AN ABSTRACT OF THE THESIS OF

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Title: Evaluation of Erosion and Sediment Loss in Furrow Irrigation with Alternative Irrigation Practices.

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Marshall J. English

Soil erosion and sediment loss from irrigated fields in the Pacific Northwest is the most serious threat to long term sustainable agricultural production. The Oregon State D.E.Q, and United State Environmental Protection Agency (EPA) are very much concerned with ground water contamination and surface water pollution in eastern oregon, particularly Malheur County. Because of the silt loam soil type, and with conventional management practices, surface irrigation results in deep percolation and sediment loss from runoff water, which contributes to ground water contamination and surface water pollution. The ground water with higher water table in this region is being contaminated through leaching of nitrate and other chemicals from irrigated fields. The ground water is the main source of domestic water in that region. Pollution of surface water also results from runoff water from irrigated fields to the rivers.

The purpose of this research was to evaluate the erosion and sediment loss with different irrigation management practices, and to suggest the best irrigation alternatives to control the erosion and sediment loss from furrow irrigation. Experimental fields were selected in Malheur County, Eastern Oregon, where 350 square miles of agricultural land has surface irrigation on a large scale, mostly by the furrow irrigation method.

Field data collected in Malheur County were used to evaluate erosion and sediment yield for a variety of different circumstances. Three different fields with different irrigation and agronomic alternatives were selected for the study, mainly for different field slopes, field lengths, and stream sizes. Data were collected for conventional furrow irrigation and for three non-standard circumstances; surge flow irrigation, mulched furrow and alternate furrow irrigation. Surge irrigation is considered an effective method to control the erosion and sediment loss in furrow irrigation. The use of straw mulching in furrow bottoms is another measure to control erosion and sediment loss in furrow irrigation, especially when irrigated fields have steeper slope.

The PC program "FUSED" developed by the U.S. Soil Conservation Service (SCS) to evaluate the impact of alternative irrigation practices, was tested and calibrated with field data from two irrigation seasons, 1993 and 1994. Based on field results and calibration of FUSED program, alternative irrigation management practices are recommended for this region in order to maintain clean ground and surface water, to keep the environment safe for human beings, and to maintain crop productivity for future generations.

The model was checked with field data, and was found to be reliable to predict sediment yield for conventional irrigation methods. The observed sediment yields for different lengths and slopes of up to 1.0 % are fairly consistent. However it should be noted that the model under estimates the sediment yields at slopes greater than 1.0 %, and gives very poor results for the mulching factor..

Evaluation of Erosion and Sediment loss in Furrow Irrigation with Alternative Irrigation Practices

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Redacted for Privacy

Head of department of Bioresource Engineering

Redacted for Privacy

Dean of Graduate School

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1.0 INTRODUCTION

1.1 Statement of the Problem

Erosion affects soil productivity because it alters the chemical, physical, and biological properties of soil. Previous research in the U.S.A. has shown that soil erosion decreases soil productivity up to 50 percent, and crop yields are decreased where top soil depths are decreased (Carter, et al., 1986). In general, soil erosion results in loss of available plant nutrients and organic matter, degradation of soil structure, decreased rooting depth, and decreased available soil water, all of which can have negative effects on soil productivity. Technology is not available to restore crop production to the potential level that would have existed without erosion. Research and technology applications are needed to preserve our soil resources in furrow irrigated areas. Application of conservation tillage, irrigation water management practices, and irrigation system improvements are suggested as the best known practices to reduce furrow erosion (Hedlund, 1992).

Sediment loss from irrigated fields has caused negative effects on mankind. It has not only represented a natural resource loss, but also polluted tail water due to transport of chemicals and other hazards and diseases from agricultural fields. Irrigation erosion causes a number of agricultural and environmental problems. The Environmental Protection Agency (E.P.A), and other organizations are very much concerned about ground water contamination and surface water pollution in Pacific Northwest region in general and Eastern Oregon in particular. This research is carried out at the agricultural experiment station in Malheur county located in Eastern Oregon. The area under study has a major problem with nitrate leaching through deep percolation, and sediment and nutrient loss in runoff drain from furrow irrigated fields.

The prediction of erosion and sediment loss is very difficult because of variation in results. This research on one field shows a minimum loss of 135 kg/ha and a maximum loss of 5731 kg/ha in the same irrigation, which is a difference of 42 times. The variation of sediment loss from one irrigation to another is also a question; for example 29705 kg/ha was measured for first irrigation in the same furrow, where 135 kg/ha was for last irrigation which is a difference of 220 times. These results are shown in table 4-6. Another research report for "Crop and Irrigation data" (U.S.D.I Bureau of reclamation 1971) shows a variation of suspended solids (ppm) from 77.58 to 7984.57, which leaves a difference of 103 times. Data were collected from a field with the same crop of winter wheat.

1.2 Objectives

The main purpose of this research was to evaluate the erosion and sediment loss on different field slopes with different management treatments, and to suggest irrigation alternatives to control the erosion and sediment loss. The specific objectives of this study were:

1) To evaluate the sediment loss with surge and continuous irrigation at low field slope (0.5%).
2) To evaluate the sediment loss in mulch and non-mulch furrows at steeper field slopes (1% to 3%) under continuous irrigation.
3) To evaluate the sediment loss for short and long furrows at different field slopes.
4) To calibrate the "FUSED. Version 1.89-2" program.
5) To evaluate alternative management practices (i.e irrigation strategies).

1.3 Factors Affecting Furrow Irrigation Erosion

Furrows provide the surface for infiltrating water to supply the evapotranspiration demand of the crop and serve to convey the supply water for the entire furrow length.

The following are the major parameters that affect the erosion and sediment loss in furrow irrigation method.

a) Field slope.

b) Furrow length.

c) Inflow rate

d) Irrigated furrow spacing.

e) Furrow irrigation application method.

f) Irrigation scheduling and water management practice.

g) Tillage practice.

h) Physical characteristics of the soil such as soil structure, soil texture, and aggregate stability.

i) Amount of crop residue available.

1.4 Soil Erosion and Sediment Loss Control Technology

Various approaches have been used to prevent or reduce furrow erosion, usually at some inconvenience to the farmer or requiring specialized machinery, and significant cost. Some of these approaches include settling ponds, requiring periodic sediment removal and redistribution (Brown et al., 1981); mini-basin and buried pipe runoff control systems (Carter, 1985); straw placement in furrows (Brown, 1985b; Brown and Camper, 1987, and Berg, 1984); creation and maintenance of permanently sodded furrows (Cary, 1986); and conservation tillage (Carter, 1990; Carter and Berg, 1991). Several research projects have been conducted to develop and evaluate different management alternatives for reducing erosion and sediment loss from furrow irrigated lands.

The furrow flow rate, and to some extent the slope, are manageable factors that affect erosion. Shortening runs is also a means of decreasing required supply rate. Furrows compacted by tractor wheels commonly have infiltration rates about 40% lower than uncompacted furrows (Kemper et al., 1982), therefore, water will move faster and will result in more runoff.

Yonts et al., (1993), concluded from the results of their studies on 76 irrigation tests comparing continuous and surge irrigation that surge irrigation is an effective method of decreasing the intake rate of the soil and allowing water to move more rapidly down the field. The soil particles are consolidated with surge flow and can not move down the field easily. As the sediment loss is directly proportional to the runoff time, the surge flow has less time of irrigation because of intermittent cycles, therefore, it leaves less sediment loss.

1.4.1 Furrow sediment and erosion program "FUSED"

The "FUSED" PC program was developed in 1987 by SCS-West National Technical Center researchers; Paul Koluvek (retired) Irrigation Engineer and Tom Spofford, Water Management Specialist in Washington State, (John D. Hedlund, 1992). The model evaluates the impact of alternative conservation practices on sediment yield and furrow erosion. It is based on a regression analysis of monitored data. Research data collected by Agriculture Research Center (ARS) at Kimberly, Idaho, on silt loam surface soils was the primary data base, data were also collected in Wyoming state on same type of soils. For each alternative the program will predict:

A. Average annual sediment yield from the field (tons/ac/yr).

B. Average erosion at the upper end of the field in terms of;

   1) Tons per acre per year.
   2) Depth of soil eroded per year.
   3) Area affected by erosion.
   4) Years to erode a given soil depth.

The present research is involved with alternative irrigation strategies, that is, field slope, furrow length, stream size, type of furrow wheel-compacted or non-wheel, and irrigation application methods (continuous and surge).

A search of the literature and discussion with individuals involved with furrow erosion research in the region indicated that FUSED was the most promising model for analysis of alternative management practices. Field data were used to calibrate the "FUSED" model. The program was run using the same input parameters of agronomic and irrigation practices and field conditions. It was then run for different irrigation input data to find the best alternative irrigation management practices to reduce soil erosion and sediment loss.

2.0 LITERATURE REVIEW

2.1 Introduction

There are approximately 10 million hectares of surface-irrigated land in the 17 Western states with 1.5 million in the three Pacific Northwest states (Washington, Oregon, Idaho) that are mostly furrow irrigated (R. E. Sojka, et al., 1992). Soils in the Pacific Northwest are particularly susceptible to furrow erosion because they are typically low in organic matter and clay, and are derived from ash or glacial loess, with weak aggregates and little structure. In these systems, substantial quantities of water are conveyed across the field each season in furrows cut from bare, recently tilled soil, making the systems inherently erosive (Berg and Carter, 1980; Brown 1985a; Everts and Carter, 1981; Brown et al., 1988, and Carter et al., 1985).
Soil erosion is the most serious threat to long term sustainable production in the Pacific Northwest. Erosion commonly removes 5 to 50 tons per hectare per year from furrow irrigated fields, and as much as 141 tons per hectare per year from the inlet (top) ends of fields (Berg and Carter, 1980; Kemper et al., 1985). As much as 50.9 tons per hectare has been reported lost from a single 24-hour irrigation of corn (Mech, 1959). Erosion is exacerbated by slopes greater than 1 %, but in gravity systems, longer furrow runs often require greater slopes in order to deliver adequate amounts of water to the bottoms of fields (Carter et al., 1985).

Erosion of cultivated soils has always caused concern to land owners. On irrigated lands of more than one percent slope, erosion is extremely critical. Directly or indirectly influencing erosion in these cultivated soils are the degree of slope, size of furrow stream, infiltration rate, moisture content of the soil, furrow shape, furrow roughness, size of soil particles, and some minor factors. A slight change in one or more of these can significantly increase the erosion rate to a damaging degree (Rhys Tovey, et al., 1962).

Irrigation erosion is a serious environmental problem needing continued research aimed toward prevention. Erosion and sediment runoff from irrigated lands result both in impacts on the farmer and his neighbors and impaired water quality for downstream users.

Sediment concentrations in irrigation return flows in southern Idaho have ranged from 0.02 to 15 grams per litter, and are often the largest single pollutant of surface drainage waters (Brown et al., 1974, 1981). Sediment generated and transported from farm fields to receiving streams and rivers results in impacts on downstream users, including irrigators, municipalities, and recreationists. Continued toleration of soil losses will likely result in unacceptable penalties and regulations (Nolte, 1985).

Soil erosion is an additive process. As top soil is lost year after year, the erosion of yesterday is costing farmers today. Erosion from some irrigated soils has been responsible for a loss of production of up to 50 percent in an 80 year period (Carter, 1986) and crop yield reductions of 25 to 50 percent have been documented by the Agricultural Research Service (ARS) where 80 years of furrow irrigation in south central Idaho have severely top soil loss (Hedlund, 1992).

Brown, et al., (1974) found that the seasonal sediment loss from fields into drains on a 161,500-acre tract was 1.78 tons/acre. Most of this sediment deposited in drains, requiring mechanized removal. Brown (1985) has showed that severe erosion occurs in the upper length segments of furrow and sedimentation occurs along length segments further down the furrow. The process varies with each irrigation.

Carter, et al., (1985) calculated that the redistribution of top soil from upper to lower ends of fields by this erosion and sedimentation process has reduced potential crop yields approximately 25%. Our efforts should be directed at stopping erosion, which will also reduce sediment concentrations in return flows. (White, et al., 1985), reported that crop fields on severely eroded soils in the southern Piedmont were only 50 % as great as those on non-eroded soils.

Soil erosion occurs when fluid in motion detaches and transports soil particles. Sedimentation occurs when the fluid transport capacity decreases. Both the hydraulic forces of moving water and soil strength and particle size are factors. Under furrow irrigation, the shear of the channel flow against the soil provides the detachment force and is a primary factor in channel transport capacity. Once sediment is detached, it will be transported by the furrow for some distance, dependent primarily upon the particle or aggregate size and density and the transport capacity of the flow. Sediment is moved as bed load that rolls, slides, and bounces along the furrow bed, and as suspended load which remains entrained in the flow. (Thomas J. Trout et al., 1986).

Flow applies shear forces to the soil surface, which causes particle detachment and movement. As flow velocities increase, shear forces increase and eventually exceed the shear stress required to overcome the cohesive forces between soil particles. As the water infiltrate the soil, the sediment deposits at the furrow surface to form a thin seal, or depositional layer (Segeren and Trout, 1991).

Surge irrigation, has recently been introduced as a method to increase surface irrigation efficiency by reducing the time and amount of water required for irrigation. This is a process of intermittently applying water in an irrigation furrow. In other comparisons of surge irrigation, Bishop et al. (1981) found advance inflow times for surge irrigation to be significantly less compared to continuous flow irrigation. They indicated that the most significant improvement occurred during the first irrigation. Podmore and Duke (1982) in their Colorado study found infiltration rates from surge irrigation nearly half of those rates for continuous irrigation. In the southern high plains of Texas, (Musick et al. 1987), irrigation tests using surge irrigation resulted in water savings by reducing water application by 31% and decreases intake rates by 24 percent.

Izuno et al. (1985) conducted a surge irrigation study in Colorado and as a part of that study observed the differences between hard and soft furrows. They concluded that the surge irrigation reduced differences in advance inflow times between furrows with different levels of compaction. Musick et al. (1985) evaluated various parameters while comparing hard (Tractor track) and soft (No tractor track) furrows. In their study, there were pronounced differences in the advance inflow times. Furrows compacted by Tractor wheels commonly have infiltration rates about 40% lower than uncompacted furrows, (Kemper et al., 1982). Consequently, supplying water to wheel-packed rather than unpacked furrows can reduce the needed supply rate by about 40%.

C. D. Yonts and D. E. Eisenhauer (1993), conducted their experiment for 76 irrigation tests comparing continuous and surge irrigation with different treatments with hard and soft rows, they concluded that surge irrigation is an effective method of decreasing the intake rate of the soil and allowing water to move more rapidly down a field. Because continuous irrigation in packed furrows performed similarly to surge irrigation, either method can provide improved irrigation management. The improvement with furrow packing occurred primarily during the first irrigation. Surge irrigation provides additional water management capabilities during the entire irrigation season.

2.2 Methods for Estimating Sediment Discharge in Furrow Irrigation

The Imhoff cone has been used in the Settleable matter Method no. 224F (Taras et al., 1971) for sewage-sludge monitoring. A variation of the technique was used to estimate erosion from a limited number of fields of silt loam in central Washington (Van Nieuwkoop, 1979).

R. E. Sojka, et al., (1992), concluded that the relationship between volume of soil settled in 1.0 liter Imhoff cones after 30 minutes settling time and actual sediment concentration (weight of sediment per unit volume of suspension) was excellent for the eight soils used in his study. Imhoff cone settling volume of suspended sediments at 30 minutes settling time can be used to make rapid assays of suspended-sediment concentrations from irrigation runoff where concentrations typically exceed 1.0 gram per litter. This technique can be used to increase the intensity of field monitoring of erosion from irrigated lands.

Tom Trout, USDA-ARS, has described the "procedure for estimating furrow irrigation erosion and sediment discharge" in his handout. He has recommended that the sediment concentration can be quickly and adequately estimated in the field with Imhoff cones. The procedure is to fill the cones to the one-liter mark with the sample. Wash down any sediment attached to the cone sides with a wash bottle. Let the sample settle without disturbance for 30 minutes. After 30 minutes, read the deposited sediment volume on the gradations at the bottom of the cone. The cone can be tapped gently to level the surface of the sediment. He further added that the calibration tests in Idaho and Washington have shown that most furrow sediments deposit in thirty minutes in Imhoff cone, and the density of the deposition in the cone is about 1 g/ml. Consequently, sediment concentration (g/L) is approximately equal to the volume of sediment in milliliters. If greater accuracy is required, 3 to 5 Imhoff cone samples representing a range of concentrations can be saved in a closed container for later analysis in the laboratory. The procedure is to filter out, dry, and weigh the sediment to determine actual concentration. Graphically plot or regress measured sediment concentrations against Imhoff cone readings to develop a linear cone calibration for the soil.

2.3 Effects of erosion on topsoil depth and soil productivity

In general, soil erosion results in loss of available plant nutrients and organic matter, degradation of soil structure, decreased rooting depth, and decreased available soil water, all of which can have negative effects on soil productivity.

Most research work on detrimental impact of soil erosion on crop production have been done in the last five years, and they represent all regions of the United States, as well as some other countries.

There are approximately 10 million hectares of surface-irrigated land in the 17 Western states with 1.5 million in the three Pacific Northwest states (Washington, Oregon, Idaho) that are mostly furrow irrigated (Sojka, et al., 1992). Soil Conservation Service (SCS) surveys conducted in 1985, and 1986 indicate that about twenty percent of the cropland has serious soil erosion (J. D. Hedlund, 1992).

Soil erosion is the most serious threat to long term sustainable production in the Pacific Northwest. Erosion commonly removes 5 to 50 tons per hectare per year from furrow irrigated fields, and as much as 141 tons per hectare per year from the inlet (top) ends of fields (Berg and Carter, 1980; Kemper et al., 1985).

The furrow irrigation has two purposes. First it is the infiltrating surface for water to enter the soil to supply the evapotranspiration demand of the crop. Secondly, it is the conveyance channel to supply water for infiltration over the entire furrow length. The erosion takes place when the water is transported in the furrow from upper end to the lower end. The topsoil depth decreases near the head ditch and downslope for a distance depending upon the slope and irrigation practice that includes the stream size. Topsoil depth is increased along the portion of the field where deposition occurs, and significant quantities of soil are lost from fields by furrow erosion. (Berg and Carter, 1980).

Erosion and sediment yield from irrigated land causes damages to the land for both the farmer and their neighbors, and impairs water quality for downstream users. Growers pay the cost of erosion through higher fertilizer costs, and other prevention measures. Erosion carries away the rich layer of soil that is filled with nutrient and fertility. D.L. Carter, (1986) reported that the top soil is lost year after year and crop yield is reduced from 25 to 50 percent.

Irrigation erosion causes a number of agricultural and environmental problems. The redistribution of top soil caused by furrow erosion can severely reduce crop production (Carter, et al., 1985). The erosion of top soil is not only a serious loss of the natural resources, but a serious economic impact on farming in that area. Special emphasis need to be given to saving the physical structure of soil resources as well as maintaining fertility.

Hedlund, (1992) reported that irrigation erosion redistributes soil within fields and causes serious sediment deposition downstream in drain, irrigation canals, streams, lakes, and reservoirs. Sediments transported from one field to another may also transport pesticides, nutrients, and disease organisms.

There is a need to recognize the consequences of unchecked erosion and sediment deposition on about twenty percent or 10-million acres of irrigated cropland in the United States with serious erosion. From recent Soil Conservation Service (SCS) survey, it can be concluded that about 20 percent of the irrigated cropland has severe erosion problems. Hedlund, (1992).

Some of the recognizable consequences of soil erosion, sediment deposition, and flooding are:

1) Increased off-farm costs such as high labor cost, equipment requirements for debris removal, land smoothing, and erosion prevention measures.
2) Reduced water quality due to sediment, nutrients, and pesticides reaching streams, ponds, and wetlands.

3) Increased off-site damage such as sediment removal from culverts, ditches, stream degradation, equipment maintenance, and direct property damage.

The amount of erosion and sediment transport depends not only on stability of the soil but also on hydraulic characteristics of the flow and furrow geometry. The most commonly recognized factors that affect the rate of erosion, transport and deposition are:

i) Physical characteristics of the soil such as soil structure, soil texture, and aggregate stability,

ii) Tillage practice, and

iii) Irrigation scheduling and water management practice, which can reduce soil losses and improve downstream soil quality.

2.4 Erosion Control Technology

During the past 15 years, several research projects have been conducted to develop and evaluate different management alternatives for reducing erosion and sediment losses from furrow irrigated lands. The efficiencies of various "Best Management Practices" for reducing erosion and sediment losses have been established, and based on the efficiencies and cost considerations, best management practices can be applied by farmers, Carter, et al., (1986).

Aarstad and Miller (1978) reported that small amounts of crop residue left in irrigation furrows effectively reduced erosion when compared to cleanly tilled furrows. Similarly, Evans et al., (1978) concluded that a combination of surge flow and the higher surface residue levels associated with reduced tillage can decrease sediment in the runoff and increase water application efficiency.

Organic polymers, mainly polyacrylamide (PAM) and polysaccharide have been used in laboratory studies to maintain soil structure and permeability of soils subject to artificial rainfall (Helalia and Letey, 1988; Shainberg et al., 1990).

R. D. Lentz, et al., (1992) concluded in their paper that anionic PAM was more effective than anionic starch copolymer for controlling furrow erosion under their experimental conditions. The PAM treatments (5-20 grams per cubic meter) of 1 to 2-

hour duration reduced sediment loss by 45 to 98% in the initial (treated) irrigation. Cumulative sediment reduction during the initial and two subsequent, untreated irrigations was 42 to 58%.

Small concentrations of polyacrylamide in irrigation water can dramatically reduce furrow erosion and sediment loss. PAM stabilizes and reduces the erodability of soil surface particles, and flocculates small particles which make them more difficult to transport. Tested PAM concentrations amounted to 0.25 to 0.67 kg/ha applications, which would cost less than $1.70 per ha per irrigation. (Thomas J. Trout and R. D. Lentz, 1993.)

Changing the method of irrigation can significantly reduce runoff and erosion. Conservation practices can be installed to trap the sediment before it is deposited in streams. The following practices can control erosion, transport, and deposition.

a) Control the slope.
b) Shorten the length of run.
c) Change of irrigation methods.
d) Install sediment traps and/or a reuse system.
e) Use of plant residues, and straw mulch in furrow bed.

Effective furrow erosion control depends upon methods to increase soil cohesion and to use plant residues to dissipate stream flow energy and to bind soil together. Applying small amount of residues to furrows can almost eliminate soil erosion and sediment loss (Miller and Aarstad, 1983; Berg, 1984; Brown, 1985). Presently, several conservation tillage regimes are being evaluated for this purpose. Limited results indicate that sediment losses can be reduced 50 to 90% by applying minimum tillage practices. (Carter, unpublished data).

Furrow irrigation on moderate slopes can lead to high rates of soil loss and low efficiency of water use. Where water intake is limiting, crop yield and quality can be adversely affected. Application of small quantity of straw mulch is a possible practical means to decrease erosion and increase water infiltration. Robert Berg (1984) showed that small quantities of straw could increase water infiltration and decrease soil loss in furrow-irrigated crops near Kimberly. Miller and Aarstad (1983) showed that at Prosser, Washington, most of measured soil loss occurring under furrow irrigation could be controlled by relatively small quantities of hand-applied straw (between 360 and 1080 lbs of straw per acre).

Clinton Shock, et al., (1988) measured sediment yield in their study on "effects of straw mulch and irrigation rate on soil loss and runoff." Soil loss at a rate of 18 tons/acre (40333 kg/ha) per irrigation occurred with water application rates of four gallons per minute per furrow. At four gallons per minute, 790 lbs per acre of straw mulch reduced soil loss to less than 3 tons per acre on the first irrigation, but soil loss rose to 8.5 tons/acre (19046 kg/ha) on the second irrigation. The soil loss on the second irrigation was exaggerated on the mulched treatment because the mulch had stimulated high water intake during first irrigation. At two gallons per minute, soil loss from strawed furrows averaged less than 0.2 ton/acre 448 kg/ha) per irrigation over 11 hours. The non-strawed furrows lost more than 3.3 tons/acre (7394 kg/ha) per irrigation. The soil loss over time was least during the initial part of both irrigations.

ARS soil scientists John S. Aarstad and David E. Miller found that when straw, adding up to slightly less than 1 ton/acre (2240 kg/ha), was uniformly placed in furrows, runoff water was cleaner (more free of soil particles) than the water entering the furrows.

Carter, et al., (1986) USDA Agriculture Research Service suggested in his study on effect of erosion on soil productivity that the most promising practices for controlling furrow erosion and sedimentation processes is the application of non-tillage or minimum tillage to furrow irrigated lands. Research is underway with promising results that no-tillage and minimum tillage can greatly reduce furrow erosion, and at the same time, significantly reduce production costs without reducing crop yields.

