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Development and use of a laboratory apparatus to study the effect of soil texture, crop history, and water potential on soil loss

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Iowa State University, 1992

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Development and Use of a laboratory apparatus
to study the effect of soil texture, crop
history, and water potential on soil loss

by

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GENERAL INTRODUCTION

Population in developing countries, especially in the tropics and subtropics, is increasing rapidly. Therefore, soil resources must be preserved (United Nations 1977).

Types of erosion include geologic (natural or normal), accelerated (sheet) interrill, rill, gully, tunnel, pedestal, pinnacle, puddle, vertical (argillic migration), streambank, valley trenching, and landslide. It is unclear which form is most serious. Agricultural researchers agree that rill and interrill erosion are more damaging, if less spectacular, than gully or landslide erosion (Food and Agricultural Organization of the United Nations 1977).

Soil erosion is perhaps the most devastating form of land degradation. In the United States, the problem remains despite more than 40 years of intense research. In fact, recent information indicates that soil loss rates are again on the rise. Nationally, 25% of cropland and 13% of rangeland are eroding at unacceptably high rates (Carter 1977, Committee on Conservation Needs and Opportunities 1986). Soil erosion is a problem for farmers and for the nation as a whole in terms of lost resources for food and fiber production, as well as increased navigation and flood control expenses due to siltation (Troeh et al. 1980, Joint Council of Food and Agriculture 1986).

Bennett (1939) proposed an annual soil loss limit of 11 metric tons/hectare and assumed that topsoil renewal in cultivated lands occurs at a rate of 10 mm every 30 years.

In what is now the United States, water erosion was recognized as a problem in the East even before the revolutionary war. Later settlers cultivating land in the South, Midwest, and Northwest abused the soil. Erosion began to extend even to the western rangeland in the latter part of the 19th century when farmers allowed sheep and cattle to overgraze to increase livestock numbers in an attempt to gain control of the eastern market meat prices. As long as there was new land to move to, early settlers used the soil until it was worn out. Soil erosion has been controlled at times, however, by terracing, strip cropping, residue management, and--recently--minimum tillage (General Accounting Office 1977).

In Pakistan, severe water erosion in the hills and in the dryland farming (barani) areas of the north have brought demands for soil conservation since at least 1877 (Anwar 1955). In 1944, Gully erosion became so severe that about 200,000 ha were said to have been permanently destroyed. In Punjab alone, wind and water erosion are responsible for 12,000 to 30,000 ha of land leaving cultivation each year (Punjab Barani Commission 1976).

Unlike agricultural engineers and agronomists, who study erosion in limited areas, geomorphologists can study continental denudation (Selby 1974). Suspended sediments in major rivers have been used to calculate the denudation rates (the rate at which the whole area lowers uniformly due to soil erosion). Judson and Ritter (1964) calculated this rate, for drainage basins as large as the Mississippi River, at 50 mm for 1,000 years. The estimated denudation rate for the United States is calculated at 60 mm per 1000 years. For smaller drainage basins, annual denudation rates can be several centimeters, and an average maximum rate of denudation has been estimated at 1 mm per year (Schumm, 1963) for areas of about 4000 km^2.

Ellison (1947) defined soil erosion as "a process of detachment and transport of soil material by erosive agents." Lowdermilk (1953) stated that civilizations collapsed when their productive farm lands were eroded because siltation destroyed productive lowlands.

Modern soil erosion research began in the United States in the 1930s. In the 1940s, equations were developed to estimate the extent of the problem. Eventually, these equations were incorporated into the Universal Soil Loss Equation (USLE) (Troeh et al. 1980), which has been applied to many soils around the world (Hudson 1985). But inasmuch as its basis is data collected from sloping test plots, the USLE fails to take into account severe rilling or gully erosion or to be adaptable to certain conservation tillage practices, sediment depositions, or topographies (Foster 1987, Meyer et al. 1977, Wischmeier 1976, Wischmeier and Smith 1978). Moreover, it was developed to characterize long-term rotation effects only. Therefore, erosion estimation with the USLE for a single rain storm is not recommended (Wischmeier 1976).

Recently, researchers have developed a Revised Universal Soil Loss Equation (RUSLE), a Modified Universal Soil Loss Equation (MUSLE), and a Water Erosion Prediction Project (WEPP), as well as many other equations assesing and predicting the potential of soil erosion hazards (Meyer and Wischmeir 1969, Foster and Meyer 1972, Foster et al. 1976, Foster 1987, Laflen et al. 1985, Laflen et al. 1987).

Most related studies have been conducted in the field. Very few have been done in controlled environments. After a thorough review of the literature, Elliot (1988) pointed out a need for studying the process of erosion in the laboratory.

Mahmood and Colvin (1990) designed and developed a laboratory apparatus with which to study the mechanics of soil erosion under controlled laboratory conditions. This dissertation reports on the development and use of this apparatus.

Explanation of Dissertation Format

This dissertation uses alternate format and consists of two papers (suitable for publication). The first presents the design and development of a laboratory apparatus with which to study the mechanics of soil erosion. The second presents measurements of sediment concentrations in flood water as affected by soil tilth, texture, and water potential. Additionally there is literature cited in the introduction and the summary follow the summary. Lastly there is general summary following the papers.

Objectives

The specific objectives of the study were as follows:

1. To design and develop a laboratory apparatus with which to study the interaction between soil properties (texture, tilth (crop history) and water potential) on soil loss.
2. To measure sediment concentrations in runoff water as affected by 1) soil texture, 2) soil tilth, and 3) soil water potential (as sediment concentration is a direct measure of soil erosion).

SECTION I. A LABORATORY APPARATUS WITH WHICH TO STUDY THE INTERACTIN OF SOIL PROPERTIES (TEXTURE, TILTH AND WATER POTENTIAL) AND SOIL LOSS BY EROSION

ABSTRACT

A laboratory apparatus was designed and developed to simulate the field conditions of soil structure, texture, and water potential, as well as field flooding and slope. The apparatus successfully duplicated water potential and slope of the field. The soil structure could not be duplicated identically because it was quite difficult to disturb the soil from the field and still maintain original soil tilth conditions.

The apparatus performed well in initial experiments. Decreased water potential increased the shear strength of the soil. Tensiometers successfully measured soil water potential levels and were read by a pressure transducer.

INTRODUCTION

Ellison (1947) defined soil erosion as "a process of detachment and transport of soil material by erosive agents." Lowdermilk (1953) stated that civilizations collapsed when their productive farm lands were eroded because siltation destroyed productive lowlands.

Erosion is an international problem that agricultural engineers and other scientists are working diligently to solve. In fact, the problem is so serious that it has the potential to deprive mankind of life sustaining materials in the form of grains, fruits, and vegetables. Because all human beings are affected by erosion either directly or indirectly, the field of erosion and soil management must acquire the information basic to its enterprise, to conserve soil and water resources. Although many studies of soil erosion have been carried out under field conditions, these studies have not always yielded fruitful results; thus Elliot (1988) recommended that soil erosion be studied under controlled laboratory conditions. Therefore keeping in mind the recomendation of Elliot (1988), an apparatus was designed and developed to study the problem of soil erosion under controlled laboratory conditions. The specific objective of the study was as follows.

OBJECTIVE

To design and develop a laboratory apparatus to study the interaction of soil properties (texture, structure and water potential) and soil loss by erosion.

LITERATURE REVIEW

Many parts of the world are encountering stagnating and declining crop yields, deterioration of soil physical properties, surface water-logging. Runoff leads to gully erosion on hillsides, and widespread submergence and mud deposition in valleys (Roose and Masson 1985). Valley's sediments are hauled afar by runoff water and finally settle when the water recedes or becomes stationary. Soil erosion and sedimentation therefore pose a profound risk to multipurpose reservoirs around the world (Narayana and Sastry 1985). It is imperative that countries establish soil conservation policies. Government executives and landholders must recognize the extent of soil erosion in their localities (Jantawat 1985); if they do not, soil erosion may be calamitous. In short, extreme erosion in upper mountainous areas and subsequent sediment conveyance in rivers traversing lower plains should be foremost in the minds of those accountable for soil and water conservation (Cuff 1985).

Early in this century, industrialization introduced certain crop production practices that helped free manpower previously needed to prepare the seedbed, to weed, and to harvest. Scientific farming, which made possible the production of ever more industrial crops such as cotton, corn, and soybean led to increased soil deterioration (Roose and Masson 1985).

Crop productivity, even for growers using ample fertilization and excellent varieties and hybrids, is not consistent in most parts of the world, both in years of great soil erosion losses and in years with insufficient quantities or poor distribution of rainfall. In most of the Third World, crop residues are eaten by cattle during the arid periods. Thus when tillage procedures are executed before planting, only small amounts of residue are left on the soil surface for protection of the soil during heavy rains (Pla et al. 1985).

Many farmers do not feel that soil erosion is a significant problem because they have not noticed a decrease in either productivity or income. For such farmers, annual productivity reductions due to soil erosion are relatively small, and losses tend to be offset by improved agricultural technology, which increases output. Nonetheless, incremental productivity cutbacks due to erosion will finally be felt because technology will not be able to offset soil losses indefinitely (Nickling and Fitzsimons 1985).

Wischmeier and Smith (1978) have developed a Universal Soil Loss Equation (USLE). It is useful to determine the adequacy of conservation measures in farm planning and to predict estimated sediment loss.

The USLE equation is as under

$$A = R\ K\ LS\ C\ P$$

where

A = average annual soil loss in Mg/ha

R = rainfall and runoff erosivity index by geographic location.

K = soil-erodibility factor, which is the average soil loss in Mg/ha per unit of erosion index for a particular soil in cultivated continuous fallow with an arbitrarily selected slope length L of 22 meters and slope steepness S, of 9 perecnt.

LS = topographic factor evaluated by the following equations.

$$L = (l/22)^x \quad .....(1)$$

where

l = slope length in meters

x = a constant, 0.5 for slopes > 4 percent, 0.4 for 4 percent, and 0.3 for < 3 percent.

and

$$S = (0.43 + 0.30s + 0.043s^2)/\ 6.574 \quad .....(2)$$

where

s = field slope in percent.

Multiplying results from equation (1) and equation (2) will give us a number for the topographic factor (LS) for a particular field.

C = cropping-management factor, which is the ratio of soil loss for given conditions to soil loss from cultivated continuous fallow.

P = conservation practice factor, which is the ratio of soil loss for a given practice to that for up and down the slope farming.

Evaluating this equation in the Philippines, De Vera (1981) reported that estimated soil losses ranged from 223 to 1017 tons per km^2, while observed sediment yield ranged from 85 to 2213 tons per km^2. The USLE overestimated the lower limit and underestimated the upper limit of observed erosion. Cooley and William (1985) reported that, compared with actual observations in Hawaii, the USLE generally overestimated soil loss. The equation also had difficulty performing well in Europe (Bollinne 1985) and in India (Singh et al. 1985); therefore, the scientists of these countries are now trying to modify the equation according to their own conditions. Rose (1985, p. 776) reported that "the purpose, strengths and weaknesses of the universal soil loss equation (USLE) as a means of inferring average annual soil erosion were a recurrent theme. The purposes for which it was developed were recognized, as was its dependence on a vast body of experimental plot data dominated geographically by results from the humid regions of the United States. Looking at it as a data summary, the USLE is not universal. The correlations that presumably exist in the data base between the equation's rainfall factor and runoff are certainly not universal, a limitation noted by Wischmeirer in warning against simple acceptance of USLE predictions for vertisols."

Rose (1985, p. 777) concluded that "the basic concept used in the USLE of an 'average annual soil loss,' is acceptable in climates similar to that in which the USLE was derived, [and] is of restricted utility." He suggested that "for much of the tropical, semitropical, arid, and semiarid world, this concept must be replaced by the concept of a probability distribution of soil loss. This replacement is needed because of the well recognized temporal variability of soil loss in such climatic regimes."

Fundamental processes can be isolated and studied separately (Wilson and Rice 1987, Foster et al. 1984a,b). Cruse and Larson (1977) conducted basic experiments to determine the effects of soil shear strength on soil detachment due to raindrop impact. Using a wetting table, they allowed a single simulated raindrop of 4.8 mm to fall from a height of 1770 mm onto a soil core. They concluded that the amount of soil detached is closely correlated with the shearing strength of the soil and that the shear strength is altered by changes in both soil bulk density and water potential.

Extensive five- and ten-year research has been conducted on specific watersheds under specific conditions, but when the same methods have been applied to other watersheds under other conditions, studies have failed to closely predict actual results. These discrepancies have been due to differences in soil and weather conditions when moving from one watershed to another (Catus 1989).

To overcome problems in the field study of soil erosion, it was decided that a laboratory apparatus should be designed and developed to aid study of the mechanics of soil erosion. Such a laboratory apparatus should be useful for study of a soil located in any part of the world by simulating its environment (Elliot 1988).
After considering the relevant literature, a laboratory apparatus was designed:

1. to simulate slope of the fields (Wischmeir and Smith 1978, Elison 1947);
2. to simulate soil water potential, that is, suction or tension of water in the soil (Cruse and Larson 1977; Francis and Cruse 1983);

3. to simulate sediment loads in water moving on the soil surface (Elison 1947); and
4. to test different soil textural classes and different soil tilth or history conditions (DeMeester and Jungerius 1978, Elison and Slator 1945).

LONG-TERM BENEFITS

A laboratory apparatus can help predict erosion hazards throughout the world. Knowing soil textural classification, soil tilth condition, slope, and other physical parameters affecting the process of soil erosion, scientists can use this apparatus to make an index of information on soil erosion, which can be readily available to international colleagues.

DESIGN OF THE APPARATUS

The basic principle in the design of this apparatus was that actual field conditions of soil texture, soil tilth, slope and soil water potential, that is, suction or tension of soil water, should be simulated as realistically as possible in the laboratory.

Acrylic was used to fabricate the soil bin, which has three compartments (see Figure A-1). To meet the first design requirement of the laboratory apparatus (slope), the downstream legs of the apparatus are adjustable, and a pair of hinges are attached to the upstream end of the soil bin to vary slope (see Figures 1 and A-1).

To meet the second design requirement of the laboratory apparatus, that is water potential, each compartment can be filled with soil with specific characteristics and exposed to a certain level of water tension, with the help of a vacuum system (Figure A-5). The vacuum system consists of a vacuum pump, vacuum hoses, and three large vacuum bottles (one for each compartment of the bin). These bottles are used to protect the vacuum pump by collecting water coming from the bin. The vacuum produced by the system is monitored by vacuum gauges (see Figures A-6).

To meet the third design requirement of the laboratory apparatus, a 450x920x1540 mm rectangular steel tank with a capacity of 636 liters was mounted on the mainframe (see Figure A-1). The outlet of the tank, extending from the back of the tank, is equipped with both a gate valve and a globe valve. The former is used to adjust flow rate; the latter to permit on/off control of water and sediment (see Figure A-2). The settings on the gate valve were calibrated with a v-notch weir, which, as used by Foster et al. (1984), was installed so that discharge onto the soil sample can be directly measured during the experiment. The water passing over the v-notch was baffled by a 76 mm high steel plate to provide a uniform flow of water over the entire surface of the soil in the bin (see Figures A-3).

To meet the fourth design requirement of the laboratory apparatus, soils with different soil textures (clay, silt and sand) and different tilth or crop histories (grass, corn-soybean and corn-corn) were brought from the field. Before placing these texture and tilth combinations, the soil was passed through the hammer mill, so that when soil is packed in the vacuum box, it resembles, a nice seed bed, ready for irrigation or planting.

Total runoff from the discharge end was collected in three large containers. Each collects runoff water from a particular section of the soil bin with a specific soil, texture and tilth (crop history) combination, and water

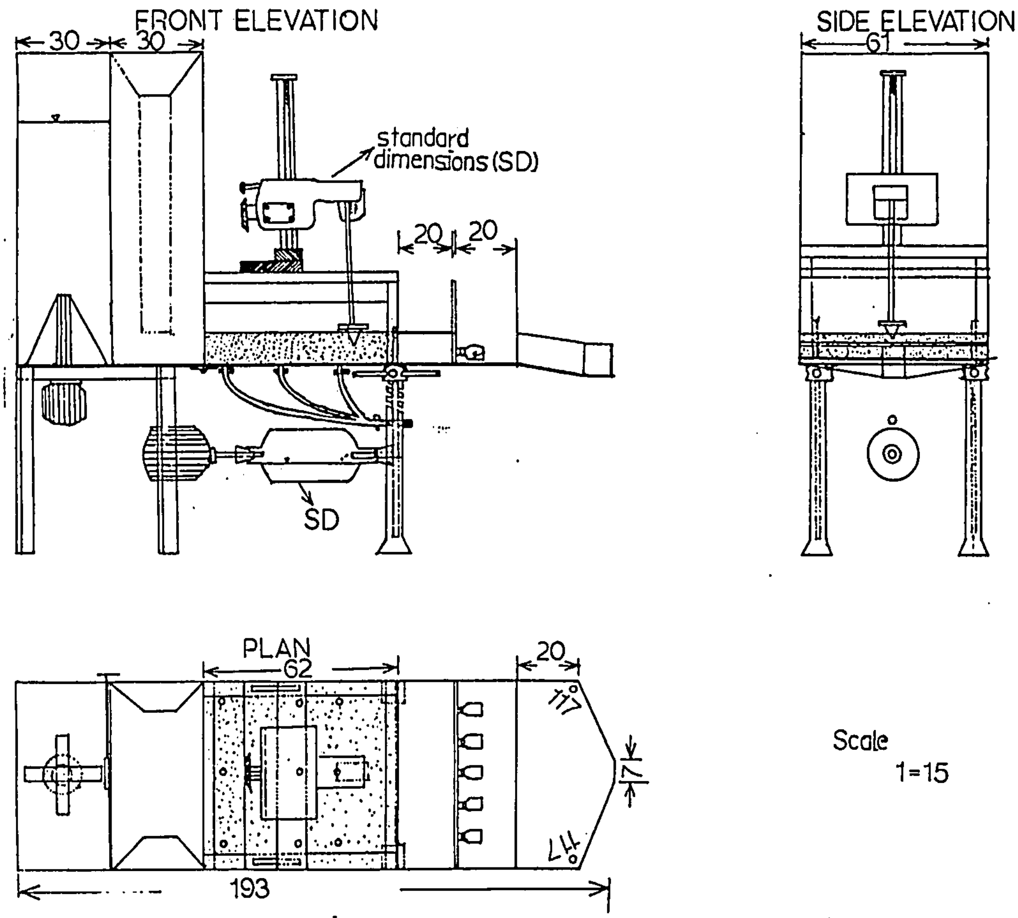

Figure 1. Isometric view of the laboratory apparatus

potential (see Figure A-4). With the help of 5-gallon buckets, nine main samples of flood water were collected from three sections of the soil bin. After the effluent of each bucket was vigorously stirred (to mix thoroughly), a beaker was used to collect one 150-ml subsample from the center of each bucket. These samples were poured into aluminum cans, which were placed in an oven set at 105 C for 24 hours.

After water was evaporated from the samples, sediments were left in the cans (such a method was used by Johnson et al. 1979). Sediments were removed carefully from the cans, and their weight was determined with an electronic balance. The average concentration (weight/volume) of these three subsamples (collected from three 5-gallon buckets used to collect runoff water from one section of the bin) yielded the total concentration of sediment collected from the respective sections of the soil bin.

PROBLEMS FACED DURING FABRICATION

Sealing the base plate with the tension paper was difficult because a small pinhole in the joints between the walls of the acrylic could result in the loss of vacuum at the bottom of the test soil.

To seal the vacuum boxes completely, acrylic cement and G.E. Silicon rubber caulking was used. To eliminate some sealing problems, separate boxes, each of which could be exposed to a different level of the vacuum, is recommended.

INITIAL EXPERIMENTATION AND FINAL TESTING OF THE LABORATORY APPARATUS

Coarse sand was poured into the soil boxes so that the depth of the sand in each box could be maintained at 50 mm. Then each vacuum box was filled with soil to a depth of 220 mm. The ceramic cups of the tensiometers were placed at a depth of 10 mm from the surface of the soil (see Figure A-7). The clamps at the end of the tensiometer tubes were open, and water was flushed through the nylon tubes of the tensiometer until the air was removed from the system. After flushing, the end of the tensiometer at which the water was injected was clamped. A plain stop cock system (see Figure A-7, A-8, and A-9) was used to measure water potential in the soil. In this system, a pressure transducer was used to read the vacuum of the tensiometers. When the needle of the pressure transducer was inserted into the rubber stopper of the tensiometer, the vacuum produced inside the tensiometer was gauged by the pressure transducer, and the value corresponding to the vacuum was read from the digital screen of the transducer.

When the tensiometers were placed, the soil in the boxes of the laboratory apparatus was exposed to the half bar suction produced by the vacuum pump. In the beginning, the drainage of water from the soil was quite rapid because the water from the macropores could drain rapidly, but later the drainage of soil water became so slow that it required 10 to 15 min to drain a few drops of soil water. The laboratory apparatus was exposed to suction for three to four days for every one-third bar suction applied, because only then could the tension in the ceramic cups placed in the soil drop to a maximum of 760 mm of water.

Calibration of the Hydraulic Tank

The hydraulic tank was filled with water; during draining, changes in height of water crest over v-notch were recorded continuously. The gate valve of the tank was opened two turns, and the globe valve was used to release the water suddenly.

Figure A-10 shows the relation between time and discharge of water through v-notch. Initially, the height of water crest over v-notch was 65 mm for two turns of the gate valve opening. But as time passed, the height of water in the hydraulic tank decreased; thus the hydraulic pressure decreased and the height of water crest decreased. This decrease continued until the water tank reached the empty state and the height of water crest approached zero and therefore the discharge approched to zero. The test was continued for 8.5 min, after which the corresponding height of water crest over v-notch was recorded as 10 mm and the corresponding discharge was 0.0002 cubic meters per second.

When correlating this relation with actual testing, the test on the erosion table lasted for 2.5 minutes, and the hight water crest ranged from 65 mm to 55 mm. The average discharge to which the test bin was exposed was

0.0013 m^3s^{-1}, while the average velocity of the runoff water was 0.36 ms^{-1}.

Effect of Water Potential on Sedimentation Concentration.

Figure 2 indicates a relation between sediment concentration and water potential. From 0 to 76 cm of water potential was used. Each time the soil was exposed to certain levels of water potential, the test was conducted by allowing water to run over the surface of the soil in the bin. Between runs all the soil in the bin was replaced with fresh soil. On average, the amount of sediment transported with water decreased with soil water potential value. Highest sediment concentration value was recorded when the soil was at saturation, that is, at a water potential of 0 cm. Similar effects were recorded by Francis and Cruse (1983), Benjamin and Cruse (1985), and Trueman et al. (1990) while studying the effects of water potential on the amount of sediment detachment and shear strength of the soil by rainfall or flooding water. The current laboratory study confirms the findings of these researchers by concluding that sediment concentration decreases with lower water potential values of soil.

