

Soil Water Recharge Function as a Decision Tool for Preseason Irrigation

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ABSTRACT

FIELD plot soil water data collected at Colby, Kansas from 1979 through 1982 were used to develop an empirical model to predict available soil water content after corn planting (0 to 1.5 m depth) from fall soil water content and fall through spring precipitation. Soil water storage and storage efficiency were both found to be negatively linearly related to fall soil water content. The overall 3-yr storage efficiency equation had a high correlation, $R^2 = 0.87$ at significance level $P > 0.01$. The soil water recharge function is centered around a water storage efficiency equation developed over wide ranges of fall through spring precipitation and fall soil water contents. Decision tools predicting the need for fall preseason irrigation based on estimates of fall soil water and the fall through spring precipitation probabilities are presented. This model's simplicity makes it practical as a criterion for determining the need for fall preseason irrigation for corn on the silt loam soils of western Kansas.

INTRODUCTION

Rising concern about declining water supplies and high pumping costs has focused attention on the efficiency of various irrigation management techniques. Preseason irrigation for corn is one management option that has been questioned. There is still a considerable amount of preseason irrigation for corn conducted in the fall in western Kansas, despite the fact that in many years overwinter precipitation will recharge the crop root zone to field capacity. Practical criteria for evaluating the need for preseason irrigation in western Kansas are needed.

Previous studies have indicated that a negative correlation exists between the initial soil water content and soil water storage from precipitation (Hobbs and Krogman, 1971; Mathews and Army, 1960; Musick, 1970; Power et al. 1973; Timmons and Holt, 1968; Wittmuss and Yazar, 1980; Willis et al. 1961).

Power et al. (1973) in a North Dakota study found that nearly all winter precipitation was lost when fall irrigation was practiced, while dryland plots stored

significant amounts of precipitation as soil water. Willis et al. (1961) observed that fall irrigation subsequently increased runoff during precipitation, thus contributing to inefficient water storage.

Mathews and Army (1960) reported soil water storage during fallow was negatively correlated with initial water content at 25 research stations in the Great Plains. Wittmuss and Yazar (1980), from an analysis of winter soil water storage for 3 years at Lincoln, NE, found storage efficiency varied from 0 to 77% depending on initial soil water, winter precipitation and tillage system.

Musick (1970) at Bushland, TX found a negative linear relationship between soil water after grain sorghum harvest and winter-precipitation storage. Winter storage efficiency, the fraction of winter precipitation stored in the soil profile, reached a maximum of 55% when clay loam soils were initially near the wilting point and decreased to nearly zero when initially at field capacity.

Similar results have been reported at northern locations. Timmons and Holt (1968) reported a negative linear relationship between soil water after corn harvest and winter soil water recharge at 10 locations in the northern United States during the mid-1960's. Hobbs and Krogman (1971) also observed, that for a number of crops in Alberta, Canada, winter soil water storage and fall soil water content had a negative linear relationship.

Stone, et al. (1981) analyzed 3 years of data from Tribune, KS, finding a negative curvilinear relationship between the rate of soil water storage and fall soil water. However, plots of each year's data suggest linear relationships with different slopes and intercepts among years.

This report will discuss the development of a model to evaluate soil water storage in terms of two variables, initial soil water content (0 to 1.5 m depth) and winter precipitation. The model can be used as a criterion for decisions concerning fall preseason irrigation for corn. Although the equation may be specific to northwest Kansas, the developmental procedure is applicable elsewhere.

PROCEDURE

The study was conducted from 1979 through 1982 at the Colby Branch Experiment Station, Colby, KS, on a deep well-drained Keith silt loam (Arid Argiustoll, fine-silty, mixed, mesic). This medium-textured loessial soil, typical of many western Kansas soils, is described in more detail by Bidwell et al. (1980). A 1.5 m crop root zone is typically considered for irrigation management, although some water may be extracted from deeper depths in dryland production. This 1.5 m soil profile will hold approximately 250 mm of plant available soil water

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at field capacity. This corresponds to a volumetric soil moisture content of approximately 0.30 cm³/cm³ and a profile bulk density of approximately 1.3 g/cm³.

The climate can be described as semi-arid with a continental-type precipitation distribution. The 70-year average annual precipitation at Colby is 473 mm. Annual lake evaporation is approximately 1400 mm.

The four treatments in the main study consisted of pre-season irrigations applied in the fall, spring, late summer or no pre-season irrigation, each replicated three times in a randomized complete block design. All irrigations were applied by furrow irrigation using cutback procedures. Irrigation flow-rates to individual furrows were evenly matched across the field with a hand-held flow measuring device, but no efforts were made to measure total inflows and runoff. However, for the purposes of this report data from each soil water sampling location is considered as point data, without regard to treatment or replication and there will be no further discussion of individual treatments. The data from the spring irrigation treatment was excluded from the regression analysis as the irrigation occurs between the period of interest, fall-spring. The data base was extended by including data from two additional fall-spring fallow studies conducted in 1979-80 on non-irrigated soils.

The plots, approximately 90 m by 9 m with approximate land slope of 0.5%, were chiseled, double disked and corrugated in the fall. Soil water contents were determined gravimetrically in 30 cm increments to 1.5 m at two sites in each plot in the fall of 1979 and the spring of 1980. Soil water measurements were made before and after fall irrigation, before and after spring irrigation, and after corn planting. Results from 1979-1980 indicated the need for more frequent monitoring of soil water, so in the fall of 1980 and again in 1981 neutron probe access tubes were installed to a depth of 1.5 m at two locations in each plot. Volumetric soil water contents were measured at each site on at least six dates during the fall-spring fallow period.