3.0 MATERIALS AND METHODS

3.1 Field Experiment Work

Field experiments were conducted to provide data for two different soils described below with cultural and irrigation application practices to evaluate soil erosion and sediment loss. The following two types of data collection were carried out at different experimental fields;

1) The hydraulics of furrow irrigation was determined by studying flow rates and infiltration vs wetted perimeter. The infiltration tests were conducted by two different methods, one by using a recirculating furrow infiltrometer, and another by monitoring the inflow and outflow measured in a furrow during each irrigation.

2) The measurement of advance rates, inflow, outflow, and sediment concentrations in each irrigation at different stream sizes, furrow runs, slopes, and other irrigation and cultural practices.

3.1.1 Experimental site

The initial field work was carried out at the Malheur Agricultural Experiment Station, Ontario, Oregon State University. This research station is situated in Eastern Oregon in Malheur county, where other researchers and scientists are also involved in different aspects of research in agriculture field. The research work was carried out on two different fields;

1) field B-3,

2) field B-7.

A large field of a cooperative grower at Bel-Air farm in the vicinity of the Agricultural Experiment Station was also used for experiment.

3.1.2 Field description

Field B-3 (Nyssa silt loam), 1.35 acres in area with steeper slope (3%), top width 235 feet, length 250 feet was selected for straw mulching treatment. Twelve out of 30 furrows were treated with straw mulching at an application rate of 800 lbs/acre in furrow bed. A total of twelve furrows were observed in this field.

Field B-7 (Green leaf silt loam), 6.5 acres area was selected for evaluation of erosion and sediment loss under surge and continuous irrigation methods. This field was laser levelled with slope 0.5%, top width 440 feet, length 650 feet. The total field was divided in 12 blocks. Six blocks were evaluated under surge irrigation and the other six blocks were evaluated under continuous irrigation. Each block had hard (tracked) and soft (non-tracked) furrows. Every alternate furrow was irrigated in field B-3 and field B-7 through out the irrigation season.

A field at Bel-Air farm (Nyssa silt loam) 31 acres was surveyed for evaluation of sediment loss at two different slopes of 1.0% and 1.5%, and three different furrow runs. This field is located 12 miles south of the Agricultural Experiment Station near Nyssa. This field has a winter wheat crop followed by two years of alfalfa crop.

3.2 Machinery and Equipment

3.2.1 Recirculating furrow infiltrometer (RFI)

The recirculating furrow infiltrometer used in the study is shown in figure 3-1. A low speed pump (about 50 RPM) Archimedes screw, constructed from a grain auger fixed in a PVC pipe, was used to lift the water from the downstream sump of the infiltrometer to a small return reservoir from which it flowed by gravity to the upstream end of the furrow section. A constant-head Marriott syphon supply tank maintained a constant water volume in the infiltrometer, Thomas J. Trout, (1991). The water volume (depth) decrease in the supply tank, which is equal to volume infiltrated minus the amount in surface storage in the furrow, was measured with every 5 minutes for first hour, and 10 to 15 minute for rest of the irrigation time.

Figure 3-1. Recirculating Furrow Infiltrometer (RFI)

3.2.2 Furrow flume

Small flumes that resemble the furrow cross-section shape, shown in figure 3-2, were placed at the mid point of the furrow 310 feet from head, and at end of the furrow 650 feet from head in each observed furrow in order to measure the flow rate at different longitudinal distances in furrow length with different time intervals.

Figure 3-2. Trapezoidal Flume.

3.2.3 Gated pipes

PVC pipes of 6 inches inside diameter, shown in figure 3-3, were used to deliver irrigation water. The automatic Surge valve was placed to turn on and off for surge irrigation. Small pits of one foot diameter and one foot deep were dug beneath each outlet from the gated pipe in order to measure inflow rates with a coffee can and stop watch. These pits also helped decrease the initial flow velocity at the furrow head.

Figure 3-3. Gated Pipe used as a irrigation source.

3.2.4 Imhoff cone

The Imhoff cones shown in figure 3-4 were used to collect sediment outflow samples from the tail water ditch at the end of the field. The samples are left in the cones for about 30 minutes to settle the sediment in the bottom. These cones are used to measure sediment concentrations which are then combined with outflow rate (l/min), and sediment yield is estimated (g/min) by multiplying the Imhoff cone reading with outflow rate.

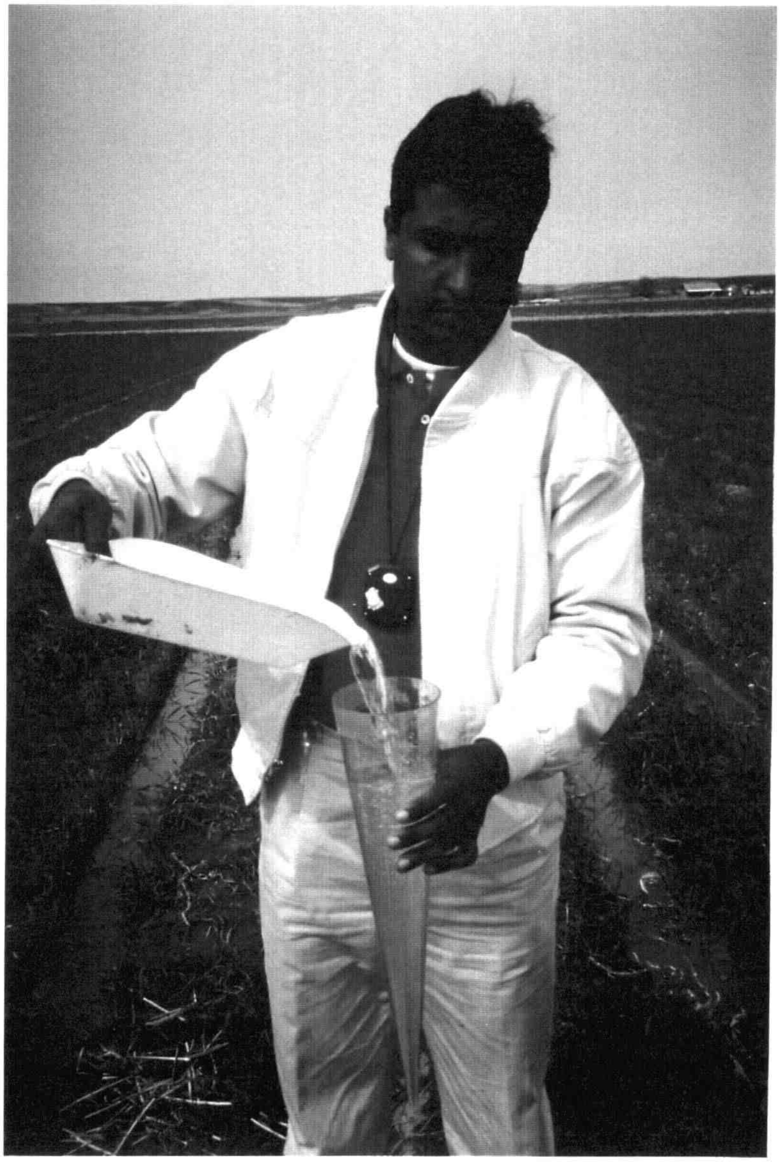


Figure 3-4. ImHoff cone used for measurement of sediment concentration.

3.2.5 Calibrated catch cans

Empty coffee cans (3.2 liter volume) were calibrated and used to measure the inflow rate from supply gated pipe. A similar can is used to measure the outflow rate at the tail ditch from each furrow and/or block of furrows. The can volume was measured with scaled cylinder.

3.3 Crops Grown (present and previous)

Cropping sequence and tillage practice greatly influence crop residue which has direct effect on erosion. Both fields had spring wheat during study, field B-3 had sugar beets in last season and field B-7 had half area sugar beets and half area onions. Since field B-3 has steeper slope (3%), this field was treated with straw mulching in furrow bed at the rate of 800 lbs/acre, the straw is shown in field photo. The wheat straw was placed by straw spreader, newly developed by Joe Hobson, retired grower in that area.

3.4 Irrigation Practice

Irrigation practice has a direct influence on the reduction in furrow erosion. Changing the method of irrigation can significantly reduce runoff and erosion. The number of irrigation sets (5), and duration of irrigation (24 hr) were designed for both fields. River water was the source of irrigation coming through a lined ditch. A gated pipe was used with adjustable inflow rate. A surge valve was fixed with gated pipe for the surge irrigation method. Figure 3-5 shows the placement of the surge valve with gated pipe. The following practices were set out for both fields to evaluate the soil erosion and sediment loss.

Figure 3-5. Surge valve and gated pipe.

3.4.1 Furrow geometry

Furrow geometry includes cross-section, length, slope, and furrow spacing. Changing any of the above parameters can significantly effect the erosion. Because of steeper slope 3.0 % in field B-3, the length of furrow was set at 250 feet, whereas field B-7 has slope 0.5 % and furrow length 650 feet. The furrow spacing and average cross-section for both fields were kept 30 inches and 24.8 square inch (160 square centimeter) respectively. A Rill meter was used to measure the cross-section of the furrow as shown in figure 3-6. Both fields were irrigated in alternate furrows, therefore, furrow spacing is considered as 60 inches for sediment loss calculations.

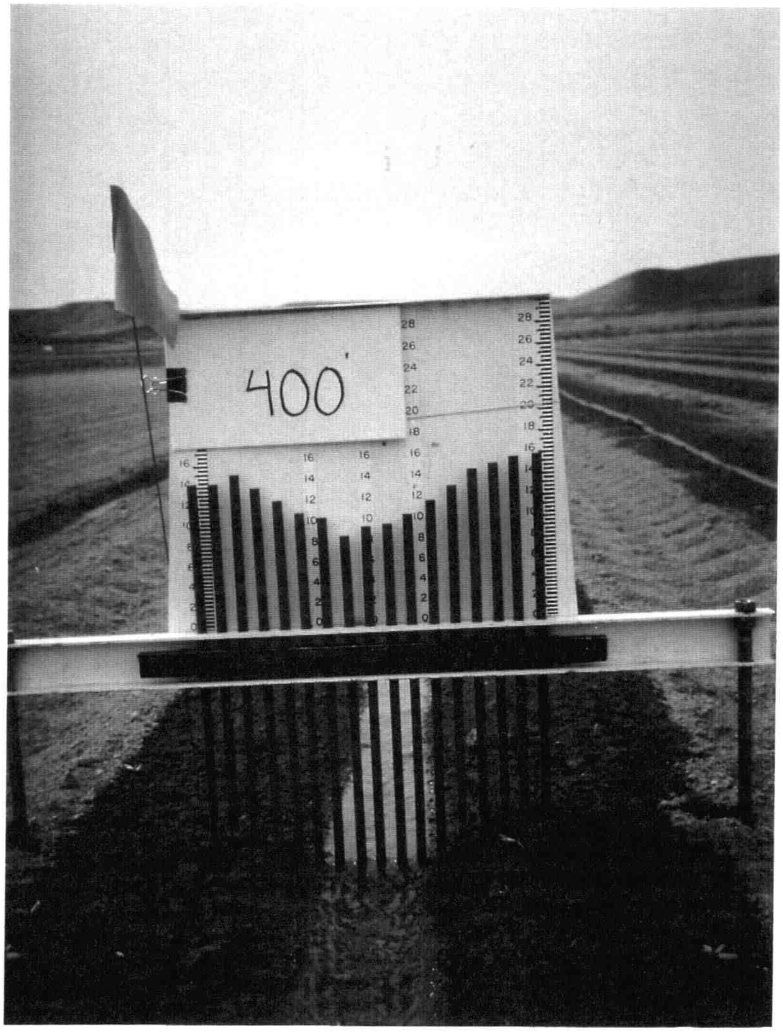


Figure 3-6. A Rill meter used to measure furrow x-section.

3.4.2 Continuous irrigation

This is also referred to as the conventional irrigation method, which is defined as the application of irrigation water in each furrow without interruption during the time of set.

3.4.3 Surge irrigation

Applying the irrigation water in each furrow with set time intermittent for ON and OFF at supply source through out the duration of irrigation is called surge irrigation system. The intermittent time for surge was fixed (45) minutes for all irrigation sets, which implied that half as much irrigation water is applied for surge-irrigation treatment blocks as compared to irrigation water for continuous-irrigation blocks in the same span of time.

3.5 Field Data Measurements

3.5.1 Method of data collection

Data collected included field location, soil map unit and/or surface soil texture, field dimensions and slope(s) in the furrow direction, spacing between irrigated furrows, crop and growth stage, tillage practice and surface residue, type and date of most recent tillage, soil surface moisture condition (qualitative), tail water ditch characteristics (slope and visible erosion/deposition), and any other characteristics or management practices that might affect erosion. Figure 3-7 shows the tail water ditch and placement of flumes at the end of furrow.

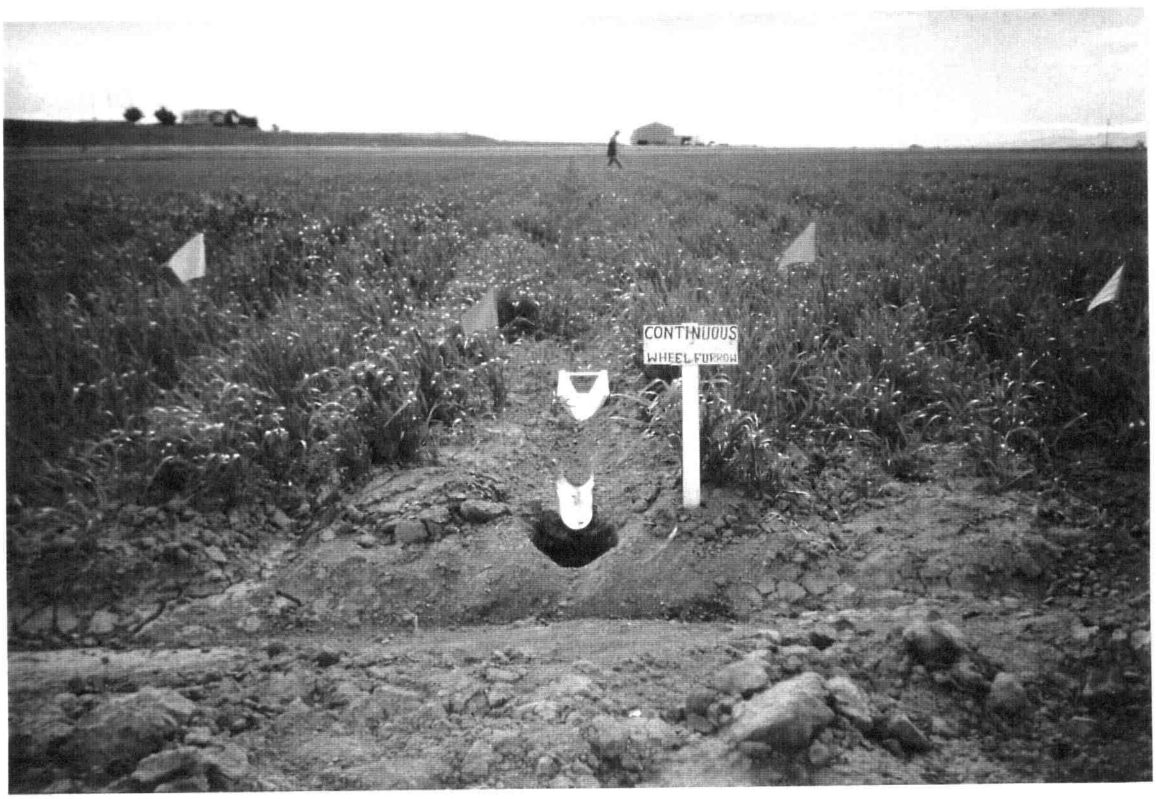


Figure 3-7. Tail water ditch and placement of Flumes.

CALCULATIONS:

To determine sediment movement mass at the measurement location the following algorithm was used:

1) Multiply the sediment concentration times the flow rate and the sample time interval to determine sediment movement mass for each time interval.

Sed. Movement(g) = Sed.Conc(g/L) * Flow Rate(L/min) * Sample Interval(min).

(The sample time interval is half of the preceding plus the half of the following sampling interval).

2) Sum the masses for all sampling intervals to determine sediment movement past the point for irrigation.

To determine net erosion or deposition between measurement points within a given furrow:

1) Calculate sediment movement differences (g) between the measurement locations. Sediment loss indicates net erosion and gain represents net deposition.
2) For furrow measurements, average calculated sediment loss/gain among similar furrows (similar flow rates, slopes, and management).
3) Divide the net sediment loss/gain between measurement locations by the land area between measurement points to get erosion or deposition in (mg/ha.)

Erosion(mg/ha) = 0.01 * [Sed. Inflow(g) - Sed. Outflow(g)] / Area irrigated(square meter).

When data are from furrows, the area irrigated by each furrow is the irrigated furrow spacing (m) times length between sampling points (m). When data are for field inflow and outflow during an irrigation set, the area irrigated is the set width (number of furrows in the set times furrow spacing) (m) times row length (m). The volume of the sediment movement (cubic meter) is the mass divided by an assumed surface soil bulk density, usually 1.3 mg/cubic meter. Plots over time of the measured flow rates and sediment concentrations help illustrate how sediment movement varies with time.

3.5.2 Furrow inflow, outflow, Imhoff cone reading measurements method

The water samples from the irrigation source were collected at the start and during the irrigation and sediment concentrations were measured with the help of Imhoff cones. Concentrations were found to be less than 0.05 grams per liter in all samples, therefore the quality of inflow water is considered as clean water, and sediment load is assumed to be negligible in inflow water for the sediment loss calculations. The inflow rate in every furrow was measured with V-notch trapezoidal flumes. Initially, three readings were taken on 15 minutes intervals and after the required inflow is established, the interval was increased up to two hours.

After the water reached the end of the furrow, the outflow from each observed furrow was measured with different time intervals using same kind of flume as shown in following figure 3-8.

Figure 3-8. Imhoff cones and flumes used to measure flow rate and sediment concentration.

The readings were measured with 15 minutes interval for first hour in each furrow and later the interval was increased up to two hours. The sediment samples were collected at every outflow reading.

The equation number (3-1) was used to calculate sediment loss from outflow measurement readings and Imhoff cone reading for individual furrow.

$$Y = Q * S_C * \Delta t * 1/A * 1/1000 \qquad (3\text{-}1)$$

where,

Y = Sediment loss (kg/ha)

Q = Outflow rate (L/min)

S_C = Sediment concentration (grams per liter)

Δt = Time interval between each reading (minute)

A = Area under irrigated furrow (hectare)

Sixty degree V-notch trapezoidal flumes were used for outflow measurements. A discharge equation for the flume was developed with a theoretical computer calibration program developed for long-throated flumes by Replogle, Bos, and Clemmens (1991). The discharge equation (4-2) for the flume is

$$Q = 0.000543\ (h-1.5)^{2.63} \qquad (3\text{-}2)$$

where the head, h, is measured vertically in centimeters (cm) and the flow rate, Q, is given in liters per minute.

The sediment concentration in grams per liter from Imhoff cone readings is calibrated for this soil type by Clint Shock et al., in Malheur County crop research annual report 1992. The calibration equation (4-3) is used for calculating sediment concentration in runoff water.

$$S_c = 1.015\ x \qquad (3\text{-}3)$$

where,

S_c = Sediment concentration (grams per liter)

x = Imhoff cone reading after 30 minutes of settlement.

table 3-1 illustrate the algorithm for calculating sediment loss from field data. The first column in this table is for elapsed time. The starting delta (t) = 10 minutes is because the water in furrow reached at this point at 41 minutes elapsed time. The third column in this table for flow is given in (cm) because, the outflow was measured with the calibrated flume scale in (cm). The sediment loss in kg/ha in table 3-1 is calculated by the product of time interval (minutes), outflow rate (liter per minute), sediment concentration (grams per liter), and then the result in grams is divided by the area (hectare) under irrigated furrow and one thousand to convert from grams/liter to kg/liter.

TABLE 3-1. Sample calculation of field data for a single furrow with 400 ft long, 1% slope, and inflow rate 8.0 gpm.

El Time (min)	Δt (min)	Flow depth (cm)	Outflow l/min	Imhof cone reading	Sedconc g/liter	Sedloss kg/ha
51	10	4	8.3	0.4	0.406	3.627
67	16	4.4	10.7	0.5	0.508	9.352
97	30	4.8	13.9	0.3	0.304	13.668
120	23	5.2	17.0	0.3	0.304	12.815
150	30	5.2	17.0	0.3	0.304	16.716
177	27	5.3	17.6	0.3	0.304	15.575
210	33	5.4	19.0	0.3	0.304	20.551
270	60	5.4	19.0	0.3	0.304	37.365
390	120	5.5	19.6	0.5	0.508	128.48
465	75	5.6	20.6	0.5	0.508	84.398
540	75	5.6	20.6	0.3	0.304	50.639
630	90	5.7	21.8	0.4	0.306	85.742
855	225	5.8	22.5	0.3	0.304	165.93
1440	585	5.8	22.5	0.3	0.304	431.41

Total sediment loss = 1076.27 (kg/ha)
Conversion: 1 ton (short) = 907.18 kgs
1 hectare = 2.47 acres
1 kg/ha = 1/(907.18*2.47) tons/acre
1076.27 kg/ha = 1076.27/(907.18*2.47) = 0.48 tons/acre

4.0 RESULTS AND ANALYSIS

4.1 Sediment loss in Conventional Furrow Irrigation

Two fields with various slopes and furrow lengths were used to evaluate sediment loss under conventional furrow irrigation. Conventional irrigation, in this case, refers to furrow irrigation with typical inflow rates that are kept constant for the duration of the irrigation, using no special soil amendments. The first field was B-7 at the Malheur Experiment Station in which data were collected for two seasons, 1993 and 1994. The second was the field on Bel-Air Farm, a cooperating farm in the vicinity of Nyssa, in which data were collected in 1994. (Data were also collected in these same fields and other fields for nonstandard furrow irrigations involving surge flow and the use of straw mulching, as discussed in later sections of this chapter).

Table 4-1 shows comprehensive data analysis for sediment loss from field B-7 of the Malheur station. The field measured 440 feet top width and 640 feet in length, with an average slope of 0.5 %. The crop was winter wheat, irrigated with gated pipe using inflow rates which were held at approximately 6.2 gallons per minute. The first irrigation started on May 11, 1993, and the last ended on July 14, 1993. All sediment samples were collected at the end of the field. Outflow was measured with flumes. One liter samples of runoff water were collected at regular intervals and were analyzed for sediment concentration using Imhoff cones. The sediment losses for five irrigations in field B-7 are shown in figure 4-1. Total sediment loss from conventional irrigated blocks was estimated in kilograms per hectare, then converted to tons per acre. (Note that the sediment mass units used here are in tons per acre for comparison with FUSED model and also because the people of that region who will be using these results are in the habit of English units). Each plot consisted of six irrigated furrows. The last column (sedloss in ton/ac) in table 4-1 is the sum of sediment loss from all six blocks divided by the area of those blocks.

Usually the erosion and sediment loss is higher in the first two irrigations and tends to decrease for subsequent irrigations. In this field the sediment loss for first irrigation 419 kg/ha (0.187 tons/ac) was measured, followed by 355.3 kg/ha (0.158

tons/ac) in second irrigation. The third and fourth irrigations have lower sediment yields of 220 kg/ha (0.098 ton/ac) and 145.7 kg/ha (0.065 tons/ac) respectively, but again the last irrigation gave the sediment yield up to 255 kg/ha (0.114 tons/ac) probably because of higher temperature and soil dryness. The total sediment loss for five irrigations is estimated as 1395.5 kg/ha (0.623 tons/ac).

TABLE 4-1. Total sediment loss (kg/ha) from conventional irrigated blocks for each irrigation from field B-7, 1993.

Irrigation#	PLOT # 2	PLOT # 3	PLOT # 5	PLOT # 7	PLOT# 10	PLOT# 12	Total ton/ac
1	150.10	243.43	641.66	653.67	413.49	411.59	0.187
2	306.24	351.40	362.42	285.51	551.03	302.95	0.158
3	116.59	309.0	305.39	92.66	249.35	246.37	0.098
4	29.13	83.18	164.37	371.09	99.70	126.34	0.065
5	133.37	152.72	356.83	462.03	231.33	192.02	0.113
Total	735.43	1139.7	1830.6	1837.9	1544.9	1279.2	0.623

The field on Bel-Air Farm was longer and steeper. Furrows in the southern part of the field had slopes of about 1.0 %, while farther north the slopes were about 1.5%. Sets of four furrows at each of these slopes were monitored. The lengths of the furrows was 1200 feet. However data were collected at 400, 800, and 1200 feet from the head of the furrow which yielded a large body of data for different furrow lengths with a minimum of additional effort. The sediment loss estimated for three different lengths are shown in table 4-2. In order to compare results from Bel-Air farm with results from field B-7 which is 600 feet long, the field data were also collected from this field at 600 feet from the head of the furrows for two different slopes of 1.0 % and 1.5 %. The average inflow rate was maintained at 8.0 gpm for each irrigation. Results from the Bel-Air farm are presented in tables 4-2 and 4-3.

