Sugarbeet Emergence Affected by Soil Moisture and Temperature*

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INTRODUCTION

Sugarbeet production is often limited by total seedling emergence. A model simulating sugarbeet emergence for given climatic conditions would provide appropriate planting schedules for maximum emergence with minimum risk. A model could also indicate when total emergence occurs to determine if an adequate stand has been established for production.

A desirable stand of sugarbeets provides uniform spacing of plants throughout the field. This is obtained by either thinning or "planting to stand". Thinning of sugarbeets is the traditional method which involves physically removing unwanted sugarbeets to obtain a desirable average plant spacing (Fornstrom, et al 1972). Though an additional field operation is required, the restrictions placed on the emerged stand are less, requiring only a relatively thick stand with little variability. The "planting to stand" concept is being used in some areas as a viable planting method (Fornstrom, 1979). This practice, involving no field operations, will require final emergence rates to be high while maintaining a low variability in emergence.

Seedling emergence is affected by the soil temperature, soil moisture, aeration, and physical impedance (Bowen, 1966). Radke and Bauer (1969) found the optimum

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(Bowen, 1966). Radkee and Bauer (1969) found the optimum root temperature for the emergence of sugarbeets to be in the range from 25 to 35°C (77 to 95°F). The percent of sugarbeet emergence was shown to decrease rapidly for temperatures falling outside this range. Hunter and Erickson (1952) found that seed too dry for germination is subject to damage or destruction by soil fungi. Hunter and Erickson also observed that sugarbeet seed must attain a moisture content of approximately 31 percent to germinate.

Sugarbeets are hardy and will germinate at low temperatures but are sensitive to temperatures -3.0°C (27°F) or below when the hypocotyl is bent pulling the seed leaves from the soil. The average last -2.0°C (28°F) temperature in the spring in the Nebraska Panhandle is April 29. (Neild & Webb 1973). The most active planting dates for sugarbeets in the Panhandle are April 1 through April 10 (Fenster and Nelson 1977). Freezing temperature then becomes an important factor in obtaining a final stand of sugarbeets.

Precipitation during April averages 3.8 cm (1.50 in) (Colville and Meyers, 1965) and has both positive and negative effects on final emergence. Sugarbeets in the Panhandle of Nebraska are not irrigated for emergence and are almost entirely dependent upon spring moisture in order to achieve emergence. Once germination has occurred, precipitation from high intensity rains can hinder emergence by causing surface crusting. Precipitation also has an affect on the performance of preemergence herbicide (Aldrich, et al 1975). If the seed has been placed in moist soil but sufficient precipitation does not occur to activate a preemergence herbicide, damage may result due to the weed competition. Aeration is not considered a problem as the soils in the Nebraska Panhandle are light and water generally does not stand in the fields for long periods of time.

The primary concern for further simulation of sugarbeet emergence is to help understand the variability in the final number of plants emerged to aid the method used to obtain a desirable stand of sugarbeets. Fornstrom and Pochop (1974) have developed a model to describe the emergence of sugarbeets as a function of soil heat units at a constant moisture content. The research presented studies the combined effect of soil moisture and soil temperature on sugarbeet germination and emergence.

EXPERIMENTAL STUDIES

The main objective of these experiments was to determine the combined effect of soil moisture and temperature on sugarbeet germination and emergence. A secondary objective was to determine to what extent two types of laboratory studies could be used to define the soil moisture and temperature affects.

Monitoring sugarbeet emergence under field conditions can be costly and time consuming. To fully define the emergence of sugarbeets as affected by soil moisture and temperature, four experiments were undertaken. The first experiment determined the potential germination, under ideal conditions, of the sugarbeet seed that was to be used in the remaining studies. The second experiment measured the germination of sugarbeet seed under varying moisture stress conditions. Concentrations of polyethylene glycol solutions (Lawlor, 1970) were used to provide a method of simulating the emergence of many varieties of sugarbeet seed under several moisture stress conditions in a short period of time.

