FIELD EVALUATION OF CORN CROP COEFFICIENTS BASED ON GROWING DEGREE DAYS OR GROWTH STAGE

by

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Summary:

This study reports the results of Colorado field tests of corn crop coefficient equations derived in Nebraska and based on either observed growth stage or cumulative growing degree days. These crop coefficients were tested for a range of planting dates and corn hybrid maturities.

Keywords:

corn, crop coefficients, growing degree days, growth stage, evapotranspiration

Field Evaluation of Corn Crop Coefficients Based on Growing Degree Days or Growth Stage

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Abstract.

This paper reports the results of Colorado field tests of corn crop coefficients derived in Nebraska based on either observed growth stage (GS) or growing degree days (GDD). These crop coefficients were tested for a range of planting dates and corn hybrid maturities. Generally, these crop coefficients estimate corn evaportanspiration (ET) more closely to water balance measurements of ET than did time-based (TB) crop coefficients. Coefficients based on observed growth stage or growing degree days simplify ET prediction and irrigation scheduling because adjustments for abnormal environmental conditions or planting dates are not necessary.

Introduction

Corn evapotranspiration (ET) can be predicted from models based on weather parameters (Jensen et al., 1990). These models predict reference ET which is then multiplied by a crop coefficient (Kco) to give estimated ET. Currently, Kco values widely used are based on time indexed from dates of planting and full cover. These time-based Kco work well under average planting and growing season conditions, but require periodic adjustment when non-average conditions occur. Crop coefficients based on growing degree days (GDD)or growth stage (GS) can automatically adjust for differences in growth due to non-average weather conditions.

Hinkle et al. (1984) derived corn crop coefficients based on observed GS or on GDD. This work was done in west-central and eastern Nebraska, with ET measured from weighing lysimeters.

The purpose of this study was to evaluate the accuracy of these GS- and GDD-based corn crop coefficients derived in Nebraska under varying planting date conditions for hybrids varying in number of days to maturity. The results are compared to both ET predicted by time-based Kco and measured ET from water balance calculations.

Procedure

The field evaluation was conducted at the Central Great Plains Research Station near Akron, CO during the 1991 and 1992 growing seasons. The soil type at this location is a Rago silt loam (fine montmorillonitic mesic Pachic Argiustoll). Three corn hybrids varying in days to maturity were planted at three planting dates (Table 1) to give a range of conditions varying from the normal planting date and temperature conditions. Growing degree days to maturity were determined from observations of these hybrids at Akron, CO during the 1987-1989 growing seasons.

Weather data were measured with an automated weather station located next to the experimental plot area. Parameters measured were daily maximum and minimum air temperature (°F), daily total solar radiation (MJ m^{-2} s^{-1}), daily average wind speed at 3 m (m s^{-1}), and daily average vapor pressure (kPa). These data were used to calculate reference ET (ETr) by the Penman-Monteith equation from the REF-ET computer program (Allen, 1990).

Precipitation was recorded manually from a standard raingage in the plot area.

Soil water measurements were taken weekly with a neutron probe at depths of 45, 75, 105, 135, and 165 cm. Soil water in the 0-30 cm layer was measured by time-domain reflectometry. Soil water was measured at four sites in each of the hybrid planting date combinations. Measured corn ET was calculated by the water balance method (Rosenberg et al., 1983) from changes in soil water content plus measured rain and irrigation. We assumed runoff and deep percolation were negligible. The plots were located on level ground, but were furrow-diked on every row to minimize runoff potential.

Table 1. Corn hybrids with respective days to maturity and growing degree days (GDD) to maturity, and planting dates.

CORN HYBRID	DAYS TO MATURITY	GDD TO MATURITY
Pioneer 3902	91	2281
Pioneer 3732	101	2405
Pioneer 3540	109	2559
PLANTING DATES	1991	1992
Early	25 April	30 April
Mid	29 May	19 May
Late	18 June	10 June

Irrigations were applied once a week through solid set, overhead sprinklers. Enough water was applied at each irrigation to bring the 0-90 cm soil layer back to field capacity to ensure a non-water-stressed plant condition. Irrigation application amounts were measured with gages at each soil water measurement location.

Corn growth stage was recorded weekly using the Hanway (1971) scale (0=emergence, 10=black layer). Leaf area index (LAI) was measured non-destructively weekly using a LI-COR Plant Canopy Analyzer (LAI-2000)[1].