TABLE 4-2. Sediment loss (tons/ac) on Bel-Air farm at three furrow lengths with same inflow rate 8.0 gpm, and slope 1.0% for wheel (W) and non-wheel (NW) furrows.

Furrow #	Irrig: #	400 ft	800 ft	1200 ft
1 (W)	1st	0.478	0.270	0.137
2 (NW)	1st	0.161	0.017	0.00
3 (W)	1st	0.190	0.126	0.141
4 (NW)	1st	0.311	0.085	0.00
Average		*0.285*	*0.124*	*0.069*
1(W)	2nd			
2 (NW)	2nd	0.202	0.101	0.074
3 (W)	2nd	0.379	0.189	0.095
4 (NW)	2nd			
Average		*0.264*	*0.132*	*0.077*
1 (W)	3rd	0.702	0.368	0.091
2 (NW)	3rd	0.220	0.132	0.069
3 (W)	3rd	0.222	0.111	0.203
Average		*0.381*	*0.204*	*0.121*
TOTAL		**0.958**	**0.474**	**0.166**

The data presented in these tables from both farms are recombined in tables 4-3 (a-c) to compare sediment yield as a function of slope. (The W and NW show as furrow type denote wheel and non-wheel furrows; see section 4.4.)

A set of four irrigated furrows at each different slope was kept under observation. The sediment loss for 0.5% slope was estimated from block # 2 with seven irrigated furrows in field B-7. The sediment loss for 1.0% and 1.5% was estimated from a large field at Bel-Air farm at two locations. The estimation of sediment loss for different slopes is shown in Table 4-3, where results can be seen for every irrigation and for every furrow and/or block. All results are calculated in tons per acre, because the model gives the result of sediment yield in these units.

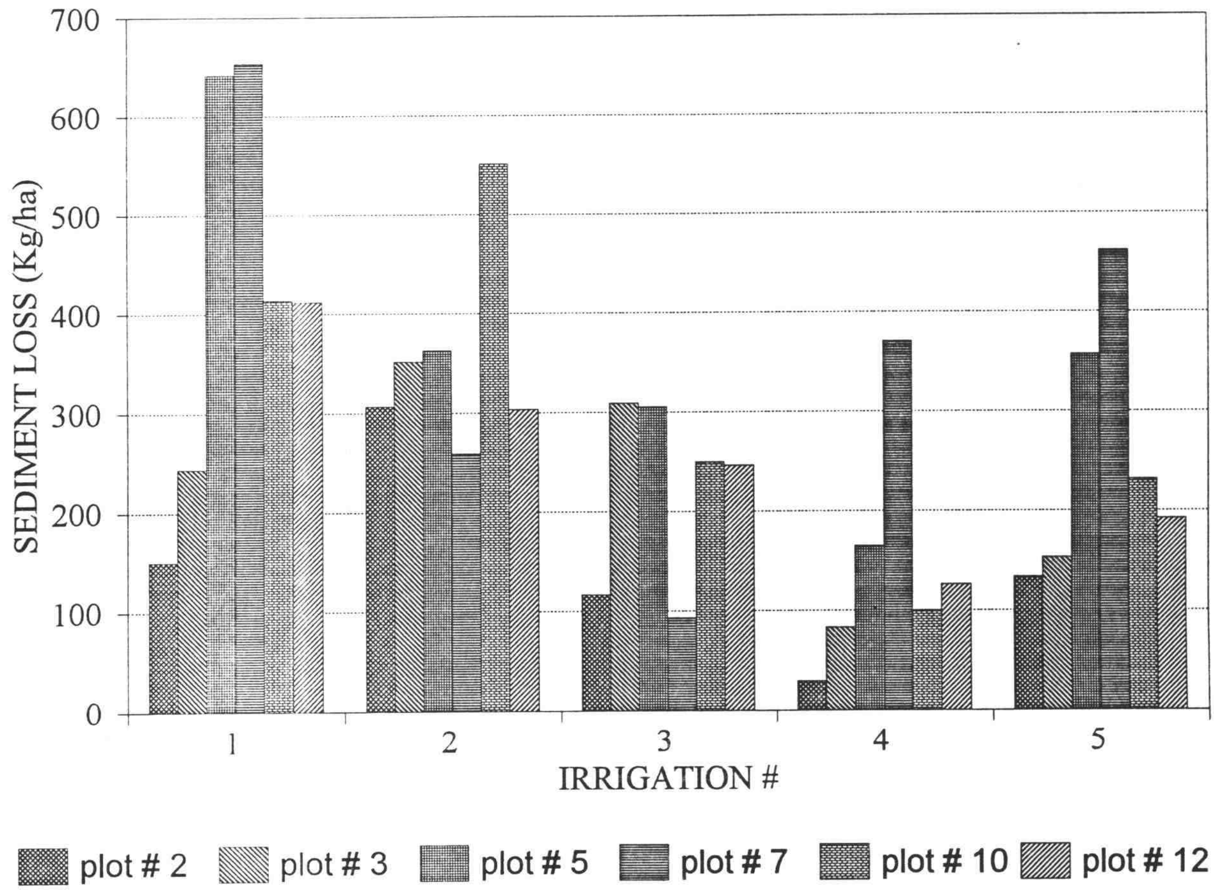


Figure 4-1. Total sediment loss from conventional irrigation method for five irrigations in field B-7, 1993.

TABLE 4-3. Sediment loss (tons/ac) measured from field B-7 and Bel-Air farms at field slopes (0.5%, 1.0%, 1.5%), inflow rate 8.0 gpm, and furrow length 600 feet.

Slope (%)	Furrow/Block #	Irrigation # 1	Irrigation # 2	Irrigation # 3	Total (tons/ac)
0.5	2	0.135	0.069	0.052	**0.257**
1.0	1(W)	0.375	0.123	0.193	0.691
1.0	2 (NW)	0.179	0.084	0.171	0.434
1.0	3 (W)	0.158	0.225	0.539	0.922
1.0	4 (NW)	0.198	0.072	0.301	0.571
Average:					**0.654**
1.5	1 (W)	4.51	3.697	--	8.205
1.5	2 (NW)	3.595	2.310	--	5.905
1.5	3 (W)	4.980	2.843	--	7.823
1.5	4 (NW)	3.846	2.267	--	6.113
Average:					**7.01**

4.2 Sediment loss in Surge Irrigated Furrows

Additional data were collected in field B-7 from six surge irrigated blocks; each block had 6 or 7 irrigated furrows. The cumulative sediment loss estimated in kilograms per hectare for five irrigations is shown in table 4-4, and results are also indicated in figure 4-2. The last column (sedloss in tons/ac) in this table is the average of sediment loss from all six blocks, converted from kg/ha to tons/ac. A comparison of sediment loss observed in surge and conventionally irrigated blocks is shown in figures 4-3 for each of five irrigations during the season. The variability of sediment loss in the two treatments is illustrated in figure 4-4.

This study showed that the surge irrigation not only decreases the sediment loss from irrigated field, but also saves irrigation water. Figures 4-3 and 4-4 show the comparison of sediment loss with conventional irrigation and surge irrigation methods. In figure 4-3, the sediment loss in the first and second irrigation using the surge method is 50% less than the sediment loss with conventional irrigation. The third and fourth irrigations gave almost the same sediment yield, but in the last (fifth) irrigation, surge gave less than one third the sediment loss of the conventional irrigation method. The total sediment loss from both methods indicates that the sediment yield is decreased by to 52 % with surge irrigation method.

TABLE 4-4. Total sediment loss (kg/ha) from Surge irrigated blocks for five irrigations from field B-7, 1993.

Irrigation #	Plot # 1	Plot # 4	Plot # 6	Plot # 8	Plot # 9	Plot #11	Total ton/ac
1	75.43	150.96	286.66	276.66	65.79	63.21	0.068
2	1.75	370.82	265.21	0.00	262.49	145.91	0.078
3	250.80	309.20	244.96	199.78	215.80	218.93	0.099
4	3.66	7.56	18.73	237.41	395.51	2.72	0.049
5	29.56	55.73	111.12	89.26	71.98	23.71	0.028
Total	361.14	794.27	926.68	803.11	1011.0	454.48	0.324

Average sediment loss for five surge irrigations was = 0.324 tons/ac (726 kg/ha). Recall that the corresponding average for conventional irrigation was 0.623 tons/ac (1395.5 kg/ha). The average reduction was therefore 48 %.

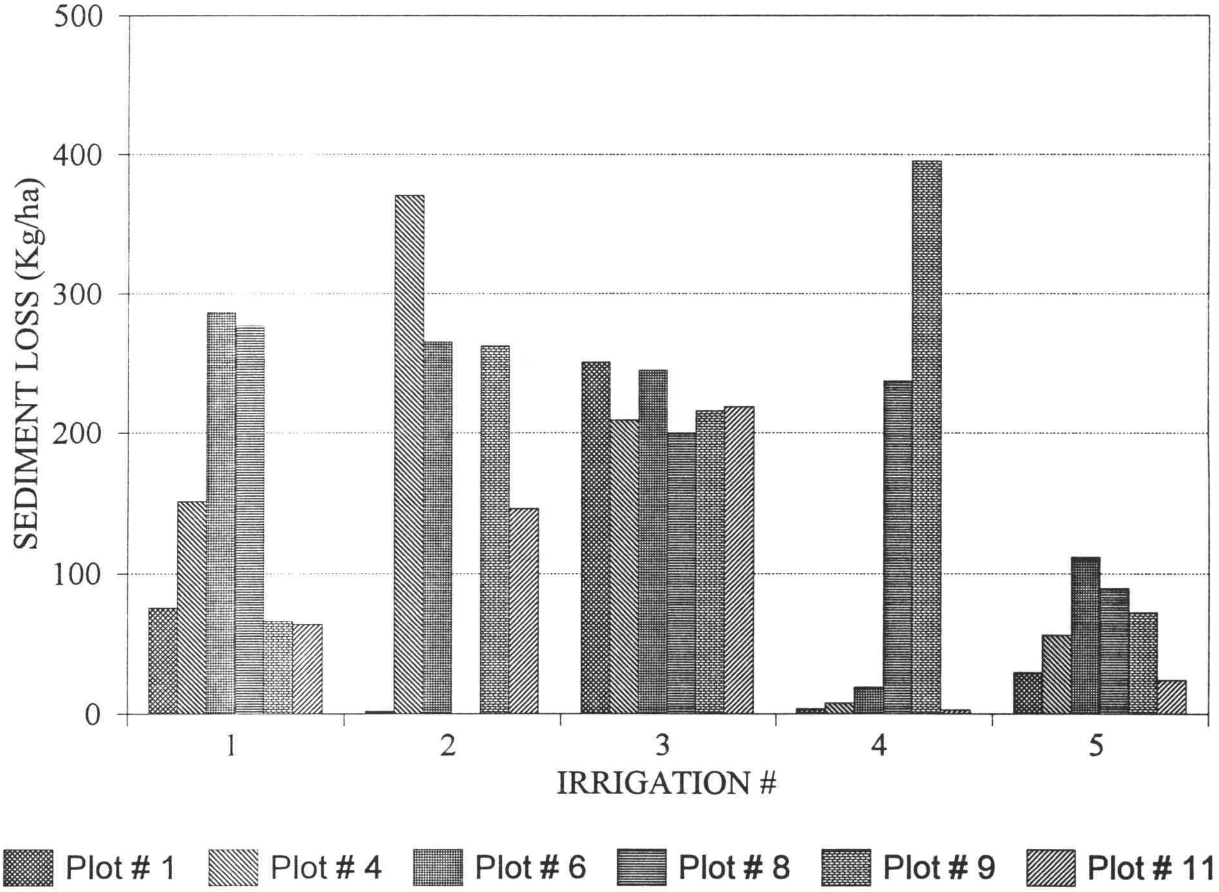


Figure 4-2. Total sediment loss from surge flow method for five irrigations in field B-7, 1993.

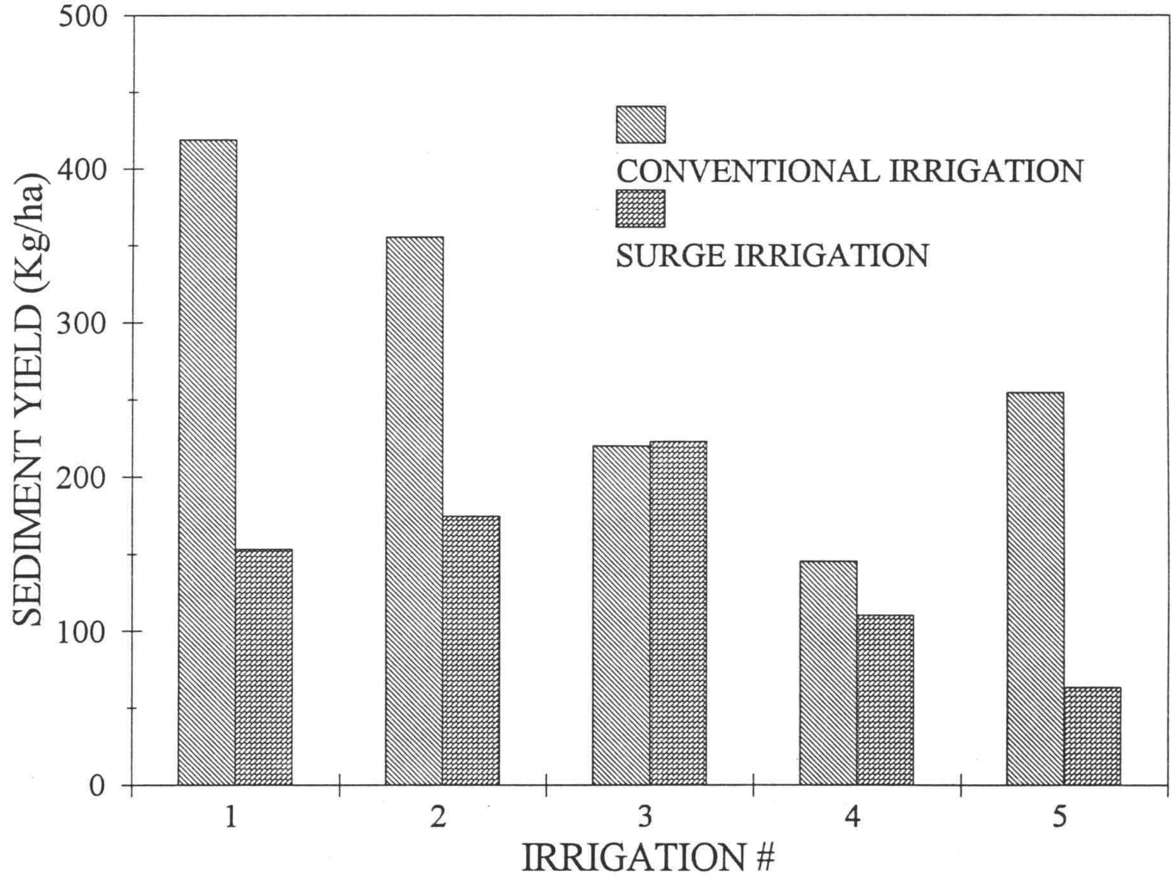


Figure 4-3. Comparison of total sediment loss from surge and conventional irrigated blocks in field B-7, 1993.

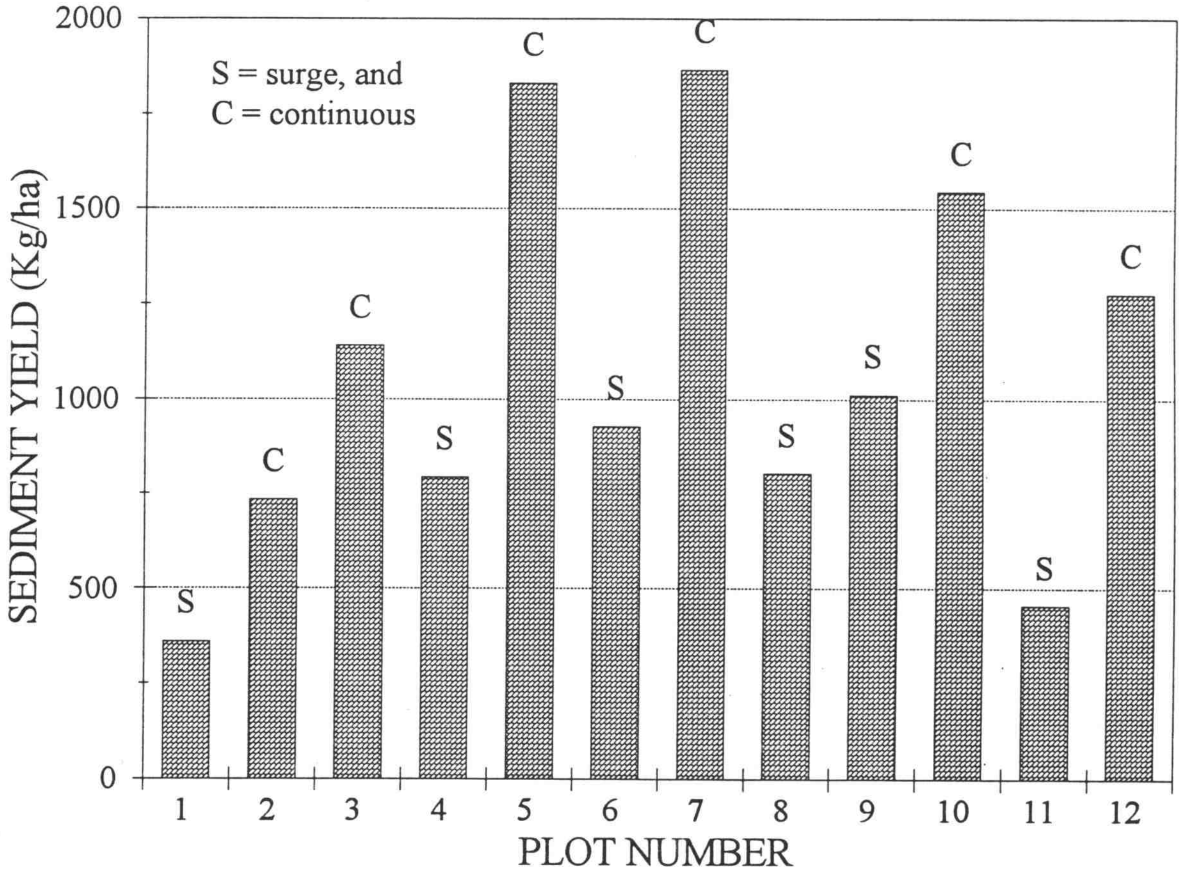


Figure 4-4. Comparison of total sediment loss estimated from individual surge and conventional irrigated blocks for five irrigation in field B-7, 1993.

4.3 Sediment loss in Mulched and Non-mulched Furrows

Straw mulching is an effective measure for erosion control in furrow irrigated fields where slopes are higher. Note that the effect of mulching is also simulated by the FUSED model. A test of erosion under mulching was conducted at the Malheur station, in field B-3. A total furrow length of 250 feet with a steep field slope of 3.0% was surveyed. Because of the steeper slope, 12 out of a total of 30 furrows were treated with straw mulching at a rate of application of 800 pounds per acre to evaluate the effectiveness of mulching on erosion and sediment loss. Equal average inflow rates of 2.2 gpm were maintained throughout all irrigations. The same setup of irrigation source and sample collection was followed as in field B-7. Total area of this field is 1.35 acres, and the area under mulched furrows was 40% of the total, that is 0.54 acre, which leaves an area of 0.81 acre for non-mulched furrows. Twelve randomly selected furrows (six mulched and six non-mulched) were selected for this study to evaluate the sediment loss, as shown in figures 4-5 and 4-6. (Note the difference in vertical scale of figures 4-5 and 4-6.) Sediment loss in field B-3 was observed to be 40 times more in non-mulched furrows than in mulched furrows. Tables 4-5, and 4-6 show the measurement of the sediment loss in field B-3.

Tremendous differences in sediment samples were observed in mulched furrows, which can be seen in the Figures 4-7 and 4-8. Straw mulching in the furrow bed was found to be an effective measure to control erosion and sediment loss in furrow irrigation. The decreasing trend in sediment loss from first to last irrigation was similar for both treatments, but, as indicated in figure 4-7, the difference in average sediment yield was 40 times less in straw mulched furrows than in non-mulched furrows. The maximum sediment loss in mulched furrows was 847 kg/ha, whereas in non-mulched furrows it was 29112 kg/ha.

TABLE 4-5. Estimation of sediment loss (kg/ha) from individual mulched furrows by conventional irrigation in field B-3.

Irrigation #	Furrow # 6	Furrow # 14	Furrow # 18	Furrow # 20	Furrow # 24	Furrow # 26	Total tons/ac
1	301.40	758.12	691.81	847.74	669.66	585.34	0.288
2	132.03	130.34	295.95	201.48	146.54	361.74	0.105
3	23.34	231.20	640.63	143.94	183.94	184.08	0.082
4	436.47	2.030	168.86	2.27	13.53	93.80	0.058
5	128.99	12.24	596.23	31.03	33.90	366.79	0.082
Total	1022.2	1133.9	2213.5	1226.5	1047.6	1591.8	0.62

TABLE 4-6. Estimation of sediment loss (kg/ha) from individual non-mulched furrows by conventional irrigation in field B-3.

Irrigation #	Furrow # 1	Furrow # 2	Furrow # 13	Furrow # 15	Furrow # 16	Furrow # 29	Total ton/ac
1	10669	29705	23040	21995	14426	29112	9.59
2	8845.7	19980	21120	15723	14440	22535	7.62
3	4481.6	16435	6520.0	5329.1	7856.9	7937.8	3.60
4	741.0	6664.5	9907.7	4904.0	3319.0	3892.6	2.18
5	193.4	134.9	8198.6	3104.1	5730.9	3514.7	1.55
Total	24931	72921	68787	51056	45774	66994	24.50

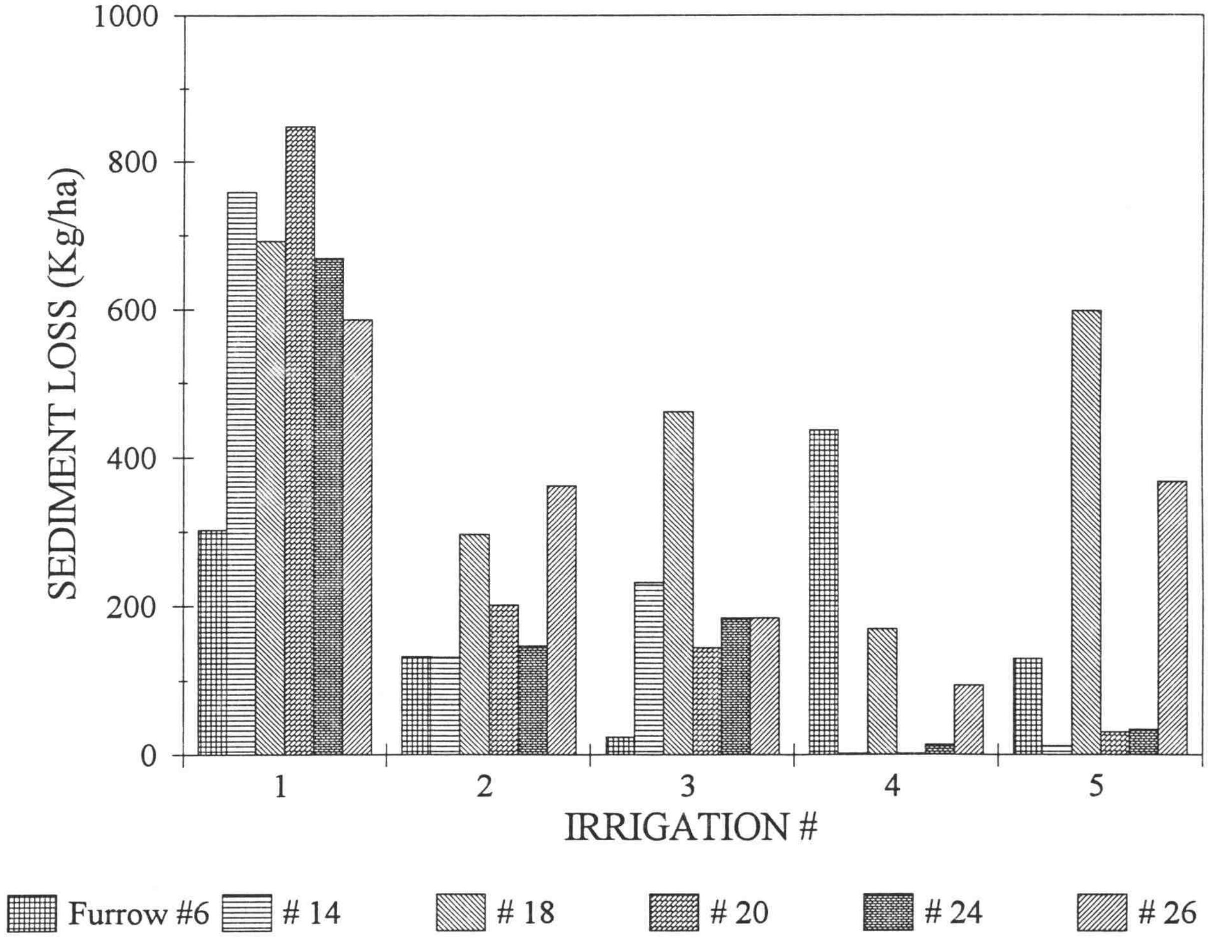


Figure 4-5. sediment loss estimated from mulched furrows for five irrigations in field B-3, 1993.

