SELECTING SPRINKLER PACKAGES WITH TILLAGE PRACTICE INTERACTION

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INTRODUCTION

Center pivot operators have a number of alternatives when selecting sprinkler packages for center pivots. Under the presumption of energy savings, many operators are converting systems from high pressure to some form of low pressure sprinkler. Several factors may determine whether a selection based solely upon energy cost is appropriate. Such factors as the potential for runoff may dictate the specific sprinkler selection to make. Actual energy cost savings will reflect more than the change in operating pressure. A change in water application efficiency or the operating efficiency of the pumping plant could reduce the energy savings actually realized.

Tillage practices for sprinkler irrigation must seek to control both runoff and erosion. Conservation tillage practices for control of erosion are well documented. However, many of these practices do not always result in an inkind reduction in surface runoff. Likewise, tillage practices meant to control runoff do not always result in reduced soil erosion. In some situations, specialized tillage may be necessary to control both runoff and soil erosion. This paper will discuss matching tillage practices reported to provide runoff and erosion protection with appropriate sprinkler packages.

The process of selecting a sprinkler package must consider the needs of the crop, capabilities of the delivery system, the field slope, the soil infiltration characteristics, the regional climatic conditions , and the management scheme of the operator. Therefore field evaluation of the proposed system operation is desirable. Based on the evaluation of the pumping plant, the soil infiltration rate, and field slope conditions, a sprinkler package can be selected which will reduce energy costs while maintaining the water application efficiency.

SOIL INFILTRATION RATE

Soil texture and the soil infiltration rate are two of the most important criteria for selecting a sprinkler package. The soil texture can be used as an indication of how water droplet impact might affect infiltration. von Bernuth and Gilley demonstrated that the potential for runoff and consequently the maximum application amount is very dependent on soil types and sprinkler packages. As water application occurs, the ability of the soil to take in water is altered by water droplet impact. The impact of water droplets on the soil's infiltration rate is not consistent between soil types. And, with each application of water the effect on infiltration could change. Thus, a sprinkler package may not generate runoff during the initial water application, but substantial runoff could be generated during later water application events. A sprinkler package should minimize the amount of runoff that is generated from all irrigation events.

The Soil Conservation Service has evaluated the soil infiltration rates for many soils across the country and the state. Soils with similar water intake characteristics were grouped into specific Intake Families. Each Intake Family has a characteristic infiltration rate curve. Intake Family Curves provide a starting point for evaluating the suitability of a sprinkler package. The soil types present in a field can be determined by consulting the soil survey map. Curves for several Intake Families are presented in Figure 1.

The impact of tillage on the suitability of a sprinkler package was demonstrated quite clearly by Gilley, et al., 1981. Their research included three types of sprinklers and three tillage treatments. Table 1 is a summary of data collected during their research. Note that interaction between a specific sprinkler and the 3 tillage treatments is particularly evident for the high pressure impact and low pressure impact sprinklers. Even more revealing is the general decline in infiltration as the operating pressure of the sprinkler decreases. These data suggest that the interaction between the soil surface condition and the sprinkler type is substantial. Thus the overall tillage program prior to the irrigation season should be geared toward developing a soil surface which minimizes the impact of the sprinkler.

SOIL SURFACE STORAGE

Soil surface storage refers to the volume of water which can be stored on the soil surface before runoff begins. Most of this storage occurs in small depressions which are clearly visible during and after and irrigation event (retention storage). Smaller amounts of storage occurs on a more temporary basis. When the water application ceases, much of this water moves downslope as runoff and leaves the soil surface (detention storage). The amount of detention and retention storage present is determined by field slope and soil surface roughness. Research is under way at Concord, NE to determine how much surface storage is provided by various tillage implements. Increasing the amount of surface storage directly reduces the potential for runoff.

At present soil surface storage is commonly based upon field slope conditions. Recent tillage practices appear to be capable of providing more storage than is predicted by field slope alone. However, the widely excepted accounting of surface storage was provided by Dillon, et al. (1972). Their data are summarized in Table 2.

