Interrelationships between soils, rainfall, runoff, and erosion were investigated on two Christmas tree plantations and one forested site. All three sites were on soils recognized as Jory soil series.

The soil characteristics examined for each site included organic matter content, aggregate fractions (size and stability), mineral components (crystalline and amorphous), and physical properties (texture, hydraulic conductivity, and bulk density). Values for organic matter contents, aggregate stability indexes, and saturated hydraulic conductivity were lower on the two cultivated Christmas tree plantations than on the timbered site.

The forested site's soil aggregates slaked less when exposed to periodate oxidation and dispersing conditions than did aggregates from the cultivated sites. All soil aggregate fractions greater than 0.25 millimeters had more organic matter than the
soil aggregate fraction less than 0.25 millimeters. The less-intensely cultivated site possessed more stable aggregates than the other cultivated plantation. It also contained more amorphous iron as indicated by oxalate extractions and electron micrographs.

Paired screened/unscreened erosion plots isolated effects of raindrop action on aggregate breakdown, surface compaction, runoff, and soil loss. The unscreened plots exposed to full raindrop impact had much more soil loss and decreased porosity compared to the screened plots which were more protected from raindrop impact. The compounding factors of intensive rototilling and subsoiling did not accelerate soil loss when the soil was protected from raindrop impact, but did reduce infiltration rates compared to the exposed soil surface.

Photographs gave evidence supporting contentions about compaction of the soil crust by raindrop impact. Thin sections of the soil surface revealed a more porous, aggregated surface on the protected (screened) plot than on the unscreened plot. Visual observations, documented with sequential photographs of the plots, revealed a slaked soil surface on the plot that had full raindrop impact and a more aggregated soil surface on the plot that had reduced raindrop impact.

The rain parameters of "kinetic energy of raindrops" times the maximum 30 minute and six hour rain intensities explained a large part of the variation in soil losses from erosion plots. The detectable differences in aggregate stability for the two
cultivated sites did not appreciably affect "soil loss" regressions. Two years of data indicate the rainfall factor in the Universal Soil Loss Equation may be useful for predicting average sheet and rill soil losses in western Oregon on the Jory soil series.
Rainfall, Surface Sealing, Runoff, and Erosion on Jory Soil Series in Western Oregon

by

Joel Thomas King

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Cropland runoff carries significant pollution to our nation's waterways. The United States has an estimated 483 million acres of cropland which produce 40 to 50 percent of the calculated four billion tons of sediment transported in rivers, streams, and lakes annually (Primental et al., 1976). This sediment with its nutrients and chemicals is considered the greatest pollutant (by volume) of our surface waters.

Cropland sediment, due to its volume, negatively affects society's environment. Excessive land degradation can result from accelerated soil loss. Cropland sediment reduces downstream channel and reservoir capacity while it decreases economic and aesthetic values of land and water for outdoor recreation and wildlife habitat. Increased flood damage, lake eutrophication, expensive channel maintenance, and other activities can be minimized with reduced sediment loss from cropland.

Throughout history, man has altered his impact on the soil resource, more often for the worse than for the better. In Mesopotamia, Syria, China, and Lebanon, man-caused erosion has depleted the soil's productivity. In the United States, an area larger than the state of Missouri has been damaged by...
erosion to where it is virtually useless for crop production (Beasley, 1972).

Man's failure to conserve and protect the soil which provides food, clothing, and shelter has also caused water pollution. An estimated 70 per cent of the sediment in our waterways result from man's activity (Murray, 1976); this man-caused sediment is increasing. "An Iowa State University research report stated the United States was losing four billion tons of soil (in 1973) through water erosion, as compared to three billion tons in 1934" (Comptroller General, 1977).

1. Constraints Influencing Erosion Control

The control of sediment from cropland will be briefly discussed by social, legal, technical, and economic constraints influencing its management.

The attitudes of farmers and of society influence the management of cropland runoff. Our population, as a whole, has experienced a heightened environmental consciousness. Rachael Carson's book Silent Spring symbolizes society's increasing awareness of man's impact on his surroundings. Also the general public has more leisure time to spend on water recreation. Undoubtedly, more time spent on waterways gives increased exposure to real or imagined water pollution problems. For example, the water skier observes turbid water in his favorite
lake, reservoir, or river.

The agricultural producers, now constituting less than five per cent of the population, have traditionally strong political and management views which have and will influence control of cropland runoff. Their views can be grouped into three categories.

The first group of producers will conserve their soil resource (with resulting improvement in runoff water quality) even if that action costs them money (Kaiser, 1977). As a group, they have money to spend on soil conservation, own the land they crop, and have more formal education.

Producers in the next category will employ soil conservation techniques only if that action will be profitable. Past U. S. agriculture policy mistakes have taught them not to act on their initiative. After World War II, many people expected a federal land bank allotment program on private marginal cropland. Many producers retired some of their cropland to conserve their soil and were disillusioned when the program did not materialize. When the allotment program was instituted following the Korean War, the money allotted by the federal government to the producers was based on the previous year's land use. Thus, a conscientious conservation farmer who had taken marginal land out of production earlier did not receive as much money as the operator who had continued to cultivate maximum acreages. Many producers and their descendants will not make the same
mistake again.

The third class of farmers oppose any government regulatory interference in their operation. They view any government action as a restriction on their personal freedom as an individual operator.

Public concern and social pressure have resulted in federal, state, and local legislation which influence control of cropland runoff.

The most comprehensive federal legislation in this respect are the 1968 and 1972 amendments to the Federal Water Pollution Control Act (Cannon, 1976). The 1968 amendment established the National Water Commission. This commission emphasized reducing water pollution to increase the usefulness of water for recreation, agriculture, and energy production. The 1972 amendments set a national goal for the complete elimination of all pollutant discharges into natural bodies of water by 1985, whenever economically achievable. Section 208 requires that all state or regional agencies develop, implement, and regulate plans for the control of nonpoint sources of pollution, including cropland runoff.

Voluntary federal programs have promoted good land use practices and sediment pollution control at its source for decades since the dustbowl occurrence in the 1930's. Most of these programs have been financed by the Agricultural Stabilization and Conservation Service of the U.S.D.A. The new
Section 208 mandates imply that more comprehensive effort is required. Fortunately, the new legislation still lets farmers and other concerned citizens work with the state or Environmental Protection Agency to discover the best management practices and implement plans to minimize water pollution.

Besides the plans required by federal legislation, some state legislation aims to regulate control of cropland runoff. Pennsylvania adopted regulations requiring land owners to develop and implement a conservation plan. New York required conservation plans for agricultural operations of 25 or more acres. Though not directly regulating cropland runoff, these laws stimulate the farmers, thoughts about their management, and its effect on their surroundings. Iowa has established soil loss limits with a maximum recommended loss limit of five tons per acre per year (Wilcox, 1972). Landowners of property damaged by violations, or commissioners of soil conservation districts can take legal action against a violator of this law.

Most local ordinances directed at rural operations do not affect cropland runoff. City annexation, though, can influence erosion control. If a producer feels his property will be annexed in the future, he is much less concerned about conserving his soil, less eager to invest in soil conservation techniques, and more concerned with a quick monetary return from his operation. All three factors can result in serious soil loss and water pollution due to intensive cropping of marginal steeper land.
The methods for controlling cropland runoff generally are not technically difficult. Permanent soil or water conservation practices and management practices can usually reduce the sediment load of cropland runoff to acceptable levels (Beasley, 1972). Management and cropping practices include the type of crop grown, crop rotations, crop residue utilization, fertility adjustments, tillage methods, and cover crops. Manipulation of these factors can greatly reduce sediment yields. Permanent soil and water conservation practices are methods and processes specifically designed to slow the runoff water and reduce the sediment loads. Contour tillage, strip cropping, terraces, grass waterways, diversions, spillways, and farm ponds are common examples of conservation practices.

The technical problems of identifying discrete levels of erosion which occur are more difficult. In the U. S. east of the Rocky Mountains, the Universal Soil Loss Equation is designed to predict gross soil loss from sheet and rill erosion. One uses the equation to predict average annual soil loss for a given field under specified land use and management, to estimate soil loss reduction from various management changes, to determine more intensive uses of a contoured, terraced, or strip cropped field, to determine maximum uninterrupted slope length of a field, and to provide local soil loss data for erosion control needs and plans (Wischmeier, 1977). Adaptations of the U.S.L.E. to areas west of the Rocky Mountains are currently
being used for soil loss prediction while research on its accuracy and modifications continue (Billings, 1976).

While, for all practical purposes, known technology can correct most crop runoff problems, the money to implement such technology may often have a higher return when used on other investments. Economic constraints often limit the social, legal, and technological potential for controlling water pollution from cropland runoff.

Upto a point, soil conservation practices may improve the financial position of the landowner. Operators grow their profits on soil and the loss of their soil may decrease their profits. In eastern Oregon and in the Palouse region of eastern Washington, loss of topsoil has been related to decreased yields. One study indicated a decrease of 0.8 bushels of wheat per acre with the loss of one inch of topsoil (Thomas, 1943). The decrease in yield resulted from the loss of nutrients and moisture holding capacity of the relatively fertile topsoil.

If one can stop this soil loss, the operator may actually increase his profits. In eastern Oregon, the wheat farmers could afford to make substantial annual investments in the land to prevent erosion losses according to Thomas (1943). At the same time, Kuhlman (1943) concluded that a farmer with a berry and dairy operation in the northern Willamette Valley of western Oregon could increase his income by 111 dollars annually if he maintained a soil conservation program. Clearly, the same
economic conditions in the 1930's and 1940's do not exist today. Both studies assumed lower interest rates of three and four per cent. Also, intensive management such as high fertilizer use was not as common as today.

A more recent study indicates that a soil conservation program can decrease the profits of the operator (Alt, 1976). A rotation of corn, soybeans, and hay, no till planting, and fall shredded corn stalks on terraced land yielded a net annual return of $20,467 while continuous corn with conventional tillage and no terraces annually yielded $25,994 for 250 tillable acres in Iowa. Obviously, in some cases, operators will make less and may even lose money when installing conservation practices.

2. History of Erosion on Agricultural Soils in Western Oregon

Contrary to current beliefs, western Oregon, with its mild Mediterranean-type rains, has and continues to experience erosion accelerated by man's activity. In February 1949, hard rains falling on partially frozen soil eroded substantial quantities of soil from the Willamette Valley. The Soil Conservation Service estimated one million tons of soil were lost from 97,000 acres of land, an average of ten tons of soil per acre. The more severe soil losses occurred where clean-tilled row crops were planted up and down hill, orchards were without cover crops, and small fall-planted grains were not protecting
the soil surface (S. C. S., 1949). In 1943, soil erosion surveys by the Soil Conservation Service reported 21 per cent of the land in the Chehalem Mountain district, north of Newberg, Oregon, had experienced moderate erosion. Five per cent of the district's land was severely eroded. Soil losses were almost exclusively limited to the cultivated uplands where improper land use and tillage practices accelerated the erosion process (S. C. S., 1943). More recently, a survey of the upper Willamette Valley has indicated that runoff from smoothed sloping fields carried significant quantities of eroded soil (Young, 1976).