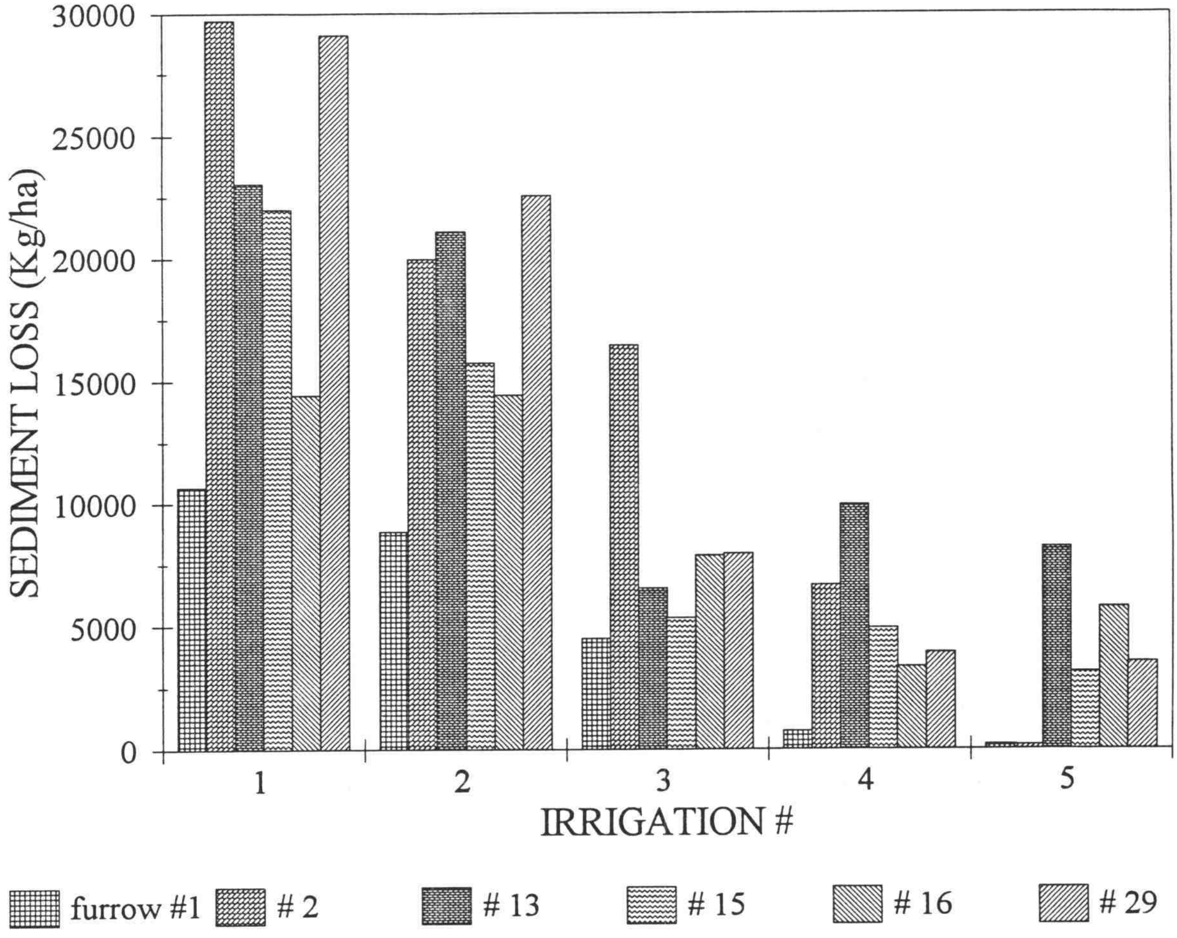


Figure 4-6. Sediment loss estimated from non-mulched furrows for five irrigations in field B-3, 1993.

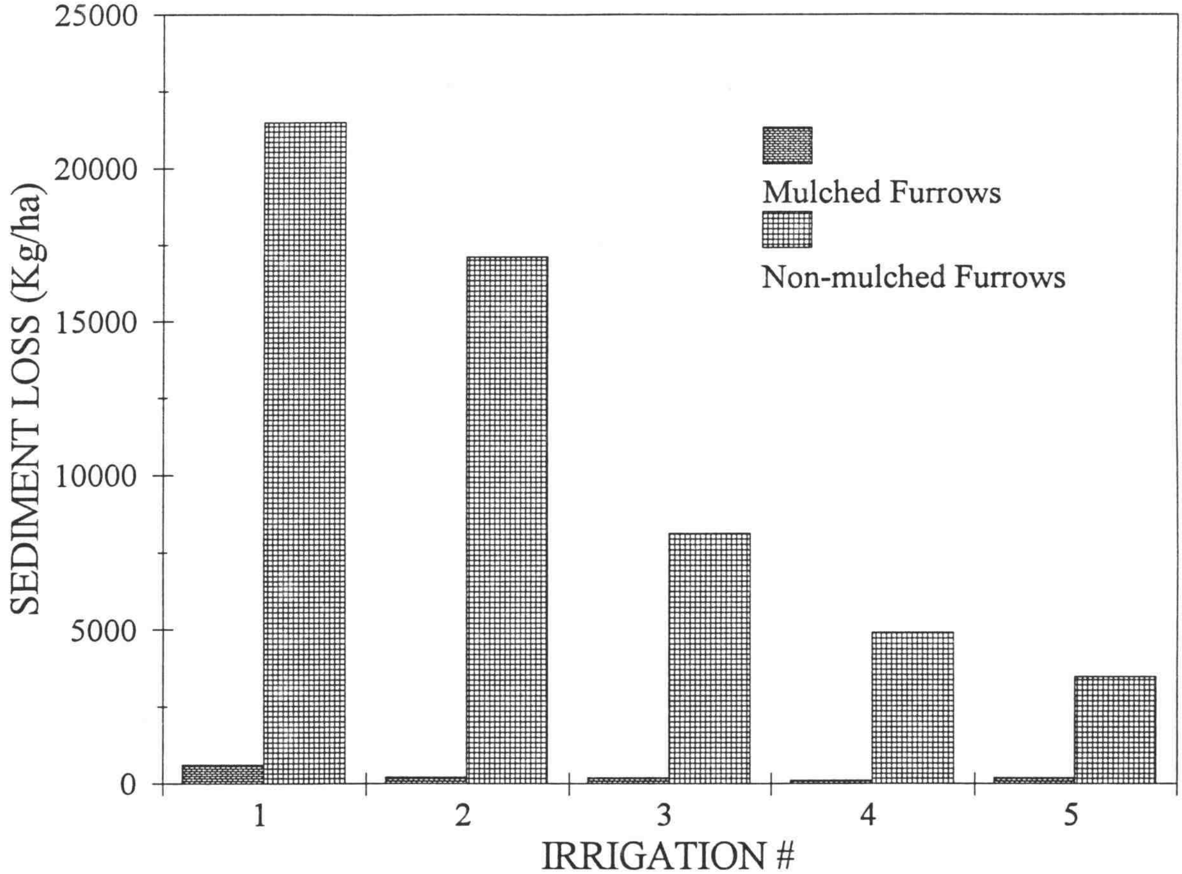


Figure 4-7. Comparison of total sediment loss from six mulched and six non-mulched furrows for five irrigations in field B-3, 1993.

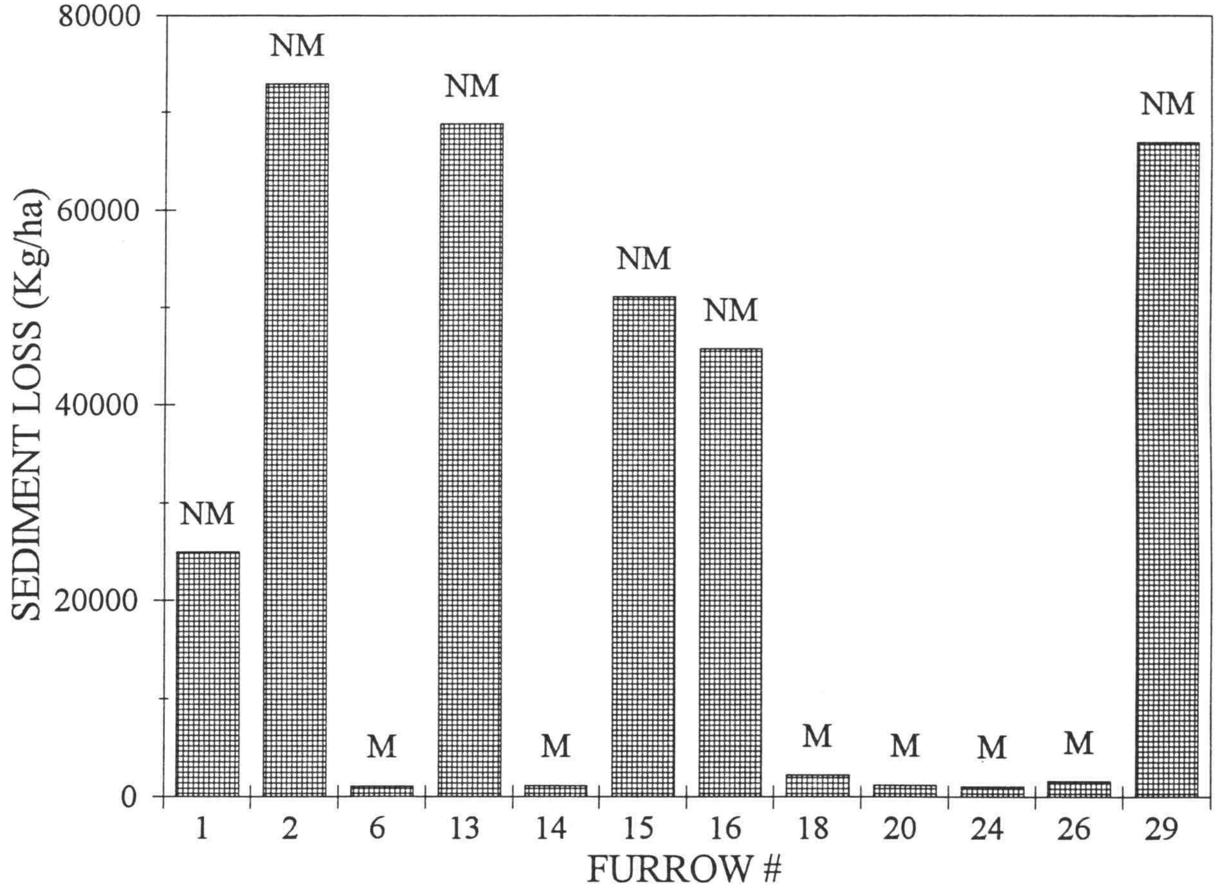


Figure 4-8. Comparison of total sediment loss from individual six mulched and six non-mulched furrows for five irrigations in field B-3, 1993.

4.4 Comparison of Wheel and Non-wheel Furrows

The sediment yield was also estimated from wheel (tracked) furrows also called hard furrows, and non-wheel (non-tracked) furrows, also called soft furrows. Data were collected for three irrigation sets at 1.0% slope, and two irrigation sets at 1.5% slope, and one irrigation at 0.5% slope. Since wheel furrows are compacted by tractor traffic during cultivation and other operations, water advances more rapidly than in non-wheel furrows. The infiltration behavior is totally different in the two kinds of furrows. The soft furrow has a higher infiltration rate and slower advance rate, whereas the hard furrow has less infiltration rate and faster advance rate. Both types of furrows have advantages and disadvantages at the same time, because higher infiltration rates cause leaching problems, and higher advance rate cause more runoff which results in higher sediment loss. The individual sediment loss for every furrow and for every irrigation is shown in table 4-3b and 4-3c. The following table 4-7 shows the differences of average sediment loss for soft and hard furrows separately, and Figure 4-9 indicates the comparison of sediment yield from soft and hard furrows at three different field slopes. It is found that the average sediment yield from soft furrows is about 73% of the sediment yield in hard furrows.

TABLE 4-7. Comparison of sediment loss (tons/ac), estimated from wheel and non-wheel furrows, and single and alternative irrigated furrows at Bel-air farm.

Slope (%)	N-wheel	Wheel	Furrow Type	Single row	Alternate
0.5	0.198	0.38	Wheel	0.193	0.088
1.0	0.507	0.81	N-wheel	0.171	0.092
1.5	5.95	7.93	Wheel	0.539	0.152
Average	2.21	3.04	Total	0.301	0.111

4.5 Sediment loss in Every-furrow and Alternate Irrigated Furrows

An independent study for every-furrow irrigation and alternate furrow irrigation method was conducted for a set of three furrows in each. Sediment yield was measured for both methods as shown in table 4-7. The average sediment yield from every-furrow irrigated furrows was estimated as 0.301 tons/acre (674 kg/ha), whereas the sediment yield from alternate irrigated furrows came to 0.111 tons/acre (250 kg/ha). It is reminded that the sediment loss is calculated for alternate furrow irrigation by taking total area under irrigation, that means the area under the alternate irrigation method is two times more than the area under every-furrow irrigation method. So it is reasonable to expect that sediment yield from alternating furrows will be on the order of 50 % as great. From the data shown in Table 4-7 it is estimated that the sediment yield with alternate furrow irrigation method is about 37 percent of the sediment yield by every-furrow irrigation method. Figure 4-10 shows the comparison of sediment yield from individual furrows and an average sediment yield from three furrows. The sediment yield for this condition, using the FUSED model, can be related by fixing the wetted furrow spacing. The model was run by considering the double wetted spacing for the alternate furrows irrigation method for different irrigation strategies. It is found that the model assumes only the area under irrigated furrow, regardless of infiltration and wetted front behavior. Therefore the sediment yield estimated by FUSED will always be about 50 percent of the every-furrow case, whereas field results show 37 percent as much sediment yield in every-furrow irrigation than in alternative furrows irrigation. The actual sediment yield for alternate furrow irrigation is therefore about 74 % of that estimated by FUSED.

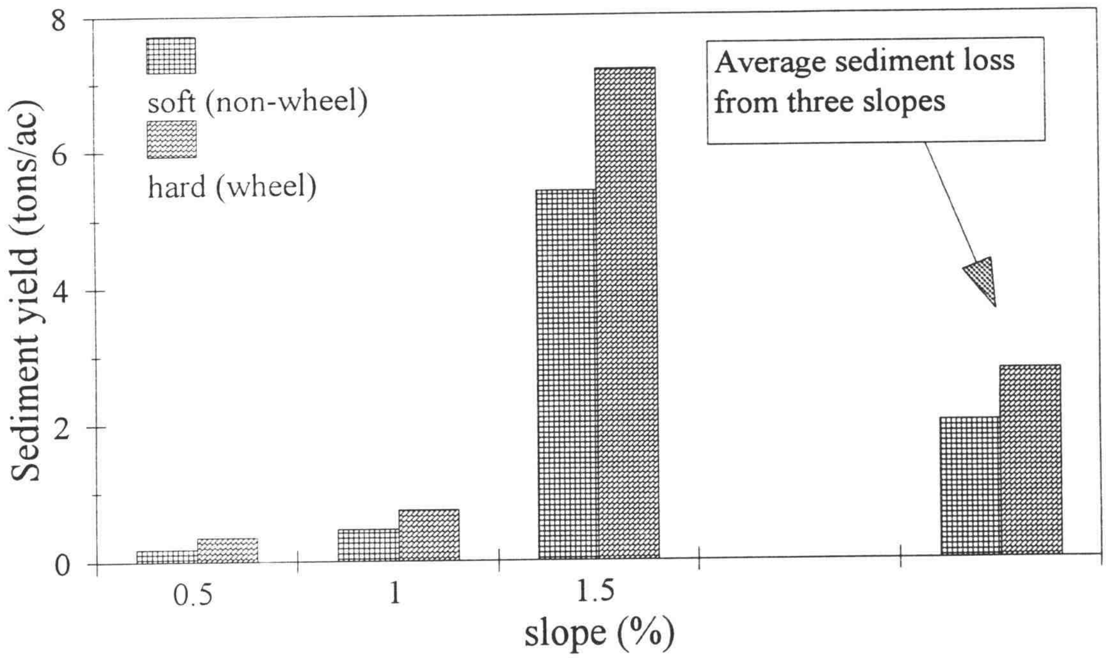


Figure 4-9. Comparison of sediment yield, estimated from hard (wheel) furrows, and soft (non-wheel) furrows.

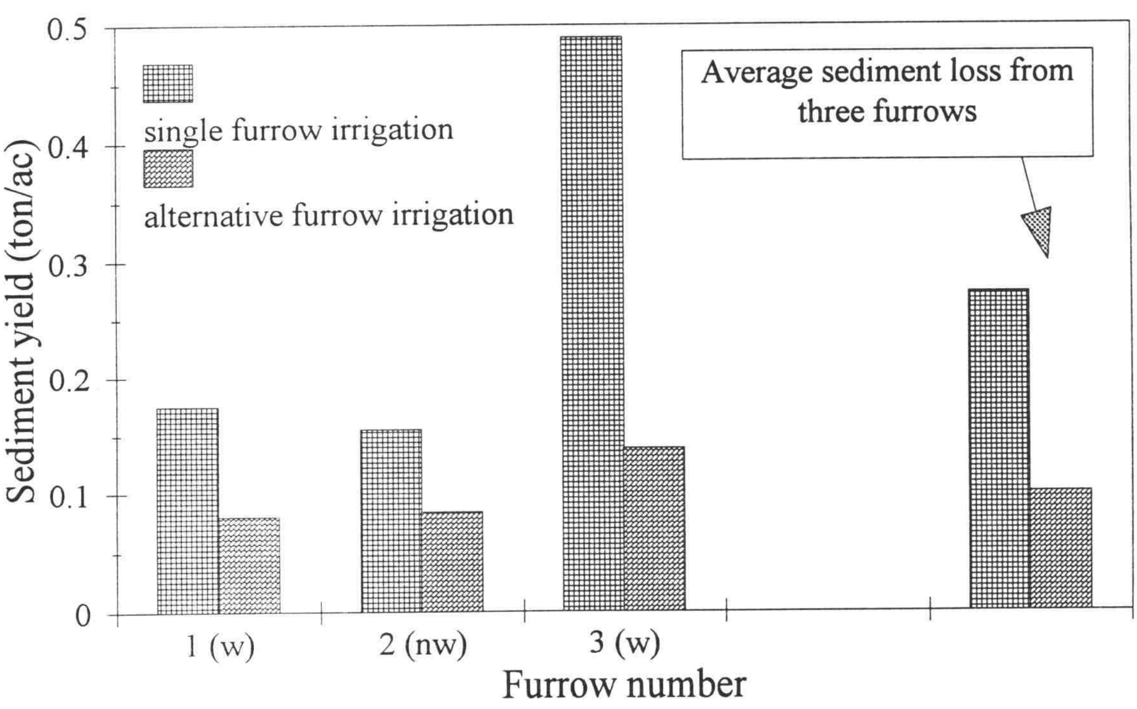
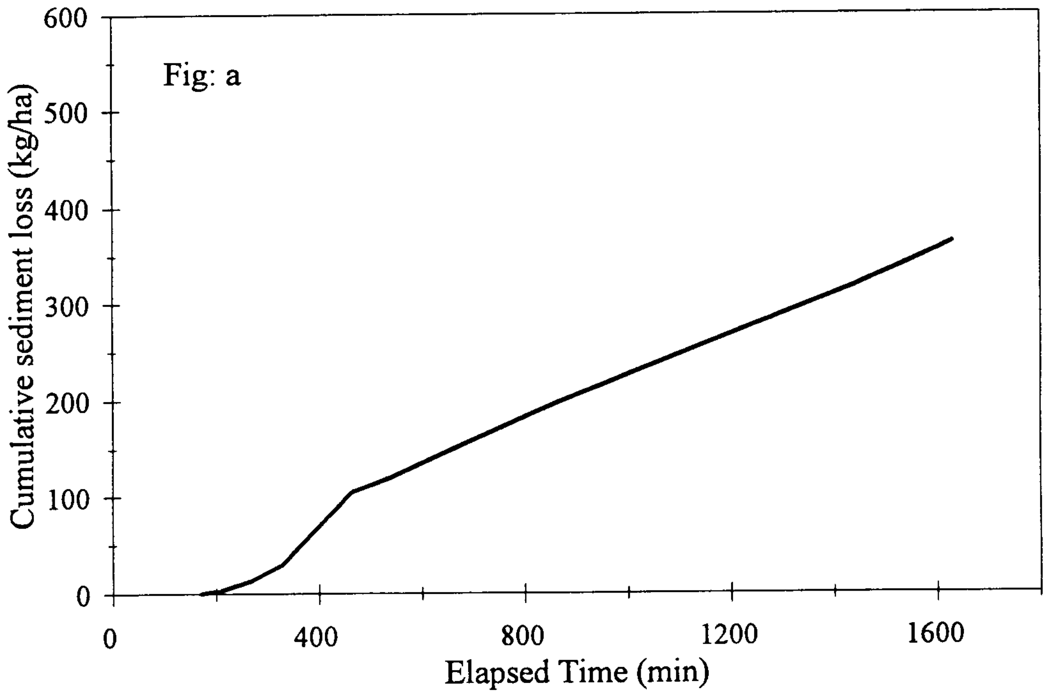


Figure 4-10. Comparison of sediment yield (tons/ac), estimated from every-furrow and alternate irrigated furrows.

4.6 Sediment Yield as a Function of Time

Sediment yield as a function of time is illustrated in Figures 4-11 through 4-14 for points at 400, 800 and 1200 feet from the head of a furrow on Bel-Air farm, with a slope of 1.0 % and an inflow rate of 8.0 gpm. Similar curves were derived from other furrows, slopes and field lengths. while the data are insufficient to develop a viable empirical relationship, they suggest that sediment yield begins slowly and increases nonlinearly during the first few hours of runoff, then continues as a roughly linear function of time until runoff ends. It was concluded that a reasonable first approximation would be to assume that where the duration of an irrigation is changed sediment yield will change proportionately.



