20% clay	Miami	Fine-loamy, mixed, mesic Typic Hapludalf	NE¼NE¼NE¼NE¼	Sec. 7	T3NR5E	Livinston Co.	26
			SE¼SE¼SW¼SE¼	Sec. 16	T5NR8W	Ionia Co.	27
			SE¼SW¼SW¼SW¼	Sec. 13	T1SR6E	Washtenaw Co.	28
			SW¼SW¼SW¼SE¼	Sec. 21	T5NR13W	Ottawa Co.	29
	Guelph*	Fine-loamy, mixed, mesic Glossoboric Hapludalf	SE¼SE¼NE¼SE¼	Sec. 9	T12NR8E	Tuscola Co.	30
Loam, cal-careous	Tappan	Fine-loamy, mixed (calcar-eous), mesic Typic Haplaquoll	SW¼NE¼NW¼NE¼	Sec. 1	T13NR7E	Tuscola Co.	31
			SW¼NE¼SE¼SE¼	Sec. 31	T13NR8E	Tuscola Co.	32
			SE¼SW¼SW¼SE¼	Sec. 25	T13NR6E	Bay Co.	33
			SW¼SW¼NW¼NW¼	Sec. 19	T14NR4E	Bay Co.	34
			NW¼NW¼NW¼NW¼	Sec. 5	T14NR14E	Bay Co.	35
Loam, non-calcareous	Parkhill	Fine-loamy, mixed, non-acid, mesic Mollic Haplaquept	SE¼SE¼SE¼NE¼	Sec. 33	T9NR2W	Gratiot Co.	36
			NE¼NE¼NW¼NE¼	Sec. 16	T10NR8E	Gratiot Co.	37
			SE¼NE¼NE¼NE¼	Sec. 3	T13NR8E	Tuscola Co.	38
			SW¼SE¼SW¼SW¼	Sec. 14	T12NR1E	Saginaw Co.	39
			SW¼NE¼NE¼NE¼	Sec. 14	T11NR1E	Saginaw Co.	40

*No Miami in Tuscola Co. Guelph is a comparable soil.

giving higher clay content in the Morley surface horizon.

Tappan and Parkhill loams were sampled to study the effect of free $CaCO_3$ on dry soil structure. Tappan is calcareous to the surface, while Parkhill is not. Tappan and Parkhill are intensively cultivated naturally poorly drained soils. Tile drainage is commonly installed for crop production (Soil Conservation Service, 1976).

Site Location in the Field

Potential sampling sites found earlier were visited in the field. A site was sampled for dry sieving and the associated analysis only if it met the following criteria:

Sampling Site Criteria

1. The site had the correct soil type according to soil maps.
2. The site was cultivated.
3. The site had little or no residue on the soil surface.
4. The soil at a site was dry.
5. The site was uncrusted. If sampling crusted soil was unavoidable, the crust was removed and the soil underneath sampled.
6. The site had secondary tillage. Secondary tillage broke down large clods resulting from plowing or previous tillage when wet, and reduced variability from site to site (Anderson and Wendhardt, 1966).
7. The site was relatively flat, with <6% slope.

8. The site was not occupied by a growing crop.
9. The site was not severely eroded. Exposure of subsoil by erosion may change the texture and organic matter content of a surface horizon.

Soil Sampling

If a site met the criteria, its location was marked on the soil map. Date of sampling, location, soil series, texture (according to the soil map), condition of surface and general observations were noted on a field evaluation sheet. The soil at each of the Parkhill and Tappan sites was tested with 0.1 NHCl for the presence of carbonates. The ten subsamples were collected from an area of approximately 25 m^2. As specified by Chepil (1962) a flat, square cornered spade was used to sample the soil to a depth of one inch. To avoid structural breakdown, Chepil stated that a soil sample collected for dry sieving be placed in a flat tray to be transported to a laboratory for air drying. Metal drawers nine inches wide and twelve inches long were used. One drawer held one subsample. Enough soil was placed in each drawer to give a depth of about one inch. This duplicated field conditions, since depth of sampling in wind erosion studies is commonly one inch (Chepil, 1962).

Before sampling, each drawer was lined with newspaper and a waxed paper interlining. Soil slid off the waxed paper very easily. In the lab, the paper and sample were lifted out of the drawer together and placed for air drying. Lifting the sample out of the drawer in this way minimized disturbance. The waxed paper interlining became the drying paper for the soil. The newspaper lining was used to add strength to the waxed paper thus preventing it from tearing as the soil sample was lifted from the drawer.

Development of Sieve

The Standard Method

Sieving to determine percent dry fractions >0.84 mm in diameter was done with a variation of the rotary sieve first developed by Chepil and Bisal (1943). The original rotary sieve has been modified several times by Chepil (1952; 1962), and once by Lyles et al., (1970).

The rotary sieve was developed to replace the less accurate method of hand sieving (Chepil and Bisal, 1943). The sieve had six concentric metal cylinders turned by an electric motor. Part of each cylinder had openings all of one size extending around the circumference of the cylinder. The openings ranged from 38 mm to <0.42 mm resulting in separation of the dry fraction into seven size classes: >38mm; 38-12.7 mm; 12.7-6.4 mm; 6.4-2.0 mm; 2.0-0.83 mm; 0.83-0.42 mm and <.42 mm.

When a soil sample was sieved, the first cylinder the soil contacted was the one with 38 mm holes (Chepil and Bisal, 1943). Clods <38 mm fell through the openings to the next cylinder, while clods >38 mm slid down the cylinder to be collected in a pan. This continued until the sample was divided into the seven size classes. The cylinders had a 4 percent slope to facilitate the sliding action. Chepil and Bisal hoped to minimize structural breakdown by the gentle 4 percent slope and a slow rotation of 14 rpm. Provisions made to attach brushes to the finest sieves to prevent clogging proved unnecessary. Clogging of fine sieves was a disadvantage of hand sieving eliminated by the rotary sieve. Elimination of the variable human factor inherent in hand sieving was another advantage of the rotary sieve.

A modification of the rotary sieve increased the number of cylinders to 13 and reduced speed of rotation to seven rpm (Chepil, 1952). A tapping device was added to dislodge dust caught on cracks and sieve openings. The original rotary sieve required laborious hand feeding of the sample, so Chepil attached an automatic feeding device. It was a conveyer belt that fed soil into the sieve at a constant 60 in^3/minute. Since the volume of soil flowing into and out of the sieve was constant, time of sieving and size of sample made no difference.

In a later paper, Chepil (1962) reported on a modified rotary sieve, presented a detailed field sampling method and listed the advantages and disadvantages of the rotary sieve. The number of cylinders was reduced to five. It was recommended "reasonably dry" soil be sampled with a flat, square cornered spade. According to Chepil, sampling dry soil reduces aggregate breakdown. Method of sample drying had little effect on results. Oven drying at 70^{o}C and air drying at room temperature produced no significant differences in sieving results.

Advantages and disadvantages of the rotary sieve are (Chepil, 1962):

<u>Advantages</u>: 1. Consistency

2. Impartiality

3. No sample size variability

4. Less structural breakdown

5. Clogging of fine sieves eliminated

<u>Disadvantages</u>: 1. Complexity of construction

2. Sieves not interchangeable.

The rotary sieve was modified a third time when sieving errors were discovered (Lyles et al., 1970). A source of error in Chepil's rotary sieve was mesh length. This is the length of perforated area in each cylinder through which soil can fall. If the mesh length is too short, the soil particles do not have sufficient time on the mesh, and incomplete separation results. Lyles and his associates increased the mesh length of each cylinder of the rotary sieve. Changes in the feeding device and power transmission eliminated more sources of error.

Although the rotary sieve represents the standard method of determining percent dry fractions >0.84 mm in diameter, it does have some disadvantages (Chepil, 1952; 1962). It is a large, complex, heavy machine, so using it in field demonstrations of wind erodibility is not possible. The rotary sieve is not available commercially; each one must be individually constructed. A simpler, less expensive version was constructed for this study.

<u>The Alternate Sieve</u>

Description of Alternate Sieve

The alternate sieve is a device for separating an air dry soil sample into two size classes. One class consists of dry soil fractions ≥0.84 mm in diameter. The other size class contains dry soil fractions <0.84 mm in diameter. The alternate sieve has one horizontally oriented cylinder 21½ inches long and 12 inches in diameter mounted on a steel frame (Figure 2). The cylinder is made of No. 20

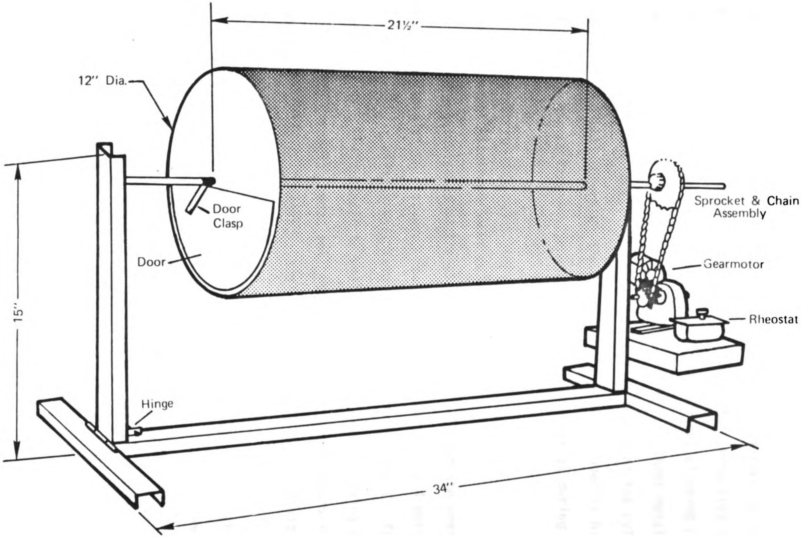

FIG. 2 THE ALTERNATE SIEVE

brass mesh screen. Number 20 screen is a standard screen size with 0.84 mm openings. The screen was purchased from Soil Test, Inc. To eliminate variability inherent in hand sieving, the cylinder is turned at a constant rate by a 1/15 Hp gearmotor. A rheostat regulates the speed of rotation. One end of the cylinder has a door, allowing placement of the soil sample into the cylinder. A piece of sheet metal cut to fit over the door prevents soil from falling out of the cylinder. The upright frame support at the loading end of the cylinder is hinged. The support can be lowered, providing the clearance needed during loading.

Development of Alternate Sieve

Characteristics of the alternate sieve reflected the needs and objectives of this study. The standard dry sieve had a 4 percent slope because it divided soil into a number of size fractions. The soil slid from one cylinder to another in the process of sieving (Chepil, 1952; 1962). Chepil needed soil divided into many size classes for wind tunnel studies (Chepil, 1950b). This project required dividing soil into two size fractions. One horizontal cylinder was sufficient.

The dimensions of the cylinder, 21½ inches long and 12 inches in diameter, related to the size of sample used for sieving. Sample size was not of major concern in the rotary sieve method. Results were independent of sample size (Chepil, 1952). The alternate sieve had no feeder device because of the horizontally oriented cylinder. These characteristics of the alternate sieve made sample size a consideration. To duplicate dry structural conditions in the field, it was decided the soil sample should make a layer about one inch deep in the cylinder.

Soil was placed into cylinders of varying sizes to determine the combinations of sample size and cylinder dimensions yielding a soil layer one inch deep. Approximately 1000 g of soil made a layer one inch deep in a cylinder 21½ inches long and 12 inches in diameter. The majority of soil samples collected varied in size from 1500 to 2500 grams. Sieving 1000 grams left ample soil for the other analyses.

Development of Sieving Procedure

The problems inherent in developing a sieving procedure were well summarized by Day (1965) when he wrote:

> The probability of a particle passing a given sieve in a given time of shaking depends upon the nature of the particle and the properties of the sieve. For example - a particle whose shape permits its passage only in a certain orientation has a limited chance of getting through, except after prolonged shaking. Furthermore, sieve openings are generally unequal in size, requiring extensive shaking before all particles have had the opportunity of approaching the largest openings. In fact, the requirement that sieving be continued to "completion" can be rarely met in most practical times of shaking. Good reproducibility requires careful standardization of procedure.

With the alternate sieve, the development of a standardized sieving procedure involved the following steps:

1. Calibration of rheostat to determine setting needed for proper speed of rotation.
2. Development of a method of inserting the soil sample into the sieve. Soil had to be spread gently into the cylinder to achieve a uniform distribution one inch deep.