3. Objectives of This Study

In western Oregon, the pronounced pattern of winter rainfall comes when the soil is least protected. Due to the regional differences in climate and soils, the effect of rainfall on bare soils is not well established. Thus, objectives of this study were to:

1. Assess the importance of raindrop impact on exposed soil surfaces.

2. Evaluate rainfall parameters as factors in the erosion process.

3. Assess certain soil characteristics thought to be important to the erosion process.
II. LITERATURE REVIEW

1. Rainfall Parameters and Soil Loss

Previous research has demonstrated repeatedly that rainfall is the start of sheet and rill erosion processes in areas where snowmelt runoff is not occurring (Hudson, 1971). Raindrops can detach soil particles and help seal the soil surface, hence reducing the infiltration rate and increasing soil loss. These properties have prompted many researchers to examine rainfall to derive easily-obtained parameters to predict soil loss.

Raindrops have long been recognized as a primary agent in detaching soil particulates. Raindrops at terminal velocity (which depends on drop size) fall at a rate up to nine meters per second contrasted with common overland flow velocities of 0.07 meters per second (Ellison, 1947). Intuitively, one reasons that energy from raindrop impact applied approximately perpendicular to the soil surface should detach substantial quantities of soil.

Much evidence exists to support raindrop impact as a detaching mechanism. Intercepting raindrops to reduce direct impact on soil particles can reduce erosion considerably (Borst and Woodburn, 1942). For example, a wire platform with straw mulch suspended one inch above the soil surface absorbed drop energy, but did not impede surface flow; soil loss was
reduced 95 per cent over that which occurred when raindrops struck the bare soil. Without the protection of vegetation or mulch, raindrops can detach a large amount of soil (Meyer et al., 1976).

Later work has reinforced the conclusions of Borst and Woodburn (Meyer et al., 1975). Field plots and soil pans with three layers of screen suspended above the soil surface to intercept raindrops had less than 25 per cent of the soil loss as from unprotected plots and pans. Particle detachment may, however, vary with rainfall intensity. Rainfall intensities used for these experiments were six to ten times the normal rain intensities one would expect in western Oregon.

Many workers have attempted to determine the particle size most susceptible to raindrop detachment. In one study, fine sand was found to be preferentially detached (Ekern, 1950). In another, overland flow increased the size of particle most easily detached (Farmer, 1973). Mazurak and Mosher (1968) demonstrated decreasing detachment rate with fractions smaller than sand size which they attributed to cohesion. They later found that aggregate sizes from 1.68 to 2.36 milliliters were most susceptible to splash (Mazurak and Mosher, 1970). Farmer (1973), Mazurak and Mosher (1968), and Palmer (1964) also agree that a thin layer of water increases raindrop impact causing more detachment of soil.
particulates

Detachment of fine sand by raindrops reportedly is proportional to the amount of energy imparted per unit area (Ekern, 1950). An initial energy of $5 \times 10^3$ ergs per cm.$^2$ was required to overcome the inertia of sand particles. Raindrops one millimeter in diameter, falling at terminal velocity (four meters per second), exert that much energy. According to Ekern, a rain intensity of only 0.13 cm. per hour supplies many drops of that one millimeter size.

Ellison (1947) reasoned that the amount of soil detached would be proportional to the detaching capacity of the rainfall and the detachability of the soil. Soil splash was found to vary with raindrop velocity, rainfall intensity, and raindrop diameter.

Mazurak and Mosher (1968 and 1970) demonstrated that soil splash of particles and aggregates was linear with rainfall intensity. Rose (1960) conversely established soil detachment as a function of raindrop momentum and time.

Besides detaching soil mass, raindrops can compact the soil surface by direct compression. Also the surface waters, muddied by raindrop action, infiltrate into the soil profile and block soil pores. The net result is a thin compacted surface crust with slow infiltration.

Lowdermilk (1930) earlier concluded that the destruction of forest litter, which exposed the soil surface,
decreased the infiltration rate and increased runoff amounts. Suspended particles in the runoff water effectively sealed soil pores. Hendrickson (1934) also agreed thin layers of silt and clay can effectively clog pores to drastically reduce infiltration. He showed that runoff waters carrying small loads of fine sediment reduced infiltration while clear water had little effect. Free (1960) related raindrop energy to a decreasing ratio of infiltration/runoff. He contended that raindrops dissipated exposed soil aggregates thereby forming a soil crust. More recently, Morin and Benyamini (1977) have quantitatively demonstrated that the major factor determining infiltration rates on bare soils was crust formation by raindrop impact.

Ellison (1945) related surface sealing to the amount of surface splash and aggregate size distributions. Soil splash was highly correlated with infiltration rate. The amount of clay and degree of aggregation also influenced the rate of water movement into the soil profile. Soils that had poor structure and a high clay content had lower infiltration rates than soils with good structure or soils with a coarser texture. Moldenhauer and Kemp (1969) demonstrated higher initial infiltration rates with larger aggregates.

Drop diameters, zero to five millimeters in size, can cause a 25 - 35 per cent reduction in the infiltration
rate due to physical compaction and surface sealing (Levine, 1952). Although it takes longer, infiltration rates can be appreciably reduced by smaller as well as larger drops. Lyles (1969) observed that ten minutes of rainfall at 5.6 cm. per hour (larger drops) was equivalent to 90 minutes of rainfall at 1.6 cm per hour (small drops). Edwards and Larson (1969) agree that more energy in the form of raindrop impact increases resistance to water movement through the surface crust. Moldenhauer and Kemp (1969) showed infiltration rates decreased as cumulative waterdrop energy increased.

Using the available information, many researchers attempted to derive empirical relationships between rain parameters and soil loss. Ekern (1954) related the erosivity of storms to the kinetic energy of flowing water and falling raindrops. He expressed the energy of shallow water flow as a function of a storm's intensity and the slope of the landscape. On fallow plots, surface sealing would reduce infiltration until the runoff was directly proportional to the storm's intensity. The reduced infiltration by sealing could be a function of raindrop intensity and/or energy. His results related soil loss to runoff by the 1.27 power of runoff. Soil loss also correlated with the storm intensity taken to the 1.58 power.

Wischmeier and Smith (1958) derived a simple procedure
for estimating the kinetic energy of raindrops striking the soil surface from recording rain gage data. Using the work of Laws and Parsons, Gurin, and Kinzer, they developed an equation describing kinetic energy as a dependent variable of constant rainfall intensity.

$$E = 916 + 331 \log_{10} i$$

$E$ = kinetic energy of falling raindrops (foot-tons per acre)

$i$ = rain intensity (inches per hour)

Regressions were then used to obtain a predictive variable for soil loss. This variable of "maximum 30 minute rainfall x the total kinetic energy of raindrops hitting the surface" (hereafter called the E.I. variable) predicted soil loss better than rainfall amount, rainfall energy, antecedent precipitation, or various other times of maximum intensities. The estimate of the correlation coefficient for the E.I. variable was 0.892. When combined with indices of soil moisture, raindrop compaction, and rainfall energy, the regression equation explained 92.1 per cent of the variation in soil losses.

According to Wischmeier, the E.I. variable appears to explain the decreasing infiltration rate during the storm and the geometrically increasing detachment and transport effect of increasing surface flow. If the intensity of storm "A" is low but long lasting, the storm's energy value will increase giving increased soil loss. Conversely, if the intensity of storm "B" is high and short, the total energy
of the storm is proportionally low. But the high intensities of
that storm "B" will predict comparable soil losses which one
might expect for the two different storm types "A" and "B".

In 1959, Wischmeier published a rainfall erosion index
variable for an universal soil loss equation. This variable
is simply the yearly sum of individual storm EI values.
This annual value explained 72 to 96 percent of the variation
in annual soil losses on fallow, tilled plots located from
Clarinda, Iowa to Watkinsville, Georgia (Wischmeier, 1959).

Wischmeier emphasized that only average losses over an
extended period could be accurately predicted. Specific
losses from single storms or single years might vary greatly
from predicted losses due to antecedent moisture, surface
compaction by raindrops, soil crusting, wind, and variations
in ground cover.

Indiscriminate use of the EI index for other parts of the
country appear unwarranted. There has been much concern as to
how well this EI variable applies to western Oregon.

Several investigators recognized a different relation-
ship between drop diameter (and therefore kinetic energy) and rain
intensity for different types of rain (Smith and Wischmeier,
1962). Orographic rains (rains due to an air mass being forced
over a physical barrier), as are common in western Oregon, are
thought to have drops not exceeding two millimeters in diameter
or intensities greater than two cm. per hour. Such median
drop diameters might be approximately half of those occurring in nonorographic rain types of equal intensities. Unfortunately, such nonorographic rain storms are the basis for Wischmeier's rain intensity-kinetic energy equation. Intensity-parameter relationships can vary with geographic location and rain type (Kinnell, 1973). Wind, moisture conditions, and time lag for the concentration of flow can have sufficient importance to possibly make rainfall parameters alone inadequate measures for predicting soil loss.

2. Soil Characteristics and Surface Sealing

That poorly aggregated soils are more susceptible to sealing has been proposed by Ellison (1947). Stallings (1957) demonstrated that a bare soil, poorly aggregated, had more than 100 tons per acre soil splash by heavy rainfall. Logically, a less-aggregated soil will have more loose clay and silt to effectively clog up the soil pores than a well-aggregated soil of similar texture. Allison (1973) concluded that while little erosion occurs on a completely aggregated fine-textured soil, no fine-textured soil has strong enough aggregates to completely stop the release of clay particles under "raindrop bombardment."

21. Organic Matter

Most investigators agree organic matter is important for
good soil structure, although the particular compounds involved and the actual bonding mechanisms are not well understood.

Organic materials maintain coarse pores in the soil by holding soil aggregates intact to prevent filling of the pores by dispersed clay. The soil aggregates can also be somewhat stable due to the organic bonding mechanisms and the hydrophobic nature of some clay-organic complexes which prevent rapid wetting and subsequent air entrapment important for aggregate slaking (Greenland, 1965).

Several investigators have emphasized the importance of organic matter in soil aggregate formation and stability. Robinson and Page (1951), after observing a decrease in aggregation in soils treated with hydrogen peroxide, concluded organic matter associated with clay particles was an important constituent for aggregate stability. Many studies (Weldon and Hide, 1942; Wilson and Fisher, 1945, Metzger and Hide, 1938) have associated a higher organic matter level with well aggregated fractions of the soil. The importance of organic matter in soil aggregation may explain why many researchers found a positive correlation between aggregation and soil organic matter content (Paschall, et al., 1935; Rynasiewicz, 1945; Lugo-Lopez and Juarez, 1959; Jones, 1961; Chester et al., 1957). Many reports have confirmed that microbial-produced gums can bind soil particles into stable aggregates (Clapp et al., 1962; Harris et al., 1963; Martin and Richard, 1963; Martin et al.,
These repeated indications of organic matter's role in soil aggregation leave little doubt concerning the importance of organic matter on soil structure. Soil organic matter affects soil aggregation which could influence soil crust formation, water infiltration, and moisture content (Allison, 1973).

Most investigators agree polysaccarides can be important aggregating agents of the soil. Extracted polysaccarides have been shown to stabilize soil aggregates (Rennis et al., 1954; Whistler and Kirby, 1956; Mehta et al., 1960). Microbiologically-produced polysaccarides have been observed to be important aggregating agents in the soil system (Geoghegan and Brian, 1946; Martin, 1945; Haworth et al., 1946; Swaby, 1949). Many researchers have correlated estimates of polysaccaride content with degree of aggregation (Swincer et al., 1969; Allison, 1973; Harris et al., 1966).