RESULTS AND DISCUSSION

Irrigation water management for corn production often results in residual available soil water in the profile after harvest. Correct decisions concerning the need for pre-season irrigation involves knowing the effects the initial soil water content and pre-season precipitation will have on the final available soil water at planting (FASW), expressed by the following equation,

$$FASW = IASW + \Delta ASW \dots\dots\dots [1]$$

where IASW is the initial available soil water content

after harvest and ΔASW the change in soil water storage during the fallow period. The initial fall available soil water content, IASW, can be measured or estimated, but the change in soil water content, ΔASW must be predicted. Since ΔASW is negatively correlated with IASW, linear and polynomial regressions were used to evaluate the relationship between ΔASW and IASW. Equations derived from each year's results were different, but all were linear of the form,

$$\Delta ASW = a + b IASW \dots\dots\dots [2]$$

where ΔASW is defined as above, IASW is the measured available soil water content to a 1.5 m soil profile depth after corn harvest, a is the intercept, and b is the slope of the line. The regression statistics for the soil moisture storage function are shown in Table 1. The difference in regression coefficients between years suggests that other factors influenced soil water storage, such as amount and distribution of snow and rainfall. For example, Musick (1970) reported striking contrasts in soil water storage due to precipitation in 3 very different years. The equations as presented in Table 1 are of little use for prediction of future soil water storage because they change significantly with the year of study. Clearly, more than initial soil water (IASW) must be used to evaluate soil water storage, ΔASW . Storage efficiency, (EFF) has been used to explain the effects of precipitation (P) on ΔASW as in equation [3]:

$$EFF = \Delta ASW / P \dots\dots\dots [3]$$

The boundary conditions for this equation are undefined EFF for P=0, and EFF=0 as P approaches infinity. However, for regression equations, caution should be used when approaching the boundaries which may be beyond the range of data. It is also possible for ΔASW to be negative due to long-term drainage or evaporation losses. As suggested by some, ΔASW might increase curvilinearly with P, especially at low precipitation rates (Stone et al., 1980). If so, EFF might vary appreciably with yearly variation in precipitation. However, Stone et al. (1980) indicated the curvilinear response of storage efficiency to precipitation amount was slight. Also, their period of investigation was November through March, typically a period of low precipitation in western Kansas. Musick et al. (1971) found soil water storage to be linearly related to precipitation in the range 70 to 350 mm. This suggests that a certain amount of precipitation would be lost to evaporation before any net soil water storage occurs. This linear relationship indicates storage efficiency to be fairly constant over a considerable range of precipitation values.

TABLE 1. LINEAR REGRESSION STATISTICS FOR SOIL WATER STORAGE EQUATIONS OF THE FORM, $\Delta ASW = a + b (IASW)$, WITH ΔASW AND IASW IN mm.

Sampling dates	Number of observations	Intercept a	Slope b	Correlation R ²	Standard error of estimate, mm
11/28/79 6/5/80	54	244	-0.925	0.943	16
11/19/80 5/11/80	18	235	-0.787	0.947	13
1/26/82 5/20/82	18	165	-0.615	0.619	21
All years	90	221	-0.814	0.858	22

TABLE 2. LINEAR REGRESSION STATISTICS FOR STORAGE EFFICIENCY EQUATIONS OF THE FORM, $EFF = c + d (IASW)$, WITH EFF IN % AND IASW IN mm.

Sampling dates and precipitation, mm*	Number of observations	Intercept c	Slope d	Correlation R^2	Standard error of estimate, %	
11/28/79 6/5/80	210	54	116	-0.44	0.944	8
11/19/80 5/11/81	266	18	88	-0.30	0.952	5
1/26/82 5/20/82	119	18	139	-0.52	0.621	17
All years	198	90	116	-0.43	0.865	11

*Precipitation between fall and spring soil water sampling.

From equation [3], it follows that if ΔASW is functionally related to IASW, then EFF must also be related to IASW. Regression analysis of EFF with IASW has indicated the following equation fits all three series of data:

$$EFF = c + d IASW \dots\dots\dots [4]$$

where EFF is expressed in percent, c is the intercept, and d is the slope of the line.

The regression statistics and the fall to spring precipitation for the 3 years are shown in Table 2. Some yearly variation occurred but the overall equation has a good correlation with an $R^2 = 0.87$ at a significance level of $P > 0.01$ (Fig. 1). However, this equation should not be used when analyzing dry soils beyond the range of the data, because a storage efficiency of more than 100% will be predicted where IASW is zero. Predicted storage efficiencies greater than 100% for dry soils may be a limitation of the linear model or inaccuracy in measurements of soil water contents or snowfall. Typically corrugated field plots collect more snow than standard rain gages.

Storage efficiencies for the driest plots were generally in the 60 to 75% range, somewhat higher than the 55% maximum value reported by Musick (1970). Infiltration differences between the Pullman clay loam at Bushland, TX and the Keith silt loam of this study might explain much of that difference. Percolation may have lowered the efficiencies cited by Musick, as the 1.2 m depth was the profile under consideration. Also evaporation during

this part of the year is probably higher at Bushland than at Colby. Winter storage efficiencies of approximately 31% on dry soils in Canada reported by Hobbs and Krogman (1971) were much less than efficiencies found in this study. Their values may have been lower because of reduced infiltration on frozen soils, sublimation of snow, or losses by percolation (sampling depth, 1.2 m). On the other hand, Timmons and Holt (1968) reported storage efficiencies as high as 77% for areas in the northern United States. Stone et al. (1981) reported maximum storage efficiencies of approximately 45% at Tribune, KS. However, for their 3-year study the maximum cumulative pre-season precipitation amount was less than 90 mm. Precipitation between November to March typically occurs in small events and evaporation might have reduced their reported storage efficiencies. Kuska and Mathews (1956) in a 25-year study at Colby, KS, found approximately 80% of the winter precipitation was stored in soils of wheat stubble fields left undisturbed until May. They reported considerable yearly variation, with overwinter storage decreasing in years when the soil was wet after harvest. The undisturbed wheat stubble traps snow and can reduce evaporation. Similarly, the corrugated fields in our study can trap snow through generally not as well as stubble. Fall corrugation is a common practice on tilled fields to reduce wind erosion in western Kansas. Storage efficiencies of our study, though higher than some reported in the literature, are reasonable.

