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Bulletin 113

Midseason Soil Water Recharge for Corn in the Northwestern Corn Belt

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Completion Report
Project No. A-042-Minn

WATER RESOURCES RESEARCH CENTER

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ABSTRACT

Incomplete soil water recharge between growing seasons and insufficient growing-season precipitation limit plant growth in southwestern Minnesota. Field experiments were conducted from 1979-81 on a Nicollet clay loam soil (Aquic Hapludoll) to determine the effects of midseason soil water recharge on corn (Zea mays L.) production. Six treatments consisting of timing and amount variables of supplemental water addition were studied. Daily precipitation and air temperatures were measured. Soil water contents and potentials were measured with a neutron probe and tensiometers, respectively.

Progressive development of soil water deficiencies occurred during the three-year study. Following a wet year in 1979, a shallow-receding water table was present during the 1980 growing season. Extensive soil water depletion to 90 cm occured in both 1980 and 81, the water table could not be detected within 200 cm of the soil surface in 1981. Despite these diverse conditions, positive and significant grain yield responses to the addition of supplemental water were observed in each year of the study. Grain yield resulting from the midseason application of 7.6 cm of water exceeded grain yield with natural precipitation by 1808, 2730, and 1847 kg/ha in 1979, 80, and 81, respectively. Grain production was enhanced as effectively by single-midseason applications of 7.6 cm of water as by "optimum irrigation" (application of 3.8 cm at 50 percent depletion of plant-available water to a soil depth of 90 cm).

In the presence of a receding water table (1980), 90 percent of the grain yield variability and 92 percent of the variability in total dry matter production (TDMP) was accounted for by the amount of supplemental water added and early-season water table depth. Response to the addition of supplemental water diminished with decreasing early-season water table depth.

Key Words: Soil water storage/ subsoil water/ irrigation

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INTRODUCTION

Fine-textured soils of the northern cornbelt produce high corn yields with seasonal precipitation aided by high water retention capacities of the prevailing soils. Nevertheless in the western parts, evapotranspiration exceeds rainfall during several weeks of the growing season (Blake 1960, Baker, et al. 1979). Thus, crop yields are strongly dependent on stored water (Holt, et al. 1964). The extent to which supplemental water would be beneficial to corn yields is largely unknown in the western half of Minnesota or Iowa.

The timing, frequency and amount of water for irrigation are less important on soils with moderate to high retention capacities than on sandy soils (DeBoer, et al., 1977; Power, et al. 1943). The fact that many of the soils of the area are capable of storing 20 to 30 cm of available water in the surface 2 m allows one to consider recharging the soil reservoir with a single large quantity of water at midseason rather than conventional irrigation in small amounts as needed.

The objectives of this study were to test the hypotheses that (1) corn would respond to supplemental water in fine-textured soils of high soil water storage capacity in an area representing the western one-third of the cornbelt, and (2) that a single, large water application at midseason to recharge the soil water reservoir would be as beneficial to the crop as more frequent, smaller additions.

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MATERIALS AND METHODS

Field studies were carried out on Nicollet clay loam at Lamberton, Minnesota during 1979 to 1982. The soil is in the Clairon-Nicollet-Webster soil association, imperfectly drained, developed on calcareous glacial till.

Six treatments were replicated four times in a randomized complete block design. The treatments, consisting of timing and amount variables of supplemental water addition are as follows: (i) natural precipitation; (ii) application of 2.5 cm of water at planting time; (iii) one 7.6 cm application prior to tasseling in early July; (iv) 2 cm at planting time plus 7.6 cm in early July; (v) three weekly applications each of 2.5 cm in early July; and (vi) "optimum irrigation", the application of 3.8 cm of water whenever plant-available water to a depth of 90 cm was 50 percent depleted. One, three, and two such applications were required for the sixth treatment in 1979, 80, and 81, respectively. In 1982, treatments v and vi were omitted, and replications were increased on the remaining treatments replications.

Supplemental water was applied to the 10 m x 10 m plots using full-circle, overhead sprinklers located at four corners of each plot. With 10 m of interplot space and a radial distribution of 9 m from each sprinkler, drift of water into adjacent plots was minimized. Water was obtained from a surface reservoir filled by normal spring runoff, water from seepage and from drain tile. Nitrate concentration of the reservoir water was less than 10 ppm during our July irrigations. Thus, negligible amounts of nitrate (less than 5 kg/ha/yr) were added with the supplemental water.

The corn was "Pioneer 3780" during the first two years of the study and "Pioneer 3732" the latter two. Both are single-cross hybrids with a Minnesota relative maturity rate (RM) of 105. Corn plants were spaced an average of 20 cm within the row and the rows were spaced 76 cm resulting in a plant population of 66,700 plants/ha. Planting dates were May 26, April 29, April 28 and May 3 in 1979 to 1982, respectively.