The third experiment observed laboratory emergence of sugarbeets using soil as a medium to simulate actual field conditions. This allows several soil moistures at a set temperature to be run easily. The final experiment determined emergence of sugarbeets under actual measured field conditions. This experiment was used to verify the germination and emergence results conducted in the laboratory.

Potential Germination

The procedure to determine the potential germination of sugarbeet seed follows closely those recommended by the Association of Offical Seed Analysts (1970). Potential germination was determined twice at the beginning of the study and once near the end. A statistical F-test was used to evaluate the total seeds germinated for each of the three replicates. The F-test showed no significant difference among replicates at the 5% level. The potential germination was determined to be 88.9%.

Stress Germination

The influence of moisture stress on the germination of sugarbeets was simulated using solutions of polyethylene glycol (average molecular wt. 6,000-75,000). The germination of sugarbeets in polyethylene glycol was carried out simultaneously with the laboratory sugarbeet emergence trials. Solutions of polyethylene glycol used represented 0, 0.15, 1.0, 5.0, 7.0, 9.0, 11.0, and 15.0 atm tension. Four replicates of each solution were tested at temperatures of 7, 10, 13, 16, and 20°C (44.6, 50.0, 55.4, 60.8, and 68.0°F). Chamber temperature was held constant throughout each test.

Seeds were placed in petri dishes on top of two layers of No. 42 Whatman filter paper soaked with 5 ml of the appropriate polyethylene glycol solution. Additional solution was added to individual petri dishes if the filter paper showed signs of drying. Drying did occur a small portion of the time, mainly in the low temperature tests but had no effect on the final test results.

Seeds were checked at least daily for germination and counts taken. Seeds were considered germinated when radicles became approximately 1 mm (.04 in) long.

One method used to evaluate the rate of germination is with the model developed by Fornstrom and Pochop (1974), given below:

$$\frac{e}{ef} = \frac{1}{\sigma\sqrt{2\pi}} \int_{0}^{HU} \exp\left\{-\frac{1}{2\sigma^2}(\log x - \mu)^2\right\} dx$$

where,

μ = sample mean = 4.505

σ = Standard deviation of sample = 0.158

x = heat units, beginning at the planting time.

With this model the emergence ratio (ratio of emergence for a given accumulated number of heat units to the final emergence) is a function of the soil heat units and follows a log-normal distribution. The time scale is fixed by the soil temperature characteristics during emergence. Laboratory emergence studies with soil moisture content, soil compaction, seed variety, and planting depth held constant indicated that the parameters of the distribution, i.e., the mean (μ) and the standard deviation (σ) of the sample also remained constant. Thus emergence time could be predicted by knowing the temperature characteristics (and thus accumulated heat units) during emergence.

The model was used in this study, first, to compare rate of emergence when both temperature and moisture varied and, secondly, to compare results obtained from the stress germination test with those obtained from the laboratory emergence study.

Heat units (HU) and the emergence rates (ER), given in equations 1 and 2, were calculated using Fornstrom and Pochops (1974) model:

$$HU = t(T - 4.4).85 \qquad (1)$$

where,

t = number of days from the planting date

T = temperature in °C

$$ER = e/e_f \qquad (2)$$

where,

e = number of plants emerged

e_f = final emergence count .

The emergence ratios were plotted as a function of heat units for each moisture content on log normal probability paper and best fit lines determined using the least squares technique. From these lines the sample mean ($\bar{x}$) and standard deviation (s) were found for each moisture content using equations 3 and 4:

$$\bar{x} - \ln\ (HU\ \%@\ 50\%\ emergence) \qquad (3)$$

$$s = \ln\ (HU\ @\ 40\%\ emergence) - \ln\ (HU\ @\ 50\%\ emergence) \qquad (4)$$

The mean values for each test ($\bar{x}$) represent the natural log of the heat units required for 50% emergence. The means for the stress germination test are given in Table 1. Statistical testing indicated different temperatures gave no change in the heat units required for germination. A significant difference of required heat units did occur due to the levels of soil moisture tension tested. As the moisture stress increased the amount of heat units needed for 50% germination also increased. The standard deviation (s) indicates the variation in heat units required for emergence. The standard deviations for the stress germination tests are given in Table 2. The variation of heat units needed for germination increases with higher temperatures and lower moisture tensions.

