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## INTRODUCTION

Jensen (4) stated, "Managers of modern irrigated farms need and want a continuing service that gives the present soil water status on each of their fields, predicts irrigation dates, and specifies the amounts of water to apply on each field." In 1975 (4) this need was met on approximately 385,000 acres in the U.S. where irrigations were scheduled on a field by field basis by commercial and agency service groups. Most service groups provided weekly estimates of soil water depletion and projected irrigation dates that were based on current climatic data. Field technicians made periodic visits to each field to verify and/or modify the predicted deficits and often to also make other cultural and agronomic recommendations.

Most service groups use computer-based simulation models to provide farmer clients with this type of information. Approximately 57 percent of the services estimated potential evapotranspiration ($ET_p$) with the Jensen-Haise equation (5) and 37 percent used a Penman (9) type of equation. Crop coefficients are used to compute actual crop evapotranspiration (ET) from the estimated $ET_p$.

The objective of this study was to develop crop coefficient data for southeast North Dakota which relate evapotranspiration rates of given crops to Jensen-Haise equation estimates of potential evapotranspiration. Curves are presented for a range of crops. These curves provide irrigation scheduling consultants with data needed to apply a relatively simple equation to water balance models.

## METHODS

Evapotranspiration data were obtained from small plot studies of water use at the Oakes Research Station located five miles south of Oakes, North Dakota. Data were also obtained from ET sites located in irrigated farm fields in the Oakes and LaMoure areas.

Water use data were obtained by monitoring soil water changes with neutron probe equipment. Measurements were made on approximate seven-day intervals and when possible just prior to and two to four days after irrigations. All irrigation water was applied by center pivot systems in farm fields and by small plot irrigators at the Oakes Station. Rainfall and irrigation amounts were measured at ET sampling sites (or access tube locations) by placing catch cans containing kerosene to minimize evaporation. Applied water was metered onto plots irrigated by small plot irrigators.

Climatic data common to a class A weather station were obtained from a site on the Oakes Station.[1]

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[1]The climatic station was established and operated by Dr. J. Ramirez of NDSU Soils Dept.

Crop cover and phenology were noted visually and recorded by photographing the ET sampling sites on dates of soil water measurements. ET sites were located on a variety of soil series including Maddock, Egeland, Gardena, Hecla, Perella, Hamar, Renshaw, Arvilla, Claire and Emden. Available water holding capacities to 48 inches in these soils ranged from about 2.5 to 3 inches in Claire and Arvilla to near 8 inches in Perella (2).

Evapotranspiration over each sampling interval ($\Delta t \approx 7$ days) was computed with the following balance equation:

$$ET_{\Delta t} = \Delta SWC + P + IR - EXCESS \quad (1)$$

Where: $ET_{\Delta t}$ = Evapotranspiration in time interval $\Delta t$; usually seven days

$\Delta SWC$ = Measured change in soil water content; usually measured to 48 inches

$P$ = Measured precipitation in time interval $\Delta t$

$IR$ = Measured net irrigation depth in time interval $\Delta t$

$EXCESS$ = Losses due to runoff and deep percolation. These losses were not measured so data suspected of exhibiting an excess were screened out of the data sets.

Potential evapotranspiration was computed with the Jensen-Haise equation:

$$ET_p = (0.014\ T_a - 0.37)R_s \quad (2)$$

Where: $ET_p$ = Potential or reference evapotranspiration in inches per day

$T_a$ = Mean daily air temperature computed as $(T_{max} + T_{min})/2$; °F

$R_s$ = Solar radiation in inches of water equivalent; heat of vaporization was taken as 585 calories/gram

Data points over each time interval were then computed as:

$$K_{c\phi} = \left(\frac{ET}{ET_p}\right)_{\Delta t} \quad (3)$$

## RESULTS

### Crop Curves

Average curves for six crops are given in Figures 1 through 6 as functions of "Days Post Emergence" (DPE) or "Days After May 1" for alfalfa. These curves represent a best fit through the data points that were obtained from three to five years of data collection. Actual data points are included in Figure 1 to illustrate the degree of variability associated with these curves. Shown also in bar graph form are the approximate standard errors(SE) for each curve.

A polynomial regression procedure was used to fit fourth order polynomial equations to each data set. The coefficients for each crop are given in Table 1 for the equation form:

$$K_{c\phi} = C_1 + C_2\,(DPE) + C_3(DPE)^2 + \ldots C_n(DPE)^{n-1}$$

Where: $K_{c\phi}$ = Crop coefficient

DPE = Time base; "Days Post Emergence"

The $K_{c\phi}$ values in Figures 1 through 6 reflect the influences of incomplete ground cover on ET in the early season with values beginning near 0.1-0.2 at emergence. $K_{c\phi}$ after emergence increases in magnitude as crop cover develops to levels near 1.1 for each crop. This magnitude exceeds levels reported by others (8, 12) and is believed to reflect in part a calibration of the Jensen-Haise equation to the Oakes area. In the ripening and dessication period of the growing season, $K_{c\phi}$ values decline for crops exhibiting this phenomena. Not shown on the alfalfa curve are reductions in $K_{c\phi}$ following harvests. At cutting $K_{c\phi}$ typically falls to about .6 and then increases again to the level of the curve in 15 to 20 days.