Undoubtedly, polysaccarides are not the only organic compounds involved in stable aggregates. Martin and others (1955) suggest certain lignins, proteins, fats, oils, and waxes could increase the stability of soil aggregates by a hydrophobic reaction which would decrease rapid wetting and consequent eruption of entrapped air, thought important in aggregate breakdown.

Plausible bonding mechanisms for organic matter have been proposed by many researchers. Clapp and Emerson (1965)
recognize three types of linkages as proposed by Emerson (1963a,b). Precipitation by divalent exchangable cations, coordination with di- and trivalent cations, and hydrogen bonding can partially explain the bonding connections. Harris and others (1966) recognize these three bond types plus Van der Waals attractive forces between clays and organic matter. Greenland (1965) emphasizes the importance of polymer charge, size, and shape. All probably contribute as bonding mechanisms.

22. Mineralogy

The mineralogical components of the soil system can affect the degree of soil aggregation in several ways. Amorphous materials, flocculation-dispersion characteristics, and the zero point of charge can influence the arrangement of soil particles.

Amorphous materials, primarily aluminum and iron oxides, may induce aggregate stability (Mitchell, et al., 1964). Jones and Uehara (1973) concluded an amorphous gel-like material on crystalline particles, viscous when wet and elastic when dry, was important for aggregate bonding. Mobilizing and depositing of iron and aluminum on soil particles can affect aggregate stability (Marshall, et al., 1962). Weldon and Hide (1942) claim sesquioxides help aggregate prairie soils. The presence of hydroxides as a thin connecting layer has also been confirmed by El Swaify and Emerson (1975).
Many workers have correlated iron oxide content with aggregation (Kemper and Koch, 1966). McIntyre (1956) related "free iron oxide" content with soil porosity. Cementation of soil particles resulted from precipitation and drying of iron oxide. Amorphous iron was correlated with aggregation as determined by wet sieving (Lutz, 1936). On Hawaiian oxisols, aggregate stability is enhanced by coatings with X-ray-amorphous, poorly crystalline oxides (Uehara, et al., 1962). A Russian soil scientist Fillippovich (1956) claimed accumulation of organic matter did not improve soil structure unless accompanied by the accumulation of iron oxide. Finally, iron oxides were found important in aggregate size distributions (Chester et al., 1957).

The mechanisms which enhances aggregation through the influence of oxides can be speculated. The aluminum hydroxy materials may promote good soil structure by reducing the shrink-swell action of some clays through tight bonding of OH-Al polymers in interlayer positions and by cementing particles together by their surface positive charges (Hsu, 1977). The hydroxylated surface of iron oxides may be a cementing agent depending on its pH and characteristic zero point of charge (Schwertmann and Taylor, 1977).

Dispersion and flocculation characteristics can greatly influence aggregate durability. If the soil environment is such that dispersion of clay is encouraged, aggregate stability
is vastly decreased and surface sealing is enhanced.

Many different mechanisms have been proposed which influence the dispersion of clay. Yellow brown earths of New Zealand have hydrous oxides of iron and aluminum which must be removed before the soils will disperse (Fields, 1962). Fields observed that soils with iron oxide content above 1.5 percent and allophane content above eight percent were hard to disperse. Uehara and Jones (1974) suggest the "variable point of charge" of the amorphous coatings is important for flocculation. They propose that positive surfaces on amorphous material are attracted to the negatively-charged crystalline surfaces. The pH of the system would influence the type and amount of charge on the variable charge surfaces. The different clay minerals can exhibit different dispersion-flocculation characteristics with different cations and concentrations saturating the cation exchange sites. The monovalent cations and dilute electrolyte solutions favor dispersion while divalent cations and concentrated electrolyte solutions promote flocculation (van Olphen, 1963).

23. Cultivation

Early cultivation theories promoted extensive tilling of the soil due to observed increased crop yields. Today, much cultivation is known to be detrimental to the long term maintenance of soil structure and consequently can increase
the soil's erosion hazard (Harris et al., 1966). From the Chehalem Mountain Demonstration Project, Mahness and Sandoz (1941) stated erosion in western Oregon is closely connected with cultivation of land on steep slopes. Others showed that cultivation could decrease aggregate stability (Beacher and Strickling, 1955) which then left the surface more susceptible to surface sealing by raindrop impact. Tillage operations can mechanically disrupt soil aggregates (Allison, 1973), compact the soil surface (Neal, 1953), and accelerate the decomposition of organic matter (Allison, 1973). The compaction alone can seriously deteriorate the soil structure especially on a clay or loam soil (Parker and Jenny, 1945).

The fact that cultivation, in the short term, increases crop yields is said to result from the release of nutrients from decomposing organic matter. Much of this organic material comes from humic materials that bind soil aggregates (Allison, 1973). Continued cultivation leads to a lower organic matter content and a lower state of soil structure (Harris et al., 1966; Allison, 1973), especially where little residue is returned to the soil.
III. MATERIALS AND METHODS

1. Soils

The soils at the three field sites (table one) chosen for examination are all classified as belonging to the Jory series (Xeric haplohumult). Two of the sites are utilized as Christmas tree plantations, but have been managed differently. Site A, located just south of Monroe, Oregon, has been extensively subsoiled (to 35 cm. depth) and rototilled for three consecutive years. This site has supported Christmas tree culture since 1965 when it was converted from a hill pasture. Christmas trees have grown at site C, located five miles southwest of Philomath, Oregon, since conversion from abandoned pasture in spring, 1976. Extensive soil working has not occurred on site C, except in planting preparation. A control site, site B, is located next to site A and is supporting a second growth forest. Its soil has not been cultivated and has not been exposed to raindrop impact in the recent past. In appendix one, a detailed soil profile description of each site is presented.

2. Methods

21. Soil Organic Matter

With the considerable evidence supporting the important
Table 1: Site Characteristics

<table>
<thead>
<tr>
<th>Site</th>
<th>Land Use</th>
<th>Vegetation</th>
<th>Slope</th>
<th>Aspect</th>
<th>Soil Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Christmas Tree</td>
<td>Douglas Fir and True Fir</td>
<td>19%</td>
<td>N</td>
<td>Xeric</td>
</tr>
<tr>
<td></td>
<td>Plantation</td>
<td></td>
<td></td>
<td></td>
<td>Haplohumult</td>
</tr>
<tr>
<td>B</td>
<td>Wood Lot</td>
<td>Douglas Fir, Poison Oak, and Fern</td>
<td>18%</td>
<td>NW</td>
<td>Xeric</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Haplohumult</td>
</tr>
<tr>
<td>C</td>
<td>Christmas Tree</td>
<td>Douglas Fir and Grasses</td>
<td>25%</td>
<td>S</td>
<td>Xeric</td>
</tr>
<tr>
<td></td>
<td>Plantation</td>
<td></td>
<td></td>
<td></td>
<td>Haplohumult</td>
</tr>
</tbody>
</table>

role of organic matter in soil aggregation, the total organic matter content of all three sites could quickly indicate some possible explanations of differences between sites and their responses to rainfall.

The organic matter contents of the bulk soil and several aggregate fractions from the three sites were obtained using the Walkley-Black titration method (Walkley and Black, 1934). Oxidation of organic matter by potassium dichromate in sulfuric acid is quantified by titrating the unconsumed potassium dichromate with ferrous ammonium sulfate. This method, also used by the O.S.U. soil testing lab, assumes the organic fraction is 58 per cent carbon with 76 per cent of the carbon actually being oxidized. The organic matter content of the different aggregate fractions (obtained by wet sieving) could indicate the importance of organic matter in soil
aggregation on these three sites. If the aggregated material had a higher carbon content than the less aggregated material, this fact would support the role of organic matter in aggregation.

Using Clapp and Emerson's (1965) approach, an attempt was made to assess the binding strength of wet crumbs from all three soils. Various methods of oxidation and extraction were used to qualitatively assess the importance of organic matter constituents thought instrumental in aggregate bonding. First, all crumbs were treated with 0.05 M sodium chloride, applied under vacuum, for 24 hours. Then systematic treatments of 0.05 sodium periodate, 0.01 M sodium pyrophosphate, 0.025 M sodium borate, and 0.01 M sodium paranitrophenol/sodium chloride solutions were applied and subjective observations on differences in the slaking and dispersion of aggregates in the respective solutions were made. The periodate-borate treatment attacks and removes polysaccharides. The pyrophosphate treatment complexes organic polymers coordinated with polyvalent cations and clays. The sodium para-nitrophenol, a dispersing agent, applies stress to the crumbs and also serves as a buffering agent. Russell (1973) states that the pyrophosphate solution also removes iron, aluminum, and calcium ions which can be active in structure stabilization. Interpretation of the results, then, are somewhat uncertain, but relative comparisons between the soils can be discussed.
22. Mineralogy

To categorize the mineralogy and the amorphous materials of the soils at each site, X-ray diffraction patterns, dithionite and oxalate extractions, and electron micrographs were examined.

Calcium and potassium saturated samples of the clay fraction from each soil were applied on petrographic slides using the technique of Theisen and Harward (1962). One of the calcium saturated samples was equilibrated at 54 percent relative humidity while other slides were solvated with either glycerol (Brown and Farrow, 1956) or ethylene glycol (Kunze, 1955). All calcium saturated samples were bathed in a 54 percent relative humidity atmosphere while their diffraction patterns were recorded. The potassium saturated slides had four sequential treatments consisting of: heating at 105°C. and analysing in dry air; no heating and analysing at 54 percent relative humidity; heating at 300°C. and analysing in dry air; and heating at 500°C. and analysing in dry air. A Phillips Norelco X-ray diffractometer with copper Kα radiation was used to analyse all slides.

Many different techniques of quantifying the aluminum and iron components of amorphous and crystalline portions of the soil system exist. A relatively simple and accepted technique was chosen that yields relative comparisons between
soil samples.

The oxalate extraction corresponds to a mild treatment yielding aluminum and iron mostly from the amorphous component (McKeague and Day, 1966). Ten milliliters of acidified ammonium oxalate (pH 3.0) were added to duplicate 0.1 g. soil samples (0-3 cm.) contained in cylinders. The cylinders were mixed by a horizontal reciprocating shaker for sixteen hours in darkness. After centrifuging to deposit clay-sized material, an aliquot of the supernatant was analysed for aluminum and iron using a Perkins Elmer 306 Atomic Absorption Spectrophotometer.

The dithionite citrate extraction technique is a stronger treatment than the oxalate extraction (McKeague and Day, 1966). Duplicate soil samples (three to four grams), 40 milliliters of 0.3 M. sodium citrate, and five milliliters of 1.0 M. sodium bicarbonate solution are equilibrated at 80 C. One adds ten milliliters of saturated sodium chloride solution and ten milliliters of acetone to promote clay flocculation. The clear supernatant is then obtained for analysis by centrifuging the mixture at 2200 rpm (4,500 G.) for five minutes. Again, the Perkins Elmer 306 Atomic Absorption Spectrophotometer was used to analyse for iron and aluminum.

Samples for X-ray fluorescence were prepared (courtesy of Mr. Reed Glasmann) by grinding approximately 20 grams of soil with a glazed diamonite mortar and pestle until all material passed through a standard sieve #230. The powdered
soil samples were pressed into pellets by using a Carver hydraulic press and steel mold to apply 22,000 p.s.i. pressure. The samples were analysed for iron with a X-ray spectograph (chromium target, pulse height analyser, flow proportional counter, scintillation counter, and a lithium fluoride crystal). An U. S. G. S. BCR-1 (Columbia River basalt) standard was used to compare results with the soil samples. All fluorescence work was analysed with a window width of 15.0 volts and a base level of 1.5 volts.

