Chiseling to Minimize the Effects of Drought

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DROUGHTS can occur erratically in the Southern Coastal Plains and possibly last up to 4 weeks. Detrimental effects of these annual droughts are increased by the low water holding capacity of sandy surface soils. The sandy soils of this area are characterized by a friable A_1 horizon underlain by a very compact sandy A_2 horizon (Campbell et al., 1974). Since neither roots nor water readily penetrate the A_2, plants mostly withdraw water from the top 25 or 30 cm of the soil profile and high intensity rains, before or after these droughts, can saturate these surface soils resulting in wet soil and plant O_2 stress (Doty, et al., 1975). Soil management practices have been developed using deeper than normal primary tillage to minimize the detrimental effects of drought on crop production and to relieve O_2 stress caused by excess water (Campbell et al., 1974 and Doty et al., 1975).

The objectives of this study were to compare the effectiveness of soil chiseling and shallow disking or moldboard plowing on the availability of measured soil water during short-term droughts and to estimate the number of additional days that chiseling, as compared with conventional moldboard plowing, will sustain a crop during a drought.

PROCEDURE

The experiment was conducted on a Varina sandy loam (Typic Paleudult) soil with a slope of less than one percent. The crops were millet (Panicum Milliaceum Var. Pearl) grown in 1969 and 1970, and sweet corn (*Zea Mays L.*Var. Silver Queen), grown in 1972 and 1973. The plot size, harvesting and sampling procedures, fertilizer application, secondary tillage operations, rainfall and runoff measurements, and irrigation system were described elsewhere (Doty et al., 1975).

The split-plot experiment consisted of primary tillage treatments as main plots and water control treatments as subplots, replicated four times. Main-plot tillage treatments were:

1 Chiseled-tilled every year to a 38-cm depth at right angles and diagonally to disrupt the compacted A_2 layer.

2 Plowed-moldboard plowed in 1969 and 1970 and disked to a 15-cm depth in 1972 and 1973.

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WATER CONTROL

Automatic plot shelters and plastic covering the soil surface were used to impose drought conditions. Four plot shelters (7.3-m wide and 7.3-m long) were constructed of steel frames with aluminum sides and could be moved on tracks and off the plots automatically in about 1.5 min. Each shelter was operated individually by a sensing switch, activated by about 0.5 mm rainfall, which energized an electric motor. On additional plots, plastic (polyethylene sheets) was laid over the soil surface between the rows and stapled around the base of the plants to eliminate infiltration of rainfall (Reicosky et al., 1975).

The 1969 - 1970 water-control treaments were:

1 Nonirrigated - rainfall only.

2 Sheltered - water by irrigation only.

3 Irrigated - 2.54-cm water applied every time about 50 percent of the available water was removed from the upper 60 cm of the soil profile.

In 1972, five water control treatments were used. Droughts were aritificially imposed at three different growth stages. All plots were irrigated equally until the droughts were imposed. On the sheltered plots drought was imposed during the vegetative stage (35 to 69 days after planting). Plastic was placed over two treatments (a) two weeks before tasseling (55 to 81 days after planting) and (b) when 20 percent of the plants were beginning to tassel (69 to 81 days after planting). The fourth treatment was irrigated throughout the entire growing season, and a fifth treatment received only natural rainfall.

In 1973, the drought treatments were imposed from tasseling to harvest of the sweet corn (55 to 86 days after planting). Also, a second treatment was irrigated throughout the growing season, and a third treatment received only natural rainfall.

To determine the number of days without rainfall, it was assumed that the irrigated treatment had adequate water, and was defined as zero days without rainfall. The number of consecutive days the nonirrigated treatment received no rainfall from tasseling to harvest and the number of days that the plastic or shelters covered the plots was recorded. This gave a measure of the number of days each plot was without rainfall and enabled the comparison of the primary tillage treatments for different lengths of time without rainfall.

Tensiometers were installed in the millet and corn row 15-, 30-, and 45-cm deep in all plots, and measurements were recorded at least three times weekly. Additional tensiometers were installed in two replications at the 60-, 90-, and 120-cm depths. Soil water contents were determined from the tensiometer reading and from the soil water suction-soil water content curves. When the soil was dry, grave-metric sampling was used to determine water content at the end of the period. Pan

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evaporation and rainfall were recorded at the experimental site.