To permit observation of the effect of soil water potential on sediment concentration, a regression model for

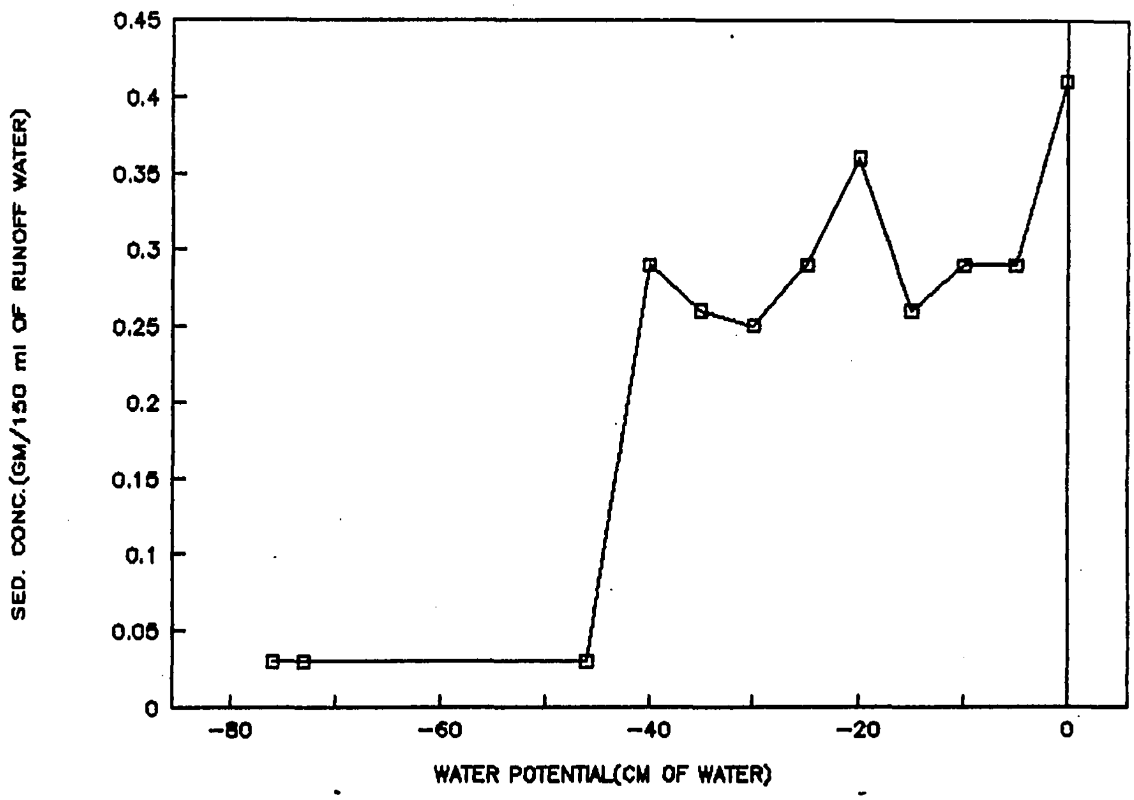

Figure 2. Relationship between sediment concentrations and different levels of water potential

eight levels of water potential (that is from 0 to 40 cm of water, except for 20 cm) was developed to improve coeficient of determination of the model, as r^2 for a model of nine data points was 0.29. This model (with eight data points) showed that average sediment concentration decreases linearly with soil water potential. Figure A-11 shows the linear regression equation and the model for sediment concentration as a function of soil water potential.

Because a great decrease in sediment concentration for each successive increment of water potential was observed, the slope of the regression line between sediment concentration and water potential was great. The best correlation was obtained between sediment concentration and water potential. The coefficient of determination (r^2) for this relation was 0.36.

SUMMARY

The apparatus described in this study allows many factors that affect soil erosion to be studied under laboratory conditions. Field conditions such as soil water potential, soil structure, soil texture, field flooding, and field slope can be studied. The interactions among these factors is a first step towards understanding and controlling the process of erosion.

Results from the initial testing were encouraging. Decreased water potential resulted in decreased sediment concentration in the run-off water. In other words, dry (partially) soils were less erosive than wet soils.

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APPENDIX A

Table A-1. Textural analysis of the soil used in the initial experimentations.

SOIL TYPE	SAND %	SILT %	CLAY %
UNKNOWN[a]	35.5	41.7	22.8

a Left over soil was taken from the greenhouse, and textural analysis was done in Soil Physics Lab. of National Soil Tilth Laboratory.

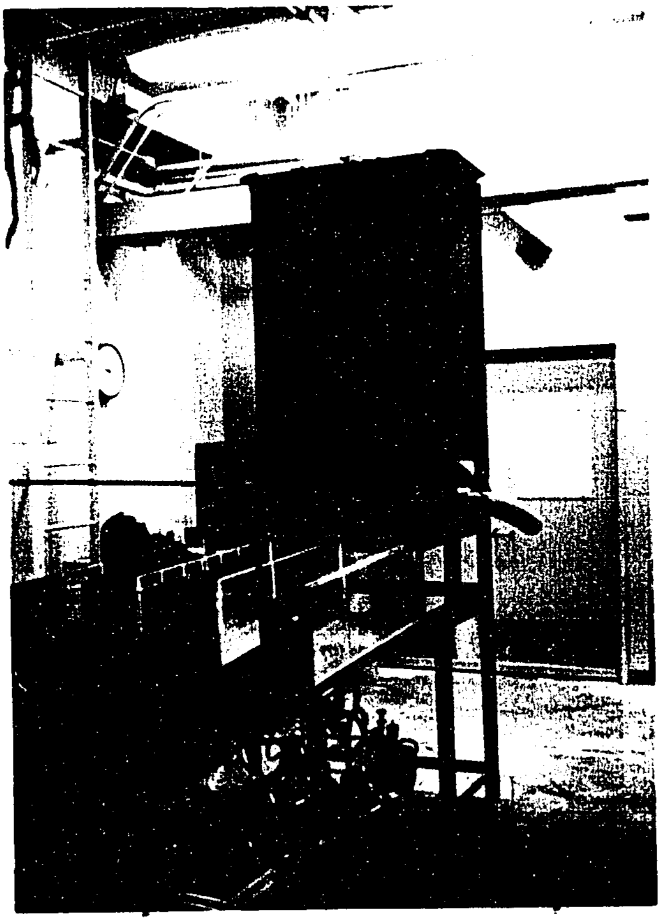

Figure A-1. Angled view of the laboratory apparatus

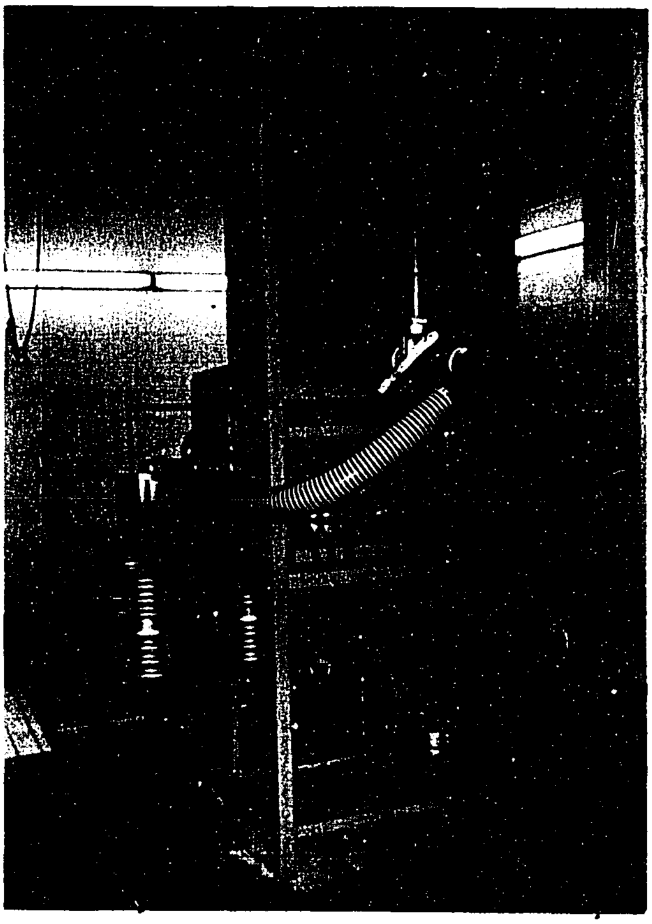

Figure A-2. View from the back of the apparatus showing gate and globe valve of the apparatus

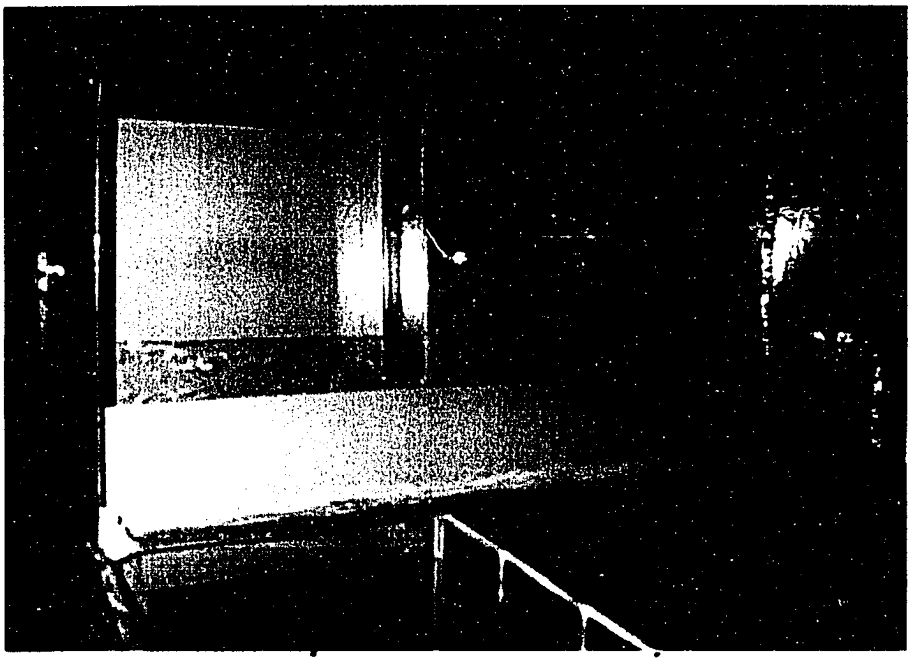

Figure A-3. View showing the v-notch of the apparatus

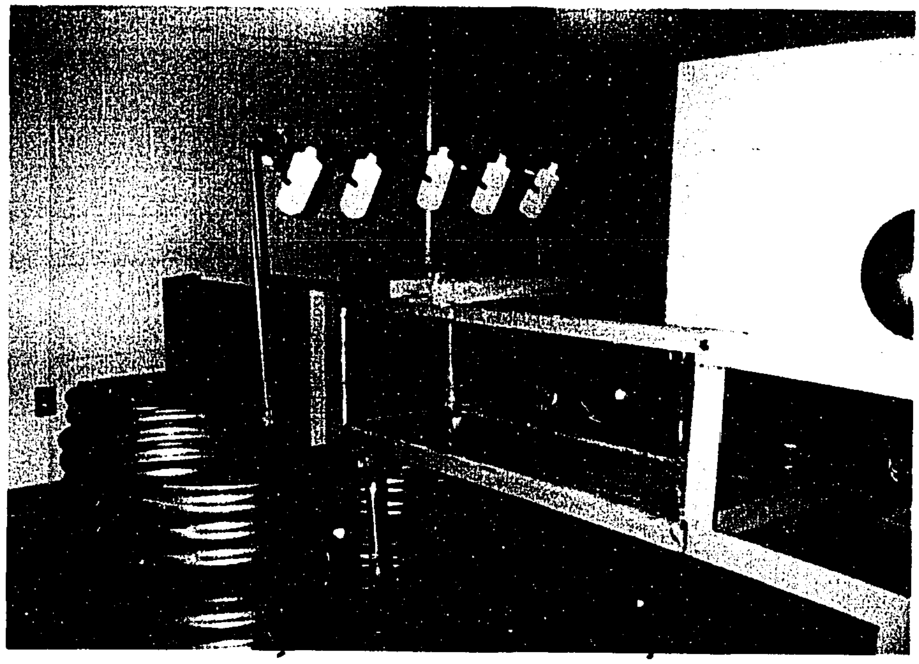

Figure A-4. View showing large containers of the apparatus

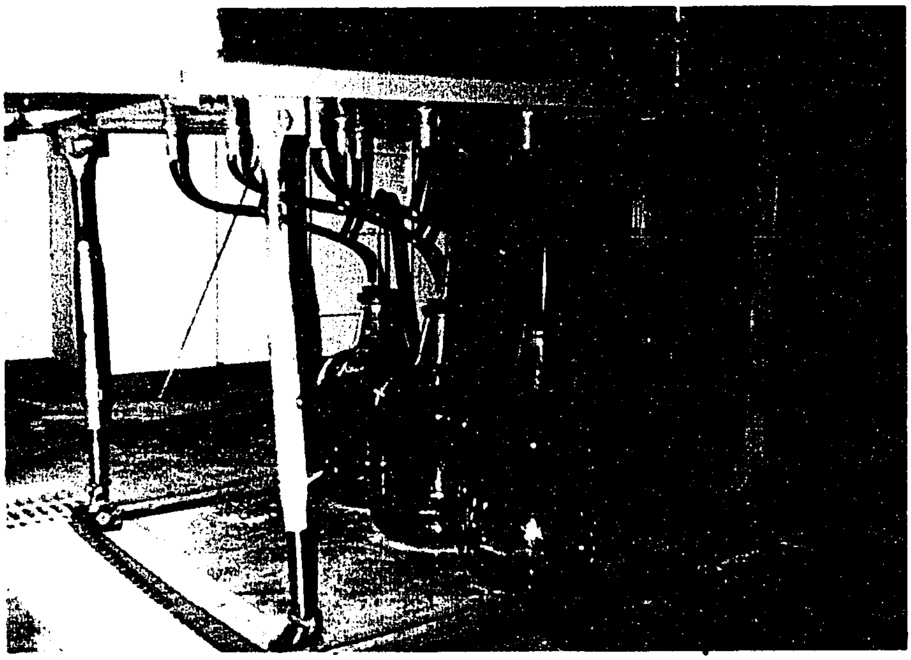

Figure A-5. View showing the large vacuum bottles

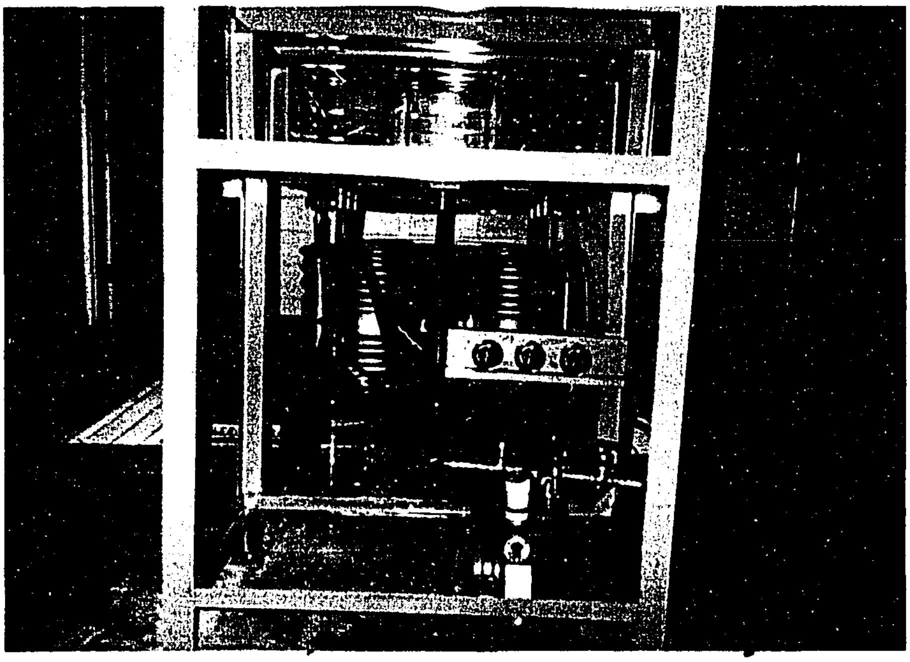

Figure A-6. View showing the vacuum pump; vacuum gauges, and vacuum hoses

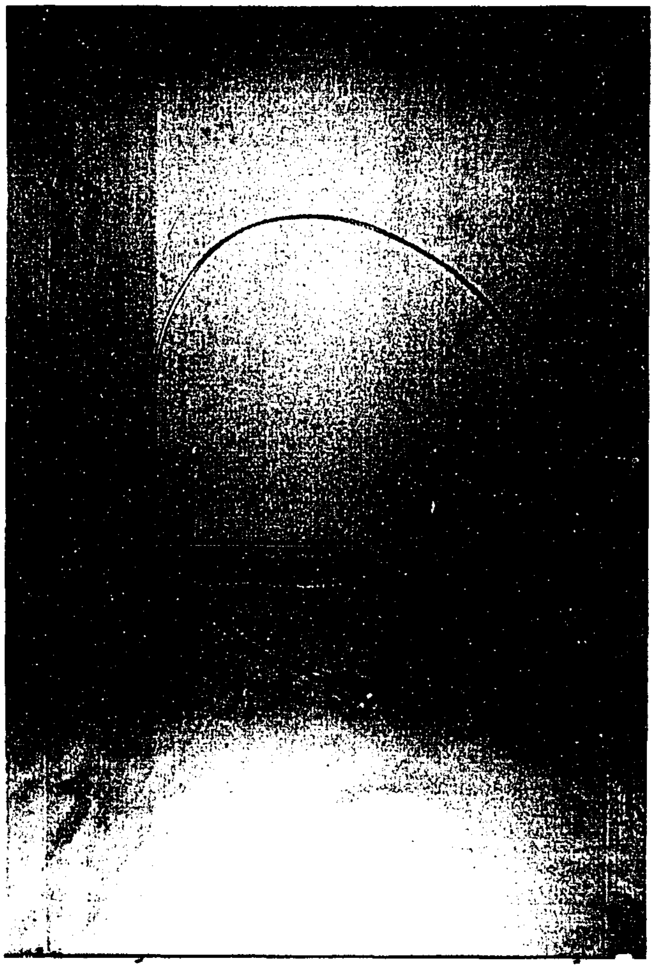

Figure A-7. View showing the tensiometer with a plain stop cock of rubber on one end and a clamp on the other

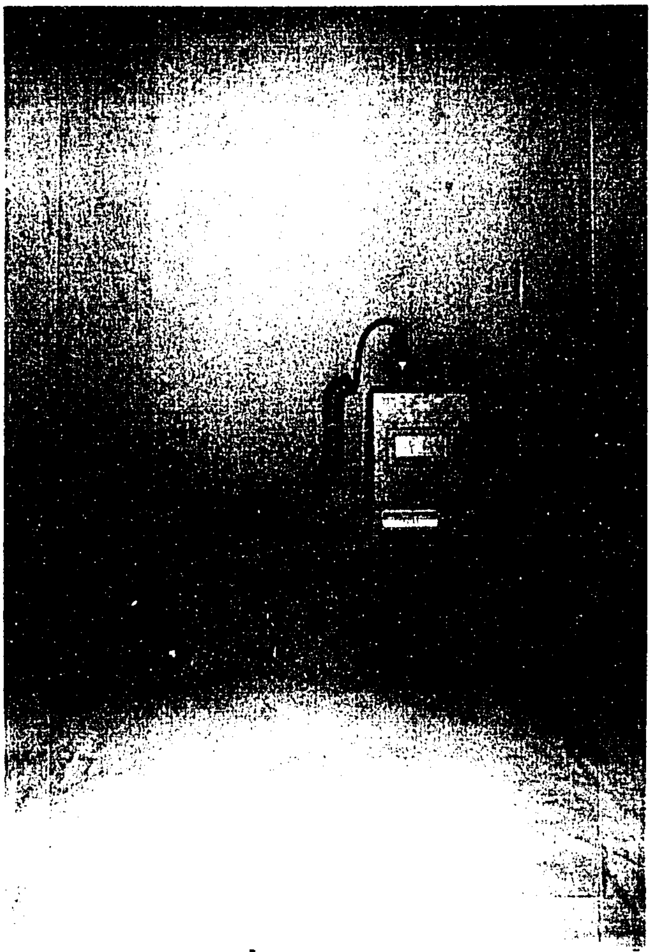

Figure A-8. View of the pressure transducer used to read the tensiometers

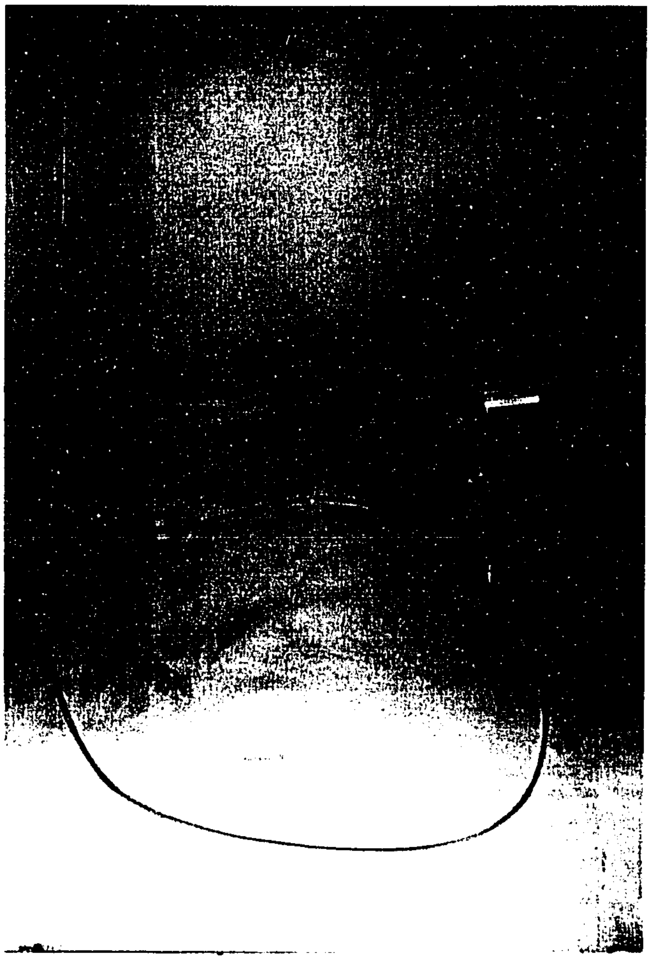

Figure A-9. View showing how pressure transducer was connected through the needle and rubber stopper with the tensiometer

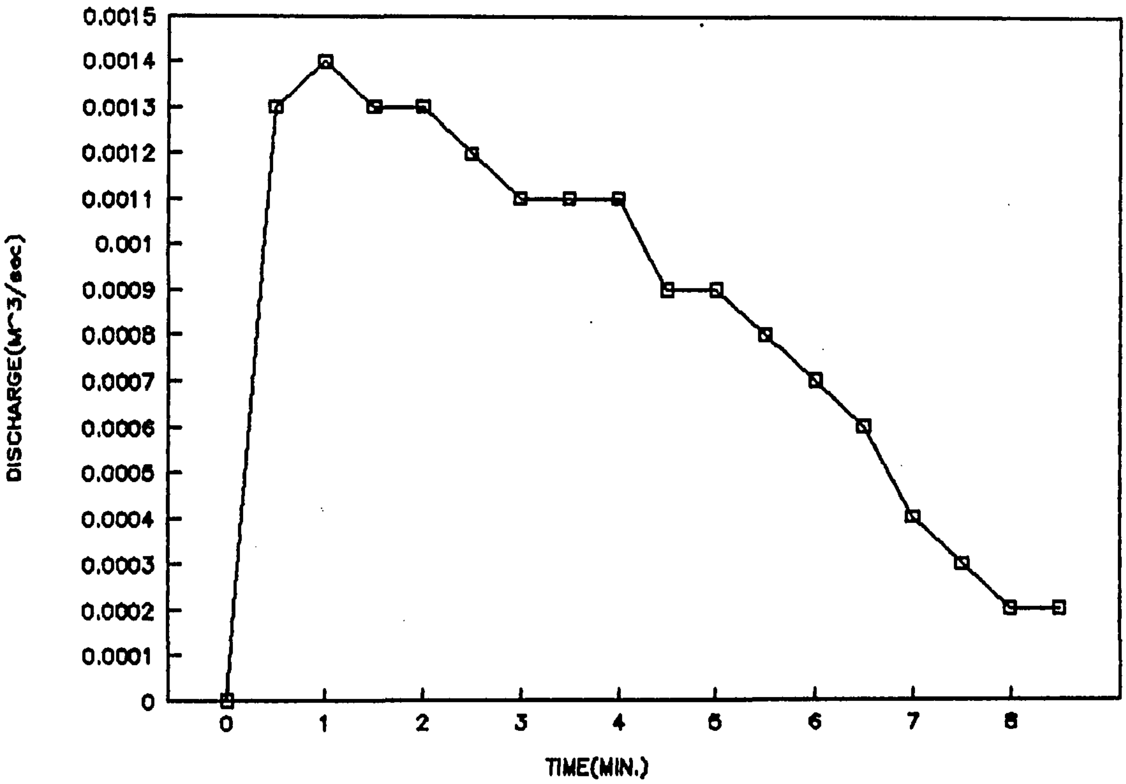

Figure A-10. Relationship between time and discharge of water through v-notch

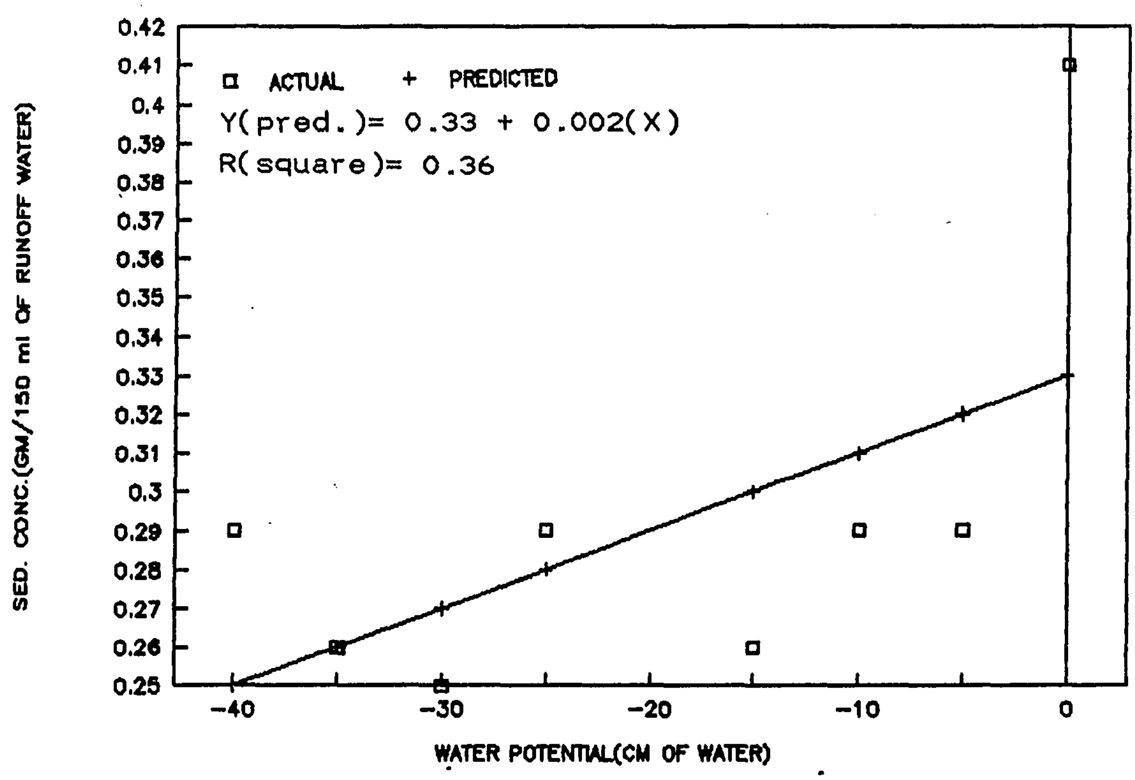

Figure A-11. Linear regression model between sediment concentration and soil water potential

SECTION II. THE EFFECT OF SOIL TEXTURE, SOIL TILTH (CROP HISTORY), AND SOIL WATER POTENTIAL ON SEDIMENT CONCENTRATION IN RUNOFF WATER.