Growing degree days were calculated as described in Hinkle et al. (1984) using the 50-90 heat stress method. Corn crop coefficients (Kco) based on GDD and GS are taken from Hinkle et al. (1984), and are given in Table 2.

The Kco for the time-based crop coefficient method are taken from Kincaid and Heerman (1974), and are given by the following equations:

$$Kco = 0.213 - 0.4276*X + 2.756*X^2 - 1.583*X^3 \qquad (1)$$

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[1]Trade names and company names are included for the benefit of the reader and do not imply any endorsement of preferential treatment of the product by the authors or the USDA.

where X is fraction of days from planting to full cover, and

$$Kco = 0.915 + 0.01195*X - 4.688E\text{-}04*X^2 + 2.75E\text{-}06*X^3 \quad (2)$$

where X is number of days after full cover, assuming full cover occurs at leaf area index of 3.0.

Additional evaporation from wet soil following rain or irrigation was computed as

$$Eadd = Kr * (0.9 - Kco) * ETr \quad (3)$$

where Kr = 0.8 for the first day after rain or irrigation
= 0.5 for the second day after rain or irrigation
= 0.3 for the third day after rain or irrigation (Duke et al., 1985)

Limits are placed on Eadd so that the summation of Eadd on days following rain or irrigation is always less than or equal to the amount of rain and/or irrigation, and Eadd equals 0 when Kco is greater than 0.9 (no evaporation from wet soil surface when full ground cover has been achieved).

Table 2. Corn crop coefficients (Kco) based on growing degree days (GDD) and observed growth stage (GS).

Growing Degree Day Method	
X	Kco
X = 0.15	Kco = 0.15
0.12 < X < 0.44	Kco = -0.18 + 2.738 * X
0.44 <= X <= 0.81	Kco = 1.02
X > 0.81	Kco = 3.208 - 2.698 * X
where X = fraction of total GDD required for maturity	
Growth Stage Method	
X	Kco
X <= 0.69	Kco = 0.15
0.69 < X < 4.27	Kco = -0.016 + 0.243 * X
4.27 <= X <= 8.17	Kco = 1.02
X > 8.17	Kco = 2.74 - 0.211 * X
where X = observed growth stage from Hanway (1974)	

Predicted corn ET (ETcorn) is calculated as

$$ETcorn = Kco * ETr + Eadd \quad (4)$$

Results and Discussion

Throughout most of the corn growing season, 1992 was cooler than 1991, resulting in a slower rate of GDD accumulation (Fig. 1). The three planting dates and three hybrids produced differences in date and duration of full cover conditions (Fig. 2). Hybrid 3902 accumulated the least amount of leaf area, and maintained it for a shorter period of time than the other two hybrids. Hybrids 3732 and 3540 were more similar in their accumulation and retention of leaf area.

In our analysis of the predictive accuracy of the various Kco methods, we present the percent error in cumulative ET between that predicted by the different Kco methods and the measured values from the water balance. This was done for the "before silking" period, and for the "after silking" period, and is shown in Figs. 3 and 4 for 1991 and 1992, respectively.

In general, the TB Kco tended to overestimate pre-silking ET. GDD and GS Kco tended to underestimate pre-silking ET for the first planting date, and tended to overestimate pre- and post-silking ET for the second planting date. In a majority of the 9 possible hybrid-planting date combinations in both years, the GDD and GS Kco estimated corn ET closer to measured ET than the TB Kco, both before and after silking (Table 3).

Analysis of the residual sums of squares (RSS) (Table 4) showed TB Kco more accurately predicted pre-silking ET in 1991 than the GDD or GS Kco. But the GDD and GS Kco gave closer estimates of corn ET for the post-silking period in 1991 and for pre- and post-silking periods in 1992. Estimates for total growing season ET were best predicted by GDD Kco in both 1991 and 1992.

Table 4 also shows the percent of possible combinations of planting date and hybrid where corn ET was predicted by the various Kco methods to within +/- 10% of measured ET.

Table 3. Number of 9 possible hybrid-planting date combinations where % error in predicted cumulative ET was less from GDD or GS Kco than from TB Kco.

Kco	1991		1992	
	Before Silking	After Silking	Before Silking	After Silking
GDD	5	7	7	5
GS	5	8	7	6

Table 4. Residual sums of squares (RSS), root mean square error (RMSE), and percent of all combinations of planting date and hybrid that had corn ET predicted to within +/- 10% of measured ET from crop coefficients based on growing degree days (GDD), observed growth stage (GS) or time (TB) for 1991, 1992 , and data combined over both years.