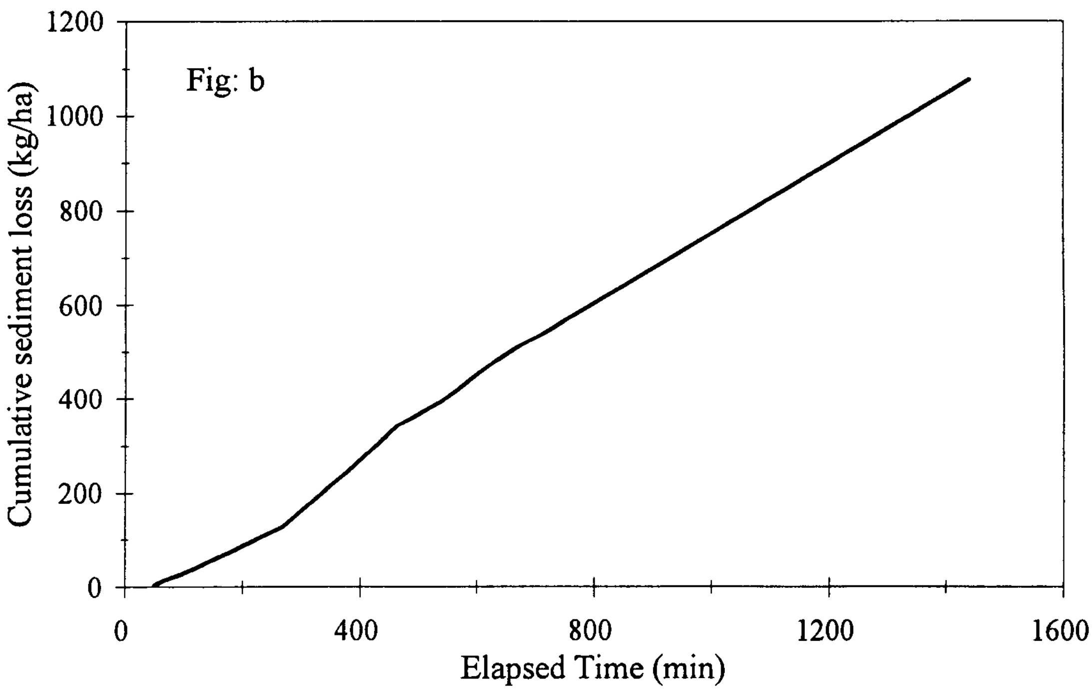
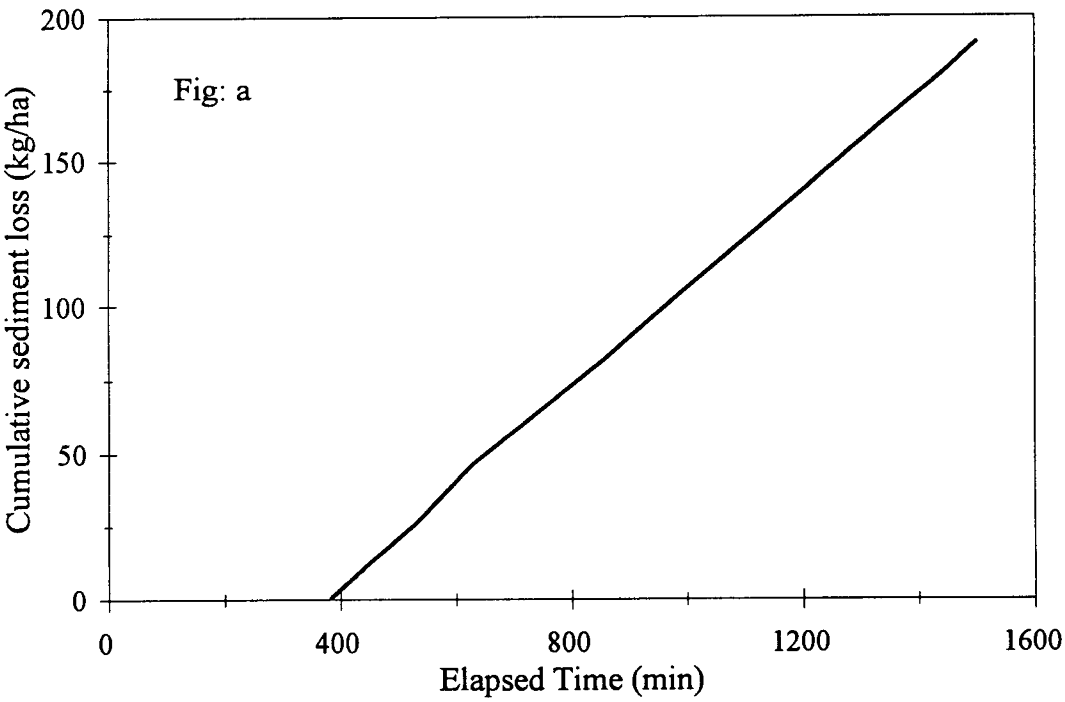


Figure 4-11. Cumulative sediment loss as a function of elapsed time at 400 feet furrow length, slope 1.0 %, (fig: a = Non-wheel, b = Wheel furrow).



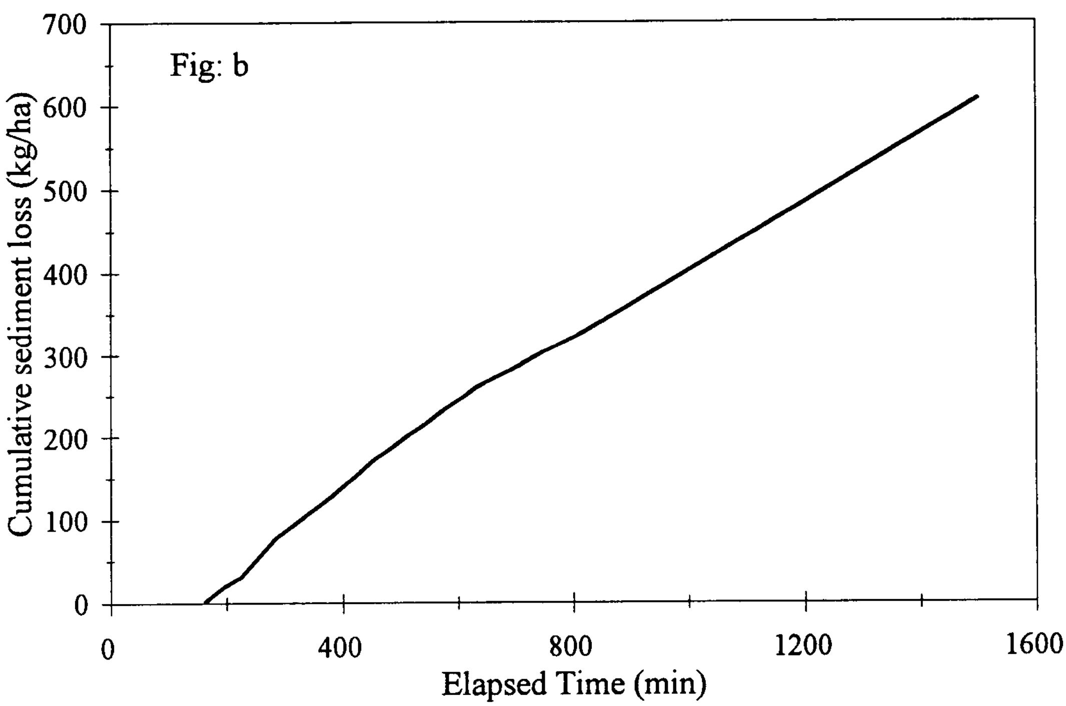


Figure 4-12. Cumulative sediment loss as a function of elapsed time at 800 feet furrow length, slope 1.0 %, (fig: a = Non-wheel, b = Wheel furrow).

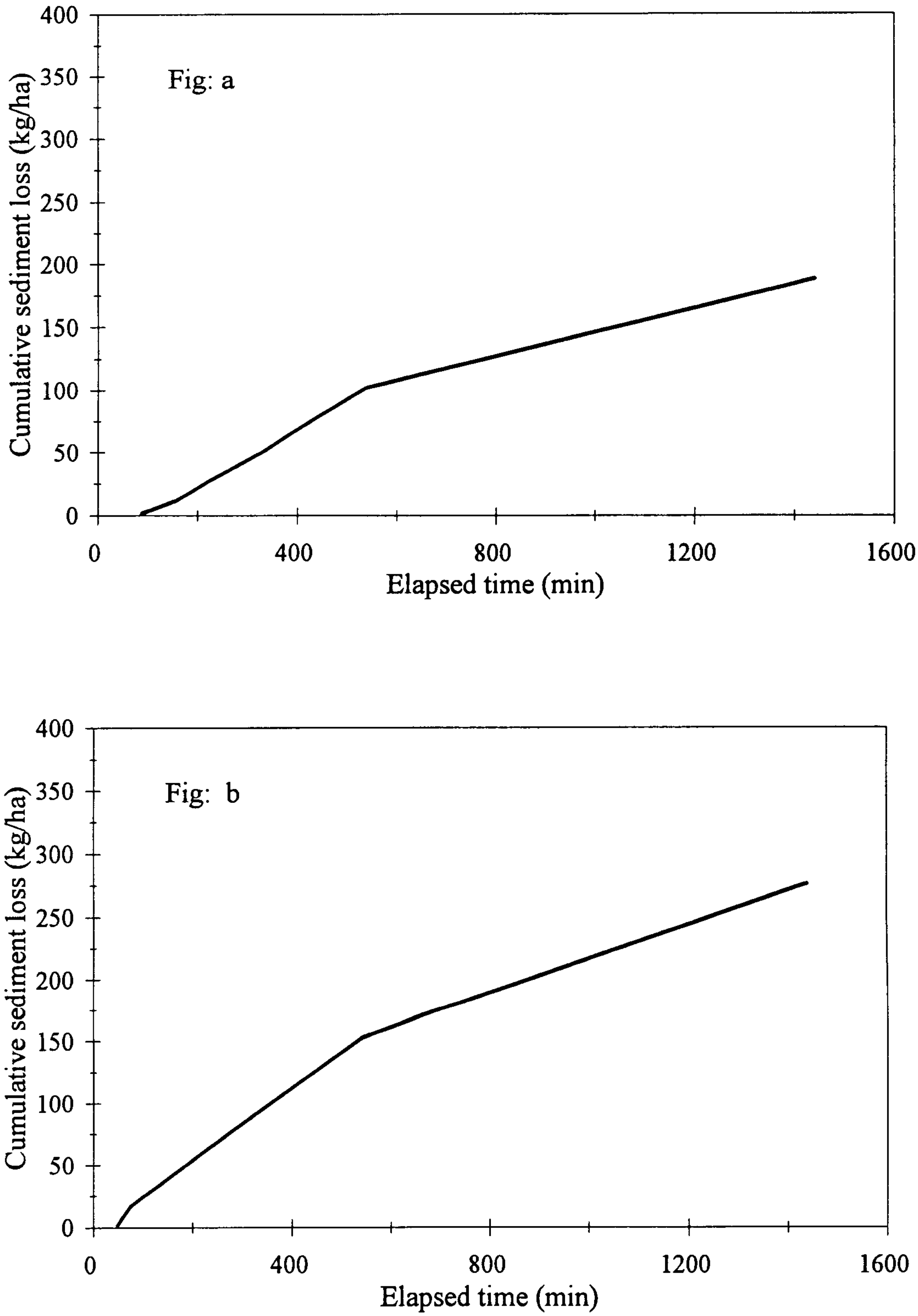
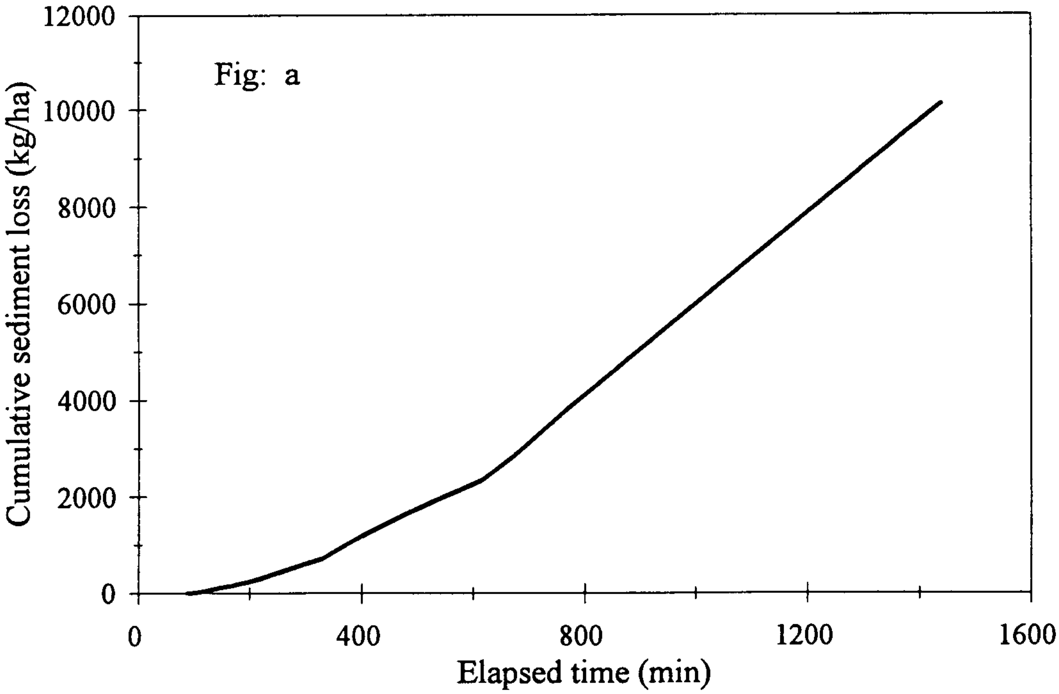


Figure 4-13. Cumulative sediment loss as a function of elapsed time at 600 feet furrow length, slope 1.0 %, (fig: a = Non-wheel, b= Wheel furrow).



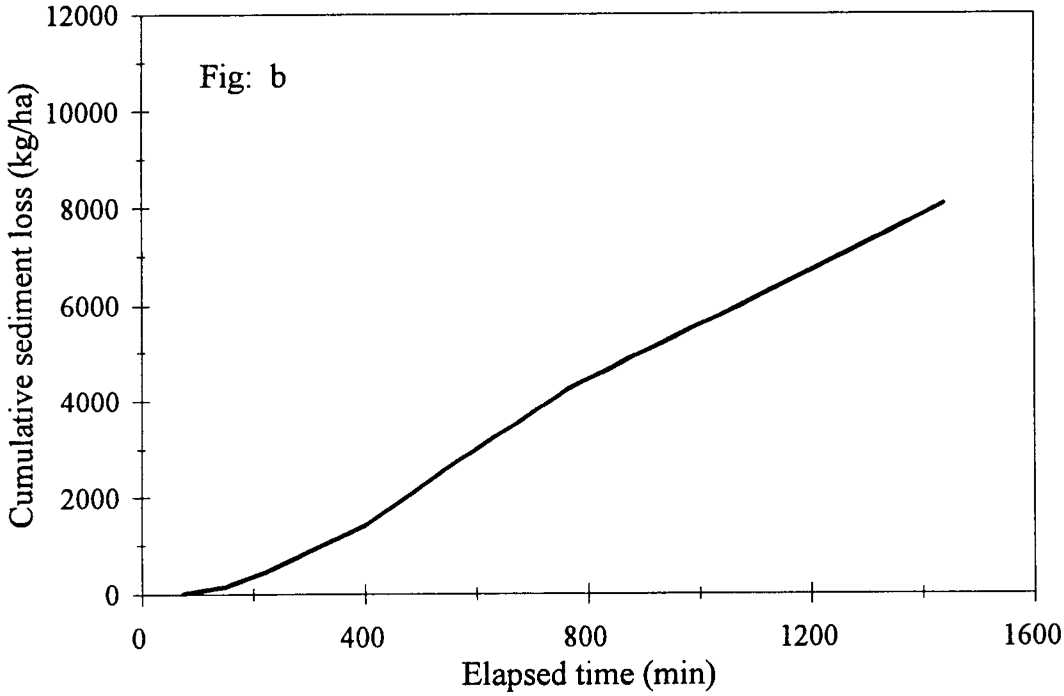


Figure 4-14. Cumulative sediment loss as a function of elapsed time at 600 feet furrow length, slope 1.5 %, (Fig: a = Non-wheel, b = Wheel furrow).

4.7 Comparison of Field Data with FUSED Model Estimates

The FUSED model is tested up to this point for conventional irrigation management practices as in field B-7, and this model is found valid to predict sediment yield for the conventional irrigation method. Tables 4-8 and 4-9 show the comparison and verification of the model with field results for each irrigation set and for cumulative sediment loss for five irrigations. A total sediment loss of 0.62 tons/acre (1383 kg/ha) was estimated from field B-7, with field slope 0.5% for five irrigations, while the total sediment loss 0.53 tons/acre (1309 kg/ha) was predicted by the FUSED model, which is a reasonably good comparison.

Figures 4-15 and 4-16 can be referred to see the comparison of sediment loss from field estimated and model estimated values. Table 4-8, and figure 4-15, indicate that the model only under estimates about 14 % less than the field results for conventional irrigation method at field slope 0.5%. Both results show an approximately linear relationship of sediment loss with the number of irrigations. Sediment loss estimated at a slope of 1.0 % for three irrigations was also a good comparison. Total sediment loss from three irrigations is 0.654 tons/acre (1467 kg/ha) for the 1.0 % slope, while the sediment loss estimated from the FUSED model was 0.62 tons/acre, an under estimation of 3.2 %.

Model estimates were not accurate at steeper slopes. Sediment loss of 6.99 tons/acre 15684 kg/ha) was measured from Bel-Air farms at 1.5 % slope for two irrigations, and 24.55 tons/ac (55032 kg/ha) from field B-3 at slope 3.0 % for five irrigations in 1993. Comparing both above results with sediment loss estimated from FUSED model, where model estimated 2.73 tons/ac (6117 kg/ha) at 1.5 % slope and 4.88 tons/ac (10935 kg/ha) at 3.0 % slope. It is learned from these experiments that the model greatly under estimated for field slopes greater than 1.0 %.

TABLE 4-8. Comparison of cumulative sediment loss (tons/ac) estimated from field B-7, (slope 0.5%, L = 640 feet, inflow rate 6.2 gpm), and field B-3, (slope 3.0%, L = 250 feet, inflow rate 2.2 gpm), and FUSED model.

Irrigation #	Sediment loss (B-7)	Cumulative (B-7)	Cumulative FUSED estimated; 0.5% slope	sediment loss (B-3)	Cumulative (B-3)	Cumulative FUSED estimated; 3.0% slope
1	0.157	0.157	0.10	9.59	9.59	0.56
2	0.186	0.343	0.20	7.62	17.21	1.42
3	0.098	0.441	0.30	3.60	20.81	2.45
4	0.065	0.506	0.41	2.18	22.99	3.61
5	0.113	0.619	0.53	1.55	24.54	4.88

TABLE 4-9. Comparison of field estimated sediment loss (tons/ac) at different slopes with FUSED model estimates.

Irrigation #	Slope 0.5 %	Slope 1.0 %	Slope 1.5 %
1	0.135	0.231	4.229
2	0.069	0.126	2.778
3	0.051	0.296	not taken
Total measured	0.256	0.654	6.99
Model estimated	0.210	0.680	2.73

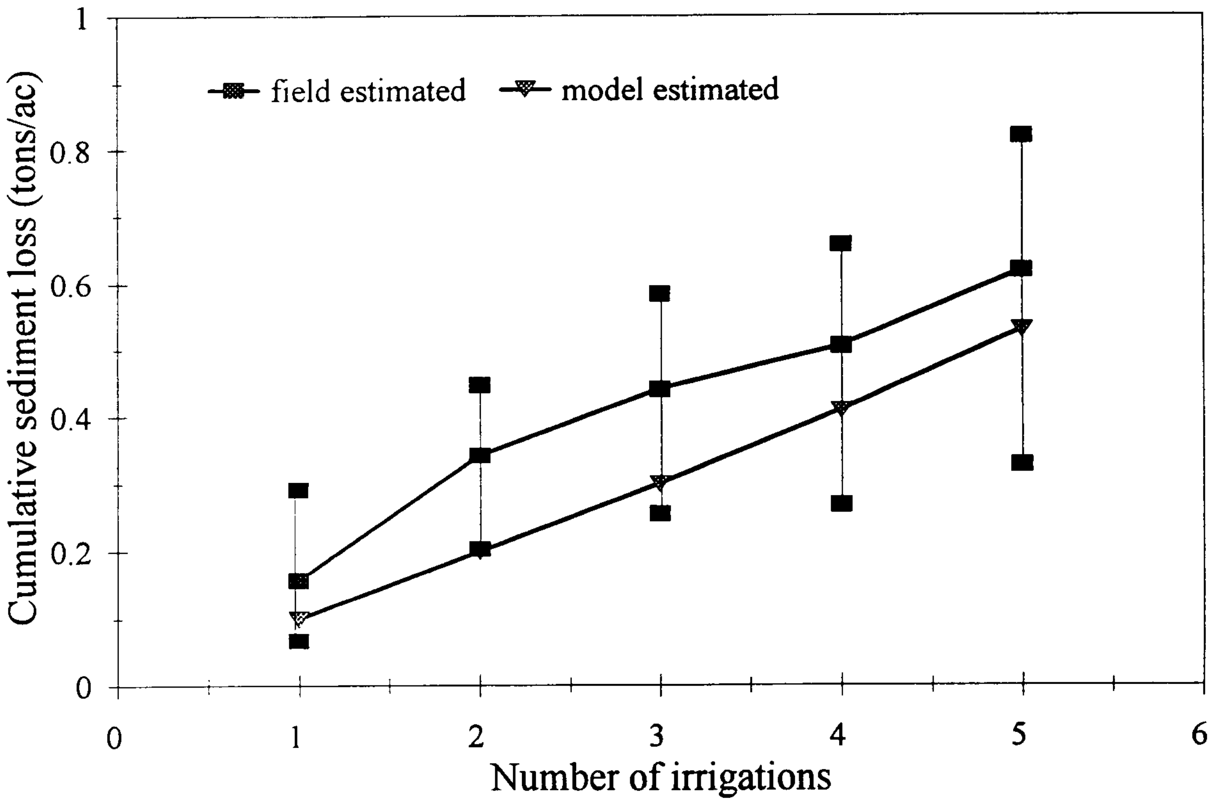


Figure 4-15. Comparison of cumulative sediment loss for five irrigations, estimated from field B-7 slope 0.5% and with FUSED model.

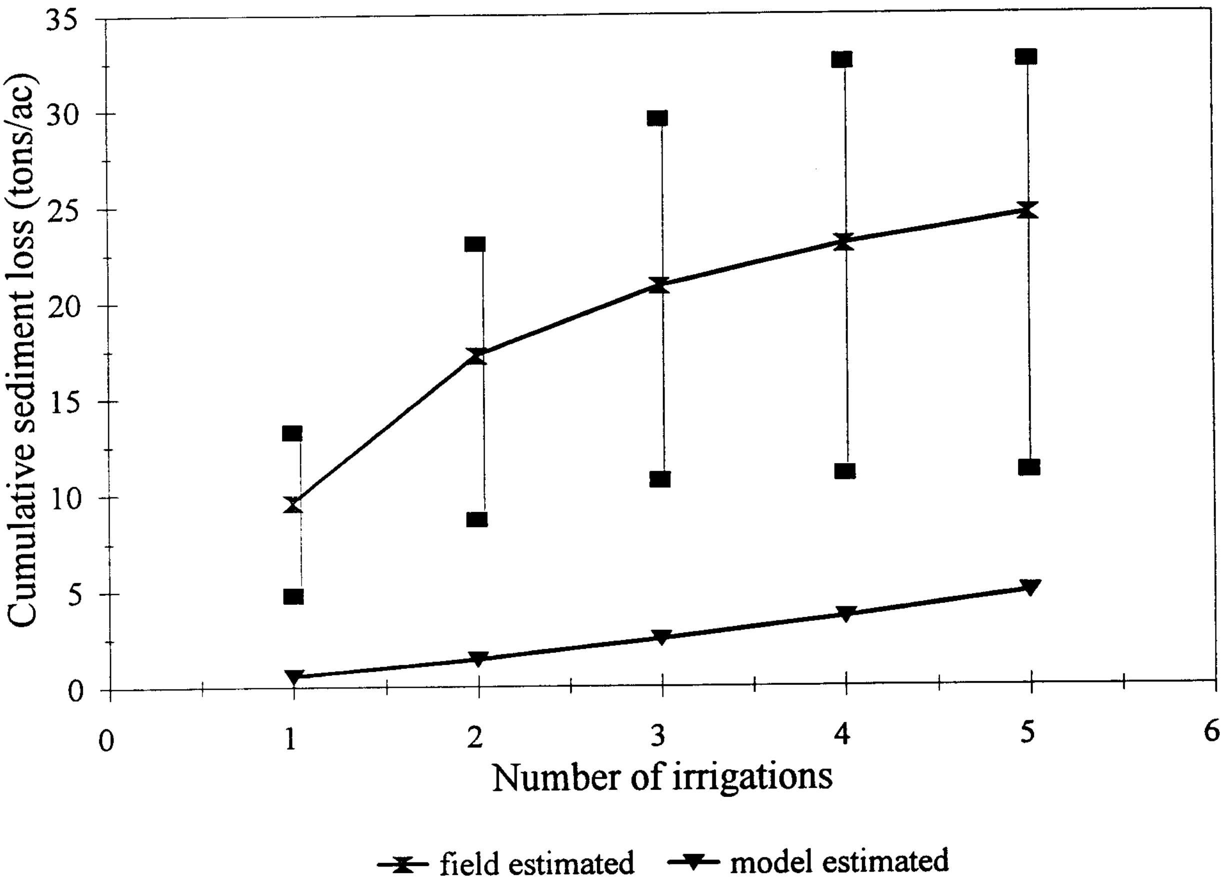


Figure 4-16. Comparison of cumulative sediment loss for five irrigations, estimated from field B-3, slope 3.0%, and with FUSED model.

The total sediment loss for three slopes is summarized in three values which can be seen in table 4-9. The model was run for the same field conditions including agronomic and irrigation practices. The Model output sheets, run on different slopes and lengths for erosion and sediment yield estimation can be seen in Appendix A. Figure 4-17 shows the comparison of sediment loss estimated with the FUSED model for three different field slopes.

The sediment loss estimated for three different furrow lengths is also compared with model results for the same conditions. The model has a good relationship with field results estimated for different furrow lengths, which can be seen in figure 4-18. The field data estimated from individual furrows for three irrigation sets are shown in following table 4-10.