The water balance equation is represented as

$$ET = P + I - R \pm S \pm F$$

where precipitation, P; irrigation water applied, I; runoff, R; change in soil water storage in the 0- to 120-m depth, ± S; and the net water transferred across the assumed lower boundary (120 cm) of root zone, ± F, were measured, and the evapotranspiration, ET, was calculated.

The net water transferred across the 120-cm boundary, ± F, was determined by the Darcy equation. The unsaturated hydraulic conductivity, as a function of water content, was determined by the method of Rose et al. (1965). The hydraulic gradient was determined from tensiometer readings between the 90- and 120-cm depths. The net water transferred across the 120-cm boundary, ± F, was calculated for each 1- or 2-day period as an algebraic sum. When F was positive, water moved up into the root-zone for crop use, and when F was negative, water drained below the root-zone.

RESULTS

The millet dry matter produced on irrigated and nonirrigated plots during drought periods in 1969 and 1970 was reported by Doty et al., 1975. Chiseling irrigated plots 38-cm deep, reduced millet dry matter yields during a slight drought in 1969, but slightly increased yields in 1970. Without irrigation, the chiseled plots had no significant effect on dry matter yields in a drought period in 1969, but increased yields from 1.01 to 1.81 Mt/ha during a 33-day drought period in 1970. This indicated that if water is available by irrigation, chiseling does not increase yields.

Table 1 shows the sweet corn dry matter produced in 1972 under the two tillage treatments during artificially imposed drought periods. The drought periods were imposed during the vegetative stage, 2 weeks before and during tasseling, and from tasseling to 87 days after planting. Again, yields were not increased by chiseling when the plots were irrigated, but the nonirrigated chiseled corn out produced the plowed. Also, as the plants grew and the roots developed deeper into the soil, the percent differences between vegetative yields of the chiseled and plowed corn increased. For example, during the vegetative stage (35 to 69 days after planting) the chiseled plots produced 31 percent more dry matter than did the plowed plots (Table 1), but during tasseling (69 to 81 days after planting), the chiseled corn produced 99 percent more dry matter than did the plowed plots.

The chiseled treatment produced significantly more fresh sweet corn ear yields than did the plowed for 7, 12, 13, and 31 days of imposed drought during 1972 and 1973 (Table 2). However, where irrigation was applied to reduce moisture stress, the total yields were not statistically different between the chiseled and plowed treatments. But, more marketable yields were produced on the chiseled than on the plowed treatment. This showed the effectiveness of chiseling the soil to disrupt the compact A_2 horizon, which allows greater root proliferation and water extraction. Our annual sweet corn fresh ear weights agreed with the dry matter yields on adjacent plots reported earlier (Doty et al., 1975).

Water Balance Related to Yield

The increase in yield of the chiseled over the plowed treatment was due, in part, to the additional water supplied by deeper rooting, which allowed the plants to extract water from a larger volume of soil, and to the movement of water upward into the root zone from the water table (Doty et al., 1975). For example, during the 1970 growing season, ET from the nonirrigated chiseled millet was 11.8 cm more than that from plowed treatment. Soil extraction (S) was 1.7 cm more and 11.4 cm more water moved (F) into the root zone (Table 3).

During the drought periods imposed on sweet corn, the increased yields associated with the chiseled soil resulted from increased soil-water availability. In 1972, under artificially imposed drought from 35 to 69 days after planting, the chiseled plots produced 0.6 Mt/ha more dry matter than the plowed (Table 1), and 0.7 cm more water (Table 4) was extracted from the chiseled soil profile. For the chiseled soil, ET was 48 percent

TABLE 1. SWEET CORN DRY MATTER YIELDS OF CHISELED AND PLOWED TILLAGE TREATMENTS DURING DROUGHT. PERIODS IN 1972 IMPOSED BY PLOT SHELTERS AND PLASTIC COVERED SOIL

Treatment	Days after planting From	To	Growth stage	Dry matter yields: Irrigated t/ha	Irrigated Percent diff.	Drought t/ha	Drought Percent diff.
Shelters							
Plowed	35	69	Veg	4.99a*		1.83b	
Chiseled				5.00a	+0.2	2.39b	+31
Plastic Covered Soil							
Plowed	55	81	2 wks. before	6.51a		5.48a	
Chiseled			and tasseling	6.18a	−0.5	6.51a	+19
Plowed	69	81	Tasseling	2.93a		1.20b	
Chiseled				2.61a	−11	2.39a	+99

*Yields followed by the same letter within the same period are not significantly different at the 5 percent level.