ABSTRACT

A laboratory apparatus capable of simulating field conditions such as soil water potential, field flooding, and slope was used to study this complex process under controlled laboratory conditions.

Three textural classes (clay, silt, and sand), three tilth (or management histories) conditions (grasses, corn-soybean rotations, and corn-corn rotations), and three water potentials (0, -5 and -15 cm) were used in this study. Soil in bins was exposed to running water.

Webster (clay) soil from a grassed area had the lowest sediment concentration. On the average, sediment concentrations from clay soils were less than those from either silty or sandy soil. Similarly, -15 cm of water potential yielded less sediment than did 0 cm of water potential. Relatively large sediment concentrations were observed for corn-soybean rotations. On the whole, soils under grasses yielded lower sediment concentrations than did soils under crop rotations.

INTRODUCTION

Soil erosion is a complex process (Wilson and Rice 1972) affected by numerous factors. These factors include slope and slope length (Swanson and Dedrick 1967, Watson and Laflen 1986), intensity and distribution of rainfall and runoff events (Long and Bowie 1963), soil shear strength (Cruse and Larson 1977, Al-Durrah and Bradford 1981, Al-Durrah and Bradford 1982, Benjamin and Cruse 1985), sediment size (Foster and Meyer 1972), soil texture (Gabriels and Moldenhaner 1978), soil tilth (Monke et al. 1977), and soil water potential or pore water pressure (Francis and Cruse 1983, Truman et al. 1990).

One of the most important factors, soil shear strength, is affected by soil texture, tilth, and water potential (Cruse and Larson 1977, Francis and Cruse 1983, Monke et al. 1977).

In previous studies, scientists have tried to monitor concentrations of sediments in flooding events and to relate these concentrations both to antecedent moisture conditions and the present conditions of agricultural lands (Long and Bowie 1963). Many studies conducted in the field have provided essential information regarding certain types of erosion processes (Wilson and Rice 1987), but very few studies have been conducted in a controlled environment (Elliot 1989).

Fundamental processes can be isolated and studied separately (Wilson and Rice 1987, Foster et al. 1984a,b). Cruse and Larson (1977) have conducted basic experiments to determine the effects of soil shear strength on soil detachment due to raindrop impact. Using a wetting table, they allowed a single simulated raindrop of 4.8 mm to fall from a height of 1770 mm onto a soil core. They concluded that the amount of soil detached is closely correlated with the shearing strength of the soil and that the shear strength is altered by changes in both soil bulk density and water potential.

Making certain changes in the design of the apparatus, Al-Durrah and Bradford (1981) repeated the experiments of Cruse and Larson (1977) and reached the same conclusion, namely, that soil detachment is highly correlated with soil shear strength.

Watson and Laflen (1986) reported an experiment in which they evaluated the effect of soil strength, slope, and rainfall intensity on interrill erosion. They used a pocket penetrometer and a torvane shear device to measure both compressive strength and shear strength of the soil. They also used a rainfall simulator to test effects of different intensities of rainstorms. They found no interaction effect of slope on rate of erosion due to intensity of rainfall. They did find soil erodability closely related to soil shear strength after rainfall.

Gabriel and Moldenhauer (1978) studied two kinds of soil, one from Iowa and the other from Belgium. These soils were tested against equal intensities of simulated rainfall storms. The investigators reported that the percentage of clay being eroded was smaller than the percentage of clay in the original soils and that most striking differences were due to texture and aggregate condition of the soils.

Monke et al. (1977) used a 4x4 foot apparatus with a 2x2 foot central test section. Using different kinds of soils with normal and excellent tilth qualities, they reported that soil loss was more limited in "excellent" than in "normal" tilth soils.

Singh (1991) developed a tilth index. The objective of his study was to develop a tilth index to quantify and measure soil tilth and verify the proposed tilth index in the field. To do this, Singh (1991) used five, soil physical properties (bulk density, penetration resistance, uniformity coeficient, organic matter, and plasticity index) and developed a procedure to calculate tilth index for any soil, for which these properties are known. Singh related tilth index with crop yields, and concluded that a better tilth index indicated a better crop yield.

Using a tension table and a rainfall simulator, Francis and Cruse (1983) evaluated the effect of soil water potential on aggregate stability. Taking ten aggregates from various soil treatments, they tested these aggregates at different levels of soil water matric potentials. They used soils with different management histories and concluded that aggregate stability increases as its matric potential decreases.

The strength of soils is often described by the Mohr-Coulomb theory of soil strength (Spangler and Handy, 1982).

$$\tau = c + \sigma' \tan\phi$$

where

τ = shear strength (KPa),

c = cohesion (KPa),

σ'= effective stress normal to the plane of failure (KPa), and

ϕ = angle of internal friction (degrees).

Cohesion and angle of internal friction are characteristics of a particular soil and depend on many factors such as bulk density, particle size distribution and soil particle arrangement (Spangler and Handy, 1982).

Foster _et al_. (1984a,b) used a rainfall simulator and designed and constructed a laboratory plot, 3.7 meters wide and 10.7 meters long, to study the relation between water velocity and soil shear stress in rill hydraulics.

Wilson and Rice (1987) designed and developed a large-scale laboratory apparatus with which to study the upland erosion process. This apparatus, however, did not permit the study of water potential effects and, because of the great size of the erosion table and of the surrounding equipment, required an area roughly 9 by 15 meters.

Endeavoring to observe the mechanics of soil erosion at close range, Mahmood and Colvin (1990) designed and developed a laboratory apparatus with which to study the effects of soil texture, soil tilth (crop history), and soil water potential on sediment concentrations in flood water. The apparatus, which had a 930-by-930 mm test bin (divided into three components) and could be accommodated in a 1.2 by 4.5 meter space, was used in the current study.

OBJECTIVE

The specific objective of this study was to measure sediment concentrations (as sediment concentration is a direct measure of soil loss) in runoff water as affected by 1) soil texture, 2) soil tilth, and 3) soil water potential.

MATERIALS AND METHODS

Data were obtained by means of a laboratory apparatus designed and developed by Mahmood and Colvin (1990) and described in section I. The laboratory apparatus shown schematically in Figure 1 (see SECTION I.) had a 930-by-930 mm soil bin from which runoff was collected. Soil was uniformly packed into the bin to 220 mm depth.

The slope of the bin was maintained at 0.3 percent. The gate valve was opened two turns, so that, the level of water above the v-notch crest was maintained at approximately 60 mm , and the discharge of water running over the surface of the soil was 0.0013 m^3 s^{-1}., having a flow velocity of 0.36 m s^{-1}.

Soil cropping histories used in this study were 1) grasses, 2) corn-soybean rotations, and 3) corn-corn rotations. The histories influence soil aggregate stability (Francis and Cruse, 1983). Therefore soil with these histories seemed to be useful for testing the ability of the soils to withstand the erosive power of overland flows for a range of water potentials, soil textures, and soil tilth (crop histories) combinations. Soil textural analysis is given in Table B-10.

Differences between excellent, intermediate, and poor tilths were reflected primarily in nitrogen content (Monke et al., 1977), and tilth index (Singh et al. 1990; Singh

1991). Organic matter was determined according to the Walkey Black method (Chapman 1965). Three types of soil textural classes were used, viz., clay loam (Webster 107; Fine-loamy, mixed, mesic Typic Haplaquolls, from the Agricultural Engineering Research Farm, Ames, Iowa), silt loam (Monona 10; Fine-silty, mixed, mesic Typic Hapludolls, from the Deep Loess Research Farm, Treyner, Iowa), and sandy soil (Hanlon 536; Coarse-loamy, mixed, mesic Cumulic Hapludolls, from the Atomic Farm, Ames, Iowa). Sand, silt, and clay fractions were determined according to the hydrometer method (Day 1965).

To obtain soil from the field, three different areas with different cropping histories on the same soil type were selected. Before disturbing soils, samples of soil for bulk density and coefficient of uniformity index analysis were taken; additionaly penetrometer readings were recorded. All these data were obtained to establish a soil tilth index for a particular site. The top soil layer 130 mm was collected, the soil was allowed to air dry (if wet), and then passed through a hammer mill before placing in the test apparatus' vacuum boxes.

Different soils were packed in these boxes to different bulk densities (see Table B-1), depending upon texture and tilth. Care was taken because the bin was made of acrylic, which is delicate, and because making the bin leakproof was quite difficult. shear strength in the laboratory was determined by means of a Swedish fall cone device. Samples of ground soil were saved for coefficient of uniformity index analysis.

After soil was passed through the hammer mill and was ready for use in the vacuum boxes, tilth values for the soils were obtained. In other words, a tilth index was determined to identify changes in tilth conditions after the soils were picked up/disturbed from the field, pulverized, and hauled to the laboratory.

After soils were packed in the vacuum boxes, they were saturated with water, and a vacuum pump was used to lower soil water potentials to desired levels. When the desired level was achieved, a Swedish fall cone was used to determine penetration resistance. Water was allowed to run over the surface of the soils packed in the boxes. Three buckets were used to collect runoff water from each box. When the first bucket (A1) was filled, it was replaced with a second (A2); when the second was filled, it was replaced with a third (A3). Runoff water from each box was kept separate (See Figure A-1 SECTION I.), and the same procedure for filling buckets was repeated for all three boxes (A, B, and C) simultaneously.

A subsample from each bucket was collected according to the following method: first, the effluent in the bucket was stirred completely. Next, a 150-ml beaker was used to take a sample from the center of each. These samples of runoff water were poured into aluminum cans, which were placed in the oven for 24 hours at 105 degrees C. On the next day, the cans were taken out of the oven. Sediments were carefully removed, and their weights recorded. An average mass of sediments from subsamples A1, A2, and A3 was reported. This average mass was used to represent sediment discharge form box A. The same procedure was repeated for boxes B and C.

EXPERIMENTAL DESIGN

A completely randomized split plot experimental design with three replications was used. Treatments were randomly assigned to three main plots (the three vacuum boxes of the laboratory apparatus introduced in Section I). Each treatment was composed of a texture and tilth combination. Three levels of texture (clay loam, silt loam, and sand loam), and three levels of tilth or crop histories (grass, corn-soybean, and corn-corn) were selected to make nine treatments, but because one tilth (corn-corn on sand) was not available near Ames, Iowa, a total of eight treatment (texture and tilth) combinations was used. Three levels (0, -5, and -15 cm) of water potential were also used. These increments, randomly developed in the soil placed in the three vacuum boxes of the laboratory apparatus, were considered subplots within each main plot. Eight treatments, viz., T1N1 (clay under grass), T1N2 (clay under corn-soybean), T1N3 (clay under corn-corn), T2N1 (silt under grass), T2N2 (silt under corn-corn), T2N1 (silt under corn-corn), T3N1 (sand under grass), and T3N2 (sand under corn-soybean), were replicated three times in a completely randomized fashion. To test for significant differences between treatment means, Duncan's test of significance was used whenever a significant F-statistic was found.

Procedure Description

Three randomized soil combinations of texture and tilth out of 24 combinations (as the corn-corn rotation was missing for sandy soil) were chosen, and each was placed in a separate box. The soil was saturated, and suction by means of a vacuum pump was applied to lower water potential to preselected randomized first values (out of 0, -5 and -15 cm) of water potential. At this stage, simulated runoff from the hydraulic tank of the laboratory apparatus was allowed to flow over the surface of the soil in the bin, and sediment-loaded runoff was collected. For the second randomized value of water potential (out of 0, -5 and -15 cm), a 50 mm layer of the soil was removed from each box and replaced with appropriate fresh soil. Soil was again saturated and suction applied with a vacuum pump to bring water potential to the randomly selected second value (out of 0, -5, or -15cm) of water potential. Again, the runoff water was allowed to flow on the surface of the soil. Similarly, for a third time, the remaining third and last value (out of 0, -5 and -15 cm) of water potential was developed in each box of the bin.

After testing the third and last value of water potential, the total soil from all three boxes was removed. The boxes were filled with the next [(4th, 5th, and 6th) for example] combinations (see Table 1) of texture and tilth (out of 24 combinations), and the procedure was repeated, to the 24th combination.

Table 1. Different combinations of texture and crop histories (tilth)

1.	T1N1 (1)	13.	T2N2 (2)
2.	T1N2 (1)	14.	T2N3 (2)
3.	T1N3 (1)	15.	T3N1 (2)
4.	T2N1 (1)	16.	T3N2 (2)
5.	T2N2 (1)	17.	T1N1 (3)
6.	T2N3 (1)	18.	T1N2 (3)
7.	T3N1 (1)	19.	T1N3 (3)
8.	T3N2 (1)	20.	T2N1 (3)
9.	T1N1 (2)	21.	T2N2 (3)
10.	T1N2 (2)	22.	T2N3 (3)
11.	T1N3 (2)	23.	T3N1 (3)
12.	T2N1 (2)	24.	T3N2 (3)

T1 = WEBSTER 107 (CLAY)
T2 = MONONA 10 (SILT)
T3 = HANLON 536 (SAND)
N1 = GRASS
N2 = CORN-SOYBEAN
N3 = CORN-CORN
1 = REPLICATION ONE
2 = REPLICATION TWO
3 = REPLICATION THREE

RESULTS AND DISCUSSIONS

Bulk Density

Before soil was disturbed, bulk density samples at all field locations were collected. Bulk density was calculated on a dry weight basis; data are presented in table B-1 and in Figure B-2. The illustration also show bulk density data for laboratory conditions, under which bulk density was calculated on a dry weight basis after the soil was collected from the field, passed through the hammer mill, and placed in vacuum boxes at the maximum compaction possible. When the box volume and the dry soil weight packed in the vacuum box was known, the bulk density for laboratory conditions were calculated. Table B-1 and Figure B-2 illustrate the bulk density (dry basis) of the soil under both field and laboratory condition. Both table and figure show that there is a great difference in terms of bulk density for field and for laboratory conditions. This was so because we could not pack the soil well in the laboratory apparatus to obtain bulk densities close to field conditions, because the apparatus was delicate and leakage might have occured. If leakage did occur, the apparatus would not have been able to maintain a vacuum and as such it would have been impossible to use the apparatus to achieve the objective for which it was designed. The results of bulk densities given in Table B-1 and in Figure B-2 are inconsistent in terms of supporting the results shown in Figure 3.

Penetration Resistance

Before soil was disturbed in the field, penetration resistance was measure at three depths. A digital penetrometer was used for this purpose. The average penetration resistance calculated and the relevant penetration data are shown in Table B-2. For laboratory conditions, a fall cone device was used to determine penetration in the soil after the soil was disturbed, passed through the hammer mill, and finally packed in the vacuum boxes of the apparatus. For the laboratory, penetration was measured after the soil reached a certain water potential level (0, -5 or, -15 cm). Again, when values for Table B-2 are compared with those for Figure 3, penetration resistance data do not support our sediment loss results.

Nitrogen Content

Table B-3 and Figure B-3 illustrate a relation between different texture and tilth (crop history) combinations and total nitrogen percentage. Total nitrogen was obtained by multiplying percentage nitrogen (of the sample) by 20 (Buckman and Brady, 1969). Table B-3, Figure B-3 and 3 generally shows a decrease in nitrogen as the texture and tilth combinations go from clay under grass to sand under corn-soybean and a general increase in sediment concentration.

Uniformity Coefficient

When bulk density samples were taken, samples of soils in the field and in the laboratory were saved for uniformity coefficient (UC) analyses. Table B-4 shows the uniformity coefficient values for laboratory and for field soils. The purpose for finding UC's was ultimately to calculate tilth index values for both types of soil.

Plasticity Index

Plasticity index values are given in Table B-6B. These values for different kinds of soils are taken directly from soil survey reports of counties from which soil was taken for experiments.

Tilth Index

Based on bulk density data, penetration resistance, nitrogen content, uniformity coefficient, and plasticity index, the soil tilth index was calculated by the procedure described by Singh (1991). Tables B-6A and B-6B and Figure B-1 show a relation between different texture and tilth (crop history) combinations and soil tilth index values for field and laboratory conditions. Tilth indices for field and laboratory conditions are not statistically different from each other at 5 % level. By comparing Figure 3 and Figure B-1, it is clear that tilth index is not consistent in supporting results of this experiment (see Figure 3 and B-1), since T1N2 (clay under corn-soybean), T2N2 (silt under corn-soybean) and T2N3 (silt under corn-corn) have comparatively high tilth index values (see Figure B-1), but inspite of high tilth index values these combinations yielded high sediment concentrations in runoff water (see Figure 3).

To permit observation of the effect of soil tilth index on sediment concentration, regression models were developed for all three levels of soil water potential (that is 0, -5 and -15 cm of water). These models show that average sediment concentration decreases linearly with increase in soil tilth index. Figure B-23 shows the linear regression equation and the model for sediment concentration as a function of soil tilth index for 0 cm of water potential.

Because a great decrease in sediment concentration for each successive increment of soil tilth index was observed for 0 cm of water potential, the slope of the regression line between sediment concentration and soil tilth index was relatively great. A normal correlation was obtained between sediment concentration and soil tilth index for 0 cm of water potential. The coefficient of determination (r^2) for this relation was 0.15.

Figure B-24 shows the linear regression equation and the model for sediment concentration as a function of soil tilth index for -5 cm of water potential. Again, the slope of the regression line is great, which indicates that for each successive increment of soil tilth index, there is a significant decrease in sediment concentration. A good correlation was obtained between sediment concentration and soil tilth index. The coefficient of determination (r^2) for this relation was 0.27.

Figure B-25 shows the linear regression equation and the model for sediment concentration as a function of soil tilth index for -15 cm of water potential. In this instance, the slope of the regression line indicates that for each successive increment of soil tilth index, there is a significance decrease in sediment concentration. A good correlation was obtained between sediment concentration and soil tilth index. The coefficient of determination (r^2) for this relation was 0.33.

Effect of Texture and Tilth (Crop History) Combinations on Sediment Concentration

Table B-9 presents results for the analysis of variance, including main plot effects, which are texture and tilth (C) combinations, with seven degrees of freedom, and subplot effects, which are water potentials (W) with two degrees of freedom. Both main plot and subplot effects have highly significant F values, namely 559.78 and 1354. 88, respectively. These values are greater than tabulated F values at both the 5% and the 1% level (see Table B-9).

It can therefore be asserted that there exist real differences in terms of the amount of sediment concentration collected from texture and tilth (TN) combinations, as well as from water potentials. Additionally, the interaction of main plot (texture and tilth) effects and subplot (water potential) effects has an F value of 102.58, which is higher than the tabulated F value at both the 5% and the 1% level. This highly significant F value shows that indeed there exist real differences in sediment collected when going from one interaction to another of main plot and subplot effects (see Table B-9). Thus, we reject the null hypothesis (according to null hypothesis, the difference between means of all the treatments is zero) for all main plot, subplot, and main/subplot interaction effects.

When all main plot, subplot, and main/subplot interaction effects (see Table B-9) were found statistically significant, we performed a Duncan's multiple range test (DMRT). The purpose of performing the DMRT (see Table B-11) was to find out whether or not there exist significant differences among the means of all eight (texture and tilth) combinations.

From Table B-11, it is clear that combinations T3N2 (sand under corn-soybean), T2N3 (silt under corn-corn), and T2N2 (silt under corn-soybean) fall in the same group; therefore, the means of these combinations are not statistically different from each other. Combinations T2N1 (silt under grass) and T1N3 (clay under corn-corn) form a second group (see Table B-11), and none of the means of these two combinations are statistically different from each other at the 5 percent level. But when these two groups are compared with other combinations such as T3N1 (sand under grass), T1N2 (clay under corn-soybean), or T1N1 (clay under grass), they all are statistically different from one another at the 5 percent level.

Among all combinations depicted in Table B-11, the combinations of group one, i.e., T3N2 (sand under corn-soybean), T2N3 (silt under corn-corn), and T2N2 (silt under corn-soybean), yielded the highest sediment concentrations. This is so because when DMRT is calculated, all combinations are arranged in ascending order (based on mean sediment concentration), that is, from highest to lowest sediment concentrations. As such, the mean sediment concentration of the last combination of T1N1 (clay under grass) in the list shown in Table B-11 was the lowest of all.

To substantiate our results, we attempted to plot (see Figures 3, B-4, B-5, B-6, 4, and 5) mean sediment concentration (dependent variable) values against texture and tilth combinations (TN) for three levels of water potential (0, -5, and -15 cm water). It can be seen that Figure 3 does not support the results of Table B-11 (DMRT). The lowest sediment concentration was observed in T1N1 (clay under grass), as shown in Table B-11.

Average maximum sediment concentrations were observed in T2N2 (silt under corn-soybean), T2N3 (silt under corn-corn), and T3N2 (silt under corn-soybean); these combinations, as shown in Table B-11, have means not significantly different from one another and have the highest sediment concentrations of all eight combinations.