### Crop Curve Accuracy

The $K_{c\phi}$ curves, as indicated earlier serve to convert an estimated $ET_p$ value to an estimate of actual crop ET. Curve position from year to year can be affected by different rates of crop development. Above or below normal temperatures in the early season vegetative growth period can somewhat shift the curves relative to the time base, days post emergence. Technicians should, therefore, visit fields periodically to carefully observe phenologic stages. Then, if needed, curve adjustments can be made by comparing growth stages in particular seasons with the average phenology vs. DPE relationships shown in each of Figures 1 through 6.

The $K_{c\phi}$ curves when used with Jensen-Haise equation estimates of $ET_p$ will be most reliable if the solar radiation input to this equation is compatible with the data that was used to derive these curves. The $R_s$ data were obtained with a silicon cell[1] solar radiometer. The calibration constant for this instrument was periodically checked by comparing measured $R_s$ on clear or cloudless days against the possible clear day solar radiation curve for the Oakes latitude. This curve was defined from data presented by Fritz (3) and is illustrated in Figure 1. It is suggested that users of the $K_{c\phi}$ curves given herein calibrate their $R_s$ measuring instruments against this curve.

[1]developed by Yellot Solar Energy Laboratory

Table 1. **Polynomial coefficients for crop curve equations where $K_{co}$ is computed as a function of days post emergence in southeast North Dakota.**

| | | |
|---|---|---|
| **Sugar Beets** | | |
| $C_1 = 0.1816588640$ | $C_2 = 7.3395297E-03$ | $C_3 = 3.288714E-04$ |
| $C_4 = -4.8427E-06$ | $C_5 = 1.75E-08$ | |
| **Corn** | | |
| $C_1 = 0.1814466119$ | $C_2 = -1.877271E-04$ | $C_3 = 7.004694E-04$ |
| $C_4 = -9.3707E-06$ | $C_5 = 3.12E-08$ | |
| **Spring Wheat** | | |
| $C_1 = 0.0697219372$ | $C_2 = 2.06960961E-02$ | $C_3 = 6.341268E-04$ |
| $C_4 = -1.80227E-05$ | $C_5 = 1.006E-07$ | |
| **Soybeans** | | |
| $C_1 = 0.1747183800$ | $C_2 = 3.1039866E-03$ | $C_3 = 5.743438E-04$ |
| $C_4 = -7.7158E-06$ | $C_5 = 2.33E-08$ | |
| **Potatoes** | | |
| $C_1 = 0.1473667026$ | $C_2 = 1.73054300E-02$ | $C_3 = 3.147318E-04$ |
| $C_4 = -8.0408E-06$ | $C_5 = 3.72E-08$ | |
| **Alfalfa** | | |
| $C_1 = 0.4507644773$ | $C_2 = 3.79602537E-02$ | $C_3 = -7.612063E-04$ |
| $C_4 = 6.1893E-06$ | $C_5 = -1.76E-08$ | |

Given also in Figure 7 are a five-year mean solar curve as observed at Oakes and a mean curve for Bismarck, ND which was based upon a 20-year record (1). These mean curves differ considerably in the May and early June period which may reflect more spring and early summer cloudiness in the climate at Oakes. A longer record, however, is needed to safely conclude this.

If daily ambient temperature, dew point temperature, wind run and net radiation data are available, the accuracy of $ET_p$ estimates can be improved by using a Penman type of equation. Jensen et al. (6) have shown that the original Penman equation must be modified in arid climates. More recently Pruit and Gupta (10) also discussed the need to calibrate the Penman equation in climates differing from the original location of its development. Stegman and Valer (11) compared $ET_p$ estimates obtained with the Jensen et al. (6) modified Penman equation to estimates of $ET_p$ with the Jensen-Haise equation. This comparison was made for Carrington, North Dakota and indicated the modified Penman equation estimates exceeded the Jensen-Haise estimates by an average 10.5 percent. Based on this comparison, it appears the curves in Figures 1 through 6 should be adjusted by about this percentage if this form of Penman equation is used to estimate $ET_p$.

Jensen and Wright (7) have demonstrated that the confidence limit at $P = .95$ for projection of an irrigation date can approach 0.4 day when their modified Penman equation is used. If the water balance model is based only upon climatic mean ET rates, the confidence limit increases to about 1.8 days. Estimates based upon the Jensen-Haise equation should fall between these values.