A Phillips Electron Microscope (transmission) was used to make electron micrographs of the clay fraction from each of the three sites. A syringe was used to apply a drop of a 0.1 percent clay solution on a TEM copper grid coated with Formvar and reinforced with a carbon film. The microscope was operated within a 60-80 KV and 15-20 ampere range.

23. Physical Characteristics of the Soil

For soil texture, U. S. D. A. particle size boundaries were used (sand 0.05 to 2.0 mm., silt 0.002 to 0.05 mm., and clay 0.002 mm.). Pipetting of the clay and silt fraction plus sieving of the sand fraction determined the particle size distribution. The procedure has been described elsewhere (Day, 1965).

Two methods of determining bulk density (clod technique
and soil core technique) helped evaluate the degree of compaction and gave an indication of soil porosity. In the clod technique, an air-dried clod is coated with paraffin, weighed in air, and then reweighed submerged in water. By Archimedes principle (an article submerged in water is lighter than its weight in air by the weight of an equivalent volume of water displaced), the bulk density of the clod is calculated. For the second method, a soil core of known volume is obtained and the bulk density then equals the oven dried weight of the soil core divided by the volume of the soil core.

To assess hydrologic differences between sites, the hydraulic conductivities of samples from the surface horizon were determined. A constant column of water over a soil core of known dimensions was used to calculate the saturated hydraulic conductivity with the equation $Q/A = k'w$ ($Q =$ flow of water per unit time, $A =$ cross sectional area of the soil core, $k =$ soil hydraulic conductivity, and $w =$ hydraulic gradient, Hillel, 1971). This method can only estimate the saturated hydraulic conductivity because the field hydraulic conductivity may vary greatly from the experimental values (Hammermeister, 1978).

A Yoder-type wet sieving machine, with 31 strokes per minute and 6.25 cm. per stroke, yielded information on the water-stable aggregate-size distributions for each soil.
Six 50 gram soil samples were wet by capillary action under atmospheric pressure and wet sieved through a network of four sieves for ten minutes. The sieve sizes were 4.7 mm., 2.0 mm., 1.0 mm., and 0.25 mm. After the ten minutes, the aggregate fractions found on each sieve were oven dried and then weighed. Using Gardner's technique (1956), one obtained the geometric mean diameter of each soil by plotting the percent by weight of aggregates larger than the particular sieve size versus the sieve size on logarithmic probability paper. The geometric mean diameter was used to compared the aggregate sizes at the different sites.

Attempts to evaluate aggregate stabilities are qualitative due to a general lack of understanding about the mechanisms important in soil aggregate bonding. Water drops with a 0.036 milliliter volume fell 29.2 cm. at a rate of 30 drops per minute onto a soil aggregate (McCalla, 1944). The number of drops until the two to four millimeter aggregates broke and until the entire aggregate passed through a one millimeter sieve were recorded. If an aggregate withstood 100 drops before breaking, it was arbitrarily regarded as 100 percent stable. When less than 100 drops broke down the aggregate, the stability index was adjusted accordingly.

24. Isolation of Raindrop Impact

The importance of raindrop impact on soil loss, soil crust
formation, and soil infiltration was isolated by paired screened and unscreened erosion plots. These plots were one meter square in area and were located side by side on both sites A and C. The screened plots had two window screens (one millimeter openings), one above the other, suspended approximately 2.5 cm. above the soil surface. A trough and connecting basin caught the runoff and sediment from each plot which were collected after each erosion event. The screen, like that used by Meyer, Foster, and Romkins (1975), intercepted raindrop impact while allowing water to flow unimpeded over the soil surface. All plots were devoid of any protecting vegetation.

After an arbitrary amount of rain had fallen on the plots during the rainy season, air permeameter readings, infiltrometer readings, and thin sections of the crust were taken. Photographic observations of the soil surface were also made. The permeameter readings, taken with an air permeameter were simply back pressure readings. A open cylinder, three cm. in diameter, contained 1.02 atmospheres constant pressure of nitrogen gas when the opening was completely blocked. When the cylinder was placed vertically into the soil surface, the gage recorded the back air pressure, which was a function of the soil porosity, pore size distribution, and moisture content. A soil that had lower porosity, more resistance to flow,
and comparable moisture content would have a higher back-pressure reading than a soil with a higher porosity and less resistance to flow. This technique was only used for relative comparisons between the screened and unscreened plots on one site at a time.

When sufficient rain had fallen on the plots, vertical thin sections of the surface crust were taken (courtesy of Mr. Reed Glasmann). After portions of the crust had been randomly selected, they were impregnated with Laminac resin (diluted with monomeric styrene for adequate penetration) for thin sectioning. The impregnation method required oven-drying the samples for 24 hours and applying the resin to the samples under a vacuum. When the vacuum was slowly released, the atmospheric pressure forced the resin into the porous media (Buol and Fadness, 1961). The impregnated sample was hardened in an oven for 12 hours at 100 C. A diamond saw then sliced the rough thin sections which were subsequently ground and mounted by conventional techniques.

The infiltration determination used an infiltrometer similar to the one described by Meewig (1971). The rain simulator was a plastic tank 61 cm. square with 242 evenly distributed needles in the bottom of the tank. The needles produced an average drop size of 2.9 mm. Rain intensities could be varied by changing the hydraulic head on the system. The intensity may vary under different parts of the applicator,
but this problem was minimized if the instrument was properly leveled (Froehlich and Hess, 1976).

Large erosion plots, used to estimate runoff quantity and gross soil loss, were five meters long and two meters wide. The plot design enabled suspended sediment to be collected in a tub via a proportional splitter while heavier transported sediment was collected in a covered trough at the base of the plot. (The plot design was from the STEEP project coordinated by Dr. Moyle Harward at the Soil Science Department, O. S. U.)

Beside each large erosion, a set of piezometers were installed (Hammermeister, 1978) to monitor saturated water conditions in the soil profile. At each site, each piezometer was placed to a depth corresponding to a soil horizon. At site A, the four depths were 12 cm., 31 cm., 74 cm., and 130 cm. Corresponding piezometer placement depths at site B were 12 cm. and 28 cm. At site C, the piezometers were placed at 15 cm., 35 cm., 75 cm., and 135 cm. below the soil surface.

26. Rain Parameters

Three instruments were used to estimate rain parameters for predicting soil loss and for comparisons with rainfall in other areas.

A Meteorology Research, Inc. recording precipitation
gage (tipping bucket mechanism) registered rainfall intensities and amounts. Using Wischmeier's relationship between rainfall intensity and kinetic energy (Wischmeier, 1958), one can then estimate the kinetic energy of raindrops striking the soil surface. A simple wedge rain gage was obtained to check the tipping bucket gage and to ensure reliable collection of rainfall data.

To directly obtain rain drop size distributions, ozalid paper was exposed to various short intervals of rainfall. The ozalid paper, being sensitive to water, was developed with ammonia gas to enable one to measure the rain splash circles. Dr. McCool of U.S.D.A.-A.R.S. (Pullman, Washington) correlated the splash circle sizes with the equivalent sphere raindrop sizes ($r^2 = 0.95$). Once the drop sizes were obtained, the median drop diameter, rain intensity, kinetic energy, and momentum of the raindrops for an individual sample could be accurately calculated. Many samples were collected and then statistically tested to see if Wischmeier's rainfall intensity to kinetic energy relationship is valid for rainfall in western Oregon.

27. Erosion Prediction

If the universal soil loss equation, in its present form, can be applied to western Oregon and the $K$, $S$, $C$, and $P$ factors are constant, then the EI values should explain the major
variation in soil loss from the erosion plots. To test this hypothesis and to test other rainfall parameters as soil loss predictive variables, best-fit linear regressions of observed rainfall statistics versus observed soil loss from both the unscreened smaller plots and the larger erosion plots were calculated and $r^2$ values compared.
IV. RESULTS

1. **Organic Matter Fraction of the Soils**

The ranking of the soils' organic matter content is predictable (figure one). The forest, site B, has the highest organic matter content (6.5%) possibly due to the high biomass production and no cultivation. The cultivated sites A and C have lower organic matter contents with site A having the lowest content between the two. Since site A has been extensively cultivated and has supported Christmas tree culture for the longer time, one would expect its organic matter content to be lowest. Whether Christmas tree culture without extensive cultivation will decrease the organic matter content over time cannot be concluded from this data, but one would speculate a decrease would occur due to lower biomass production and accelerated oxidation.

The organic matter content of the five aggregate-size classes used in the wet sieving technique follows a pattern for all three sites. On each site, the aggregate fraction less than 0.25 mm. always had a lower organic matter content than the aggregate fractions greater than 0.25 mm. (figure two). This circumstantial evidence supports the importance of organic matter in aggregate bonding with soil crumbs greater than 0.25 mm. The fraction of the soil less than 0.25 mm. probably contains many elemental sand-size particles which
Figure 1: Organic Matter Content at Sites A, B, and C

Percent Organic Matter

A B C

4
3
2
1

Figure 2: Organic Matter Content of Aggregate Soil Fractions

Aggregate Diameters

1: 44.7 mm.
2: 2.0 to 4.7 mm.
3: 1.0 to 2.0 mm.
4: .25 to 1.0 mm.
5: < 0.25 mm.
would have little organic matter associated with it.

The qualitative results of the periodate oxidation studies (table two) indicate several items. Considering only the two compound treatments, the only treatment to initiate aggregate slaking on all three sites was the periodate extract (0.01 M NaIO₄). This would indicate that polysaccharides were important for aggregate strength on all these sites. The salt solution alone produced some slaking on site A, indicating weak aggregate bonding possibly due to divalent exchangeable cations while the other two sites (B and C) possessed other stronger bonding mechanisms to keep the crumb stable. The two cultivated sites A and C had their aggregates slaking when exposed to the pyrophosphate solution, possibly emphasizing the role of true humic colloids in aggregate stabilization.

The periodate borate treatment initiated more slaking and dispersion on all three sites, which can be interpreted as the periodate solution opening the polysaccharide rings while the borate solution takes out the polyadhyde chains (Clapp and Emerson, 1965). The same solution, with the dispersing agent (NaCl/p-nitrophenol) added, produced more slaking and dispersion on the cultivated sites while the forest soil aggregates remained the same. The forest soil could successfully resist further stress (the dispersing solution) due to some unknown mechanism the two cultivated sites did not possess. The forest site, being undisturbed for


Table 2: Periodate Oxidation Studies

<table>
<thead>
<tr>
<th>Site</th>
<th>p*</th>
<th>A</th>
<th>A+B</th>
<th>A+P</th>
<th>A+I</th>
<th>A+I+B</th>
<th>A+I+B+p</th>
<th>A+P+I+p</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>S</td>
<td>D**</td>
<td>S</td>
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<td>A</td>
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<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>4</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

* p = 0.01 M Na p-nitrophenol/NaCl
A = 0.05 M NaCl
B = 0.025 M NaB<sub>4</sub>O<sub>7</sub>
P = 0.01 M NaP<sub>2</sub>O<sub>7</sub>
I = 0.05 M NaIO<sub>4</sub>

** First number (S) indicates relative slaking (0 - no slaking; 4 - complete slaking). Second number (D) indicates relative dispersion (0 - no dispersion; 4 - complete dispersion).
long periods of time, possibly has the mechanism of more organisms to slowly mix humic material plus has ample production of organic matter from many sources especially when compared to the monoculture of a Christmas tree plantation.