Year		Total Growing Season			Before Silking			After Silking		
		GDD	GS	TB	GDD	GS	TB	GDD	GS	TB
1991	RSS	24.3	34.8	34.5	13.1	17.1	5.6	7.3	7.7	39.0
	RMSE	1.74	2.08	2.08	1.28	1.46	0.84	0.95	0.98	2.21
	Percent within 10%	78	78	78	56	56	67	89	89	33
1992	RSS	14.5	17.2	25.4	6.4	8.2	8.3	7.7	4.4	36.9
	RMSE	1.35	1.47	1.78	0.90	1.01	1.02	0.98	0.74	2.15
	Percent within 10%	89	89	89	67	56	22	56	67	33
Combined	RSS	38.8	51.9	59.9	19.6	25.4	13.9	15.0	12.1	75.9
	RMSE	1.51	1.75	1.88	1.07	1.22	0.90	0.94	0.84	2.11
	Percent within 10%	83	83	83	61	56	44	72	78	33

Conclusions

Crop coefficients developed in Nebraska based on growing degree days or growth stage can be used to predict corn ET in northeastern Colorado. These crop coefficients generally produce more accurate estimates of corn ET than time-based crop coefficients over a wide range of planting dates, hybrid maturity lengths, and growing season temperature conditions. Coefficients based on observed growth stage or growing degree days simplify ET prediction and irrigation scheduling because adjustments for abnormal environmental conditions or planting dates are not necessary.

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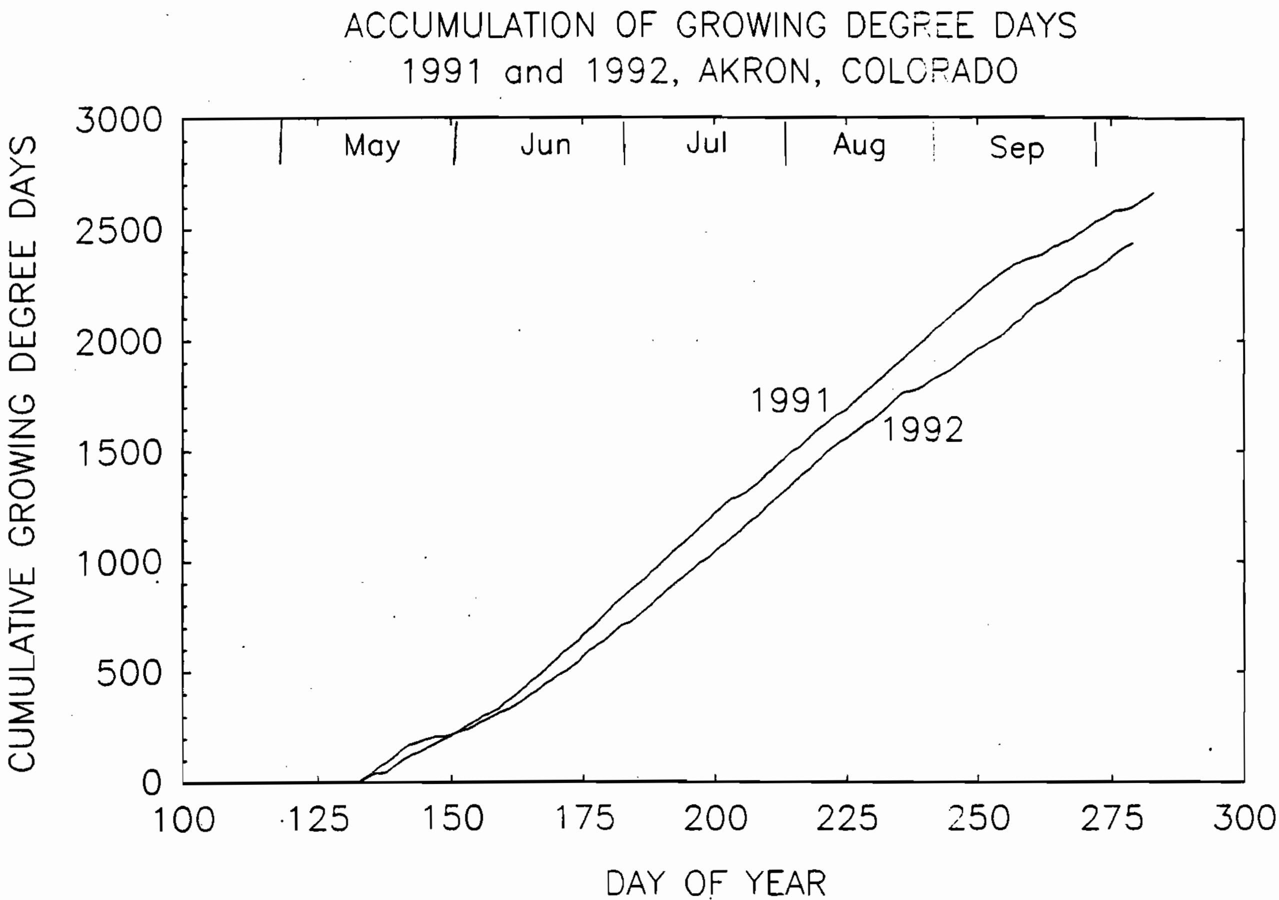