The crop curves presented herein have also been tested in a trial scheduling service by the authors. Year end checks of predicted vs. measured soil moisture deficits indicated good agreement was usually achieved. However, to achieve good agreement all inputs to the water balance computation must be accurate. Some uncertainty is often associated with the amount of irrigation water actually applied. Therefore, it is important that a technician visit each field on 7-14 day intervals to verify amounts and when necessary to correct the predicted soil moisture deficit.

### Root Zone Development

Water balance scheduling depends on definition of available water holding capacities in each field. This capacity depends in turn on soil types and the active root zone depth. In this study, depth advance was analyzed in each season at each ET sampling site. This analysis was accomplished by computing $ET/ET_p$ ratios for successive 6-inch increments of profile depth. That is, $ET/ET_p$ ratios over each time interval were computed for the 0-6″, 0-12″, 0-18″, etc. succession of depths to 48 inches. Data examination showed that the $ET/ET_p$ ratios would typically increase in magnitude from increment to increment until little or no water was being lost from the next 6-inch increment. A comparative analysis of the $ET/ET_p$ ratios was thus used to estimate the approximate rooting depth with time after crop emergence. Data from periods of excessive rainfall or irrigation were deleted.

Attempts to separate out the effects of differing soil types on root zone development did not produce further refinement of the data. Consequently, the data for each crop were lumped over all soil types from which ET data were obtained. While this may appear unrealistic in view of the range of soils involved, soil moisture sampling in coarse textured profiles such as Arvilla and Claire consistently revealed that corn roots did withdraw moisture to depths approaching four feet.

Curves of root zone advance are given in Figures 8 through 12 for sugar beets, corn, potatoes, wheat and soybeans. These data should be viewed as approximate information for the computation of available water capacities and selection of allowable depletions.

No root zone curve was developed for alfalfa. Water use was measured at depths below four feet for this crop. However, with water management regimes that will supply sufficient water for attainment of maximum yield potential, the major ET supply was observed to come from the upper four feet of root zone.

## SUMMARY

Crop curves as needed by commercial irrigation scheduling services have been developed for six crops. These curves are most applicable to southeast North Dakota and Jensen-Haise equation estimates of $ET_p$. Some user cautions were discussed, particularily with regard to the need for periodic field visits. These visits should be made to verify that crop phenology development is compatible with the crop curve position relative to the time base "Days Post Emergence." Curve position can then be adjusted as needed. Field test of a trial scheduling service has also revealed the need for periodic field visits to update and/or verify predicted deficit levels. Discrepencies between predicted and measured deficits are often associated with inaccuracies in reported amounts of applied irrigation water.

Curves showing approximate root zone advance with time after emergence are also presented. These curves should help users to better define available water holding capacities and allowable depletions in the early growing season.

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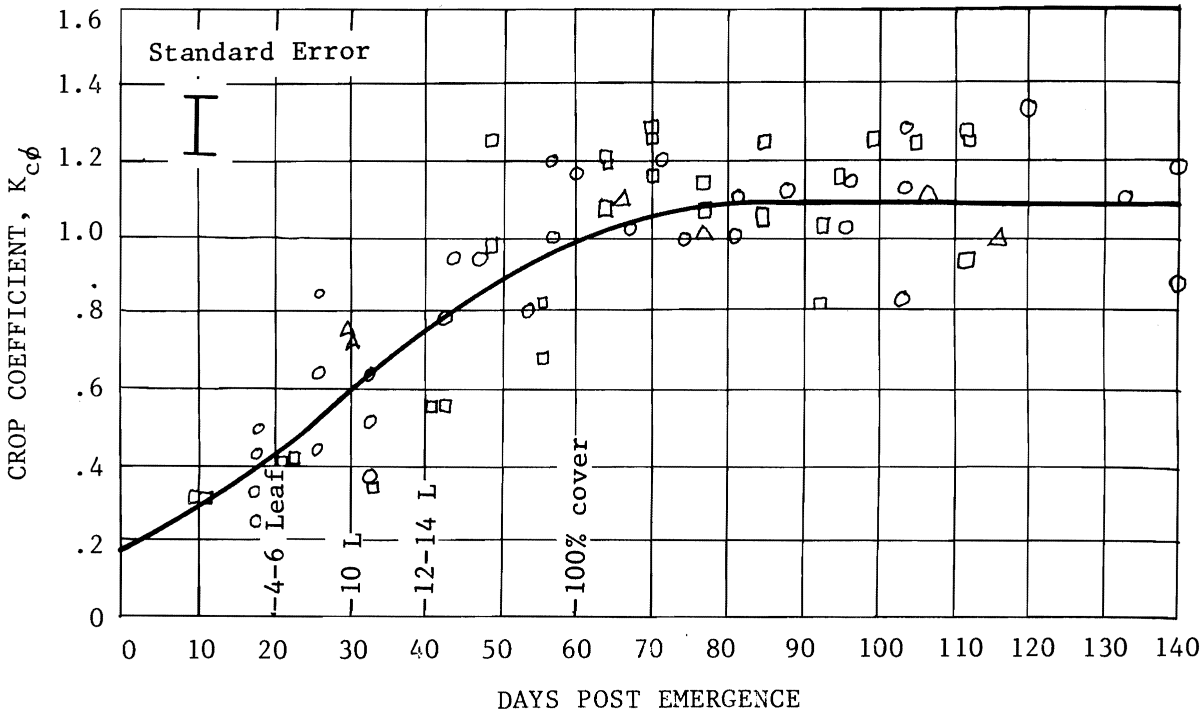