Plots were fall-moldboard plowed with spring disking for seedbed preparation. Fall fertilizer was applied at a rate of 247 kg/ha of nitrogen, 112 kg/ha P_2O_5, and 112 kg/ha K_2O expect through oversight was not applied for the 1981 crop. Herbicides and insecticides were used each year except for insecticide in 1979.

Corn grain was harvested using a two-row combine harvester and yield of shelled corn was corrected to 15.5 percent water content. Total dry matter production (TDM) was measured in 1980 by cutting corn plants from a 9.3 m^2 area in each plot on September 9.

Water release curves of soil at five depths, 10-20, 40-50, 70-80, 100-110, and 130-140 cm were determined. Soil samples were obtained at 8 sites, 2 sites randomly chosen in each block, using a hydraulic probe. Undisturbed soil cores were desorbed at air pressures of -0.1, -0.33, and -1.0 bars. Disturbed samples passing a 2-mm sieve were used for measurement of 2, 5, 10, and 15-bar percentages.

Neutron probe (Campbell Pacific Nuclear Corporation, Model 503 Hydroprobe) calibrated in situ was used on a weekly basis to determine soil water contents at depths of 20, 45, 75, 105, and 135 cm. PVC access tubes 3.8 dia. were installed, one per plot, using a hydraulic probe with a cutting tip equal in diameter to the outside diameter of the access tubes. Soil cores to a depth of 150 cm were divided into 10-cm segments and oven dried for bulk density determination.

Soil water potentials were measured in 2 replicates of three treatments in 1979 and 1980. In 1980 tensiometers were installed at depths of 20, 40, 80, 120, and 200 cm in each plot primarily to monitor depth to water table, the presence of which was indicated by our 1979 data. In 1981 the water table could no longer be detected within 200 cm of the soil surface following a lower than normal fall 1980 and early spring 1981 recharge precipitation.

RESULTS AND DISCUSSION

Corn Yield Effects

Positive yield responses to a single, heavy midseason irrigation were observed in three of the four years (Table 1). Treatment effects were found to be significant at the 0.01 probability level in 1979 and 80. In 1981 the midseason irrigation gave a positive response when accompanied by irrigation at planting time. Based on the 1979-81 averages, all treatments receiving midseason irrigation showed significantly increased corn grain yield using Tukey's w-procedure (hsd) as the criterion for comparison of treatment means. Corn grain yields on plots recharged with midseason irrigation exceeded those measured for the natural-precipitation treatment by 1808, 2730, and 1005 kg/ha in 1979, 80, and 81, respectively. No differences in yields were observed in 1982.

The importance of soil water reserves in this area should help to explain the yield responses. Figure 1 shows the 5-foot profile reserves for Lamberton in each year plotted against the 1964-82 mean. Reserves were considerably higher than the means in 1979 and 1982, essentially normal except for low values around the end of July in 1980 and low until August 1 in 1981. Yield responses are consistent with the soil water reserves except for 1979. In that year yields were generally depressed because of lower than normal monthly temperatures, amounting to -1.0°, -0.6 and -1.4° C for the months of June, July and August respectively. Though this was unusual, there is little reason to assume that this would result in a greater yield response to supplemental water than reserves would suggest.

The low seasonal water reserves in 1980 and 1981 are also seen in Figure 2 where volumetric water contents in unirrigated plots are shown approaching the 15 bar percentage in successive 30-cm depth increments to a depth of 90 cm during the growing seasons. No significant differences between treatment mean grain yield of the 7.6 cm-at-midseason and optimum-irrigation treatments were measured in the three years conparisons were made. We conclude that recharging the depleted soil water reserves at midseason with 7.6 cm supplemental water was as effective as conventional irrigation scheduling for increasing corn production on the Nicollet clay loam soil. Furthermore, there was no difference whether water was added at one time or at 3 weekly intervals.

Total dry matter produced (TDM) measured in 1980 responded to supplemental water addition in much the same way as did grain yield (Table 2). All treatments in which water was applied during midseason increased TDM significantly at the 0.05 level. Variability to the extent of 72 and 62 percent of grain yield and TDM respectively was explained on the basis of total irrigation water applied.

Several variables independent of treatment effects were measured in each plot during 1980: (i) early-season available soil water (ESAW) to depths of 90 and 150 cm (measured June 4); (ii) soil bulk density (Db) in 10-cm increments to 150 cm; (iii) plant population; and (iv) depth to water table on June 12, taken to represent initial water table depth (IWTD). No significant linear correlations existed between either grain yield or TDM and the above variables. As a result, the proportion of yield variability explained was not improved using multiple linear regression with total water applied as an independent variable and ESAW, Db, plant stand, and IWTD as additional independent variables.