The second highest combination in the list is T3N1 (sand under grass), as is clear from Figure 3 and Table B-11. In Table B-11, T3N1 has the second highest sediment concentration, with a significantly different mean from the other combinations. The third highest average sediment concentrations, as is clear from Figure 3, is T1N2 (clay under corn-soybean); this fact is also supported by Table B-11. The fourth highest average sediment concentration, as can be seen in Figure 3, seems to be combinations T1N3 (clay under corn-corn) and T2N1 (silt under grass); this fact is again supported by Table B-11, in which T2N1 (silt under grass) and T1N3 (clay under corn-corn) are of the same group.

The letters A, B, C, D, and E in Table B-11 signify that the mean sediment concentrations of these combinations or groups of combinations are significantly different from each other. Thus, Figure 3 supports the findings of Table B-11.

The differences among combinations (T1N1 to T3N2 as independent variables) become clear as we observe Figures B-8 and B-9, which are plotted using mean sediment concentration values in Table B-8. Figure 4 shows a relation between soil textures and mean sediment concentrations for three levels (0, -5, -15) of water potential. It is clear from Figure 4 that, overall, clay

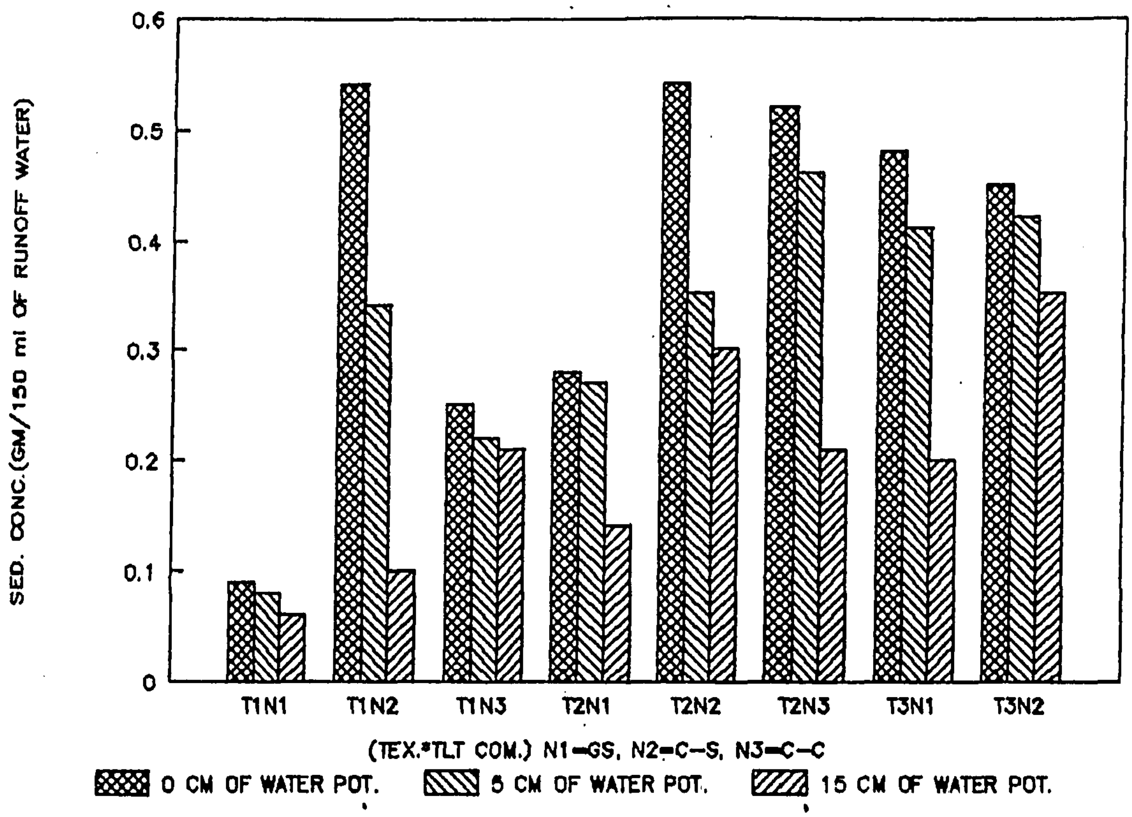

Figure 3. Relationship between texture and tilth (crop history) combinations and sediment concentrations

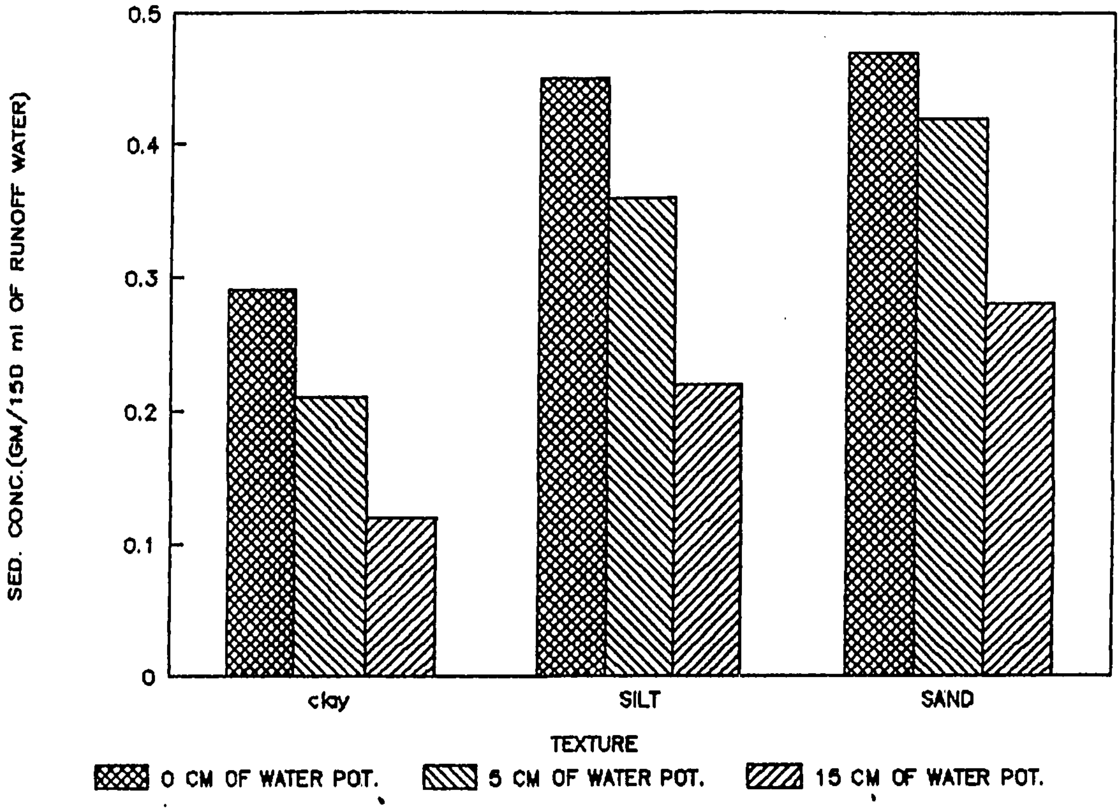

Figure 4. Relationship between soil texture and total mean sediment concentration for different water potentials

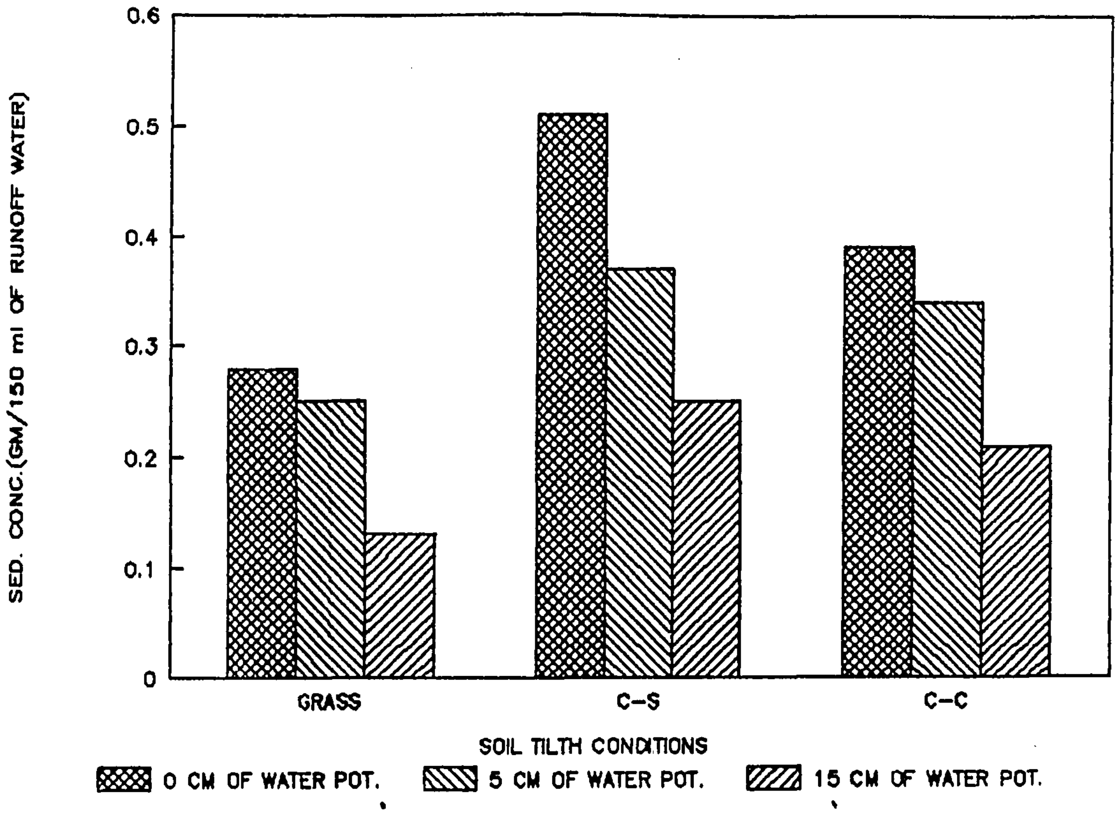

Figure 5. Relationship between different crop histories and total mean sediment concentrations for different water potentials

soils had lower sediment concentrations than did silty or sandy soils. Additionally, silty and sandy soils yielded very similar average sediment concentrations (see Figure 4).

Figure 5 illustrates a relation between crop histories (tilth) and sediment concentration for three levels (0, -5, and -15 cm) of water potentials. Clearly, grasses in almost all instances yielded lower sediment concentrations than did either corn-soybean or corn-corn combinations. Additionally, the corn-soybean combinations usually yielded relatively high sediment concentrations.

Figure B-4 illustrates a relation between texture and sediment concentration for three crop histories (grass, corn-soybean, and corn-corn) at zero cm water potential. At this water potential, corn-soybean rotation yields relatively high sediment concentrations for all textures (clay, silt, and sand). In grasses, sediment concentration increases from clay to silt and finally to sandy soils. Similarly, for corn-corn rotation, sediment concentration increases from clay to silt soils. Thus, for grasses and corn-corn rotations, fine textured soils (clay) yielded lower concentrations than did either medium (silty) or coarse textured (sandy) soils at 0 cm water potential.

Figure B-5 illustrates a relation between texture and sediment concentration for three crop histories (grass, corn-soybean, and corn-corn) at -5 cm water potential. At this water potential, sediment concentration for grasses increased from clay to silt soils, but decreased from clay to sand. For corn-soybean rotations, the sediment concentration increased from clay to silt to sandy soils. For corn-corn rotations, both clay and silt soils yielded approximately equivalent sediment concentrations.

Figure B-6 shows a relation between soil texture and mean sediment concentration for three levels of crop histories at -15 cm water potential. Evidently, sediment concentration for grasses increased from claylike to silty to sandy textured soils. Additionally, sediment concentration increases for corn-soybean rotation history from clay to silt to sand textured soils. Sediment concentrations for corn-corn rotations were approximately equivalent for clay and silt textured soils.

Table B-13 shows the summary of significance levels of least significance difference $(Lsd)^{0.05}$ test for the effect of texture and tilth (crop history) on sediment concentration. It is clear from the table that for the texture the least significance differences among clay versus silt, clay versus sand and silt versus sand are all statistically significant (at 5 percent level) for 0, -5 and -15 cm of water potential. Similarly for tilth (crop history) the least significance differences (Lsd) among grass versus corn-soybean, grass versus corn-corn were significant (at 5 percent level) for 0, -5 and -15 cm of water potential. However when corn-soybean versus corn-corn were evaluated for least significant difference test, it was found that Lsd value [for this relation (c-s v/s c-c)] was only significant for 0 cm of water potential, but it was not significant for -5 and -15 cm of water potential (see Table B-13).

As a result of evaluation of the effect of texture and tilth (crop history) on sediment concentration, it was concluded that sediment concentration was higher in silty and sandy soils than in claylike soils for all three water potentials. In similar studies, Meyer and Harmon (1984), Wischmeir and Mannering (1969), Meyer and Harmon (1979), Meyer et al. (1980), and Rhoton et al. (1982) confirm that erosion from medium texture (silt) and coarse texture (sand) was more than that from fine texture (clay) soil.

In their opinion, fine textured soil tends to be cohesive and difficult to detach, and particles usually consist of sizable aggregates; coarse texture soils, on the other hand, tend to be relatively easy to detach although their sediments are difficult to transport; and medium textured soils tend to be easiest to detach and to transport.

The same phenomena were confirmed in this study although rainfall was not used as an erosive agent; only flood water was; and although it was found that sediment concentration obtained from sandy and silty soils was more than that obtained from claylike soils. In similar studies Meyer and Harmon (1984), studied the susceptibility of 18 soils to interrill erosion.

These investigators concluded that silt and silt loam soils were the most erodible, that clay soils were the least erodible, and that sandy soils fell somewhere in between. The most probable reason for their finding is that because claylike soils are fine in texture, they form strong aggregates (except in the case of corn-soybean rotation); whereas medium textured (silt) and coarse textured (sand) soils are loosely bound, and hence when the momentum of overland flow interacts with these particles, they are easily transported.

Regarding crop history (tilth), the corn-soybean rotation yielded the greatest sediment concentration, the corn-corn rotation yielded the next greatest concentration, and grasses in almost all treatments yielded the lowest sediment concentrations for all three water potentials. In similar studies carried out by Ellsworth et al. (1991), Oschwald and Siemens (1976), Laflen and Moldenhaur (1979), Browning et al. (1942), Albert et al. (1985), Albert and

Wendy (1985), Fahad et al. (1982), and Bathke and Blake (1984), erosion from a soil under corn-soybean rotation is high.

All these researchers are of the opinion that the main cause of high erosion rates from the fields of corn-soybean rotation is that soil under corn-soybean cultivation becomes loose and thus relatively vulnerable to the erosive power of rain or of flooding water. In this study, too, almost all sediment concentrations were higher in corn-soybean rotations than in corn-corn rotations or in grasses.

Browning et al. (1942) attributed the loosening effect of soybean cultivation to the plant's canopy effect, to the desiccating action of roots, and to the kind of aggregation resulting from the decomposition of tops, roots, and nodules of soybean plants. In this study, the effect may have occurred because, in addition to the loosening effect on the soil of the corn-soybean rotation, surface crusting blocked soil pores, which in turn increased surface runoff, therefore as the volume of water running over the surface of soil was more, it carried more momentum, thus had more erosive power, as such yielding more sediment concentration specially in cases where the soil is in loose condition (such as soil under corn-soybean rotation).

Effect of Water Potential on Sediment Concentration

Table B-9 summarizes significance levels for the ANOVA of the effects of texture and crop histories (C) and of water potentials (W) on sediment concentration. Water potential in the subplot effect with two degrees of freedom has a highly significant F value, namely 1354.88, which confirms that real differences exist in terms of the amount of sediment concentration collected from one water potential level to another. Thus, we reject the null hypothesis (according to null hypothesis, the difference between means of all the treatments is zero).

Because the water potential effect was significant, a Duncan's multiple range test (DMRT) was performed to determine whether any real differences existed among treatment means at all three water potential levels. Table B-12 shows Duncan's grouping for the water potential treatments. The table illustrates that mean sediment concentrations collected for the three water potential levels are all significantly different from one another at the 5 percent level.

Figure 3 elaborates on the effect of water potential, illustrating a relation between texture and tilth (crop history) combinations and sediment concentration. Starting from T1N1 (clay under grass) to T3N2 (sand under corn-soybean) on the x-axis, in almost all instances sediment concentration decreases with water potential. Additionally, for all combinations, T1N2 (clay under corn-soybean) and T2N2 (silt under corn-soybean) are seemingly most affected by a change in water potential.

The most probable reason for this effect is that clay and silt are fine and medium textured soils and therefore their particles are relatively light and easy to transport. Moreover, corn-soybean cultivation has a loosening effect on soil, and this effect may be the result of either the kind of nitrogen fixed in the soil or the root proliferation patterns of soybean plants. Yet these chemical and biological processes taking place under soybean cultivation are not well understood.

Because of the aforementioned loosening effect under corn-soybean rotation, clay and silt particles are not well bound together to form aggregates, and hence these relatively loose particles are easily transported by flowing water. Particles are easily transported when soils are saturated (at 0 cm of water potential), because the critical shear stress at this point is quite limited and it is quite easy for the flowing water to carry with it any particles lying its way.

But when the water potential of the soil drops, the internal friction of particles increases, the critical shear stress increases, and it becomes less likely that the flowing water will detach particles with its momentum. Hence, when water potential decreases, sediment concentration in runoff water decreases simultaneously, a relation quite evident in both T1N2 (clay under corn-soybean) and T2N2 (silt under corn-soybean).

Figures B-4, B-5, and B-6 illustrate the relation between soil texture and mean sediment concentration for different crop histories as affected by three water potential levels, namely 0 cm (Figure B-4), -5 cm (Figure B-5), and -15 cm (Figure B-6). When these figures are compared, it is evident that the overall maximum sediment concentration in Figure B-4 is 0.54 gram per 150 ml runoff water (which is for corn-soybean rotation on silt), that the overall maximum sediment concentration in Figure B-5 is 0.46 gram per 150 ml runoff water (which is for corn-corn rotation on silt), and that the overall maximum sediment concentration of Figure B-6 is 0.35 gram per 150 ml runoff water (which is for corn-soybean rotation on sand). Clearly, as water potential decreases from 0 to -5 to -15 cm of water, overall maximum sediment concentration decreases from 0.54 to 0.46 and to 0.25 grams per 150 ml runoff water, irrespective of texture or tilth (crop history).

In Figures B-4 and B-5, the water potential effect was separated according to texture and tilth, respectively. In these figures, the mean of sediment concentration was plotted against texture (clay, silt, and sand) and crop history (grass, corn-soybean rotation, and corn-corn rotation). In Figures B-4 and B-5, it is evident once again that in each texture and tilth, the sediment concentration decreases from 0 to -5 to -15 cm water potential.

To permit observation of the effect of soil water potential on sediment concentration, regression models were developed for all eight tilth and texture combinations. These models show that average sediment concentration decreases linearly with soil water potential. Figure B-7 shows the linear regression equation and the model for sediment concentration as a function of soil water potential for T1N1 (clay under grass).

Because a great decrease in sediment concentration for each successive increment of water potential was observed for T1N1 (clay under grass), the slope of the regression line between sediment concentration and water potential was relatively great. The best correlation was obtained between sediment concentration and water potential for T1N1 (clay under grass). The coefficient of determination (r^2) for this relation was 1.0.

Figure B-8 shows the linear regression equation and the model for sediment concentration as a function of soil water potential for T1N2 (clay under soybean). Again, the slope of the regression line is great, which indicates that for each successive increment of water potential, there is a significant decrease in sediment concentration. The best correlation was obtained between sediment concentration and water potential. The coefficient of determination (r^2) for this relation was 0.98.

Figure B-9 shows the linear regression equation and the model for sediment concentration as a function of soil water potential for T1N3 (clay under corn-corn). In this instance, the slope of the regression line indicates once again that sediment concentration decreases with soil water potential. A good correlation was obtained between sediment concentration and water potential. The coefficient of determination (r^2) for this correlation was 0.79.

Figure B-10 shows the linear regression equation and the model for sediment concentration as a function of soil water potential for T2N1 (silt under grass). The slope of the regression line indicates that for each successive increment of water potential there is a decrease in sediment concentration. The best correlation was obtained between sediment concentration and water potential. The coefficient of determination (r^2) for this relation was 0.93.

Figure B-11 shows the linear regression equation and the model for sediment concentration as a function of soil water potential for T2N2 (silt under grass). The slopes of the regression line in this case and in the case of T1N3 (clay under corn-corn) show approximately the same change in sediment concentration for each successive incremental decrease in water potential. The same degree of correlation between sediment concentration and water potential was found in T1N3 (clay under corn-corn). The coefficient of determination (r^2) for this relation was 0.76.

Figure B-12 shows the linear regression equation and the model for sediment concentration as a function of soil water potential for T2N3 (silt under corn-corn). The slope of the regression line is similar to both that of T1N2 (clay under corn-soybean) and that of T2N1 (silt under corn-corn). Again, the slope of the regression line confirms that for every successive increment of water potential there is a decrease in sediment concentration. Again, a good correlation was found between sediment concentration and water potential of the soil inasmuch as the coefficient of determination (r^2) was 0.98.

Figures B-13 and B-14 show linear regression equations and models for T3N1 (sand under grass) and T3N2 (sand under corn-soybean rotation), respectively. The slope of these regression lines indicate that for each successive increment decrease in water potential there is a definite decrease in sediment concentration. A good correlation was found between sediment concentration and water potential of the soil. The coefficient of determination (r^2) for these cases were 0.99 for T3N1 and 0.99 for T3N2.

Figure B-26 shows the linear regression equation and the model for sediment concentration as a function of soil water potential for all texture and tilth (crop history) combinations. The slope of the regression line indicates that for each successive increment of water potential there is a decrease in sediment concentration. When data from all texture and tilth (crop history) combinations were pooled and when a regression model was developed for the data (pooled), a normal correlation still existed between sediment concentration and water potential. The coefficient of determination (r^2) for this relation was 0.29.

To permit observation of the effect of soil water potential on shear strength of the soil (measured by using fall cone device), regression models were developed for all eight tilth and texture combinations. These models show that average shear strength increases linearly with soil water potential. Figure B-15 shows the linear regression equation and the model for shear strength as a function of soil water potential for T1N1 (clay under grass).

Because a great increase in shear strength for each successive increment of water potential was observed for T1N1 (clay under grass), the slope of the regression line between shear strength and water potential was relatively great. The best correlation was obtained between shear strength and water potential for T1N1 (clay under grass). The coefficient of determination (r^2) for this relation was 0.96.

Figure B-16 shows the linear regression equation and the model for shear strength as a function of soil water potential for T1N2 (clay under soybean). Again, the slope of the regression line is great, which indicates that for each successive increment of water potential, there is a significant increase in shear strength. The best correlation was obtained between shear strength and water potential. The coefficient of determination (r^2) for this relation was 0.93.

Figure B-17 shows the linear regression equation and the model for shear strength as a function of soil water potential for T1N3 (clay under corn-corn). In this instance, the slope of the regression line indicates that shear strength partially increases with soil water potential. As such a poor correlation was obtained between shear strength and water potential. The coefficient of determination (r^2) for this correlation was 0.075. The cause for this poor correlation was unknown.

Figure B-18 shows the linear regression equation and the model for shear strength as a function of soil water potential for T2N1 (silt under grass). The slope of the regression line indicates that for each successive increment of water potential there is an increase in shear strength. About normal correlation was obtained between shear strength and water potential. The coefficient of determination (r^2) for this relation was 0.49.

Figure B-19 shows the linear regression equation and the model for shear strength as a function of soil water potential for T2N2 (silt under grass). The slopes of the regression line indicates that for each successive increment of water potential there is an increase in shear strength of the soil. A good correlation between shear strength and water potential was found in T1N3 (clay under corn-corn). The coefficient of determination (r^2) for this relation was 0.79.