Storage efficiency was negative for some plots in 1979-1980 because of initial soil water contents above "field capacity". Over time, drainage continued and the spring soil water amounts were less than the fall amounts. This is not unusual because "field capacity" is a somewhat arbitrary point where rapid drainage ceases. It is often defined as the amount of water in the soil 3 days after a large rain or irrigation. Though deep drainage is not a total loss from the soil profile, as it may return to the aquifer, it is a loss in this storage efficiency equation, since we are concerned only with the top 1.5 m. This deep drainage is also soil water which is unlikely to be recovered by plant roots where irrigation is practiced.

As noted earlier, EFF will approach zero as P approaches infinity because a given soil profile does not have infinite storage capacity. In our study, "field capacity" was approximately 250 mm, although more water can be stored on a short-term basis. Indeed, storage efficiencies for 1980-1981 were low due to excessive precipitation. Storage efficiencies for November through March 31 (precipitation 113 mm), compared with those of November through May 11 (precipitation 266 mm), are shown in Fig. 2. Many of the plots were approaching "field capacity" on March 31. The additional 153 mm of precipitation between March

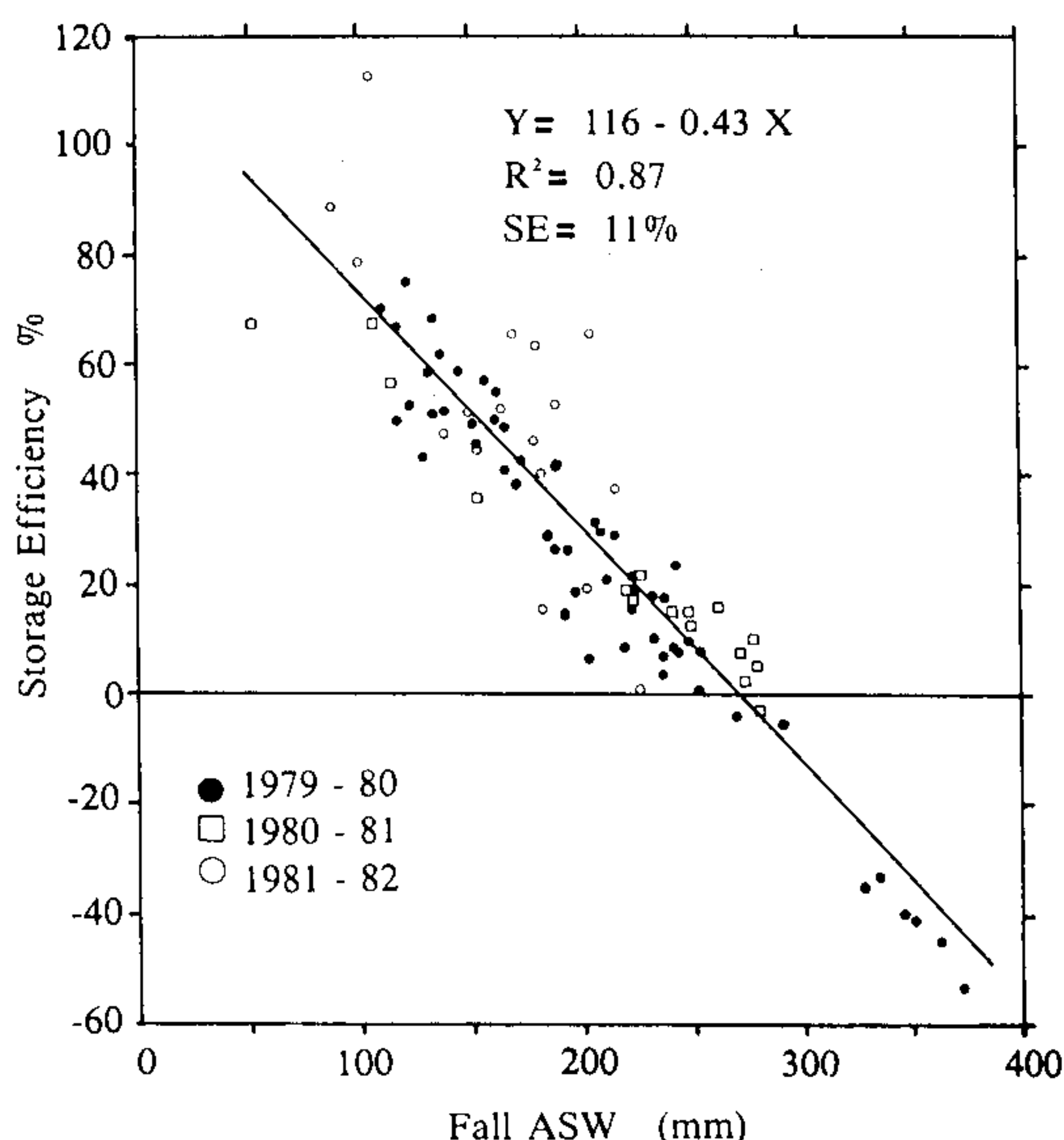


Fig. 1—Relationship of storage efficiency (0-1.5 m depth) to fall available soil water content.