Plant stand and Db, as potential sources of variation, were omitted from subsequent statistical analysis. Large within-treatment differences in ESAW and IWTD, controlled ineffectively by our experimental design, encouraged further investigation of their importance.

Water Table Effects

On June 12, 1980 perched water table depths of 54, 85, 158 and 71 cm were measured in the four replicates of the optimum-irrigation treatment. Adding to the potential importance of water table depths, within-treatment differences of available water measured to 90 cm and 150 cm persisted throughout the growing season. Consistent within-treatment differences in water table depths were observed until late July, when treatment-mean water table depths exceeded 200 cm. (Fig. 3).

The greatest proportion of yield variability in 1980 was accounted for by extending multiple regression analysis to polynomial regression with supplemental water applied and initial water table depth (IWTD) as independent variables. While linear regression explained 72 percent of the grain yield variability with the amount of supplemental water applied as the independent variable (i e., treatment effects only), the second-degree polynomial described in Table 3 explained 90 percent of the variability. Similarly, 92 percent of the variability in TDM is explained (Table 3) as opposed to 62 percent by the treatment effects.

The importance of water table depth as a factor affecting yields measured in 1980, was augmented by the development of negative hydraulic potential gradients from 80-120 and 120-200 cm (Fig. 4). The magnitude of upward water movement indicated by these negative gradients, could not be determined since unsaturated hydraulic conductivities were unavailable.

Upward movement of water between 80 and 120 cm began in early July (Fig. 4A). Conductance of water from 200 to 120 cm began approximately one month later in response to similar but smaller gradients (Fig. 4B). Hydraulic potential gradients were unknown whenever soil water potential at one of the measurement depths (80, 120,or 200 cm) fell below tensiometric measurement capabilities. Only optimum-irrigation (11.4 cm in 1980) in conjunction with above-normal August rainfall, caused downward drainage of water as indicated by positive hydraulic potential gradients.

Treatment differences suggested in Fig. 4A and 4B cannot be attributed to treatment differences in water table depth (Fig. 3). It would be reasonable to assume that the magnitude of the gradients were affected by treatments implemented in 1980 since water content of the soil near the surface was certainly affected. However, differences were not significant owing to large within-treatment differences.

Figures 5 and 6 show predicted grain yield and TDM respectively, using the simplest form of each second-degree polynomial equation in Table 3. Both linear terms and the interaction terms were statistically significant components of the regression equations used to predict grain yield and TDM. One exponential term proved to be significant for prediction of TDM with our 1980 data.

Contour plots shown in Figures 5 and 6 demonstrate that within the range of water table depths shown, predicted crop responses (grain yield and TDM) increased with decreasing IWTD when little or no supplemental water is applied. In agreement with the findings of Follett et al. (5), with receding water table conditions, response to the addition of supplemental water diminishes with decreasing early-season water table depth.

Finally, data collected in 1980 suggest maximum corn production is achieved at our site with the largest addition of supplemental water and IWTD greater than 80 cm for grain and around 100 cm for dry matter production.

CONCLUSIONS

Soil water reserves form an essential and significant amount of water for corn production in the western corn belt. Reserves are often extensively depleted during the growing season in southwestern Minnesota. For the Nicollet clay loam soil, the results of this investigation suggest corn production can be increased significantly with a relatively small (7.6 cm) midseason addition of supplemental water in some years. The importance of supplemental water additions each year depends to some extent on soil water reserves at the time of its application. Diminished yield increases from midseason soil water recharge can be expected when ET requirements of the corn are partially fulfilled by flow of water from a shallow perched water table that is common in the area in the spring but disappears during the summer.

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Treatment	1979 †	1980 †	1981 †	1982 †	1979-81 average §	1979-82 average
	kg/ha					
Natural precipitation	4292 a	5541 a	5071 a	8020 a	4968 a	5731
2.5 cm, planting		5529 a	5830 ab	8051 a		
7.6 cm, midseason	6100 b	8271 b	6075 ab	8001 a	6815 b	7112
2.5 cm, planting 7.6 cm, midseason		8842 b	6596 b	8158 a		
Three weekly applications of 2.5 cm each, July	5780 ab	7487 b	5817 ab		6361 b	
3.8 cm, 50% depletion	5083 ab	8704 b	5836 ab		6541 b	
H.S.D. (.05)	1657	1870	1098		1343	

† Means in the same column followed by the same letter are not significantly different at the 0.05 level using Tukey's w-procedure (hsd).

§ Three-year averages were not calculated for the 2.5 cm at planting and 2.5 cm at plant 7.6 cm at midseason treatments since no supplemental water was added at planting in 1979.

Table 1. Annual corn grain yield and three-year average yield as affected by the addition of supplemental water.