Figure B-20 shows the linear regression equation and the model for shear strength as a function of soil water potential for T2N3 (silt under corn-corn). The slope of the regression line confirms that for every successive increment of water potential there is an increase in shear strength. Again, a good correlation was found between shear strength and water potential of the soil. The coefficient of determination (r^2) for this relation was 0.86.

Figures B-21 and B-22 show linear regression equations and models for T3N1 (sand under grass) and T3N2 (sand under corn-soybean rotation), respectively. The slope of these regression lines indicate that for each successive increment decrease in water potential there is a definite increase in shear strength. A good correlation was found between shear strength and water potential of the soil. The coefficient of determination (r^2) for these cases were 0.97 for T3N1 and 1.0 for T3N2.

It is concluded that there is a definite decrease in the amount of sediment collected, irrespective of texture and crop history, when going from 0 to -5 to -15 cm water potential, as because the shear strength of the soil increases, hence it becomes harder for the runoff water to detach particales from the soil mass. In similar studies, Cruse and Larson (1977), Al-Durrah et al. (1981,1982), Francis and Cruse (1983), Benjamin and Cruse (1985), and Trueman et al. (1990) confirm that soil detachment decreases and soil's shear strength increases with decrease in water potential. All these researchers are of the opinion that shear strength of soil particles increases as water potential decreases and that therefore the soil becomes more resistant to the erosive power of both rain and flowing water.

This study confirms that there is a decrease in sediment concentration when water potential decreases. A possible explanation of this effect is that when water potential decreases due to the vacuum applied, there is a suction effect on the whole soil mass, and as water drains out of soil macropores, soil mass shrinks (more at -15 cm than at 0 cm water potential), which increases the particle to particle contact. Hence, the internal cohesive forces between particles increase, which in turn increases the shear strength of the soil. The water flowing on the surface of the soil has a shear velocity, and to detach and transport the soil particle, the shear velocity must overcome the critical shear stress of the particle.

To oppose deformation due to this shear velocity, particles resist (due to their weight) on the surface of the soil in the opposite direction. The shear stress on the soil surface increases as the velocity and the density of runoff water increases. Because shear velocity is directly proportional to the square root of shear stress, and as shear stress and shear velocity act in same directions. Therefore shear velocity can dominate only in detachment and transport of soil particles when the shear velocity acting on the soil surface increases shear stress (bed) greater than the critical shear stress of the soil particles (Vanoni, 1977). This effect is easy to achieve when soil is at saturation (that is at 0 cm of water potential), since particles are loosely bonded and their crtical shear stress, to set them in motion is low. Hence as the shear velocity overcomes the critical shear stress of the particles, they start moving (as is the case when the soil has 0 cm water potential). However, on the other hand, due to the great internal friction between particles at -15 cm water potential, the shear strength among particles on the surface layer is high and hence shear velocity cannot do much damage to soils in terms of detachment and transport of soil particles. Thus, we obtained lower sediment concentrations at -15 cm than at either -5 or 0 cm water potential.

A special technique for removing 50 mm of the soil layer was used (see experimental procedures) to avoid hauling huge masses of soil. The data obtained demonstrated that there was a difference only of plus or minus 0.01 mg sediment loss when the whole soil mass was moved compared with the treatment in which only 50 mm of the soil layer was removed in order to see the effect of the same level of water potential. After a least significant difference (Lsd) $_{0.05}$ test was performed, this difference (of 0.01 mg) was not statistically significant. Thus the technique of removing 50 mm of soil layer to study the effect of the second level of randomized water potential was considered reliable.

SUMMARY AND CONCLUSION

A split-plot design was used. Twentyfour texture*tilth (TN) combinations were placed in the main plot while three water potentials (0, -5, and -15 cm of water) were randomized in the subplot. For each second and third water potential in the subplot, a 50 mm layer of used, soil was removed and replaced with fresh, soil.

Runoff water samples were collected with the aid of 5-gallon buckets; therafter the effluent of the buckets was stirred vigorously, and a 150-ml subsample was collected from the center of each. These samples were poured into Aluminum cans, and the cans were placed in the oven at 105 degrees celsius for 24 hours. The water was evaporated, and the sediments left in the cans and removed carefully for weighing. The study produced a number of significant findings:

1. Sediment concentration in runoff water was low while using Webster (clay loam) soil, especially when the soil came from a site under grass. A possible explanation is that clay (under grass) may have more aggrigation of soil particles than clay under corn-soybean or corn-corn rotation.
2. Corn-soybean rotation in almost all cases yielded higher sediment concentrations in runoff water, than did the grass or corn-corn rotation. Some literature

has suggested that soybean has a loosening effect on soil, therefore when the soil particles are loosely bonded, it is very easy for the runoff water to transport these particles downstream, especially in fine textured (clay) and medium textured (silt) soils.

3. Sediment concentration in runoff water decreased in almost all cases when moving from 0 to -15 cm of water potential A possible explanation is soil shrinkage. This might increase the shear strength of the soil and cause the soil to become more resistant to the erosive power of overland flows.

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APPENDIX B

Table B-1. Bulk density (dry basis) of the soil under field and laboratory conditions

TREATMENT	LAB. COND. Mg/M**3	FIELD COND. Mg/M**3	DESCRIPTION
T1N1	0.92	1.63	CLAY(GRASS)
T1N2	1.05	1.49	CLAY(C-S)
T1N3	0.99	1.49	CLAY(C-C)
T2N1	0.97	1.46	SILT(GRASS)
T2N2	1.09	1.38	SILT(C-S)
T2N3	1.04	1.43	SILT(C-C)
T3N1	1.09	1.53	SAND(GRASS)
T3N2	1.23	1.48	SAND(C-S)

Table B-2. Average penetration force (of cone penetrometer) and average penetration resistance values ofsoil under field conditions

LOCATN.	TRT.	REP.I	REP.II	REP.III	AVE.PEN. Pounds	AVE.RES. MPas
AERC	T1N1	54.3	61.4	54.8	56.83	1.96
AERC	T1N2	5.8	41.1	50.6	32.5	1.12
AERC	T1N3	28.4	68.9	93.6	63.63	2.19
TREYNER	T2N1	13.9	7.4	80.6	33.96	1.17
TREYNER	T2N2	27.1	53.0	73.8	51.3	1.77
TREYNER	T2N3	41.1	48.7	47.7	45.83	1.58
ATM.FARM	T3N1	18.7	17.4	24.2	20.1	0.69
ATM.FARM	T3N2	4.3	8.5	25.9	12.9	0.44

Table B-3. Nitrogen content values of the soils

TRT.	DESCRIPTION	NITROGEN (%)	TOTAL* N (%)
T1N1	CLAY (GRASS)	0.31517	6.303
T1N2	CLAY(C-S)	0.37629	7.525
T1N3	CLAY(C-C)	0.20003	4.000
T2N1	SILT(GRASS)	0.27259	5.451
T2N2	SILT(C-S)	0.16050	3.210
T2N3	SILT(C-C)	0.22239	4.447
T3N1	SAND(GRASS)	0.11940	2.388
T3N2	SAND(C-S)	0.11819	2.364

*Nitrogen (%) is multiplied by 20 to get total nitrogen.

Table B-4. Uniformity coeficient values for laboratory and field soils

TRT.	DISCRIPTION	LAB. SOIL	FIELD. SOIL
T1N1	WEB.(GRASS)	5.21	6.05
T1N2	WEB.(C-S)	5.93	3.49
T1N3	WEB.(C-C)	6.69	4.95
T2N1	SILT(GRASS)	9.68	9.49
T2N2	SILT(C-S)	5.75	9.49
T2N3	SILT(C-C)	44.70	21.12
T3N1	SAND(GRASS)	2.86	4.48
T3N2	SAND(C-S)	6.05	7.39

Table B-5. Mean values of fall cone penetration for soils under laboratory conditions

FOR 0 CM OF WATER POTENTIAL

TRT.	REP.I	REP.II	REP.III	MEAN. OF REP. mm
T1N1	12.0	12.2	13.3	12.5
T1N2	9.5	9.2	10.5	9.7
T1N3	11.5	10.5	9.0	10.3
T2N1	18.0	16.5	15.5	16.7
T2N2	14.0	14.7	14.5	14.4
T2N3	9.0	9.2	10.0	9.4
T3N1	13.5	13.7	14.7	13.9
T3N2	19.5	19.2	20.0	19.6

FOR 5 CM OF WATER POTENTIAL

TRT.	REP.I	REP.II	REP.III	MEAN. OF REP.
T1N1	9.7	11.3	10.0	10.3
T1N2	10.0	8.3	9.3	9.2
T1N3	6.8	7.2	6.5	6.8
T2N1	8.2	8.8	9.0	8.6
T2N2	15.0	16.5	15.5	15.7
T2N3	10.2	9.0	9.9	9.7
T3N1	12.0	13.0	12.5	12.5
T3N2	17.5	18.2	17.0	17.6

FOR 15 CM OF WATER POTENTIAL

TRT.	REP.I	REP.II	REP.III	MEAN.OF REP.
T1N1	9.0	8.5	9.7	9.1
T1N2	6.5	5.7	5.7	5.9
T1N3	8.0	7.8	8.7	8.2
T2N1	8.8	9.4	8.7	9.0
T2N2	10.8	10.0	11.0	10.6
T2N3	6.5	5.8	6.0	6.1
T3N1	10.0	9.5	9.0	9.5
T3N2	15.5	14.2	15.0	14.9

Table B-6A. Mean shear strength and soil tilth index values of the soil under controlled laboratory conditions

TRT	SHEAR STRENGTH (N/M**2)	SHEAR STRENGTH MPas	*SOIL TILTH INDEX VALUES.
	WATER POTENTIAL 0 CM OF WATER.		
T1N1	3930.95	0.0039	0.99
T1N2	6496.91	0.0064	0.99
T1N3	5752.26	0.0057	0.94
T2N1	4092.44	0.0040	0.98
T2N2	5492.44	0.0054	0.88
T2N3	1290.82	0.0129	0.95
T3N1	9359.23	0.0093	0.71
T3N2	4757.06	0.0047	0.83
	WATER POTENTIAL -5 CM OF WATER.		
T1N1	5763.41	0.0057	0.99
T1N2	7220.67	0.0072	0.99
T1N3	13158.25	0.0131	0.94
T2N1	15146.39	0.0151	0.98
T2N2	4631.58	0.0046	0.88
T2N3	12140.99	0.0121	0.95
T3N1	11639.80	0.0116	0.71
T3N2	5902.86	0.0059	0.83
	WATER POTENTIAL -15 CM OF WATER.		
T1N1	7489.53	0.00749	0.99
T1N2	17379.13	0.01737	0.99
T1N3	9211.70	0.00921	0.94
T2N1	14139.96	0.01413	0.98
T2N2	10097.52	0.01009	0.88
T2N3	30448.32	0.03044	0.95
T3N1	20152.02	0.02015	0.71
T3N2	8207.47	0.00820	0.83

* Tilth indices under field and laboratory conditions are not statistically different from each other at 5 % level.

Table B-6B. Soil tilth index and plasticity index values for soils under field conditions

TREATMENTS VALUES	DESCRIPTION	* TILTH INDEX
T1N1	CLAY(GRASS)	0.79
T1N2	CLAY(C-S)	0.86
T1N3	CLAY(C-C)	0.87
T2N1	SILT(GRASS)	0.93
T2N2	SILT(C-S)	0.86
T2N3	SILT(C-C)	0.91
T3N1	SAND(GRASS)	0.79
T3N2	SAND(C-S)	0.79

PLASTICITY INDEX:	
WEBSTER 107	15
MONONA 10	17.5
HANLON 536	7.5

* Tilth indices under field and laboratory conditions are not satistically different from each other at 5 % level.

Table B-7. Mean sediment concentration values for different levels of water potential

0 CM OF WATER POTENTIAL

TRT.	REP.I	REP.II	REP.III	MEAN SED. CONC. gm/150 ml
T1N1	0.08	0.10	0.09	0.09
T1N2	0.54	0.52	0.55	0.54
T1N3	0.25	0.23	0.26	0.25
T2N1	0.27	0.29	0.28	0.28
T2N2	0.52	0.55	0.54	0.54
T2N3	0.52	0.50	0.55	0.52
T3N1	0.48	0.51	0.46	0.48
T3N2	0.43	0.45	0.46	0.45

- 5 CM OF WATER POTENTIAL

TRT	REP.I	REP.II	REP.III	MEAN SED. CONC.
T1N1	0.07	0.08	0.09	0.08
T1N2	0.34	0.35	0.32	0.34
T1N3	0.23	0.21	0.22	0.22
T2N1	0.27	0.26	0.28	0.27
T2N2	0.34	0.37	0.35	0.35
T2N3	0.48	0.46	0.45	0.46
T3N1	0.41	0.39	0.42	0.41
T3N2	0.40	0.42	0.44	0.42

-15 CM OF WATER POTENTIAL

TRT	REP.I	REP.II	REP.III	MEAN SED. CONC.
T1N1	0.05	0.06	0.06	0.06
T1N2	0.10	0.09	0.10	0.10
T1N3	0.21	0.20	0.21	0.21
T2N1	0.14	0.13	0.14	0.14
T2N2	0.29	0.31	0.31	0.30
T2N3	0.21	0.20	0.22	0.21
T3N1	0.20	0.19	0.21	0.20
T3N2	0.35	0.36	0.34	0.35

Table B-8. Mean sediment concentrations (mg/150 ml of water) for different textures and crop histories under different levels of water potentials

0 CM OF WATER POTENTIAL

	GRASS	CORN-SOYBEAN	CORN-CORN
CLAY	0.09[a]	0.54[b]	0.25[c]
SILT	0.28[a]	0.54[b]	0.52[c]
SAND	0.48[a]	0.45[b]	

-5 CM OF WATER POTENTIAL

CLAY	0.08[a]	0.34[b]	0.22[c]
SILT	0.27[a]	0.35[b]	0.46[c]
SAND	0.41[a]	0.42[b]	

-15 CM OF WATER POTENTIAL

CLAY	0.06[a]	0.10[b]	0.21[c]
SILT	0.14[a]	0.30[b]	0.21[c]
SAND	0.20[a]	0.35[b]	

aMean of three observations.
bMean of three observations.
cMean of three observations.

Table B-9. Summary of significance levels for anova for the effect of texture and crop histories and water potential on sediment concentration

				Significance levels for F-test		
S.V	DEGREE OF FREEDOM	SS	MS	OBSERVED F	TABULATED F 5%	TABULATED F 1%
TEX.TILTH (C)	7	0.865245	0.12361	559.78**	2.66	4.03
M	1	0.04218	0.04218	183.42**	4.49	8.53
N	1	0.08867	0.08867	385.53**	4.49	8.53
ERROR(A)	16	0.00353	0.00023			
WATER POT. (W)	2	0.47988	0.23994	1354.88**	3.28	5.29
CXW	14	0.25431	0.01816	102.58**	2.02	2.70
ERROR(B)	32	0.00566	0.00017			
TOTAL	71					

CV(A)= 4.92%.
CV(B)= 4.41%.

**Values are highly significant

Look for table B-11, and B-12

M = Orthogonal contrast of clay verses silt and sand

N = Orthogonal contrast of grass verses crop rotations

Table B-10. Textural analysis* of different soils used in this study

SOIL TYPE	SAND %	FINE SILT %	COARSE SILT %	CLAY %
WEBSTER 107	27.3	20.1	24.8	27.8
MONONA 10	1.6	43.0	29.8	25.6
HANLON 536	39.6	28.8	14.1	17.5

*The textural analysis was done in Dr Fenton's lab. on Nov. 6 1991.

Table B-11. Treatment grouping from Duncan's multiple range test

** TEX. x HIS.	N	MEAN SED. CONC. mg/150 ml	* DUNCAN GROUPING
T3N2	9	0.405	A
T2N3	9	0.398	A
T2N2	9	0.397	A
T3N1	9	0.363	B
T1N2	9	0.323	C
T2N1	9	0.228	D
T1N3	9	0.224	D
T1N1	9	0.075	E

*Means with same letter are not significantly different. Significance level used is 0.05. Mean square error (a) used = 0.000221
**Texture and tilth (crop history) are one combination.
DESCRIPTION
T3N2 (sand under corn-soybean)
T2N3 (silt under corn-corn)
T2N2 (silt under corn-soybean)
T3N1 (sand under grass)
T1N2 (clay under corn-soybean)
T2N1 (silt under grass)
T1N3 (clay under corn-corn)
T1N1 (clay under grass)

Table B-12. Treatment grouping from Duncan's multiple range test

Water potential (cm of water)	N	MEAN SED. CONC.	*DUNCAN GROUPING
0	24	0.392917	A
-5	24	0.318750	B
-15	24	0.195000	C

*Means with same letter are not significantly different. Significance level used is 0.05. Mean square error (b) used = 0.000177

Table B-13. Summary of significance levels of least significance difference $(Lsd)_{0.05}$ test for the effect of texture and tilth (crop history) on sediment concentration

difference in sed. conc.(gm sed. /150 ml water)

water pot. (cm of water)	0^{**}	-5^{**}	-15^{**}
Clay v/s silt	0.09^{*}	0.11^{*}	0.14^{*}
clay v/s sand	0.15^{*}	0.25^{*}	0.20^{*}
Silt v/s sand	0.06^{*}	0.14^{*}	0.06^{*}
Grass v/s c-s	0.35^{*}	0.17^{*}	0.10^{*}
Grass v/s c-c	0.20^{*}	0.16^{*}	0.11^{*}
c-s v/s c-c	0.15^{*}	0.01^{ns}	0.01^{ns}

** cm of water
* statistically significant at 5 percent level
ns statistically nonsignificant at 5 percent level

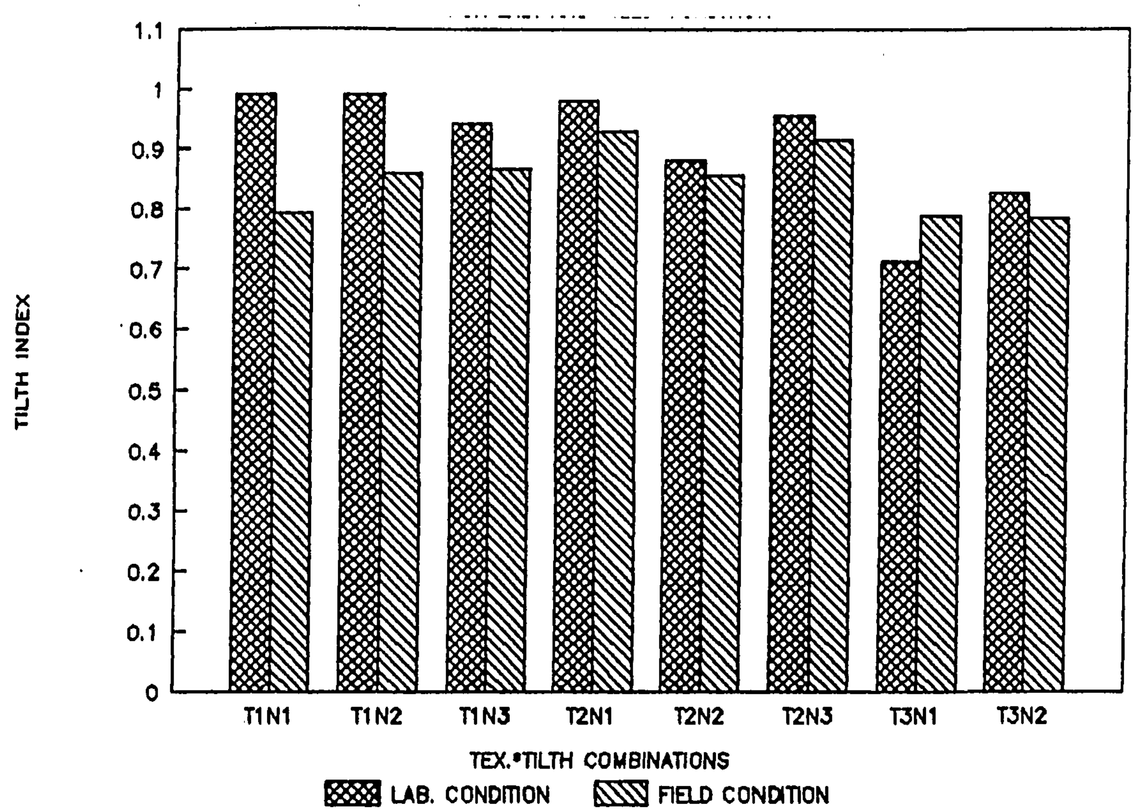

Figure B-1. Relationship between different texture tilth combinations and soil tilth index values for field and laboratory conditions

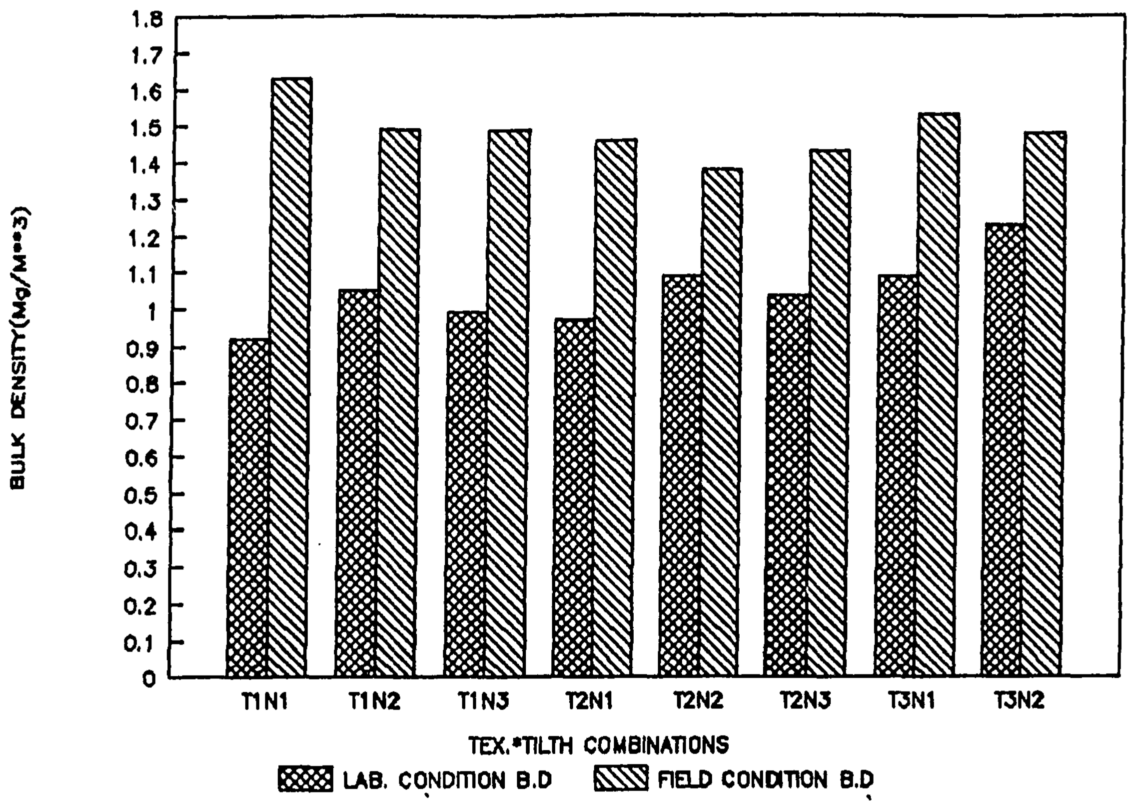

Figure B-2. Relationship between different texture*tilth combinations and bulk density values for field and laboratory conditions