TABLE 2. ANNUAL SWEET CORN PRODUCED FROM PLOWED AND CHISELED SOIL WITH DROUGHT IMPOSED FROM TASSELING TO HARVEST

Treatment	Days without rain	Yields sweet corn fresh ear weights 1972 (t/ha)	1973 (t/ha)
Plowed	Irrigated	14.0ab	18.3a*
Chiseled	Irrigated	14.7ab	19.1a
Plowed	7	——	13.7c
Chiseled	7	——	17.8b
Plowed	12	12.9b	——
Chiseled	12	16.1a	——
Plowed	13	11.8b	——
Chiseled	13	16.1a	——
Plowed	26	14.2ab	——
Chiseled	26	16.6a	——
Plowed	31	——	13.4c
Chiseled	31	——	19.2ab

*Yields followed by the same letter during the same year are not significantly different at the 0.05 level.

TABLE 3. WATER BALANCE FOR MILLET FOR THE GROWING SEASON IN 1970

Treatment	Water balance *P + I - R ± S ± F = ET (cm)	Pan evaporation (cm)
Plowed	34.7 + 0.0 - 5.5 + 4.5 + 8.6 = 42.3	84.7
Chiseled	34.7 + 0.0 - 6.8 + 6.2 + 20.0 = 54.1	84.7
Plowed plus irrigated	34.7 + 38.1 - 7.8 + 1.5 - 0.3 = 66.2	84.7†
Chiseled plus irrigated	34.7 + 38.1 - 10.9 + 3.5 - 0.1 = 65.3	84.7

*P = Precipitation
I = Irrigation applied
R = Runoff
S = Change in soil water storage
F = Net water transferred across lower boundary
ET = Evapotranspiration

†80 percent of pan evaporation = 67.8 cm

of pan evaporation. From 55 to 81 days after planting, the nonirrigated chiseled plots produced 1.03 Mt/ha more dry matter than did the plowed and 4.3 cm more water was extracted from the chiseled soil profile. For the plowed and chiseled plots, ET was 56 and 84 percent of pan evaporation, respectively. For 69 to 81 days after planting, 1.19 Mt/ha more dry matter was produced on the chiseled than on the plowed plots, and plants on the chiseled soil extracted 1.9 cm more water than did those from the plowed soil profile, and ET was 49 to 71 percent of pan evaporation for the plowed and chiseled soils, respectively.

In 1973, drought was imposed during the tasseling stage. On the chiseled soil, 5.8 Mt/ha more sweet corn (Table 2) and 1.0 Mt/ha more dry matter were produced than on the plowed plots. The ET from the chiseled soil was 3.8 cm more than that from the plowed soil (Table 5), 2.2 cm from soil extractions (S) and 1.6 cm that moved up (F) into the root zone. The ET was 53 and 72 percent of pan evaporation for the plowed and chiseled soil, respectively. The other water balance data for 1973 was similar (Table 5).

Millet on the chiseled soil were able to withdraw water from a larger volume of soil due to deeper rooting (Fig. 1); our findings agreed with those of Campbell et al., 1974 and Doty et al., 1975. From May 8 to June 11, the early growing season of the millet, the chiseled plots produced 0.8 Mt/ha more millet than the plowed plots. On June 10, the end of the period, millet on the plowed treatment had removed water from the soil to about the 30-cm depth, whereas those on the chiseled treatment had removed water from the soil to about the 60-cm depth. From June 11 to June 24, the millet on the chiseled plots produced about 0.6 Mt/ha more dry matter than that on the plowed plots, and removed more water from the soil to a 120-cm depth. From June 24 to July 15, the chiseled plots produced about 0.4 Mt/ha more millet than did the plowed.

Effect of Chiseling on Days with Rainfall

In 1970, for 33 days, only 5 mm of rain fell. During this drought, the millet on the chiseled treatment grew almost as fast as that on the plowed-irrigated treatment between 13 to 24 days (Fig. 2), whereas the millet on the plowed treatment grew at the rate of the plowed-irrigation treatment for only 5 days. This indicated that the water available in the chiseled soil is sufficient to supply water for at least 8 to 24 days longer than that in the plowed soil.

