Research Technical Completion Report

LOW ENERGY IRRIGATION FOR THE PACIFIC NORTHWEST

By

T.S. Longley
Assistant Research Professor
Department of Agricultural Engineering

Idaho Water Resources Research Institute
University of Idaho
Moscow, Idaho 83843

March, 1985

The research on which this report is based was financed in part by the United States Department of the Interior as authorized by the Water Research and Development Act of 1978 (P.L. 95-467).

Research Technical Completion Report
B-056-IDA

LOW ENERGY IRRIGATION FOR THE PACIFIC NORTHWEST

by

T.S. Longley
Assistant Research Professor
Department of Agricultural Engineering

Submitted to

U.S. Geological Survey
United States Department of the Interior
Washington, D.C. 20242

Idaho Water Resources Research Institute
University of Idaho
Moscow, Idaho 83843

March, 1985

ACKNOWLEDGEMENTS

Special thanks are in order for the Agricultural Engineering and Development Company of Richland, Washington for their financial support in this project and Chateau Ste Michelle for neutron probe soil moisture measurements.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

Page

LIST OF TABLES

ABSTRACT

Basin tillage (surface storage enhancement by soil roughening) has been shown to be effective in controlling runoff from small grain plots irrigated with application rates up to 115 mm/hr and total applications up to 75 mm with a single line of low pressure spray sprinklers. A grain stand reduction problem encountered with the use of basin tillage was overcome with modification to the hanger arrangement on the double disc openers on the drill. After these modifications, basin tilled treatments of spring wheat produced stands and yields not significantly different from conventional tillage.

Yield, soil moisture, and runoff data were collected from plots comparing reservoir tillage to basin tillage and conventional tillage in replicated plots for spring wheat, corn, and potatoes. Soil moisture comparisons indicated that more moisture was retained for crop use with the reservoir system as opposed to conventional tillage and basin tillage. Runoff measurements also indicated that no runoff occurred using reservoir tillage, and from 10 to 60 percent of the water applied left the field with conventional tillage. Yield increases of 9.5 percent with spring wheat, 31 percent with corn, and 22 percent with potatoes were recorded for the plots treated with reservoir tillage versus those with conventional tillage.

Microclimate measurements were made 15, 27 and 40 m downwind of an operating low pressure sprinkler lateral on a number of different days with varying wind conditions. Marked decreases in vapor pressure deficit (VPD) were consistently observed at the 15 m position relative to conditions 9 m upwind of the system. This reduction in VPD

resulted primarily from a reduction in dry bulb temperature. Windspeed did not appear to affect the magnitude and spatial distribution of these changes. Replicated evapotranspiration (ET) measurements were made on four crop species (alfalfa, dry beans, wheat and potatoes) which showed small but significant reductions in ET at the 15 m position for all species but dry beans, which showed a substantial decrease. For alfalfa, ET was significantly increased 27 and 40 m downwind of the system.

INTRODUCTION

Low energy or reduced pressure irrigation has become popular in the Pacific Northwest because of the potential for substantial cost savings for growers. This interest has been occasioned by large power rate increases brought on by nuclear plant financial failures and shortages of additional low-cost hydropower sites. Two types of low pressure equipment have been developed for use with sprinkler irrigation: reduced pressure impact nozzles and spray sprinklers.

Reduced pressure nozzles for impact sprinkler heads come in two types--one with a deforming rubber orifice that squeezes down on the spray stream as the nozzle pressure is increased, and the other with variations on a round orifice using an elongated perimeter to break up the stream better at lower pressure. These nozzles have been very successful for lowering the minimum operating pressure of an impact head from about 45 psi (200 kpa) to 30 psi (20 kpa).

The spray-type sprinklers are designed to operate at pressures less than 15 psi (100 kpa). These sprinklers operate well down to 10 psi, but reliable flow control (usually by pressure regulation) is difficult at these lower pressures. The biggest problem encountered with the spray-type sprinklers is the reduced radius of throw, which can lead to serious runoff problems on some soils.

Runoff is the biggest single concern in the use of low pressure spray-type sprinklers. Section I of this report deals with the most promising solution to the runoff problem--basin or reservoir tillage. Basin tillage is the process whereby soil is dragged and periodically dumped in the furrow between crop rows to create small dams and basins between the dams and the crop rows, typically 50 to 75 cm (2 to 3 ft) long. Reservoir tillage is a somewhat similar process, except rather than dragging soil, holes are punched below the original soil surface with paddle blades, creating a reservoir that is much more resistant to erosion than the loose soil in basin tillage dams. Droplet spray drift, and its possible effects on crop evapotranspiration downwind from the operating sprinkler, is another concern with low pressure spray-type sprinklers. Section II deals with this problem in detail. Because the droplet size distribution is much smaller than with impact heads, the spray-type sprinklers are much more susceptible to both wind drift and evaporation.

Section II also contains a dissertation study of the mechanism of spray evaporation and wind drift from spray-type sprinklers. A computer model was developed to predict evaporation and wind drift under varying climatic conditions, sprinkler operating heights and sprinkler operating pressures.

PART I

RUNOFF CONTROL UNDER LOW ENERGY IRRIGATION

Introduction

Irrigated crop production has become less profitable in the Pacific Northwest in recent years because power rate increases have exceeded the annual increases in commodity prices. Although irrigation costs are typically not more than 10 to 15 % of the total production budget, in many cases the change in electric power costs will mean the difference between a profit or loss at the end of a crop cycle. In the Pacific Northwest, large acreages of three types of field crops are irrigated: (1) grain or other closely seeded crops, such as peas, lentils, and alfalfa, (2) potatoes, and (3) other row crops such as sugarbeets, corn, and seed crops.

In this region approximately 4.5 million hectares (11 million acres) are irrigated and of that amount, about 1.2 million hectares (3 million acres) are planted to grains or other solid seeded crops (excluding alfalfa and potato). This paper examines the use of basin tillage for runoff control and a reduction in translocation of soil with these two categories of crops.

Objectives

The objectives of this research were to document surface water storage improvement under basin tillage vs conventional tillage for runoff control. The study specifically compares: (1) grain plots treated with basin tillage vs no basin tillable, and (2) determining the effect of field slope on runoff or translocation of soil in grain or potato land treated with basin tillage.

Previous Research

Aarstad and Miller (1973) were the first to use basin tillage under center pivot irrigation and by using small basins between rows, were able to reduce runoff from 40% to 1% of the applied water. Increased yields of sugarbeets and potatoes under center pivots also were reported from the use of basin tillage. Residue incorporation (alfalfa) between rows also yielded similar results. Prior to this experience, basin tillage was used primarily in dryland production during the fallow period and was reported by numerous authors to be ineffective for increasing yields [Danial (1950,Kuska & Matthews (1956), and Luebs (1962)]. Lyle and Bordovsky (1979) tested the advantages of basin tillage as a major component of the Low Energy Precision Application (LEPA) irrigation system. Basin tillage was compared to sprinkler and furrow irrigation in terms of water-use efficiency, energy-use efficiency and the interaction between basin tillage and each irrigation treatment. An economic analysis of each method also was prepared to determine which might prove to be the most feasible for use by irrigators. Apparently, the first work on basin tillage in irrigated grain production was done by Longley (1981) using basin tillage in conjunction with a low energy hybrid irrigation system that combined the most desirable features of row crop trickle irrigation and wheel lines.

No reports are available on measurement of basin volumes (both before and after the irrigation season) or runoff potential on various slopes. Basin direction, with respect to slope and crop being grown, has also apparently not been addressed.

Procedure

The procedure in this series of experiments was to compare the shape, size (capacity) and performance of basins created for the purpose of increasing surface storage in irrigated potatoes and grain. In order to do this, basin-tilled areas were compared with non-basin tilled areas for slopes of 7, 10 and 12%. Because the testing has not been completed on the 12% clopes, only the data for the 7 and 10% slopes are presented here.

To determine the hydraulic limitations of basin tillage for the medium textured silt loam to sandy loam soils encountered in southeastern and southcentral Idaho, numerous evaluations were made with a lateral move/center pivot simulator. Sites were selected for each slope to determine the effect of slope on runoff. All soils were Declo silt loam with steady state intake rates of approximately 6 mm/hr (1/4 inch/hr). The center pivot/lateral move simulator was 40 m (130 ft) long and linearly nozzled to deliver from 0.1 to 0.3 l/sec/m (0.5 to 1.5 gal/min/ft) of lateral. To obtain runoff data, the simulator was started at full speed at the bottom of each slope. The speed was then decreased as the simulator moved up the slope. This resulted in a variable application duration. Visual runoff observations were made for each speed and application rate (nozzle) combination.

When the potato experiments were carried out, all plots were planted on the contour. In order to simulate a potato planted area, hiller shovels were attached to a tool bar on a three point hitch, producing rows approximately 36 inches on center and about 8 inches high from the top of a hill to the bottom of the furrow. The basin tillage machines then were used to create the dikes between the rows.

The furrow diker manufactured in Blackfoot, Idaho by the Milestone Corporation uses a heavy 250 kg/row (550 lb/row) plate wheel with six sharpened paddles affixed perpendicular to the circumference of the plate wheel on the outer edge. The plate wheel is allowed to turn freely as the implement moves across the field and the weight of the plates "punches" the blades into the soil, creating a small depression. The other furrow diker was manufactured by Ansley and Sons in Lockney, Texas and uses a tripping paddle wheel to drag soil for about 1 m (3 to 4 ft), creating a basin, and then dumps the accumulated soil in a dike as the paddle wheel is tripped and advances to the next position.

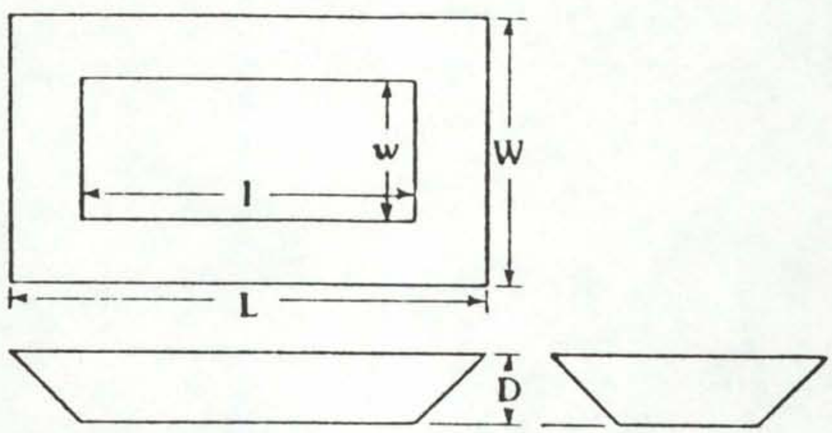
In order to document the change in surface storage capacity that occurred over a season, basin capacities were measured with sand after planting, but before irrigation took place. Those volumes were compared with basin volumes taken just after harvest. The change in volume due to the moisture conditions and freeze-thaw cycles of winter, thus including the measurements, were made on winter wheat. To measure basin capacity, each basin in the test was filled with sand from a graduated container. The sand was filled to the point where if it were water, it would have run out of the basin. This procedure resulted in a reasonably accurate comparison between basins that had just been formed and drilled through and basins that had weathered one irrigation season.

Results

Results of the basin tillage tests for potato plots were excellent for runoff and fair to good for the simulated grain plots. The ability of the basins to weather the irrigation season was not measured in potato plots but was measured in the winter wheat plots.

The mean dimensions of a number of basins and a drawing of basin shape and size is shown in Figure 1. This shape diagram characterizes basins made with the Ansley furrow diker on simulated grain plots. In potatoes, the only difference in the shape created by the Ansley diker was the total depth (indicated by a capital D in the lower left column in the figure). Rather than .08 m (3.1 inches) the basin was approximately .15 m deep (6 inches). The shape of the Milestone basins was similar to the Ansley basins in potatoes, but the Milestone basins were somewhat closer together and not as deep. The Milestone basins were 0.5 m (18 to 20 in) long and .089 to .10 m (3-1/2 to 4 inches) deep and approximately .15 m (6 in) wide at the bottom.

BASIN SHAPE & DIMENSIONS



MEAN DIMENSIONS IN METERS

D	W	L	w	l
0.08	0.41	1.00	0.15	0.63

Figure 1. Basin shape and dimensions

Table 1 compares basin volumes just after planting to those that had weathered a winter and an irrigation season in winter wheat. There was a 27% reduction in basin capacity through the course of the growing season for winter wheat (planting to harvest). Although no measurements were taken, the reduction in basin capacity over the irrigation season in spring wheat is expected to be the same or slightly less. Visual observations in potatoes in the 1980 season indicate that the change in basin capacity was similar in magnitude to that in winter wheat.

Figures 2 and 3 indicate the performance of the two dikers tested in grain or simulated grain on 7 and 10% slopes. The top curve in each figure shows the beginning of runoff for various system speeds and nozzle flow rates without any special tillage. The lower curves compare the performance of the Ansley and Milestone dikers--the area below each curve indicates where runoff is occurring.

Table 1. Basin volume measurements before and after growing season.