3. Determination of sieving time. The delicate nature of secondary aggregates was a problem (Chepil, 1953a). The difficulty involved achieving good separation of the non-erodible from the erodible fractions without excessive breakdown of secondary aggregates.

Calibration

The speed of rotation of the alternate sieve was to be 7 rpm, the speed Chepil found best in his analyses of soil for wind erodibility (Chepil, 1952). The rheostat connected to the motor was calibrated by loading the sieve with 1000 grams of glass beads 1 mm in diameter. This gave the speed of rotation with a constant weight. The weight of a soil sample in the cylinder may change a great deal during sieving, so the rheostat was calibrated with the sieve empty. Results are in Table 1 of Appendix I.

Sample Placement

A long handled metal scoop was constructed to place soil into the cylinder. The portion of the scoop that held the soil sample was 20 inches long. It was curved into a half circle, allowing it to fit into the sieve. A representative 1000 grams sample was weighed on a piece of tared waxed paper, then gently slid off the weighing paper into the scoop. The scoop was then inserted into the sieve through the end opening and slowly tipped, spreading the soil evenly across the bottom of the cylinder.

Sieving Time

Bulk samples of three different textured soils were collected. Each bulk sample weighed approximately 15 kg. The bulk samples were test soils in the determination of sieving time. The textures of the bulk samples were loamy sand, sandy loam and loam. Three textures insured the sieving time decided upon was valid over a range of particles size distributions. An additional 21 samples of the sandy loam were collected. When a final sieving procedure was developed, the 21 samples were sieved to determine reproducibility of results. Twenty-one samples also gave an indication of the variability in percent aggregation >0.84 mm in diameter that may be encountered at a site.

Sieving time was determined by investigating changes in the amounts of soil falling through the mesh vs. time. Data was graphed as cumulative percent <0.84 mm vs. time (seconds) to find if there was a point beyond which the amount of soil falling through the screen did not change appreciably. To collect the data from each sieving, tared waxed paper sheets were placed under the cylinder to catch the soil fractions smaller than 0.84 mm in diameter. Each sheet was labeled with seconds of sieving.

The following procedure was used to determine the cumulative percentage of soil that had fallen through the mesh over a certain time span. If the time span was, for example, 90 seconds, and the cumulative percentage was to be determined every 10 seconds, nine tared sheets of waxed paper were placed under the cylinder. The sheets were labeled, from the top, 10, 20, 30, 40, 50, 60, 70, 80, and 90 seconds. A weighed soil sample was then placed into the cylinder, the end door closed and the sieve turned on. After 10 seconds of sieving, the sieve was stopped. The sheet of waxed paper marked "10" was removed, with its load of soil, for weighing. This was repeated eight more times, for a total of 90 seconds sieving time.

A weighed soil sample was placed into the sieve initially, so the percentage of the total sample that had fallen through could be calculated for all nine of the 10-second intervals. The sum of the nine percentages gives the total percentage of soil fallen through the mesh over 90 seconds of sieving. A graph of cumulative percent <0.84 mm vs time could then be generated from this data. This technique was used with the bulk soil to arrive at the selected sieving time.

The loamy sand bulk sample was the first soil used in determining the sieving time. If aggregate breakdown during sieving was to be a problem, it would probably be most noticeable on the sandiest of the three textures - loamy sand (Chepil, 1953b).

A representative 1000 g. loamy sand sample was first sieved for 10 minutes. Soil was collected and weighed every 60 seconds. This was done only once, for the 60 second time interval was too long. Much of the soil had already fallen through the screen by the end of 60 seconds (Figure 3). Breakdown of the secondary aggregates >0.84 mm in diameter was also apparent. The aggregates were irregularly shaped at the start of sieving. As sieving progressed, the aggregates began to round and decrease in size. Only a very few rounded aggregates were retained on the sieve at the end of 10 minutes sieving.

The 10 minute sieving time and 60 second interval were accordingly shortened to 240 seconds and 30 seconds respectively. Five

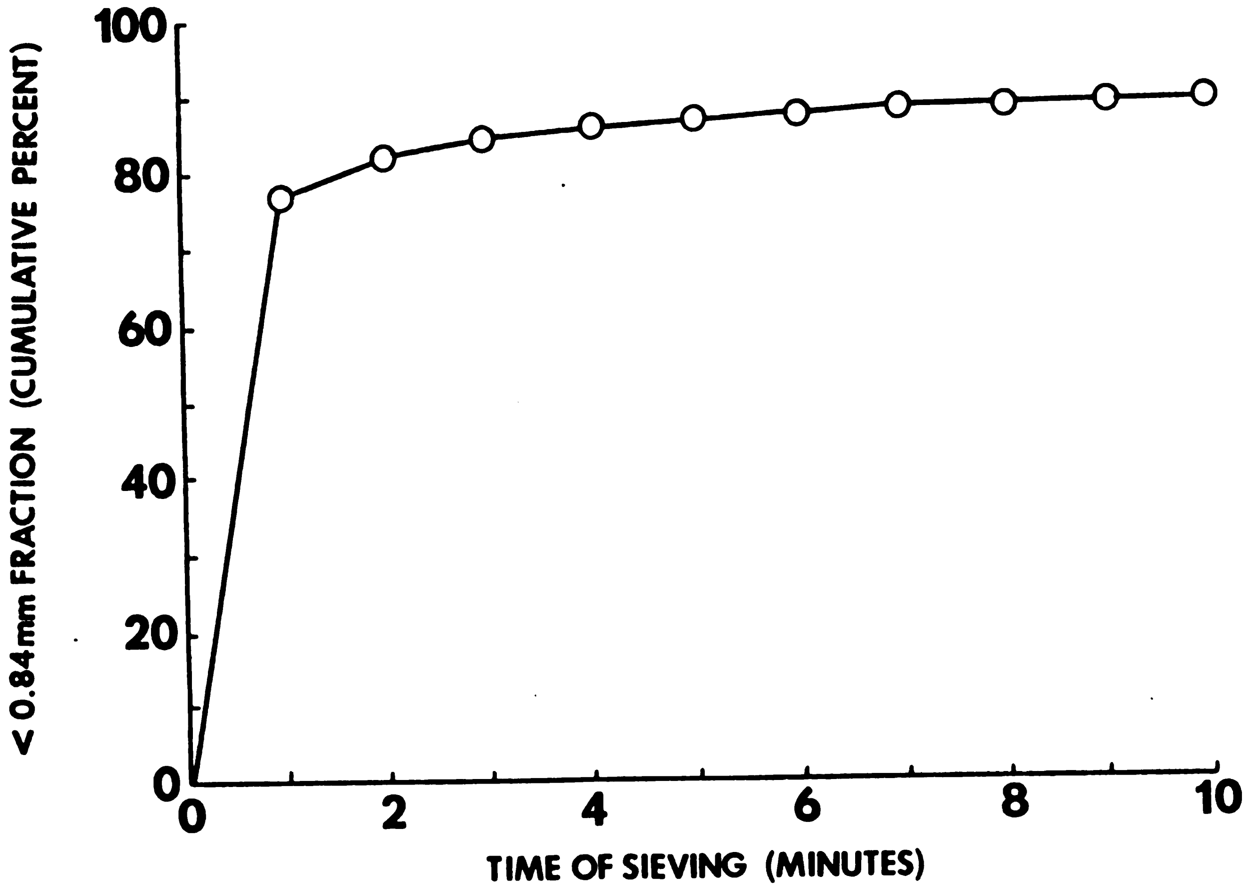

Fig. 3. Change in <0.84 mm fraction during sieving a loamy sand soil (one minute intervals).

samples were sieved in this manner. The data was averaged and graphed (Fig. 4). The amount of soil falling through the sieve did not change appreciably after 90 seconds of sieving. Sieving time was then shortened to 90 seconds. The 30 second interval was still too long, so the time interval was set at 10 seconds. Five replications were sieved, using the 90 second sieving time and 10 second intervals.

To eliminate the contribution of aggregate breakdown, a sample of the loamy sand bulk supply was passed through a flat 4 mm sieve. This removed many aggregates contributing to breakdown, for the stability of secondary aggregates is inversely related to their size (Chepil, 1952). The flat sieve was shaken as little as possible to lessen aggregate breakdown. Soil fractions <4.0 mm in diameter were then sieved for 90 seconds, using 10 second intervals. Three replications were done using this variation of the sieving technique.

Subsamples of the loam and sandy loam bulk soils were then sieved. Three replications of each were sieved for 90 seconds, stopping the sieve every 10 seconds. Three more replications of each were passed through the flat 4 mm sieve, and the soil sieved for 90 seconds with 10 second intervals. The results for all three textures were averaged and graphed as cumulative percent <0.84 mm vs time (Fig. 5). The graph showed the interrelationships between the three textures, and the effects of aggregate breakdown. The difference between the two lines representing each texture is due to aggregate breakdown. As texture became finer, percent >0.84 increased and aggregate breakdown decreased.

On the basis of this graph, all soils were sieved for 40 seconds. The reasons were:

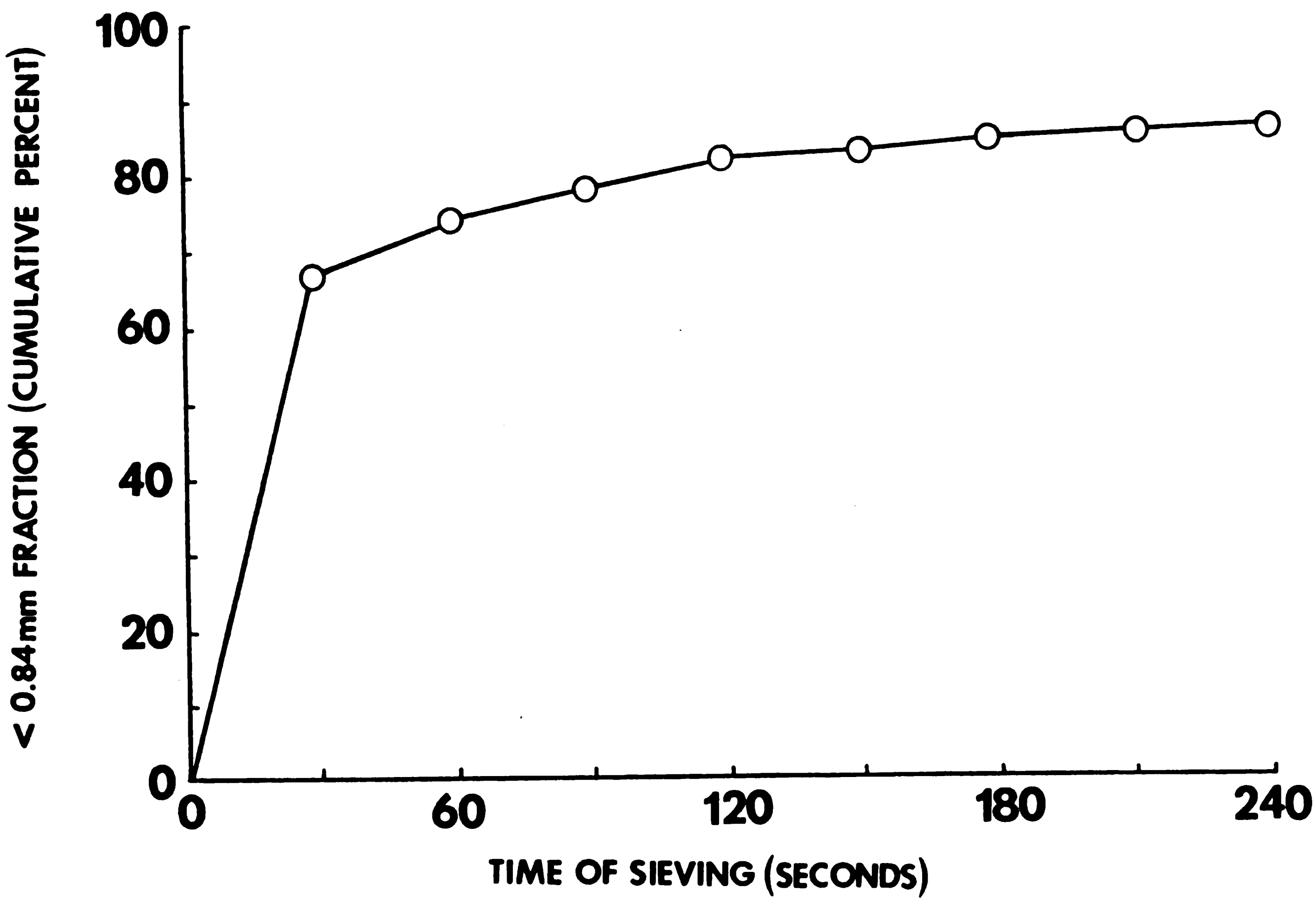

Fig. 4. Change in <0.84 mm fraction during sieving a loamy sand soil (30 second intervals).