2. Mineralogical Fraction of the Soils

The X-ray diffractograms show similar mineral components for both sites A and C. A strong seven Å peak denotes a kaolin like mineral common to both sites (and to the Jory Soil Series in general) which then disappears at the 500°C treatment. Both sites have a small ten Å peak which could be interpreted as a mica-like mineral. Both A and C exhibit poor organization and crystallinity of 2:1 components (14-16 Å), but these components in C were less well-organized than in A.

The dithionite and oxalate extractions show only two obvious differences between the sites. Site C had approximately twice as much iron extracted as site A or B for both the dithionite and oxalate treatments (Table 3).

The interpretation of the iron content is somewhat confusing. Obviously, more oxalate extractable iron was in the soil at site C compared to the other sites. However, the role of amorphous iron in soil aggregation is not well understood. According to Spycher (1977), the Jory soil probably does not have continuous films of iron hydroxide in the subsurface layers. From this indication alone, the form
Figure 3: X-ray Diffraction Patterns from Clay-Sized Material at Site A

- K 500°C
- K 300°C
- K dry
- K 54% RH
- Ca-Glycerol
- Ca-Ethylene Glycol
- Ca 54% RH

$d(A)$

7 10 14
Figure 4: X-ray Diffraction Patterns from Clay-Sized Material at Site C

K 500 °C.
K 300°C.
K dry
K 54% RH
Ca-Glycerol
Ca-Ethylene Glycol
Ca 54% RH

d(A) 7 10 14
of iron in the surface layer can only be speculated. Perhaps the larger iron concentration does indicate more amorphous iron-rich connective gels whose soil aggregation role is somewhat obscure.

Table 3: Fe and Al Contents of Sites A, B, and C

<table>
<thead>
<tr>
<th>Site</th>
<th>Oxalate Extraction</th>
<th>Dithionite Extraction</th>
<th>Total Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fe (%)</td>
<td>Al (%)</td>
<td>Fe (%)</td>
</tr>
<tr>
<td>A</td>
<td>1.8</td>
<td>0.35</td>
<td>8.6</td>
</tr>
<tr>
<td>B</td>
<td>1.7</td>
<td>0.39</td>
<td>6.8</td>
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<tr>
<td>C</td>
<td>3.2</td>
<td>0.34</td>
<td>13.6</td>
</tr>
</tbody>
</table>

The crystalline iron content (dithionite Fe extraction minus the oxalate Fe extraction) and total iron content are also found in higher concentrations in samples from site C compared to site A. This is probably a result of different parent materials at sites C and A.

Electron micrographs of the clay-size fraction from site A (figures five and six) reveal relatively clean mineral surfaces compared to the cloudy coatings present on the soil from site C (figures eight and nine) and to some extent on soil from site B (figure seven). This coating could be an amorphous gel as reported by Jones and Uehara (1973). The coatings found at site C (figures eight and nine) could be poorly crystalline
ferrihydrate possibly accounting for the high iron content in the oxalate extract for site C. Closer examination of the micrographs of sites A and B reveal a similar though less electron dense coating than that on site C.

Hexagonal crystals suggesting kaolin type clays (figures five and seven) confirm the seven Å peaks from the X-ray diffractograms of sites A and B. On site C, small circular globules (0.2 to 0.3 micrometers in diameter) are the same size and shape as spherical halloysite as described by Mckee and Brown (1977). Electron diffraction patterns reveal some crystalline components (figure 9) in the spheres. The 7.31 Å peak (Ca - 54 percent relative humidity) for site C also suggests halloysite compared to the 7.24 Å peak for site A.

3. Physical Characteristics of the Soils

The surface soil textures for all three sites are either a clay loam or a silty clay. The surface texture of site A, when compared to site C, has less clay, though in adequate amounts to form many clay-organic matter bonds important in maintaining strong soil structure. Conversely, if site C did not possess or maintain a well-structured characteristic, it would be more impermeable to water than site A due to the high clay content. Site B's surface soil texture is very similar to site A (Table four).

Site A has a higher bulk density in the surface horizon (which is probably a result of compaction from the rototilling
Figure 5: Particles from Clay-Sized Material at Site A

View 1

View 2
Figure 6: Particles of Clay-Sized Fraction From Site B

Figure 7: Coatings on Clay-Sized Fraction From Site C
Figure 8: Cloudy Material (Possibly Ferrihydrate) Mixed with Possible Halloysite from Site C

Figure 9: Electron Diffraction Pattern and Possible Halloysite from Site C
and subsoiling machinery) than either site B or site C (table five). Compaction would likely make the largest pores smaller, thereby decreasing the soil conductivity very rapidly (Hillel, 1971). The soil at site B has relatively more interclod pore space than A or C as indicated by the low bulk density obtained with the core technique. Probably these interclod pores are relatively large which then could conduct water at saturation very rapidly (which one would expect for a forested Jory soil).

Table 4: Soil Texture at all Three Sites (0-6 cm.)

<table>
<thead>
<tr>
<th>Site</th>
<th>Texture</th>
<th>% Clay</th>
<th>% Silt</th>
<th>% Sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td>31</td>
<td>31</td>
<td>38</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td>30</td>
<td>29</td>
<td>41</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td>42</td>
<td>41</td>
<td>17</td>
</tr>
</tbody>
</table>

Table 5: Bulk Density of the Surface Horizons (0-6 cm.)

<table>
<thead>
<tr>
<th>Site</th>
<th>Paraffin Clod Technique (g./cm³)</th>
<th>Core Technique (g./cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1.68</td>
<td>1.29</td>
</tr>
<tr>
<td>B</td>
<td>1.50</td>
<td>1.05</td>
</tr>
<tr>
<td>C</td>
<td>1.44</td>
<td>1.18</td>
</tr>
</tbody>
</table>
A high saturated hydraulic conductivity is dependent on the larger pores for fast water transmission. One can conclude that soil from site B has a larger volume of macropore space than either site A or C (table six). This agrees with the bulk density discussion. The differences between the hydraulic conductivities of sites A and C are less obvious. The samples from the rototilled and subsoiled plots at site A display a much lower saturated hydraulic conductivity which probably results from deteriorated soil structure and compaction. Otherwise, sites A and C do not differ greatly in their relative hydraulic conductivity values.

Table 6: Hydraulic Conductivities of Surface Horizons (0-6 cm.)

<table>
<thead>
<tr>
<th>Site</th>
<th>Saturated Conductivity (cm./hr.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (not rototilled and subsoiled)</td>
<td>4.1</td>
</tr>
<tr>
<td>A (rototilled and subsoiled)</td>
<td>0.6</td>
</tr>
<tr>
<td>B</td>
<td>49.1</td>
</tr>
<tr>
<td>C</td>
<td>3.4</td>
</tr>
</tbody>
</table>

In a heavy textured soil, a relatively high hydraulic conductivity could result from a stable soil structure in the form of water-stable aggregates. The wet-sieved aggregate distributions from these three soils (figure ten) demonstrate
the soil with the highest conductivity (site B) and highest organic matter content also possesses more and larger water-stable aggregates. Such is reasonable because this site has never been cultivated and thus maintains a relatively strong structure.

More stable aggregates should withstand raindrop impact and forces due to wetting better than unstable aggregates. Aggregates from site B did withstand drop bombardment longer than soil from site A or C (table seven). Aggregates from site A were less stable than those from site C. One would expect site A to have more runoff and, as a result, more erosion due to crust formation from raindrop impact than site C if aggregate stability plays an important role in resisting crust formation. The aggregate stability data follows the same trend as the organic matter content. The site with the lowest aggregate stability index also has the lowest organic matter content (site A). The more stable aggregates from site B have the highest organic matter content.

Table 7: Aggregate Stability by Drop Technique

<table>
<thead>
<tr>
<th>Site</th>
<th>Initial Aggregate Breakup (number of drops)</th>
<th>Aggregates Passing Through 1 mm. sieve (number of drops)</th>
<th>O. M. Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>26*</td>
<td>45</td>
<td>2.7</td>
</tr>
<tr>
<td>B</td>
<td>64</td>
<td>97</td>
<td>6.5</td>
</tr>
<tr>
<td>C</td>
<td>34</td>
<td>85</td>
<td>4.3</td>
</tr>
</tbody>
</table>

*All figures are the average of 100 trials.
Figure 10: Wet-Sieving Aggregate Size Distributions**

<table>
<thead>
<tr>
<th>Site</th>
<th>Geometric Mean Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>A*</td>
<td>1.05 mm.</td>
</tr>
<tr>
<td>A</td>
<td>1.3 mm.</td>
</tr>
<tr>
<td>B</td>
<td>14.5 mm.</td>
</tr>
<tr>
<td>C</td>
<td>1.4 mm.</td>
</tr>
</tbody>
</table>

*rototilled and subsoiled
** average of six replications

% by weight of aggregates not passing through "y" mm. sieve size
4. **Isolation of Raindrop Effects**

The unprotected (unscreened) plot exposed to raindrop impact always had more than twice as much soil loss as the paired plot protected from raindrop impact by the two suspended screens (table eight). Because the main difference between the paired plots is the reduction of raindrop impact, this data strongly supports the importance of raindrop impact in the erosion process at both sites A and C. Refer to the erosion prediction results for regressions of rain parameters versus the soil loss from the unprotected plots (pp. 71-73).

The existence of soil pedestals (figure 11) on exposed soil surfaces at sites A and C also suggest the importance of raindrop impact. These pedestals exist solely because some cover (twigs, stones, etc.) protected the underlying soil from falling raindrops. The unprotected soil surrounding the pedestals was actively being eroded, compacted, and splashed by raindrops. If the surrounding soil in the area of the soil pedestal (figure ten) was eroded away, it would be equivalent to a soil loss of 80 metric tons per hectare.

The air permeameter data from site C (table nine) also illustrate differences between the screened and unscreened plots. Clearly, the soil surface of the unscreened plot had less porosity than that of the protected plot's surface.