After planting but before irrigation		After winter wheat harvest	
m^3	ft^3	m^3	ft^3
0.015	0.53	0.011	0.40
0.013	0.47	0.013	0.47
0.017	0.60	0.013	0.47
0.015	0.53	0.009	0.33
0.017	0.60	0.008	0.270
0.015	0.53		
Means	0.15 m^3	0.11 m^3	

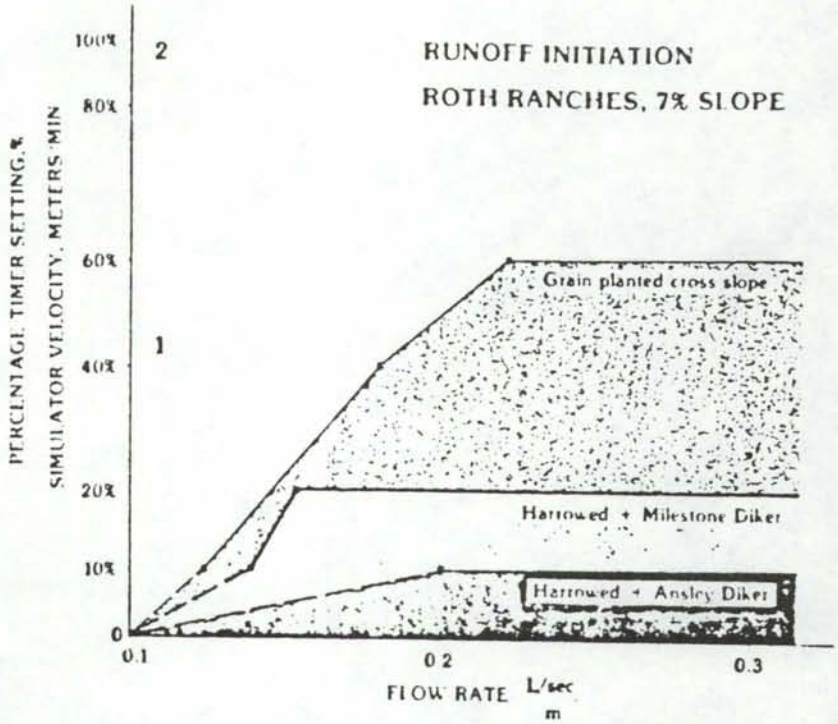


Figure 2. Comparison of runoff from plots treated with different basin tillage equipment on 7% slope.

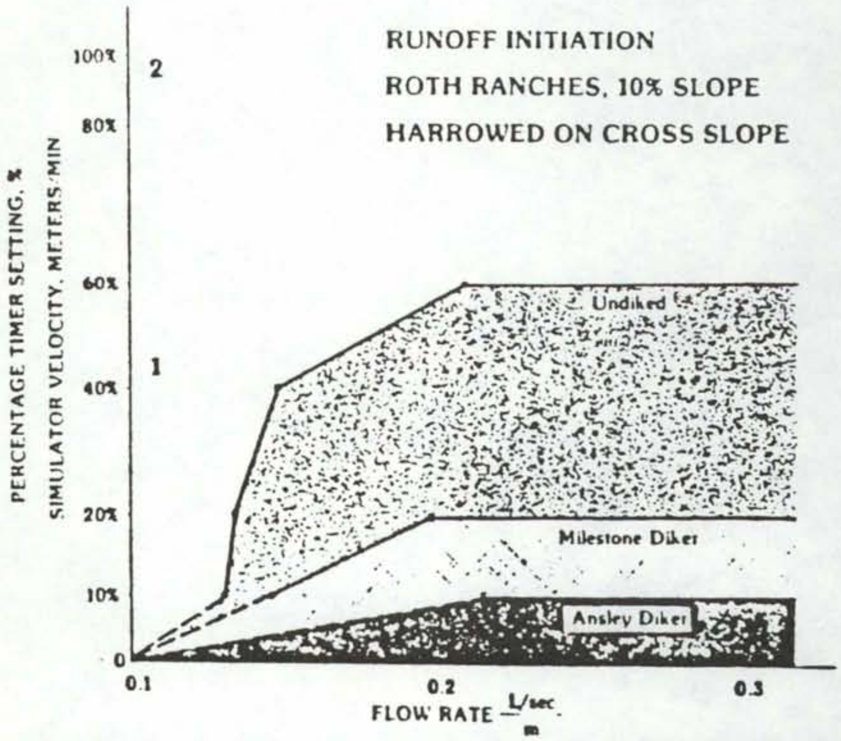


Figure 3. Comparison of runoff from plots treated with different basin tillage equipment on 10% slope.

Figures 4 and 5 show the simulated performance of the Ansley and Milestone dikers in potatoes. Note that no runoff occurred when the Ansley machine was used on the 7% slope (minimum system speed in this case was 10% on the percentage timer, or 0.23 m/min). For a 10 percent timer setting, the total application is 1 mm (3.2 in) and the application rate is 122 mm/hr (4.8 in/hr) at the downstream end of the system, where the flow rate is 0.3 l/sec/m (1.5 gpm/ft). Because of the time limitations on the operation of the simulator, no comparisons were made with potato hills without basin tillage during 1982. It was expected that these check treatment curves would fall somewhere above the check treatments for grain. The Ansley dike forms deeper basins and tends to prevent runoff slightly better than the Milestone. One other consideration, however, is that front end cultivators are required on harvesting equipment to remove the Ansley dikes, whereas none are needed with the Milestone machine.

Conclusions

The overall performance of both basin tillage machines tested for surface storage enhancement and subsequent runoff reduction was encouraging, both in grain and potato plots. More data are needed, however, in potato plots without basin tillage, and grain and potato plots with basin tillage up and down slope instead of on the contour.

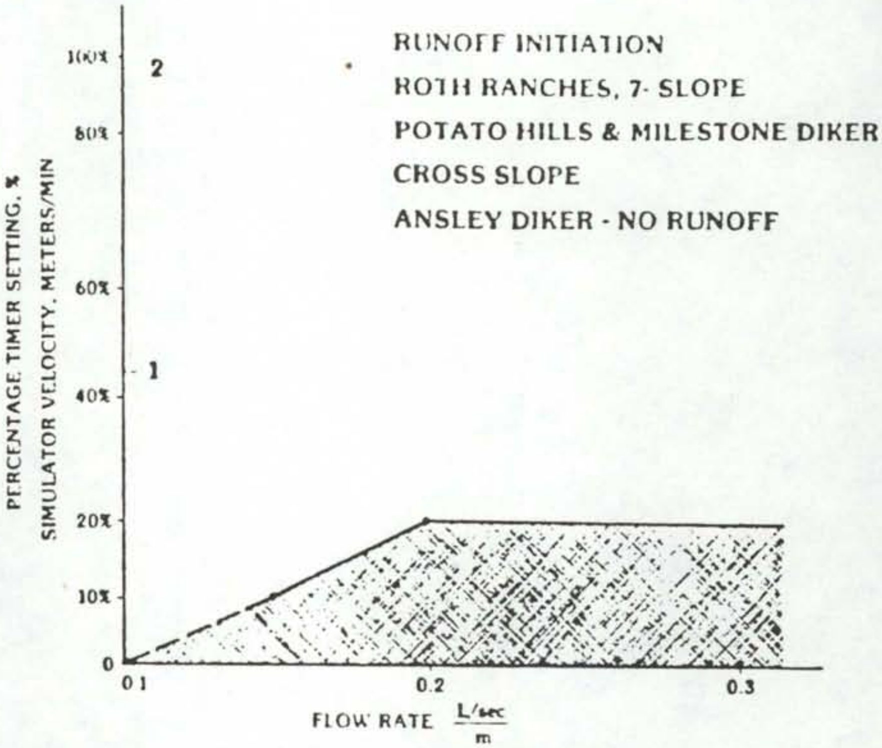


Figure 4. Performance of Ansley and Milestone dikers on 7% slope in potato hills.

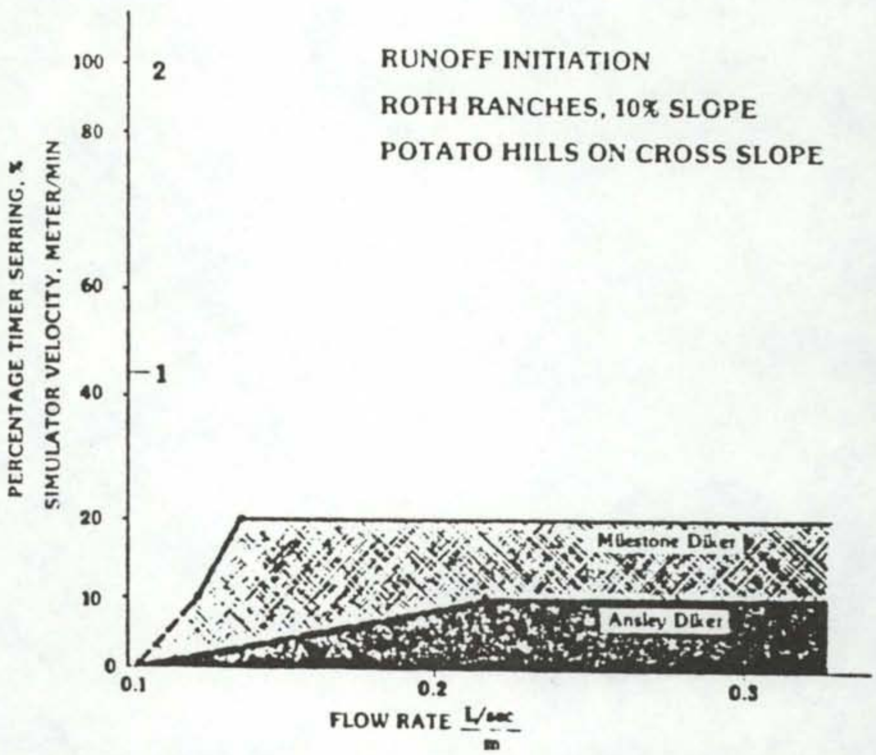


Figure 5. Performance of Ansley and Milestone dikers on 10% slope in potato hills.

BASIN TILLAGE FOR IRRIGATED SMALL GRAIN PRODUCTION

Introduction

Basin tillage is the process of using tillage equipment to roughen or otherwise modify the soil surface by creating small basins for runoff control. The literature documents the effectiveness of basin tillage for runoff control in both irrigated and dryland row crops and indicates substantial yield improvements as a result of the improved application uniformity of water in irrigated crops. Problems have arisen, however, with basin tillage in irrigated small grain production because of the tendency of standard drills to produce uneven stands in rough, basin-tilled soil. Basin tillage also has been tested extensively during the fallow year in the high plains wheat producing states (dryland) with little documented success.

The premise of the basin tillage method is that if water from the irrigation system can be trapped where it falls to the ground and not allowed to move in the field, it can be applied with uniform application at virtually any pressure that the irrigation system will permit. Consequently, there is considerable interest in the development of basin tillage for irrigated small grain production. This paper describes work conducted at the University of Idaho Research & Extension Center at Aberdeen, Idaho relating to adaptation of basin tillage to irrigated small grain production and the consequences of adoption of this practice on a commercial scale.

Objectives

The objectives of this project were to adapt basin tillage to irrigated small grain production by: (1) overcoming the stand reduction problem associated with basin tillage and conventional drills and (2) establishing the hydraulic limitations of basin tillage in terms of precipitation (irrigation) rate, duration, and soil slope.

The roughening of the soil surface associated with basin tillage tends to cause a substantial reduction in germination because seed planted in the bottom of the basins tends to be placed too shallow, and seed planted in the excavated soil is too deep. Drill modifications appeared to be the best method of overcoming these problems.

Previous Research

Aarstad and Miller (1973) were the first to use basin tillage under center-pivot irrigation by using small basins between rows. They were able to reduce runoff from 40% to 1% of the applied water, and reported that basin tillage increased yields of sugarbeets and potatoes under center pivots. Prior to this work, basin tillage was used primarily in dryland wheat production in the high plains for water storage during the fallow period, and was reported by numerous authors to be ineffective for increasing yields [Danial (1950), Kuska & Mathews (1956), and Luebs (1962)]. Lyle and Dixon (1977) developed and tested two types of furrow dikers for rainfall retention on the Texas high plains, one using a raising shovel and another a tripping shovel design. He found the tripping shovel device was preferable in most applications. Lyle and Bordovsky (1979) also tested basin tillage as a major component of the Low Energy Precision Application (LEPA) irrigation system which was compared to sprinkler and furrow irrigation in terms of water-use efficiency, energy-use efficiency, and the interaction between basin tillage and each irrigation treatment. An economic analysis of each method identified basin tillage as a cost-effective component of the LEPA and sprinkler systems.

The first work on basin tillage in irrigated small grain production was reported by Longley (1981) using basin tillage in conjunction with a low energy hybrid irrigation system that combined the most desirable features of row crop trickle irrigation and wheel lines. The stand reduction problem was first documented in this study and reported to be approximately 10%. The fact that there was a 10% reduction in stand was not particularly detrimental, but the erratic spacing of the stand was believed to reduce yields (visual observation). It then was decided to begin testing various drill modifications in an attempt to overcome this yield reduction.

Procedures

To document the problems associated with basin tillage in irrigated small grain production, an experiment was started in 1981 with spring wheat to determine: (1) the effect of the basin direction with respect to planting direction, (2) the effect of seeding rates, and (3) whether basin tillage would be less detrimental prior to or after seeding had taken place. Plots were arranged in a randomized complete block with ten treatments and six replications of soft white spring wheat (cv. Fieldwin). Seeding rates were 79 and 112 kg/ha (70 and 100 lb/acre). These rates were used with all direction and timing combinations, wherein the basins were made in the same direction or perpendicular to the drill travel; seeding was done before or after basin tillage was completed. These replicated treatments also included two checks planted without basin tillage to document the standard yield at both seeding rates (Table 1). An end wheel drill with drag chains trailing each double disk was used because of the stand reduction noticed in earlier work with a conventional drill with gang press wheels. This reduction in stand with the conventional drill was carefully documented again in 1983.

A similar yield experiment was conducted in 1982 with the same design but only four treatments and seeding rates of 79 and 157 kg/ha (70 and 140 lb/acre). The variety Dirkwin was used in the 1982 trials and all plots were planted in the same direction as the basin tillage, after the basins were established. Two replicated check treatments were again planted without basin tillage (one at each seeding rate). A stand reduction and poor stand uniformity were noticed in both spring wheat trials, so drill modifications were made to overcome the problem. A John Deere[1] 8000 series end wheel drill was obtained which had individually sprung press wheels and depth bands to ensure uniform planting depth. After some initial experimentation, the spring loading arrangement on the hangers for each individual double disk opener was modified to operate with higher down force in the bottom of the basin to seed more uniformly through the uneven soil conditions produced by the basins.

Replicated stand counts were made in 1982 and 1983 to determine if the drill modifications were successful in overcoming the non-uniformity of stand difficulty with the conventional drill. Replicated spring wheat yield data were again obtained in 1983, using

---

1. The use of trade names does not constitute endorsement of manufacturer's products by the author or the University of Idaho. Trade names are used to identify style and design of equipment.

an experimental design similar to the previous yield experiments, except the modified drill was used to seed all basin tilled plots.