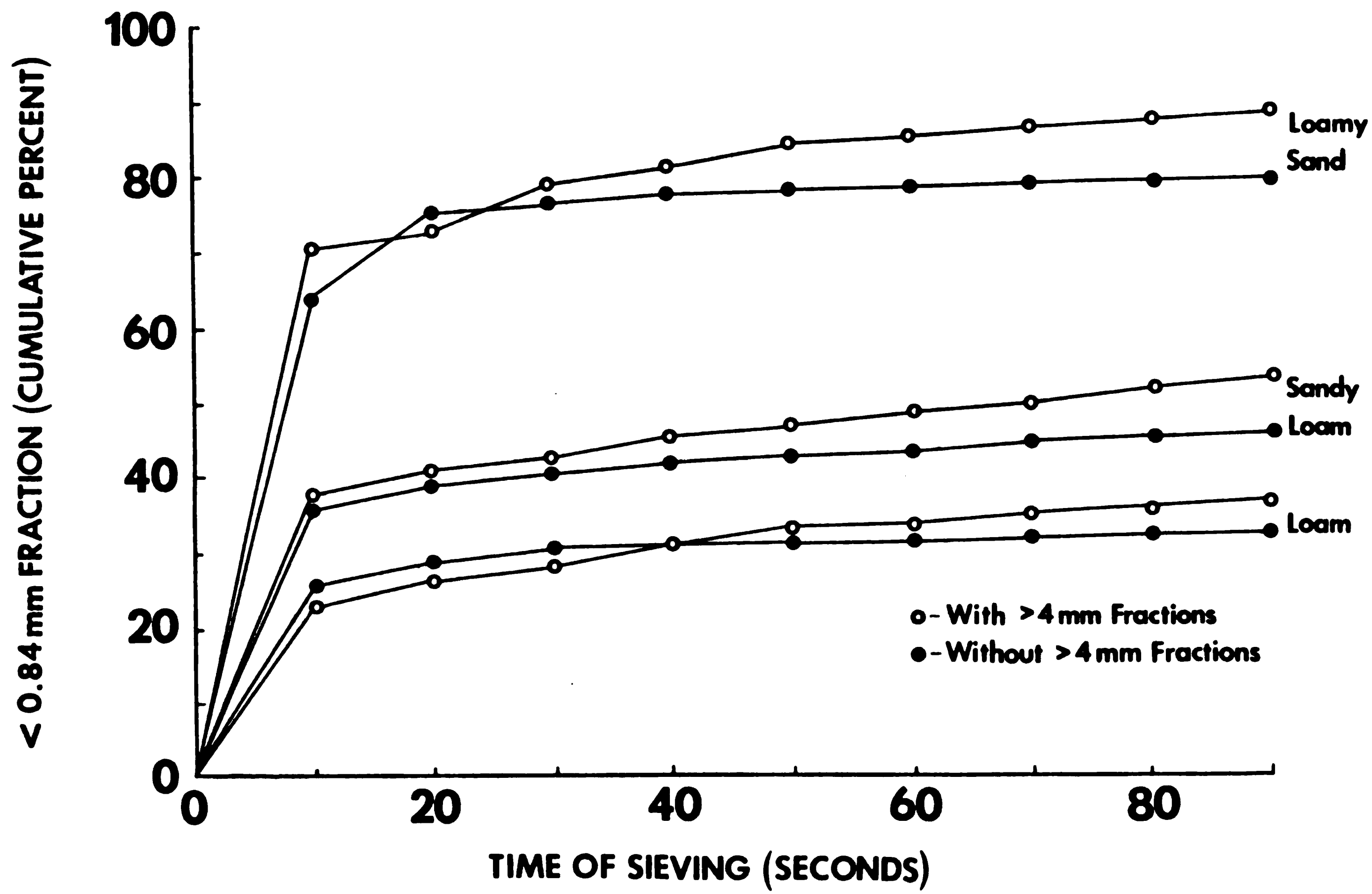

Fig. 5. Change in 0.84 mm fraction during sieving loamy sand, sandy loam and loam soils with and without removing >4 mm fraction.

1. The 90 second cumulative percentage for soil with aggregates >4.0 mm in diameter removed was assumed the correct value for percent dry fractions <0.84 mm. With aggregates >4.0 mm removed, there was very little change in cumulative percent <0.84 mm beyond even 30 seconds. This was true for all three textures.
2. For all three soils, the 40 second percentage with aggregates >4.0 mm in diameter present was only slightly greater than the 90 second percentage for soil without aggregates >4.0 mm in diameter.

Final Sieving Procedure

The final sieving procedure for erodibility determinations involved collecting the subsamples and transporting them to the lab as described previously. After the subsamples were air dried, residue was removed from the soil as suggested by Chepil (1962). Stones >3/4 inch in diameter were also removed. Stones of this size were taken out of the samples because they would have an abnormal crushing effect on the aggregates during sieving. A 1000 g sample was placed into the scoop, deposited into the cylinder, and the end opening closed. A tared piece of waxed paper placed under the cylinder caught the dry fractions <0.84 mm in diameter. After 40 seconds of sieving, the motor was turned off and the soil deposited on the waxed paper was weighed. Soil remaining on the screen was discarded and the inside of the cylinder cleaned with a vacuum cleaner. The 21 subsamples of sandy loam collected with the bulk sandy loam were sieved using this procedure. The alternate sieving technique gave reproducible results (Table 2 of Appendix I).

The formula used to determine percent dry fractions >0.84 mm was:

$$P = \frac{S - X}{S} (100)$$

where:

P = percent dry soil fractions >0.84 mm in diameter

S = sample weight (g)

X = weight dry fractions <0.84 mm in diameter after 40 seconds sieving (g)

Associated Analysis

Five of the 10 subsamples collected at each site were analyzed for particle size distribution and organic carbon. Inorganic carbon was also determined for the five calcareous loam soils. The hydrometer method of Day (1965) was used for particle size analysis. Inorganic carbon was determined according to Bundy and Bremner (1972). Inorganic carbon content is an index of free calcium carbonate. Organic carbon content of the soils was determined using the Walkely-Black method (Allison, 1965).

RESULTS AND DISCUSSION

Comparison of WEG Percent >0.84 mm and Actual Percent >0.84 mm

The initial analysis of the sieving data was based on the assumption that the texture of the sample was the same as the texture indicated by the soil mapping unit.

The >0.84 mm percentage was determined for the ten subsamples from each site (Table 1, Appendix 2). A one way analysis of variance was used to determine if the sites for an assumed texture or subdivision of loam were significantly different in their percentage of dry fractions >0.84 mm in diameter. For an assumed texture and subdivision of loam, each of the five sites was considered a treatment. Every analysis of variance performed, one for each assumed texture and subdivision of loam, showed a significant difference between the treatment means. The results of Tukey's Multiple Comparison test are summarized in Table 6 (Steel and Torrie, 1960).

The average >0.84 mm percentage for each assumed texture and subdivision of loam was then considered a treatment. An analysis of variance revealed significant differences in wind erodibility existed between textures and subdivisions of loam. The results of Tukey's

TABLE 6

ASSUMED TEXTURES-RESULTS OF TUKEY'S TEST

Assumed Texture	WEG	>0.84 mm (%) Sieving	WEG	Difference[2]	Site	% Mean(>0.84 mm)[1]	
Fine Sand	1	11	1	10	1	8	AB*
					2	4	A
					3	11	BC
					4	20	D
					5	14	C
Loamy Sand	2	37	10	27	11	38	BC
					12	28	AB
					13	21	A
					14	46	CD
					15	53	D
Loamy Fine Sand	2	30	10	20	6	5	A
					7	12	A
					8	41	B
					9	49	C
					10	44	BC
Sandy Loam	3	77	25	52	16	50	A
					17	83	BC
					18	89	C
					19	87	C
					20	76	D
Loam, <20% Clay	5	78	40	38	26	89	C
					27	69	A
					28	80	BC
					29	79	BC
					30	75	AB
Loam, >20% Clay	6	82	45	37	21	78	AB
					22	83	BC
					23	86	CD
					24	91	D
					25	74	A
Loam, non-calcareous	5	75	40	35	36	88	D
					37	76	BC
					38	52	A
					39	73	B
					40	84	CD
Loam, calcareous	4L	81	25	56	31	78	B
					32	95	D
					33	67	A
					34	87	C
					35	77	B

*Any two means of the same texture followed by the same letter are not significantly different from each other at P=.01 by Tukey's test.

[1]Mean of 10 subsamples from the five sites.

[2]Difference between mean sieving percent >0.84 mm and WEG %.

test were:

Assumed Texture or Subdivision	Mean >0.84 mm (%)
Fine Sand	11 A*
Loamy Fine Sand	30 B
Loamy Sand	37 B
Sandy Loam	77 C
Loam, non-calcareous	75 C
Loam, calcareous	81 C
Loam, <20% clay	77 C
Loam, >20% clay	82 C

*any means followed by the same letter are not significantly different at P = .01 using Tukey's test.

Based on this analysis, the soil textural classes and subdivisions of loam fell into three groups. Fine sand appeared the most erodible, with an average of 11 percent of its dry fractions >0.84 mm in diameter. Loamy fine sand and loamy sand make up the next group. All the loams, including sandy loam, comprise the third, least erodible group.

However, particle size analysis of the soils revealed inconsistencies between the mapping unit texture and the actual texture of the soil. Particle size data for each site is given in Table 1 of Appendix II. The five sampling sites of the soil assumed to be calcareous loam were extremely variable in texture. Two sites were sandy clay loam, and there was one site each of silty clay, silty clay loam and clay loam. Textural analysis of the other soils revealed three sand sites and a total of three clay loam sites. It was felt a minimum of three sites were needed to provide a valid estimate of wind erodibility at the sampling time. Analysis of the erodibility of two additional textures, clay loam and sand, was then possible. A comparison of assumed and actual textures, by site, are given in Table 7. The

TABLE 7

ASSUMED AND ACTUAL TEXTURES BY SITE

Site	Assumed	Actual
1	Fine Sand	Sand
2	Fine Sand	Fine Sand
3	Fine Sand	Sand
4	Fine Sand	Loamy Fine Sand
5	Fine Sand	Sand
6	Loamy Fine Sand	Fine Sand
7	Loamy Fine Sand	Fine Sand
8	Loamy Fine Sand	Loamy Fine Sand
9	Loamy Fine Sand	Loamy Sand
10	Loamy Fine Sand	Loamy Fine Sand
11	Loamy Sand	Loamy Sand
12	Loamy Sand	Loamy Sand
13	Loamy Sand	Loamy Sand
14	Loamy Sand	Sandy Loam
15	Loamy Sand	Loamy Sand
16	Sandy Loam	Sandy Loam
17	Sandy Loam	Clay Loam
18	Sandy Loam	Sandy Loam
19	Sandy Loam	Loam
20	Sandy Loam	Sandy Loam
21	Loam (>20% clay)	Loam (13% clay)
22	Loam (>20% clay)	Loam (15% clay)
23	Loam (>20% clay)	Loam (22% clay)
24	Loam (>20% clay)	Loam (20% clay)
25	Loam (>20% clay)	Loam (18% clay)
26	Loam (<20% clay)	Loam (17% clay)
27	Loam (<20% clay)	Loam (12% clay)
28	Loam (<20% clay)	Loam (19% clay)
29	Loam (<20% clay)	Loam (19% clay)
30	Loam (<20% clay)	Loam (20% clay)
31	Loam, free $CaCO_3$	Silty Clay Loam, free $CaCO_3$
32	Loam, free $CaCO_3$	Clay Loam, free $CaCO_3$
33	Loam, free $CaCO_3$	Silty Clay, free $CaCO_3$
34	Loam, free $CaCO_3$	Sandy Clay Loam, free $CaCO_3$
35	Loam, free $CaCO_3$	Sandy Clay Loam, free $CaCO_3$
36	Loam, no free $CaCO_3$	Clay Loam, no free $CaCO_3$
37	Loam, no free $CaCO_3$	Sandy Loam, no free $CaCO_3$
38	Loam, no free $CaCO_3$	Sandy Loam, no free $CaCO_3$
39	Loam, no free $CaCO_3$	Sandy Loam, no free $CaCO_3$
40	Loam, no free $CaCO_3$	Sandy Loam, no free $CaCO_3$

reorganization of sites by actual texture is given in Table 8. The textures included in Table 8 are those actually analyzed statistically for differences in erodibility. The two loam subdivisions of < and >20 percent clay were analyzed together. Differences in clay between the two subdivisions were within error.