Treatment	Total dry matter
	metric tons/ha.
natural precipitation	11.90 a
2.5 cm, planting	12.44 a
7.6 cm, midseason	15.31 b
2.5 cm, planting 7.6 cm, midseason	16.05 b
three-weekly applications of 2.5 cm each, July .	15.35 b
3.8 cm, 50% depletion	15.91 b
H.S.D. (.05)	2.98

† Means followed by the same letter are not significantly different at the 0.05 level using Tukey's w-procedure (hsd).

Table 2. Total dry matter production (TDM) of corn as affected by the addition of supplemental water in 1980.

	Regression Coefficients						
Yield	a	b	c	d	e	f	R^2
Grain Yield	9968.79	-403.10	-44.620	11.342	-.0816	7.190	.904
Grain Yield §	10541.13	-273.68	-60.309			7.017	.899
TDMP	14.291	-.5369	.0372	.0170	-.00067	.0110	.916
TDMP δ	14.349	-.4941	.0350		-.00067	.0110	.916

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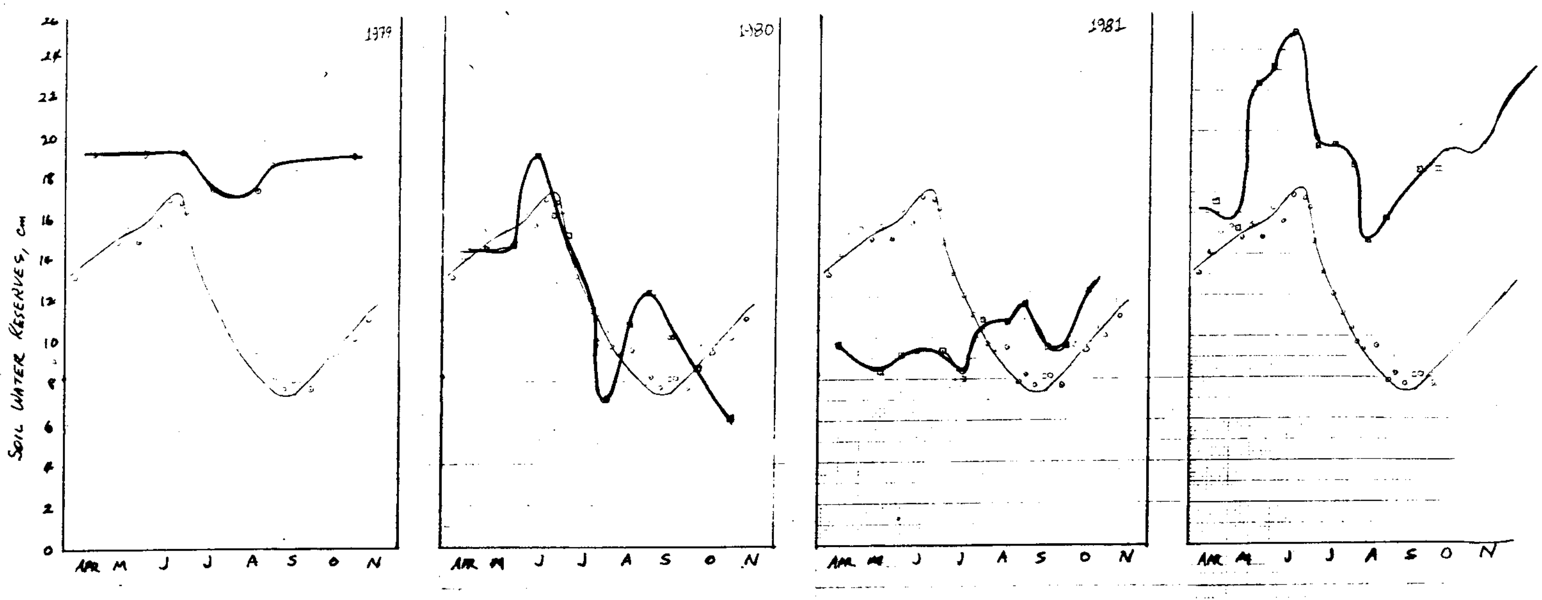
† $Z = a + b(X) + c(Y) + d(X)^2 + e(Y)^2 + f(X)(Y)$, where Z = grain yield (kg/ha) or TDMP (metric tons/ha); X = total irrigation water applied (cm); and Y = initial water table depth (cm).

§ The effects of the exponential terms were not significant at the 0.05 level.

δ The effect of one exponential term was not significant at the 0.05 level.

Table 3. Coefficient of second-degree regression between two measures of 1980 corn production, grain yield and total dry matter production (TDM), and total supplemental water applied and initial water table depth.

Figure 1. Comparison of monthly growing season soil wawter reserves at Lamberton, MN with 19 year (1964-82) mean.