To determine the hydraulic limitations of basin tillage (susceptibility to runoff) for the medium textured silt loam soils encountered in southeastern and southcentral Idaho, numerous evaluations were made with a lateral move/center pivot simulator. Sites were selected with slopes of 7, 10 and 12% to determine the effect of field slope on runoff. All soils were Declo silt loam with steady state intake rates of approximately 6 mm/hr (1/4 inch/hr). The center pivot or lateral move simulator was 40 m (130 ft) long and nozzled with uniformly increasing application rates to deliver from 0.1 to 0.3 1/sec/m (0.5 to 1.5 gal/min/ft) along the length of the lateral. To obtain runoff data, the simulator was started at full speed (2 m/min) at the bottom of each slope. The system speed was then decreased as the simulator moved up slope to vary the application duration. To obtain these reduced speeds, the percentage timer was set at 60%, 40%, 20%, and finally 10%. These settings corresponded to velocities of 1.30, 0.93, 0.48, and 0.22 m/min respectively. The system speed was changed every 10 m as the machine advanced up the slope. Visual runoff observations were then made for each speed and application rate (nozzle) combination.

Three tillage treatments were compared in these experiments. The first was conventional clean tillage with seeding from a press wheel drill. The second was a hole punching tyupe machine manufactured by Milestone Inc., which uses a heavy plate wheel (250 kg/row) with up to six sharp-edged paddles affixed perpendicular to the outer edge of the plate wheel. The plate wheel is allowed to turn freely as the implement moves across the field and the weight of the plates "punches" the blades into the soil, creating a small depression. The third treatment was a machine manufactured by Ansley which uses a tripping paddle wheel to drag soil for about 1 m (3 to 4 ft), creating a basin, and then dumps the accumulated soil in a dike as the paddle wheel is tripped and advances to the next position.

Results and Discussion

All basin tillage treatments, with the exception of basin tillage after parallel seeding, tended to reduce yields in the 1981 spring wheat trial (Table 2). The non-uniform stands caused by the basin tillage treatments induced sufficient variability in plot yields to partially obscure the treatment effects. In the 1982 spring wheat trials, higher seeding rates and basin tillage both tended to reduce yield (Table 3), although the differences were not significant. The results of the stand count experiment comparing basin to conventional tillage with a conventional drill, showed a 22% stand reduction in the basin tilled plots (Table 4).

Drill modifications were made to overcome the non-uniform stand in the basins. Downward force on the double disks was measured at 98 Newtons (22 lb) when 13 cm deep at the lowest point in the bottom of the basins, and 258 Newtons (58 lb) at the normal planting depth of 5 cm. A moment arm calculation was then made on the spring hanger arrangement and, as a result, several changes were made: (1) the spring hangers (A & B) were lengthened and (2) the attachment point of the spring was moved forward on the double disk hanger (from C to D), as indicated in Figure 6. As a result of these modifications, forces on the double disks were 307 Newtons (69 lb) at the normal planting depth, and

Table 2. Effects of basin tillage on spring wheat yields (kg/ha), 1981.2/

Treatment	Seeding Rate, kg/ha 79	113
Basin tillage before seeding:		
Parallel seeding	4480 a	4170 ab
Perpendicular seeding	3710 b	4080 ab
Basin tillage after seeding:		
Parallel seeding	4200 ab	4480 a
Perpendicular seeding	4280 ab	4180 ab
Conventional tillage	4810 a	4480 a

2/ Treatments with the same letter are not significantly different ($\alpha = 0.05$) using Duncan's MRT.

Table 3. Effects of basin tillage on spring wheat yields (kg/ha), 1981.2/

Seeding rate		Yield kg/ha	bu/ac
Ansley Diker	154 kg/ha (140 lb/acre)	6288	93.5 a
Ansley Diker	79 kg/ha (70 lb/acre)	6981	103.8 a
Conventional tillage	154 kg/ha (140 lb/acre)	6550	97.4 a
Conventional tillage	79 kg/ha (70 lb/acre)	7310	108.7 a

2/ Treatments with the same letter are not significantly different ($\alpha = 0.05$) using Duncan's MRT.

196 Newtons (44 lb) at the bottom of the basins. Stand count and yield comparisons for the modified drill are shown in Table 5. Neither the stem counts nor the yields were significantly different, indicating that the drill modifications were successful.

The results of the hydraulics tests on the 7 and 10% slopes, when tillage and planting were done on the contour, are shown in Figure 7. The area under each curve indicates the combinations of system speed and flow rate that produce runoff in the plot areas. For purposes of comparing tillage treatments, curves representing tillage treatments with less area underneath the curve indicate better runoff control. To illustrate one such combination, when the lateral is moving at

Table 4. Effect of basin tillage on spring wheat stand counts using conventional drill, 1983.[2/]

	Stem counts/1.7 m row Means (8 reps)
Basin tilled	96.6 a
Conventional tillage	125.0 b

Table 5. Effects of basin tillage on spring wheat stand and yield using modified end wheel drill (1983).[2/]

	Stem counts/1.7 m row Means (8 reps)	Yield kg/ha
Basin tilled	105.9 a	4330 a
Conventional tillage	100.9 a	4520 a

2/ Treatments with the same letter are not significantly different ($\alpha = 0.05$) using Duncan's MRT.

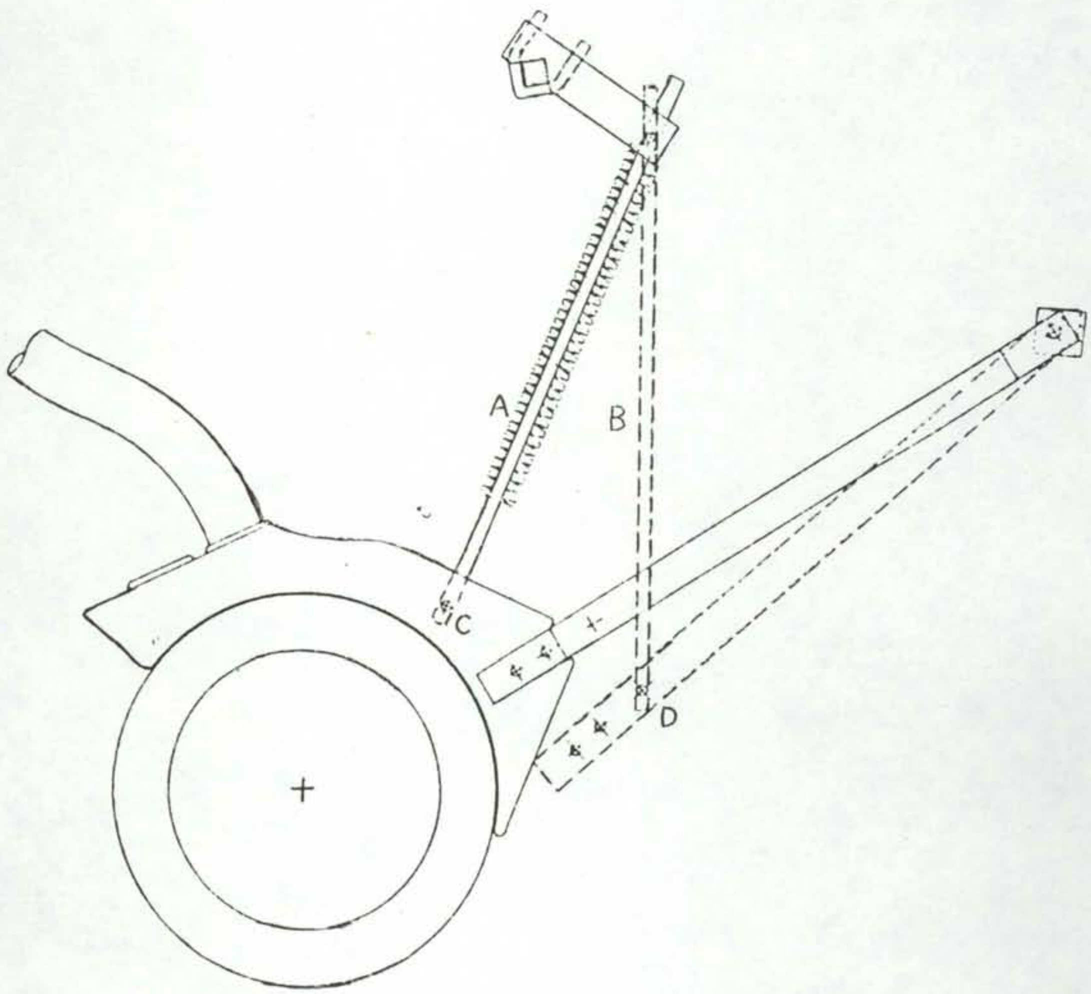


Figure 6. Double disc and hanger. Dotted lines indicate modified position of hanger as drill travels through basins. Note repositioning of hanger attachment point and lenthening of spring hanger rod.

RUNOFF INITIATION FOR TILLAGE AND PLANTING
UP AND DOWN SLOPE

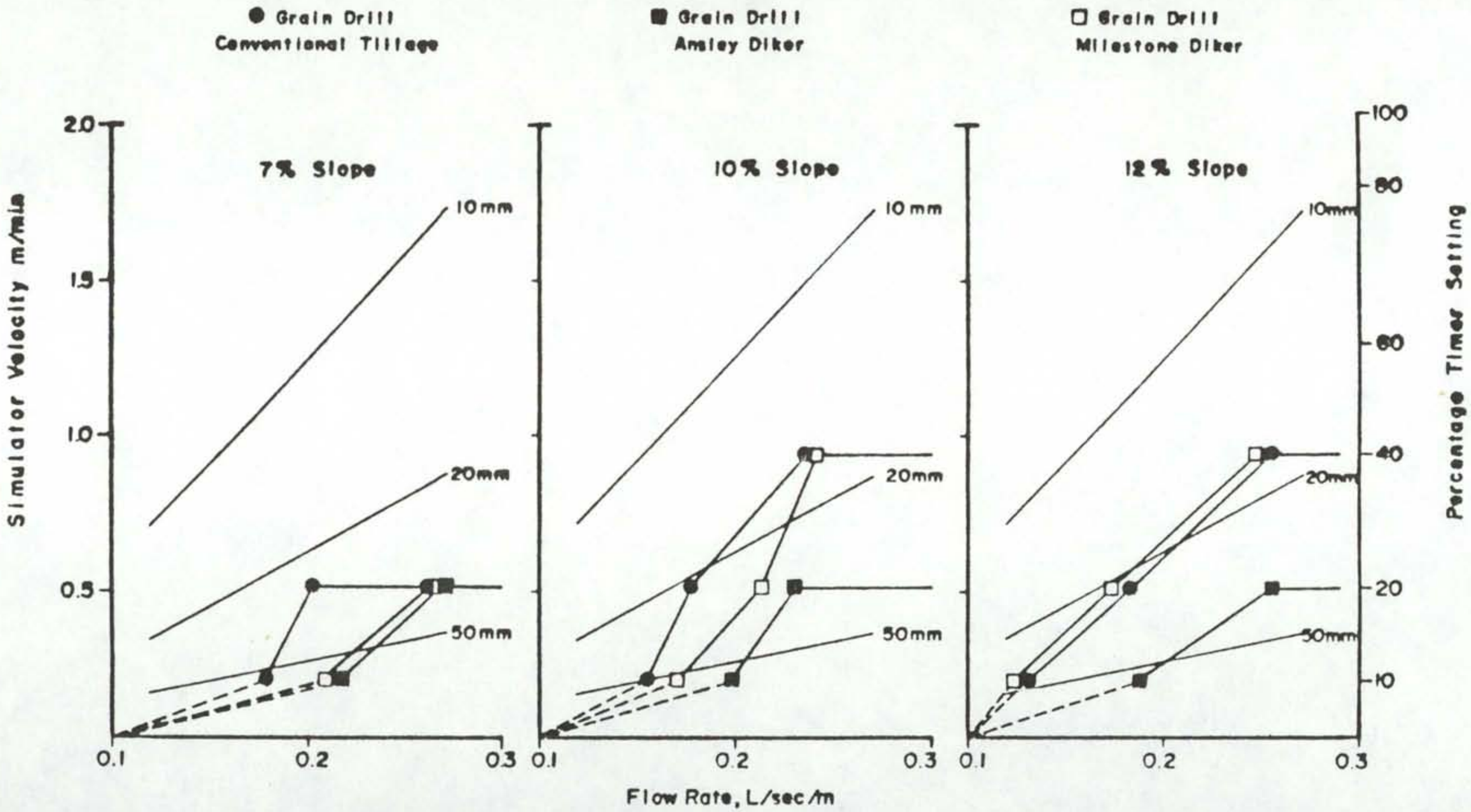


Fig. 7. Results of runoff tests for grain planted on slope contour.

22 cm/min (10% on the percentage timer) near the end where the flow rate is 0.3 L/sec/m (1.5 gpm/ft), water is being applied at 122 mm/hr (4.8 in/hr), and the total application is 81 mm (3.2 in). The soil-dragging type machine (Ansley) performed better on both slopes than the hole punching type machine manufactured by Milestone, which was designed specifically for row crop operations (potatoes).

Figure 8 shows a similar comparison for 7,10, and 12% slopes where tillage and planting took place straight up and down the slope. On the 7% slope, the Ansley and Milestone machines performed similarly, reducing runoff only slightly. On the 10 and 12% slopes, the Ansley machine controlled runoff better than conventional tillage or the Milestone machine, which produced similar results.

Conclusions

Two main conclusions are apparent from the results of this study:

1) Spring hanger modifications to an end wheel type drill were successful in overcoming the small grain stand reduction problem encountered with conventional drills with gang type press wheels. These modifications are relatively inexpensive, but end wheel drills are not popular with growers with large acreages.

2) The soil dragging type machine was most successful in controlling runoff in irrigated small grain plots on slopes up to 12%. Total water applications could be approximately doubled (from 20 mm to 40 mm) before runoff began using this machine as compared with conventional tillage.