Table 1. Mean heat units ($\bar{x}$) required for germination of sugarbeets in the stress germination test using polyethylene glycol.

Simulated Moisture Stress (atm)	Temperature (°C) 7	13	16	20	Avg.
			x		
0	3.64	3.60	3.56	3.55	3.59^{c†}
.15	3.74	3.60	3.48	3.59	3.60^{c}
1	3.77	3.72	3.44	3.63	3.64^{c}
5	3.72	3.96	4.04	3.86	3.89^{b}
7	3.97	4.15	4.15	4.23	4.12^{a}
Avg.	3.77	3.80	3.73	3.77	3.77

†Average values followed by different letters are significantly different at the 0.05 level. Average values with no superscript letter indicate no significant difference.

Final germination percentages for the stress germination test are given in Table 3. At temperatures above 10°C (50°F), very little change in the total number of plants germinated were found. As moisture tension decreased the germination counts tend to increase. The maximum germination occurred at the lowest levels of stress and the highest temperatures.

Hough (1979) did a similar study using a mixture of sodium chloride and calcium chloride to determine the final emergence of sugarbeets under various moisture stress conditions at one temperature. Final germination as a

Table 2. Standard deviation (s) of the heat units required for germination of sugarbeets for the stress germination test.

Simulated Moisture Stress (atm)	Temperature (°C) 7	13	16	20	Avg.
			s		
0	0.36	0.44	0.53	0.73	$0.52^{a\dagger}$
0.15	0.34	0.40	0.60	0.47	0.45^{a}
1	0.37	0.45	0.58	0.53	0.48^{a}
5	0.30	0.17	0.28	0.40	0.29^{b}
7	0.19	0.20	0.20	0.24	0.21^{c}
Avg.	0.31^{b}	0.33^{b}	0.44^{a}	0.47^{a}	0.39

† Average values followed by different letters are significantly different at the 0.05 level. Average values with no superscript letter indicate no significant difference.

Table 3. Final germination (E_g) of sugarbeets for the stress germination test.

Simulated Moisture Stress (atm)	Temperature (°C) 7	10	13	16	20	Avg.
			%			
0	63	80	80	85	84	$78^{a\dagger}$
0.15	49	87	87	76	79	75^{a}
1	40	88	66	77	78	70^{b}
5	12	60	41	50	54	43^{c}
7	3	13	22	34	32	21^{d}
Avg.	33^{c}	65^{a}	50^{b}	64^{ab}	65^{a}	57

†Means followed by different letters are significantly different at the 0.05 level. Average values with no superscript letter indicate no significant difference.

function of simulated moisture tension using data from Hough's test and the germination stress test is plotted in Figure 1 and shows a good correlation with a linear correlation coefficient of 0.96.

Laboratory Emergence

Soil was used as a growth medium to better simulate actual field conditions in the laboratory. The sandy clay loam soil used in the sugarbeet emergence trials is found on the University of Nebraska Panhandle Station where the

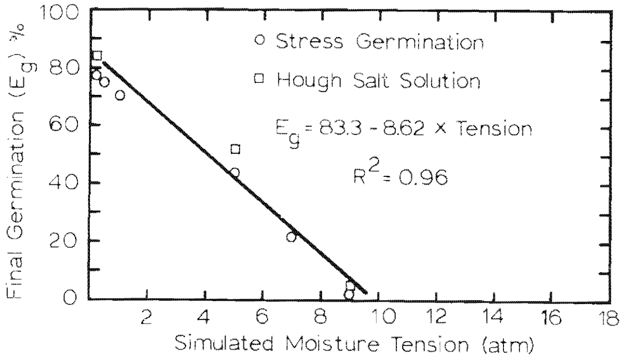

Figure 1. Comparison of Hough's salt solution sugarbeet emergence test and germination stress tests.

field studies were conducted and is also commonly found in the North Platte Valley. To remove any viable weed seed present in the sample, the soil was first autoclaved for one hour at a temperature of 121°C (250°F) and a pressure of 1.1 kg/cm^2 (15.6 lb/in^2). After air drying, the soil was passed through a 2 mm (0.8 in) sieve to obtain a homogenous sample and placed into plastic bags. Soil moisture samples were taken and distilled water was added to assure that proper moisture contents were attained. The soil was placed in a Freas (Model 818) germination chamber and mixed three times daily for three days to allow the soil temperature and soil moisture to reach equilibrium. At the end of this period, the soil was transferred to trays 28 x 17 x 13 cm (11 x 7 x 5 in) and covered with plastic bags.