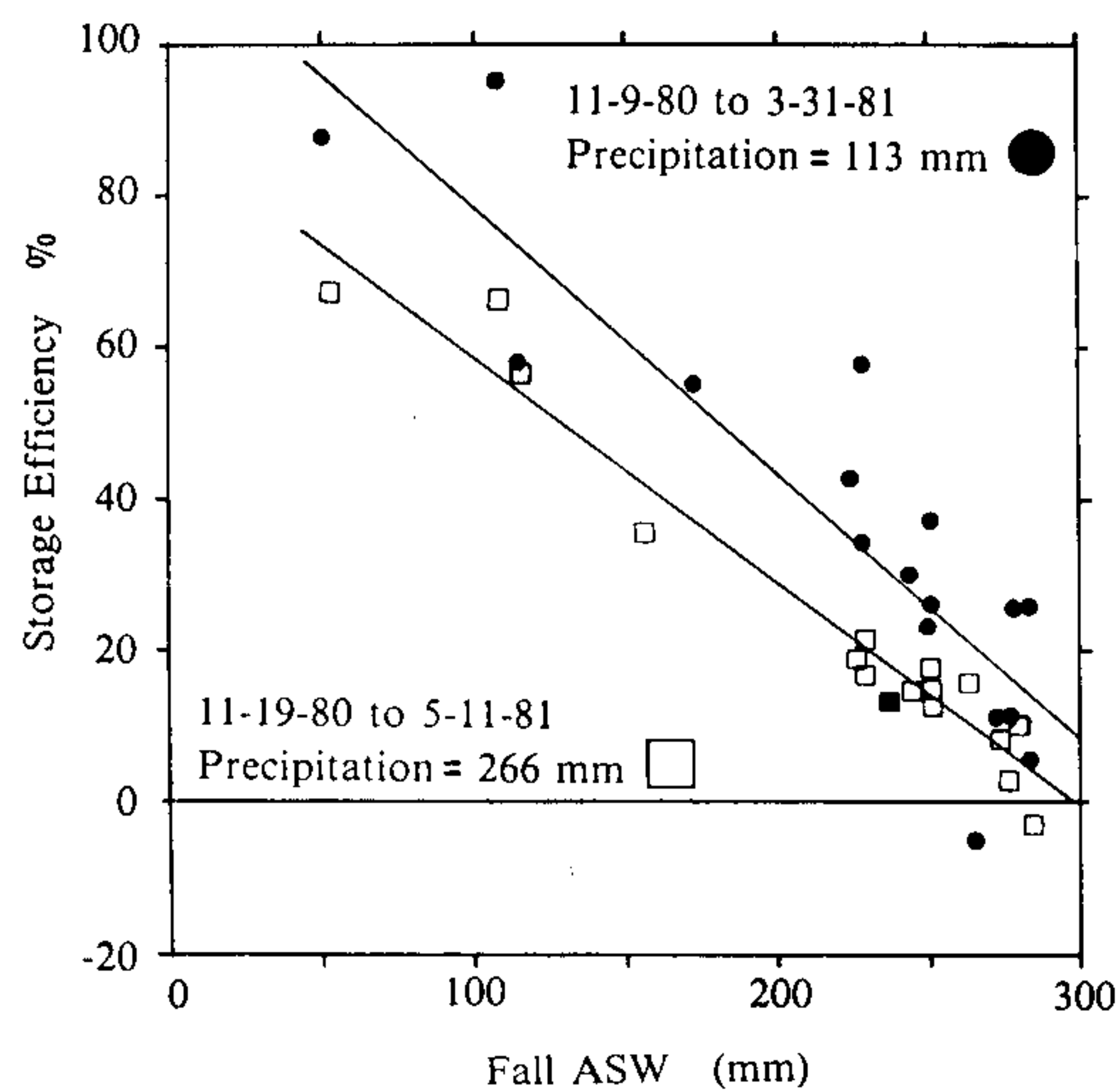


Fig. 2—Storage efficiency as a function of fall available soil water compared during periods of limiting and unlimiting precipitation.