For some textures, the sampling sites now encompassed more soil types than originally planned. It was imperative though to have the sampling sites of a given textural class actually of that texture. Texture is the basis for placing soils into WEG's.

The sampling sites reorganized by actual texture were analyzed using the statistical procedure described previously. Table 9 summarizes the results of Tukey's test.

For all textures, there were significant differences between two or more of the sites. This shows the effects differences in management and environment can have on erodibility. No attempt was made to control these factors in this study. In Kansas, the erodibility of soil sites also varied because of management and environmental differences (Chepil, 1953b). An analysis of variance performed on the textural means of Table 9 revealed significant differences in wind erodibility between some textures. The results of Tukey's test are:

Actual Texture	Mean >0.84 mm (%)
Sand	10 A*
Fine Sand	7 A
Loamy Sand	38 B
Loamy Find Sand	35 B
Sandy Loam	68 C
Loam	81 D
Clay Loam	89 D

*Two means followed by the same letter are not significantly different from each other at P = .01 using Tukey's test.

TABLE 8

SITES REORGANIZED BY ACTUAL TEXTURE

Texture	Series	Site No.
Sand	Oakville	1
	Oakville	3
	Oakville	5
Fine Sand	Oakville	2
	Tedrow	6
	Tedrow	7
Loamy Fine Sand	Oakville	4
	Tedrow	8
	Minoa	10
Loamy Sand	Tedrow	9
	Selfridge	11
	Selfridge	12
	Metea	13
	Menominee	15
Sandy Loam	Metea	14
	Metamora	16
	Metamora	18
	Parkhill	20
	Parkhill	37
	Parkhill	38
	Parkhill	39
	Parkhill	40
Loam	Metamora	19
	Morley	21
	Morley	22
	Morley	23
	Morley	24
	Morley	25
	Miami	26
	Miami	27
	Miami	28
	Miami	29
	Guelph	30
Clay Loam	Metamora	17
	Tappan	32
	Parkhill	36

TABLE 9

ACTUAL TEXTURES-RESULTS OF TUKEY'S TEST

		>0.84 mm (%)				%
Texture	WEG	Sieving	WEG	Difference[2]	Site	Means (>0.84 mm)[1]
Sand	1	10	1	9	1	8 A*
					3	11 AB
					5	12 B
Fine Sand	1	7	1	6	2	4 A
					6	6 A
					7	12 B
Loamy Sand	2	38	10	28	9	50 CD
					11	38 BC
					12	28 AB
					13	21 A
					15	53 D
Loamy Fine Sand	2	35	10	25	4	20 A
					8	41 B
					10	44 B
Sandy Loam	3	68	25	43	14	46 A
					16	50 A
					18	89 C
					20	76 B
					37	76 B
					38	52 A
					39	73 B
					40	84 BC
Loam, <20% clay	5	81	40	41	19	87 EF
					21	78 BC
					22	83 CDE
					23	86 DEF
					24	91 F
					25	74 AB
					26	86 DEF
					27	69 A
					28	80 BCD
					29	79 BCD
					30	75 AB
Clay Loam, <35% clay	6	89	45	44	32	95 C
					36	88 B
					17	83 A

*Any two means of the same texture followed by the same letter are not significantly different at P=.01 using Tukey's test.

[1]Mean of 10 subsamples from the five sites

[2]Difference between mean sieving percent >0.84 mm and WEG %.

The textures analyzed fall into four groups. Fine sand and sand make up the most erodible group, followed by loamy sand and loamy fine sand in the second group. The erodibility of sandy loam is significantly different from all the other textures. It is the sole member of the third group. Loam and clay loam make up the fourth, least erodible group.

The textures fell into only three groups when erodibility was analyzed on the basis of the mapping unit. The removal of the clay loam and loam sites from the group of sandy loam sites caused the separation of sandy loam from loam and clay loam. Farm Advisors must remember this variability in texture when assisting cooperators with wind erosion problems. If the texture of a field is inconsistant with the mapping unit texture, the erodibility of the soil may be misjudged.

For the textures studied, the average >0.84 mm percentage was higher than the percentage of the WEG into which the texture was assigned (Table 9). The percentages were also higher than those found by Chepil (1953b; 1955a). Soils of irrigated Colorado sugar beet field and soils of the Southern Coastal Plains also had erodibilities lower than those reported by Chepil and lower than those of the WEG's (Carreker, 1966; Simmons and Dotzenke, 1974). The higher percentage of non-erodible clods in the Michigan soils studied is probably due to environmental and cultural differences between the Great Plains and Michigan. The higher average moisture contents of Michigan soils likely contribute to the decreased erodibility (Lyles and Woodruff, 1961; Soil Survey Staff, 1965). Cultivation forms a greater number of large clods as the moisture content of the soil at cultivation increases.

At time of sampling, sandy loam, loam and clay loam had on the average more than 66 percent of their dry fractions >0.84 mm in diameter. If 66 percent or more of the surface soil is composed of non-erodible fractions, it is considered resistant to wind erosion (Woodruff and Siddoway, 1973). The high percentages for sandy loam, loam and clay loam does not mean they will always be resistant to wind erosion. The wind erodibility of a soil can change from season to season or from day to day (Chepil, 1953a; Bisal and Furguson, 1968).

The soils in this study were sampled in a non-crusted, recently cultivated conditions. Soils were collected from May 8, 1979 to June 1, 1979, so recent cultivation at Michigan's higher springtime soil moisture contents may explain the extremely cloddy condition of the finer soils. The sandy soils sampled were also less erodible than the WEG's would indicate. The magnitude of the difference between the actual percent >0.84 mm and the WEG percent >0.84 mm decreased as soil texture became coarser than sandy loam. Sandy soils are not as susceptible to the aggregating effects of tillage as are finer textured soils (Woodruff et al., 1977). The lower the clay and silt content of a soil, the less its dry clod structure will be influenced by tillage. Sandy soils also have lower water holding capacities, so they are less likely to form large durable clods at tillage. These data indicate the present WEG classifications may not adequately reflect the springtime erodibility of Michigan soils.

Effect of Soil Properties on Wind Erodibility

Organic Matter and Calcium Carbonate

The organic matter and calcium carbonate contents of the soils studied are given in Table 1, Appendix II. The affects of organic matter decomposition on water stable aggregates are well documented (Harris et al., 1966). Calcium carbonate and the decomposition of organic matter have also been shown to affect the dry aggregate structure of Great Plains soils (Chepil and Woodruff, 1963).

Organic matter and calcium carbonate, by themselves, had no significant influence on wind erodibility of these Michigan soils (Figures 6 and 7). Over the range of organic matter and calcium carbonate contents studied, the effects of organic matter and $CaCO_3$ may have been too small to detect by sieving. The influence of clay, silt and sand may have masked any effects organic matter and calcium carbonate had.

Clay, Silt and Sand

The percentages of clay, sand and silt were each plotted against percent dry fractions >0.84 mm in diamater (Figures 8, 9 and 10). Each point is the mean of a site. A second degree polynomial fit the data best.

Clay

Figure 8 illustrates the relationship between clay and the erodibility of a soil. As percent >0.84 mm increases, the erodibility of soil decreases. As clay increases from 3 percent (the smallest clay percentage measured) the erodibility of soil decreases. The

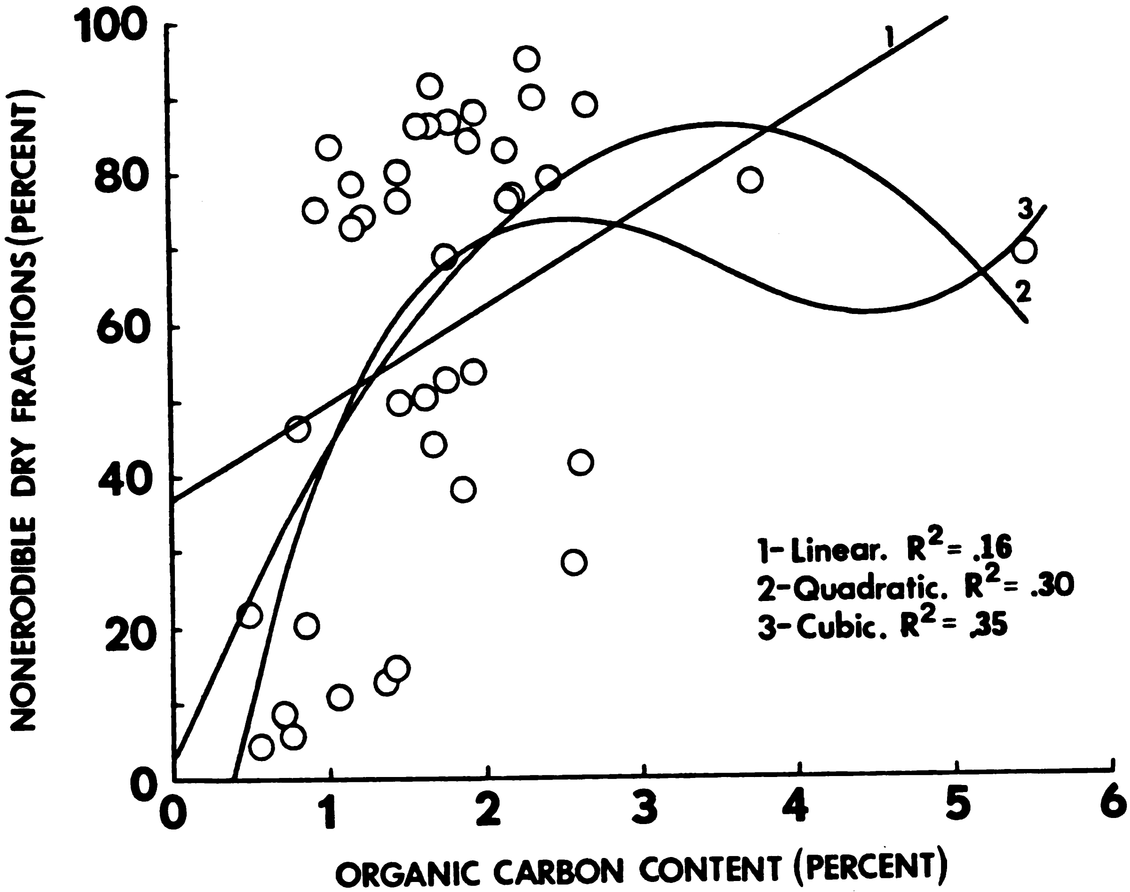

Fig. 6. Relationship between organic carbon and >0.84 mm fraction.