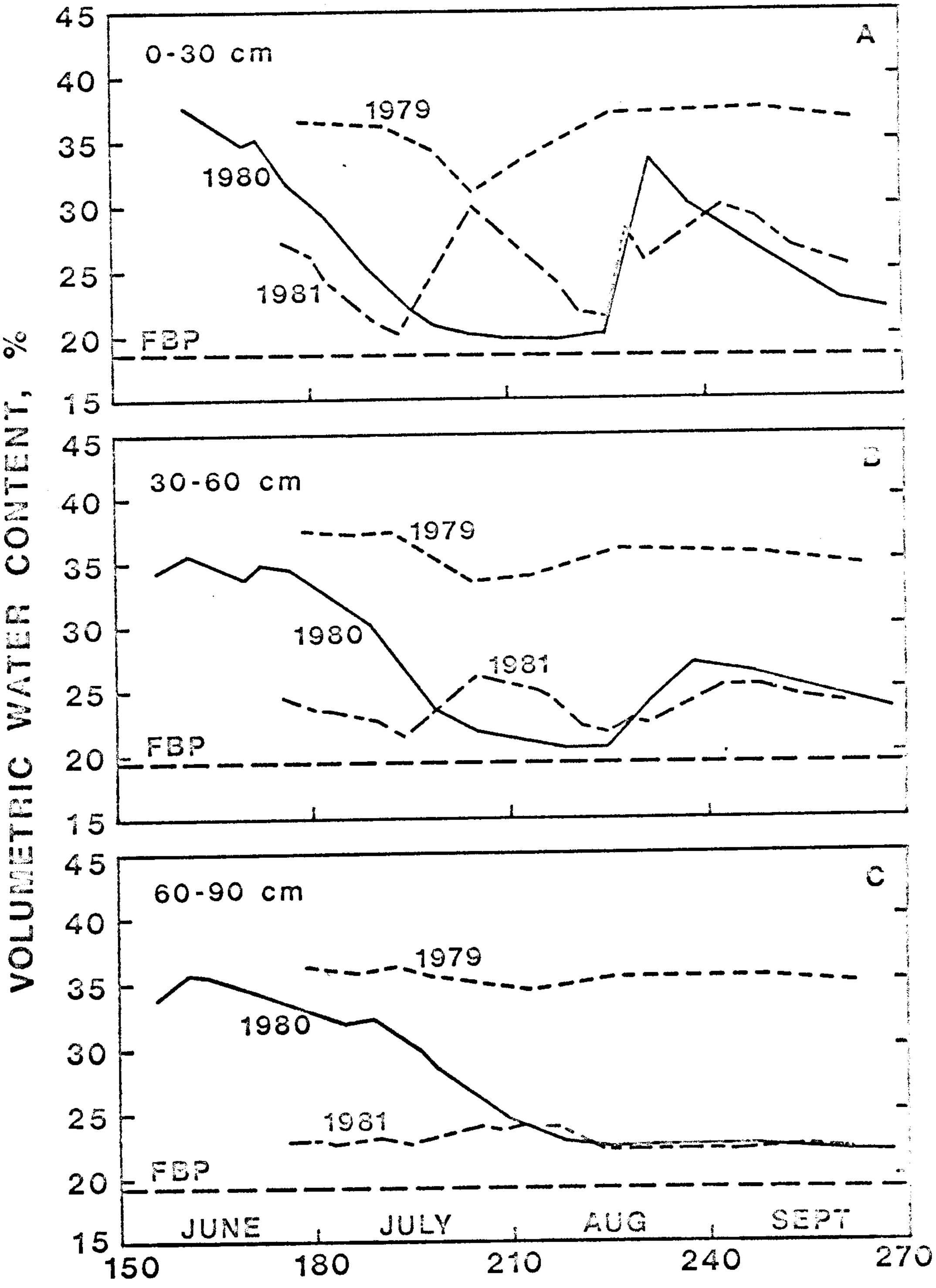


Figure 2. Soil water Content at three depths with only natural precipitation during 1979, 80, and 81.