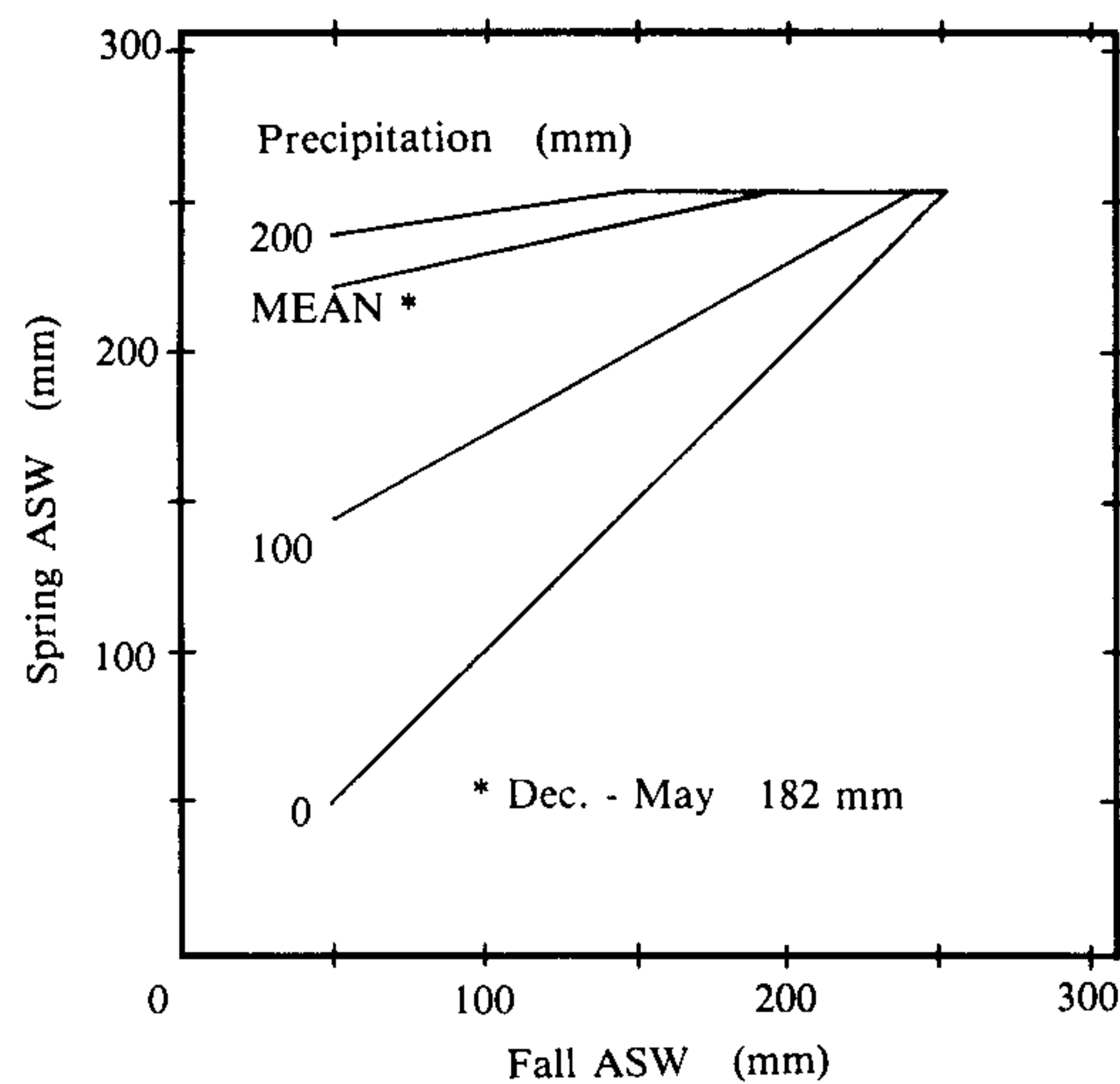


Fig. 3—Predicted available soil water (0-1.5 m depth) at planting in relation to fall soil water and total December-May precipitation.

31 and May 11 exceeded the remaining available storage in the profile of even the drier plots, and as a result storage efficiencies decreased. Some of this decreased efficiency can be attributed to runoff and evaporation, but most was probably loss to profile drainage below 1.5 m, the depth to which soil water content was measured.

The preceding discussion emphasizes the need to "calibrate" a storage efficiency equation with data from years when the precipitation does not grossly exceed the storage capacity. When precipitation is abnormally high, high amounts of storage may be indicated by such a "calibrated" equation, but these storage amounts can be easily truncated back to values comparable to storage capacity of the soil. During the period 1979-1982, fall to spring precipitation did not grossly exceed storage capacity of the drier soils, at least for a significant portion of the fallow period. As a result, our equation should be reasonably valid over a considerable range of precipitation amounts.

Rearrangement of equation [3] and substitution into equation [1] yields:

$$\text{FASW} = \text{IASW} + (\text{EFF} \times \text{P}) \dots \dots \dots [5]$$

and substituting the overall 3-year relationship of EFF to IASW (Table 2) into equation [5] yields:

$$\text{FASW} = \text{IASW} + ((1.16 - 0.0043 \text{ IASW}) \times \text{P}) \dots \dots [6]$$

where all variables are expressed in mm.

Now FASW can be predicted from two variables, IASW and P. Fig. 3 shows how various IASW and precipitation amounts can affect FASW. This figure illustrates that even when soil water is low in the fall, with average December through May precipitation, FASW will exceed 90% of field capacity. In addition some storage is likely to occur in June when the corn evapotranspiration rate is less than the precipitation. The resulting FASW for $P = 0$ is likely to be reduced somewhat from the 1:1 relationship shown due to evaporation and percolation depending on the IASW level and the water contents of the different depths.

Although the fall through spring precipitation can not be predicted in advance, probability values of

precipitation can be used for predicting FASW. Fig. 4 shows the cumulative December-May precipitation amounts for Colby, KS, based on exceedance probabilities using a Log Pearson Type III distribution. Using the exceedance probabilities in Fig. 4 and the relationship expressed in equation [6], the probability of needing preseason irrigation to reach a specified percentage of "field capacity" can be determined (Fig. 5). With a fall available soil water content (IASW) of 150 mm there is a 60% chance of needing irrigation to reach 100% of "field capacity". Accepting 80% of "field capacity" and an IASW of 150 mm, the probability of needing irrigation is only 5%. In addition to determining if the irrigation is needed, it is useful to know the amount of preseason irrigation required. Many surface irrigation systems do not have the ability to apply a small irrigation amount evenly across a recently corrugated field. In this case, a decision needs to be made whether to accept a lower level of soil water at planting and not irrigate in the fall, or whether to apply a larger irrigation amount realizing that some of the fall through spring precipitation may be lost to deep drainage. Fig. 6 shows the net irrigation required at various IASW to achieve a desired certainty of reaching field capacity. Net irrigation in this case implies the increase in IASW over the non-irrigated value. The equations are handled as before with the new IASW reflecting the increase due to irrigation. The efficiency of the irrigation process itself