WATER APPLICATION PATTERN

The rate water is supplied to the soil surface has a direct impact on the potential for surface runoff. That water application rate is determined by the sprinkler radius of throw, the distance from the pivot point, the total system length and the flow rate supplied to the system. The peak application rate normally occurs directly adjacent to the pivot pipeline and at the outside end of the system. The peak application rate is constant regardless of the application amount or travel speed of the system. Typical water patterns for 5 different sprinkler types are presented in Figure 2.

For modelling purposes, elliptical shaped water application patterns have been found to give the most accurate results. The water application patterns in Figure 2 are from the outside end of a system 1340 feet long with a flow rate of 800 gpm. If the flow rate was reduced, the peak application rate would be lower because less water would be applied to the same area. If the system length was reduced, the peak application rate would be greater since the same amount of water would be applied to a smaller area. Finally, if the radius of throw was reduced, the peak application rate would increase because the same amount of water would be applied in a shorter period of time. Thus, the impact of changing from one sprinkler package to another can have a pronounced effect. Attempts should be made to select a sprinkler device with a low water application rate over a high application rate.

PROBLEM IDENTIFICATION

Runoff is a concern associated with sprinkler irrigation systems. Many center pivots are operated on moderate to steep terrain. The movement of water downslope is a natural occurrence if water is applied at rates greater than the soil infiltration rate. Water moving over the soil surface tends to pick up soil and some plant nutrients from the soil surface. The best time to determine if a runoff problem exists is during the later stages of the irrigation season. If the problem is severe, surface drainage channels will be carrying water off the field during rainfall or irrigation events.

For moderate runoff cases, water will move from the location where it falls on the ground to some other location of the field. The soil surface provides an indication that runoff has occurred. Running waters leave small channels or rills often rimmed with intermixed soil and organic matter particles. These channels have downslope outlets similar to the delta areas of a river. Thus the best place to observe moderate runoff problems is at the base of the hill where water would normally enter a surface drainage channel.

Minor runoff problems must be observed in the field during an irrigation event. Minor runoff problems can be observed in areas of extreme field slope or the outside edge of the pivot. For systems with full circle water application patterns, runoff will be most noticeable on the back side of the pivot. While this problem does not generally cause soil erosion, small channels of water are noticeable during the irrigation event. Water moves over very short distances in many cases.

POTENTIAL CAUSES

The development of low and medium pressured sprinkler packages has compounded the potential for runoff. Increases in runoff, due to the irrigation system, occur because of two main factors: 1) system peak application rate; and 2) water droplet impact. As the operating pressure of the system is reduced the peak application rate increases and in general the water droplet size increases. Runoff amounts of 60-65% of the water applied have been recorded from fields irrigated by low pressure sprinklers (Addink, 1975). Runoff amounts of only 22% were recorded for portions of the field irrigated by high pressure sprinklers. Therefore, depending on the situation, altering tillage practices may not be necessary to control a runoff problem. Instead a change in the design of the irrigation system may be required.

The impact energy supplied by water droplets causes a thin crust to be developed on the soil surface. Research conducted in South Dakota indicates that as the impact energy increased, the infiltration rate of the soil decreased (Mohammed, and Kohl, 1986). Their results show that the soil infiltration rate for an unprotected soil surface decreased from 5.3 inches per hour to 1.85 inches per hour after just one hour of water application. Soils protected by a burlap cover experienced no reduction in infiltration rate. Prior to crop canopy development, the soil infiltration rate can be reduced by water droplet impact by over 50%. During the early portion of the growing season, crop residue cover will absorb much of impact of water droplets. Thus, crop residue plays a big role in reducing runoff.

WATER CONSERVATION

The second concern related to tillage is the impact the operation will have on the availability of soil moisture to the plant. In water limiting conditions, every inch of water can be important to harvested yields. Stored soil moisture takes on a different role under irrigated conditions. Since water evaporated from the soil surface can be replaced by irrigation, the limitation to final yield is not as critical. However, with a narrowing profit margin, the cost of applying each additional inch of water must be carefully considered. Costs of additional tillage equipment, horsepower and labor must also be considered. Consequently, under sprinkler irrigated conditions, a severe runoff problem is necessary to justify using tillage to reduce runoff.

Key differences between three different interrow tillage practices will now be discussed as alternative tillage practices for severe runoff problems. Each of these practices has been field tested at two locations as a layby treatment. If weed control is not a concern, some of these practices could be implemented shortly after planting. The main drawback to that approach is that the desired impact on the soil profile would not take place for implements using a subsoil shank.