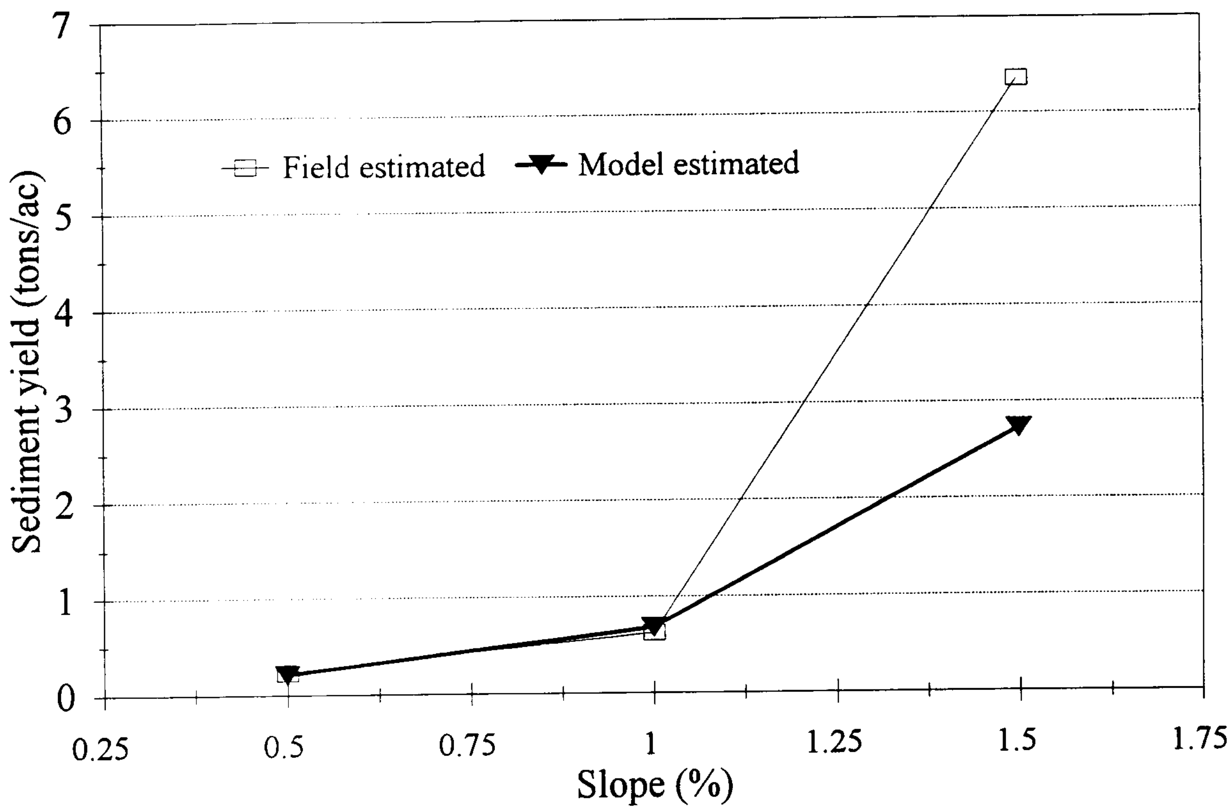


Figure 4-17. Comparison of sediment yield, estimated for three different slopes from field data, and from FUSED model.

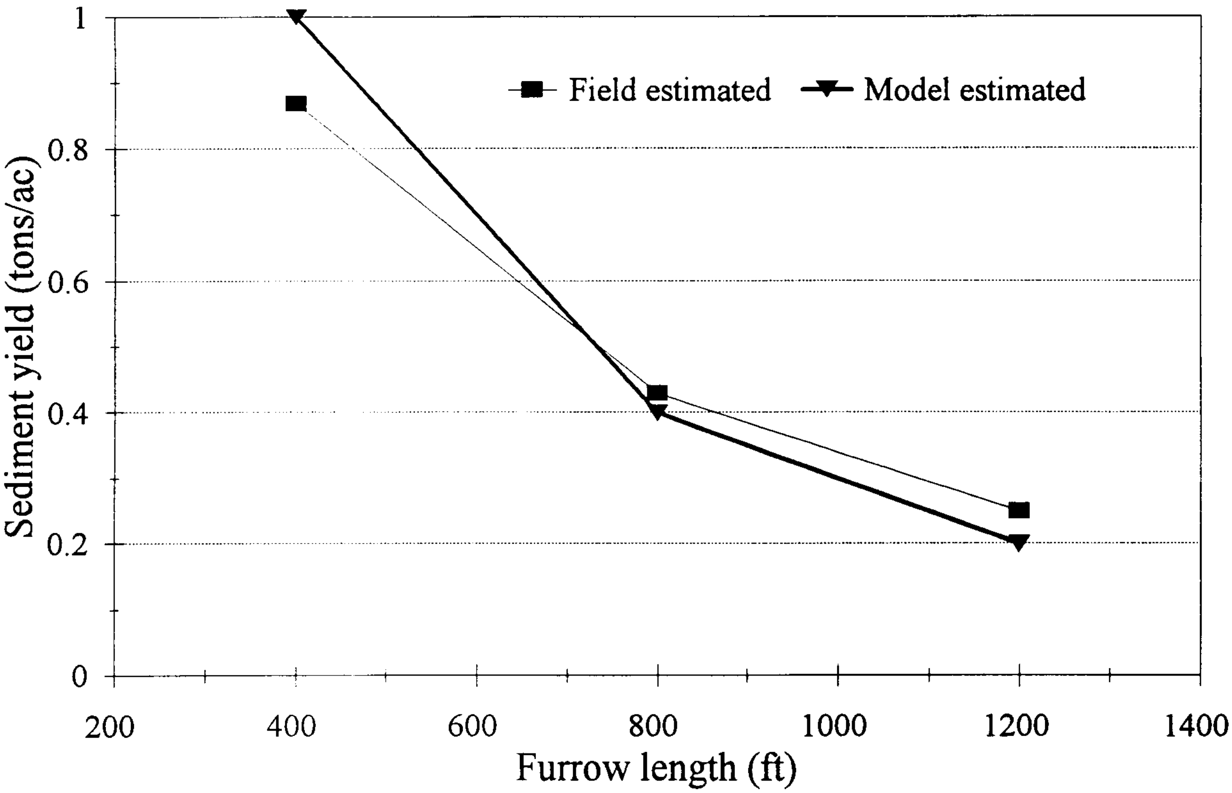


Figure 4-18. Comparison of sediment yield estimated for three different furrow lengths from Bel-Air farm and FUSED model.

TABLE 4-10. Comparison of field estimated sediment loss (tons/ac) on slope 1.0% at Bel-Air farm for different furrow lengths with FUSED model estimates.

Irrigation #	Length 400 ft	Length 800 ft	L = 1200 ft
1	0.285	0.124	0.069
2	0.291	0.145	0.085
3	0.381	0.204	0.121
Total Field estimated	0.958	0.474	0.275
FUSED Model estimated	1.190	0.450	0.260

4.8 Adaptation of the Original Model

Additional data have been used to derive multipliers which adjust the model estimates to account for several factors not explicitly simulated by FUSED, including:

1) Surge irrigation vs: continuous (conventional) irrigation.
2) Wheel (hard furrow) vs: non-wheel (soft furrow).
3) Mulched furrow vs: non-mulched furrow.

An improved mulching factor was derived from the data since model estimates with mulching were very poor.

sediment yield estimated from field B-7 for five irrigations 1993, (refer to tables 4-1 and 4-4) was compared for surge and continuous irrigation, and results are compared in figures 4-3, and 4-4. The total sediment loss from six continuous irrigated blocks is measured as 0.623 tons/acre (1395.5 kg/ha), whereas the total sediment loss from six surge irrigated blocks is measured as 0.32 tons/acre (716 kg/ha). These results imply that the average sediment yield with surge irrigation method is 52 percent of the continuous irrigated method, which is about half of the continuous irrigation method. In other words the sediment yield from continuous irrigated furrows is 1.94 times the sediment yield from surge irrigated furrows. Therefore, it is recommended that sediment yield can be estimated for the surge irrigation method by using FUSED and taking half of the model prediction for continuous irrigated method.

The sediment yields estimated from Bel-air farms for wheel and non-wheel furrows were analyzed to find a multiplier to predict the sediment yield when either one is estimated. From table 4-7, the average sediment yield from non-wheel is about 73% of the wheel furrows. In other words the sediment yield from wheel furrows is 1.36 times the sediment yield from non-wheel furrows.

The sediment yields estimated from field B-3 for mulched and non-mulched furrows are shown in tables 4-5 and 4-6. Model estimates of the sediment yield for mulched furrows was 1/3 of the yields estimated by the model for non-mulched furrows for field conditions as in B-3. However the field results showed sediment yields of 24.5 tons/acre (55081 kg/ha) from non-mulched furrows, about 40 times greater than the 0.62 tons/acre (1383 kg/ha) from mulched furrows. The error is so great that it is not possible to rely on the model's estimation of the effects of mulching. Consequently, a multiplier of 0.025 is recommended to account for mulching effect.

4.9 Levels of Significance

The field data for different multipliers were statistically analyzed, using analysis of variance levels of significance for each multiplier.

1) Surge irrigation vs continuous (conventional) irrigation.

The field data of average sediment loss for five irrigations in each block under both irrigation methods is used, (see appendix C for detail calculation). The analysis showed that results are significant at 0.99 confidence level.

2) Wheel (hard furrow) vs non-wheel (soft furrow).

The field data for two different slopes were used; at slope 1.0 % , data were used for three irrigations and four furrows in each irrigation, and at slope 1.5 %, data were used for two irrigations and four furrows in each irrigation, (see appendix C for detail calculation). The analysis showed that results are significant at 0.90 confidence level for slope 1.0 %, but not significant at 0.90 for slope 1.5 %.

3) Mulched furrow vs non-mulched furrows.

The field data of average sediment loss for five irrigations in each furrow under both treatments is used, (see appendix C for detail calculation). The analysis showed that data are significant at 0.999 confidence level.

5.0 APPLICATION OF THE "FUSED" MODEL

The FUSED model was used to analyze erosion under furrow irrigation in Malheur County. General relationships to be used for estimating furrow erosion associated with standard irrigation practices were derived, and these are presented below. The model was also used to estimate the erosion that might occur if alternative practices for furrow irrigation or other means of controlling erosion are implemented.

5.1 Erosion Under Conventional Irrigation Practices

Having established that the FUSED model simulates erosion and sediment yield with reasonable accuracy for low slopes under Malheur County conditions, the model was then used to derive a set of standard curves for both erosion and sediment yield under conventional irrigation practices. Conventional practices are defined here as continuous irrigation, with inflow rates that are typically used in that area, irrigating every furrow and with no soil amendments to control erosion. Two field lengths were assumed for this analysis, 600 and 1200 feet, both of which are common field lengths. Slopes in that area are typically between 0.5 and 2.0 percent. A set of four different inflow rates, ranging from 6.3 to 15.8 gpm were used. The simulated rates of erosion and sediment yield are shown in Tables 5-1 and 5-2, and illustrated in figures 5-1 through 5-4. These general tables and graphs will be convenient reference tools for individuals in Malheur County who might be concerned with soil loss and sedimentation of surface waters. However they should only be used with the warning that erosion on the steeper slopes may be substantially greater than predicted by FUSED. The FUSED model output sheets, run with two different slopes and two different inflow rates, each for 600 feet and 1200 feet field length for erosion at upper end and sediment yield estimations, are provided in Appendix B.

TABLE 5-1. Estimation of erosion at upper end (eroson = tons/ac/yr), and sediment yield (sedlos = tons/ac/yr) for field length 1200 feet by FUSED model.

Slope	Inflow rate 6.3 gpm		Inflow rate 9.5 gpm		Inflow rate 12.6 gpm		Inflow rate 15.8 gpm	
%	eroson	sedlos	eroson	sedlos	eroson	sedlos	eroson	sedlos
0.5	8.0	0.21	13.2	0.41	18.5	0.65	24.3	0.93
1.0	11.8	0.70	19.3	1.36	27.2	2.14	35.7	3.07
1.5	14.7	1.42	24.2	2.73	34.0	4.29	44.6	6.17
2.0	17.3	2.32	28.3	4.49	39.8	7.05	52.3	10.13

TABLE 5-2. Estimation of erosion at upper end (eroson = tons/ac/yr), and sediment yield (sedlos = tons/ac/yr) for field length 600 feet by FUSED model.

Slope	Inflow rate 6.3 gpm		Inflow rate 9.5 gpm		Inflow rate 12.6 gpm	
%	eroson	sedlos	eroson	sedlos	eroson	sedlos
0.5	8.0	0.56	13.2	1.08	18.5	1.69
1.0	11.8	1.84	19.3	3.56	27.2	5.59
1.5	14.7	3.71	24.2	7.16	34.0	11.25
2.0	17.3	6.09	28.3	11.75	39.8	18.97

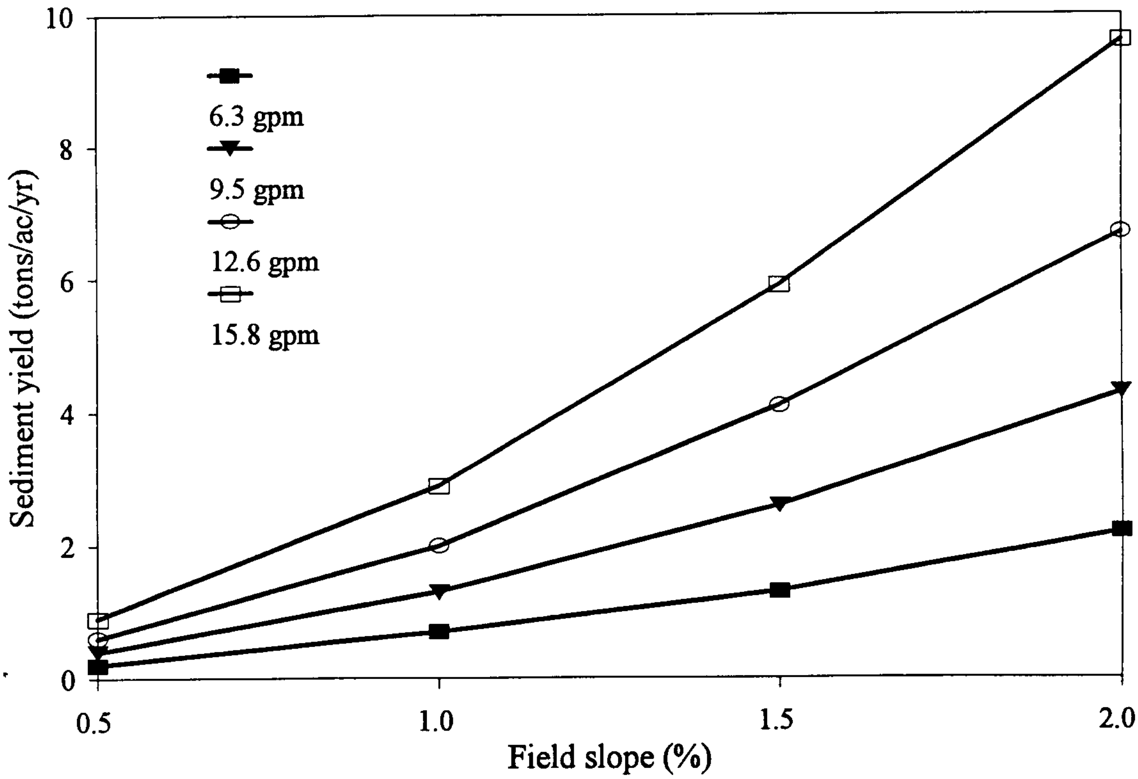


Figure 5-1. Estimation of sediment yield (tins/ac/yr) as a function of field slope, using FUSED model for various inflow rates at 1200 ft furrow length.

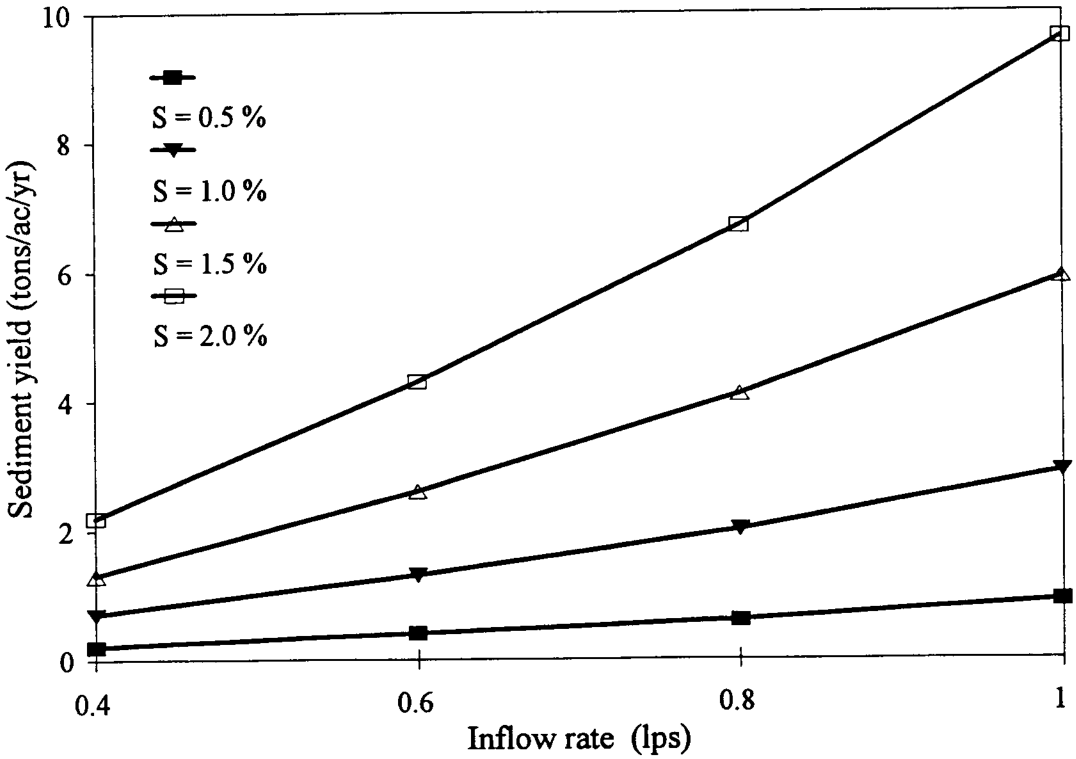


Figure 5-2. Estimation of sediment yield (tons/ac/yr) as a function of inflow rate, using FUSED model for various field slopes at length 1200 feet.

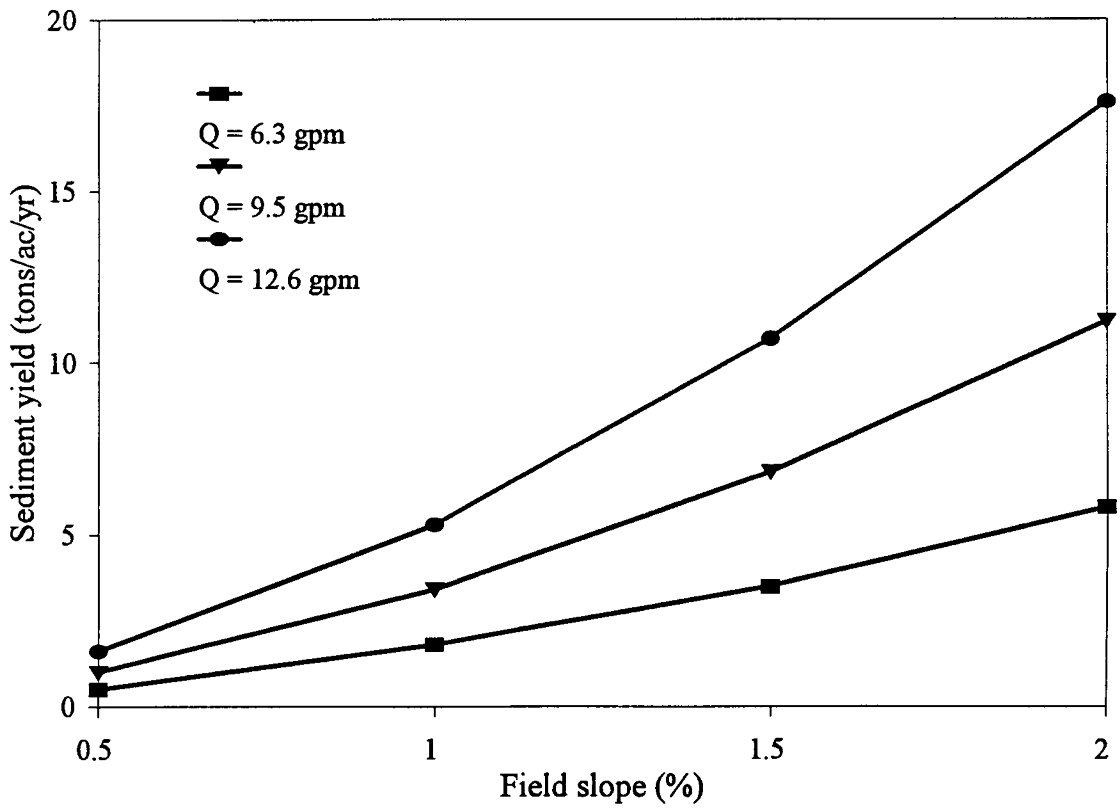


Figure 5-3. Estimation of sediment yield (tons/ac/yr) as a function of field slope, using FUSED model for different inflow rates at 600 feet furrow length.

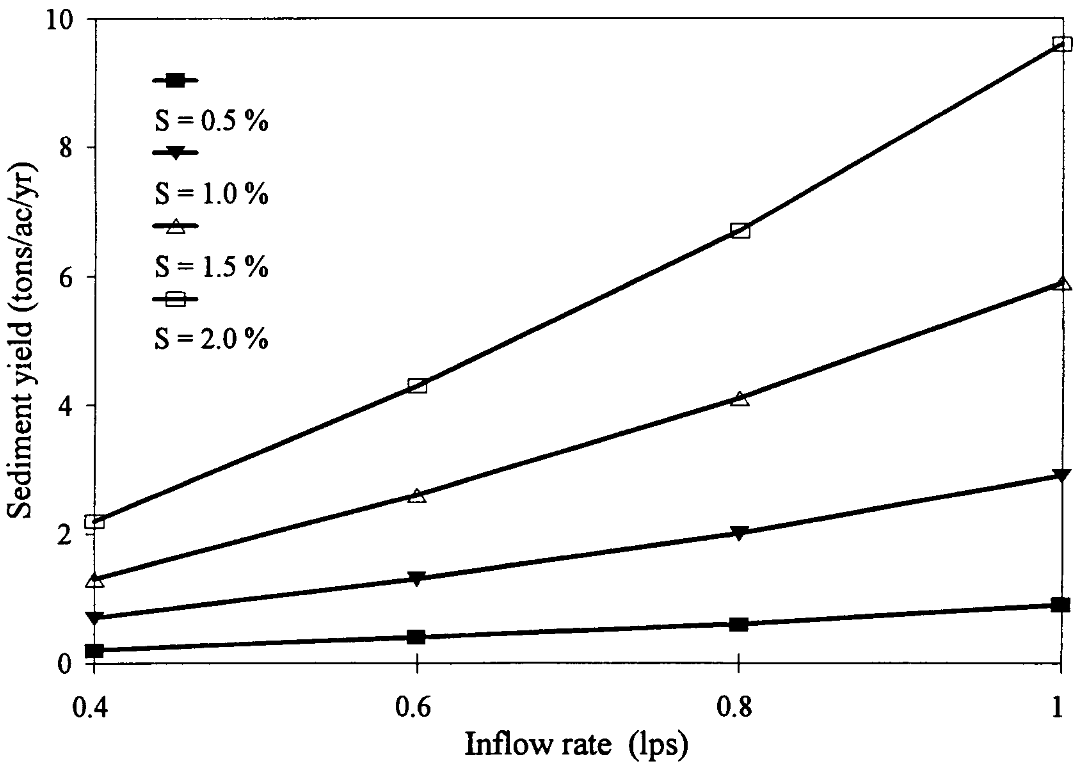


Figure 5-4. Estimation of sediment yield (tons/ac/yr) as a function of inflow rate, using FUSED model for different field slopes at 600 feet furrow length.

5.2 Alternative Practices

The problem of sediment loss can be reduced by selecting one of the alternative methods of irrigating, or by using such techniques as mulching. Erosion is not the only problem for this region; nitrate leaching must also be considered. Alternatives that reduce nitrate leaching may make erosion worse and vice versa. The best alternative irrigation management options are discussed below. For each of the options considered, not only erosion and sediment yield, but also irrigation efficiency, adequacy, runoff, and leaching were estimated in order to relate erosion and sediment yield to the potential for nitrate leaching and the effectiveness of irrigation.

5.3 A Case Study for Optimum Irrigation Management with Alternate Practices

A case study on Bel-air farm in Malheur County was performed for;

a) Conventional irrigation practices, and

b) Alternative irrigation practices.