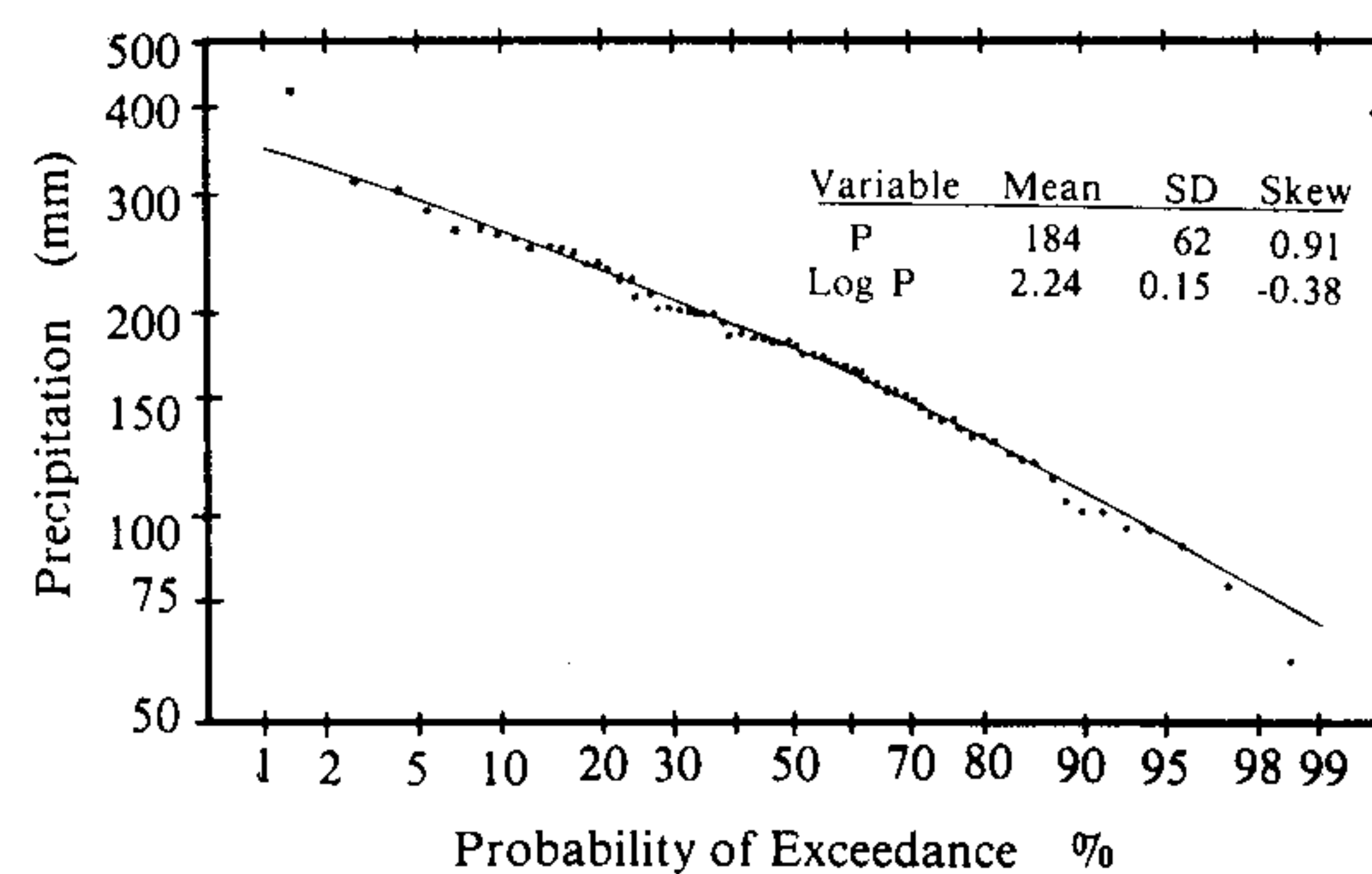


Fig. 4—Probability of exceedance for total December through May precipitation at Colby, Kansas (1914-1984) using a Log Pearson Type III distribution and the associated statistics.