LAYBY SUBSOILING

Layby subsoiling utilizes a chisel shank operated to a depth of 10 to 14 inches midway between the crop rows. Manufacturer's recommended speed of travel is approximately 5-6 mph. The idea is to partially shatter and uplift the soil profile increasing the infiltration rate and creating a rough soil surface. This practice is most effective when soil conditions are relatively dry and when controlled traffic is practiced. If the operation takes place under moist soil conditions less shattering occurs. Research in Nebraska and South Dakota, has indicated that runoff can be reduced and in some cases increased yields can result from the use of this practice (DeBoer and Beck, 1982 and Gilley, et al., 1981). DeBoer and Beck (1982) reported 70% less runoff from center pivot irrigated plots which were subsoiled compared to those receiving conventional tillage.

Most of the research conducted using this practice has taken place under relatively low field slope conditions (<5%). Preliminary investigations in Nebraska under steeper slopes (>9%) have suggested that under some soil conditions the shank opening can provide a channel for water to flow in. Visual inspections have shown that on occasion water moved down into the shank opening then downslope before returning to the surface some distance away. An other observed drawback to this operation is that the shattering affect of the shank can send the plant into temporary moisture stress. A prolonged hot dry period after the tillage operation, could affect soil moisture and final yields.

BASIN TILLAGE

The basin tillage implement consists of a small paddle or set of disk blades installed behind the rear shanks of a cultivator. The paddle or disk blade drags soil for a preset distance of 3-8 feet before depositing the soil across the row. The soil deposited creates a small dam and the area upslope becomes a small water storage area or basin. Lyle and Bordovsky (1981) reported that runoff from center pivot irrigation on relatively low field slopes was reduced from 10% down to less than 1% of the water applied using basins.

A potential drawback of this tillage is that individual dams can be washed out resulting in an increasing volume of water entering the basin downslope. The worst case would involve failure of all of the basins. The resulting runoff could be similar to the untilled situation and soil erosion loss would be greater. For the research reported below, the implement appeared to have difficulty making basins sufficient to store large amounts of water.

IMPLANTED RESERVOIR

The implanted reservoir is essentially a combination of the basin tillage and subsoiling concepts. Like the subsoiler, the implanted reservoir implement utilizes a chisel shank operated at a depth of 10-14 inches to shatter and uplift the soil profile. Manufacturer's recommended speed of travel is approximately 5-6 mph. Somewhat analagous to the basin tiller, the implanted reservoir implement has a large paddle wheel which creates mini-reservoirs at 2 foot spacings. The main difference between the basin tiller and implanted reservoir implements is that the mini-reservoirs created by the implanted reservoir are below ground level. The benefit of this implement is that it creates a substantial amount of surface storage. Hence, the use of this type of implement would appear to adequately control runoff from sprinkler irrigated fields.

Since moisture stress is also possible with this implement, developers recommend applying 0.5-0.8 inches of water immediately after the tillage operation. The most significant drawback of this implement is that it is the most energy intensive practice of the three. Horsepower requirements range from 20-25 horsepower per row depending on the soil type and the depth of tillage.

RUNOFF CONTROL

The three practices described above were evaluated at the Northeast Center, Concord, NE and the South Central Center, Clay Center, NE. The study took place during the 1987 growing season. Water was supplied to 5' X 36' plots using a continuous application rainfall simulator. The water droplets and application rate were similar to the last span of a center pivot equipped with low pressure spray sprinkler package. The field conditions for each location were:

	Clay Center	Concord
Crop	Sorghum	Corn
Field slope, %	1.0	10.0
Soil type	silt loam	silt loam
Tillage Time	July	June
Speed of travel, mph	5.5	5.5
Depth of shank, in.	12.0	12.0
Application rate, in/hr	4.6	4.6
Replications	4	3

Runoff amounts for Concord and Clay Center are presented in Figures 3 and 4, respectively. At Concord, the conventional tillage practice was a single disk and plant treatment. The curves indicate that the three interrow tillage practices all reduced runoff compared to the conventional treatment. High individual plot variability caused there to be no significant difference in the amount of runoff despite the range of from less than 2% to greater than 36% (1-18 mm) of the water applied. Data in Table 3 summarize some of the water application data for the Concord location. Note that the saturated infiltration rates do not follow the same trend as total runoff. The saturated infiltration rate is greatest for the implanted reservoir treatment. However, the basin treatment has the lowest saturated infiltration rate of any treatment, yet it has the second lowest total runoff amount recorded at Concord. This indicates that increasing the infiltration rate will reduce runoff, but it does not account for all of the runoff control that was provided.