In 1972 and 1973, the drought treatments were imposed artificially. The number of consecutive days the chiseled as compared with the plowed treatment would supply water are estimated in Fig. 3. The percent yield increase of the chiseled treatment over the plowed treatment is plotted on the y-axis vs. the number of consecutive days without rainfall on the x-axis. These data indicated that chiseling would increase yields up to a maximum of about 34 percent for about 34 days without rainfall. The estimation curve fitted to the

TABLE 4. WATER BALANCE FOR SWEET CORN PRODUCED BY TWO TILLAGE TREATMENTS DURING ARTIFICIALLY IMPOSED DROUGHTS DURING 1972

Treatment	Days after planting From	To	Water balance *P + I - R ± S ± F = ET (cm)	Pan evaporation (cm)
			Vegetative period	
Plowed	35	69	0.0 + 0.0 - 0.0 + 7.2 - 0.1 = 7.1	16.3
Chiseled			0.0 + 0.0 - 0.0 + 7.8 - 0.0 = 7.8	
			2 weeks before and tasseling	
Plowed	55	81	0.0 + 0.0 - 0.0 + 8.7 - 0.1 = 8.6	15.4
Chiseled			0.0 + 0.0 - 0.0 + 13.4 - 0.5 = 12.9	
			Tasseling period	
Plowed	69	81	0.0 + 0.0 - 0.0 + 4.6 - 0.2 = 4.4	8.9
Chiseled			0.0 + 0.0 - 0.0 + 6.3 + 0.0 = 6.3	
			Irrigated treatment	
Plowed	35	81	13.5 + 15.2 - 0.0 + 2.2 - 0.2 = 30.7	25.2
Chiseled			13.5 + 15.2 - 0.2 + 4.1 - 2.5 = 30.1	

*P = Precipitation
I = Irrigation applied
R = Runoff
S = Change in soil water storage
F = Net water transferred across lower boundary
ET = Evapotranspiration

TABLE 5. WATER BALANCE FOR SWEET CORN PRODUCED BY TWO TILLAGE TREATMENTS DURING ARTIFICIALLY IMPOSED DROUGHT DURING TASSELING IN 1973

Treatment	Days after planting From	Days after planting To	*P + I − R ± S ± F = ET (cm)	Pan evaporation (cm)
			Imposed drought	
Plowed	55	86	0.0 + 0.0 − 0.0 + 11.4 − 1.0 = 10.4	19.8
Chiseled			0.0 + 0.0 − 0.0 + 13.6 + 0.6 = 14.2	
			Natural rainfall	
Plowed	55	86	14.2 + 0.0 − 6.5 + 9.7 − 1.0 = 16.4	19.8
Chiseled			14.2 + 0.0 − 7.5 + 10.7 − 0.4 = 17.0	
			Irrigated treatment	
Plowed	55	86	14.2 + 5.1 − 6.4 + 5.5 − 3.0 = 15.4	19.8
Chiseled			14.2 + 5.1 − 6.6 + 6.6 + 0.4 = 19.7	

*P = Precipitation
I = Irrigation applied
R = Runoff
S = Change in soil water storage
F = Net water transferred across lower boundary
ET = Evapotranspiration

data in Fig. 3 showed that when the soil moisture was adequate with irrigation, chiseling only increased yields about 5 percent. After 10 consecutive days without rainfall, yield was increased by about 25 percent due to chiseling. After about 20 days without rain, yield was increased about 34 percent, and for 30 consecutive days without rain, yield was increased about 30 percent. As the number of days without rain increased, the correlation between yield and extended drought became more difficult to define. However, the estimated curve does show that chiseling increased yields by about 30 percent for 15 to 20 days without rainfall. The total number of estimated drought days, expected 2 out of 10 yr for the Coastal Plains of South Carolina, is 9 days in May, 16 in June, 15 in July, 10 in August, and 9 days in September (Van Bavel et al., 1957). Most short-term droughts in the Coastal Plains do not exceed 20 days, and chiseling would effectively increase yields during droughts of this length for both sweet corn and millet.