Raindrops decreased the porosity of an exposed soil surface by formation of a soil crust. The thin sections of
Table 8: Effect of Raindrop Impact on Soil Loss

<table>
<thead>
<tr>
<th>Site A*</th>
<th>Site C*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td>Rain Collected (cm.)</td>
</tr>
<tr>
<td></td>
<td>Screened</td>
</tr>
<tr>
<td>10/23/77</td>
<td>0.7</td>
</tr>
<tr>
<td>10/27/77</td>
<td>1.2</td>
</tr>
<tr>
<td>10/31/77</td>
<td>3.2</td>
</tr>
<tr>
<td>11/04/77</td>
<td>1.2</td>
</tr>
<tr>
<td>11/10/77</td>
<td>1.3</td>
</tr>
<tr>
<td>11/17/77</td>
<td>1.8</td>
</tr>
<tr>
<td>11/25/77</td>
<td>13.1</td>
</tr>
<tr>
<td>11/28/77</td>
<td>2.6</td>
</tr>
<tr>
<td>12/05/77</td>
<td>5.1</td>
</tr>
<tr>
<td>12/09/77</td>
<td>2.0</td>
</tr>
<tr>
<td>12/16/77</td>
<td>22.6</td>
</tr>
</tbody>
</table>

* The soil losses are less from the screened plots on both sites at the 0.1 level of probability.
Figure 11: Soil Pedestal at Site A
Table 9: Permeameter Readings at Site C*
After 49.5 cm. of Rainfall

<table>
<thead>
<tr>
<th>Screened Plot</th>
<th>Unscreened Plot</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \overline{x} = 2.55 \text{ lb/in}^2 )</td>
<td>( \overline{x} = 5.67 \text{ lb/in}^2 )</td>
</tr>
<tr>
<td>(.17 atm.)</td>
<td>(.39 atm.)</td>
</tr>
<tr>
<td>( s = 0.51 )</td>
<td>( s = 0.63 )</td>
</tr>
<tr>
<td>( n = 6 )</td>
<td>( n = 6 )</td>
</tr>
</tbody>
</table>

*Statistically different at 0.025 level of probability

the soil crust (figures 12 and 13) and photographs of the surfaces (figures 14 and 15) at site C support the raindrop theory. The occurrence of crust formation on the unprotected plot at site C after 49.5 cm. of rainfall is indicated by a compacted smooth surface layer of particles with little visible porosity. The paired protected plot (figure 13) exhibits a rough, porous surface. One can see from photographs of the soil surface (figures 14 and 15) that the protected surface has more aggregation compared to the surface of the unscreened plot.

The infiltration rates of the paired plots at site C also support the air permeameter data. Raindrop impact commonly reduces the porosity, as discussed earlier, and thereby reduces infiltration rates. The measured runoff from two December storms (table ten) and subsequent infiltration measurements (figure 16) reflect effects of raindrop compaction and surface
Figure 12: Thin Section of Surface Exposed to Raindrop Impact (After 54 cm. Rain)

Figure 13: Thin Section of Surface Protected from Raindrop Impact (After 54 cm. Rain)
Figure 14: Unprotected Soil Surface at Site C After 27 cm. Rain

Figure 15: Protected Soil Surface at Site C After 27 cm. Rain
sealing. The runoff from the unscreened plot during the 6.4 cm. rainstorm (Dec. 15 - Dec. 16, 1977) was twice as much as that from the screened protected plot. The measured infiltration capacity for the unscreened plot was approximately 4.5 cm./hr. while the protected plot had a higher capacity of 5.8 cm./hr. (figure 16).

Table 10: Effect of Raindrop Impact on Runoff and Sediment at Site C

<table>
<thead>
<tr>
<th>Storm and Rain</th>
<th>Protected Plot</th>
<th>Unprotected Plot</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Runoff (liters)</td>
<td>Soil Loss (g./m.²)</td>
</tr>
<tr>
<td>Dec. 7-14, 1977</td>
<td>14 cm. rain (140 liters)</td>
<td>45</td>
</tr>
<tr>
<td>Dec. 15-16, 1977</td>
<td>6.4 cm. rain (64 liters)</td>
<td>22</td>
</tr>
</tbody>
</table>

The permeameter readings at site A (table 11) illustrate a compounding factor of management affecting the porosity of the soil. The screened plot was on a subsoiled and rototilled site while the adjacent unprotected plot had not been subsoiled and rototilled. The recorded permeability value, after 67.4 cm. of rainfall, for the screened plot was 0.64 atm. The rototilled and subsoiled surface, even though protected from raindrop impact, had higher permeameter readings
Figure 16: Infiltration Curves for Plots at Site C

- Screened Plot
- Unscreened Plot

$i = 6.6 e^{-2.6 \times 10^{-3} t}$  
$r^2 = 0.77$

$i = 6.2 e^{-7.0 \times 10^{-3}}$  
$r^2 = 0.81$
indicating a lower porosity than the unprotected plot. The higher permeameter values for the screened plot are interpreted as due to the intense cultivation.

Table 11: Permeameter Readings on Site A*

<table>
<thead>
<tr>
<th>Screened, Rototilled, and Subsoiled Plot</th>
<th>Not Screened, Not Rototilled, and Not Subsoiled Plot</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \bar{x} = 9.43 \text{ lb./in.}^2 )</td>
<td>( \bar{x} = 3.07 \text{ lb./in.}^2 )</td>
</tr>
<tr>
<td>( (0.64 \text{ atm.}) )</td>
<td>( (0.19 \text{ atm.}) )</td>
</tr>
<tr>
<td>( s = 1.99 )</td>
<td>( s = 1.24 )</td>
</tr>
<tr>
<td>( n = 7 )</td>
<td>( n = 7 )</td>
</tr>
</tbody>
</table>

*Statistically different populations at the 0.025 level of probability.

This effect of management could decrease the infiltration rate. Indeed, the measurements of infiltration demonstrate a lower infiltration rate on the rototilled and subsoiled plot compared to the unprotected, unrototilled, and unsubsoiled plot with final infiltration capacities of 2.0 cm./hr. and 5.0 cm./hr. respectively (Figure 17).

5. Erosion Prediction

Site B, the forested erosion plot, had no soil loss from overland flow (table 12), emphasizing the importance of cover (litter layer) and high infiltration capacities in preventing
Figure 17: Infiltration Curves for Plots at Site A

- Not screened, not Rototilled, and not Subsoiled
- Screened, Rototilled, and Subsoiled

\[ i = 6.3 \times 10^{-3} e^{-5.0 \times 10^{-3} t} \]
\[ r^2 = 0.88 \]

\[ i = 4.0 \times 10^{-2} e^{-1.8 \times 10^{-2} t} \]
\[ r^2 = 0.76 \]
soil loss. It had very little runoff compared to the cultivated plots (tables 13 and 14). For example, when 22.6 cm. of rain fell on the ten-meter-square erosion plots at sites A and B for the period December 9-16, 1977, the forested plot at site B had only 27 liters of runoff (one percent runoff) and no soil soil; the Christmas tree plot on site A had over 623 liters of runoff (over 28 percent runoff) and 3.3 kilograms of soil loss. The forested site's high aggregate stability, high porosity, and protection from raindrop impact by the litter layer sustained a high infiltration capacity.

From the limited data obtained in the 1976-77 rain season, the rainfall parameters $EI_{30 \text{ min.}}$ and $EI_6 \text{ hr.}$ explained the greatest percent variation (figures 19 and 20) in soil losses collected from the large plot at site A. Kinetic energy of falling raindrops (obtained from relation of Wischmeier and Smith, 1958) explained little variation (figure 18). The data points were few due to a record drought; thus caution should be exercised in using only this data.

The 1977-78 rain season provided many more data points because of the addition of site C's large erosion plot, the small erosion plots, and the return of more "normal" climatic conditions. The $EI_{30 \text{ min.}}$, $EI_6 \text{ hr.}$, and kinetic energy of falling raindrops variables adequately predicted the soil losses from the large plots at sites A and C (figures 21, 22, and 23). Note that the
Table 12: Rain Amounts and Plot Data at Site B

<table>
<thead>
<tr>
<th>Date</th>
<th>Rainfall Amount (cm.)</th>
<th>Sediment Yield (metric tons/hectare)</th>
<th>Runoff (liters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/31/77</td>
<td>8.1 (810)</td>
<td>0</td>
<td>2.2</td>
</tr>
<tr>
<td>11/25/77</td>
<td>46.0 (4600)</td>
<td>0</td>
<td>10.0</td>
</tr>
<tr>
<td>12/16/77</td>
<td>57.7 (5770)</td>
<td>0</td>
<td>6.0</td>
</tr>
<tr>
<td>12/27/77</td>
<td>10.7 (1070)</td>
<td>0</td>
<td>2.0</td>
</tr>
</tbody>
</table>
Table 13: Rain Parameters and Plot (2x5 m) Data at Site A from Sept., 1977 to Jan., 1978

<table>
<thead>
<tr>
<th>Date</th>
<th>Amount (cm)</th>
<th>Max. 30 min. Intensity (cm)</th>
<th>Max. 6 hr. Intensity (cm)</th>
<th>&quot;Kinetic* Energy&quot; (joules/m²)</th>
<th>Sediment Loss (metric tons/hectare)</th>
<th>Runoff (liters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/20</td>
<td>3.4</td>
<td>-**</td>
<td>-</td>
<td>-</td>
<td>0.4</td>
<td>51</td>
</tr>
<tr>
<td>9/23</td>
<td>0.7</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>9/27</td>
<td>1.2</td>
<td>0.25</td>
<td>0.36</td>
<td>50</td>
<td>0</td>
<td>0.04</td>
</tr>
<tr>
<td>10/07</td>
<td>1.5</td>
<td>0.25</td>
<td>0.58</td>
<td>186</td>
<td>28</td>
<td>64</td>
</tr>
<tr>
<td>10/23</td>
<td>0.7</td>
<td>0.38</td>
<td>0.71</td>
<td>121</td>
<td>27</td>
<td>50</td>
</tr>
<tr>
<td>10/27</td>
<td>1.2</td>
<td>0.25</td>
<td>0.69</td>
<td>149</td>
<td>22</td>
<td>60</td>
</tr>
<tr>
<td>10/31</td>
<td>3.2</td>
<td>1.27</td>
<td>1.07</td>
<td>419</td>
<td>312</td>
<td>262</td>
</tr>
<tr>
<td>11/04</td>
<td>1.2</td>
<td>0.25</td>
<td>0.51</td>
<td>137</td>
<td>20</td>
<td>41</td>
</tr>
<tr>
<td>11/10</td>
<td>1.3</td>
<td>0.13</td>
<td>0.58</td>
<td>149</td>
<td>11</td>
<td>51</td>
</tr>
<tr>
<td>11/13</td>
<td>0.7</td>
<td>0.15</td>
<td>1.07</td>
<td>88</td>
<td>8</td>
<td>23</td>
</tr>
<tr>
<td>11/17</td>
<td>1.8</td>
<td>0.13</td>
<td>0.69</td>
<td>227</td>
<td>17</td>
<td>92</td>
</tr>
<tr>
<td>11/25</td>
<td>13.1</td>
<td>1.27</td>
<td>1.78</td>
<td>1680</td>
<td>1257</td>
<td>2260</td>
</tr>
<tr>
<td>11/28</td>
<td>2.6</td>
<td>1.52</td>
<td>1.50</td>
<td>430</td>
<td>385</td>
<td>380</td>
</tr>
<tr>
<td>12/04</td>
<td>5.1</td>
<td>0.66</td>
<td>2.06</td>
<td>688</td>
<td>270</td>
<td>830</td>
</tr>
<tr>
<td>12/09</td>
<td>2.0</td>
<td>0.43</td>
<td>1.32</td>
<td>268</td>
<td>70</td>
<td>210</td>
</tr>
<tr>
<td>12/16</td>
<td>22.6</td>
<td>1.02</td>
<td>2.41</td>
<td>2930</td>
<td>1750</td>
<td>4160</td>
</tr>
<tr>
<td>12/22</td>
<td>1.9</td>
<td>0.41</td>
<td>0.79</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>12/27</td>
<td>3.1</td>
<td>0.51</td>
<td>1.22</td>
<td>618</td>
<td>184</td>
<td>442</td>
</tr>
<tr>
<td>1/05</td>
<td>7.9</td>
<td>1.02</td>
<td>2.62</td>
<td>1802</td>
<td>1074</td>
<td>2770</td>
</tr>
<tr>
<td>1/08</td>
<td>6.1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1/17</td>
<td>6.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1/24</td>
<td>2.7</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.3</td>
<td>106</td>
</tr>
</tbody>
</table>

*Calculated from KE = 0.67(916 + 331 log i)(a), where KE" = joules/m², a = in. of rain, and i = rain intensity (in./hr.) (Wischmeier and Smith, 1958).