Surface runoff at Clay Center shows that all three interrow tillage treatments provided excellent runoff control. Curves presented in Figure 4 indicate very little difference in total runoff amounts. The conventional treatment at Clay Center was a hiller used to develop furrows for surface irrigation. Approximately 20% runoff was recorded from the hiller treatment. While surface runoff would be expected to be lower under 1% slope, if a channel is supplied for water to flow in, runoff can still be a problem. The data presented in Table 4 indicate that runoff amounts were reduced by the infiltration rates. The saturated infiltration rates were from 1-2.75 in/hour greater at Clay Center than those recorded at Concord. This factor alone would reduce the runoff potential by approximately 50%. Again, the lowest runoff was recorded from the implanted reservoir treatment.

SOIL EROSION LOSS

Soil loss recorded for Concord and Clay Center is presented in Figures 5 and 6, respectively. Significantly greater soil loss was recorded for the subsoil treatment at Concord compared to the other treatments. At the time of the rainfall simulations, the soil surface was loose and granular for all treatments. Upon visual inspection, the opening left by the subsoil shank provided a channel for water to move down slope. Most of the soil loss originated from the side slopes of the channel. These data indicate that producers must be aware that shank openings from a subsoiler or anhydrous applicator will provide excellent water conveyence channels on steep slope areas. These channels may increase soil loss and should be avoided. If 4"-6" deep basins are formed by the basin tiller, it would provide adequate control of soil loss on up to 10% slopes.

Soil loss for the three interrow treatments at Clay Center were very similar to the levels recorded at Concord up to two inches of application depicted in Figure 4. However, as water application continued, soil loss at Clay Center did not increase as rapidily. This fact is indicated by the difference in total soil loss recorded in Tables 3 and 4. This verifies that field slope becomes more of a factor as the application time increases.

The conventional treatment recorded far greater soil loss than did the other treatments. As indicated in Table 4, the soil loss for the conventional treatment was significantly greater than the implanted reservoir treatment. Since the conventional treatment was designed to encourage runoff, it is not suprising that it had the greatest soil loss. No significant differences were noted between the other treatments. These data indicate that while runoff can be a concern on 1% field slopes, many tillage practices will be capable of controlling soil loss effectively.

ADDITIONAL CONSIDERATIONS

This type of runoff control does not come about without cost. The major drawback of the implanted reservoir and subsoiler is that they require about 20-25 horsepower per row. The purchase cost of the subsoiler or implanted reservoir ranges from $5,000-$6,500 for a 5 row unit. Cost for the basin tillage equipment is approximately $300 per row with little extra horsepower requirements. Installation costs must be offset by higher yields, less water application or the need to control runoff from the field due to state and/or federal legislation. All Nebraska evaluations have indicated no yield advantage to using these practices. However, soil moisture samples taken after harvest have indicated that more water is stored in the soil profile at the end of the year. Consequently, the only potential advantage to using these implements appears to be in the water conservation area.

In this part of the country, the implanted reservoirs and basins have remained largely intact if the implement is operated according to the manufacturer's recommendations. Small combines tend to drop into the depressions causing a rough ride. The main problem is with the narrow rear wheels. This problem can be remedied by not placing reservoirs or basins in the rows to be travelled by the combine or the combine could be retrofitted with wider wheels on the rear of the machine.

Years with above normal precipitation in the fall can delay harvest due to wet soil conditions. Generally this condition would be most severe in low lying field areas. If soil moisture is a problem at harvest time the use of these practices may compound the problem.

SUMMARY

A sprinkler package selection should be made after careful consideration of the operating efficiency of the system. Surface runoff and reduced pumping efficiency can effect the cost of irrigation substantially. Under relatively flat conditions several tillage practices are available which can reduce runoff. Under steep slope conditions, fields with low intake rate soil may need to create additional surface storage in order to control runoff.