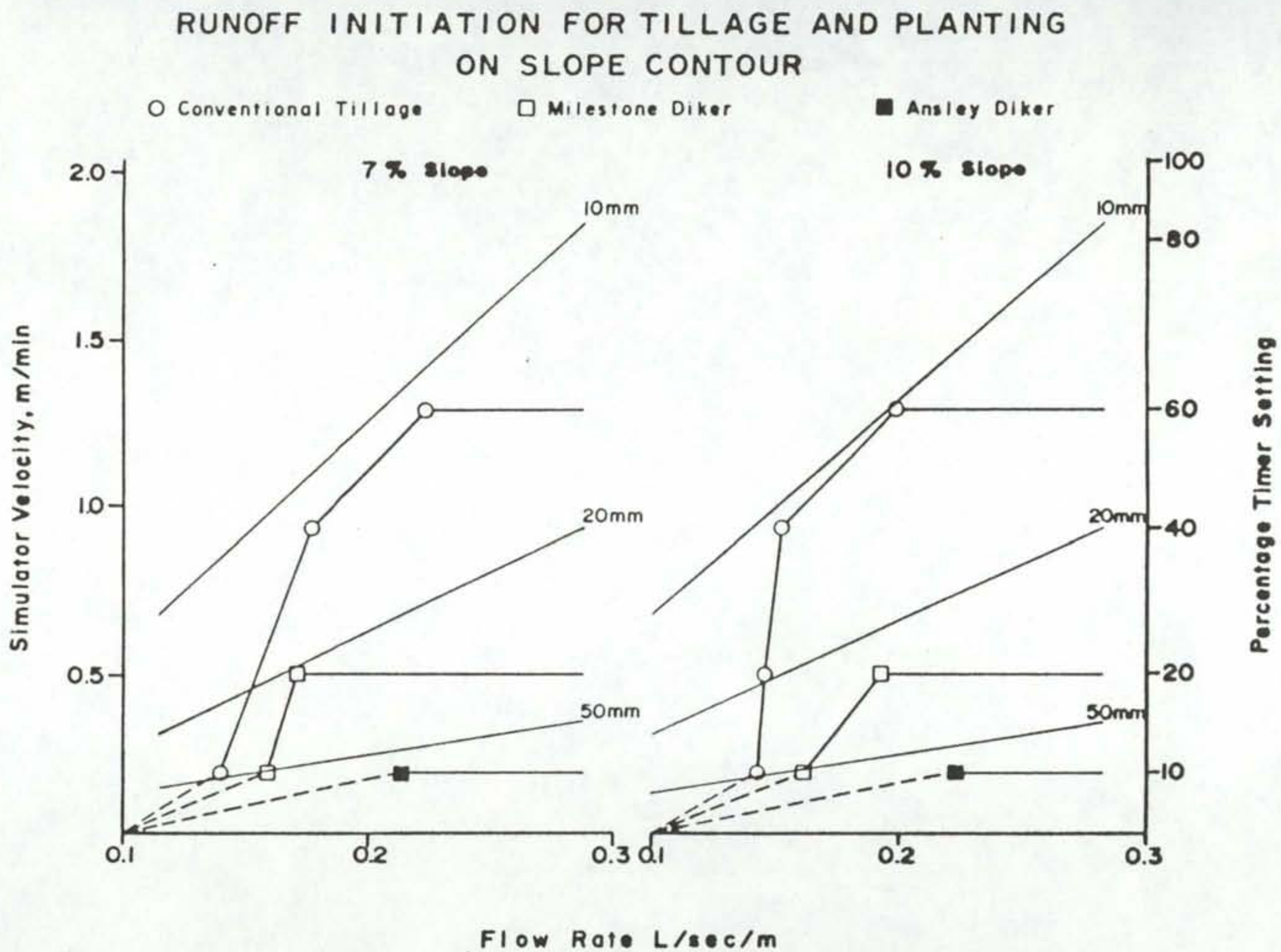


Fig. 8. Results of runoff tests for grain planted up and down slope.

RESERVOIR TILLAGE FOR CENTER PIVOT IRRIGATION

Introduction/Objectives

Reservoir tillage is the process by which small holes or depressions are punched in the soil (usually between crop rows in the furrow) to prevent runoff of water from irrigation or rainfall. This is in contrast to basin tillage in which soil is dragged and periodically dumped in the furrow, creating basins between the small dams. The advantage of the reservoir tillage system over basin tillage is that most of the surface storage created in the reservoir tillage process is below the original ground surface, resulting in less erosion than with basin tillage where the dams are composed of loose soil.

The objectives of this study were to: 1) Compare reservoir tillage with basin tillage and conventional tillage in replicated plots of small grain, corn, and potatoes under center pivot irrigation in commercial production; 2) Document the disposition of water applied with a center pivot irrigation system on tillage plots with measurement and comparison of soil moisture and runoff for each plot; 3) Document the stand reduction caused by reservoir tillage in small grains, and to determine whether seeding after reservoir farming could overcome this stand reduction.

Literature Review

Basin tillage was tried several decades ago in the high plains for moisture conservation during fallow years in dryland wheat production, but was found to be ineffective [Danial 195), Kuska and Mathews (1956), and Luebs (1962)]. Lyle and Dixon (1977) and Lyle and Bordovsky (1979) developed and tested two types of furrow dikers (basin tillage machines): one using a raising shovel and another a tripping shovel design, and found them very successful for rainfall retention on the Texas high plains.

Aarstead and Miller (1973) were the first to use basin tillage under center pivot irrigation, and were able to reduce runoff from 40 percent to one percent of the applied water. They reported that basin tillage increased yields of sugarbeets and potatoes.

The first work on basin tillage in irrigated small grain production was reported by Longley (1981) using basin tillage in conjunction with a low energy hybrid irrigation system that combined the best features of row crop trickle irrigation and wheel lines. A stand reduction was first documented in this study and reported to be about 10 percent. Longley (1984) also reported replicated stand and yield reductions associated with basin tillage in replicated plots but solved this problem using a modification to the drill disc opener spring and hanger system.

Procedures

I. Row Crops

Corn and potato plots were planted in the outer two spans of a commercial center pivot irrigation system. The corn plots were located at Chateau Ste Michelle on sandy soil (circle 106) with an 8.5 percent slope and loamy sand (circle 420) with a 10 percent slope. The existing seeding was used for all plots (planted in the first week of May) and planting was straight up and down the slopes. The fertility program included replant applications of 157 kg N, 78 kg P, 75 kg K, 45 kg S, 5.6 kg Zn and 1.1 kg Boron per hectare. An additional 180 kg N per hectare was injected through the irrigation system throughout the season. A preplant application of 2.7 kg a.i./ha of Atrazine was used for weed control. Tillage treatments (all at layby time June 1) included reservoir tillage with the Dammer Diker (manufactured by Agricultural Engineering and Development Co., Richland, Washington); reservoir tillage with the Water-Saver (manufactured by the Milestone Corp., Blackfoot, Idaho) at lay-by time, and a check with no tillage. Both sets of plots had four replications of each tillage treatment in a randomized complete block design.

Soil moisture was monitored throughout the season in circle 106 using a neutron probe to a depth of 90 cm in 30 cm increments. Replicated spot checks also were made in circle 420 with the gravimetric method to document soil moisture differences at various times during the growing season.

Runoff from single rows in each plot was measured periodically with fiberglass trapezoidal furrow flumes to obtain a runoff hydrograph. From four to eight flumes were operated at the same time as the center pivot lateral passed over the plots. Flow measurements were made at one to two minute intervals during this time.

Yield measurements were made by harvesting the corn from 3.6 m of row on August 28 in circle 106 and September 25 and October 29th in circle 420. Each plot received the standard irrigation scheduling program used on the commercial portion of each circle. Irrigation amounts for an individual irrigation were kept relatively constant at 5.6 mm/revolution in circle 106 and 7.1 mm/revolution in circle 420.

The procedures used in the potato plots at the K2H farm were essentially the same as those used on the corn plots, with the exception that a basin tillage treatment was added with a soil dragging type machine (manufactured by Ansley and Sons, Lockney, Texas). The soil at the K2H farm was sandy loam with a slope of seven percent and irrigations were normally 9.6 to 10.9 mm/revolution. The fertility program included applications of 140 kg N, 250 kg P_2O_5, and 336 kg k_2O per hectare with 308 kg/ha N applied later in the season through the irrigation system.

Yields were measured by digging 2.7 m of row from each plot and weighing all tubers over two inches in diameter. Statistical analysis of the early yields on the potato plots was not possible because two of the replications were washed out early in the season by an irrigation system malfunction. A later harvest was done with all four replications on September 24, 1984, however. Plots were planted in a randomized complete block design with four replications of each tillage treatment.

Small Grains

A spring wheat trial similar to the row crop experiments described above was planted at the Childs ranch near Arlington, Oregon. The soil was a silt loam with a slope of 1.5 percent. Treatments were: 1) conventional tillage, 2) reservoir tillage alone after regular seeding, and 3) reservoir tillage after regular seeding with an after-seeding at the rate of approximately 45 kg/ha in the areas disturbed by the tillage. These plots were also planted in a randomized complete block design with four replications of each tillage treatment.

The after-seeding was accomplished with a unique system developed by the grower, Mr. David Childs. A drill box was mounted on the frame of the Dammer Diker, from which PVC tubes directed the seed to the disturbed area behind each "spider" or hole punching wheel on the machine. This seed falling onto the soil surface behind the tillage machine was germinated using several light water applications with the center pivot. Similar after-seeding has been done at other locations using aerial applications, but at considerably higher cost.

In order to determine the best after-seeding rate using reservoir tillage, another spring wheat experiment was conducted at the University of Idaho Research and Extension Center-Aberdeen (RECAB). The treatments in this experiment included reservoir tillage with the Water Saver, both with and without the ripping shank normally mounted in front of the tillage wheel. Other reservoir tillage treatments included the Dammer Diker without after-seeding and the Dammer Diker with 11, 22 and 45 kg/ha of after-seeding in the disturbed area, as well as a check with conventional tillage.

This experiment was designed specifically to test the effects of reservoir tillage on the stand of spring wheat. The experimental design was a randomized complete block with eight replications and irrigation provided with a solid set hand line system.

Results

I. Row Crops

The soil moisture differences measured with the neutron probe in the corn in circle 106 at Chateau Ste Michelle are shown in Figure 9. From these curves, it is evident that soil moisture levels were maintained higher in all 90 cm of the profile using the Dammer Diker than with the Milestone machine or the check. The reason for this is probably the larger reservoir created with the Dammer Diker. Because of the positive depth control with the tool jack system, it is possible to punch much deeper depressions in the soil using the Dammer Diker

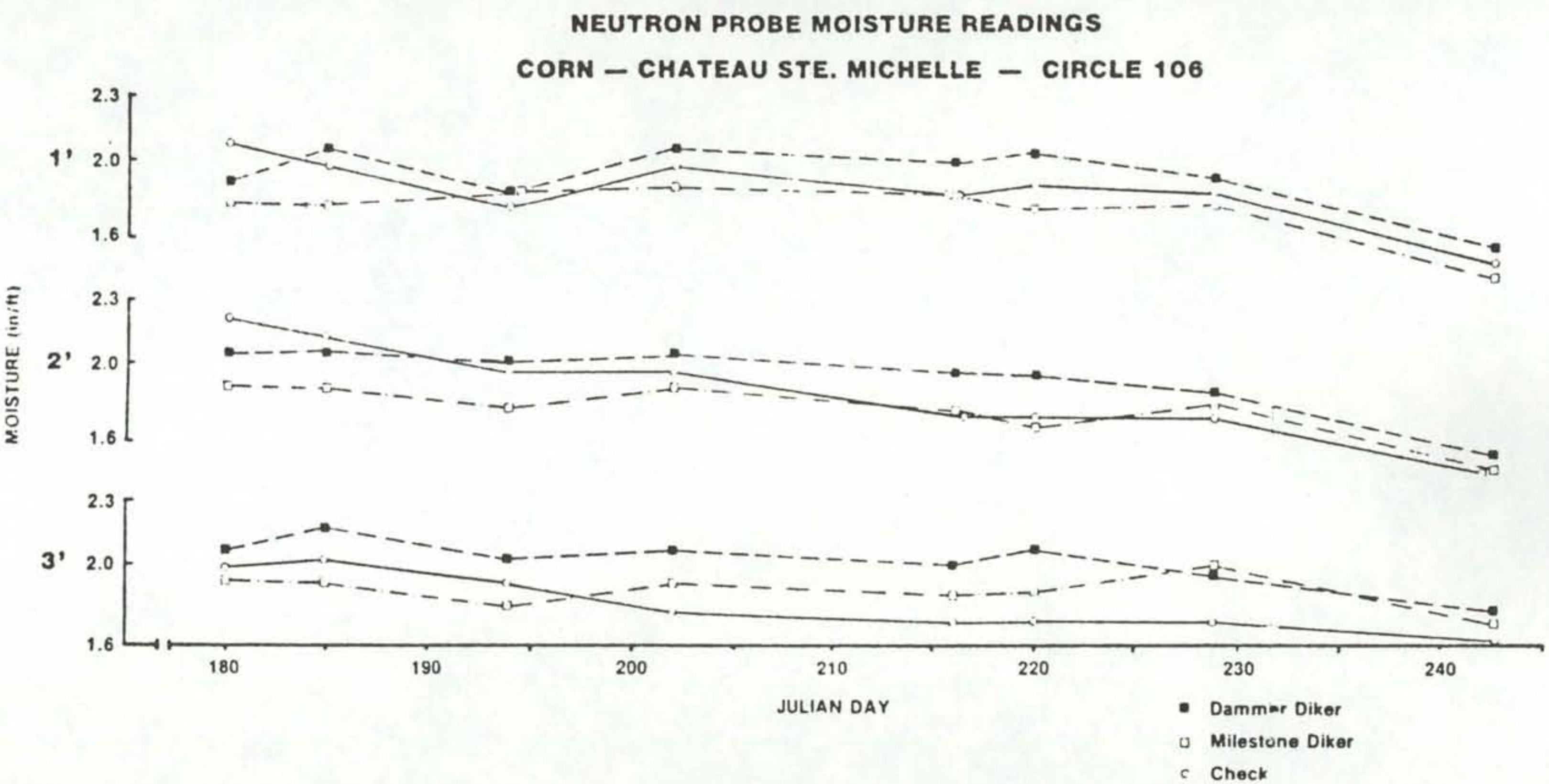


Fig. 9. Sort moisture levels for various tillage treatments in corn (circle 106 Chateau Ste. Michelle).

than is possible with the machine manufactured by Milestone, which uses only the weight of the wheel to force the implement into the ground. This trend also is shown in the soil moisture samples taken on August 7 and August 29, 1984 in the corn plots in circle 420 (Figure 10).