Eighteen seeds were planted in each tray to a depth of 2.5 cm (1 in) after which, the soil was compacted with a pressure of 0.7 kgf/cm^2 (1 lb/in ^{2}). Moisture contents tested were 9.0, 11.0, 13.0, 15.0, 17.0, and 19.0 percent moisture (dry wt. basis). These correspond to 19.9, 7.0, 2.7, 1.2, 0.64, and 0.35 atmospheres of soil moisture tension, respectively, determined from pressure plate analysis of the soils used. Four replicates of each moisture level were tested at temperatures of 7, 10, 13, 16, and 20°C (44.6, 50.0, 55.4, 60.8, and 68.0°F).

Checks for emergence were made periodically until initial emergence was noted. Emergence counts were taken as deemed necessary, several times daily at high temperatures, and less frequently at low temperatures. This test monitored seedling emergence and not germination.

Following each test, those seeds which failed to emerge during the test period were removed and soil moisture samples taken to determine moisture levels.

To prepare for the next test, the soil was mixed periodically at a new temperature and allowed two days to reach equilibrium. The planting and monitoring procedure described above was repeated for each test using the same soil throughout.

The mean value ($\bar{x}$) and a standard deviation (s) for each test were calculated in a manner similar to that used for the stress germination study. The mean values ($\bar{x}$) for the emergence study are given in Table 4. Different temperature levels resulted in a small difference of the mean heat units required for emergence. Different moisture levels caused a significant difference in the heat unit requirements to attain 50% emergence.

Table 4. Mean heat units ($\bar{x}$) required for emergence of sugarbeets in the laboratory emergence test.

Moisture Stress (atm)	Temperature (°C)					
	7	10	13	16	20	Avg.
0.35	4.50	4.52	4.31	4.36	4.46	4.43^{c}†
0.64	4.64	4.28	4.62	4.37	4.34	4.45^{c}
1.2	4.47	4.53	4.33	4.44	4.46	4.44^{c}
2.7	4.55	4.53	4.85	4.69	4.76	4.68^{a}
7.0	4.60	4.65	4.40	4.62	4.81	4.62^{b}
Avg.	4.55^{a}	4.50^{b}	4.50^{b}	4.49^{b}	4.56^{a}	4.52

†Means followed by different letters are significantly different at the 0.05 level. Average values with no superscript letter indicate no significant difference.

The standard deviation (s) for each test is given in Table 5 and indicate only a small difference resulting from the moisture and temperature levels tested.

The final emergence data, given in Table 6 indicate no significant difference due to test temperatures but did show significance with moisture levels. Final emergence percentages were found best at low moisture stress regardless of the temperature.

Table 5. Standard Deviation (s) of the heat units required for emergence of sugarbeets for the laboratory emergence test.

Moisture Stress (atm)	Temperature (°C) 7	10	13	16	20	Avg.
	s					
0.35	0.09	0.11	0.11	0.11	0.11	0.11^{b†}
0.64	0.08	0.18	0.14	0.12	0.11	0.12^{b}
1.2	0.10	0.09	0.12	0.12	0.21	0.13^{b}
2.7	0.18	0.14	0.12	0.16	0.33	0.19^{a}
7.0	0.08	0.12	0.13	0.08	0.18	0.12^{b}
Avg.	0.10^{b}	0.13^{b}	0.12^{b}	0.12^{b}	0.19^{a}	0.13

†Means followed by different letters are significantly different at the 0.05 level. Average values with no superscript letter indicate no significant difference.