Interrow tillage practices have been used to provide soil surface storage and increase soil infiltration rate. Clear identification of severe runoff is recommended prior to use of energy intensive alternatives. Careful timing of the tillage practice and controlled traffic will increase the effectiveness of the practice and extend the effective lifetime of the tillage practice.

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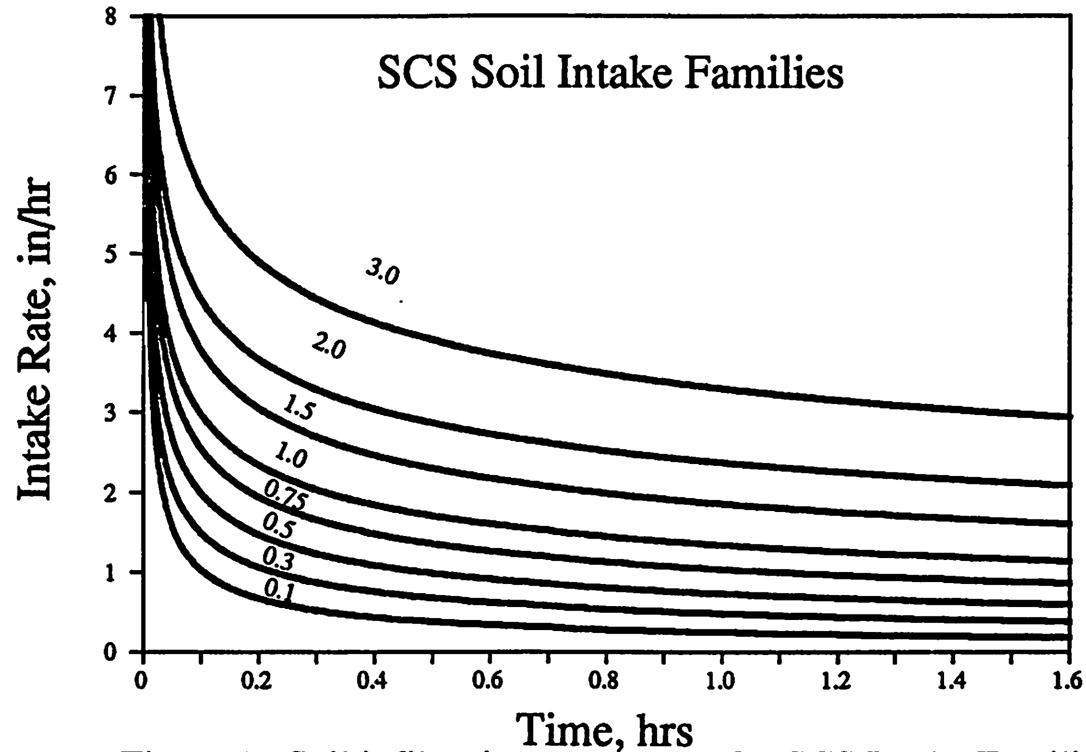

Figure 1. Soil infiltration rate curves for SCS Intake Families between 0.1 and 3.0.