**Missing data due to recording rain gage failure.
Table 14: Rain Parameters and Plot (2x5 m) Data at Site C from Sept., 1977 to Jan., 1978

<table>
<thead>
<tr>
<th>Date</th>
<th>Rain Parameters</th>
<th>Sediment Loss</th>
<th>Runoff</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Amount (cm.)</td>
<td>Max. 30 min.</td>
<td>Max. 6 hr.</td>
</tr>
<tr>
<td>9/26</td>
<td>4.1</td>
<td>0.36</td>
<td>0.33</td>
</tr>
<tr>
<td>9/29</td>
<td>1.1</td>
<td>0.30</td>
<td>0.76</td>
</tr>
<tr>
<td>10/23</td>
<td>0.8</td>
<td>0.30</td>
<td>0.84</td>
</tr>
<tr>
<td>10/27</td>
<td>0.9</td>
<td>0.30</td>
<td>0.28</td>
</tr>
<tr>
<td>10/30</td>
<td>2.4</td>
<td>0.66</td>
<td>0.94</td>
</tr>
<tr>
<td>11/03</td>
<td>2.2</td>
<td>0.30</td>
<td>0.91</td>
</tr>
<tr>
<td>11/07</td>
<td>1.3</td>
<td>0.41</td>
<td>0.64</td>
</tr>
<tr>
<td>11/15</td>
<td>2.1</td>
<td>0.30</td>
<td>0.43</td>
</tr>
<tr>
<td>11/23</td>
<td>3.5</td>
<td>0.25</td>
<td>1.02</td>
</tr>
<tr>
<td>11/29</td>
<td>8.5</td>
<td>1.02</td>
<td>2.16</td>
</tr>
<tr>
<td>12/05</td>
<td>3.3</td>
<td>0.51</td>
<td>1.57</td>
</tr>
<tr>
<td>12/09</td>
<td>1.7</td>
<td>0.30</td>
<td>1.04</td>
</tr>
<tr>
<td>12/14</td>
<td>14.0</td>
<td>1.02</td>
<td>2.29</td>
</tr>
<tr>
<td>12/16</td>
<td>6.4</td>
<td>1.02</td>
<td>2.79</td>
</tr>
<tr>
<td>12/20</td>
<td>0.6</td>
<td>0.15</td>
<td>0.25</td>
</tr>
<tr>
<td>12/31</td>
<td>3.6</td>
<td>0.56</td>
<td>0.81</td>
</tr>
<tr>
<td>1/05</td>
<td>3.9</td>
<td>- **</td>
<td>-</td>
</tr>
<tr>
<td>1/08</td>
<td>3.4</td>
<td>- **</td>
<td>-</td>
</tr>
<tr>
<td>1/15</td>
<td>6.5</td>
<td>- **</td>
<td>-</td>
</tr>
<tr>
<td>1/17</td>
<td>2.8</td>
<td>- **</td>
<td>-</td>
</tr>
</tbody>
</table>

*Calculated from "KE" = 0.67(916 + 331 log i)(a), where "KE" = joules/m², a = in. of rain, and i = rain intensity (in./hr.) (Wischmeier and Smith, 1958).

**Missing data due to recording raingage failure.
Figure 18: Soil Loss and Kinetic Energy Values at Site A for March-May, 1977

Soil Loss 1
(metric tons/hect.)

Kinetic Energy (foot-tons/acre)

\[ y = (8.5)(10^{-4})x - 0.1 \]
\[ r^2 = 0.35 \]

Figure 19: Soil Loss and EI30 min. Values at Site A for March-May, 1977

Soil Loss 2
(metric tons/hect.)

EI30 min. Values

\[ y = (1.8)(10^{-3})x - 0.1 \]
\[ r^2 = 0.91 \]
Figure 20: Soil Loss and $E_{16\text{hr.}}$ Values at Site A for March-May, 1977

Soil Loss (metric tons/hect.)

$y = (8.6)(10^{-4})x - 0.05$

$R^2 = 0.85$

Figure 21: Soil Loss and $E_{30\text{min.}}$ Values for Sites A and C for Sept., 1977 to Jan., 1978

Soil Loss (metric tons/hect.)

$y = (1.6)(10^{-3})x - 0.04$

$R^2 = 0.88$

* Site A
○ Site C

(no soil loss at site B)
Figure 22: Soil Loss and $E_{16}$ hr. Values for Sites A and C for Sept., 1977 to Jan., 1978

Soil Loss (metric tons/hect.)

* Site A
○ Site C

(no soil loss at site B)

$y = (6.9)(10^{-4})x - 0.3$

$r^2 = 0.90$

Figure 23: Soil Loss and Kinetic Energy Values for Sites A and C for Sept., 1977 to Jan., 1978

Soil Loss (metric tons/hect.)

* Site A
○ Site C

(no soil loss at site B)

$y = (6.9)(10^{-4})x - 0.2$

$r^2 = 0.89$
y intercepts of these regressions are not statistically different from zero, but the slopes of the regressions are statistically different from zero. These correlation coefficients for these three rainfall parameters at each site (table 15) are not statistically different from each other. That is, one parameter does not explain the soil loss variation with any greater accuracy than the others given this set of data. The regressions of soil loss from the one meter-squared plots against the three rain parameters also provided a good data fit with $r^2$ values ranging from 0.88 to 0.99 (figures 24 to 29).

Table 15: Soil Loss and Rain Parameter Regressions for 1977-1978 Rain Year

<table>
<thead>
<tr>
<th>Site</th>
<th>Plot Type</th>
<th>N</th>
<th>$r^2$ Values $^*$</th>
<th>kinetic energy</th>
<th>$E_{I_{30}}$ min.</th>
<th>$E_{I_{6}}$ hr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1 m.$^2$</td>
<td>10</td>
<td>0.99</td>
<td>0.93</td>
<td>0.98</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>10 m.$^2$</td>
<td>17</td>
<td>0.96</td>
<td>0.92</td>
<td>0.94</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>1 m.$^2$</td>
<td>11</td>
<td>0.90</td>
<td>0.89</td>
<td>0.90</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>10 m.$^2$</td>
<td>16</td>
<td>0.76</td>
<td>0.78</td>
<td>0.81</td>
<td></td>
</tr>
</tbody>
</table>

$^*$ All $r^2$ values significant at 0.01 level of probability.

** Plot had a change in cover due to weed growth.

One must acknowledge the importance of erosion data collection over a period of years. Due to time constraints, this data only represents two years collection and should only
Soil Loss (g./m.²)

Figure 24: Soil Loss and 'Kinetic Energy' Values for Small Plots at Sites A and C for Sept., 1977 to Jan., 1978

- Site C
- Site A

\[
y = 0.3x - 52
\]

\[r^2 = 0.94\]
\[n = 22\]

"Kinetic Energy" \((\xi(0\xi + 331 \log(i)))(a)\), where \(i = \text{rain intensity (in./hr.)}\)
\(a = \text{inches of rain}\)
Figure 25: Soil Loss and EI_{30 min} Values for Small Plots at Sites A and C for Sept., 1977 to Jan., 1978

- Site A
- Site C

\[ y = 0.44x - 3.6 \]

\[ r^2 = 0.94 \]

\[ n = 22 \]
Figure 26: Soil Loss and $E_{16\text{ hr}}$ Values for Small Plots at Sites A and C for Sept., 1977 to Jan., 1978

$y = 0.19x - 8$

$r^2 = 0.94$

$n = 22$

Soil Loss $(g./m.^2)$

Site A

Site C
be viewed as preliminary results.

That these rainfall parameters can explain the variation in soil loss from the erosion plots could be expected. From the paired screened/unscreened small plots, the importance of raindrop impact was confirmed. The statistics which describe the average energy of these drops then could describe its erosive action if overland flow by itself is not detaching soil particles.

Caution should be exercised when extrapolating this relationship between soil and rainfall to other soil conditions. A saturated soil profile could change this relationship due to the buoyancy of particles at the surface. If a profile did become saturated, all rainfall would become overland flow potentially increasing the erosion hazard. No saturated conditions, as indicated by pxiometric measurement, were recorded at the surface for sites A, B, and C. A frozen ground could require more or less energy to remove the same amount of soil and the runoff would be increased in most cases increasing the energy at the soil surface.

When the data points from both sites A and C were combined for regression analysis (figures 21, 22, and 23), the relationship between the rainfall parameters and soil loss was still strong. The average soil loss for any given storm could be predicted at either site by the rainfall variables. The differences in aggregate stability and slope between sites were not great enough to greatly influence the soil's
interaction with rainfall as reflected in these regressions. However, neither plot had a long slope where overland flow would greatly influence the detachment of soil particles. At site A, with a lower infiltration rate on the cultivated rows that run up and down the slope, one would expect the channeling of water to accelerate soil loss. The lower $r^2$ values for site C (table 15) could be partially explained by the variability in soil cover; a gradual breakdown of exposed soil aggregates could also explain some deviations. The first high energy storm (collected 11/29/77, table 14, page 66) produced little soil loss, but did dissipate some exposed soil aggregates.

All of these regressions have a concentration of points near the origin. Many storms of relatively low intensity and kinetic energy occur through the year compared to a few storms of high sustained intensity and kinetic energy. Undoubtedly, the $r^2$ values for the regressions are higher because of this concentration.

6. **Comparison of Rainfall Characteristics**

From 40 samples of actual raindrop splashes from June, 1977 to March, 1978, a comparison was made of the relationship of rain intensity and kinetic energy of falling raindrops to that relationship presented by Wischmeier and Smith (1958).
The samples varied in rain intensity (0.41 to 29.2 mm./hr.), energy (2.9 to 25.2 joules/mm. of rain/m.²), and median drop diameter (1.87 to 2.56 mm.). (Median drop diameters for the Laws and Parsons equation (1943) at the same rain intensities have a corresponding range of 1.05 to 2.29 mm.) The largest raindrop recorded was calculated as 3.6 mm. in diameter while the actual splash marks (figure 27) measured up to 25 mm. in diameter. (In nature, raindrops greater than six mm. in diameter are very rarely observed (Mason, 1971).) In total, approximately 12,000 splash diameters were measured from 200 seconds of rainfall on approximately 208 cm.² surface area.

When the median drop diameters (the drop size at which 50 percent of the rain volume is in smaller drops) were plotted against the rain intensities (figure 28), a pattern similar to the graphs of previous measurements in Europe (Leonard, 1904) and Washington, D.C. (Laws and Parsons, 1943) resulted. The points were somewhat scattered indicating a variability of drop sizes with a given rain intensity.

When the rain intensities were plotted against the kinetic energies of the falling drops, a widely scattered pattern resulted (figure 29). The data did not differ significantly from the reported relationship due to the wide scatter of points. The point scatter may be a reflection of the natural rainfall variability and/or experimental error. Such experimental error could result from the inaccuracy of drop measurement and
and the inaccuracy of data collection. During the higher intensity periods, an average of 2.6 drops per second fell on one cm.\(^2\) of ozalid paper. Undoubtedly, less than accurate exposure times (3 - 15 seconds) and drops falling on previous splash marks could lead to error. The errors in exposure time would be an unbiased error while the drop on drop overlap would be a systematic error leading to artificially lower energies.