**Figure 1. Sugar beet crop curve for Jensen-Haise method of estimating evapotranspiration in SE North Dakota.**

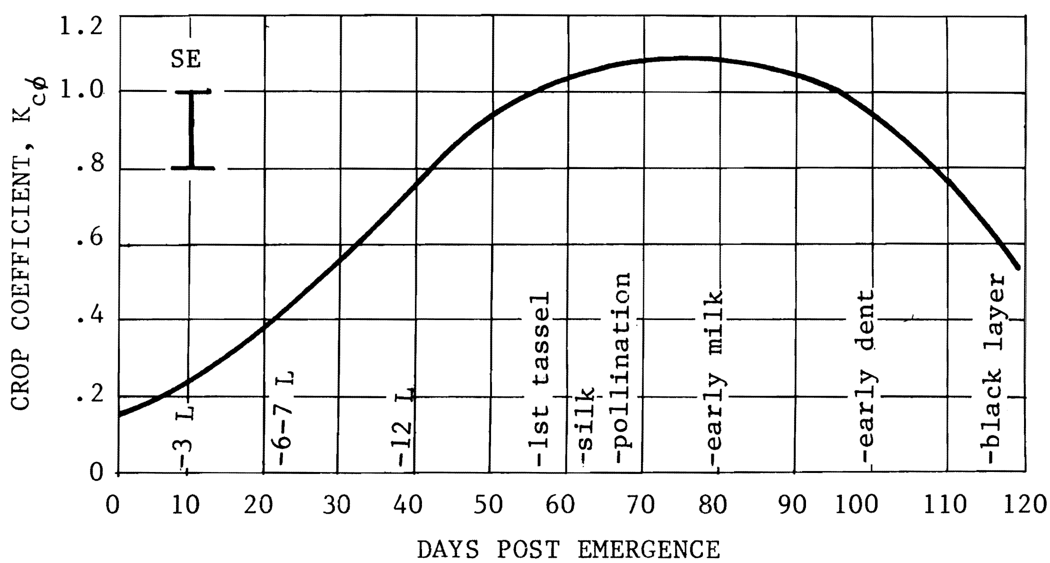


**Figure 2. Corn crop curve for Jensen-Haise method of estimating evapotranspiration in SE North Dakota.**

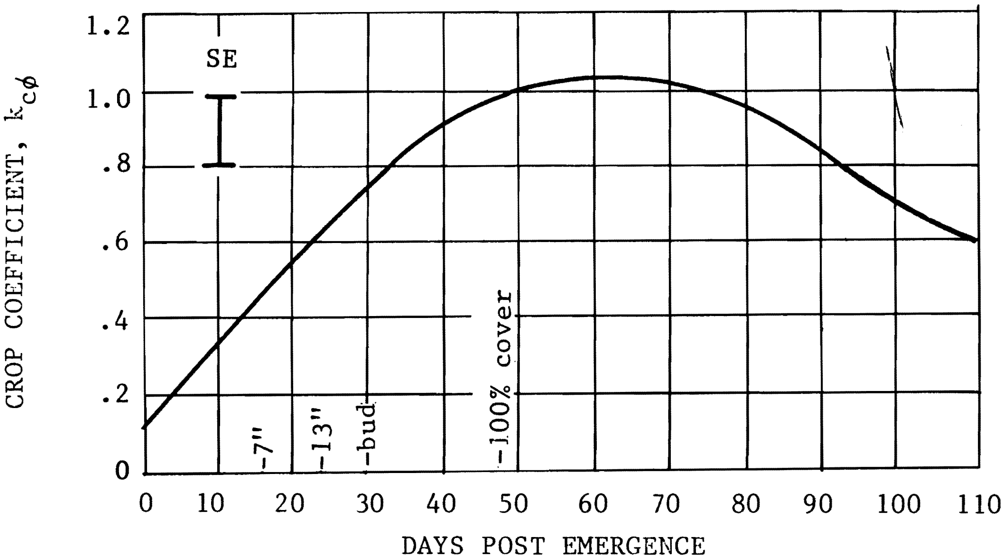