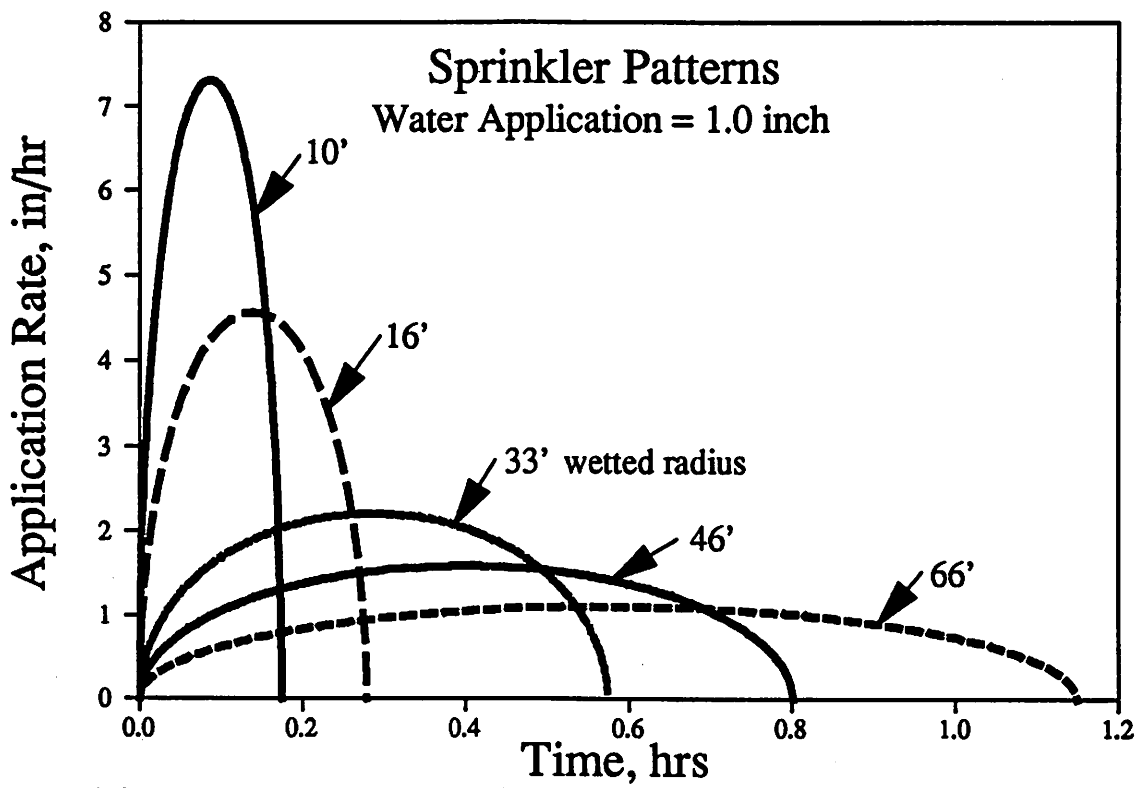

Figure 2. Water application patterns of sprinkler packages with wetted radii of 10', 16', 33', 46' and 66' for a 1 inch water application.

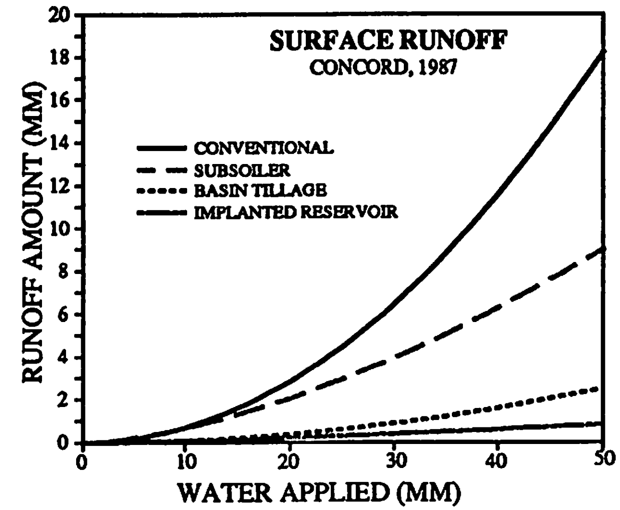

Figure 3. Surface runoff amounts for various interrow tillage practices under 10% field slopes.

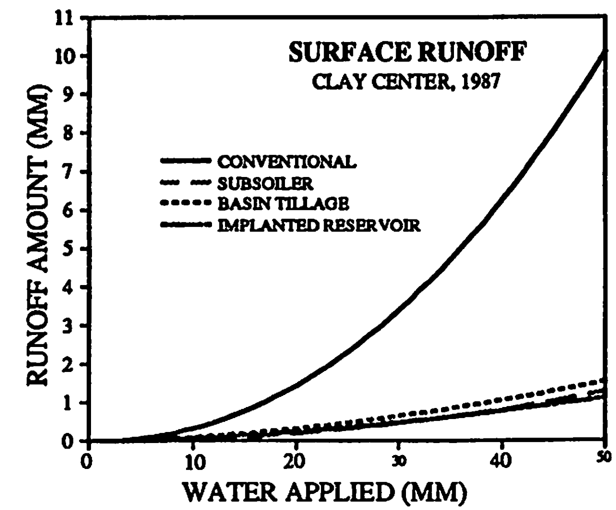

Figure 4. Surface runoff amounts for various interrow tillage practices under 1% field slopes.