Though the points are widely scattered, two general characteristics about the rain samples can be stated. First, all samples had raindrops larger than one mm., the size previously reported to be erosive (Ekern, 1950). Even low rain intensities then could be considered potentially erosive
Figure 31: Relation of Median Drop-Size to Rainfall Rate

- **Corvallis, Ore. Data (1977-78)**
- **Lenard (1904), Europe**
- **Laws and Parsons (1943), Wash., D. C.**
Figure 32: Observed and Predicted Relationship Between Rainfall Intensity and Kinetic Energy of Falling Raindrops

K.E. = 916 + 331 \log_{10} i

K.E. = 782 + 284 \log_{10} i^*

r^2 = 0.47

* This regression is statistically meaningless due to wide scatter of points.

Rainfall Intensity (inches per hour)
if the storm lasted a significant period of time. Second, no definite trend was evident between rain characteristics obtained in western Oregon and those used to calculate the R factor for the Universal Soil Loss Equation. Rain energy in western Oregon was not always lower than the energy of corresponding rain intensities from locations where the R factor has been used extensively.
V. DISCUSSION

The discussion will include a summary of results, management implications, and erosion prediction problems.

1. Summary of Results

The total organic matter content for soils at all three sites followed the same trend as the aggregate stability indexes. The undisturbed forest soil (site B) had the highest aggregate stability index as determined by water drops and the highest organic matter content while site A had the lowest organic matter content and the lowest aggregate stability index. Other strong implications of organic matter existing in aggregate bonding mechanisms (organic content of aggregate fractions and periodate oxidation studies) support its importance (Allison, 1973) in stabilizing soil crumbs.

The relatively high aggregate stability at site C could be partly due to the higher iron content and its effect on soil aggregation. The electron micrographs reveal somewhat more amorphous coatings at site C than at site A or B which may be iron gel-like material similar to that suggested by Jones and Uehara (1973). The strongly suggested presence of halloysite at site C may also account for a higher aggregate stability (Taskey, 1978).

The two cultivated sites (A and C) had smaller aggregate
size distributions. The soil at site A, being intensively cultivated, had the lowest crumb stability and crumbs from site C were less stable than the aggregates from the uncultivated site B. This trend is consistent with observed detrimental impact of cultivation on soil structure and reduced infiltration rates as reported by Meyer and Manning (1961). Little surface runoff and no erosion occurred on site B whose soil and litter layer were undisturbed.

The dramatic effect (visually obvious and photographically documented) of raindrop impact on soil losses and crust formation was strongly supported by observations of thin sections, air permeameter readings, infiltrometer data, and soil losses from erosion plots at site C. The infiltration rate patterns follow the theoretical considerations of Hillel and Gardner (1970). The effect of cultivation at site A masked surface crust formation by raindrop impact as illustrated by infiltrometer, permeameter, and hydraulic conductivity data.

Hydraulic conductivity values of the A horizon at site A did not greatly influence soil loss from the erosion plots when the surface was protected from raindrop impact. The erosion plots probably were not long enough to have significant detachment by overland flow. When restrictive hydraulic conductivity values exist, exposed soil crusts form, or saturated profiles occur, sites could be expected to have additional soil loss over a long slope due to detachment and
transport of soil particles from increased surface flow of water.

$E_{30\ min}$ and $E_{6\ hr}$ rainfall statistics explained a major portion of the variation in soil losses from the erosion plots. The differences in aggregate stability between the soils at site A and C were not reflected in the trends detected by regressions of rainfall statistics and soil loss.

2. Implications for Management

Extreme views, because of uncertainties about the future, confound discussions about soil losses and land management. One view leads to exploitation of the land resource for a quick return on an investment in the belief that land is expendable because of future technology. The other extreme view demands preservation of the land resource, does not accept risks that could be detrimental to the land resource, and tolerates lower profits. A third belief, a compromise between the two extremes, is to use common sense to reduce excessive soil loss.

If producers decide that their soil losses from exposed soil surfaces are excessive, a cover crop could be a management option. By conjecture, the cover crop, much like the screened plot could protect some soil from raindrop impact, minimize excessive soil loss and maintain the active fraction organic matter content of the soil. As a progress report by the Pacific Northwest Experiment Station showed more than
40 years ago (McGrew and Horner, 1935) and as emphasized recently (Young, 1976), the rolling residual hill soils of the Willamette Valley, if not protected by a cover, suffer accelerated water erosion. A cover crop, though it may not eliminate soil loss, could reduce splash and rill erosion.

3. Erosion Prediction Problems

The regressions of the EI values and soil losses indicate the rainfall factor may be useful for erosion prediction in western Oregon. However, the equation used to calculate the kinetic energy values for the EI variables from rainfall intensities is not a strong absolute relationship. A wide variability in median drop sizes and kinetic energy values for a constant rain intensity existed. Thus, the EI variables could not be expected to predict observed soil losses stochastically. Rather, average soil losses could be predicted from which individual storm losses may vary considerably.

Annual EI values have been correlated with two-year six-hour rainfall probabilities by the relationship \( EI = 27.4P^{2.17} \) (Wischmeier, 1974). In western Oregon, these values can be expected to vary greatly over short distances due to the large varience in rainfall amounts with orographic land forms. Serious miscalculations may result if adequate rain data are not available over short distances where annual rainfall amounts may vary considerably.
BIBLIOGRAPHY


APPENDICES
Appendix I
Soil Profile Descriptions

1. Site A

Ap 0-25 cm., light yellowish brown (10YR6/4) silty clay loam, brown (10YR5/3) when wet; moderate fine granular structure; friable (moist), sticky, plastic (wet); strongly acid (pH 5.2); many fine and very fine roots; many very fine irregular pores; abrupt smooth boundary.

A3 25-37 cm., yellowish brown (10YR5/6) silty clay loam, brown (10YR4/3) when wet; moderate fine granular and moderate fine subangular blocky structure; firm (moist), sticky, very plastic (wet); strongly acid (pH 5.3); common very fine roots; many very fine irregular pores; clear smooth boundary.

B1 37-70 cm., brown (7.5YR5/4) silty clay loam, dark brown (7.5YR4/4) when wet; moderate medium subangular blocky structure; firm (moist), sticky, and plastic (wet); strongly acid (pH 5.2); common fine roots; many very fine tubular pores; few thin clay films; few black concretions; gradual smooth boundary.

IIB21t 70-90+ cm., reddish brown (2.5YR5/3) silty clay, red (2.5YR4/6) when wet; moderate medium subangular blocky structure; firm (moist), sticky, slightly plastic (wet); strongly acid (pH 5.2); few fine roots; common very fine tubular pores; common moderately thick clay films; common medium black stains; few medium reddish yellowish (7.5YR6/8) weathered fragments.

2. Site B

O1 7-0 cm., Needles and twigs partially decomposed.

A1 0-21 cm., reddish brown (5YR4/3) light silty clay loam, dark reddish brown (5YR3/3) when wet; moderate medium granular structure; firm (moist), sticky, and very plastic (wet); many fine roots; strongly acid (pH 5.4); many fine irregular pores; clear smooth boundary.

A3 21-33 cm., yellowish red (5YR5/6) silty clay loam, reddish brown (5YR4/4) when wet; moderate medium subangular blocky structure; firm (moist), sticky, and very plastic
(wet); medium acid (pH 5.7); common very fine and fine roots; common very fine irregular and tubular pores; clear smooth boundary.

B₁ 33-52 cm., red (2.5YR4/6) heavy silty clay loam, dark red (2.5YR3/6) when wet; moderate coarse subangular blocky; firm (moist), sticky, and plastic (wet); strongly acid (pH 5.5); common fine roots, medium and coarse roots; many fine tubular pores; few fine black concretions; clear smooth boundary.

IIB₂₁t 52-82 cm., red (2.5YR4/6) silty clay, also red (2.5YR5/6) when wet; moderate medium subangular blocky structure; very firm (moist), slightly sticky, plastic (wet); strongly acid (pH 5.3); few fine roots; common very fine tubular pores; common moderately thick clay films; few reddish yellow (7.5YR6/8) weathered fragments; common coarse black stains; many red (2.5YR4/6) shot 1 to 4 mm.; gradual wavy boundary.

IIB₂₂t 82-107+ cm., red (2.5YR4/6) silty clay, red (2.5YR5/6) when wet; moderate medium subangular blocky structure; firm (moist), slightly sticky, slightly plastic (wet); strongly acid (pH 5.2); many moderately thick clay films; many reddish yellow (7.5YR6/8) weathered fragments.

3. Site C

A₁ 0-20 cm., reddish brown (5YR4/3) clay loam; moderate fine granular structure; firm, slightly sticky, and slightly plastic; many fine and very fine roots; many very fine interstitial pores; few fine black concretions; strongly acid (pH 5.4); clear smooth boundary.

A₃ 20-43 cm., reddish brown (5YR4/4) clay loam; moderate fine granular structure; firm, slightly sticky, and plastic; common fine roots; many fine interstitial pores; strongly acid (pH 5.4); clear, wavy boundary.

B₁ 43-56 cm., reddish brown (5YR4/4) clay loam; weak fine and very fine subangular blocky grading into a fine granular structure; friable, slightly sticky, and plastic; common fine roots; common interstitial pores; strongly acid (pH 5.5); abrupt, wavy boundary.

IIB₂₁t 56-94 cm., red (2.5YR4/6) silty clay; moderate, medium subangular blocky structure; firm, sticky, and plastic; few fine roots; common tubular pores; common moderately thick clay films; strongly acid (pH 5.3); gradual, wavy boundary.
IIB$_{22}$t 94-145 cm., red (2.5YR4/6) silty clay; moderately strong, medium coarse subangular blocky structure; firm, very sticky, and very plastic; few fine roots; many moderately thick clay films; strong brown (7.5YR5/8) weathered fragments 2 to 5 mm. in size; common black stains; strongly acid (pH 5.3); gradual wavy boundary.

IIB$_{23}$t 145+ cm., red (2.5YR4/6) silty clay; weak medium and coarse subangular blocky structure; firm, sticky, and plastic; many strong brown (7.5YR5/7) coarse fragments 2 to 5 mm. in size; strongly acid (pH 5.3).
Appendix II  

Soil Splash Cups

An attempt was made to correlate soil splash with rainfall parameters. Soil splash cups, patterned after Ellison's (1947) design, were used to measure soil splash. Air-dried soil samples from each site were screened through an eight mm. sieve and placed in the respective cups (figure 30). After the entire cup was weighed, the soil was permitted to take up water from a glass canning jar via an asbestos wick. It was then exposed to rainfall and the amount of soil splash was determined by reweighing the air-dried sample.

The splash cup design had several defects. First, some soil loss occurred through the hole where the wick entered the sample container. Air-drying the samples required long periods of time. Also, the variability between duplicate samples was quite high. All three factors hindered the effectiveness of the splash cups as a research tool.

Examination of photographs of the splash cups (figure 30) revealed visual differences between soils. The two cultivated sites (A and C) had much less visual evidence of good soil structure after exposure to 3.1 cm. rainfall than did the soil from site B. This trend agrees with the discussion in the text.
Figure 30: Soil Splash Cups After 3.1 cm. Rainfall