Two computer simulation models were used to estimate sediment loss, leaching, efficiency, and adequacy for both above practices. The first, FUSED, was used to estimate sediment yield with different irrigation and agronomic practices, where an alternative practice involved an irrigation duration different from 24 hours, the estimate of sediment yield was changed proportionately. A second model, SRFR ver-20.5, "A computer program for simulation of flow in surface irrigation" was used to estimate runoff, leaching, efficiency, and adequacy. The large field in Bel-Air farm was selected as an example for a case study which has a common dimension of 1200 x 1200 feet with an area of 31 acres. This field is already described in previous section 3.1.2. A range of inflow rates from 0.5 to 0.8 lps or (8.0 to 12.7 gpm) were analyzed for above required results. The inflow rates (0.5 to 0.7) lps or (8.0 to 11.0 gpm) for field slopes 1.0% to 1.5%, and inflow rates (0.35 to 0.45) lps or (5.6 to 7.1 gpm) are found to be the common practice in that region.

The first set of inflow rates was run for the following conventional irrigation practices;

a) Irrigation duration 24 hours

b) Furrow length 1200 feet

c) Furrow spacing 30 inches (0.76 meter)

d) Field slope 1.5 %

The results for above conditions at various inflow rates are shown in table 5-3(a).

A second set of inflow rates was run for various irrigation durations chosen to maintain a high irrigation efficiency and specified adequacy of about 85 percent, and to decrease sediment loss and water leaching. These results are shown in table 5-3(b), where sediment loss and leaching are significantly decreased, and the desired efficiency and adequacy are maintained.

A third set of inflow rates used the same strategy of changing irrigation duration to achieve specified adequacy and high efficiency, but with increased furrow spacing from 30 to 60 inches (0.76 to 1.52 meter) is commonly done as with alternating furrow irrigation. It is already learned from field data that the average sediment loss is decreased up to 40 % by irrigating every other furrow. Though this approach needs a longer irrigation duration, it leaves with less leaching and results in higher efficiencies and adequacies, as indicated in table 5-3(c). However these are indications from parallel research by Raja (personal communication, that efficiencies may in fact be much lower than indicated by SRFR.

Another study for alternate practice was performed with field length decreased to the half of total length. The same strategies were tested as in the above three cases but using a field length of 600 feet. The FUSED model and field data for conventional irrigation practices show that the sediment yield is increased up to 2 to 3 times by decreasing the field length in half for a given inflow rate. It is possibly because once erosion comes down from the upper end of field, it starts depositing partially at the lower end of field as flow rate decreases and partially leaves the field with runoff water. Therefore, furrows with longer lengths receive more deposition region and furrows with shorter lengths receive less deposition region. The alternate option of decreasing the irrigation duration was selected to decrease the sediment yield for shorter field lengths. Tables 5-4(b-c) shows that the sediment yield are decreased by lowering the irrigation duration. The estimated results from this option are compared with the sediment loss for conventional irrigation practice as shown in 5-4(a). The good advantage of short field length is to minimize the leaching because of the faster advance.

The SRFR model was checked for conventional and alternate irrigation practices for a case study. The standard curves have been derived for conventional and alternative practices. Two field lengths were assumed for this study, 600 feet and 1200 feet, which are common field lengths in that region. A set of four inflow rates ranging from 0.5 to 0.8 Lps (8.0 to 12.7 gpm) for 1200 feet field and 0.3 to 0.45 Lps (4.8 to 7.1 gpm) for 600 feet field were used. The simulated results of runoff, leaching, efficiency, adequacy, and sediment yields are shown in tables 5-3(a-c) and 5-4(a-c), and are illustrated in figures 5-5 through 5-7. These general tables and graphs will be convenient reference tools for individuals in malheur County.

TABLE 5.3 a SRFR and FUSED model runs for conventional irrigation practices at field slopes of 1.5 % and furrow length 1200 feet.

Inflow rate Lps	Inflow rate gpm	Duration hrs	Runoff (cm)	Leaching (cm)	Efficiency (%)	Adequacy %	Sediment loss ton/ac
0.5	8.0	24	0.0	4.9	65	71	0.24
0.6	9.5	24	0.7	7.0	59	94	0.31
0.7	11.0	24	2.4	8.4	51	100	0.39
0.8	12.7	24	4.3	9.5	44	100	0.50

TABLE 5.3 b SRFR and FUSED model runs for various irrigation durations at field slopes of 1.5 % and furrow length 1200 feet.

Inflow rate Lps	Inflow rate gpm	Duration hrs	Runoff (cm)	Leaching (cm)	Efficiency (%)	Adequacy %	Sediment loss ton/ac
0.5	8.0	32	0.0	8.67	54	84	0.32
0.6	9.5	20	0.30	4.63	68	84	0.26
0.7	11.0	18	0.98	4.06	68	87	0.30
0.8	12.7	15	1.54	3.15	70	84	0.31

TABLE 5.3 c SRFR and FUSED model runs for alternate irrigated furrows at various irrigation durations with field slope 1.5 % and furrow length 1200 feet.

Inflow rate Lps	Inflow rate gpm	Duration hrs	Runoff (cm)	Leaching (cm)	Efficiency (%)	Adequacy %	Sediment loss ton/ac
0.5	8.0	48	0.1	3.5	74	80	0.24
0.6	9.5	38	1.5	2.5	73	84	0.25
0.7	11.0	34	2.5	2.0	70	84	0.28
0.8	12.7	32	3.6	2.0	66	88	0.33

TABLE 5.4 a SRFR and FUSED model runs for conventional irrigation practices at field slopes of 1.5 % and furrow length 600 feet.

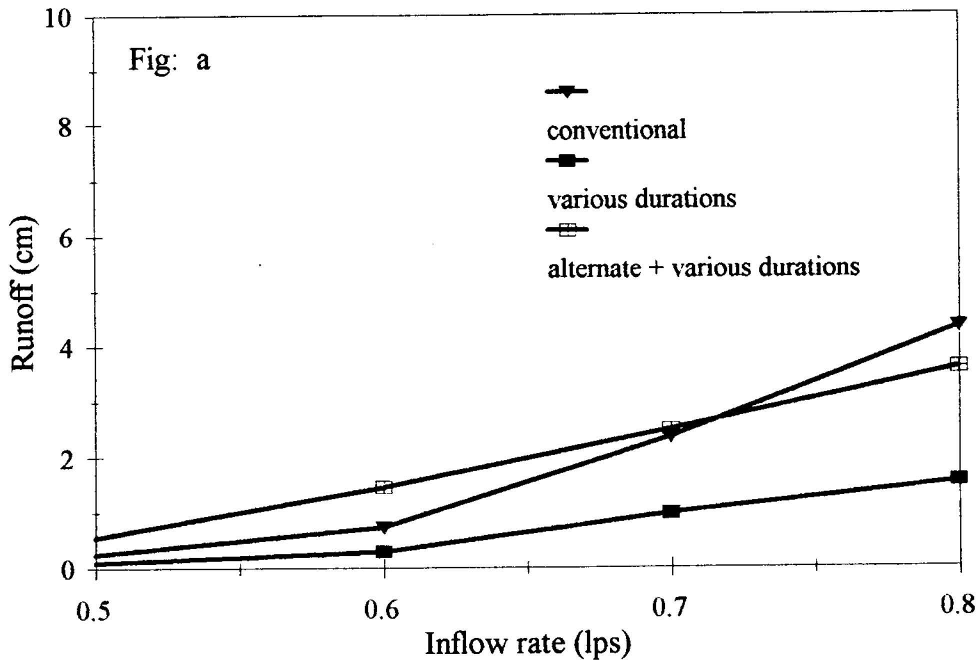
Inflow rate Lps	Inflow rate gpm	Duration hrs	Runoff (cm)	Leaching (cm)	Efficiency (%)	Adequacy %	Sediment loss ton/ac
0.30	4.8	24	1.6	6.1	59	100	0.27
0.35	5.6	24	3.6	7.1	51	100	0.35
0.40	6.3	24	5.9	7.9	44	100	0.42
0.45	7.1	24	8.4	8.5	40	100	0.52

TABLE 5.4 b SRFR and FUSED model runs for various irrigation durations at field slopes of 1.5 % and furrow length 600 feet.

Inflow rate Lps	Inflow rate gpm	Duration hrs	Runoff (cm)	Leaching (cm)	Efficiency (%)	Adequacy %	Sediment loss ton/ac
0.30	4.8	20	0.90	3.8	70	87	0.23
0.35	5.6	17	1.70	2.8	71	88	0.25
0.40	6.3	15	2.48	2.2	70	88	0.26
0.45	7.1	14	3.40	1.9	67	87	0.30

TABLE 5.4 c SRFR and FUSED model runs for alternate irrigated furrows at various irrigation durations with field slope 1.5 % and furrow length 600 feet.

Inflow rate Lps	Inflow rate gpm	Duration hrs	Runoff (cm)	Leaching (cm)	Efficiency (%)	Adequacy %	Sediment loss ton/ac
0.30	4.8	38	2.3	1.6	74	84	0.22
0.35	5.6	34	3.4	1.1	70	80	0.26
0.40	6.3	32	4.7	1.0	66	80	0.28
0.45	7.1	31	6.1	1.0	61	84	0.34



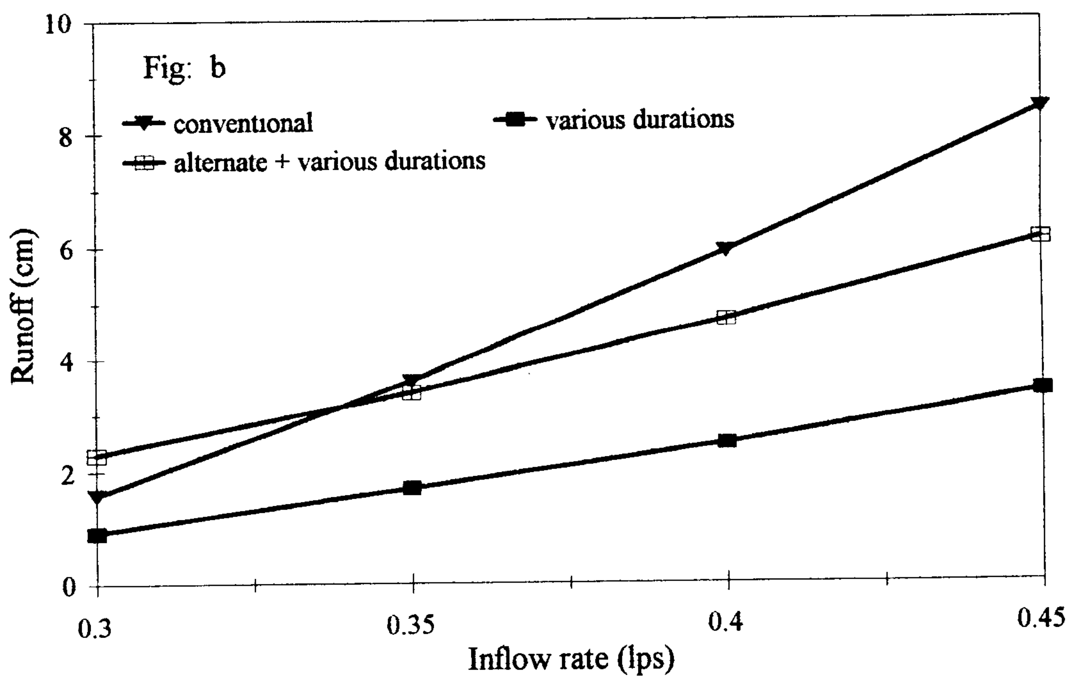
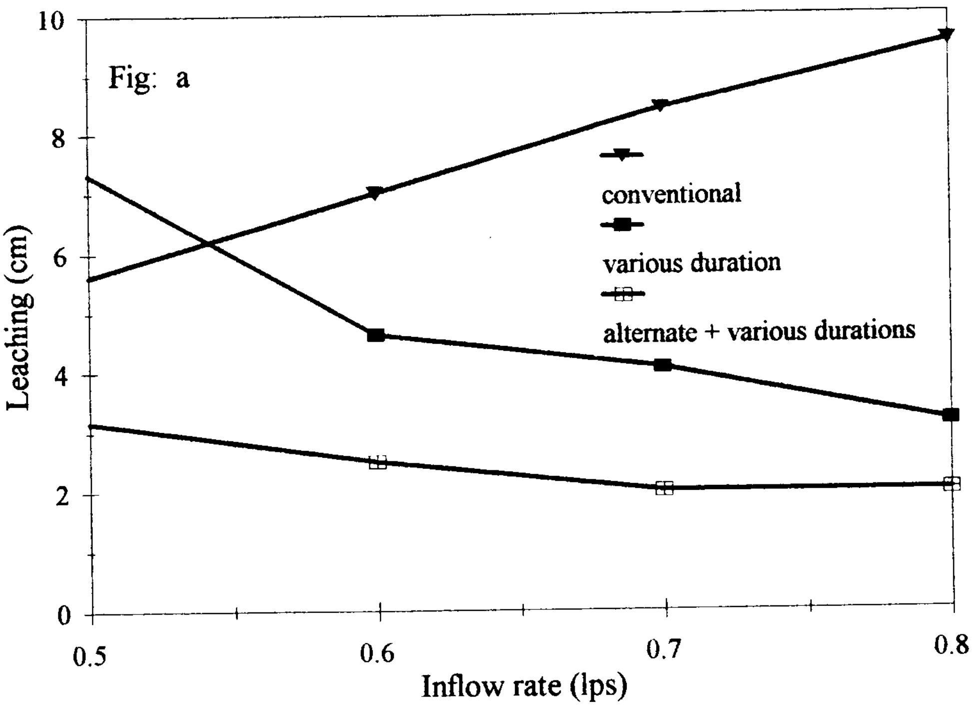


Figure 5-5. Estimation of runoff (cm) using SRFR model for conventional and alternate irrigation practices at; (a) 1200 feet, and (b) 600 feet.



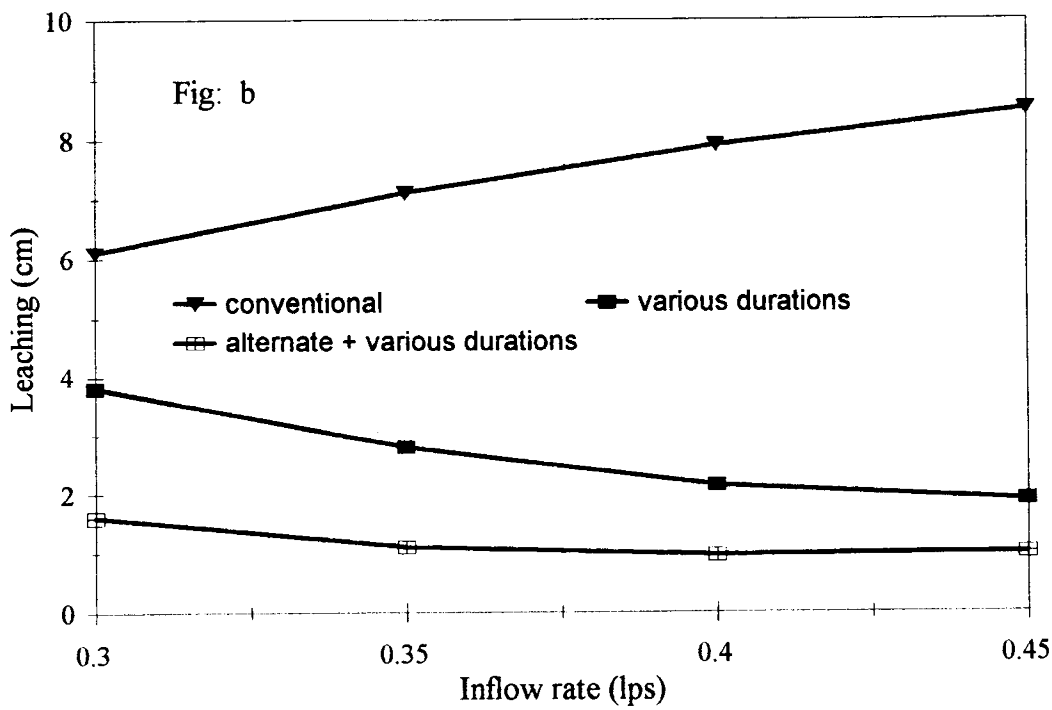
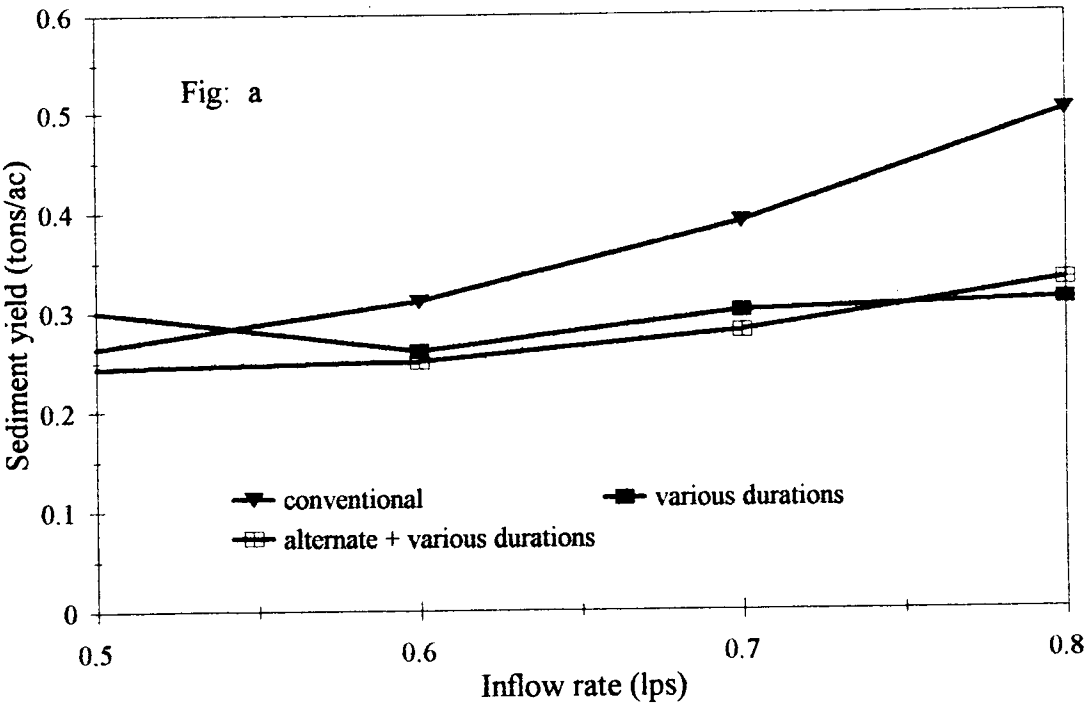


Figure 5-6. Estimation of leaching (cm) using SRFR model for conventional and alternate irrigation practices at; (a) 1200 feet, and (b) 600 feet.



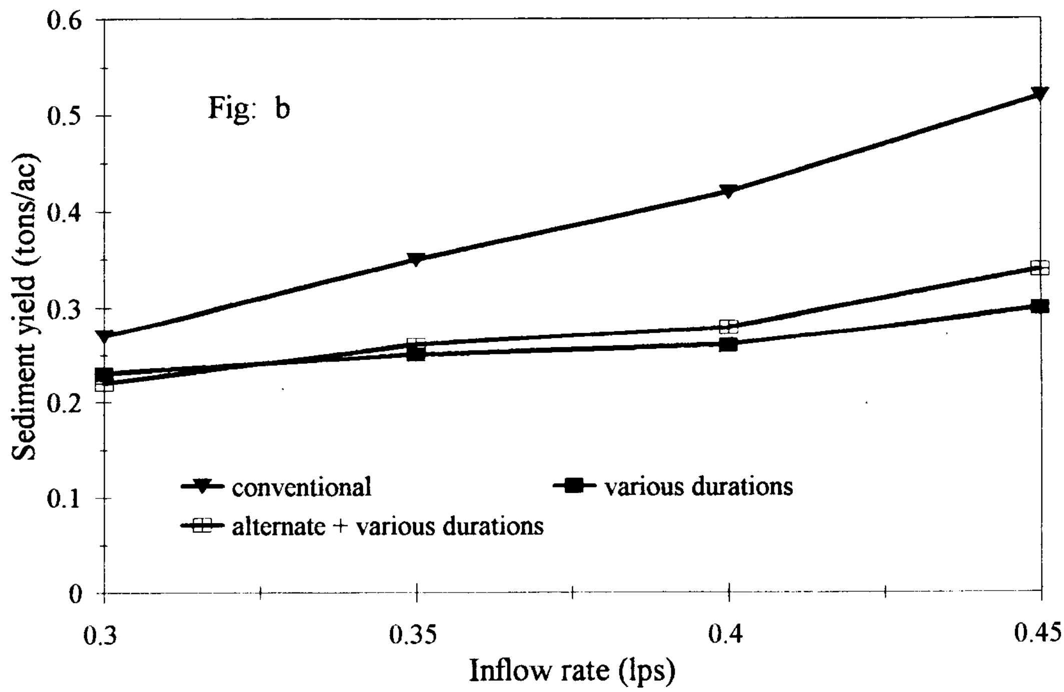


Figure 5-7. Estimation of sediment yield (tons/ac) using FUSED model for conventional and alternate irrigation practices at; (a) 1200 feet, and (b) 600 feet.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The main objective of this research was; 1) to evaluate sediment yield under conventional and alternative irrigation practices, 2) to test the PC program "FUSED" and adapt it for use in Malheur county, and 3) to suggest alternative irrigation management practices to control sediment yield while also considering deep percolation that results in nitrate leaching.

following table show the configuration of field data collected for each alternative irrigation method.

TABLE 6-1. Summary of field data collected for each alternative irrigation method.

Irrigation strategy	Number of irrigations	Total furrows or block of furrows involved
Conventional		
Slope (0.5 %)	5	30 blocks
Slope (1.0 %)	3	12 furrows
Slope (1.5 %)	2	8 furrows
Slope (3.0 %)	5	30 furrows
Surge flow	5	30 blocks
Mulched vs non-mulched	5	60 furrows
Wheel vs non-wheel	5	20 furrows
Every-furrow vs alternate furrow	1	6 furrows

The Fused model was checked with field estimated data, which were collected in Malheur County in 1993 and 1994, under different irrigation and agronomic practices. While not sufficient to recalibrate this complex model, the present data are adequate for a general assessment of its ability to predict sediment loss, and the data also can be used to derive adjustments to account for non-standard circumstances.

Experimental fields were selected in Malheur County eastern Oregon, an area which Oregon State DEQ and U.S. E.P.A. have designated a critical area for ground water contamination and surface water pollution resulting mainly from surface irrigation, particularly from furrow irrigation method. Two fields were selected at Malheur Agricultural Experiment Station and one other field at Bel-Air farm in the vicinity of Nyssa, provided by a cooperating farmer was also used. Data from these field fields were used to assess model performance.

The overall conclusion is that the model gives reasonable estimates of sediment loss for low to moderate slopes under conventional irrigation, but under-estimates the sediment loss associated with steeper slopes. The model estimates of reduction in sediment yield with the application of straw mulching in furrow bottom were quite inaccurate. These conclusions are supported by the field results observed in 1993 from field B-7 and field B-3 for the 1st, 2nd, 3rd, 4th, and 5th irrigation events. Field estimated results and model estimated results are shown in tables 4-8, 4-9, and figures 4-15 and 4-16. The model only under estimates about 5.4 % less than the field results for conventional irrigation method. The model was also tested for different field lengths and slopes. The comparison of results are shown in figure 4-16 through 4-18, in which the model shows a good relationship for different field lengths, and for field slopes up to 1.0 %. After testing the model for higher field slopes of 1.5% and 3.0%, it was found that the model under estimates the sediment yields for higher field slopes, as illustrated in figures 4-16 and 4-17.

The FUSED model does not predict sediment yield for surge flow, hard and soft furrows separately, or for irrigation durations, other than standard 24 hour duration. Therefore, different multipliers were derived to account for those factors. Also FUSED estimates of erosion under mulching were very poor, so an improved mulching factor was derived from the field data. With regard to these other factors, the following adjustments are recommended:

(a) An average sediment yield of 0.62 tons/acre (1383 kg/ha) was measured from conventional irrigated fields and 0.32 tons/ac (716 kg/ha) from surge irrigated fields for five irrigations, which implies that the sediment yield under surge irrigation is 52 % of the sediment yield with conventional irrigation method.

(b) The average sediment yield from hard furrows is 1.36 times the sediment yield from soft furrows.

(c) A tremendous reduction in sediment yield was observed with mulching in field B-3. The sediment yield was measured at 24.5 tons/acre (55081 kg/ha) from non-mulched furrows, which is about 40 times greater than the 0.62 tons/acre (1383 kg/ha) from mulched furrows. The model estimates yields about 3 times greater for non-mulched furrows, which is not a reliable estimate. The straw mulching in furrow bottom was found to be an effective measure to control erosion and sediment yield in furrow irrigation for fields with steeper slope.