**Figure 3. Potato crop curve for Jensen-Haise method of estimating evapotranspiration in SE North Dakota.**

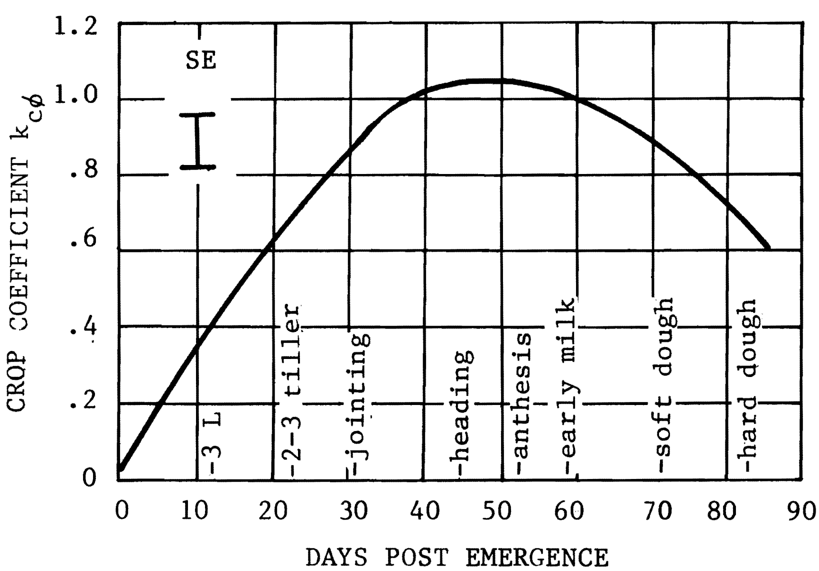


**Figure 4. Spring wheat crop curve for Jensen-Haise method of estimating evapotranspiration in SE North Dakota.**

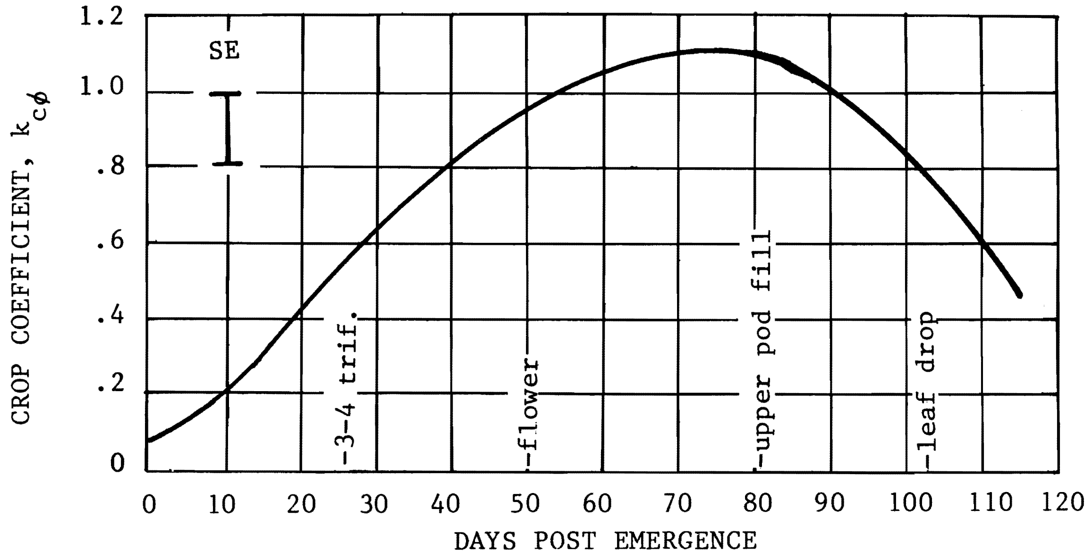


**Figure 5. Soybean crop curve for Jensen-Haise method of estimating evapotranspiration in SE North Dakota.