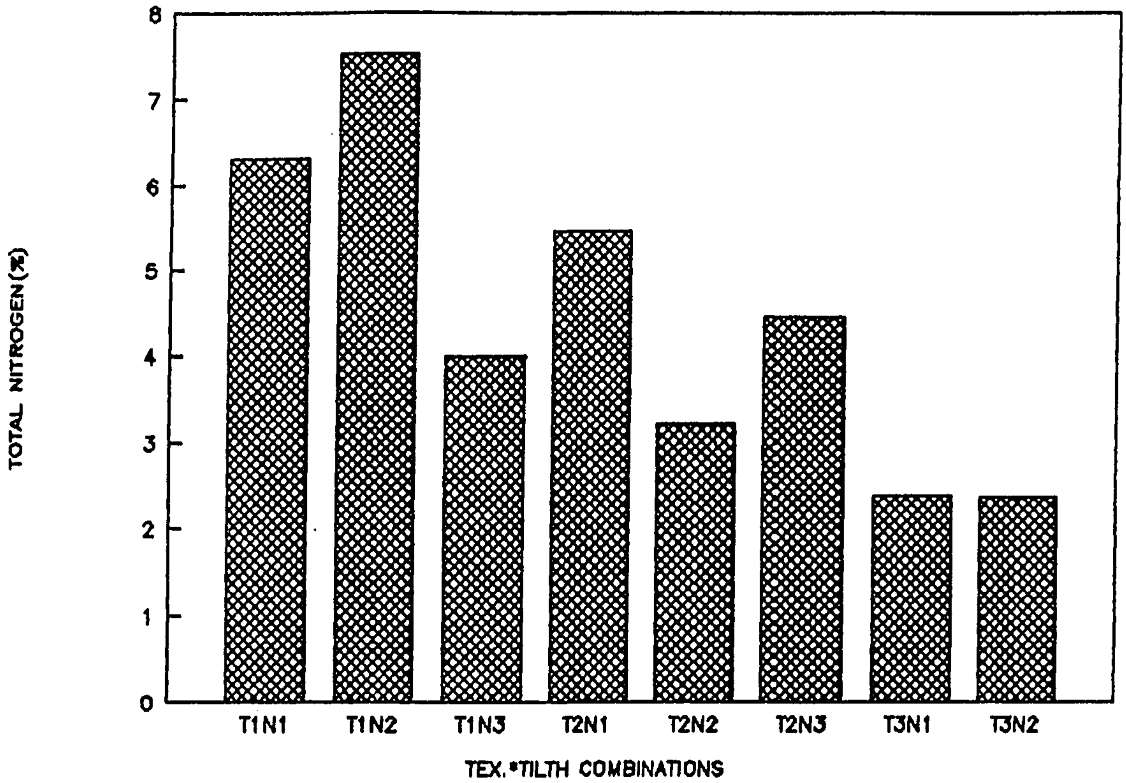

Figure B-3. Relationship between different texture*tilth combinations and total nitrogen of the soil

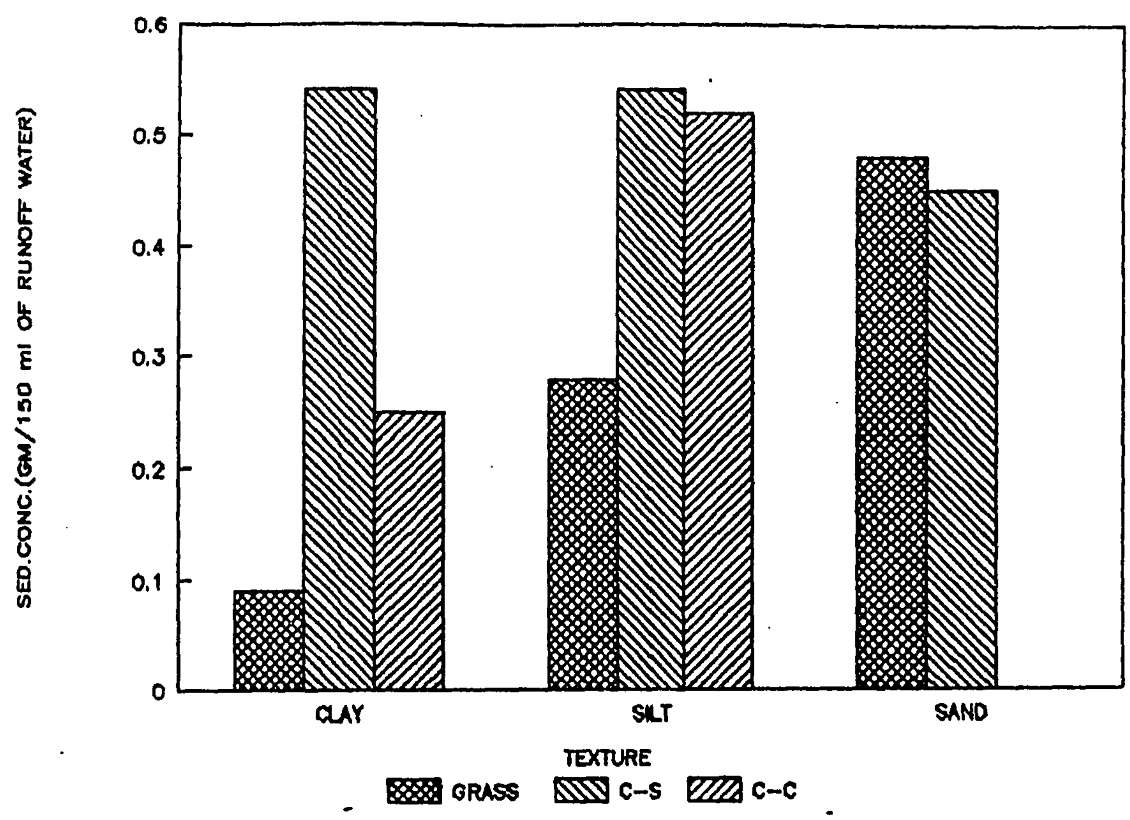

Figure B-4. Relationship between soil texture and mean sediment concentration for 0 cm of water potential

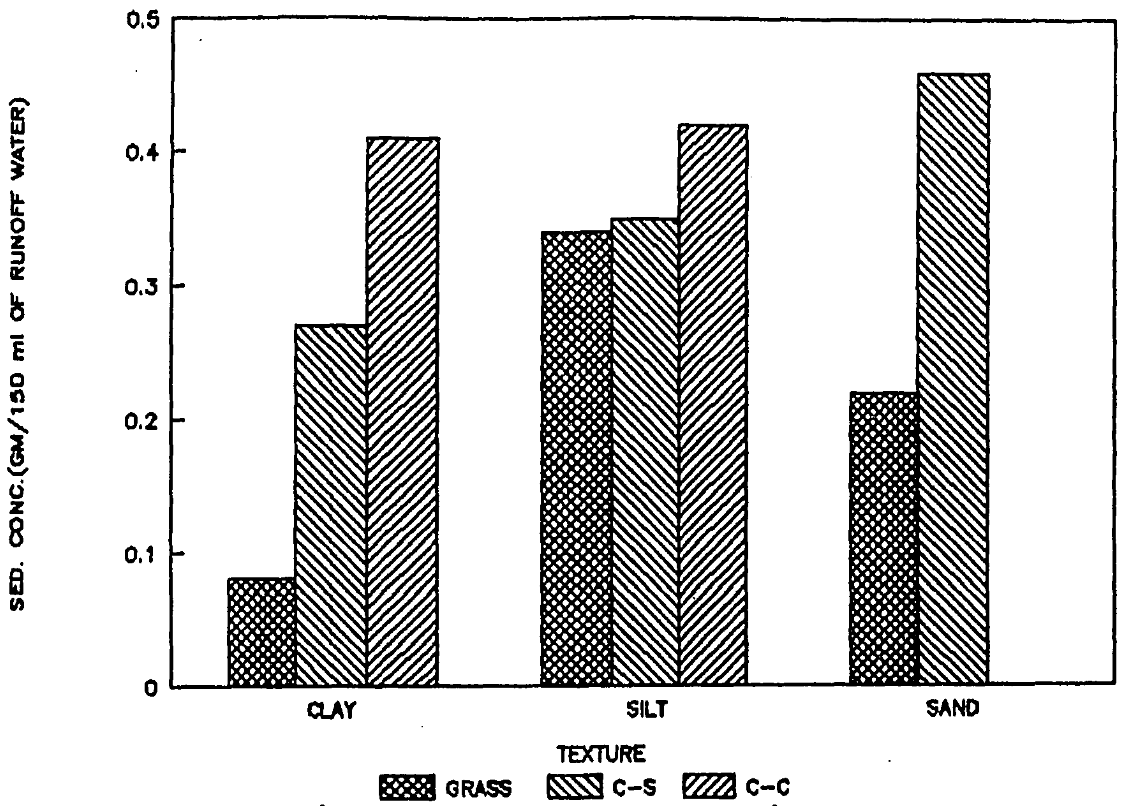

Figure B-5. Relationship between sol texture and mean sediment concentration for -5 cm of water potential

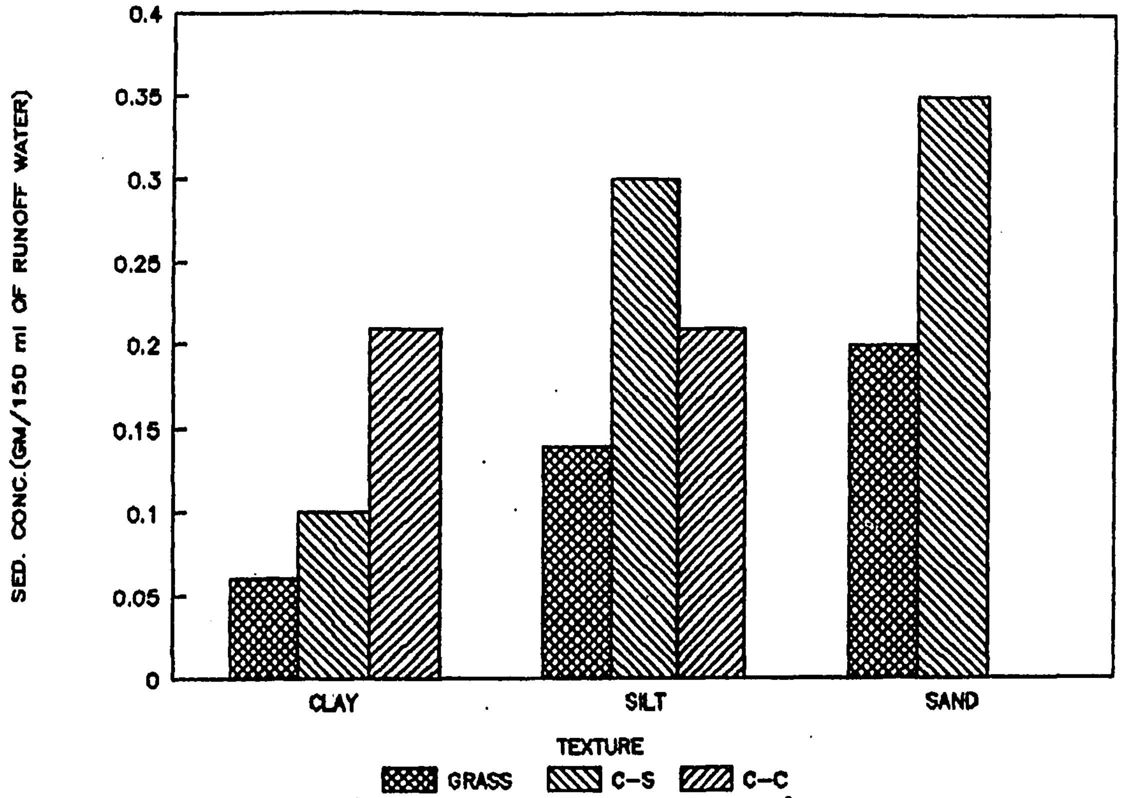

Figure B-6. Relationship between soil texture and mean sediment concentration for -15 cm of water potential

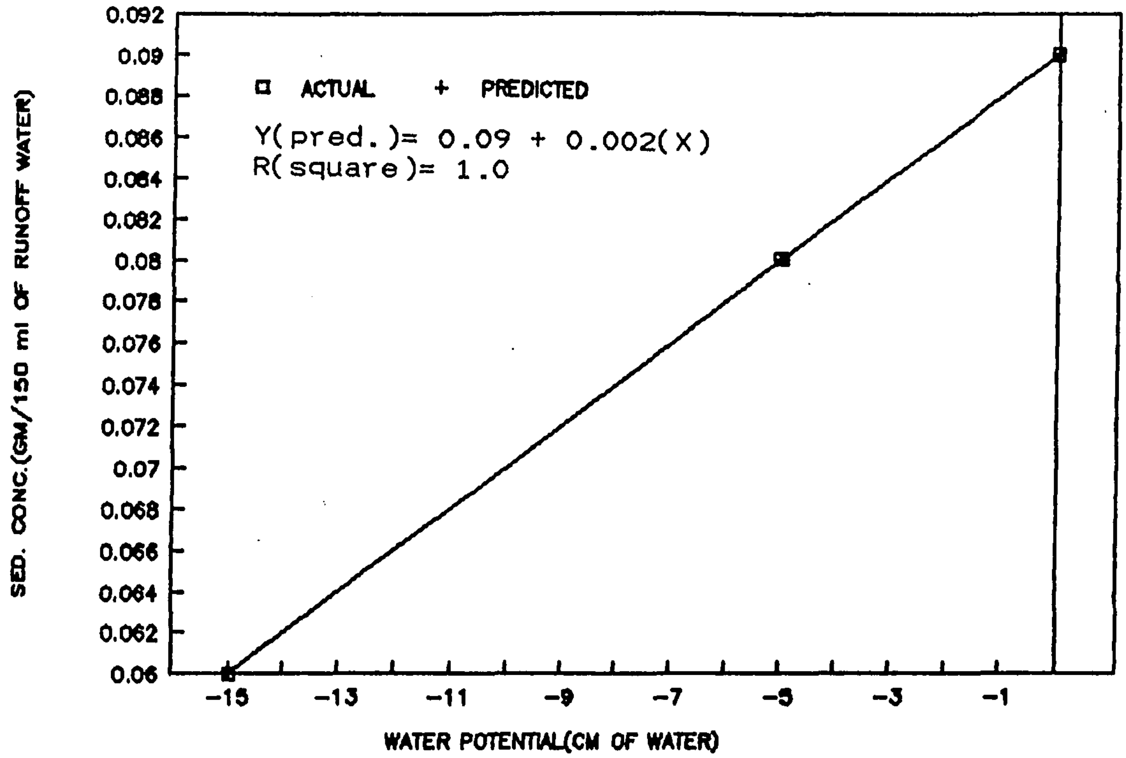

Figure B-7. Linear regression model between sediment concentration and soil water potential for T1N1 (clay under grass)

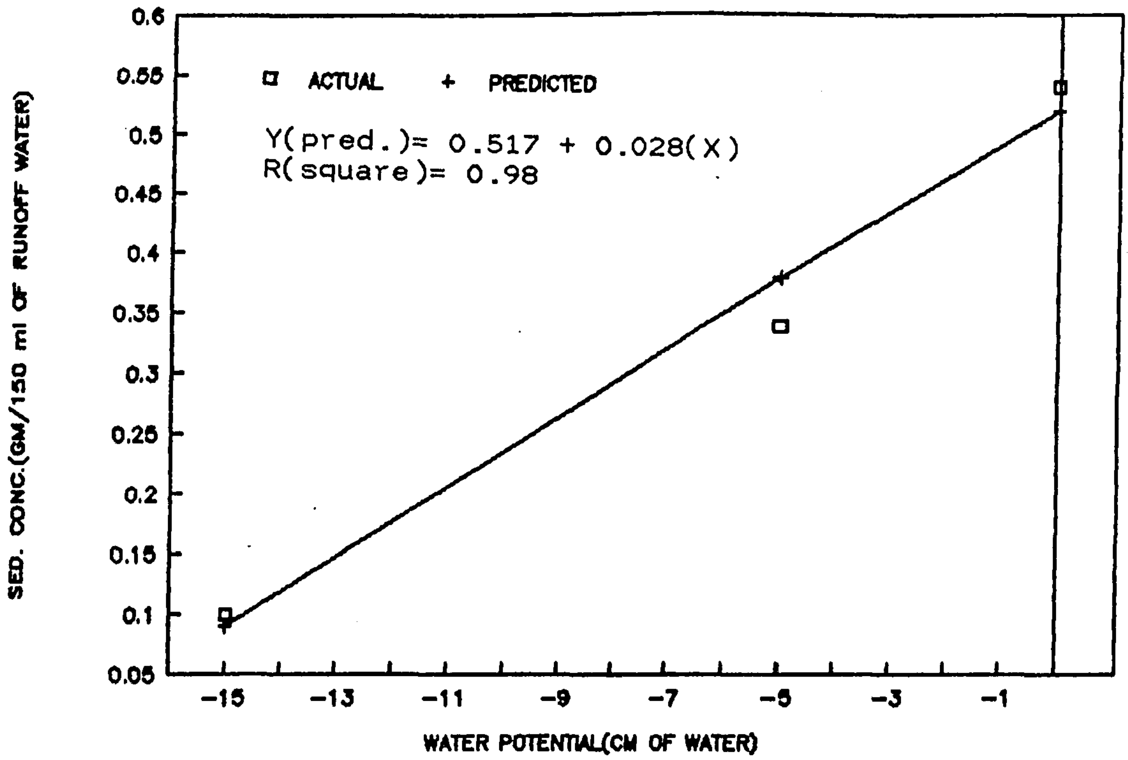

Figure B-8. Linear regression model between sediment concentration and soil water potential for T1N2 (clay under corn-soybean)

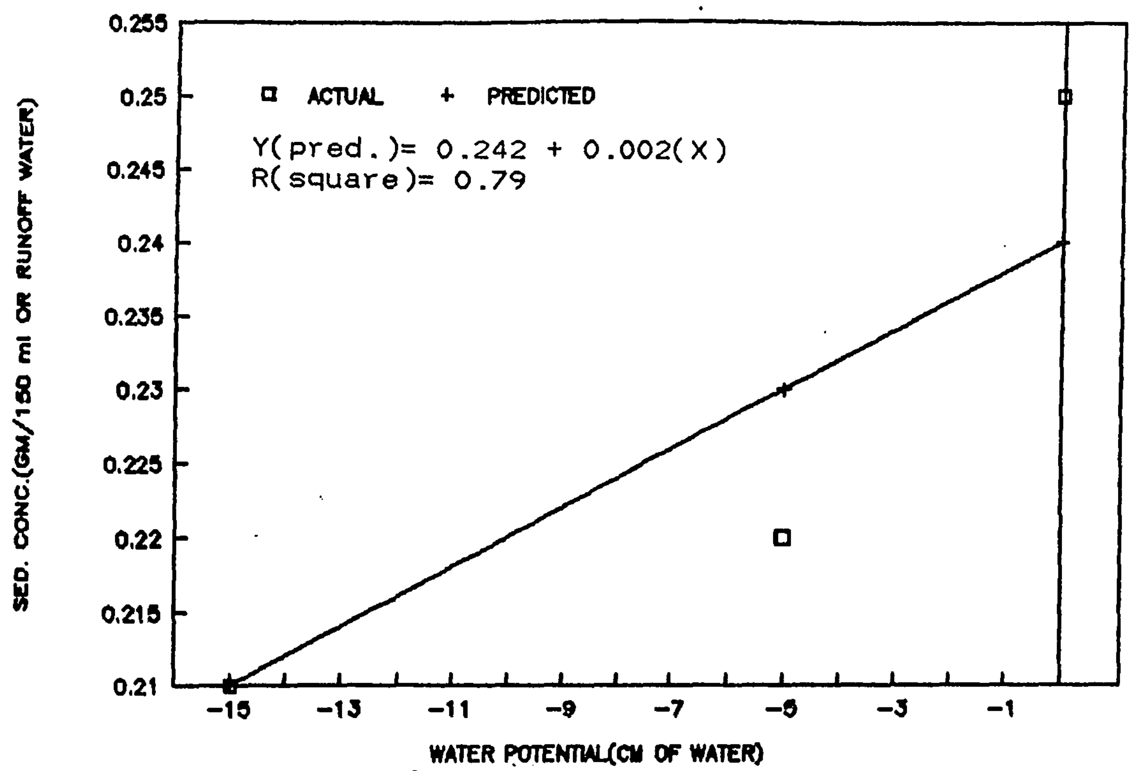

Figure B-9. Linear regression model between sediment concentration and soil water potential for T1N3 (clay under corn-corn)

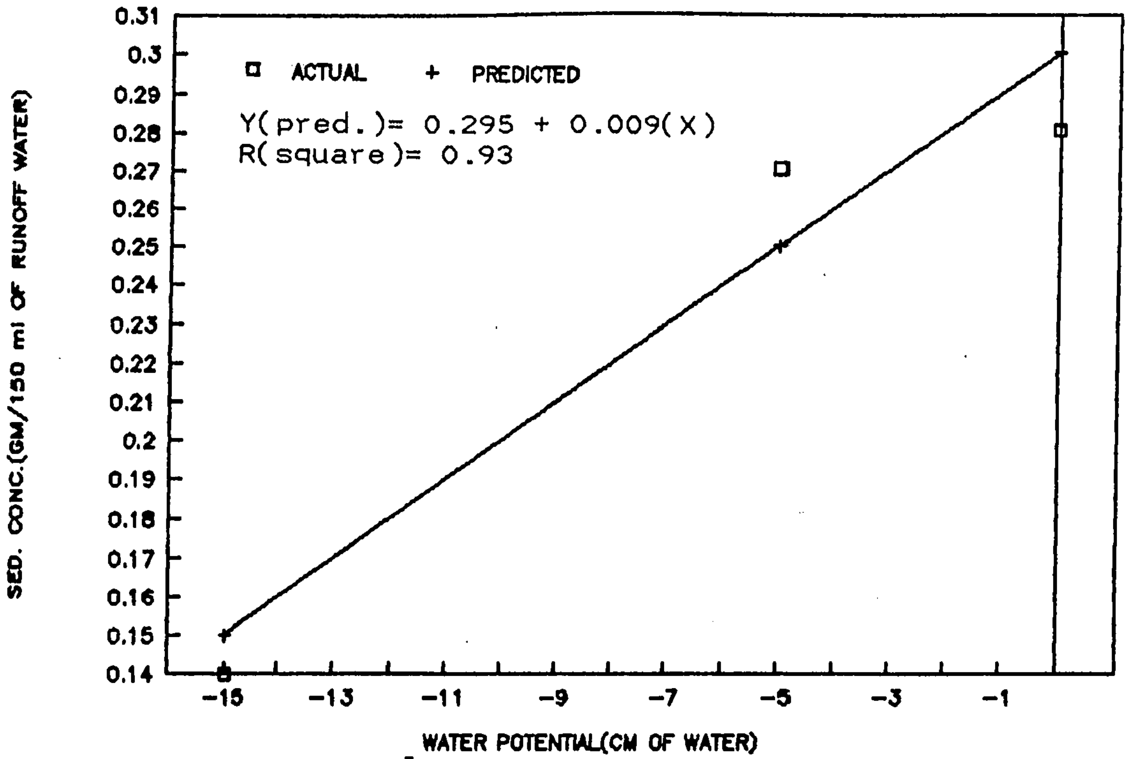

Figure B-10. Linear regression model between sediment concentration and soil water potential for T2N1 (silt under grass)