The runoff hydrographs obtained from the check tillage treatments for the corn circles 106 and 420 at Ste Michelle on June 20, 1984 are shown in Figures 11 and 12, respectively. On this date, no runoff was measured in either reservoir tillage treatment, but up to 30 percent of the applied water left the field as runoff in the wheel rows in the check treatment. The same trend was apparent in the runoff hydrographs obtained on July 18, 1984, but wheel tracks no longer were discernible and thus were not labelled in Figures 13 and 14. The runoff, however had increased substantially--up to 60 percent of the applied water in the check treatments. At this time in the growing season runoff still was not occurring in either reservoir tillage treatment.

The yield comparisons for the early harvest taken on August 29, 1984 in circle 106 are presented in Table 6. In this case, the Dammer Diker produced a 31 percent yield increase over the check tillage treatment, which was significant at α=0.01 using the LSD comparison. From these yield data, it is obvious that water retention in the furrow on steep slopes translates into a substantial yield increase. The yields from circle 420 are shown in Table 7. Although not statistically different, there is a trend for a yield increase with both reservoir tillage treatments.

The gravimetric soil moisture comparisons taken on August 7, 1984 in the potato plots at the K2H farm are shown in Figure 15. All of the tillage treatments tested showed an increase in soil moisture in both

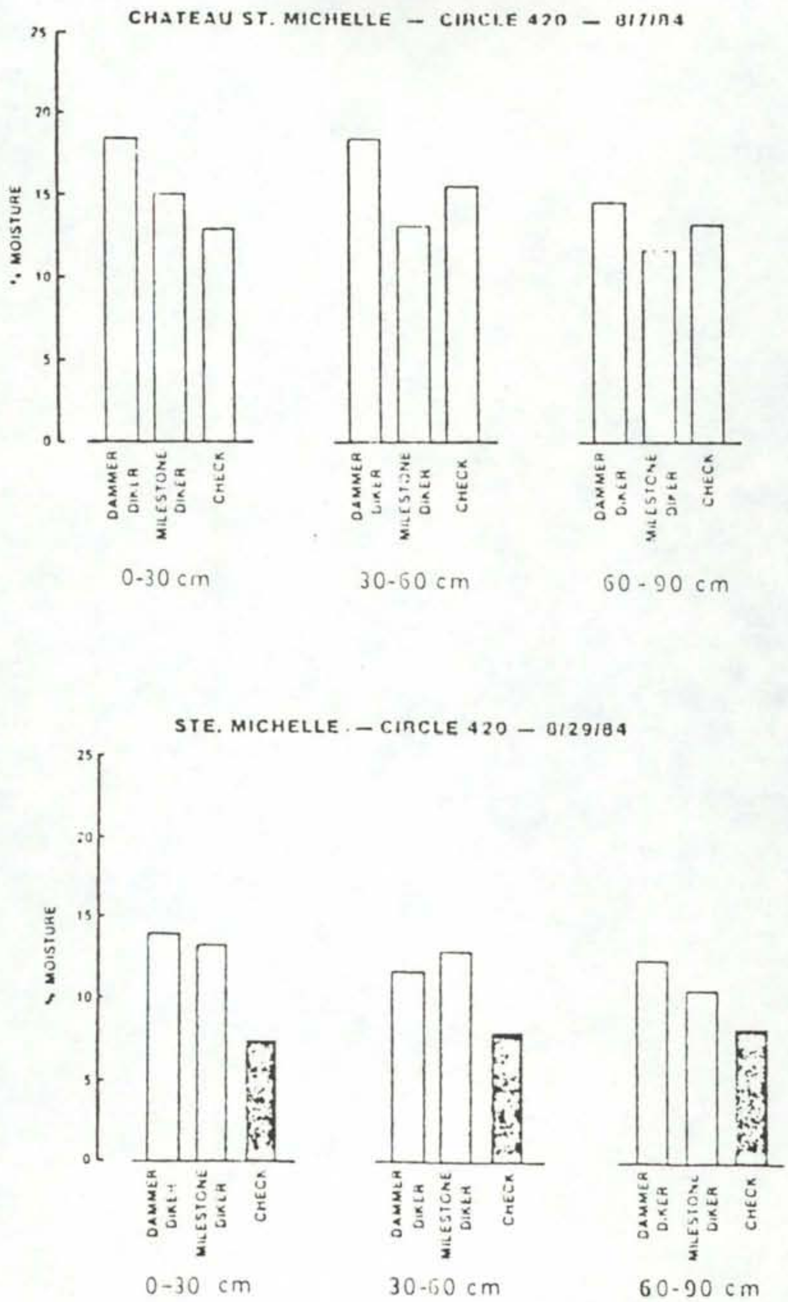


Figure 10. Soil moisture comparisons for various tillage treatments in corn (circle 420, Chateau Ste. Michelle).

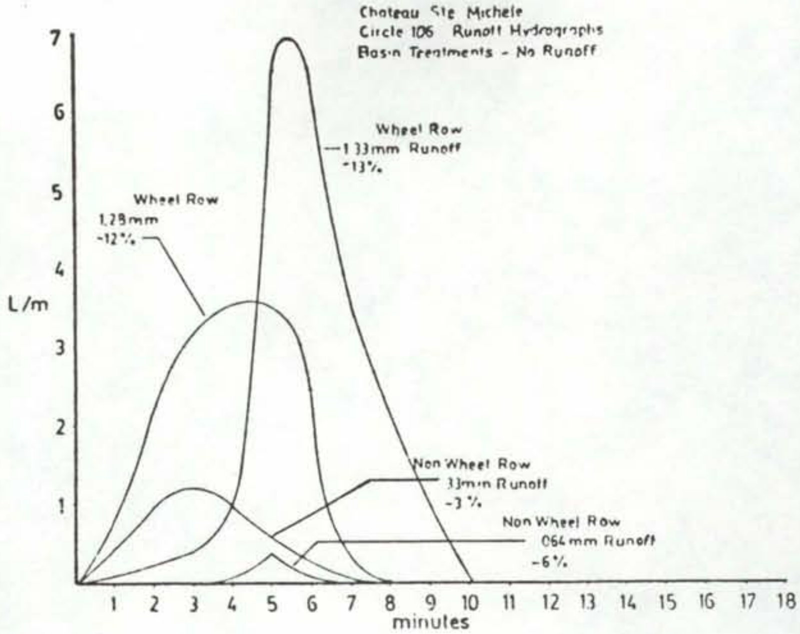


Figure 11. Runoff Hydrograph for check tillage treatment in circle 106

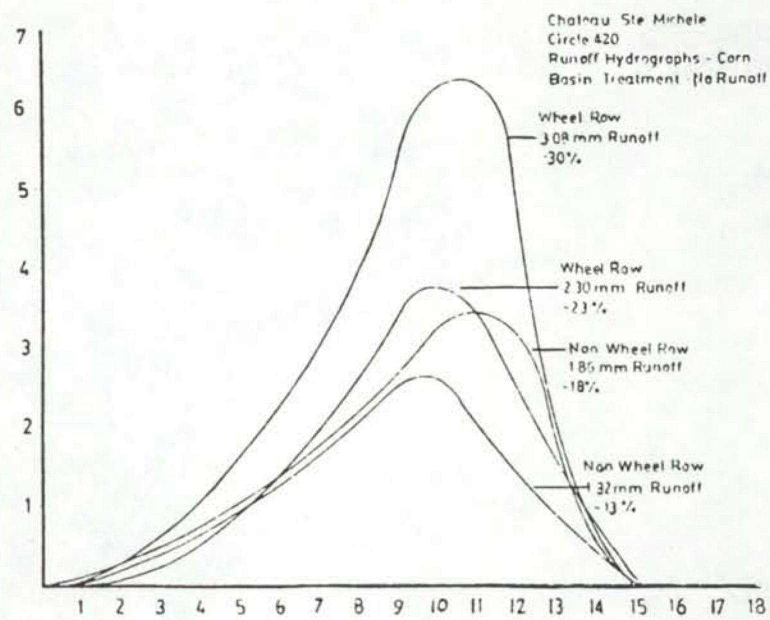


Figure 12. Runoff Hydrograph for check tillage treatment in circle 420

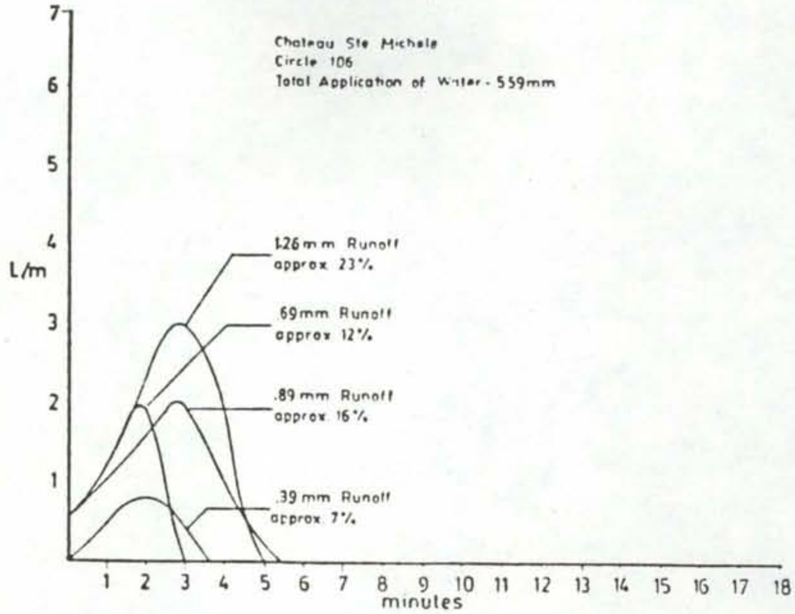


Figure 13. Mid season runoff hydrograph for check tillage treatment in circle 106.

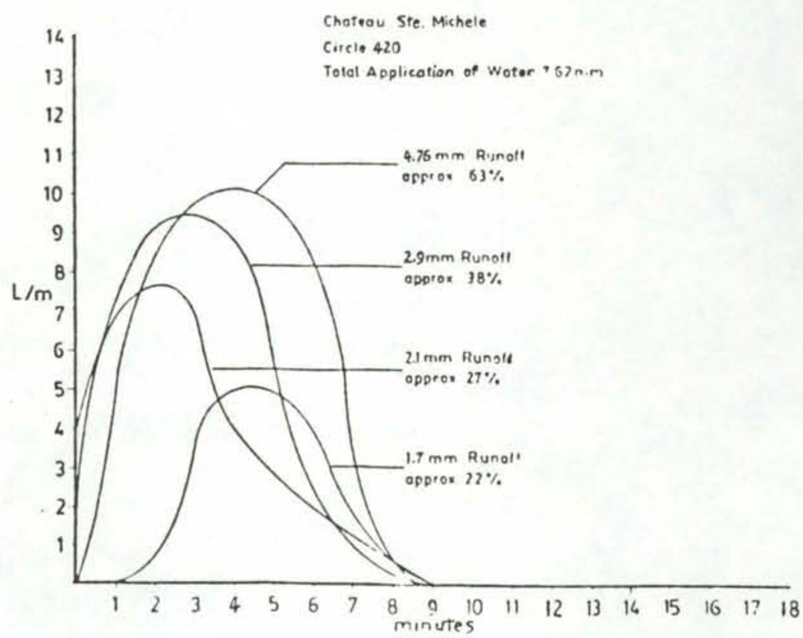


Figure 14. Mid season runoff hydrograph for check tillage treatment in circle 420.

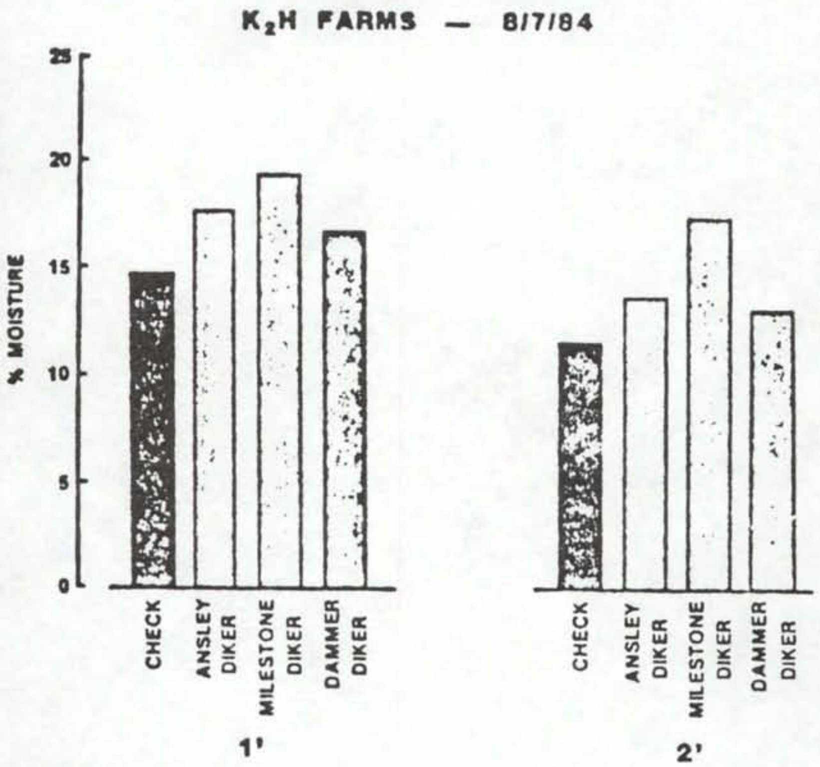


Figure 15. Comparison of soil moisture for various tillage treatments in potatoes.