Figure 1. Cumulative 50-90 stress growing degree days versus time for 1991 and 1992 at Akron CO.

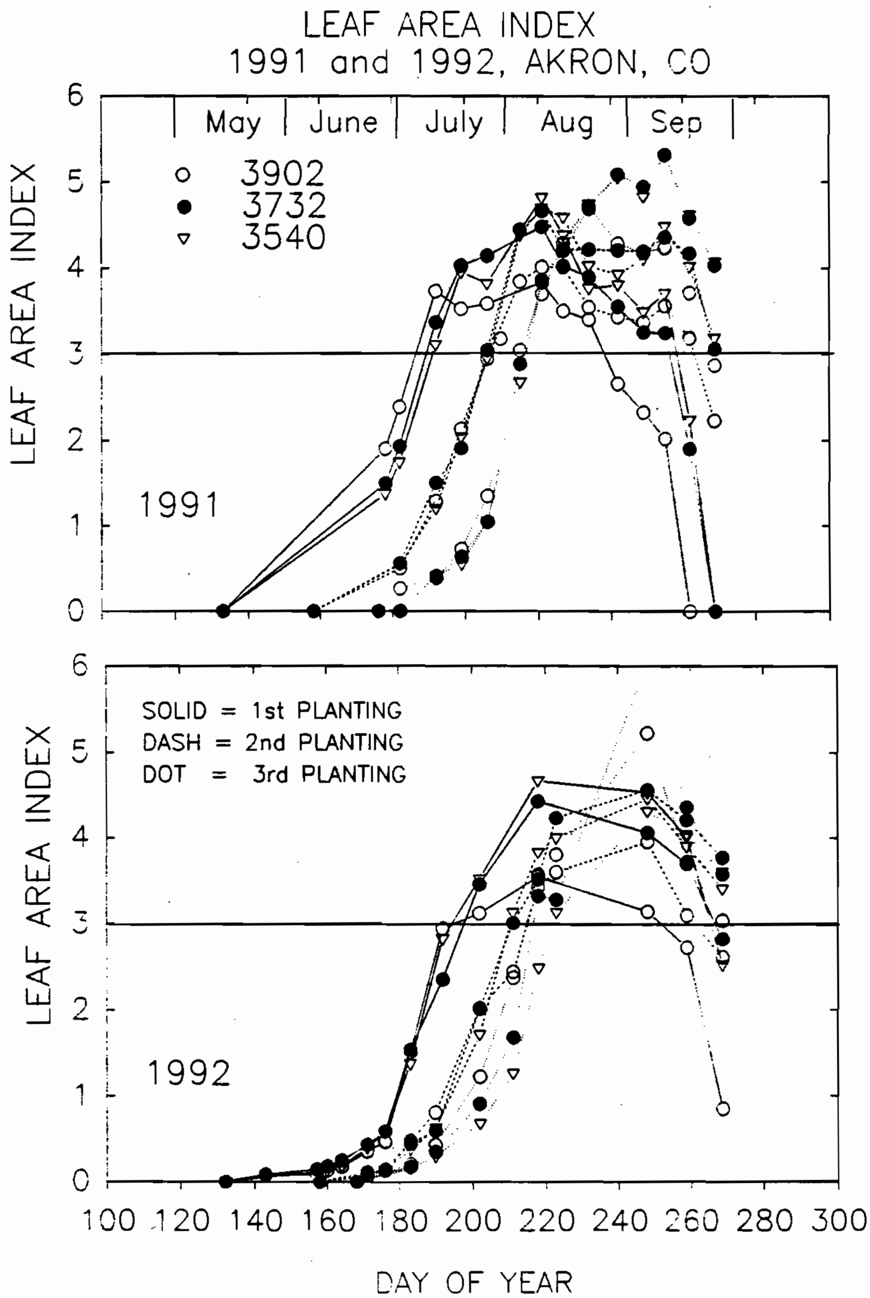

Figure 2. Leaf area Index for the three corn hybrids and three planting dates, for 1991 and 1992.