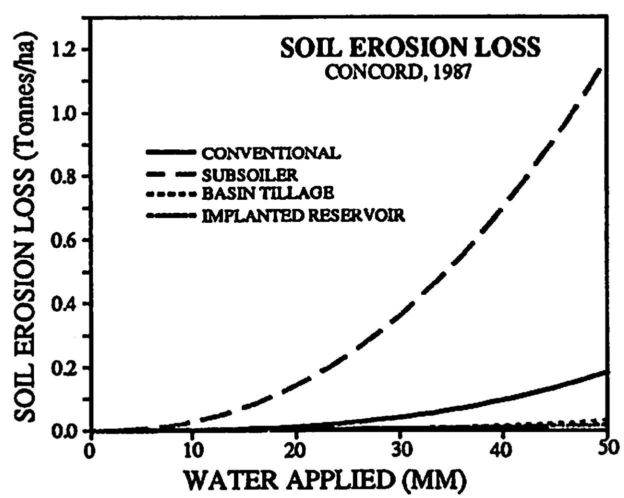

Figure 5. Soil erosion loss recorded for various interrow tillage practices under 10% field slopes.

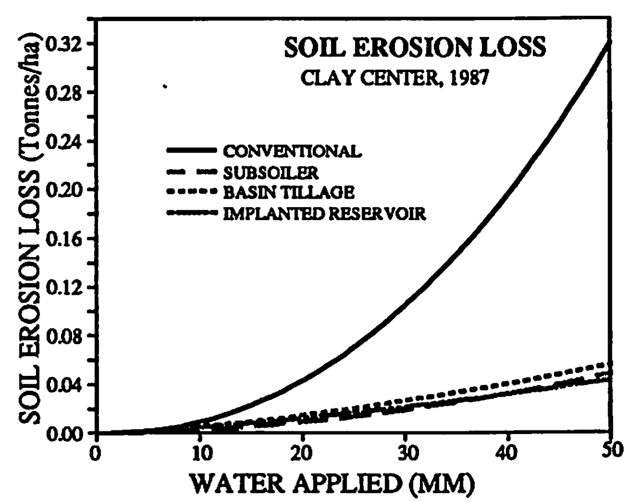

Figure 6. Soil erosion loss recorded for various interrow tillage practices under 1% field slopes.

Table 1. Infiltration rates for a Sharpsburg silty clay loam after one hour of water application by various types of sprinklers (Gilley, et al., 1981).

	Tillage Treatment		
Sprinkler Type	Till Plant	Disk	Chisel
High Pressure Impact	8.3	6.3	15.4
Low Pressure Impact	3.0	2.6	7.5
Low Pressure Spray	4.5	3.0	2.6

Table 2. Soil surface storage estimates based upon field slope.

Field Slope (%)	Soil Surface Storage (inches)
> 5	0.0
3-5	0.1
1-3	0.3
< 1	0.5

taken from Dillon, et al., 1972.

Table 3. Average runoff and erosion losses from interrow tillage practices at Concord, NE under 10% slopes.

Treatment	Water Applied (inches)	Runoff (inches)	Saturated Infiltration Rate (in/hr)	Soil Loss (lb/ac)
Subsoil	4.2	0.6a *	3.12a	4,200a
Implanted Reservoir	4.8	0.3a	3.63a	278b
Basin Tiller	4.4	0.7a	2.77a	654b
Reduced Tillage	4.2	0.6a	3.35a	1,146b

- all data the average of 4 replications
* data in the same column followed by the same letter are not significantly different at the 0.05 level.

Table 4. Average runoff and erosion losses for various interrow tillage treatments at Clay Center, NE under 1% slopes.

Treatment	Water Applied (inches)	Runoff (inches)	Saturated Infiltration Rate (in/hr)	Soil Loss (lb./ac.)
Subsoil	5.4	0.7a *	4.72a	313a
Implanted Reservoir	6.0	0.4a	5.51a	211a
Basin Tiller	4.9	0.7ab	4.76a	368a
Conventional	3.7	1.0b	5.11a	674b

- all data the average of three replications
* data in the same column followed by the same letter are not significantly different at the 0.05 level.