Table 6. Early corn yield data, Chateau Ste Michelle, circle 106, 8.5% slope, harvested August 28, 1984.

Treatment	Yield wet Metric T/ha
1. Check	15.0 b*
2. Milestone	17.2 ab
3. Dammer Diker	19.7 a
LSD's = 5%	3.11
1%	4.68

Table 7. Early corn yield data, Chateau Ste Michelle, circle 420, 10% slope, 1984.

Treatment	Yield (Kernal & Cob) Ton (Metric)/ha Dry Sept 25	Wet Oct 29
1. Dammer Diker	16.1 b*	22.8 a
2. Milestone	16.8 ab	22.8 a
3. Conventional	15.9 a	21.1 a
LSD's = 5%	2.35	
1%	1.03	

* Treatments with the same letter are not significantly different at P=0.95 using Duncan's MRT.

the first and second 30 cm as compared with the check, with the Milestone Water Saver showing the highest soil moisture in both cases.

Piping failures of the dikes between the reservoirs or basins were evident in most of these plots at the time that runoff measurements were made. An example of these measurements is shown in Figure 16, which indicates nearly equal runoff from three of the four tillage treatments. Because of the failure of many of the reservoirs and basins, it was not anticipated at first that yield data from these plots would be meaningful, but as the season progressed, some settling of the dikes in the furrows occurred, and a difference in plant health was noticed between the checks and the reservoir tillage treatments. The checks were suffering from "early dying" and the reservoir tillage treatments remained relatively healthy. For this reason, an early yield sample was obtained from two replications of each treatment on August 29, 1984 to determine if full season yield and grade data were worth obtaining. The results of this yield sample are shown in Table 8.

Although statistical comparisons are not available with only two replications, it is interesting to note that the highest yields were obtained from use of the Dammer Diker, which showed a 22 percent increase over the check. This yield difference is probably due to partial retarding of the runoff flow by the remains of the reservoirs, even though most of them had failed due to piping.

Table 9 shows the yield and quality data taken from all four replications on September 24, 1984. The total yields were not statistically different, but there was a strong trend for an increase with the reservoir tillage treatments. The yield of #1 and #2

Table 8. Early potato yield data, U & I Corporation, K2H Farm, circle 420, 10% slope, 1984

Treatment	Early Potato Yield -- 29 Aug 84 Metric Tons/ha
1. Check	34.0
2. Ansley	39.4
3. Milestone	40.5
4. Dammer Diker	41.4

Table 9. Early potato yield data, U & I Corporation, K2H Farm, circle 320, 7% slope, 1984.

Treatments	Total Yield	Yield #1, #2	%
	Metric Tons/ha		Useable
1. Check	32.0 a*	16.8 b	49 b
2. Ansley	40.5 a	34.3 a	84 a
3. Milestone	36.7 a	23.1 ab	64 ab
4. Dammer Diker	30.0 a	19.5 ab	64 ab
LSD's = 5%	17.9	14.1	24
10%	14.8	10.1	20

* Treatment with the same letter are not significantly different at P=0.95 using Duncan's MRT.

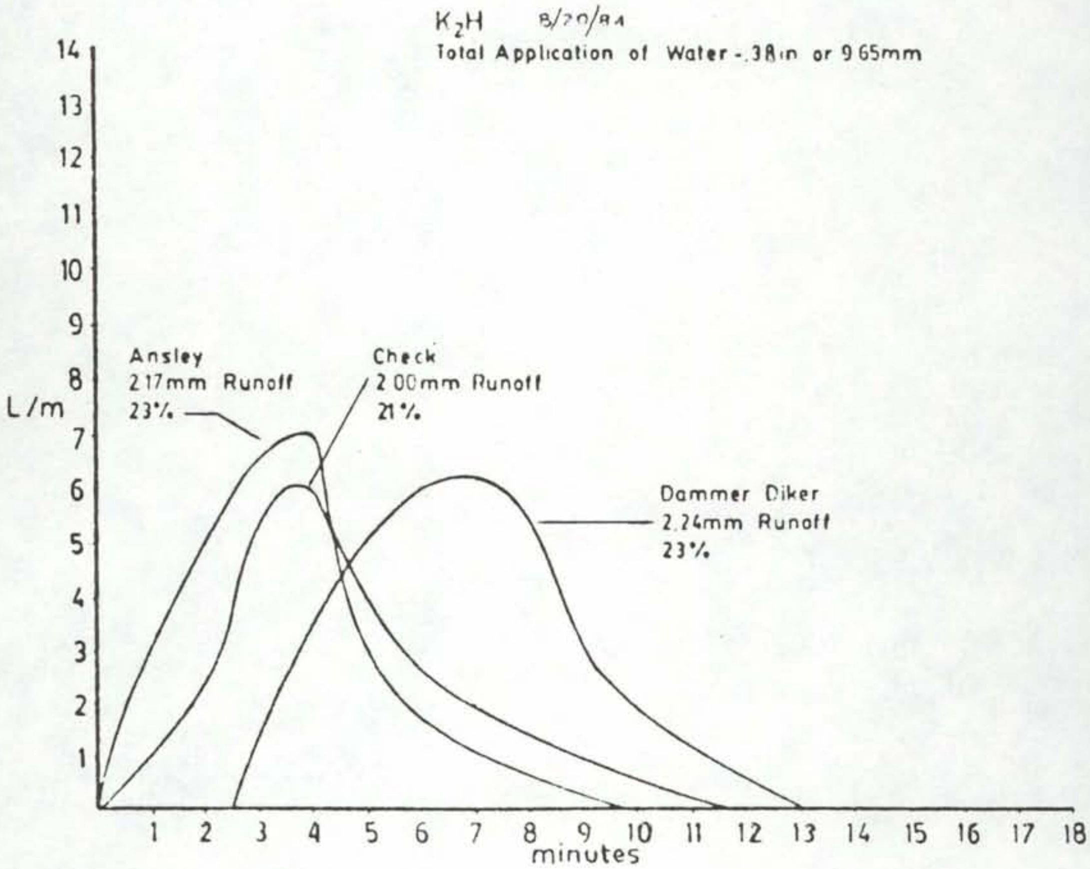


Figure 16. Runoff hydrographs showing little difference in runoff for various potato tillage treatments in late season.

potatoes with the highest reservoir tillage treatment, the Dammer Diker, showed a 104 percent increase over the check. The percent of useable potatoes was 71 percent higher than the check. From these comparisons with this treatment, reservoir tillage, and in particular the Dammer Diker, caused a significant improvement in the yield of useable potatoes over the standard practice.

Small Grains

Only stand and yield data were obtained for the small grain plots harvested early enough to be reported in this study. The data obtained in the spring wheat plots at the Childs ranch are shown in Table 10.

The stand counts taken on March 30, 1984, just after emergence (one- to three-leaf stage) indicate a severe stand reduction due to both reservoir tillage treatments when compared with the check plots. The stand counts taken eight weeks later show that the after-seeding and tillering of the plants tended to reduce this stand difference, especially in the plots treated with afterseeding. The yields also indicate that, although there was a stand reduction in the reservoir tilled plots, the extra trapped moisture tended to produce yields equal to the check plots. When the afterseeding was used, however, a 9.5 percent yield increase was obtained over the check treatment, even though considerably more lodging of the reservoir tilled plots was apparent.

The yield data from the stand density trial at RECAB are presented in Table 11. Although most of the differences were not significantly statistically different, the highest yields were obtained with the Dammer Diker reservoir tillage treatment with after-seeding at the rate of 45 kg/ha in the disturbed area.

Table 10. Owens soft white spring wheat stand and yield data obtained at the Childs Ranch, 1984.

Treatment	Means (4 replications)		
	Stand Counts (stems/m^2)		Yield
	3/30	5/29	kg/ha
1. Check	213	1033	7008 b
2. Dammer Diker	117	806	6988 b
3. Dammer Diker + after-seeding	174	1064	7680 a
LSD 5%	44	254	544

*Treatments with the same letter are not significantly different at P=0.95 using Duncan's MRT.

Table 11. Soft white spring wheat yield data from the stand-vs-tillage reseeding trials at Aberdeen Research and Extension Center, 1984.

Treatment	Yield-kg/ha
1. Milestone, No-rip	4838
2. Dammer Diker	4637
3. Check	4973
4. Milestone	4032
5. Dammer Diker + 10 lb/A reseed	4637
6. Dammer Diker + 20 lb/A	4906
6. Dammer Diker + 40 lb/A	5376
LSD's 5%	551
10%	457

Conclusions

The following conclusions may be made from the data collected in this study: 1) Substantial runoff or translocation of soil occurs on steep slopes under center pivot irrigation without remedial tillage--even if the soil is very sandy and water applications are light; 2) this runoff can be effectively controlled using reservoir tillage and careful water management, resulting in substantial yield increases in both row crops and small grains; and 3) The stand reduction due to the use of reservoir tillage in small grains can be be effectively offset by after-seeding at the rate of 45 kg/ha in the disturbed areas.

PART II

EVAPOTRANSPIRATION DOWNWIND OF LOW PRESSURE SPRINKLER SYSTEMS

Introduction

Water and energy conservation have become important public issues in recent years. Shortages of both have caused prices to spiral upward and as a result irrigation equipment manufacturers and growers alike have become interested in reduced pressure operation for sprinkler systems. Reduced pressure packages have been available for several years now for center pivot and lateral move machines, and recently manufacturers have introduced nozzles specifically designed to be used on semi-stationary systems such as wheel and hand lines.

Low pressure spray heads (used on center pivot and lateral move systems) come in many variations from part-circle to full circle and from fixed flat impact spray plates to oscillating grooved cones. The principal parts are all similar, however, and include a round nozzle or orifice releasing a vertical jet to the atmosphere which impinges on a spray plate positioned perpendicular to the jet near the nozzle. The spray plates come in many shapes including flat, concave, convex, grooved, conical, etc. These heads normally are operated at 100 to 175 kPa (15-25 psi). The spray has the two distinguishing characteristics that the wetted diameter of throw is reduced from that of impact heads (~ 10 m as opposed to ~ 30 m), and the droplet size distribution is shifted from mean sizes of 3 to 6 mm to .5 to 2 mm.

This change in droplet size distribution leads one to believe that the spray-type heads (those with the greatest pressure savings) are more susceptible to losses from spray evaporation and wind drift. The increase in drop surface area per unit volume with the smaller droplet sizes increases the opportunity for evaporation, as the evaporation rate is directly proportional to the surface area. The smaller average mass and momentum associated with those smaller drops also increases the distance they can be displaced by wind. Many investigators have lumped losses due to evaporation and spray drift together into "spray losses." This approach has been due largely to difficulties encountered with experimental techniques necessary to separate these losses.

In addition to the greater tendency for spray evaporation, the possibility of microclimate change downwind of the operating sprinkler system exists, and from these changes, we can further hypothesize that evapotranspiration (ET) rates are affected. Should these ET effects be significant, they could eventually lead to changes in ET modeling, irrigation scheduling practices and irrigation system design procedures.

Objectives

The objectives of this investigation were:

1. To determine if there are changes in microclimate downwind of an operating low pressure sprinkler system and to determine if windspeed affected the magnitude and spatial distribution of these microclimate changes.

2. To determine if, and to what extent, evapotranspiration was affected downwind of the operating sprinkler system.

3. To determine if the various crops adapted to the climate at this research location were affected differently by these microclimate

changes. These crops included dry beans, potatoes, wheat, and alfalfa.

Literature Review

Christiansen (1942), in his now classic treatise on sprinkler irrigation, assumed that water on plant leaves during sprinkling should reduce crop ET, but Burgy and Pomeroy (1958) showed that ET from wet and dry grass plots was nearly equal. The same conclusion was reached by McMillan and Burgy (1960) using paired lysimeters.

Frost and Schwalen (1955) compared ET losses in sprinkled areas with dry areas and bare soil, finding that these losses during the sprinkling period could be neglected because they are nearly equal to losses where sprinkling is not occurring. They also showed that dry leaf ET equalled or exceeded wet leaf ET under the same conditions.

Frost (1963) also found that ET during sprinkling is about equal to nonsprinkled ET, and that ET losses during sprinkling should not be added to spray losses at wind velocities under 2.26 m/sec (5 mph). These studies were concerned only with the area within the sprinkler pattern and did not address the conditions prevailing downwind from the sprinkled area.

Kraus (1966) was the first to report significant changes in microclimate outside of the sprinkler pattern. He measured relative humidity increases of as much as 30% which were not correlated to windspeed downwind of an operating sprinkler lateral. Depths of wind drift deposition were also measured by the magnesium dioxide method, and shown to be negligible. Changes in ET downwind of the sprinkler, therefore, could be attributed solely to microclimate effects. He concluded that for windspeed conditions below 3.62 m/sec (8 mph), a reduction in crop ET occurs downwind of the sprinkler due to a decrease in the vapor pressure deficit. For winds in excess of 3.62 m/sec (8 mph), the net ET in the drift area was consistently higher than in the dry area, as was reported also by McMillan & Burgy (1960). Kraus explained this by stating that under relatively high wind conditions, plants in dry areas tend to become stressed causing a partial closing of the stomatal openings and a subsequent reduction of evapotranspiration. On the other hand, in the drift area, plants were not stressed by wind conditions, due to the fact that a wetter climate prevailed and evaporation occurred at a relatively high rate. He further concluded that wind velocity is the largest factor affecting the change in ET rates.

Kohl and Wright (1974) developed a model of the climatic change due to the operation of a sprinkler line, and found that the model yielded temperature reudctions of only 1.0 and 0.7°C for windspeeds of 2 and 3 m/sec, respectively and corresponding vapor pressure increases of only 0.6 and 0.4 mb respectively for spray losses of 5%. Careful measurement of microclimate downwind of a hand-line lateral (standard single nozzle rotating sprinkler heads) verified the estimates made with the two equations which predicted only slight changes in microclimate. No measurements were made of plant evapotranspiration under these conditions, but they postulated that the differences would be small because of the small differences in microclimate.