**

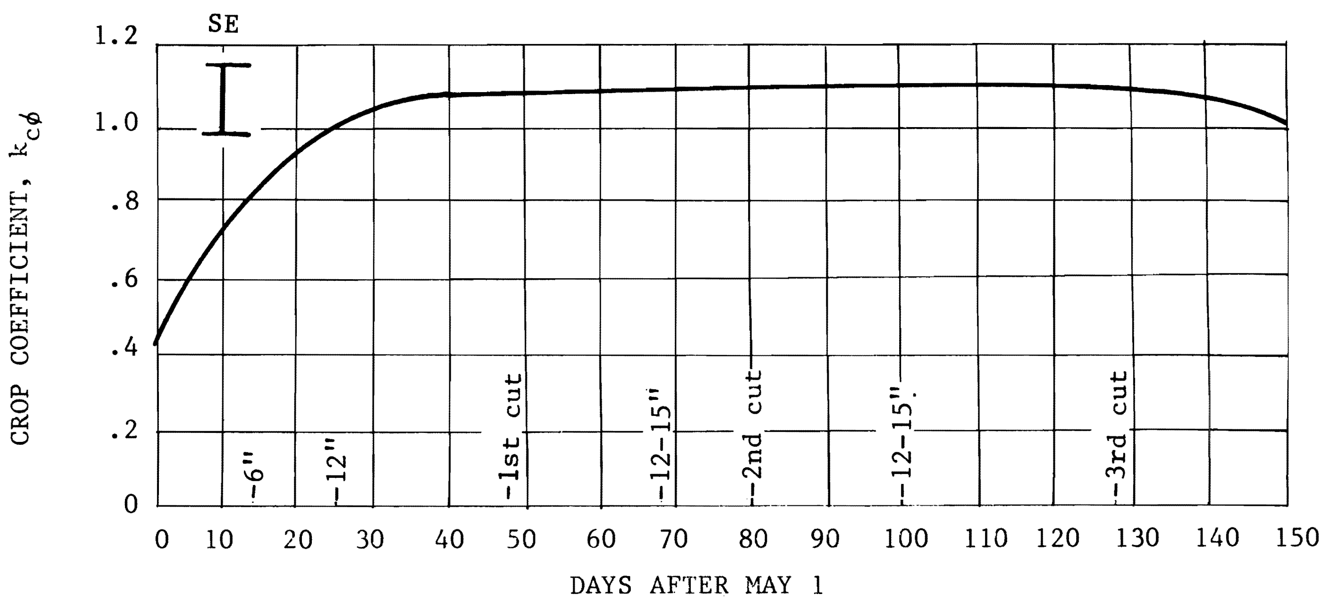


**Figure 6. Alfalfa crop curve for Jensen-Haise method of estimating evapotranspiration in SE North Dakota.**

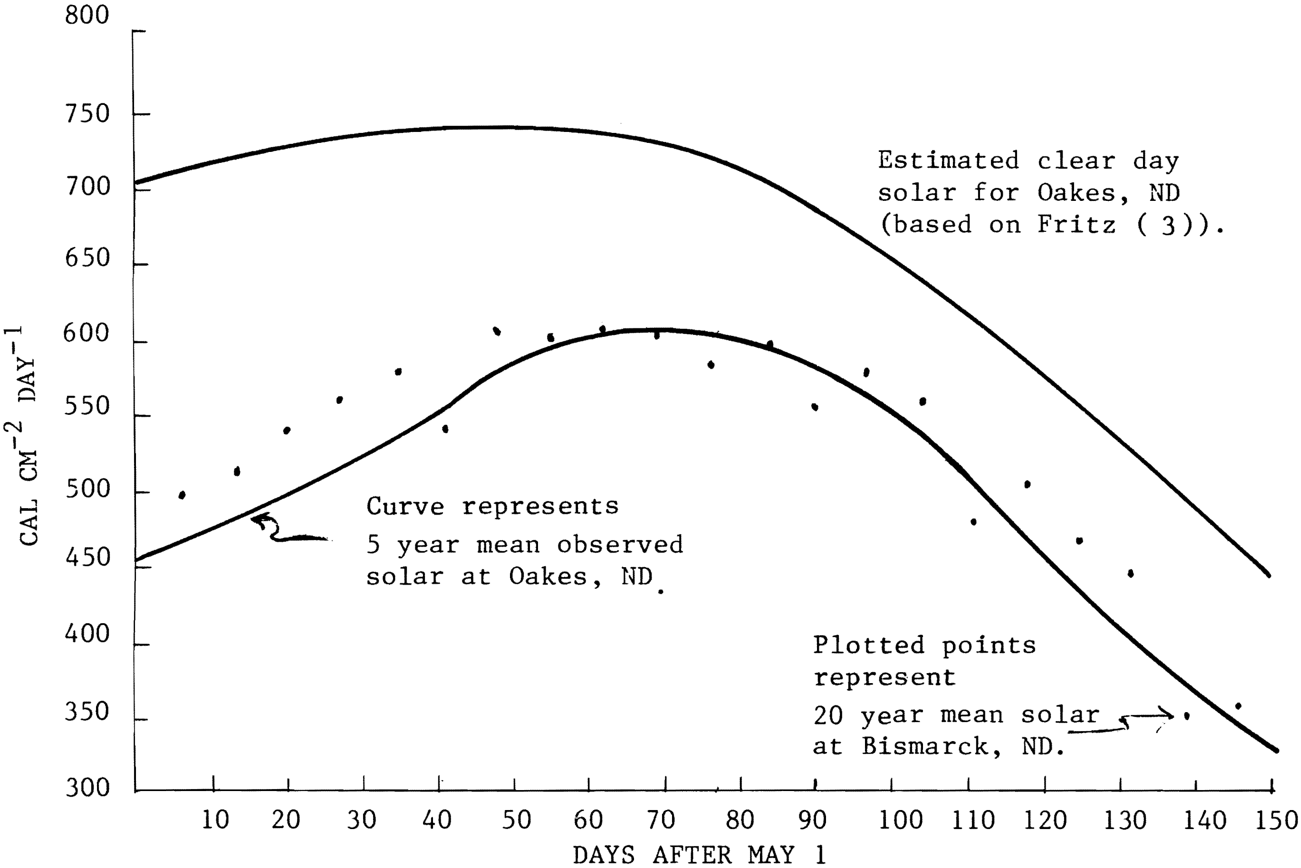


**Figure 7. Observed mean daily solar radiation at Oakes, North Dakota compared with long record for Bismarck and estimated clear day solar curve.**