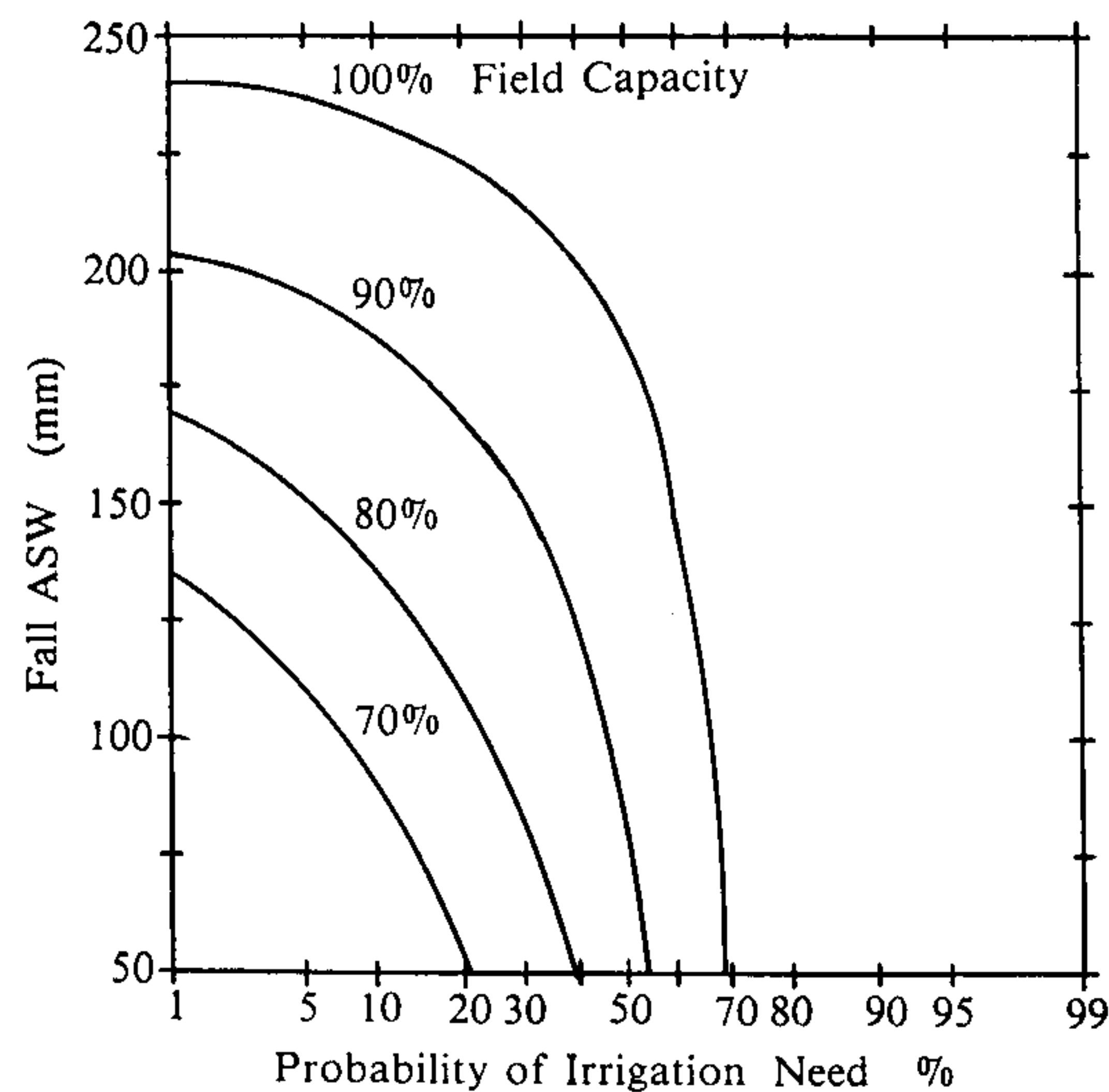


Fig. 5—Probability of needing fall preseason irrigation to reach a specified percentage of field capacity by June 1 as affected by fall soil water content (0-1.5 m depth) at Colby, KS.