(d) The average sediment yield from alternate irrigated furrows was found to be 37 percent as much as observed when every furrow was irrigated. The model predicts about 50 percent less for alternate irrigation method, which is reasonably consistent with field results.

Two simulation models were used to suggest the best alternative irrigation practices in Malheur County. The first, FUSED, was used to derive a set of standard curves for erosion and sediment yield under conventional irrigation practices. These results are shown in tables 5-1, 5-2 and illustrated in figures 5-1 through 5-4. The second model, SRFR, was used to derive a set of standard curves for runoff, leaching, efficiency, and adequacy under conventional and alternate irrigation practices. These simulated results are shown in tables 5-3(a-b) and 5-4(a-b), and illustrated in figures 5-5(a-b) through 5-7(a-b). These general tables and graphs will be convenient reference tools for individuals who might be concerned with soil loss and sedimentation, but the user should be warned that estimates may be low for steeper slopes.

6.2 Recommendations

Several recommendations have evolved from these studies for irrigation management practice and for future research to control erosion and sediment loss in furrow irrigation. The main purposes of this study were to evaluate the sediment loss with conventional and alternate irrigation practices, to suggest the best alternate options to over come this problem, and to test the PC program "FUSED" and adapt it for use of Malheur County. The following suggestions are recommended to control the sediment loss and water leaching with alternate irrigation practices under furrow irrigation method.

1) The sediment loss can be reduced up to 50 % with the application of surge flow in furrow irrigation.
2) Application of mulching, an effective measure to control sediment loss at steeper field slopes, can be used to minimize sediment loss up to 40 times less than the control methods.
3) Irrigating alternate furrows is found an easy method to control sediment loss. sediment yield with alternate furrow irrigation was 37 % as much as every-furrow irrigation.
4) Avoiding or minimizing furrow bed compaction can also reduce sediment yield. The sediment yield from packed furrows was found to be 1.36 times the sediment yield from soft furrows.
5) Doubling the furrow length is another measure to control the sediment loss in furrow irrigation. This study showed that the sediment loss is decreased as the furrow length is increased. The average 50 % sediment yield can be decreased by doubling the furrow length.
6) Irrigating the field with flexible irrigation durations is found to be an effective method to control sediment loss and water leaching while maintaining desired irrigation efficiency and adequacy. In one example of decreasing irrigation duration from 24 hours to 18 hours, estimates of sediment loss decreased from 0.4 tons/ac to 0.3 tons/ac, estimated water leaching was decreased from 8.4 cm

to 4.1 cm, and estimated efficiency increased from 51 % to 68 %, though the adequacy was decreased from 100 % to 87 %.

It is a priority of the grower to adopt one of the alternate options, whether to minimize sediment loss, or to decrease water leaching. Two of the above alternatives have conflicting effects on each other. Irrigating soft furrows and increasing furrow length will result in decreased sediment loss but will increase water leaching. On the other hand irrigating hard furrows and shortening furrow length will result in increased sediment yield but decreased water leaching.

Since it was difficult to select one of above options, the FUSED and SRFR models were run for two different furrow lengths and inflow rates with various irrigation durations to find out the optimum alternate management practices. Tables 5-1 through 5-4, and Figures 5-1 through 5-7 are easy reference tools to find out the best option for the interest of anyone.

The FUSED model needs to be enhanced and modified to make it efficient to predict sediment yield for the following conditions;

1) Enhancement to estimate sediment yield for surge flow,
2) Enhancement to estimate sediment yield for hard and soft furrows separately,
3) Modification to estimate sediment yield for slopes greater than 1.0 %,
4) Modification to estimate sediment yield for mulching application,

The FUSED model also need to be checked for different inflow rates, therefore, more field data is required for measurement of sediment loss at different inflow rates.

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APPENDICES

Appendix A. Fused Model Outputs for Different Field Slopes and Lengths

U. S. Department of Agriculture   Soil Conservation Service

FURROW SOIL LOSS EVALUATION

(Version 1.89-2 for Idaho, Oregon, Washington)

Landowner: OREGON STATE UNIVERSITY

Location: Malheur County

Field Office: Agricultural Experiment Station Ontario

Date: June 8, 1994

Technician: Abdul F. Tunio

Acres Involved:-- 6.0 acres

Field Width:--- 440 feet

Crop grown last season:--- ONION

Crop being grown this year:--- SPRING WHEAT

Type of furrow irrigation:-- Gated Pipe

Type of furrow end:--- Moderately Convex

Number of irrigations:-- 3

Tillage: number of cultivations (equivalent) -------------------------- 5

Inflow rate: -- 8.0 gpm

Furrow slope: -- 0.5 %

Furrow length: --- 600 feet

Furrow spacing: -- 60 inch

Soil weight: --- 80 lbs/cu ft

Soil series: Greenleaf silt loam series. (Cohesive soil)

Percent of area: --- 100 %

D50 particle size for this soil series: ------------------------------------ 0.0010 mm

Sediment yield estimated for this soil series: -------------------------- 0.21 tons/ac/yr

Erosion at upper end: -- 2.7 tons/ac/yr

U. S. Department of Agriculture | Soil Conservation Service

FURROW SOIL LOSS EVALUATION

(Version 1.89-2 for Idaho, Oregon, Washington)

Landowner: OREGON STATE UNIVERSITY

Location: Malheur County

Field Office: Agricultural Experiment Station Ontario

Date: June 8, 1994

Technician: Abdul F. Tunio

Acres Involved:-- 6.0 acres

Field Width:-- 440 feet

Crop grown last season:--- ONION

Crop being grown this year:--- SPRING WHEAT

Type of furrow irrigation:-- Gated Pipe

Type of furrow end:--- Moderately Convex

Number of irrigations:-- 3

Tillage: number of cultivations (equivalent) ----------------------------- 5

Inflow rate: --- 8.0 gpm

Furrow slope: -- 1.0 %

Furrow length: --- 600 feet

Furrow spacing: -- 60 inch

Soil weight: --- 80 lbs/cu ft

Soil series: Greenleaf silt loam series

Percent of area: --- 100 %

Cohesive soil

D50 particle size for this soil series: ---------------------------------- 0.0010 mm

Sediment yield estimated for this soil series: --------------------------- 0.68 tons/ac/yr

Erosion at upper end: --- 3.9 tons/ac/yr

U. S. Department of Agriculture — Soil Conservation Service

FURROW SOIL LOSS EVALUATION

(Version 1.89-2 for Idaho, Oregon, Washington)

Landowner: BEL-AIR FARMS
Location: Malheur County
Field Office: Agricultural Experiment Station Ontario
Date: June 8, 1994
Technician: Abdul F. Tunio

Acres Involved:-- 31 acres
Field Width:-- 1200 feet
Crop grown last season:--- ALFALFA
Crop being grown this year:-- SPRING WHEAT
Type of furrow irrigation:-- Siphon Tube
Type of furrow end:-- Moderately Convex
Number of irrigations:--- 3
Tillage: number of cultivations (equivalent) --------------------------- 5

Inflow rate: --- 8.0 gpm
Furrow slope: -- 1.5 %
Furrow length: --- 600 feet
Furrow spacing: -- 60 inch
Soil weight: --- 80 lbs/cu ft
Soil series: Nyssa silt loam series
Percent of area: -- 100 %
Cohesive soil
D50 particle size for this soil series: ------------------------------------- 0.0010 mm
Sediment yield estimated for this soil series: --------------------------- 2.73 tons/ac/yr
Erosion at upper end: -- 9.9 tons/ac/yr

U. S. Department of Agriculture — Soil Conservation Service

FURROW SOIL LOSS EVALUATION

(Version 1.89-2 for Idaho, Oregon, Washington)

Landowner: BEL-AIR FARM

Location: Malheur County

Field Office: Agricultural Experiment Station Ontario

Date: June 8, 1994

Technician: Abdul F. Tunio

Acres Involved:-- 31 acres

Field Width:--- 1200 feet

Crop grown last season:-- ALFALFA

Crop being grown this year:-- SPRING WHEAT

Type of furrow irrigation:-- Siphon Tube

Type of furrow end:--- Moderately Convex

Number of irrigations:-- 3

Tillage: number of cultivations (equivalent) --------------------------- 5

Inflow rate: --- 8.0 gpm

Furrow slope: --- 1.0 %

Furrow length: -- 400 feet

Furrow spacing: --- 60 inch

Soil weight: --- 80 lbs/cu ft

Soil series: Nyssa silt loam series

Percent of area: --- 100 %

Cohesive soil

D50 particle size for this soil series: ------------------------------------ 0.0010 mm

Sediment yield estimated for this soil series: --------------------------- 1.19 tons/ac/yr

Erosion at upper end: -- 3.9 tons/ac/yr

U. S. Department of Agriculture — Soil Conservation Service

FURROW SOIL LOSS EVALUATION

(Version 1.89-2 for Idaho, Oregon, Washington)

Landowner: BEL-AIR FARM

Location: Malheur County

Field Office: Agricultural Experiment Station Ontario

Date: June 8, 1994

Technician: Abdul F. Tunio

Acres Involved:-- 31 acres

Field Width:--- 1200 feet

Crop grown last season:-- ALFALFA

Crop being grown this year:-- SPRING WHEAT

Type of furrow irrigation:--- Siphon Tube

Type of furrow end:-- Moderately Convex

Number of irrigations:--- 3

Tillage: number of cultivations (equivalent) ---------------------------- 5

Inflow rate: -- 8.0 gpm

Furrow slope: -- 1.0 %

Furrow length: --- 800 feet

Furrow spacing: -- 60 inch

Soil weight: -- 80 lbs/cu ft

Soil series: Nyssa silt loam series

Percent of area: --- 100 %

Cohesive soil

D50 particle size for this soil series: ------------------------------------ 0.0010 mm

Sediment yield estimated for this soil series: ---------------------------- 0.45 tons/ac/yr

Erosion at upper end: --- 3.9 tons/ac/yr

U. S. Department of Agriculture | Soil Conservation Service

FURROW SOIL LOSS EVALUATION

(Version 1.89-2 for Idaho, Oregon, Washington)

Landowner: BEL-AIR FARM

Location: Malheur County

Field Office: Agricultural Experiment Station Ontario

Date: June 8, 1994

Technician: Abdul F. Tunio

Acres Involved:-- 31 acres

Field Width:-- 1200 feet

Crop grown last season:-- ALFALFA

Crop being grown this year:--- SPRING WHEAT

Type of furrow irrigation:--- Siphon Tube

Type of furrow end:--- Moderately Convex

Number of irrigations:--- 3

Tillage: number of cultivations (equivalent) -------------------------- 5

Inflow rate: -- 8.0 gpm

Furrow slope: -- 1.0 %

Furrow length: --- 1200 feet

Furrow spacing: -- 60 inch

Soil weight: -- 80 lbs/cu ft

Soil series: Nyssa silt loam series

Percent of area: -- 100 %

Cohesive soil

D50 particle size for this soil series: ------------------------------------ 0.0010 mm

Sediment yield estimated for this soil series: ---------------------------- 0.26 tons/ac/yr

Erosion at upper end: -- 3.9 tons/ac/yr

Appendix B. Fused Model Outputs for Different Slopes and Inflow rates at 600 and 1200 feet Furrow Lengths

U. S. Department of Agriculture Soil Conservation Service

FURROW SOIL LOSS EVALUATION

(Version 1.89-2 for Idaho, Oregon, Washington)

Landowner: OREGON STATE UNIVERSITY

Location: Malheur County

Field Office: Agricultural Experiment Station Ontario

Date: June 8, 1994

Technician: Abdul F. Tunio

Acres Involved:-- 6.0 acres

Field Width:--- 440 feet

Crop grown last season:--- ONION

Crop being grown this year:--- SPRING WHEAT

Type of furrow irrigation:--- Gated Pipe

Type of furrow end:--- Moderately Convex

Number of irrigations:-- 5

Tillage: number of cultivations (equivalent) -------------------------- 5

Inflow rate: -- 6.3 gpm

Furrow slope: -- 1.0 %

Furrow length: --- 600 feet

Furrow spacing: --- 30 inch

Soil weight: -- 80 lbs/cu ft

Soil series: Greenleaf silt loam series. (Cohesive soil)

Percent of area: -- 100 %

D50 particle size for this soil series: ------------------------------------ 0.0010 mm

Sediment yield estimated for this soil series: -------------------------- 1.84 tons/ac/yr

Erosion at upper end: -- 11.8 tons/ac/yr

U. S. Department of Agriculture — Soil Conservation Service

FURROW SOIL LOSS EVALUATION

(Version 1.89-2 for Idaho, Oregon, Washington)

Landowner: OREGON STATE UNIVERSITY

Location: Malheur County

Field Office: Agricultural Experiment Station Ontario

Date: June 8, 1994

Technician: Abdul F. Tunio

Acres Involved:-- 6.0 acres

Field Width:-- 440 feet

Crop grown last season:--- ONION

Crop being grown this year:--- SPRING WHEAT

Type of furrow irrigation:-- Gated Pipe

Type of furrow end:-- Moderately Convex

Number of irrigations:-- 5

Tillage: number of cultivations (equivalent) -------------------------- 5

Inflow rate: -- 6.3 gpm

Furrow slope: -- 1.5 %

Furrow length: --- 600 feet

Furrow spacing: -- 30 inch

Soil weight: --- 80 lbs/cu ft

Soil series: Greenleaf silt loam series

Percent of area: -- 100 %

Cohesive soil

D50 particle size for this soil series: ------------------------------------ 0.0010 mm

Sediment yield estimated for this soil series: --------------------------- 3.71 tons/ac/yr

Erosion at upper end: -- 14.7 tons/ac/yr

U. S. Department of Agriculture   Soil Conservation Service

FURROW SOIL LOSS EVALUATION

(Version 1.89-2 for Idaho, Oregon, Washington)

Landowner: OREGON STATE UNIVERSITY
Location: Malheur County
Field Office: Agricultural Experiment Station Ontario
Date: June 8, 1994
Technician: Abdul F. Tunio

Acres Involved:-- 6.0 acres
Field Width:--- 440 feet
Crop grown last season:-- ONION
Crop being grown this year:-- SPRING WHEAT
Type of furrow irrigation:--- Gated Pipe
Type of furrow end:-- Moderately Convex
Number of irrigations:--- 5
Tillage: number of cultivations (equivalent) -------------------------- 5

Inflow rate: -- 9.5 gpm
Furrow slope: --- 1.0 %
Furrow length: -- 600 feet
Furrow spacing: --- 30 inch
Soil weight: -- 80 lbs/cu ft
Soil series: Greenleaf silt loam series
Percent of area: -- 100 %
Cohesive soil
D50 particle size for this soil series: ------------------------------------ 0.0010 mm
Sediment yield estimated for this soil series: --------------------------- 3.56 tons/ac/yr
Erosion at upper end: --- 19.3 tons/ac/yr

U. S. Department of Agriculture — Soil Conservation Service

FURROW SOIL LOSS EVALUATION

(Version 1.89-2 for Idaho, Oregon, Washington)

Landowner: OREGON STATE UNIVERSITY
Location: Malheur County
Field Office: Agricultural Experiment Station Ontario
Date: June 8, 1994
Technician: Abdul F. Tunio

Acres Involved:-- 6.0 acres
Field Width:--- 440 feet
Crop grown last season:-- ONION
Crop being grown this year:-- SPRING WHEAT
Type of furrow irrigation:--- Gated Pipe
Type of furrow end:-- Moderately Convex
Number of irrigations:--- 5
Tillage: number of cultivations (equivalent) ------------------------------ 5

Inflow rate: -- 9.5 gpm
Furrow slope: --- 1.5 %
Furrow length: -- 600 feet
Furrow spacing: --- 30 inch
Soil weight: -- 80 lbs/cu ft
Soil series: Greenleaf silt loam series
Percent of area: -- 100 %
Cohesive soil
D50 particle size for this soil series: ----------------------------------- 0.0010 mm
Sediment yield estimated for this soil series: ---------------------------- 7.16 tons/ac/yr
Erosion at upper end: --- 24.2 tons/ac/yr

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FURROW SOIL LOSS EVALUATION

(Version 1.89-2 for Idaho, Oregon, Washington)

Landowner: OREGON STATE UNIVERSITY

Location: Malheur County

Field Office: Agricultural Experiment Station Ontario

Date: June 8, 1994

Technician: Abdul F. Tunio

Acres Involved:-- 6.0 acres

Field Width:-- 440 feet

Crop grown last season:-- ONION

Crop being grown this year:-- SPRING WHEAT

Type of furrow irrigation:-- Gated Pipe

Type of furrow end:--- Moderately Convex

Number of irrigations:-- 5

Tillage: number of cultivations (equivalent) ---------------------------- 5

Inflow rate: -- 6.3 gpm

Furrow slope: --- 1.0 %

Furrow length: -- 1200 feet

Furrow spacing: -- 30 inch

Soil weight: -- 80 lbs/cu ft

Soil series: Greenleaf silt loam series

Percent of area: -- 100 %

Cohesive soil

D50 particle size for this soil series: ----------------------------------- 0.0010 mm

Sediment yield estimated for this soil series: --------------------------- 0.70 tons/ac/yr

Erosion at upper end: -- 11.8 tons/ac/yr

U. S. Department of Agriculture — Soil Conservation Service

FURROW SOIL LOSS EVALUATION

(Version 1.89-2 for Idaho, Oregon, Washington)

Landowner: OREGON STATE UNIVERSITY

Location: Malheur County

Field Office: Agricultural Experiment Station Ontario

Date: June 8, 1994

Technician: Abdul F. Tunio

Acres Involved:-- 6.0 acres

Field Width:-- 440 feet

Crop grown last season:-- ONION

Crop being grown this year:-- SPRING WHEAT

Type of furrow irrigation:--- Gated Pipe

Type of furrow end:-- Moderately Convex

Number of irrigations:--- 5

Tillage: number of cultivations (equivalent) -------------------------- 5

Inflow rate: -- 6.3 gpm

Furrow slope: --- 1.5 %

Furrow length: -- 1200 feet

Furrow spacing: --- 30 inch

Soil weight: -- 80 lbs/cu ft

Soil series: Greenleaf silt loam series

Percent of area: -- 100 %

Cohesive soil

D50 particle size for this soil series: ------------------------------------ 0.0010 mm

Sediment yield estimated for this soil series: -------------------------- 1.42 tons/ac/yr

Erosion at upper end: --- 14.7 tons/ac/yr

U. S. Department of Agriculture | Soil Conservation Service

FURROW SOIL LOSS EVALUATION

(Version 1.89-2 for Idaho, Oregon, Washington)

Landowner: OREGON STATE UNIVERSITY
Location: Malheur County
Field Office: Agricultural Experiment Station Ontario
Date: June 8, 1994
Technician: Abdul F. Tunio

Acres Involved:-- 6.0 acres
Field Width:--- 440 feet
Crop grown last season:-- ONION
Crop being grown this year:-- SPRING WHEAT
Type of furrow irrigation:--- Gated Pipe
Type of furrow end:-- Moderately Convex
Number of irrigations:--- 5
Tillage: number of cultivations (equivalent) -------------------------- 5

Inflow rate: --- 9.5 gpm
Furrow slope: --- 1.0 %
Furrow length: -- 1200 feet
Furrow spacing: -- 30 inch
Soil weight: -- 80 lbs/cu ft
Soil series: Greenleaf silt loam series
Percent of area: -- 100 %
Cohesive soil
D50 particle size for this soil series: ------------------------------------ 0.0010 mm
Sediment yield estimated for this soil series: --------------------------- 1.36 tons/ac/yr
Erosion at upper end: --- 19.3 tons/ac/yr

U. S. Department of Agriculture | Soil Conservation Service

FURROW SOIL LOSS EVALUATION

(Version 1.89-2 for Idaho, Oregon, Washington)

Landowner: OREGON STATE UNIVERSITY

Location: Malheur County

Field Office: Agricultural Experiment Station Ontario

Date: June 8, 1994

Technician: Abdul F. Tunio

Acres Involved:-- 6.0 acres

Field Width:--- 440 feet

Crop grown last season:-- ONION

Crop being grown this year:--- SPRING WHEAT

Type of furrow irrigation:--- Gated Pipe

Type of furrow end:-- Moderately Convex

Number of irrigations:-- 5

Tillage: number of cultivations (equivalent) --------------------------- 5

Inflow rate: -- 9.5 gpm

Furrow slope: -- 1.5 %

Furrow length: --- 1200 feet

Furrow spacing: -- 30 inch

Soil weight: -- 80 lbs/cu ft

Soil series: Greenleaf silt loam series

Percent of area: -- 100 %

Cohesive soil

D50 particle size for this soil series: ------------------------------------ 0.0010 mm

Sediment yield estimated for this soil series: -------------------------- 2.73 tons/ac/yr

Erosion at upper end: -- 24.2 tons/ac/yr

Appendix C. Statistical analysis of significant levels for different multipliers

1) Significance level for surge vs continuous irrigation.

Surge irrigation		Continuous irrigation	
data	sq error	data	sq error
72.23	5298.38	147.09	17382.3
158.85	191.27	227.94	2600.18
185.34	1625.7	366.13	7603.49
160.62	243.36	367.59	7860.24
202.21	3270.7	308.98	902.882
90.92	2926.8	255.85	532.779

Mean:	145.02	278.93
Sum of sq error:	13556.2	36881.9

Over all results

Mean:	211.976
Sum of sq error:	50438.1

$k = 2$, $Nc = Ns = 6$

where,

k = number of treatments, Nc = number of samples under continuous irrigation method, and Ns = number of samples under surge irrigation method.

Assumed null hypothesis, where all means are the same.

$$F_{stat} = 10.666$$

$$F_{1, 10, 0.99} = 10.04$$

Since F stat > $F_{1, 10, 0.99}$, therefore, hypothesis is rejected, which implies that the means are not the same, and data are significant at 0.99 confidence level.

2) Significance level for wheel furrow vs non-wheel furrow at two field slopes.

(a) Slope 1.0 %

Wheel furrow		Non-wheel furrow	
data	sq error	data	sq error
0.34	0.0092	0.063	0.0027
0.112	0.0174	0.076	0.0015
0.175	0.0048	0.155	0.0016
0.144	0.01	0.18	0.0042
0.204	0.0016	0.065	0.0025
0.489	0.06	0.15	0.0012

	Wheel furrow	Non-wheel furrow
Mean	0.244	0.115
Sum of sq error	0.103	0.014

Over all results.

Mean: 0.1794

Sum of sq error 0.1168

k = 2, Nw = Nnw = 6

where,

k = number of treatments, and Nw = number of samples under wheel furrows, and Nnw = number of samples under non-wheel furrows.

Assumed null hypothesis, where all means are the same.

F stat = 4.274

$F_{1, 10, 0.90}$ = 3.29

Since F stat > $F_{1, 10, 0.90}$, therefore, hypothesis is rejected, which implies that all means are not the same, and data are significant at 0.90 confidence level.

(b) Slope 1.5 %

Wheel furrow			Non-wheel furrow	
data	sq error		data	sq error
	4.09	0.2068	3.262	0.2875
	3.354	0.0791	2.095	0.3978
	4.518	0.7792	3.489	0.5825
	2.579	1.1157	2.057	0.4472

Mean	3.635	2.726
Sum of sq error	2.181	1.715

Over all results.

Mean:	3.1805
Sum of sq error	3.896

k = 2, Nw = Nnw = 4

where,

k = number of treatments, and Nw = number of samples under wheel furrows, and Nnw = number of samples under non-wheel furrows.

Assumed null hypothesis, where all means are the same.

F stat = 2.545

$F_{1, 6, 0.90}$ = 3.78

Since F stat < $F_{1, 6, 0.90}$, therefore, hypothesis is not rejected, which implies that data are not enough to be significant at 0.90 confidence level.

3) Significance level for mulched vs non-mulched furrows.

Mulched furrows		Non-mulched furrows	
data	sq error	data	sq error
204.4	4914.01	4986	36353664
226.8	2275.29	14584	12734906
442.7	28291.24	13757	7516371
245.3	852.64	10211	647059.4
209.5	4225.2	9155	3461088
318.4	1927.21	13399	5681549

Mean:	274.5		11015.4
Sum of sq error:	42485.39		66394637

Over all results

Mean:	5644.95
Sum of sq error:	66437123

k = 2, Nm = Nnm = 6

where,

k = number of treatments, Nm = number of samples under mulched furrows, and Nnm = number of samples under non-mulched furrows.

Assumed null hypothesis, where all means are the same.

$$\text{Fstat} = 52.097$$

$$F_{1,\,10,\,0.999} = 21.04$$

Since F stat > $F_{1,\,10,\,0.999}$, therefore, hypothesis is rejected, which implies that the means are not the same, and data are significant at 0.999 confidence level.