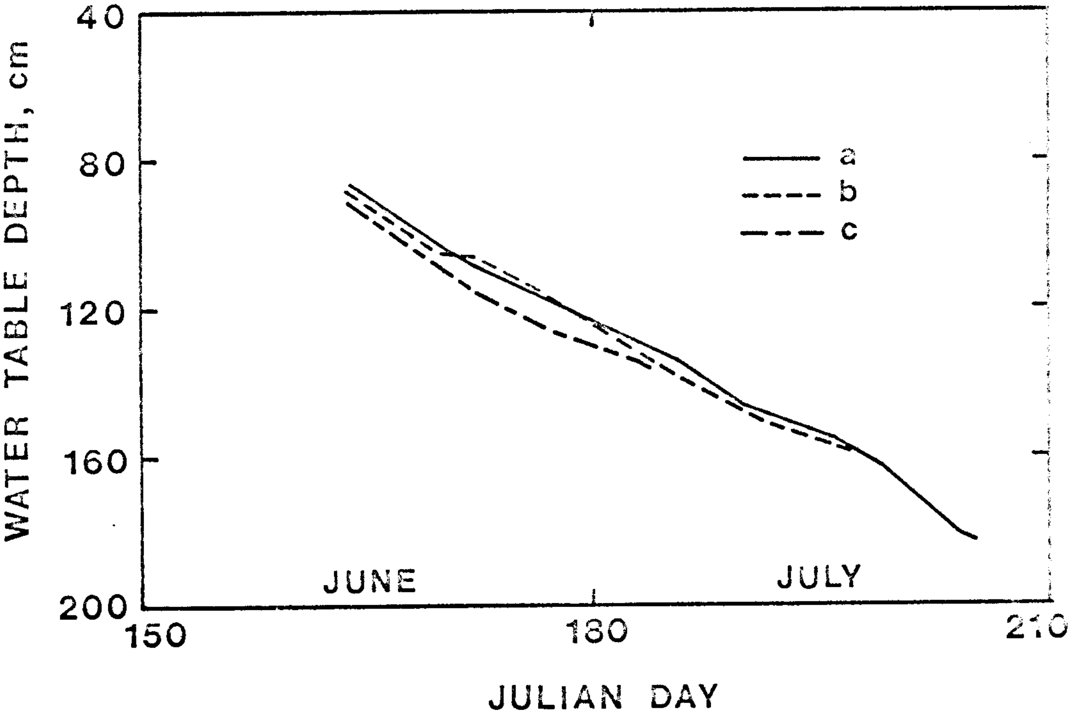


Figure 3. Mean water table depth as affected by the (a) natural precipitation, (b) 7.6 cm at midseason, and (c) optimum irrigation treatments during 1980.