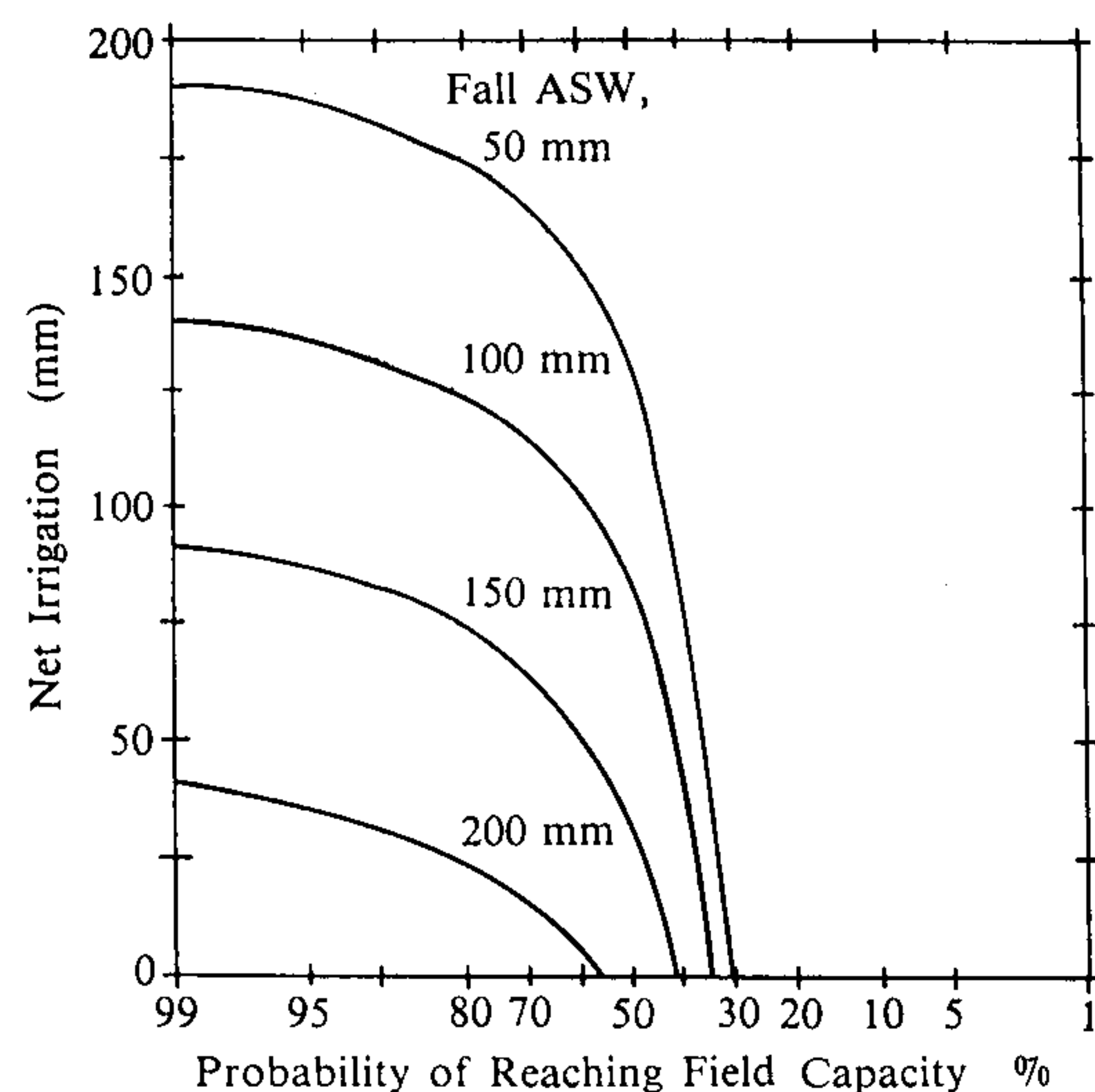


Fig. 6—Probability of reaching field capacity by June 1 with various initial fall soil water contents (0-1.5 m depth) as affected by net preseason irrigation amounts at Colby, KS.

will be related to system type and design. With IASW at 150 mm, a fall net irrigation amount of 50 mm will give an approximately 60% probability of reaching 100% of "field capacity". An increase to 80% probability is possible if a 75 mm irrigation amount is applied. Regardless of what level of probability the producer is willing to accept, in some years soil water content at planting will be deficient, which could have a significant impact on crop yield. The probability of not having sufficient soil water in the seed zone for germination is very low due to high probabilities of some precipitation in late April or early May. In some years germination may be delayed beyond the optimum date due to insufficient precipitation. However, fall preseason irrigation is no guarantee there will be sufficient seed zone soil water in the spring. The deficiencies below the seed zone might be reason for concern. However, most irrigation systems have excess capacity in June and could add a significant amount of water to a deficient soil profile before the peak water use period of July through August.

CONCLUDING DISCUSSION

A model has been developed to be used as a tool in the decision-making process concerning fall preseason irrigation of corn on the silt loam soils of northwest Kansas. This model can help the irrigator make a decision about whether or not to irrigate in the fall to insure adequate soil water for the next crop season. Using probability, the irrigator can determine the need for irrigation as well as determining what irrigation amount is necessary to reach a desired soil water content at planting. The procedure used to develop this model could be used in other regions, even though the coefficients are likely to be site specific.

The model suggests that in most years fall preseason irrigation for corn is not needed to recharge the soil profile in northwest Kansas. A rational approach, such as this model provides, could result in the largest single water savings an irrigator could obtain in a single season.

The authors do not intend to infer that preseason irrigation should never be used. The purpose is to

elaborate on what criteria are important in the decision-making process and to provide an approach for evaluating the need for fall preseason irrigation. Preseason irrigation is a tool that should be used wisely to minimize unnecessary costs and water use.

References

1. Bidwell, O. W., E. E. Banbury, W. L. Barker, and G. E. Muilenburg. 1980. The Colby Branch Experiment Station and agriculture in northwest Kansas with special mention of soils. Kansas Agr. Exp. Sta. Bulletin 636. Kansas State University, Manhattan, KS. 44 pp.
2. Hobbs, E. H. and K. K. Krogman. 1971. Overwinter precipitation storage in irrigated and non-irrigated Chin loam soil. Canadian J. Soil Sci. 51:13-18.
3. Kuska, J. B. and O. R. Mathews. 1956. Dryland crop-rotation and tillage experiments at the Colby Branch Experiment Station. USDA Circular No. 979. 87pp.
4. Mathews, O. R. and T. J. Army. 1960. Moisture storage on fallowed wheatland in the Great Plains. Soil Sci. Soc. Amer. Proc. 24:414-418.
5. Musick, J. T. 1970. Effect of antecedent soil water on preseason rainfall storage in a slowly permeable irrigated soil. J. Soil and Water Conserv. 25:99-111.
6. Musick, J. T., W. H. Sletten, and D. A. Dusek. 1971. Preseason irrigation of grain sorghum in the southern High Plains. TRANSACTIONS of the ASAE 14(1):93-97.
7. Power, J. F., J. J. Bond, W. A. Sellner, and H. M. Olson. 1973. Effect of supplemental water on barley and corn production in sub-humid regions. Agronomy J. 65:464-467.
8. Stone, L. R., R. E. Gwin, Jr., and P. Gallagher. 1980. Overwinter soil water loss. In: Proceedings of Kansas Irrigation Workshop. Kansas Water Resources Research Institute and Kansas State University. Barton County Community College, Great Bend, KS. February 19-20, 1980. pp. 7-20.
9. Stone, L. R., R. E. Gwin, Jr., and P. Gallagher. 1981. Fall irrigation's net benefit in March. Kansas Water News. Kansas Water Resources Board, Topeka, KS. Irrigation Issue 2, Vol. 23, No. (1-2):12-17.
10. Timmons, D. R., and R. F. Holt. 1968. Soil water recharge during the dormant period in the northwest Corn Belt. J. Soil and Water Conserv. 23:177-180.
11. Willis, W. O., C. W. Carlson, J. Alessi, and H. J. Haas. 1961. Depth of freezing and spring runoff as related to fall soil moisture level. Canadian J. Soil Sci. 41:115-123.
12. Wittmuss, H. and A. Yazar. 1980. Moisture storage, water use and corn yields for seven tillage systems under water stress. In: Proc. of the ASAE Publication 7-81. ASAE, St. Joseph, MI 49085, 281 pp.