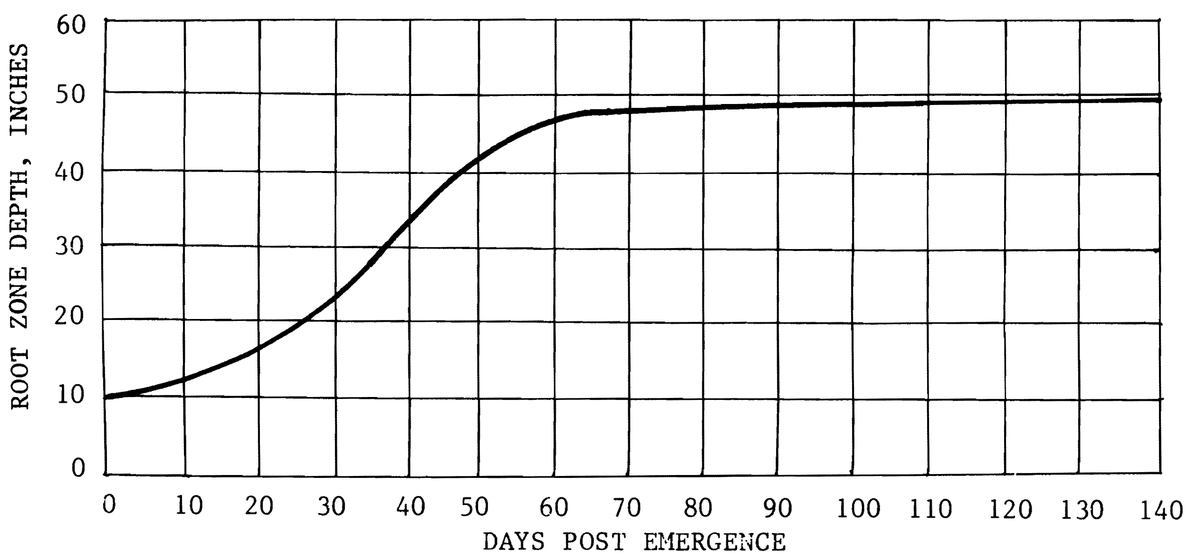


**Figure 8. Root zone depth development vs. days post emergence for sugar beets.**

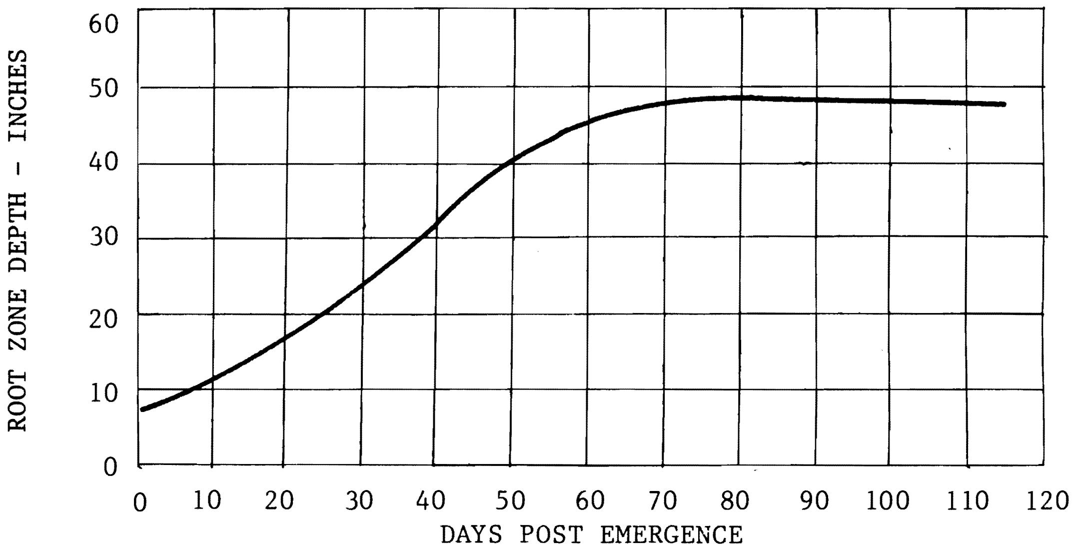


**Figure 9. Root zone depth development vs. days post emergence for corn.**

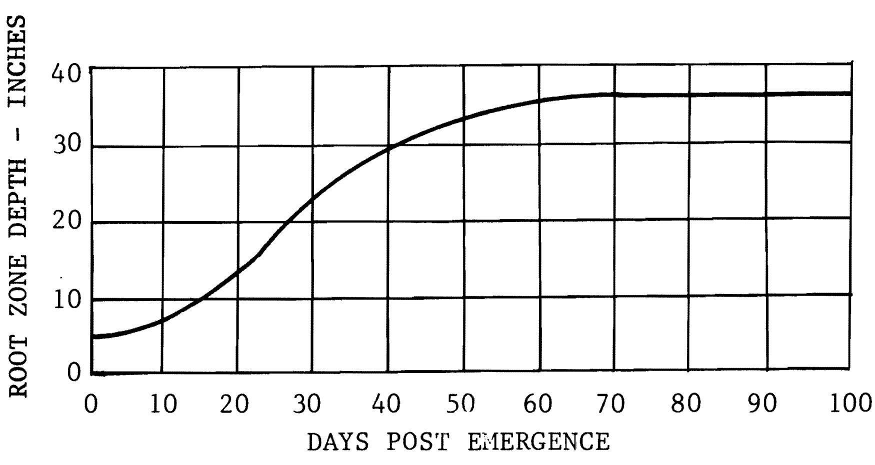