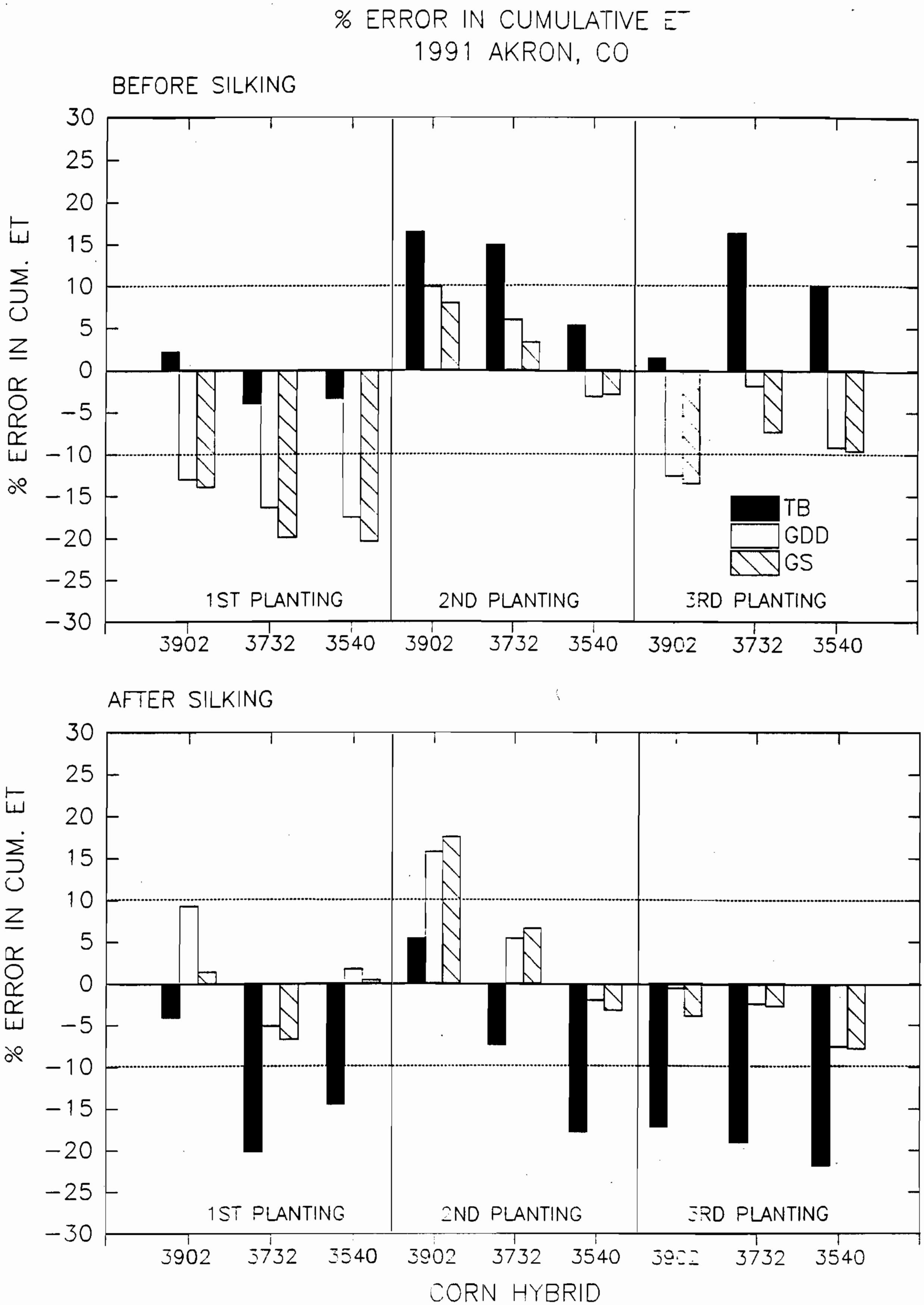

Figure 3. Percent error in predicted cumulative ET compared to measured ET for three crop coefficient models, three corn hybrids, and three planting dates in 1991.