Table 6. Final emergence (E_f) of sugarbeets for the laboratory emergence test.

Moisture Stress (atm)	Temperature (°C) 7	10	13	16	20	Avg.
	%					
0.35	72	91	89	98	90	87^{a†}
0.64	90	85	93	85	94	89^{a}
1.2	87	90	93	85	89	89^{a}
2.7	85	79	85	79	62	80^{b}
7.0	57	67	61	56	60	60^{b}
Avg.	78	82	84	80	79	81

†Means followed by different letters are significantly different at the 0.05 level. Average values with no superscript letter indicate no significant difference.

Aura (1975) studied the effects of soil moisture on sugarbeet emergence with sand and clay soils. Final emergence as a function of soil moisture tensions using data from Aura's tests and the laboratory emergence study is plotted in Figure 2, with a linear correlation coefficient of $R^2 = .90$.

Field Emergence

Emergence trials of sugarbeets were conducted in the spring of 1977 at the University of Nebraska Panhandle

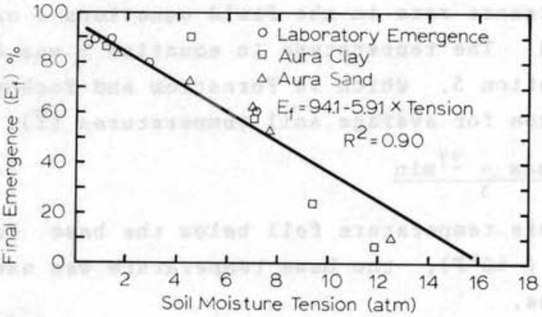

Figure 2. Comparison of Aura's sugarbeet emergence tests with laboratory emergence tests.

Station to establish a test procedure for collecting data. In 1978 a refined procedure was used to obtain more extensive data.

The procedure involved planting Great Western Pelleted Mono-Hy D2 sugarbeet seed in a sandy clay soil at approximately one week intervals, weather permitting. This resulted in six plantings: March 31, April 7, April 14, April 21, April 27, and May 9. Each test was irrigated immediately after planting to assure moist soil conditions for seed germination. Soil temperature at a depth of 2.5 cm (1 in) were monitored continuously for each treatment area using a Ledds and Northrup multi-channel strip chart recorder. Four copper-constantan thermocouples were connected in parallel to obtain an average temperature readout of an area 1.5 meters (5 ft) in diameter for each test. By making a vertical cut near the seed row, the thermocouple wires were pushed in place from the horizontal. Therefore, each thermocouple was positioned at a depth of 2.5 cm (1 in) in the seed row with approximately a 7.5 cm (1 in) diameter of undisturbed soil surrounding it.

Moisture content of the surface soil was determined approximately every third day by taking gravimetric samples. Three replicates of two 5 cm (2 in) core samples were taken in each test plot.

To determine the mean ($\bar{x}$) and standard deviation (s) of the emergence rate in the field equations 1 and 2 were again used. The temperature in equation 1 was calculated using equation 5, which is Fornstrom and Pochop's (1974) approximation for average soil temperatures ($\overline{T}$).

$$\overline{T} = \frac{T_{max} + 2T_{min}}{3} \qquad (5)$$

When this temperature fell below the base temperature of 4.4°C (40°F), the base temperature was used in the calculations.

The final emergence counts taken in the field are given in Table 7. Later plantings produced higher final emergence counts with the exception of the April 27th planting. A reason for this exception was not determined. No significant difference was found in the rate of sugarbeet emergence, with the mean ($\bar{x}$) and standard deviation (s) comparable to values found in the lab. The moisture content in the field never fell below 16 percent and soil crusting was not evident. Thus, soil moisture and physical impedance was not considered a stand limiting factor.

Table 7. Mean ($\bar{x}$) and standard deviation (s) of heat units required for sugarbeet emergence and final emergence (Ef) for the field emergence tests.