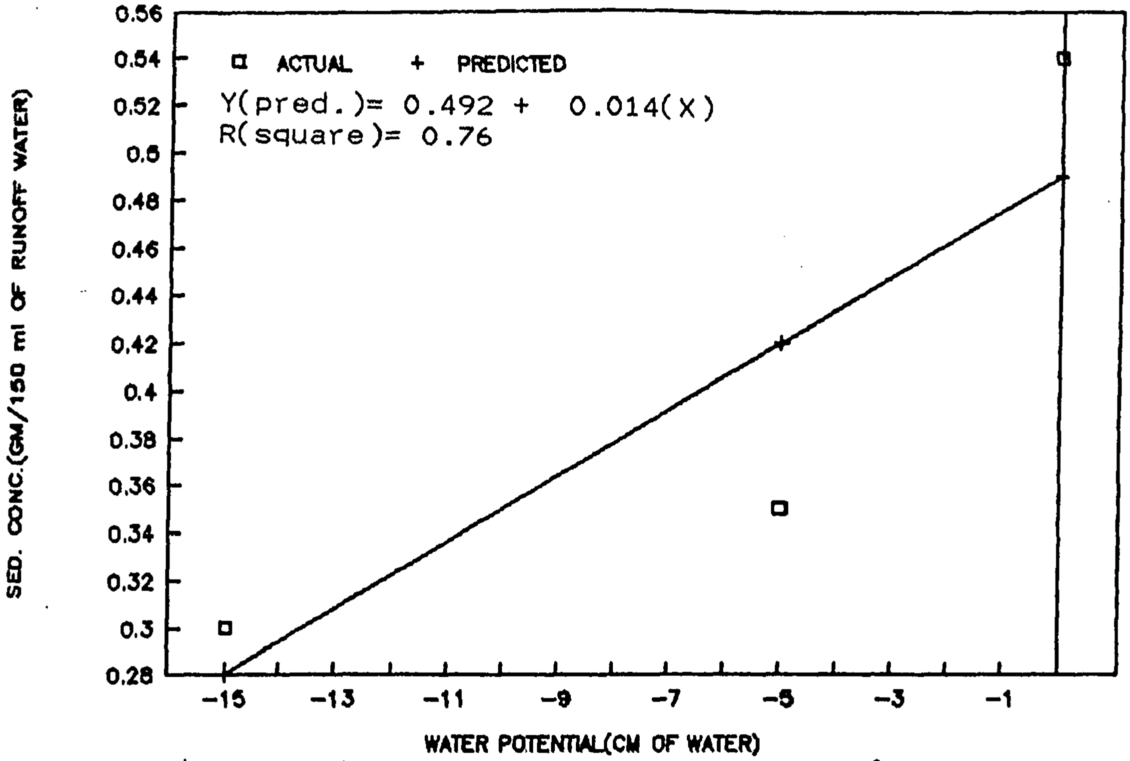

Figure B-11. Linear regression model between sediment concentration and soil water potential for T2N2 (silt under corn-soybean)

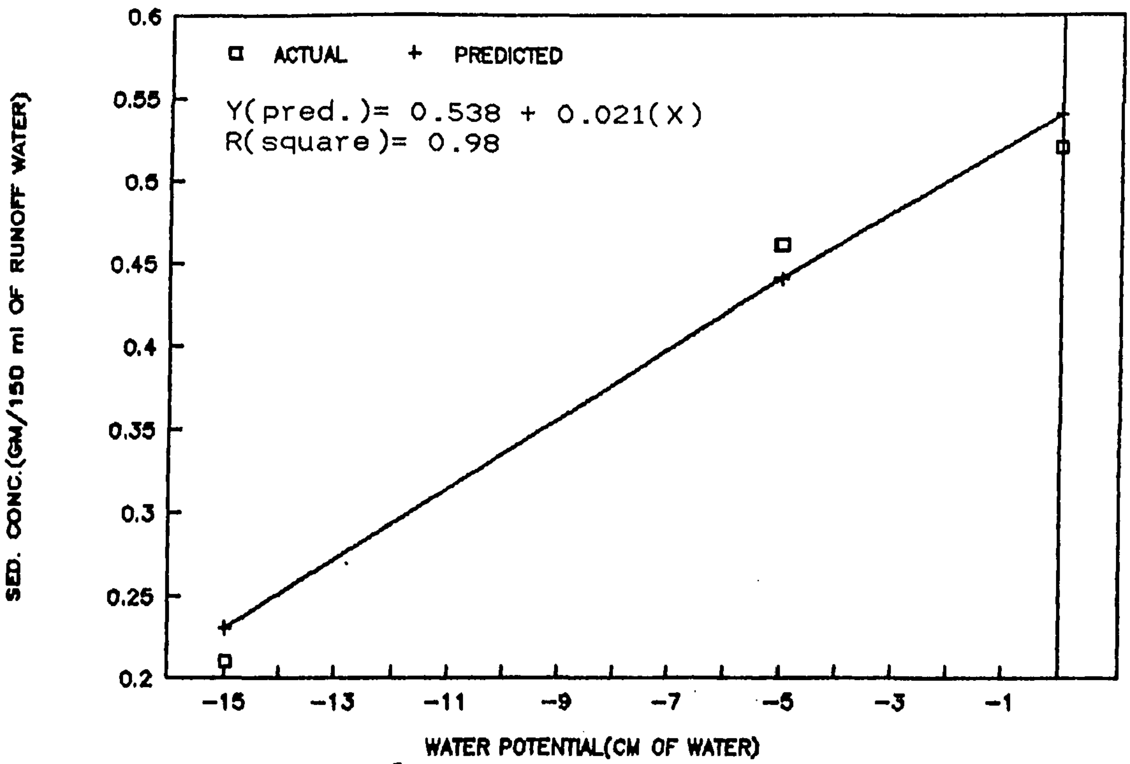

Figure B-12. Linear regression model between sediment concentration and soil water potential for T2N3 (silt under corn-corn)

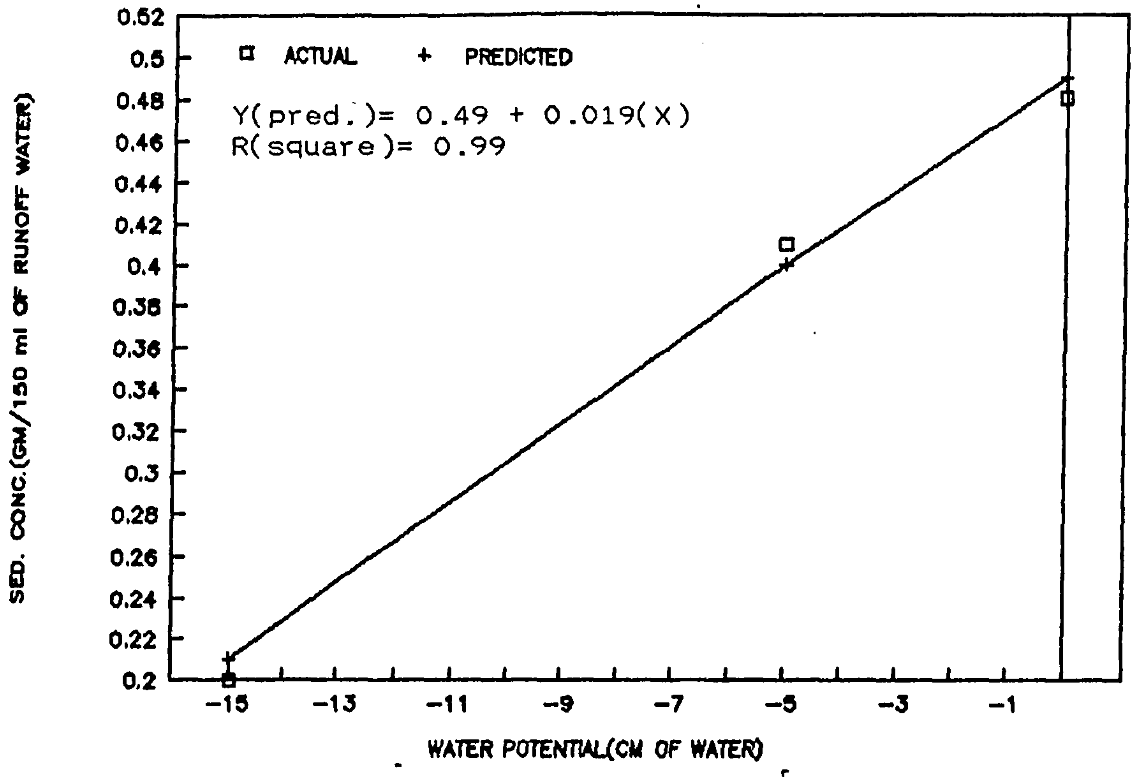

Figure B-13. Linear regression model between sediment concentration and soil water potential for T3N1 (sand under grass)

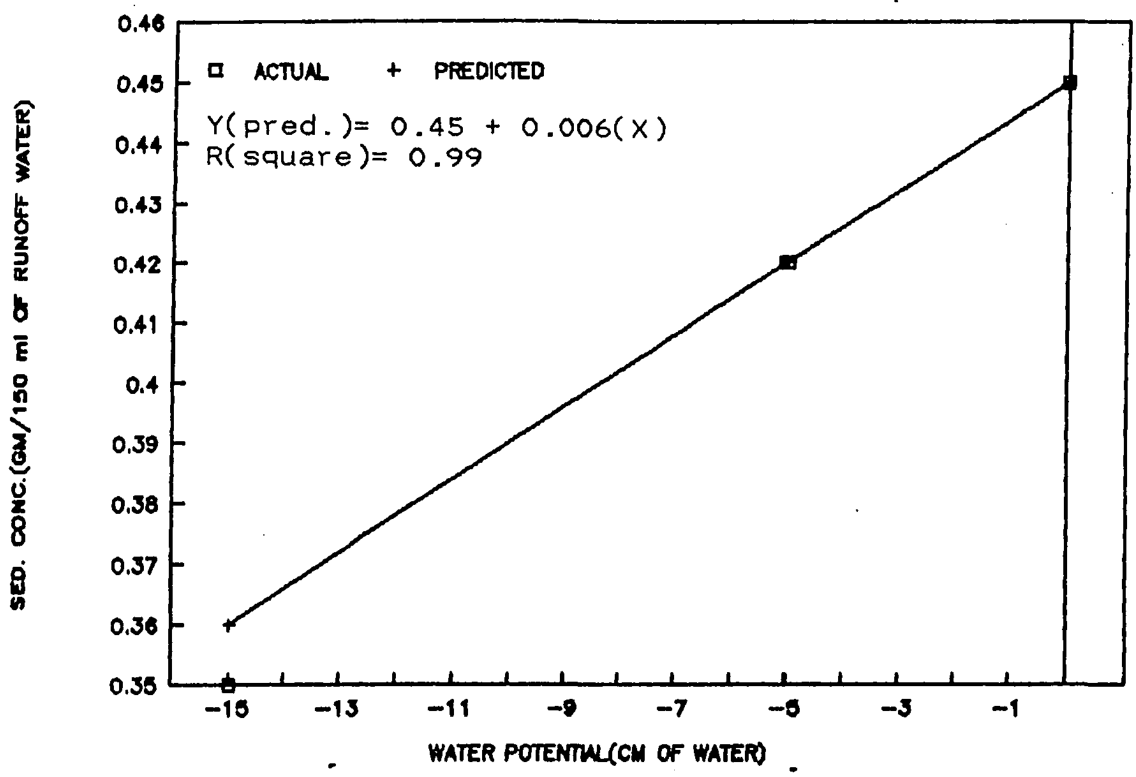

Figure B-14. Linear regression model between sediment concentration and soil water potential for T3N2 (sand under corn-soybean)

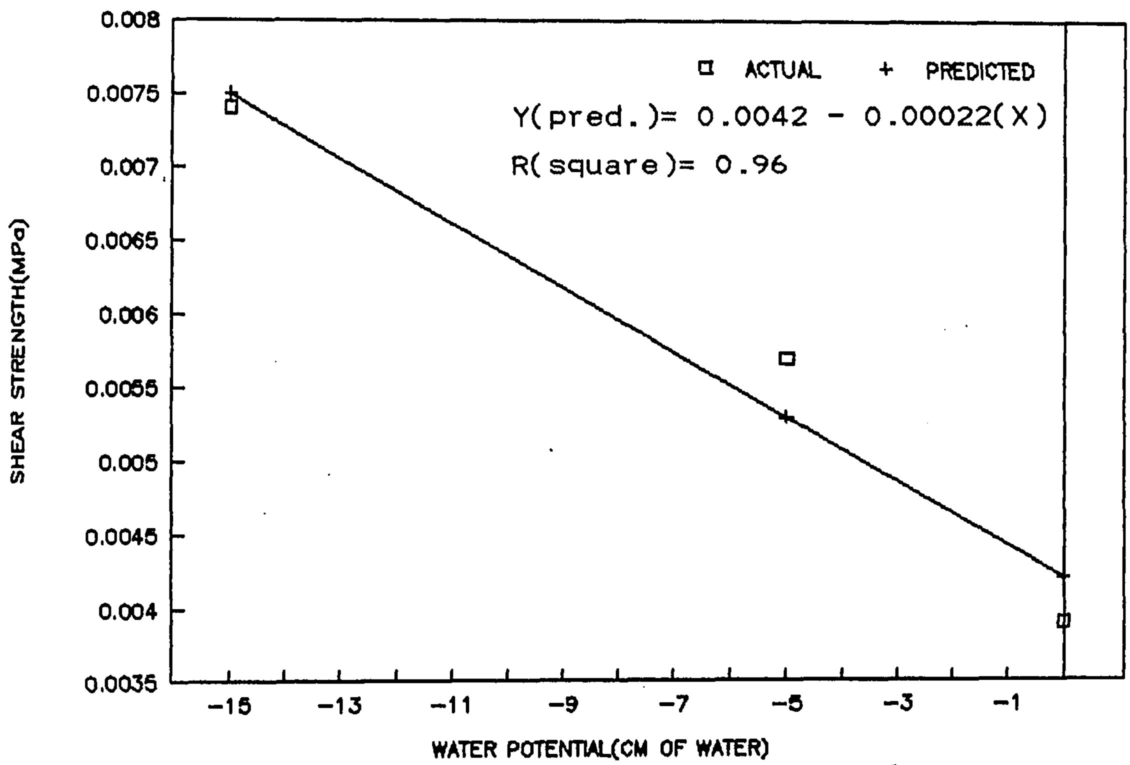

Figure B-15. Linear regression model between shear strength and soil water potential for TINI (clay under grass)

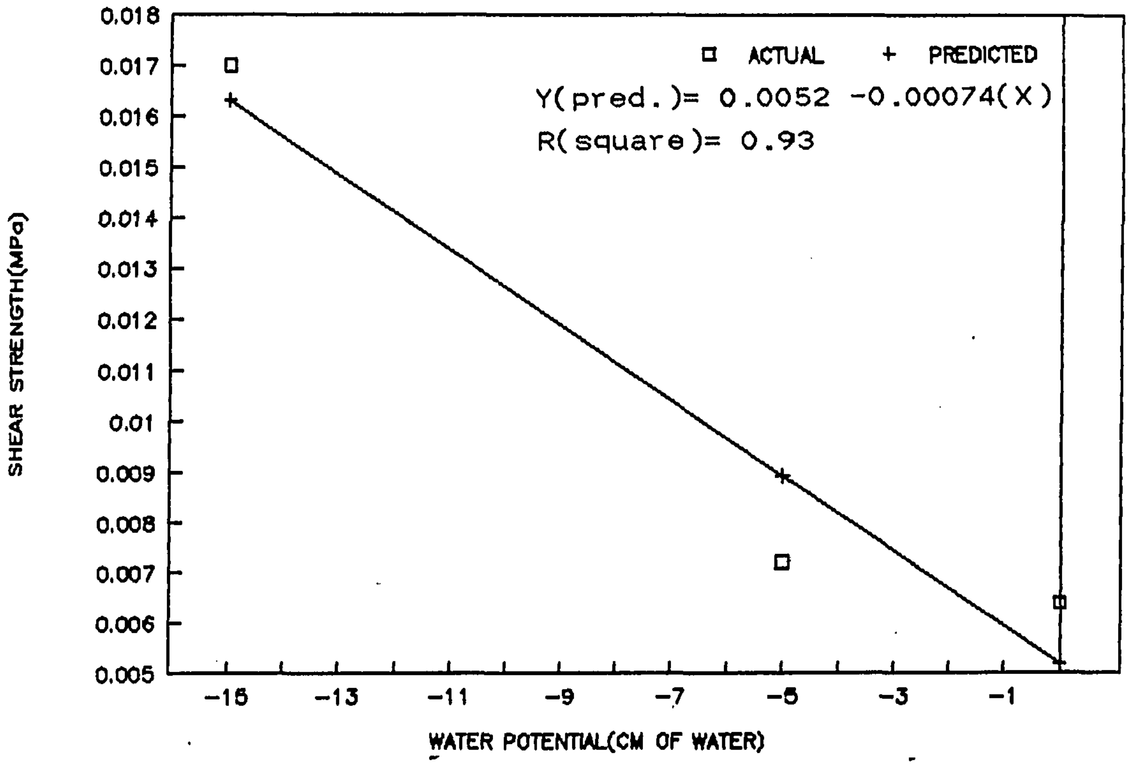

Figure B-16. Linear regression model between shear strength and soil water potential for T1N2 (clay under corn-soybean)

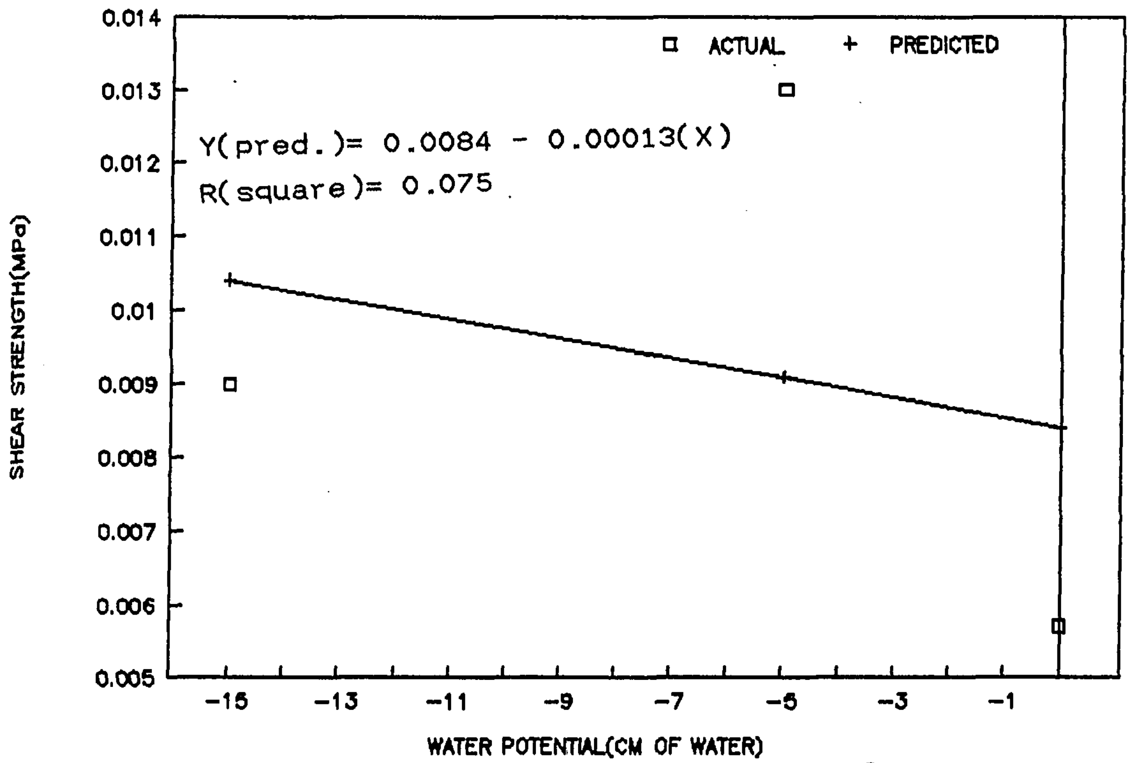

Figure B-17. Linear regression model between shear strength and soil water potential for T1N3 (clay under corn-corn)

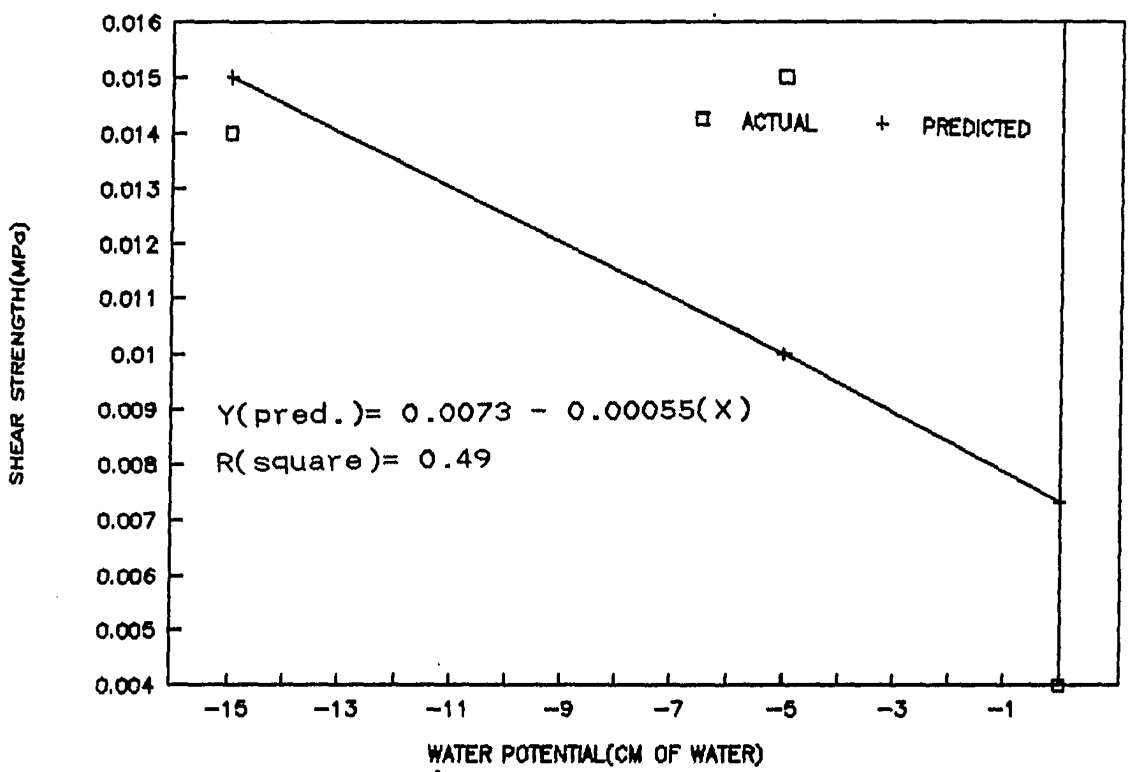

Figure B-18. Linear regression model between shear strength and soil water potential for T2N1 (silt under grass)

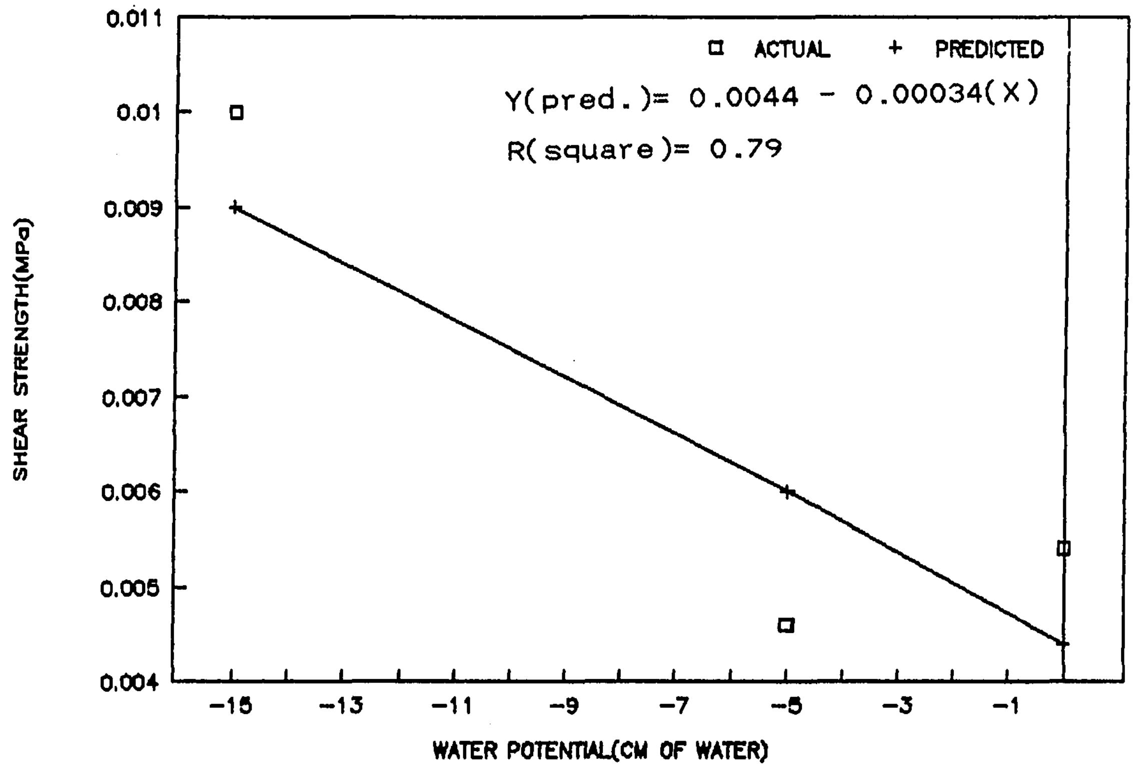

Figure B-19. Linear regression model between shear strength and soil water potential for T2N2 (silt under corn-soybean)