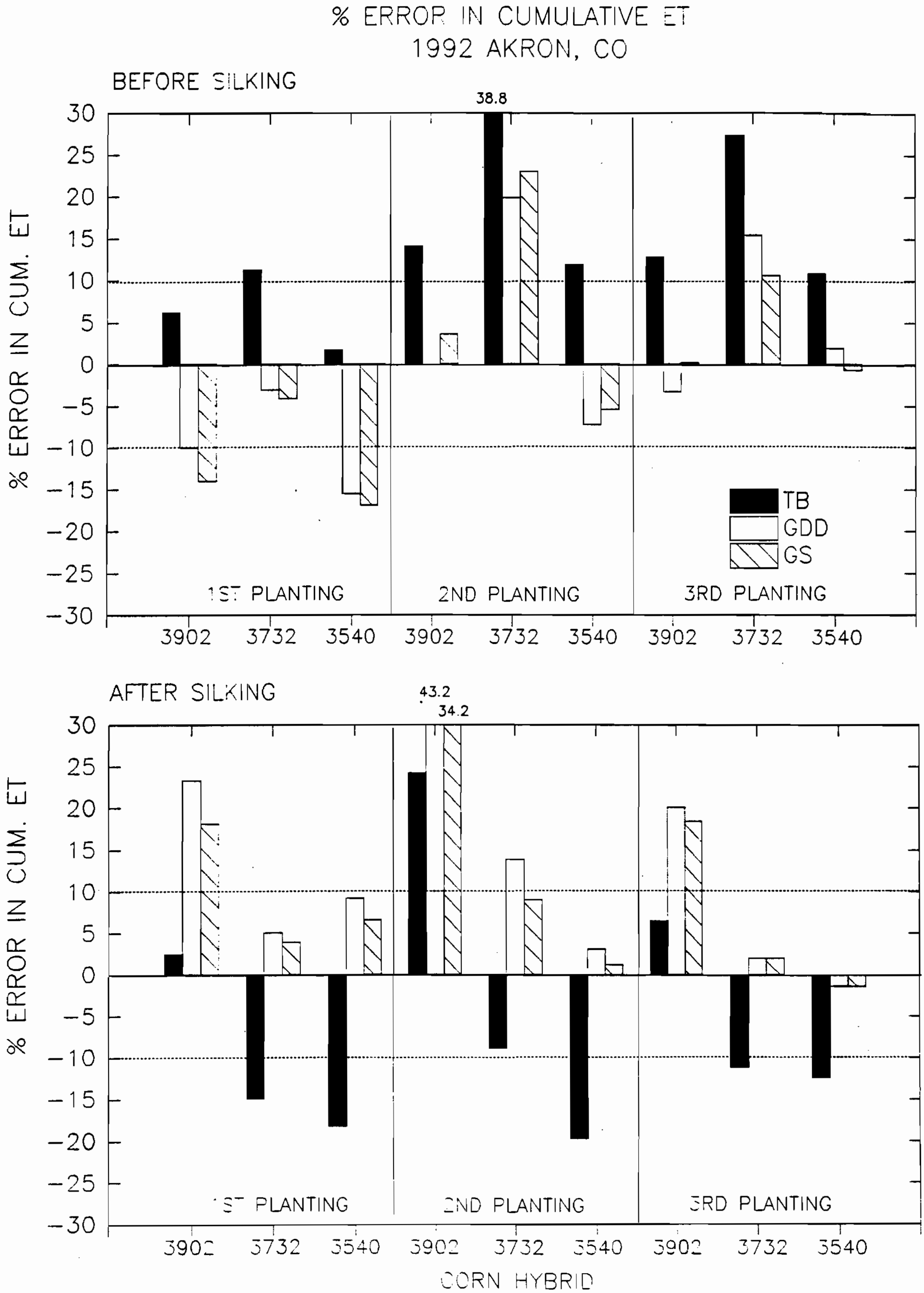

Figure 4. Percent error in predicted cumulative ET compared to measured ET for three crop coefficient models, three corn hybrids, and three planting dates in 1992.