Procedures

Figure 17 shows the experimental setup used for this study. A moveable sprinkler boom 25 m long was fitted with spray type sprinklers

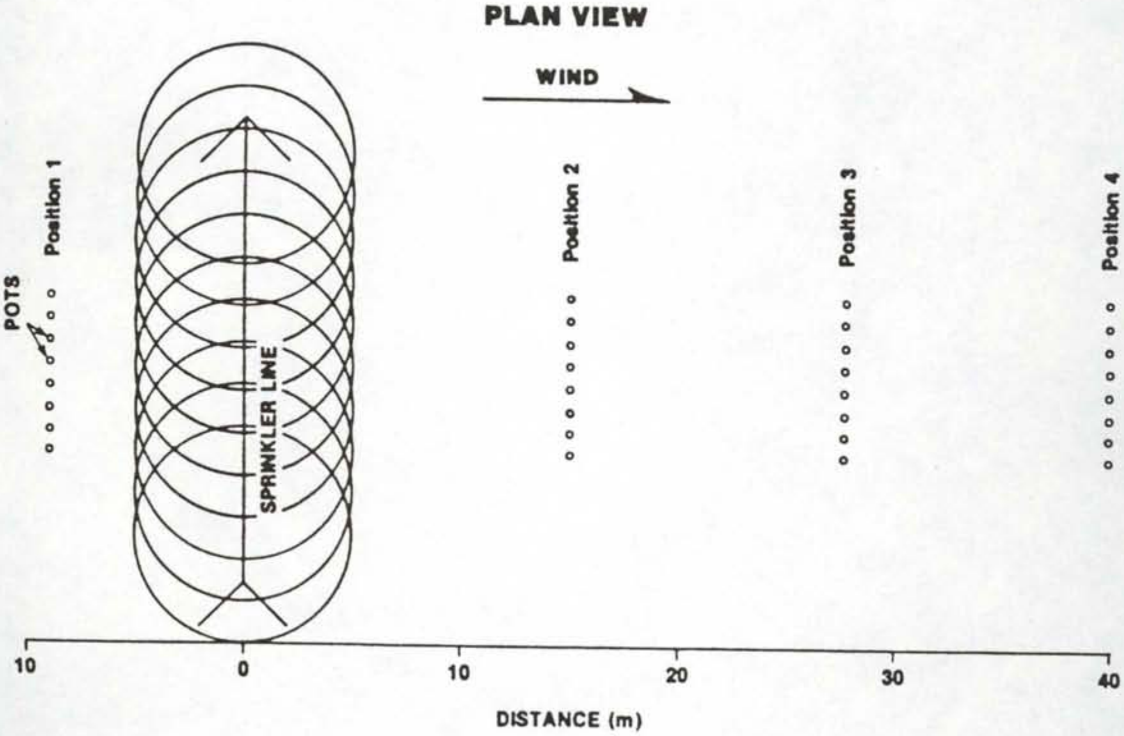


Figure 17. Schematic drawing showing relative locations of sprinkler lateral, pot row positions, and wind direction.

(Nelson Spray I with 3.18 mm nozzles) on a 1.5 m spacing, at 3.5 m height. The boom was oriented perpendicular to the direction of wind run. The sprinklers were operated at 170 kPa (25 psi), yielding a flow rate of 0.097 l/sec per meter of lateral (0.47 gpm/ft).

Rows of 8 pots each of the same crop species were placed 9 m upwind and 15, 27, and 40 meters downwind of the operating sprinkler. These rows are hereafter referred to as positions 1, 2, 3, and 4. The plant species tested included alfalfa (*Medicago sativa*, cv. Gladiator), dry beans (*Phaseolus vulgaris*, cv. great Northern), potatoes (*Solanum tuberosum* cv. Russet Burbank) and soft white spring wheat (*Triticum aestivum*, cv. Owens). The pots for the beans and wheat wheat were approximately 20 cm in diameter by 20 cm deep. The potato pots were 30 cm in diameter by 35 cm deep, and the alfalfa pots were 4 cm in diameter by 30 cm deep. Each pot was numbered for identification. The rows of pots (also referred to as "positions") were spaced far enough from the operating sprinkler so that no free water fell onto the leaves in any position.

The plants in the alfalfa pots were trimmed so that the canopy diameter was approximately the same as the pot diameter. The bean plants had a canopy approximately the same diameter as the pots, and the wheat and potato plants were staked so that canopy diameter did not exceed the pot diameter. For simplicity, the pot area was used in all ET calculations.

The ground surface in the test area was covered with Kentucky bluegrass which was well watered and clipped to a height of about 10 cm. During the test period, the pots were placed on the ground surface, so that the canopy began at the pot height from the ground.

The alfalfa and bean canopy heights were approximately 20 to 25 cm, and the wheat and potato canopy heights were 60 to 80 cm.

The test procedure involved weighing each pot with an electronic balance, and then reweighing each pot after one hour. Pots in position 1 were then rerandomized and relocated to position 2, the pots in position 2 were then moved to position 3, etc., so that at the end of a 4 hr test period, each pot had been in each position for 1 hr. The time between weighings was recorded so that accurate ET estimates could be made. Photosynthetic contributions to dry weight were ignored since differences among treatments would likely be small. Measured ET was calculated by the following relation:

$$ET = \frac{\Delta W}{\Delta t \ Ap} \qquad (1)$$

Where ΔW is the weight change of the pot in grams over the test period Δt, and Ap is the area of the pot. The density of the water was assumed to be 1.0 gm/cm^3.

During each test period, wet bulb (T_{wb}) and dry-bulb T_{db}) temperatures were recorded at each position at approximately 15 min intervals. Solar radiation and windspeed and direction were also recorded at approximately 20 min intervals. To convert incoming solar radiation, R_s, to net radiation, R_n, net radiation measurements were made simultaneously with solar radiation for four days. (Jensen, 1973), a linear regression of the form $R_n = K_1 R_s - K_2$ was developed where $K_1 = 2.56 \times 10^4$ and $K_2 = 3.02 \times 10^6$.

To compare the ratio of actual to potential ET for the different row positions, a normalization procedure was developed using the following relation:

$$ET_r(j) = \frac{\left.\dfrac{ET(j)}{ET_p}\right|_{t = t_j}}{\left.\dfrac{ET\ (j=1)}{ET_p}\right|_{t = t_1}} \qquad j = \text{row position} \tag{2}$$

where ET_r (j) is the normalized evapotranspiration ratio at the jth position, ET (j) is the actual measured evapotranspiration at position; and the hourly potential ET (ET_p) at position one is given by the relationship:

$$ET_p = \frac{\frac{\Delta}{\Delta+\gamma}\ (R_n) + \frac{\gamma}{\Delta+\gamma}\ 0.654(0.750+0.115U_2)\ \Delta e}{585} \tag{3}$$

from Jensen (1973), where Δ is the slope of the saturation vapor pressure vs. temperature curve, and γ is the psychrometric constant, U_2 is the daily wind run at 2 m, and Δe is the vapor pressure deficit.

ET_r was calculated for an individual pot in row j (j=1,4) by taking the ratio of the measured ET of that pot to the potential ET_p during the test period when the pot was in position j. This ratio was then divided by the ratio of the actual ET of that same pot when it was in position 1 (Upwind of the sprinkler) to ET_p during the period when the pot was in that upwind position. By using ET_p in this ratio, the time of test and canopy size and height above surroundings are eliminated. The normalized ET_r, however, may magnify the effect of the sprinkler spray, but nevertheless should give a relative indication of the sprinkler effects on different plant species, to determine if further, more detailed measurements are worthwhile in a normally cropped field situation with a full canopy.

When hourly (ET_p) calculations made with equation 3 were compared with actual ET measurements made in the field, it was found that actual ET's were generally much higher (up to 2 x) than the calculated ET_p estimates, and dividing each term by 24 to give an hourly estimate will yield a low figure because ET_p is near zero at night. Second, because the crop canopy in each pot is completely exposed to the advective currents, the advective component of the actual ET could be considerably higher than in a full cover crop situation.

Analysis of Variance:

In the absence of a classical experimental design model, the data for a given test day were analyzed using the general model presented in Table 12.

Table 12. General model used for statistical analysis of ET data.

Source	DF
4 Positions (1)	3
4 Times (T)	3
32 Pots:position	31
Position*Time	9
Error	81
Total	127

The position*time interaction was used as the mean square error term to test the significance of the position and time treatment effect. The method for comparing treatment means was Duncan's multiple range test, and the means indicated on Figs. 4 through 6 with the same letter are not significantly different ($\alpha = 0.05$).

Results

Figures 18 and 19 show T_{wb} and T_{db} and RH as a function of distance from the sprinkler line and the effect of wind speed on each. Sprinkler discharge causes T_{db} to drop several degrees downwind of the system, but has little effect on T_{wb}. There is also a marked increase in the RH downwind of the sprinkler line. Wind velocity within the measured range apparently does not affect the magnitude or spatial distribution of these temperature or RH changes.

These increases in relative humidity directly downwind of the sprinkler lateral and the corresponding reductions in vapor pressure deficit (VPD) are in close agreement with the results reported by Kraus (1966), for windspeeds less than 3.62 m/sec (8 mph). Winds in excess of 3.62 m/sec were frequently encountered in the course of data collection for this study, but at these higher wind velocities, the wind direction was highly variable and did not allow continuous data collection for a four-hour period, which was necessary to make the statistical comparisons. The T_{db} depressions shown in Fig. 18 are considerably larger than those reported by Kohl and Wright (1974), probably due to the fact that they were using conventional rotating sprinkler heads operated at relatively higher pressures (375 kPa). Another study currently in progress by the author provides evidence that the smaller droplet size distribution for low pressure spray

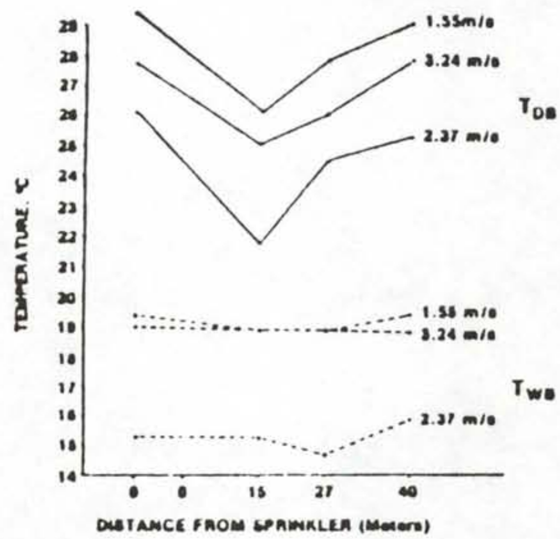


Figure 18. T_{db} and T_{wb} related to sprinkler lateral location.

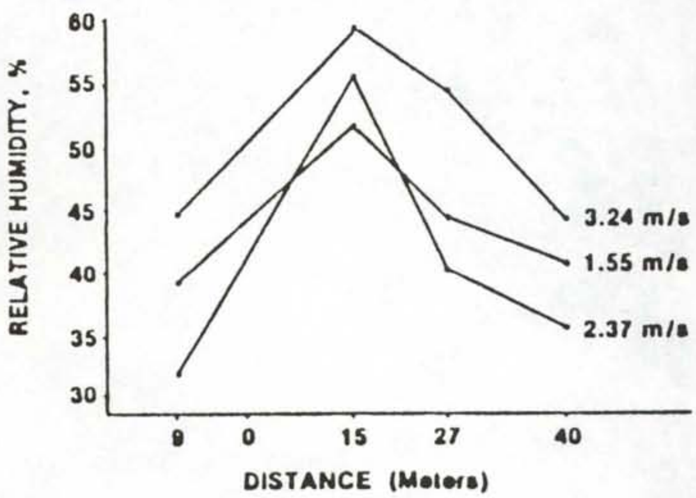


Figure 19. The relationship of RH to sprinkler lateral location.

sprinklers creates a potential for much larger spray losses. These spray losses then contribute to the large reduction in VPD or increase in RH that was documented in this study, as opposed to the smaller changes shown by Kohl and Wright (1974).

In all tests analyzed, the time, position, and time * position interaction effects on ET_r were significant ($\alpha = 0.05$), and in most cases, the variance between pots was also significant. In this analysis, the mean values of ET_r in positions 2 to 4 were compared to ET_r in position 1 (which by definition was always 1.0). The mean ET_r values for each time period were also compared.

For alfalfa, (with the exception of one test), mean ET_r values in position 2 directly downwind of the sprinkler were generally lower than the means in positions 1, 3, and 4. This reduction in ET at position 2 coincides with a substantial reduction in VPD, as indicated by the VPD data presented in Fig. 20. Since the vapor pressure gradient between the leaf and the surrounding air is the primary driving force for transpiration (Jensen, 1973), it is reasonable to assume that the reduction in VPD was responsible for the observed reduction in ET.