**Figure 10. Root zone depth development vs. days post emergence for potatoes.**

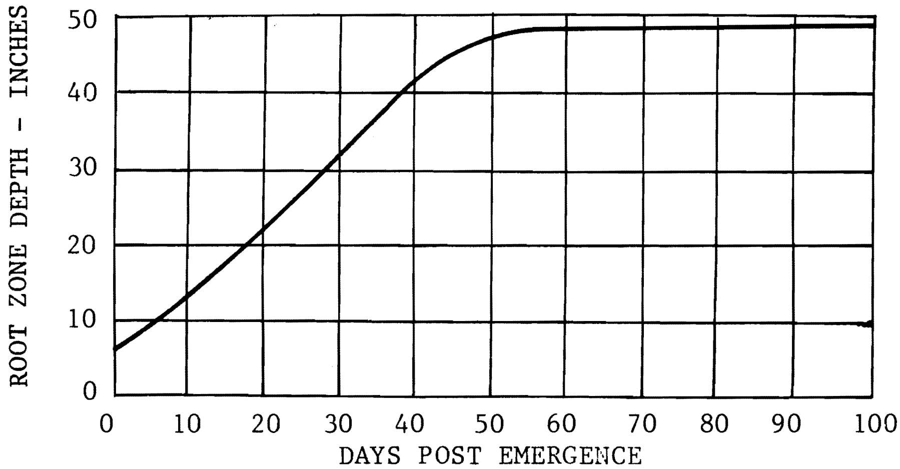


**Figure 11. Root zone depth development vs. days post emergence for wheat.**

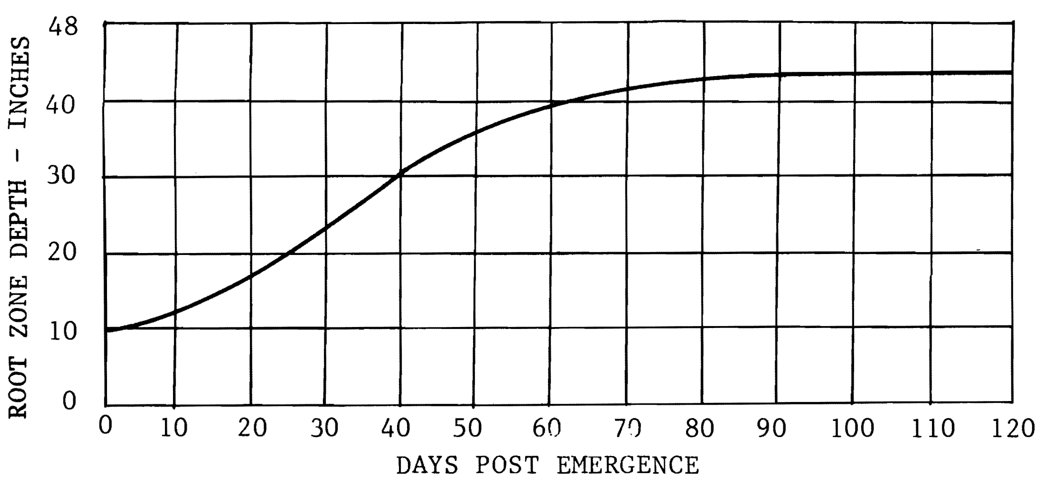


**Figure 12. Root zone depth development vs. days post emergence for soybeans.**