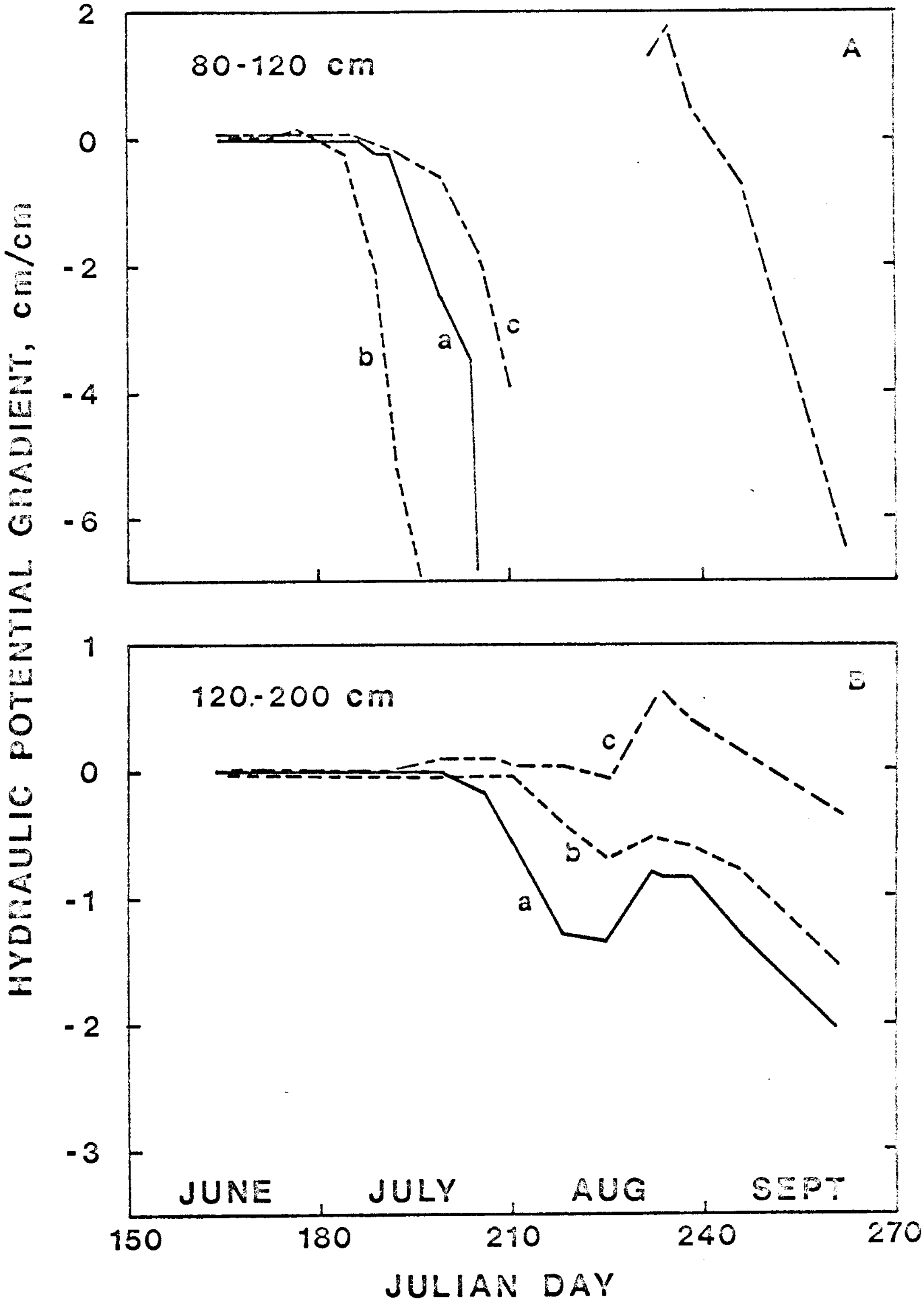


Figure 4. Mean hydraulic potential gradients of the (a) natural precipitation, (b) 7.6 cm at midseason, and (c) optimum irrigation treatments at the 80-120 and 120-200 cm depths during 1980.

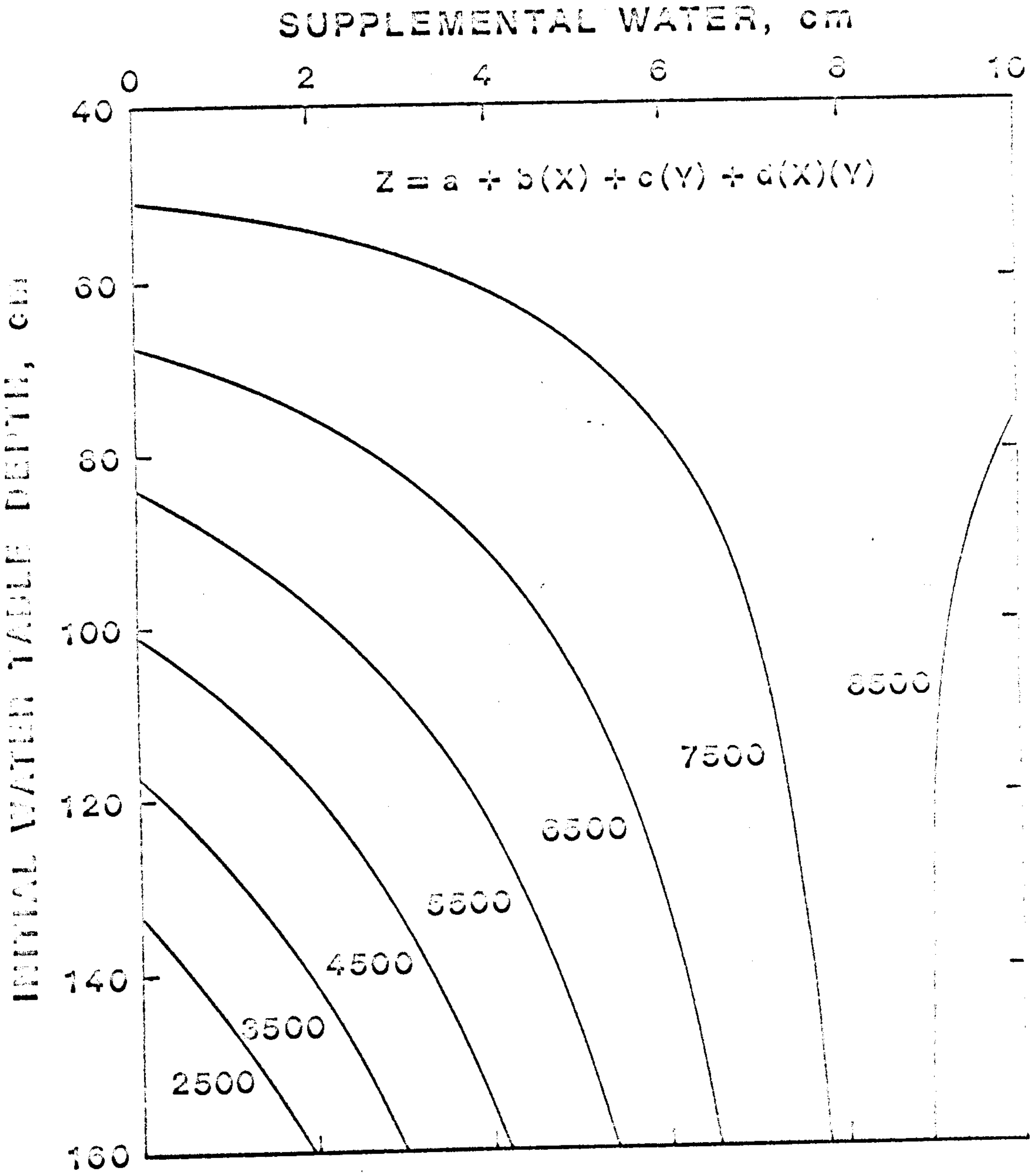


Fig. 5. Corn grain yield as a function of supplemental water added in 1980 (X) and initial water table depth (Y). Numbers near contour lines denote predicted yields (Z) in kg/ha.