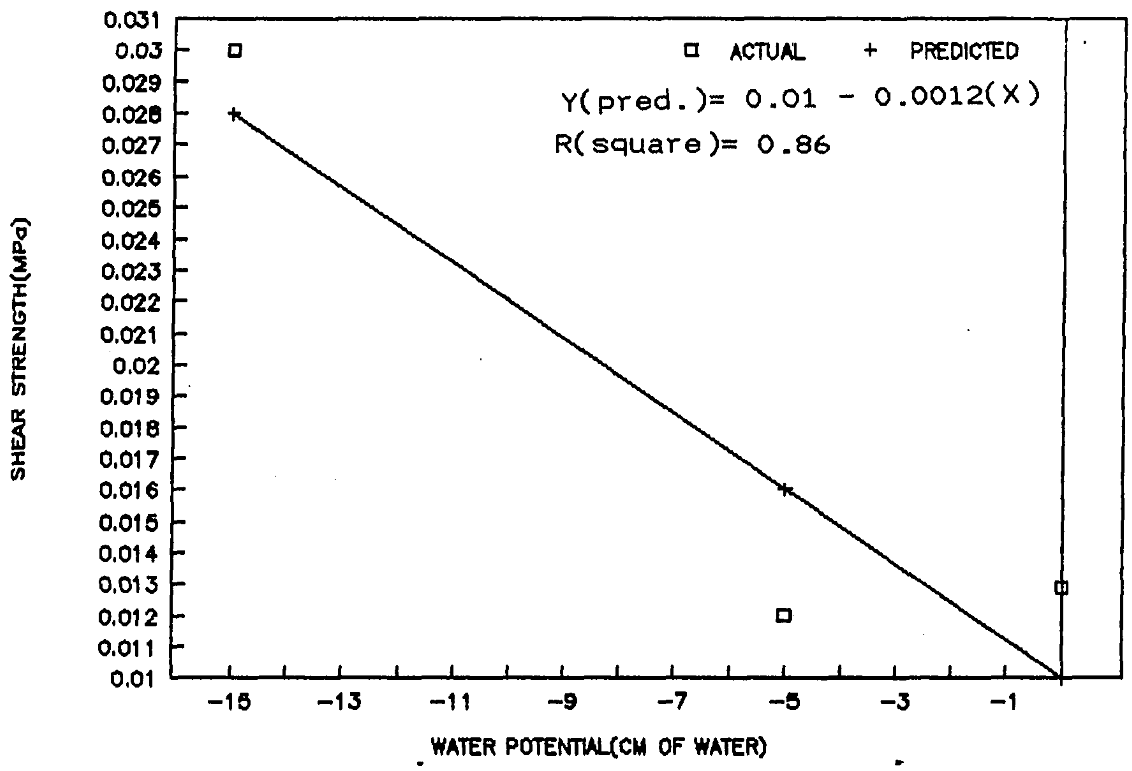

Figure B-20. Linear regression model between shear strength and soil water potential for T2N3 (silt under corn-corn)

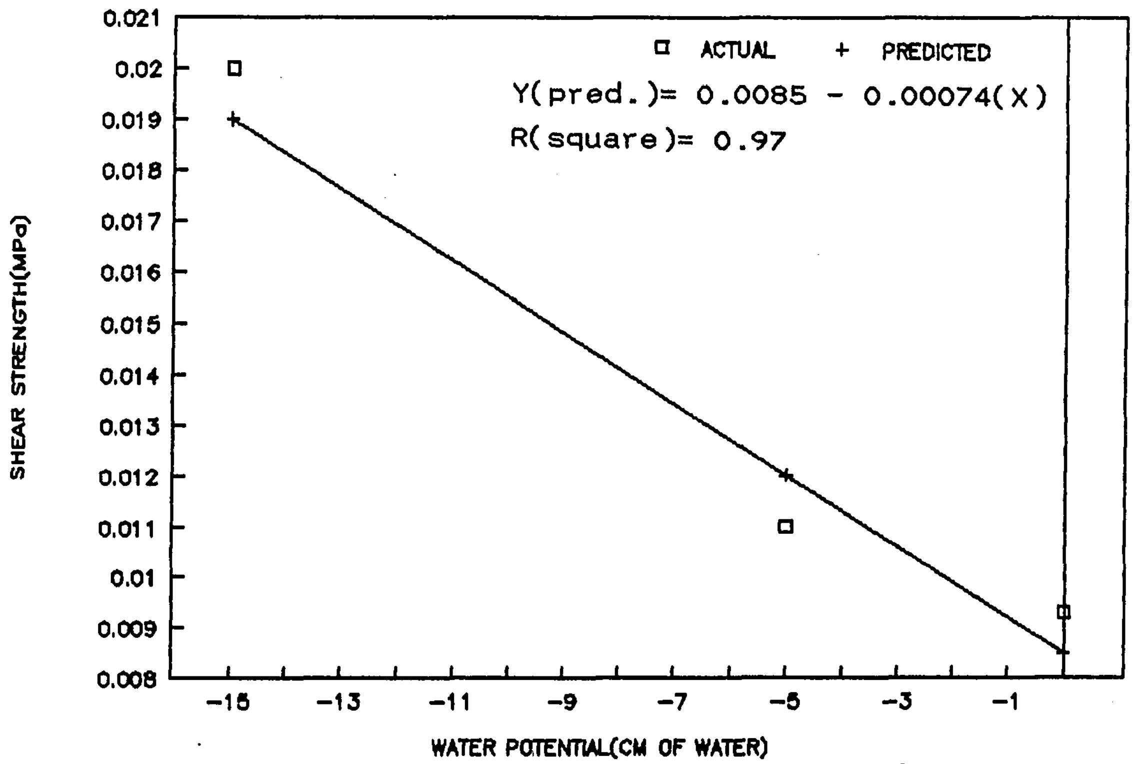

Figure B-21. Linear regression model between shear strength and soil water potential for T3N1 (sand under grass)

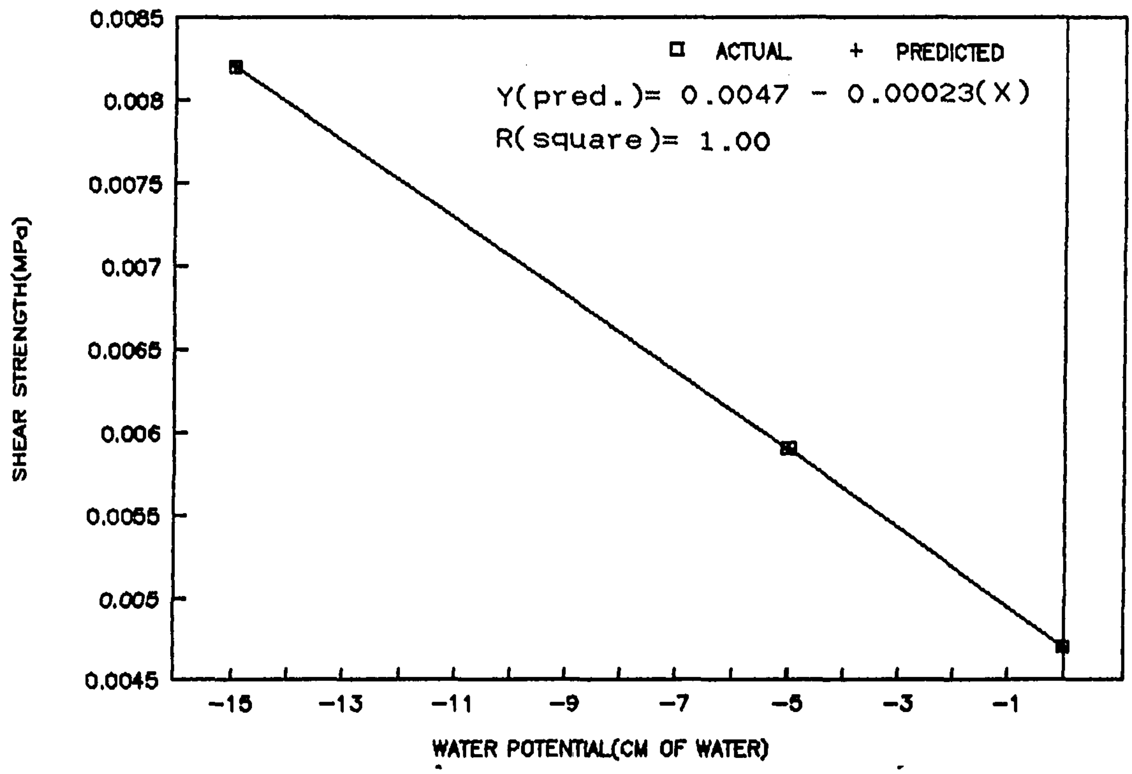

Figure B-22. Linear regression model between shear strength and soil water potential for T3N2 (sand under corn-soybean)

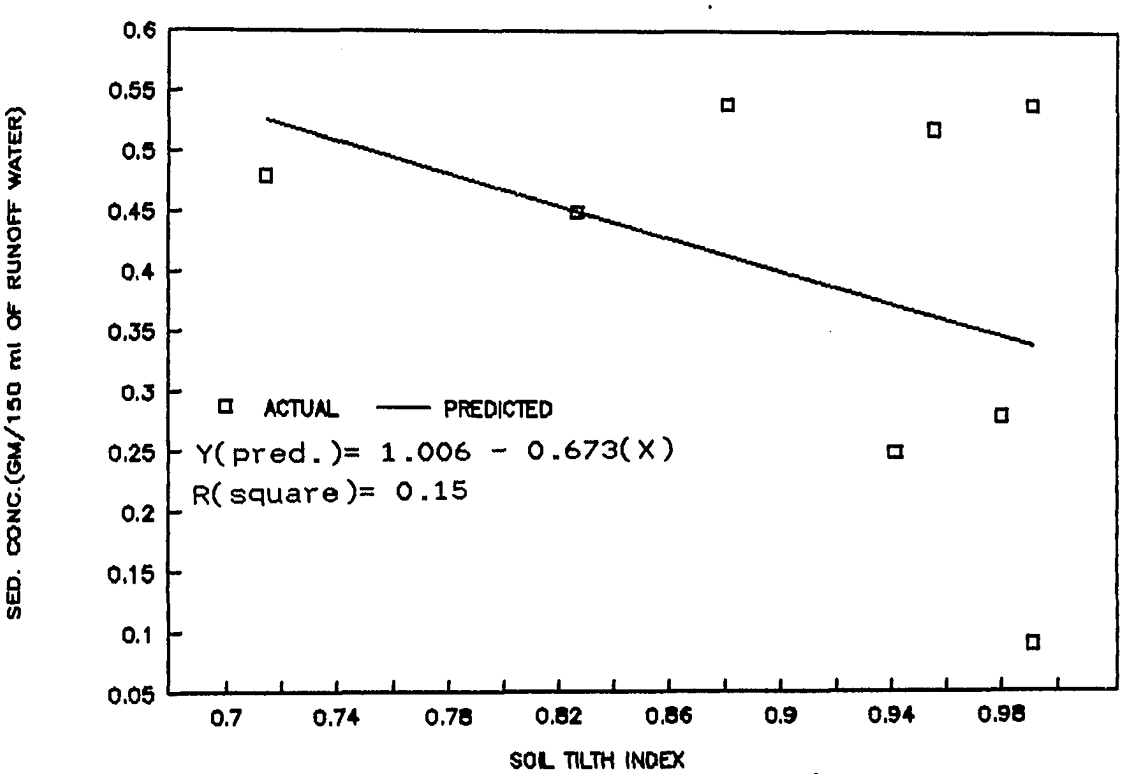

Figure B-23. Linear regression model between sediment concentration and soil tilth index for 0 cm of water potential

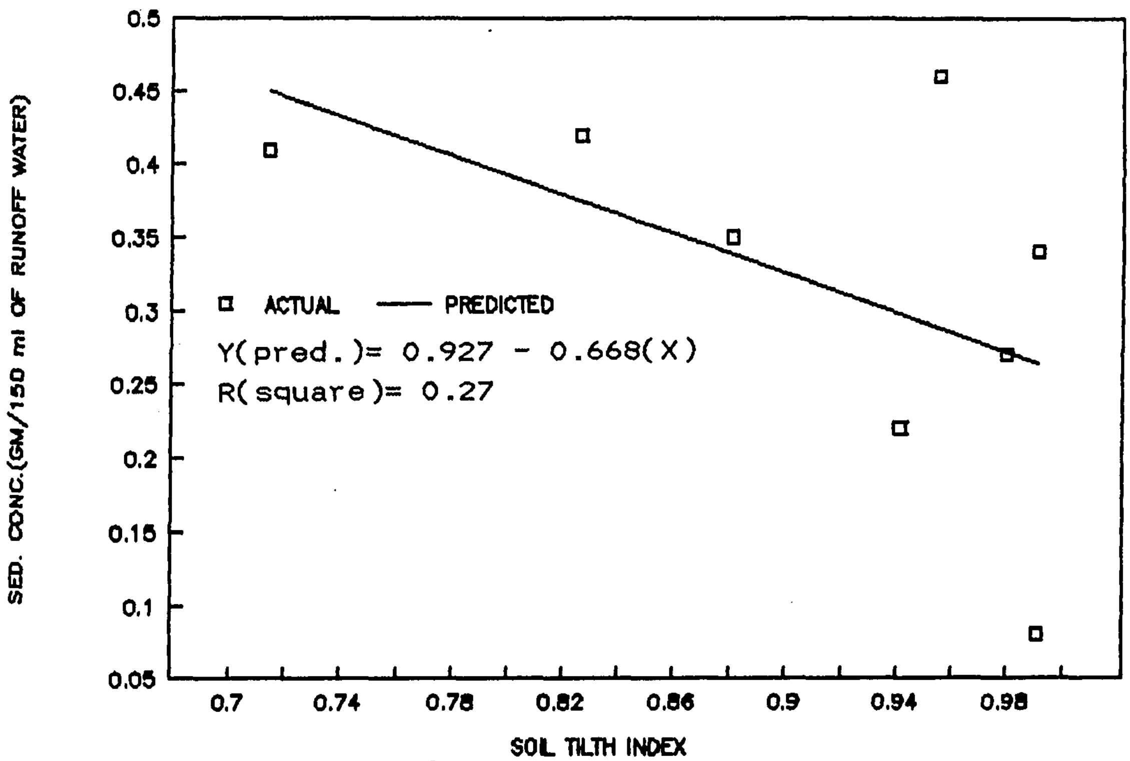

Figure B-24. Linear regression model between sediment concentration and soil tilth index for -5 cm of water potential

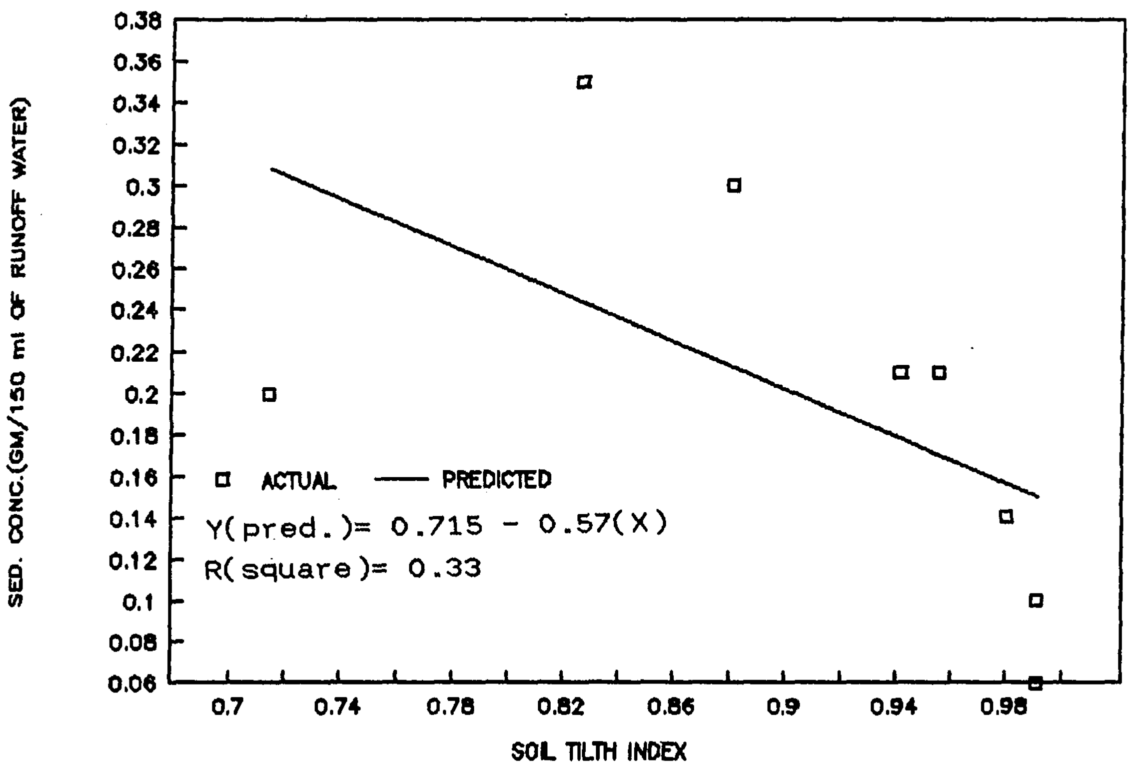

Figure B-25. Linear regression model between sediment concentration and soil tilth index for -15 cm of water potential

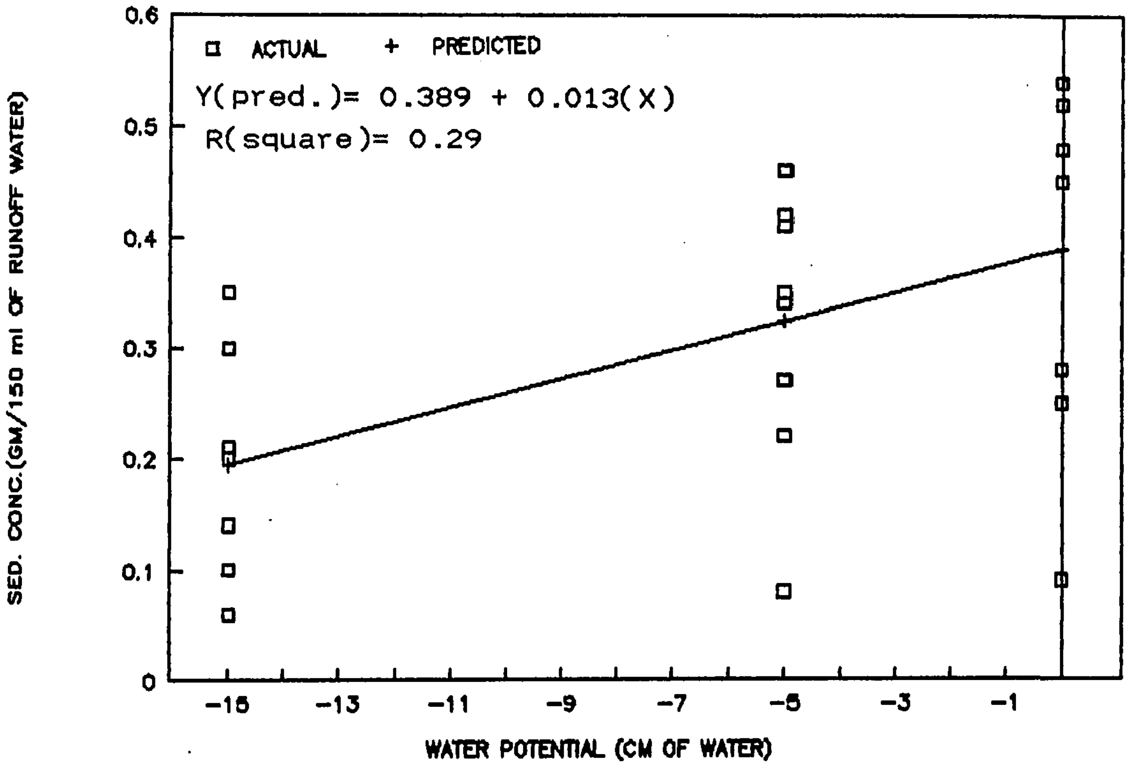

Figure B-26. Linear regression model between sediment concentration and soil water potential for all texture, and tilth (crop history) combinations

GENERAL SUMMARY

The apparatus described in this study allows many factors that affect soil erosion to be studied under laboratory conditions. Field conditions such as soil water potential, soil structure, soil texture, field flooding, and field slope can be studied. The interactions among these factors is a first step towards understanding and controlling the process of erosion.

Results from the initial testing were encouraging. Decreased water potential resulted in decreased sediment concentration in the run-off water. In other words, dry soils were less erosive than wet soils.

The apparatus was used to complete a split-plot experiment. Twentyfour texture*tilth (TN) combinations were placed in the main plots while three water potentials (0, -5, and -15 cm of water) were randomized in the subplots. For each second and third water potential in the subplot, a 50 mm layer of used, soil was removed and replaced with fresh, soil.

Runoff water samples were collected with the aid of 5-gallon buckets; therafter the effluent of the buckets was stirred vigorously, and a 150-ml subsample was collected from the center of each. These samples were poured into Aluminum cans, and the cans were placed in the oven at 105 degrees celsius for 24 hours. The water was evaporated, and the sediments left in the cans and removed carefully for weighing. The study produced a number of significant findings:

1. Sediment concentration in runoff water was low while using Webster (clay loam) soil, especially when the soil came from a site under grass.
2. Corn-soybean rotation in almost all cases yielded higher sediment concentrations in runoff water, than grass or corn-corn.
3. Sediment concentration in runoff water decreased in almost all cases when moving from 0 to -15 cm of water potential.

RECOMMENDATIONS FOR FUTURE WORK

In the course of this study a number of difficulties were experienced.

1. It was quite difficult to make vacuum boxes leakproof.
2. It was difficult to maintain constant bulk density for all combinations, because of the delicacy of the vacuum boxes.

On the basis of these observations and experiences, a number of recommendations are made for future researchers:

1. Instead of dividing one large box into three compartments, fabricate separate boxes to avoid difficulties in making vacuum boxes leakproof.
2. Place a layer of nylon mesh 50 mm from the soil surface to protect the hydraulic conductivity through the main soil mass. Replace 50 mm of the wet soil layer with fresh dry soil to test the second and the third levels of water potential.
3. Build the vacuum boxes quite strong so that bulk density can be maintained constant under both laboratory and field conditions.
4. Reduce depth of the soil bin so that limited soil is required to fill and empty vacuum boxes.
5. Keeping texture, tilth (crop history), and water potential constant, use laboratory apparatus to evaluate the effects of sediment load in runoff water,

slope of soil bin, and discharge of runoff water on sediment concentration.

6. Determine weight of empty evaporation cans. Then when runoff water (150 ml) is poured into aluminum cans, place these cans in an oven at 105 degree C for 24 hours, after which, when the water is evaporated, the sediments remaining indicate the final weight of the cans. The difference between initial and final can weights will give one directly the weight of sediments collected during a runoff event.

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