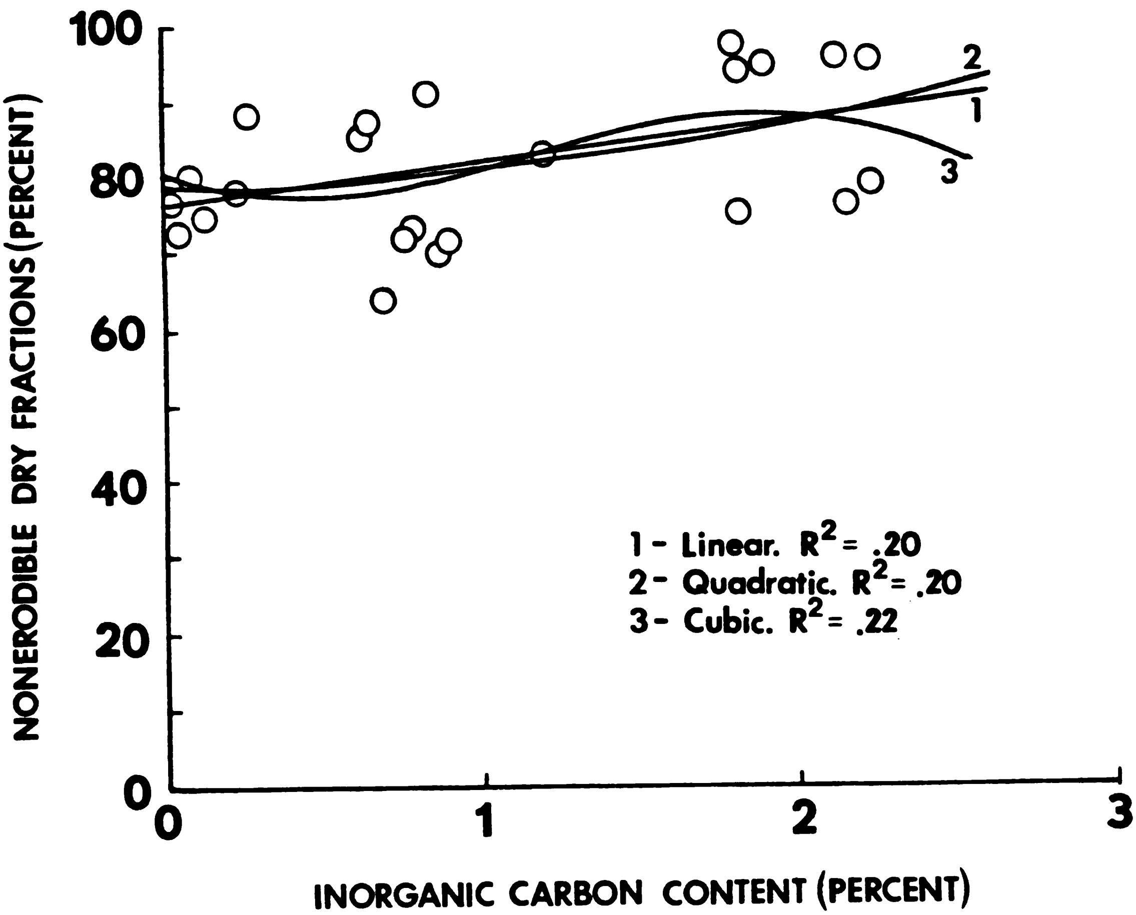

Fig. 7. Relationship between inorganic carbon and >0.84 mm fraction.

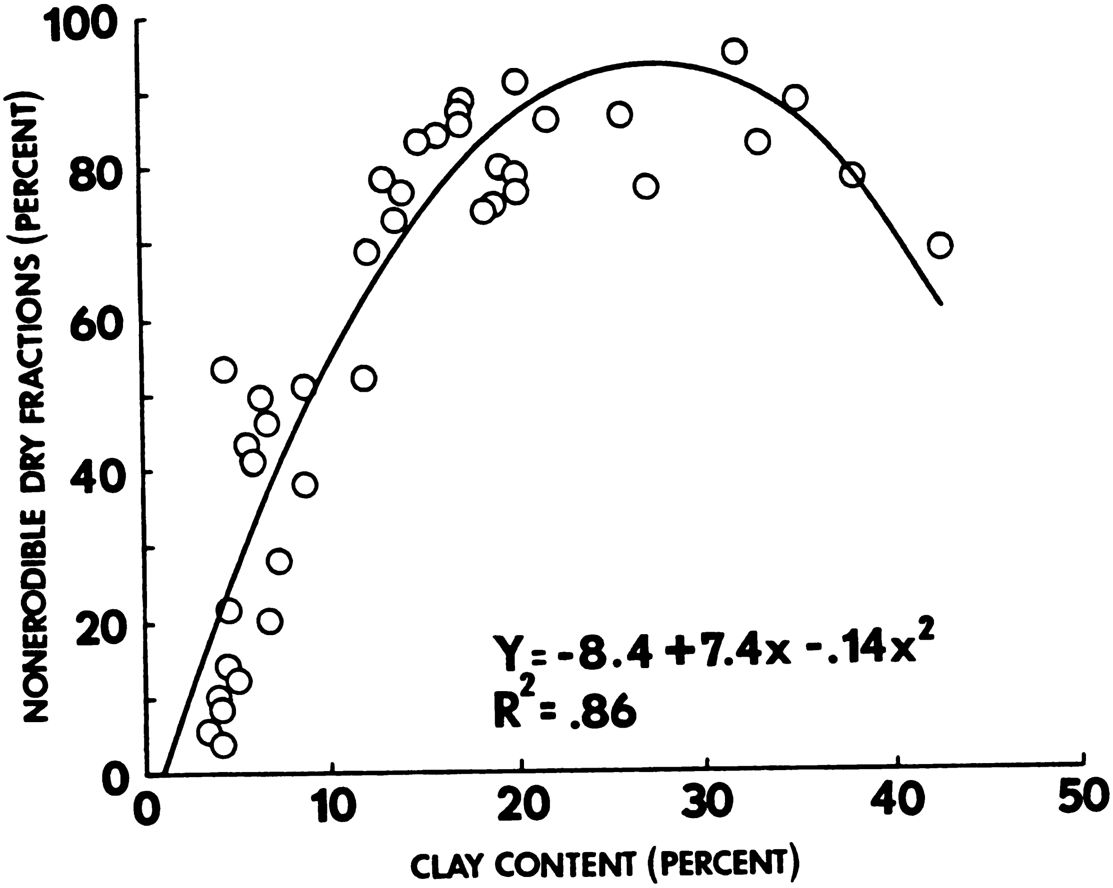

Fig. 8. Relationship between clay and >0.84 mm fraction.

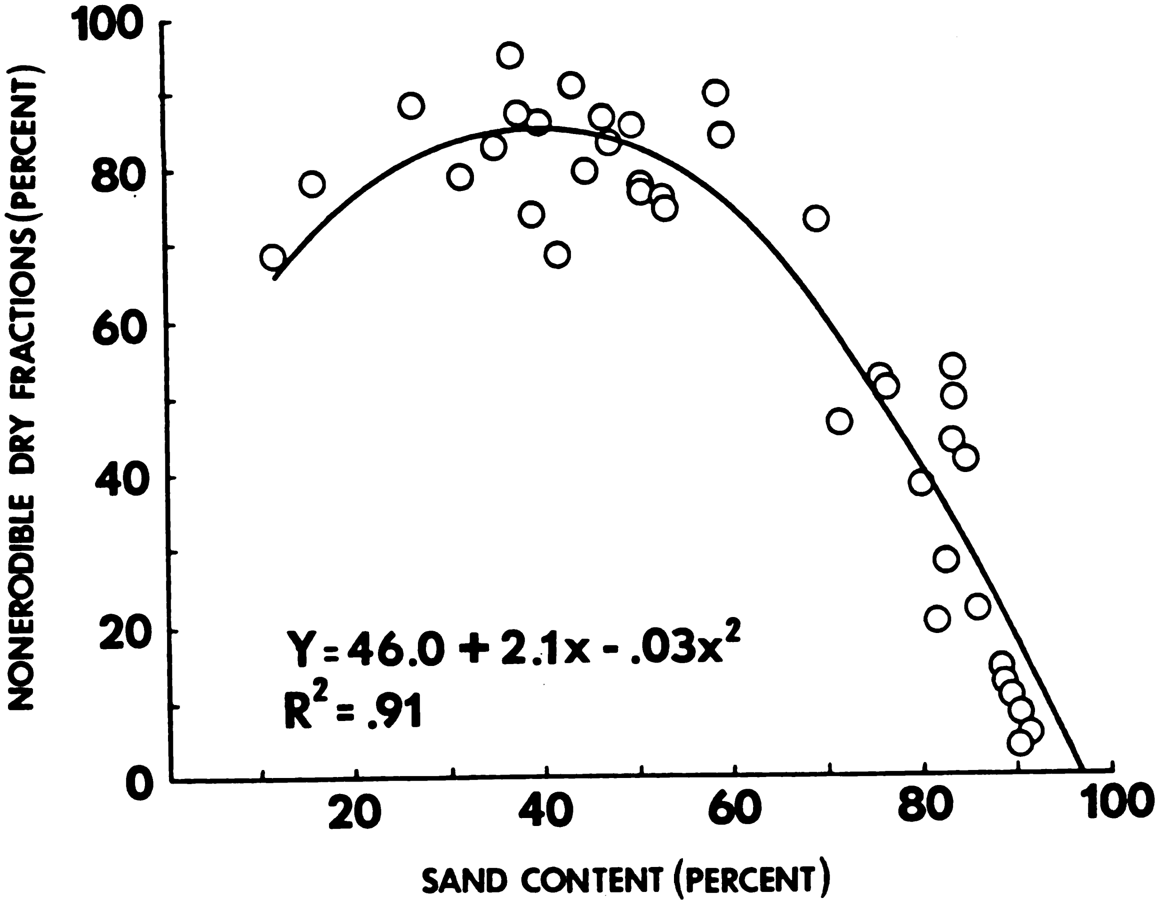

Fig. 9. Relationship between sand and >0.84 mm fraction

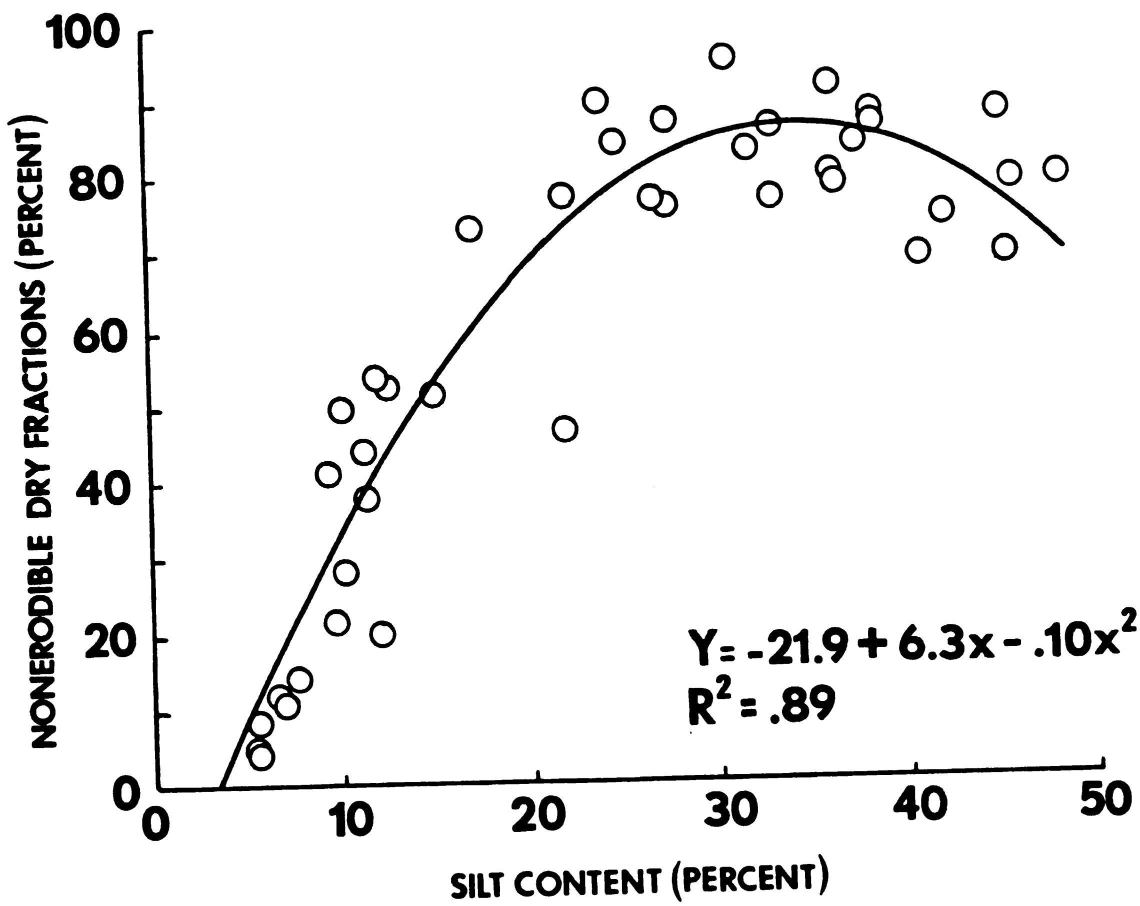

Fig. 10. Relationship between silt and >0.84 mm fraction.

erodibility of soil decreases up to a clay content of about 27 percent. Above 27 percent clay, the susceptibility of soil to wind erosion begins to increase. In soils of Western Canada, Kansas and Nebraska this same relationship was seen (Chepil, 1953a; 1955a; Chepil and Woodruff, 1963). The initial decrease in erodibility with increasing clay was found to be due to the cementing effects of clay in clod formation. That conclusion is supported by the results of this study.