Economic Effects of Chiseling

The best measure of the effects of any treatment is the net return received over and above the cost of applying the treatment. Based on the results of Williamon (1972) and McMartin and Bergan (1968), the chiseled treatment cost $21.50/ha more than the plowed treat-

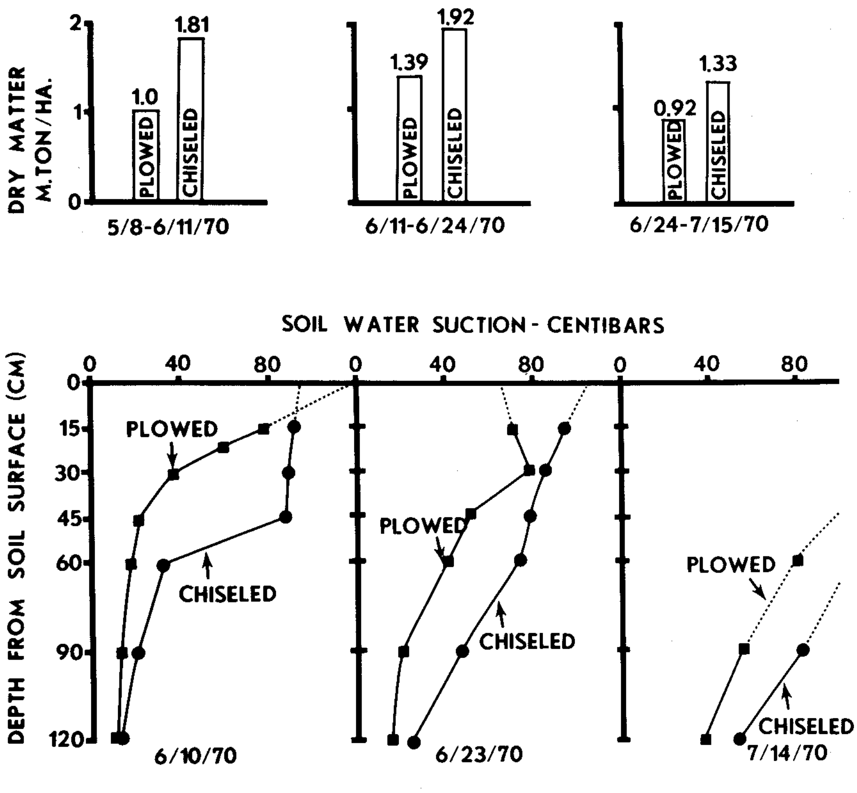

FIG. 1 Millet dry matter yield from plowed and chiseled soils and corresponding soil water suction at harvest.

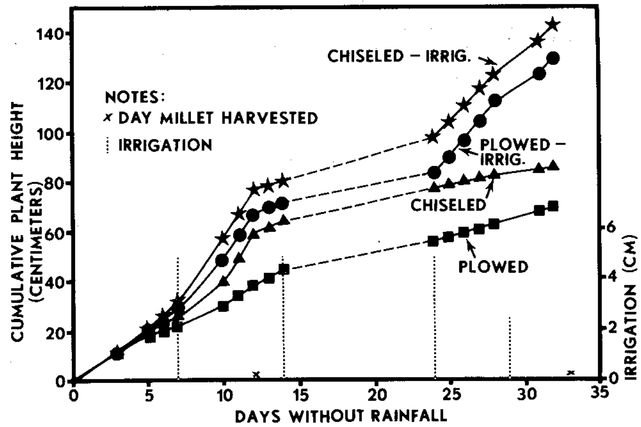

FIG. 2 Cumulative millet plant height for consecutive days without rainfall.

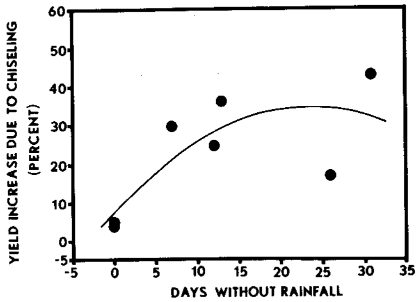

FIG. 3 Average yield increase [sweet corn ear + husk fresh weight] produced by chiseled soil over plowed solid vs. consecutive days without rainfall during tasseling to harvest.

ment, and the irrigation cost of applying irrigation by gated pipe (18 and 13 cm) was \$62.00/ha and \$57.00/ha in 1972 and 1973, respectively. The increase in net return of sweet corn at 50 cents/doz of marketable (>15 cm long) ears, with the cost of irrigation and tillage subtracted, are shown in Table 6. In 1972 on the nonchiseled plots, the more expensive (\$62.00/ha) irrigated treatment actually produced less marketable ears than the nonirrigated treatment. Thus, irrigation on the plowed treatment showed an average loss of \$299/ha in net returns. On plots where soil was chiseled and irrigated, the average net returns were \$168/ha more than with conventional plowed tillage. The average net returns for the chiseled over the plowed treatments were \$234, \$532, and \$402/ha for 12, 13, and 36 days without rain, respectively.