The means in positions 3 and 4 were significantly higher than the upwind position 1 as shown in Fig. 20, but were not generally different from one another. This slight increase in ET downwind of the sprinkler lateral in positions 3 and 4 was probably due to more favorable climatic conditions prevailing for stomatal opening, as suggested by Kraus (1966) for the case of winds in excess of 3.62 m/sec, namely that stomatal conductance is slightly increased relative to the drier upwind condition. In each of these figures, the mean VPD for each hour of the

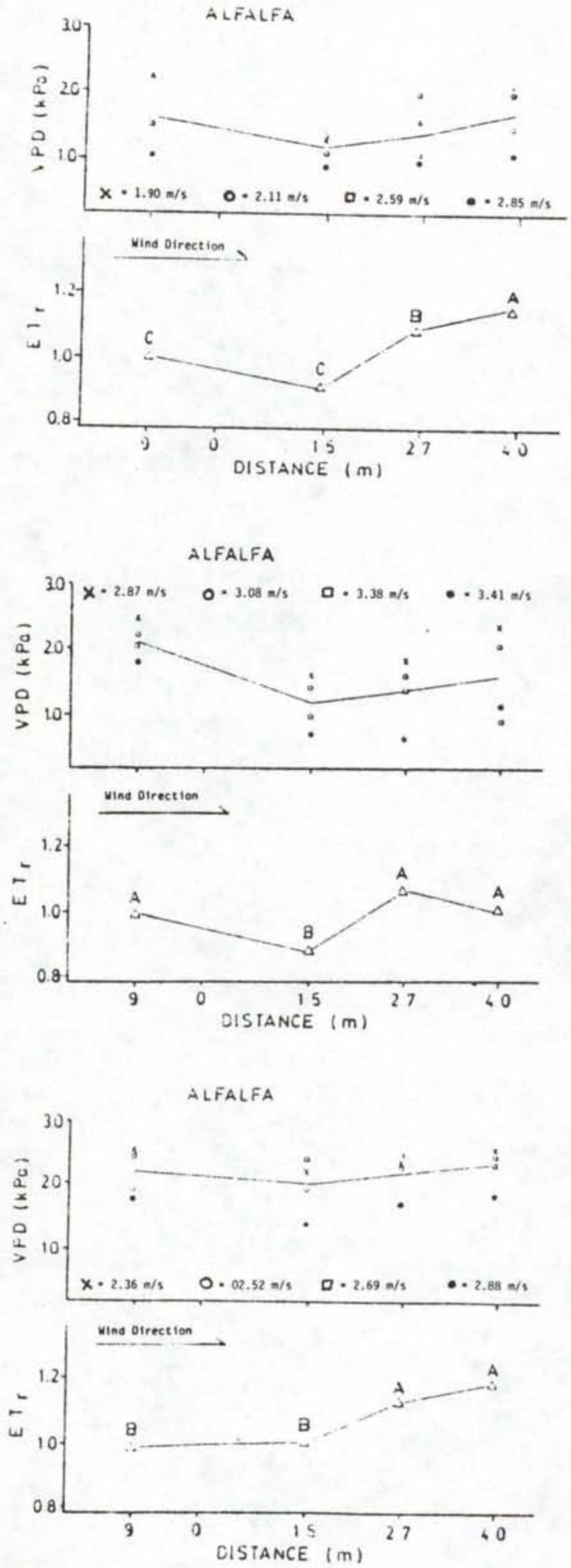


Fig. 20 Graphical representation of vapor pressure deficit and evapotranspiration for varying windspeeds with alfalfa.

test is shown above the ET_r plots. Data points with the same symbol indicate mean VPD's at each position over the same one hour time period. The mean VPD for each position is denoted by the solid line. For the alfalfa, there was generally more variability in VPD measurements than in tests involving the other crops. There is a strong trend for a reduction in VPD directly downwind from the sprinkler in each test.

Figure 21 shows two graphical comparisons of ET_r for wheat. In this case, all the positions downwind (Nos. 2, 3, 4) had ET_r values significantly less than position 1. The same relation is shown in Figure 22 for potatoes and beans. It is interesting to note that the drop in ET_r in position 2 is much greater for beans than any other crop, indicating that the stomatal response of beans to changes in VPD was significantly greater than that of the other species tested.

In each of these cases, the VPD plots show the same trends as the ET_r plots--VPD is reduced substantially directly downwind of the sprinkler lateral and rises gradually as distance increases downwind.

It is evident from these comparisons that the different crop species tested responded quite differently to similar changes in microclimate. The comparison of alfalfa to the other crops and the large reduction in ET_r for beans in position 2 are the most striking examples of these differences.

Time

For all crops except wheat and one test on alfalfa, there was a significant difference among the means for each time period. The ET rate was typically higher during the first hour and declined toward the fourth hour. This was most likely due to the increasing soil moisture

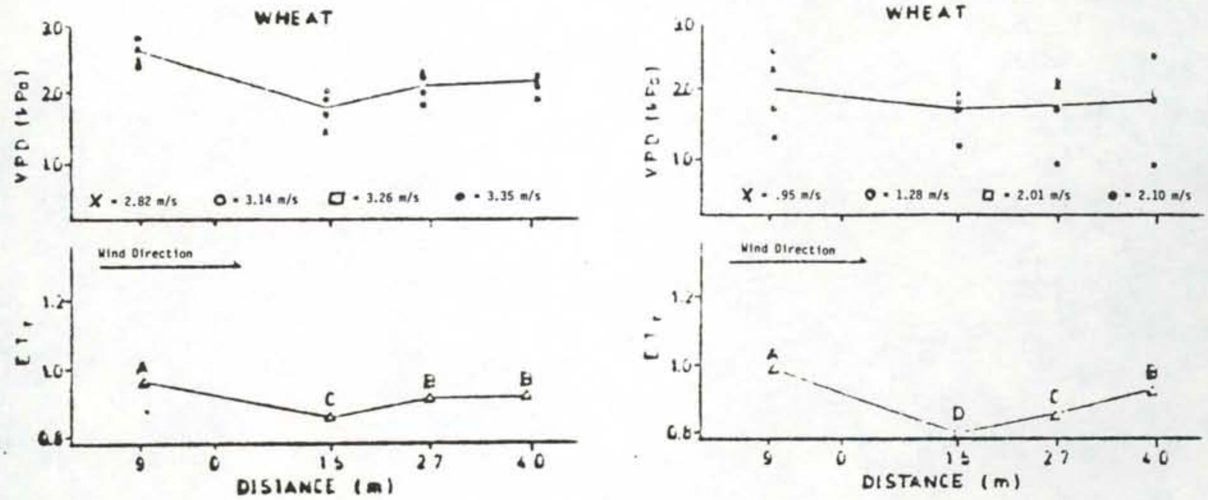


Fig. 21. Graphical representation of vapor pressure deficit and evapotranspiration for varying windspeeds with wheat.

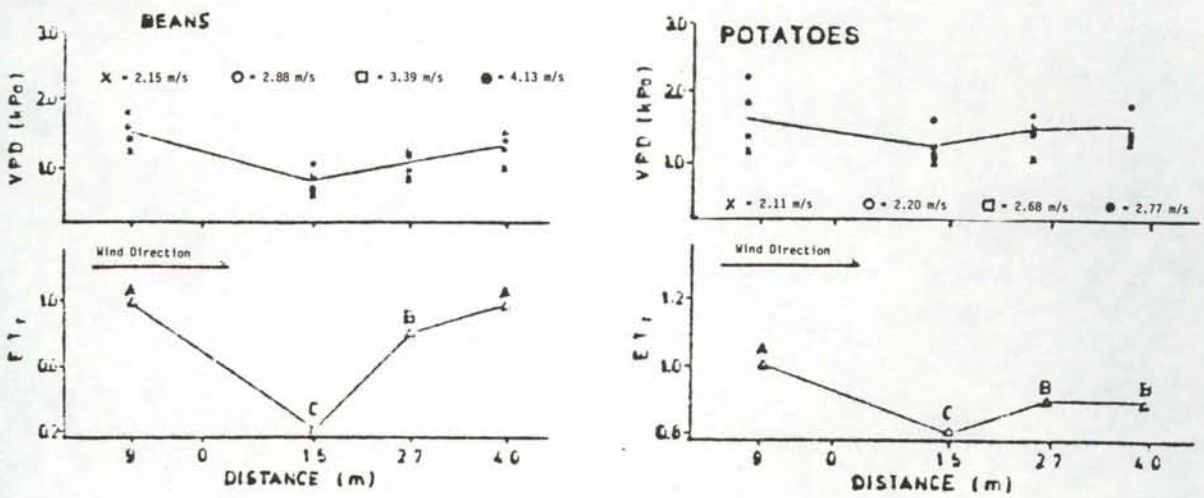


Fig. 22. Graphical representation of vapor pressure deficit and evapotranspiration for varying windspeeds with beans and potatoes.

tension with time as the moisture content of the pot depleted, because additional water was not added during the test. The reason the trend was not evident in the wheat was because of the low rate of consumptive use compared to the other crops (the wheat had begun to senesce slightly when the data were collected).

Although the time * position interaction was significant in the analysis of variance, no trends were evident.

Conclusions and Recommendations

The data presented herein clearly show the reduction of crop ET downwind of an operating low pressure sprinkler lateral, which is generally accompanied by a commensurate reduction in VPD. The significance of this ET reduction is that spray losses to evaporation and wind drift are partially or wholly mitigated by reduced ET of the crop downwind of the lateral. This is in contrast to some of the literature cited where higher pressure impact type sprinklers were used.

In addition to showing changes in ET and VPD downwind from the sprinkler lateral, beans responded much more dramatically to these microclimate changes than did alfalfa, wheat or potatoes. The potatoes also appeared to respond more strongly to VPD reductions downwind, indicating a need for further research to compare ET changes of various crops under the same conditions.

Because of the success encountered in attempting to measure changes in ET downwind of an operating low pressure system, the following recommendations are offered for further research:

1. Use a longer lateral in a commercial field to determine the spatial effect of changes in microclimate on ET.

2. From these changes, estimate the effect on irrigation scheduling and the possible effects on seasonal water use on a full field basis.

PART III

CONCLUSIONS

Low pressure sprinkler systems make up the majority of new center pivot irrigation systems sold in the Pacific Northwest and center pivots, in turn, make up the majority of new irrigation systems (Larsen, personal communication). Many power utilities have also sponsored promotional programs to encourage conversion of existing systems to low pressure, which have been generally very successful. This success has been due in large part to the favorable economics of the conversions (Longley et al., 1980).

The most noticeable problem of runoff has been effectively controlled using reservoir tillage and careful water management. This technology has been so successful, in fact, that it has enabled irrigation of much finer textured soils with center pivot irrigation than was previously thought possible. Adoption of this practice has been much more rapid in some areas than others. For example, in the corporate farming areas of Tri-Cities, Washington and Hermiston, Oregon, virtually every large farm is using reservoir tillage of one form or another, whereas in the irrigated areas of southern Idaho, reservoir tillage is practiced on only a very limited acreage. A demonstration or promotional program on the part of the Extension Service in this area would be very helpful.

Evaporation and wind drift with low energy sprinklers are problems that have not been addressed in sufficient depth to develop clear-cut recommendations for irrigators. The computer model presented in the previous section should be very useful in developing recommendations for water and energy saving irrigation scheduling schemes. This model needs further field testing before being applied on a large scale, however.

Research programs are currently underway at both Washington State University and the University of Idaho to better define evaporation and wind drift effects under low pressure sprinklers, and more definitive results should be forthcoming in the near future.

A critical analysis of the potential for additional energy savings using updated irrigation scheduling methods and results from evaporation and wind drift modelling is instructive at this point. The authors estimated the potential energy savings in Idaho from low pressure conversion at about 10%, and Shearer and Hansen (1982) estimated the potential savings at 12 to 15 percent for the entire Pacific Northwest. The potential savings over a large area from improved irrigation management for control of wind drift and evaporation losses would certainly be less than 5 percent, and possibly as low as 2 to 3 percent. Research in this area has certainly entered into the realm of diminishing returns. Most of the major gains in energy saving technology for large-scale irrigation have already been achieved with the development of low pressure sprinklers and reservoir tillage to control runoff from the irrigation system.

Another area where marginal gains are possible in energy saving technology is in pressure regulation or flow control for low pressure spray type sprinklers. Most of the flow control devices currently being marketed are spring-loaded pressure regulators that are only accurate down to pressures of 15 to 20 psi, whereas the spray type sprinklers operate adequately at pressures as low as 5 to 10 psi, provided runoff from the soil surface can be controlled. In low-lift applications, this pressure or energy savings (from 10 to 15 psi) may save up to 40% of the energy required to operate the system.

In conclusion, great strides have been made in the successful application of energy-saving technology in the sprinkler irrigation industry in the Pacific Northwest in the past 5 years. The most important aspect of this progress has been the development of runoff control through reservoir and basin tillage. Small incremental gains are possible in energy savings and uniformity of water application at lower pressures, but most of the technology for these improvements is already available, and merely needs implementation on a larger scale.

REFERENCES

Aarstad, J.S. and D.E. Miller. 1973. Soil management to reduce runoff under center-pivot sprinkler system. J. Soil and Water Conservation 28(4):171-173.

Burgy, R.H. and C.R. Pomeroy. 1958. Interception losses in grassy vegetation. Amer. Geophys. Union, Trans. 39:1095-1100.

Christiansen, J.E. 1942. Irrigation by sprinkling. California Agr. Expt. Stn. No. 670.

Danial, H.A. 1950. Water conservation for wheat production in Oklahoma. Soil Sci. of Amer. Proc. 15:408-412.

Frost, K.R. and H.C. Schwalen. 1955. Sprinkler evaporation losses. Agr. Eng. 36(8):526-528.

Frost, K.R. 1963 Factors affecting evapotranspiration losses during sprinkling. Amer. Soc. Agr. Eng., Trans. 6(4):282-283, 287.

Jensen, M.E. 1973. Consumptive use of weater and irrigation water requirements. A report prepared by the Technical Committee on Irrigation Water Requirements of the Irrigation and Drainage Division of the American Society of Civil Engineers.

Kohl, R.A. and J.L. Wright. 1974. Air temperature and vapor pressure changes caused by sprinkler irrigation. Agron. Journal 66:85-88.

Kraus, J.H. 1966. Application efficiency of sprinkler irrigation and its effects on microclimate. Trans ASAE, p. 642.

Kuska, J.B. and O.R. Mathews. 1956. Dryland crop-rotation and tillage experiments at the Colby (Kansas) Branch Experiment Station, Woodward, OK. USDA Circ. 917.

Longley, T.S. 1981. Low energy hybrid irrigation system. In: Water Forum 81, p. 65-73.

Longley, T.S. 1984. Basin Tillage for Irrigated Small Grain Production. In: Water Today and Tomorrow, Amer. Soc. of Civil Engineers, New York, New York, p. 338-345.

Luebs, R.E. 1962. Investigation of cropping systems, tillage methods, and cultural practices for dryland farming at the Fort Hays, (Kansas) Branch Experiment Station. Kansas Agr. Sta. Bull. 449.

Lyle, W.M. and D.R. Dixon. 1977. Basin tillage for rainfall retention. Transactions of the Amer. Soc. of Agr. Engineers 20(6):1013-1021.

Lyle, William M. and James P. Bordovsky. 1979. Traveling low energy precision irrigator. In:Irrigation & Drainage in the Nineteen-eighties, Amer. Soc. of Civil Engineer, New York, New York, p. 121-32.

McMillan, W.D. and R.H. Burgy. 1960. Interception loss from grass. J. Geophys. Res. 65(8):2389-2394.