The increase in erodibility above a certain clay content was attributed to the more pronounced effects of freezing and thawing and wetting and drying (Chepil, 1954b). Soils high in clay have greater water holding capacities and generally, a higher shrink-swell potential (Taylor and Ashcroft, 1972). Upon wetting, swelling causes stresses leading to clod breakdown. When a soil freezes, the expansion of freezing water fractures clods. Freezing effects are probably very important in Michigan. When freezing occurs, Michigan soils are usually moist.

Sand

Figure 9 illustrates the relationship of sand and wind erodibility. At very high sand contents, eg. 90 percent, the soil is extremely erodible. As sand content decreases, so does the susceptibility of soil to wind erosion. Soil appears least erodible at about 38 percent sand. As the percentage of sand decreases below 38 percent, the soil erodibility again increases.

The increase in erodibility seen with sand contents above 38 percent is due to the non-cohesive nature of sand grains (Chepil and Woodruff, 1963). Sand consists of non-collodial grains of quartz and other inert minerals. Grains of sand do not have the cementing effects important in secondary aggregate formation (Chepil, 1953a).

The decrease in erodibility as sand contents fall to about 38 percent is probably due to the cementing effects of the greater percentages of silt and clay in the soil. These same relationships seen in Great Plains soils were also attributed to the cementing effects of clay and silt (Chepil, 1955a, b). The importance of silt and clay is well illustrated in the steep slope of the curve at very high sand contents. A small increase in silt or clay apparently causes a large increase in dry fractions >0.84 mm in diameter. This was demonstrated in Kansas by Chepil (1955a). The first increments of clay or silt added to sand were very effective in reducing the erodibility of the sands.

As sand continues to decrease below 38 percent, the erodibility of soil again rises. This is probably due to the finer texture (higher clay and silt contents) of the soils with these low sand contents. As shown by Figure 8 the erodibility of soil increases as the percentage of clay rises above about 27 percent.

Silt

The relationship of silt and dry clod structure is shown in Figure 10. Wind erodibility decreases as silt increases up to about 35 percent. Erodibility then increases as silt increases above 35 percent. The initial decrease in erodibility associated with increasing silt contents may be caused by the cementing effects of silt. The importance of silt as a cementing agent in dry clod formation has been shown for soils of the Great Plains (Chepil, 1953a).

Two factors may be contributing to the increase in erodibility above 35 percent silt. Of the soils sampled, most of those with the high silt contents also had clay percentages above 30. The decrease in dry aggregation above 35 percent silt may also be caused by the nature of aggregates formed when silt is the primary cementing agent. Silt forms softer aggregates when it is the primary cementing agent (Chepil, 1955a). Mechanical breakdown of the softer secondary aggregates during sieving may have contributed to the lower percentages. From these relationships it can be concluded sand has an overall negative effect on dry aggregation, while silt has an overall positive effect. Clay appears to influence wind erodibility in either a positive or negative manner, depending on the amount of clay present.

The derivative of each equation was taken to arrive at the value of X (percent clay, sand or silt) resulting in maximum Y (percent >0.84 mm). Maximum resistance to wind erosion occurred at 27 percent clay, 35 percent silt and 38 percent sand. On the basis of Figures 8, 9 and 10 soil with maximum resistance to wind erosion has a clay content ranging from 24-30 percent, a silt content from 30-40 percent and a sand content from 31-45 percent. The mean percentages of each size fraction are: 27, 35 and 38 percent of clay, silt and sand respectively. The summation percentage equals 100.

These optimum clay, silt and sand percentages are very close to the two different sets of percentages estimated by Chepil (1940, as cited by Chepil, 1955a; 1953b; 1955a). In 1940, Chepil studied the wind erodibility of some soils of Western Canada. The greatest degree of cloddiness occurred in soils having about 20, 38 and 42 percent clay, silt and sand, respectively. These percentages are extremely close to the percentages of 27, 35 and 38 estimated from Figures 8, 9 and 10.

In 1955, Chepil found Nebraskan and Kansan soils gave optimum resistance to wind erosion when they contained 20-30 percent clay, 40-50 percent silt and 20-50 percent sand. This agrees well with the clay, silt and sand ranges of 24-30 percent, 30-40 percent and 31-45 percent estimated from Figures 8, 9 and 10. This similarity demonstrates the validity of the alternate sieve as a method of determining percent dry fractions >0.84 mm in diameter. Chepil (1955a) felt differences in parent material may be a factor in the discrepancy between the optimum silt contents for the Canadian and Nebraskan/Kansan soils. The Nebraskan and Kansan soils were loessial in origin, while most of the Canadian soils had glacial till parent material. The very close optimum percentages of the Canadian study and of this study support Chepil's contention. The majority of the soils in this Michigan study had glacial till parent material.

SUMMARY AND CONCLUSIONS

The wind erodibility of some Michigan soils was studied. Forty sites representing 13 soil series and seven surface textures were sampled. The soils were analyzed for their organic matter and calcium carbonate contents, and for their percentages of sand, silt and clay. An alternate version of the standard rotary sieve was developed. Percent non-erodible dry fractions >0.84 mm for each soil was determined using the alternate sieve.

The variability in erodibility from site to site within each texture was analyzed. The average >0.84 mm percent for each texture was then compared to the >0.84 mm percent of the WEG to which each texture was assigned. Analysis of the effects of clay, silt and sand on wind erodibility revealed the particle size distribution resulting in maximum resistance to wind erosion. The following conclusions were made:

1. There were significant differences in the wind erodibility between sites of the same texture. Variations in environment and management from site to site were most likely responsible for the observed differences.
2. For every texture studied, the average >0.84 mm percentage, as determined by alternate sieving, was higher than the percentage for the WEG to which the texture was assigned. Differences in

soil moisture at time of tillage may have contributed to a large portion of the discrepancy between actual and assigned textures. The magnitude of the difference between the actual and assigned textures decreased as soil texture became coarser. Coarser textured soils have lower water holding capacities and are generally drier when tilled. Based on these data, the present WEG assignments may not adequately reflect the springtime erodibility of Michigan's soils.

3. Organic matter and calcium carbonate had no significant effect on wind erodibility over the ranges studied. For Michigan conditions it is possible the effects of organic matter and calcium carbonate may have been overshadowed by the influence of clay, silt and sand.

4. There were significant curvilinear relationships between clay and wind erodibility, between silt and wind erodibility and between sand and wind erodibility. Second degree polynomial equations fit the data best. Sand had an overall negative influence on the non-erodible dry fractions, while silt had an overall positive influence. The effect of clay on the non-erodible dry fractions was variable, depending on the clay content of the soil. An increase in clay up to about 27 percent decreased

erodibility of soil. Above 27 percent clay, wind erodibility increased as clay content increased. These same clay, silt and sand relationships were described previously for soils of Western Canada and the Great Plains.

5. A medium textured soil containing 24-30 percent clay, 30-40 percent silt and 31-45 percent sand was found most resistant to wind erosion. The percentages agree very well with the optimum percentages for soils of Western Canada and the Great Plains.
6. These findings show for the first time that clay, silt and sand have the same effect on the wind erodibility of Michigan soils as they do on Western Canadian and Great Plains soils. This indicates the basic effects of the primary particles on dry clod structure are the same between areas with widely different environments and cultural practices.
7. There is a commonality of conclusions between the Great Plains studies, where standard rotary sieving was used, and this Michigan study, where alternate sieving was used. This demonstrates the validity of the alternate sieve as a method of determining the wind erodibility of soils.

APPENDIX I

TABLE 1

CALIBRATION RESULTS

Empty		1000 g Glass Beads	
Setting	rpm	Setting	rpm
0	0	0	0
1	0	1	0
2	0	2	0
3	1	3	1
4	2	4	1-2
5	4	5	4
6	5	6	5
7	6	7	6
8	6	8	6
9	6-7	9	6-7
10	7	10	7

TABLE 2

SIEVING RESULTS-21 TEST SAMPLES

Sample No.	>0.84 mm (%)	Sample No. (cont)	>0.84 mm (%) (cont)
1	16	12	18
2	13	13	9
3	20	14	10
4	16	15	20
5	20	16	19
6	18	17	17
7	18	18	14
8	16	19	18
9	17	20	19
10	14	21	17
11	13	x=16.25	s=3.06

APPENDIX II

TABLE 1

PARTICLE SIZE DISTRIBUTION AND ORGANIC AND INORGANIC CARBON CONTENTS OF SOILS

Site	>0.84 mm (%)	Clay (%)	Silt (%)	Sand (%)	Sand Fraction(%)*					Texture*	OC (%)
					VCo	Co	M	F	VF		
1-1	9	5	5	90	0.9	20.5	28.5	34.6	4.2	s	0.7
-2	8	5	5	90	1.0	20.0	25.5	37.1	4.8	s	0.8
-3	14	5	7	88	1.0	23.0	25.2	35.0	4.7	s	0.9
-4	5	7	5	88	1.3	25.4	25.3	33.4	3.9	s	0.7
-5	8	3	5	92	1.0	30.6	17.2	34.8	5.1	s	0.7
-6	9	5	5	90	1.4	27.0	21.8	34.2	4.4	s	0.6
-7	12										
-8	7										
-9	5										
-10	7										
	$\overline{x}$ = 8										
	s = 3										
2-1	5	3	5	92	0.8	6.3	19.4	60.0	4.2	fs	0.5
-2	5	5	5	90	0.9	8.1	19.2	57.4	3.9	fs	0.5
-3	5	5	6	89	0.5	5.1	18.4	60.2	5.1	fs	0.6
-4	3	5	5	90	0.4	6.5	16.9	60.2	5.2	fs	0.5
-5	3	1	7	93	0.5	5.7	15.4	61.7	5.4	fs	0.5
-6	5	7	5	87	0.5	6.9	20.2	57.0	4.3	fs	0.8
-7	3										
-8	6										
-9	6										
	$\overline{x}$ = 4										
	s = 1										

*s = Sand; l = loam, c = clay, si = silt, f(F) = fine, vf (VF) = very fine, Co = coarse, VCo = very coarse, M = medium.

TABLE 1 - Continued

Site	>0.84 mm (%)	Clay (%)	Silt (%)	Sand (%)	Sand Fraction(%) VCo	Co	M	F	VF	Texture	OC (%)
3-1	12	3	8	89	1.7	12.5	20.7	46.7	6.8	s	0.9
-2	11	3	6	92	1.8	12.2	21.0	46.3	7.1	s	0.9
-3	12	5	5	90	1.2	11.7	22.4	47.0	6.9	s	1.2
-4	11	3	8	90	2.0	12.5	20.4	45.8	7.3	s	1.1
-5	9	5	7	88	1.6	12.0	23.3	44.0	6.5	s	1.2
-6	10	5	8	87	1.5	14.5	21.2	45.0	7.1	s	1.1
-7	9										
-8	11										
-9	14										
-10	10										
	$\bar{x}$ = 11										
	s = 1										
4-1	15	5	10	85	0.6	5.7	18.1	53.0	5.1	lfs	0.7
-2	17	8	8	84	0.2	5.5	18.3	51.3	4.5	lfs	1.0
-3	27	11	16	73	0.7	6.4	15.5	45.1	7.7	lfs	1.0
-4	19	3	13	85	0.7	5.2	16.6	50.5	6.9	lfs	0.8
-5	20	8	13	79	0.6	3.9	16.8	46.7	7.0	lfs	0.9
-6	17										
-7	22										
-8	23										
-9	23										
-10	18										
	$\bar{x}$ = 20										
	s = 3										

TABLE 1 - Continued

Site	>0.84 mm (%)	Clay (%)	Silt (%)	Sand (%)	Sand Fraction(%) VCo	Co	M	F	VF	Texture	OC (%)
5-1	12	3	7	90	2.0	19.2	30.1	34.2	2.4	s	1.3
-2	13	3	5	92	1.7	19.5	31.6	33.4	2.4	s	1.4
-3	14	6	12	82	1.6	23.4	27.0	33.8	2.6	ls	1.4
-4	9	5	7	88	1.6	15.8	29.4	38.0	3.3	s	1.4
-5	12	5	6	89	1.8	19.4	28.4	35.8	2.9	s	1.6
-6	12										
-7	11										
-8	10										
-9	14										
-10	37										
	$\bar{x}$ = 14										
	s = 8										
6-1	5	3	5	92	0.7	9.6	24.9	48.8	4.2	fs	0.9
-2	6	5	7	88	0.9	13.4	23.0	48.1	4.1	fs	0.9
-3	5	5	6	89	1.2	15.2	21.0	48.7	4.4	fs	0.8
-4	4	3	3	94	0.7	9.4	23.7	50.5	4.9	fs	0.6
-5	5	5	6	89	0.7	10.0	21.8	50.8	4.9	fs	0.9
-6	4	0	5	95	1.5	12.3	23.7	49.8	4.5	fs	0.5
-7	5										
-8	8										
-9	4										
-10	9										
	$\bar{x}$ = 6										
	s = 2										