In 1973, plots that were irrigated but not chiseled showed an average net return of \$356/ha, but on plots that were chiseled and irrigated the average net return was \$671/ha. For 7 and 31 days without rainfall, the average net return above the additional cost of tillage was \$498 and \$873/ha, respectively.

SUMMARY AND CONCLUSIONS

Millet and sweet corn were grown on a Varina sandy loam soil with a compact A_2 horizon disrupted by chiseling to a depth of 38 cm. Yields were compared from different water management schemes, irrigation, natural rainfall and droughts imposed by artificial means.

Chiseling the soil to disrupt the A_2 horizon increased millet dry matter and sweet corn ear yields significantly. In fact, the chiseled soil produced yields comparable with irrigated non-chiseled soil.

More water was available for plant use in the chiseled soil than in the non-chiseled. As much as 12 cm more water was used (ET) by the plants on the chiseled treatment than on the plowed (non-chiseled) treatment during the growing season. The additional water came from the roots extracting water from a larger volume of soil and from water that moved into the root zone from the shallow water table.

Data, from millet dry matter yields and sweet corn fresh ear weights and the number of consecutive days without rain, indicate that chiseling the soil will have a significant effect on reducing drought conditions in the Southern Coastal Plains. Chiseling the soil to disrupt the compact A_2 horizon will sustain millet and sweet corn production from 8 to 24 days longer under drought conditions than moldboard plowing or shallow disking and harrowing.

Chiseling the soil to a depth of 38 cm to disrupt the compact A_2 horizon tended to alleviate short-term drought with net return greater, even with droughts of 26 and 31 days, than on conventionally plowed soils that were irrigated.

Since most drought periods in the Coastal Plains are short-term, less than 20 days in length, chiseling may be as effective as supplying water by irrigation on the crops of sweet corn and millet.

References

1 Campbell, R. B. D. C. Reicosky and C. W. Doty. 1974. Physical properties and tillage of paleudults in the Southeastern Coastal Plains. Journal of Soil and Water Conservation 29(5):220-224.

2 Doty, C. W., R. B. Campbell and D. C. Reicosky. 1975. Crop response to chiseling and irrigation in soils with a compact A_2 horizon. TRANSACTIONS of the ASAE 18(4):668-672.

3 McMartin, Wallace and R. O. Bergan. 1968. Irrigation practices and cost in North Dakota. North Dakota State University Bull. 474.

4 Reicosky, D. C., R. B. Campbell and C. W. Doty. 1975. Diurnal fluctuation of leaf-water potential of corn as influenced by soil matric potential and microclimate. Agron. J. 67:380-385.

5 Rose, C. W., W. R. Stern and J. E .Drummond. 1965. Determination of hydraulic conductivity as a function of depth and water content for soil *in situ*. Aust. J. Soil Res. 3:1-9.

6 Van Bavel, C. H. M., L. A. Forest and T. C. Peele. 1957. Agricultural drought in South Carolina. South Carolina Agricultural Experiment Station, Clemson University Bull. 447.

7 Williamon, Paul S. 1972. 1971 charges for custom work in South Carolina. Clemson University Bull. AE347, p.8-9.

TABLE 6. INCREASE IN NET RETURNS ABOVE IRRIGATION AND TILLAGE COST BASED ON 50 CENTS/DOZ FOR MARKETABLE EARS (> 15 cm LONG) SWEET CORN FOR 1972 AND 1973

Treatment applied	Days without rain	Increase of net return \$/ha
1972		
Irrigation only	0	- \$299
Irrigation plus chiseling	0	168
Chiseling only	12	234
Chiseling only	13	532
Chiseling only	26	402
1973		
Irrigation only	0	\$356
Irrigation plus chiseling	0	671
Chiseling only	7	498
Chiseling only	31	873