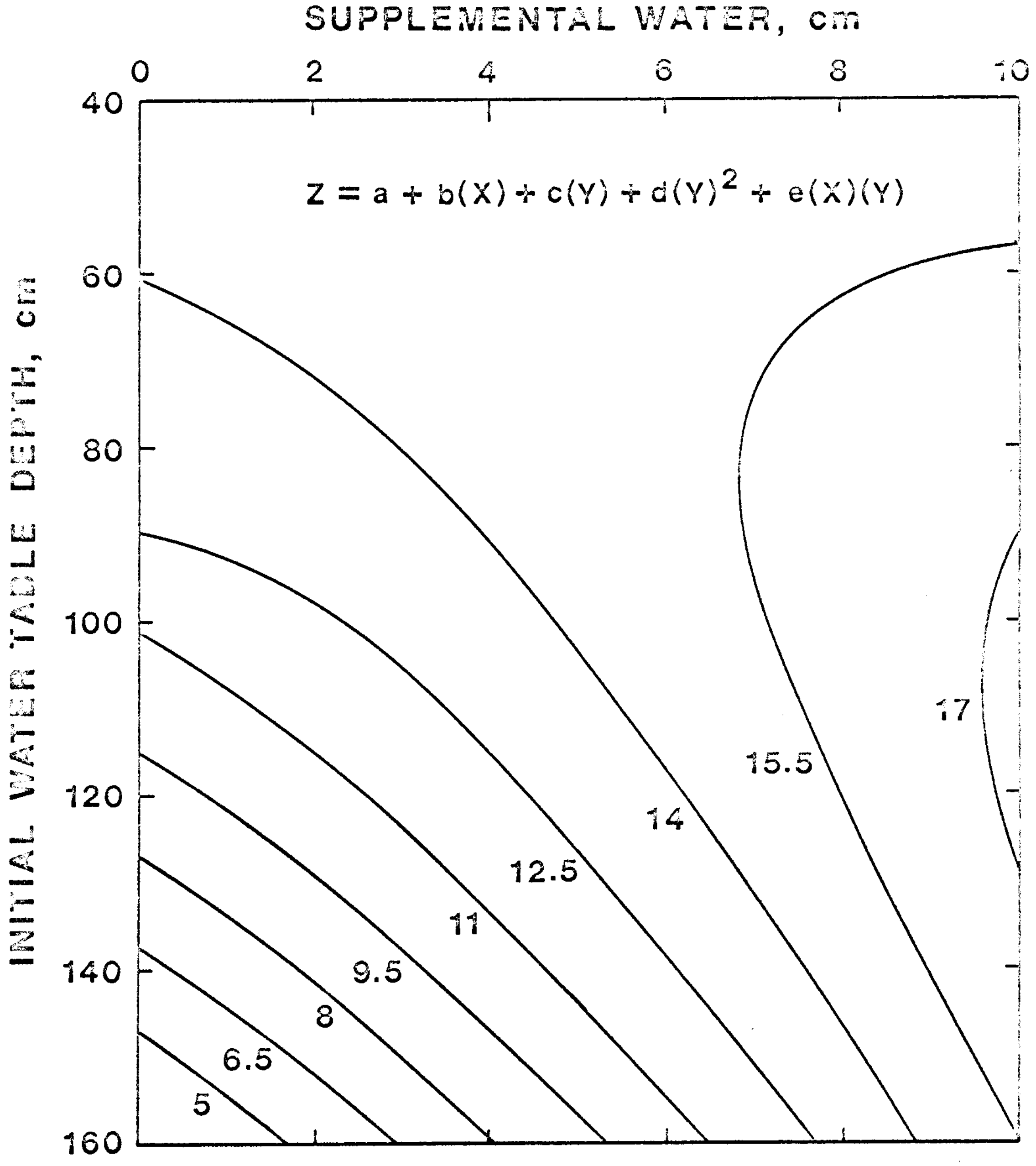


Fig. 6. Total dry matter production as a function of supplemental water added in 1980 (X) and initial water table depth (Y), Numbers near contour lines denote predicted yields (Z) in metric tons/ha.