TABLE 1 - Continued

Site	>0.84 mm (%)	Clay (%)	Silt (%)	Sand (%)	Sand Fraction (%) VCo	Co	M	F	VF	Texture	OC (%)
7-1	15	5	4	91	0.2	4.9	16.6	59.1	4.6	fs	1.4
-2	5	5	8	87	0.3	4.4	17.0	61.8	4.2	fs	1.1
-3	7	5	5	90	0.3	4.8	17.7	60.6	4.2	fs	1.3
-4	12	5	6	89	0.3	6.3	18.4	58.5	4.3	fs	1.2
-5	12	5	9	86	0.2	6.1	15.0	59.7	4.9	fs	1.5
-6	20	4	7	88	0.1	3.2	16.0	61.3	5.0	fs	1.6
-7	13										
-8	7										
-9	15										
-10	18										
	$\bar{x}$ = 12										
	s = 5										
8-1	49	5	9	86	0.2	1.4	6.7	65.4	8.4	lfs	2.8
-2	40	8	10	82	0.2	1.2	7.1	65.2	8.1	lfs	2.9
-3	34	6	9	86	0.1	2.1	7.6	68.7	6.3	lfs	2.6
-4	36	6	8	86	0.2	1.9	7.8	66.2	6.7	lfs	2.6
-5	45	3	11	86	0.2	1.7	7.4	65.9	7.1	lfs	2.4
-6	46	8	9	83	0.2	2.5	7.1	66.6	7.1	lfs	2.4
-7	50										
-8	36										
-9	41										
-10	39										
	$\bar{x}$ = 41										
	s = 6										

TABLE 1 - Continued

Site	>0.84 mm (%)	Clay (%)	Silt (%)	Sand (%)	Sand Fraction(%) VCo	Co	M	F	VF	Texture	OC (%)
9-1	50	3	13	85	2.0	20.8	20.4	34.7	4.3	ls	1.5
-2	51	8	9	84	2.1	13.8	19.8	36.4	3.8	ls	1.6
-3	54	5	11	84	2.1	22.2	19.0	34.4	4.2	ls	1.5
-4	56	8	10	82	1.8	18.6	24.2	34.1	3.9	ls	1.4
-5	47	11	10	80	2.0	14.6	26.6	34.6	4.1	sl	1.4
-6	49	5	8	87	2.1	21.6	20.7	33.6	4.7	ls	1.3
-7	43										
-8	47										
-9	58										
-10	44										
	$\bar{x}$ = 50										
	s = 5										
10-1	45	5	10	84	1.2	5.1	7.3	43.9	19.9	lfs	1.4
-2	47	5	11	84	0.8	3.6	6.0	43.9	21.6	lfs	1.6
-3	49	5	11	84	0.8	3.9	7.4	44.8	19.4	lfs	1.6
-4	42	5	12	83	0.7	3.6	7.1	45.8	20.0	lfs	1.5
-5	38	6	11	84	0.8	3.7	8.0	45.7	19.5	lfs	1.5
-6	43	8	12	80	0.9	3.5	8.4	45.3	18.3	lfs	2.5
-7	44										
-8	44										
-9	54										
-10	35										
	$\bar{x}$ = 44										
	s = 5										

TABLE 1 - Continued

Site	>0.84 mm (%)	Clay (%)	Silt (%)	Sand (%)	Sand Fraction(%) VCo	Co	M	F	VF	Texture	OC (%)
11-1	63	13	13	75	0.7	9.2	26.9	33.1	3.5	sl	2.3
-2	51	11	13	76	0.8	11.9	25.3	32.9	3.5	sl	2.3
-3	43	8	11	82	0.8	10.5	24.5	38.1	4.3	ls	2.0
-4	29	10	8	82	0.6	12.8	21.6	40.6	5.0	ls	1.6
-5	16	3	17	80	0.7	9.6	25.1	44.9	4.6	ls	1.2
-6	36	8	8	85	0.8	11.8	23.0	40.9	4.7	ls	1.8
-7	51										
-8	38										
-9	29										
-10	21										
	$\bar{x}$ = 38										
	s = 15										
12-1	26	8	10	82	0.9	8.9	24.6	46.8	2.1	ls	1.8
-2	29	8	10	83	0.6	7.7	19.9	51.9	3.2	ls	2.4
-3	34	6	13	82	0.5	7.1	22.3	49.3	2.7	ls	2.7
-4	28	7	10	82	0.7	8.8	21.9	48.4	2.4	ls	2.7
-5	32	8	8	84	0.7	15.7	18.4	44.0	2.1	ls	2.9
-6	21										
-7	25										
-8	29										
-9	27										
	$\bar{x}$ = 28										
	s = 4										

TABLE 1 - Continued

Site	>0.84 mm (%)	Clay (%)	Silt (%)	Sand (%)	Sand Fraction(%) VCo	Co	M	F	VF	Texture	OC (%)
13-1	23	5	10	85	1.2	11.6	24.3	42.1	4.4	ls	0.5
-2	14	5	6	89	1.1	11.8	22.7	42.8	4.7	s	0.5
-3	13	5	13	82	0.7	11.9	20.7	42.1	5.2	ls	0.5
-4	24	3	10	87	1.2	12.4	23.3	42.3	4.4	s	0.5
-5	22	5	10	85	1.2	11.2	24.2	41.9	4.2	ls	0.5
-6	21										
-7	21										
-8	18										
-9	27										
-10	29										
	$\bar{x}$ = 21										
	s = 5										
14-1	49	8	23	70	0.9	5.0	9.8	33.5	12.3	sl	1.0
-2	40	7	21	72	0.6	4.5	9.5	38.3	12.2	sl	0.8
-3	32	7	25	68	0.7	6.4	12.1	38.1	11.0	sl	0.8
-4	37	1	22	78	0.6	6.6	10.5	38.2	11.0	ls	0.8
-5	44	10	20	70	1.0	5.6	8.3	36.5	11.8	sl	0.8
-6	38										
-7	51										
-8	57										
-9	62										
-10	57										
	$\bar{x}$ = 46										
	s = 10										

TABLE 1 - Continued

Site	>0.84 mm (%)	Clay (%)	Silt (%)	Sand (%)	Sand Fractions(%) VCo	Co	M	F	VF	Texture	OC (%)
15-1	45	3	10	87	0.3	7.7	25.2	47.8	4.2	ls	2.0
-2	53	5	10	85	0.4	8.0	25.0	45.8	4.2	ls	2.0
-3	65	7	17	77	0.4	12.3	20.2	43.8	4.5	ls	1.6
-4	53	2	10	88	0.3	6.7	24.3	44.9	4.5	s	2.2
-5	61	5	14	81	0.4	8.3	22.6	43.4	4.4	ls	2.0
-6	48										
-7	54										
-8	61										
-9	45										
-10	49										
	$\bar{x}$ = 53										
	s = 7										
16-1	45	8	14	79	0.2	2.3	9.0	63.1	4.0	sl	1.4
-2	50	5	14	81	0.4	2.0	7.3	65.0	5.0	sl	1.1
-3	48	5	14	81	0.4	2.4	8.0	66.0	4.0	sl	1.1
-4	52	13	18	69	0.1	2.0	8.0	56.1	5.2	sl	2.3
-5	54	13	14	73	0.2	1.2	7.0	55.0	6.0	sl	2.0
-6	55	8	18	74	0.2	1.3	6.1	59.1	5.7	sl	1.6
-7	41										
-8	42										
-9	49										
-10	65										
	$\bar{x}$ = 50										
	s = 7										

TABLE 1 - Continued

Site	>0.84 mm (%)	Clay (%)	Silt (%)	Sand (%)	Sand Fraction(%) VCo	Co	M	F	VF	Texture	OC (%)
17-1	88	34	32	34	1.9	3.0	3.9	16.0	4.9	cl	2.3
-2	77	35	31	34	2.0	3.2	4.2	15.9	5.4	cl	2.1
-3	82	28	31	41	1.8	3.4	4.8	22.6	6.8	cl	1.9
-4	80	35	32	33	2.6	3.5	4.5	17.2	5.3	cl	2.2
-5	78	32	34	34	2.3	3.5	4.7	19.3	5.6	cl	2.3
-6	86										
-7	86										
-8	85										
-9	82										
-10	85										
	$\bar{x}$ = 83										
	s = 4										
18-1	89	17	21	62	0.9	4.1	9.8	35.2	8.6	sl	2.5
-2	91	16	21	64	0.9	4.4	10.1	35.7	8.6	sl	2.4
-3	90	18	25	57	1.1	4.5	8.9	31.8	8.4	sl	2.2
-4	90	19	25	56	1.0	5.3	7.7	30.4	8.5	sl	2.2
-5	88	17	27	56	1.1	4.8	8.7	29.9	8.2	sl	2.1
-6	90										
-7	94										
-8	89										
-9	86										
-10	88										
	$\bar{x}$ = 89										
	s = 2										

TABLE 1 - Continued

Site	>0.84 mm (%)	Clay (%)	Silt (%)	Sand (%)	Sand Fraction(%) VCo	Co	M	F	VF	Texture	OC (%)
19-1	89	21	45	34	0.5	2.1	3.7	11.3	5.3	l	1.9
-2	93	19	44	38	0.5	2.3	4.2	12.7	7.7	l	2.0
-3	89	16	47	37	0.6	3.2	5.5	15.5	7.7	l	2.2
-4	80	13	52	35	0.5	2.9	5.2	15.9	8.9	sil-l	1.9
-5	82	16	38	46	0.6	2.8	5.0	16.3	9.3	l	1.7
-6	88										
-7	88										
-8	88										
-9	95										
-10	82										
	$\bar{x}$ = 87										
	s = 5										
20-1	77	16	34	50	1.0	6.0	10.0	24.0	5.0	l-sl	1.7
-2	73	13	33	54	1.0	6.0	9.0	24.0	6.0	sl	1.4
-3	78	15	30	55	1.0	5.0	10.0	25.0	6.0	sl	1.5
-4	75	13	31	56	1.0	7.0	9.0	27.0	5.0	sl	1.3
-5	72	13	38	49	1.0	5.0	9.0	28.0	6.0	l	1.3
-6	77										
-7	81										
-8	81										
-9	75										
-10	75										
	$\bar{x}$ = 76										
	s = 3										

TABLE 1 - Continued

Site	>0.84 mm (%)	Clay (%)	Silt (%)	Sand (%)	Sand Fraction(%) VCo	Co	M	F	VF	Texture	OC (%)
21-1	80	16	29	56	1.2	7.4	12.2	25.0	0.3	1	1.0
-2	74	13	33	54	1.2	6.2	11.0	23.0	6.3	1	1.2
-3	82	13	43	44	0.7	5.4	6.5	18.0	6.0	1	1.3
-4	77	11	45	45	0.8	4.7	6.4	16.5	6.0	1	1.2
-5	75	13	33	55	0.9	7.0	10.4	23.0	7.0	1	1.1
-6	77										
-7	81										
-8	76										
-9	79										
-10	82										
	$\bar{x}$ = 78										
	s = 3										
22-1	83	14	36	50	1.1	6.8	7.6	20.4	6.1	1	1.0
-2	88	16	36	48	1.1	6.1	8.6	20.4	6.3	1	1.0
-3	77	12	36	52	0.9	6.4	8.2	22.5	6.6	1	1.0
-4	83	11	40	49	1.1	5.5	7.7	20.3	6.5	1	1.0
-5	88	21	40	39	1.0	4.9	6.6	16.0	4.7	1	1.0
-6	85										
-7	87										
-8	80										
-9	78										
-10	83										
	$\bar{x}$ = 83										
	s = 4										

TABLE 1 - Continued

Site	>0.84 mm (%)	Clay (%)	Silt (%)	Sand (%)	Sand Fraction(%) VCo	Co	M	F	VF	Texture	OC (%)
23-1	84	23	38	39	0.6	3.7	6.7	22.0	5.8	1	1.5
-2	85	25	38	37	0.6	3.5	5.9	17.0	4.8	1	1.6
-3	87	17	38	45	0.9	3.6	7.1	22.1	6.2	1	1.6
-4	89	22	39	39	0.8	3.1	6.3	19.3	5.8	1	1.8
-5	87	23	38	39	1.1	3.7	6.1	19.0	5.6	1	1.4
-6	86										
-7	87										
-8	85										
-9	86										
-10	86										
	$\bar{x}$ = 86										
	s = 1										
24-1	94	23	38	40	1.2	5.6	9.1	18.9	6.1	1	1.7
-2	91	17	35	48	1.1	7.6	8.2	19.8	6.4	1	1.6
-3	94	23	37	40	1.1	5.5	7.1	17.0	5.3	1	1.7
-4	92	17	36	47	1.2	7.0	8.0	19.2	5.8	1	1.8
-5	91	21	36	43	1.4	5.3	7.7	17.2	5.4	1	1.7
-6	90										
-7	95										
-8	90										
-9	89										
-10	89										
	$\bar{x}$ = 91										
	s = 2										

TABLE 1 - Continued

Site	>0.84 mm (%)	Clay (%)	Silt (%)	Sand (%)	Sand Fraction(%) VCo	Co	M	F	VF	Texture	OC (%)
25-1	65	21	42	37	0.5	4.6	7.9	12.7	3.3	l	1.3
-2	66	23	44	33	0.6	7.0	7.9	13.7	3.5	l	1.3
-3	74	15	45	40	0.6	5.5	9.0	15.0	4.0	l	1.2
-4	79	15	40	45	0.5	6.9	6.3	14.0	3.8	l	1.0
-5	75	18	40	43	0.5	5.5	10.7	16.7	4.0	l	1.2
-6	73										
-7	76										
-8	75										
-9	78										
-10	81										
	$\bar{x}$ = 74										
	s = 5										
26-1	87	15	37	48	1.4	8.3	9.4	23.0	6.0	l	1.5
-2	90	24	30	46	1.4	8.0	8.2	22.0	5.3	l	1.6
-3	81	16	31	54	2.0	8.3	10.0	24.0	6.0	sl	1.7
-4	89	16	35	49	1.4	7.2	9.0	21.3	6.0	l	2.0
-5	81	14	38	48	2.0	6.4	10.0	22.0	6.0	l	1.5
-6	86	18	29	53	2.0	6.2	11.2	23.4	6.4	l	1.6
-7	84										
-8	88										
-9	91										
-10	84										
	$\bar{x}$ = 86										
	s = 3										

TABLE 1 - Continued

Site	>0.84 mm (%)	Clay (%)	Silt (%)	Sand (%)	Sand Fraction(%) VCo	Co	M	F	VF	Texture	OC (%)
27-1	72	11	41	48	2.0	7.1	9.2	19.0	5.0	1	1.8
-2	74	9	41	50	1.2	7.0	10.2	20.0	5.2	1	1.7
-3	64	17	43	40	1.1	7.0	8.4	19.0	5.1	1	1.8
-4	72	12	41	48	1.4	7.0	9.0	19.2	5.3	1	1.7
-5	73	11	40	50	1.4	7.3	9.2	20.2	5.1	1	1.7
-6	62	13	40	47	1.3	7.0	10.3	20.0	5.4	1	2.0
-7	67										
-8	71										
-9	65										
	$\bar{x}$ = 69										
	s = 5										
28-1	80	17	34	50	1.6	8.0	6.5	19.6	6.0	1	1.8
-2	80	22	34	44	1.7	7.0	6.5	17.3	5.1	1	1.4
-3	84	17	39	45	1.8	5.0	7.4	18.5	5.6	1	1.4
-4	82	25	37	38	1.6	6.5	6.6	17.6	9.9	1	1.3
-5	80	16	36	48	1.3	6.1	7.1	20.1	6.1	1	1.4
-6	76										
-7	80										
-8	87										
-9	73										
-10	80										
	$\bar{x}$ = 80										
	s = 4										

TABLE 1 - Continued

Site	>0.84 mm (%)	Clay (%)	Silt (%)	Sand (%)	Sand Fraction(%) VCo	Co	M	F	VF	Texture	OC (%)
29-1	81	22	30	48	0.8	7.1	10.7	19.3	5.0	l	1.0
-2	86	20	29	51	0.9	10.2	8.8	19.4	5.0	l	1.0
-3	80	18	34	48	0.8	7.3	11.1	20.9	5.3	l	0.9
-4	66	13	20	67	0.9	16.3	10.2	24.7	5.7	sl	0.9
-5	73	22	26	53	0.9	11.3	12.7	22.9	5.1	l	0.9
-6	79										
-7	74										
-8	75										
-9	70										
-10	68										
	$\bar{x}$ = 75										
	s = 6										
30-1	84	21	50	29	0.5	3.6	7.0	13.6	3.3	l	2.6
-2	77	19	48	33	0.5	4.2	8.5	16.8	3.8	l	2.1
-3	84	21	49	30	0.5	3.8	6.3	13.8	3.5	l	2.4
-4	80	22	50	28	0.5	3.7	4.5	11.2	2.9	sil	2.4
-5	67	17	44	39	0.6	4.3	8.2	17.4	4.2	l	2.7
-6	80										
-7	86										
-8	84										
-9	78										
-10	78										
	$\bar{x}$ = 79										
	s = 6										

TABLE 1 - Continued

Site	>0.84 mm (%)	Clay (%)	Silt (%)	Sand (%)	Sand Fraction(%) VCo	Co	M	F	VF	Texture	OC (%)	IC (%)
31-1	80	37	45	17	0.2	1.8	1.3	7.1	3.7	sicl	3.3	2.2
-2	83	38	47	14	0.1	0.9	0.9	5.6	4.2	sicl	4.0	1.2
-3	75	38	44	19	0.3	1.4	2.0	7.3	4.5	sicl	3.7	1.8
-4	76	39	47	15	0.2	1.7	1.6	7.4	4.4	sicl	4.0	2.1
-5	78											
-6	74											
-7	83											
-8	83											
-9	80											
-10	75											
	$\overline{x}$ = 78											
	s = 3											
32-1	96	34	34	33	0.8	7.1	11.0	13.6	3.1	cl	2.3	2.2
-2	94	33	31	36	0.9	7.9	9.7	13.5	3.0	cl	2.4	2.0
-3	95	30	31	39	0.8	6.9	10.5	13.5	3.2	cl	2.4	2.2
-4	94	31	31	38	1.0	9.4	10.8	13.9	3.0	cl	2.2	1.8
-5	97	32	30	41	1.1	10.5	10.1	14.6	3.3	cl	2.2	1.9
-6	96											
-7	93											
-8	94											
-9	96											
-10	96											
	$\overline{x}$ = 95											
	s = 1											

TABLE 1 - Continued

Site	>0.84 mm (%)	Clay (%)	Silt (%)	Sand (%)	Sand Fraction(%) VCo	Co	M	F	VF	Texture	OC (%)	IC (%)
33-1	72	43	42	16	0.2	0.7	0.6	4.1	3.3	sic	5.5	0.7
-2	64	43	45	12	0.2	0.6	0.5	3.4	3.0	sic	5.7	0.7
-3	72	40	48	12	0.1	0.9	0.5	4.5	3.8	sic	5.3	0.9
-4	74	45	47	8	0.1	0.6	0.7	4.4	3.9	sic	4.9	0.8
-5	70											
-6	66											
-7	67											
-8	69											
-9	67											
-10	68											
	$\bar{x}$ = 69											
	s = 3											
34-1	85	29	27	43	0.5	7.6	11.5	18.4	3.8	cl	1.7	0.6
-2	87	28	27	46	0.7	8.6	11.3	19.2	4.0	scl	1.8	0.7
-3	87	27	29	44	0.7	8.0	11.7	18.4	4.0	scl	1.8	0.6
-4	91	20	32	48	0.4	6.5	12.0	18.4	3.9	l-scl	1.8	0.8
-5	88	25	24	51	0.6	7.5	13.6	19.7	3.9	scl	2.0	0.2
-6	89											
-7	89											
-8	84											
-9	80											
-10	86											
	$\bar{x}$ = 87											
	s = 3											

TABLE 1 - Continued

Site	>0.84 mm (%)	Clay (%)	Silt (%)	Sand (%)	Sand Fraction(%) VCo	Co	M	F	VF	Texture	OC (%)	IC (%)
35-1	72	27	24	49	0.5	7.7	13.5	20.3	4.7	scl	2.2	0.02
-2	80	29	22	49	0.5	11.4	9.6	19.0	4.3	scl	2.5	0.03
-3	77	24	21	54	0.5	7.4	14.1	20.0	4.4	scl	2.2	0.04
-4	75	28	23	49	0.6	11.9	10.6	19.4	4.2	scl	2.2	0.1
-5	78	27	21	53	0.8	8.8	13.4	19.7	4.2	scl	2.1	0.2
-6	76											
-7	77											
-8	75											
-9	79											
-10	80											
	$\overline{x}$ = 77											
	s = 3											
36-1	89	35	44	21	0.9	4.3	4.5	10.7	2.5	cl	2.6	
-2	93	36	37	27	1.0	4.2	7.0	12.0	2.4	cl	2.7	
-3	84	38	34	27	1.0	4.9	6.9	11.4	2.2	cl	2.7	
-4	85	31	36	33	0.9	5.6	7.1	13.3	2.8	cl	2.7	
-5	90	35	40	25	0.8	2.8	6.1	10.8	2.5	cl	2.6	
-6	92											
-7	92											
-8	85											
-9	86											
-10	89											
	$\overline{x}$ = 88											
	s = 3											

TABLE 1 - Continued

Site	>0.84 mm (%)	Clay (%)	Silt (%)	Sand (%)	Sand Fraction(%) VCo	Co	M	F	VF	Texture	OC (%)
37-1	72	18	25	57	1.1	7.6	10.5	26.1	6.3	sl	2.5
-2	78	21	21	58	1.2	7.9	10.4	28.1	6.5	sl	1.9
-3	72	19	26	55	1.3	6.1	11.7	26.5	6.8	sl	2.1
-4	83	21	26	53	0.7	6.2	10.6	24.5	6.4	sl	2.3
-5	84	21	37	42	1.2	6.6	9.0	23.0	6.4	l	2.1
-6	76										
-7	74										
-8	75										
-9	70										
-10	81										
	$\bar{x}$ = 77										
	s = 5										
38-1	54	11	13	77	0.8	19.6	26.0	24.7	3.2	sl	1.8
-2	44	10	7	83	1.8	25.7	30.3	22.6	2.9	sl	1.5
-3	57	8	10	82	1.3	29.3	24.3	23.2	3.0	ls	1.5
-4	64	14	18	68	0.6	12.7	25.0	25.2	3.1	sl	2.0
-5	67	16	15	69	0.6	13.7	27.9	23.1	3.0	sl	2.0
-6	39										
-7	44										
-8	29										
-9	67										
	$\bar{x}$ = 52										
	s = 13										

TABLE 1 - Continued

Site	>0.84 mm (%)	Clay (%)	Silt (%)	Sand (%)	Sand Fraction(%) VCo	Co	M	F	VF	Texture	OC (%)
39-1	69	12	15	73	1.6	13.7	11.2	34.0	6.8	sl	1.1
-2	78	15	15	70	2.4	13.0	13.8	29.2	6.1	sl	1.2
-3	75	16	20	64	1.5	9.9	15.1	30.9	6.3	sl	1.4
-4	77	13	20	67	2.0	10.4	15.4	29.5	6.0	sl	1.1
-5	72	13	15	72	2.5	12.0	14.0	31.0	6.5	sl	1.2
-6	80										
-7	73										
-8	71										
-9	68										
-10	68										
	$\bar{x}$ = 73										
	s = 4										
40-1	84	17	27	56	0.9	4.9	10.2	26.2	8.4	sl	1.8
-2	85	15	24	61	1.0	5.5	9.7	27.3	8.4	sl	2.0
-3	86	13	27	60	1.3	5.8	9.3	26.7	8.2	sl	2.0
-4	83	21	22	57	0.8	6.7	8.8	28.6	9.0	sl	1.9
-5	83	13	24	63	0.8	6.0	9.5	29.8	8.4	sl	1.9
-6	83										
-7	84										
-8	84										
-9	85										
-10	83										
	$\bar{x}$ = 84										
	s = 1										

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