Planting Date	Heat Units	Heat Units	Final Emergence (E_f)
	$\bar{x}$	s	%
March 31	4.29	0.33	60
April 7	4.26	0.25	72
April 14	4.35	0.22	75
April 21	4.28	0.17	81
April 27	4.65	0.25	49
May 9	4.55	0.30	77
Avg.	4.39	0.25	69

RELATIONSHIP OF STUDIES

Three parameters were used as indicators of emergence properties, the mean and standard deviation needed to define the rate of emergence in the Fornstrom and Pochop model and the final emergence percentage.

The stress germination test seems to be inadequate for describing the relationship for all emergence parameters. Absolute values for the heat unit requirements and final germination percentages were expected to differ from those obtained from the emergence and field studies since the seedlings did not have to emerge through a layer of soil. However, the trend lines for the emergence parameters also differed significantly. As shown in Figures 3 and 4 both the mean and standard deviation are correlated with moisture tension in the stress test. There is very little correlation of the standard deviation in the emergence test, with no correlation of the mean. Final emergence relationships for the stress germination tests also differed from the emergence tests as shown in Figures 1, 2, and 5. The linear relationship for the final emergence as a function of soil moisture indicate for example that attaining a final emergence of 50% requires that the tension be less than about 4 atm for the stress germination test. Tensions of up to 8 atm attained 50% or better emergence in the laboratory emergence test. Field emergence rates of 50% were observed by Fornstrom et al (1979) for tensions up to 9 atm.

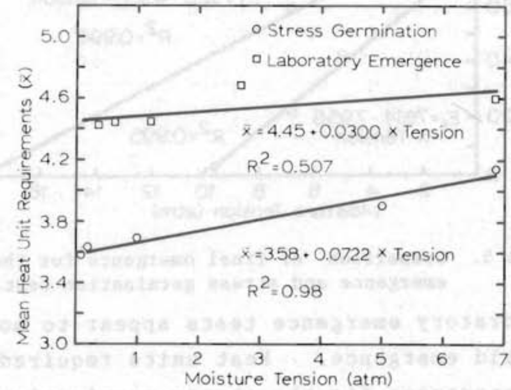

Figure 3. Comparison of the mean heat unit requirements for emergence of the laboratory emergence and stress germination tests.

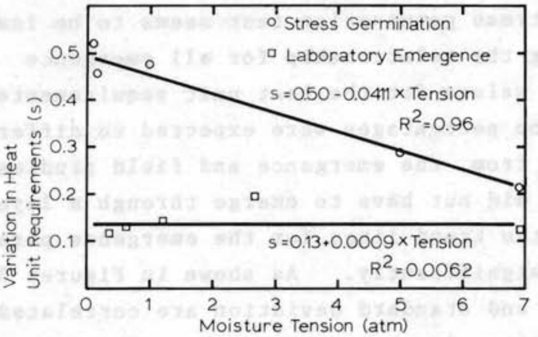

Figure 4. Comparison of the variation in heat unit requirements for emergence of the laboratory emergence and stress germination tests.

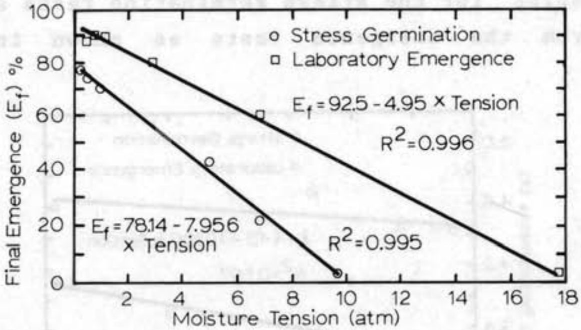

Figure 5. Comparison of final emergence for the laboratory emergence and stress germination test.

The laboratory emergence tests appear to more nearly simulate field emergence. Heat units required to reach 50% and 84% emergence for the stress germination, laboratory emergence, and field studies are given in Table 8. Heat unit values to obtain given levels of emergence found from the laboratory test followed closely the values measured from the field test, while the values for the stress germination test were much lower. Moisture condition during the field study conducted in the spring of 1978 was not a limiting factor to emergence and thus, could not be compared with the range of moisture tensions simulated in the laboratory. As indicated earlier, however, field data of Fornstrom et al (1979) does seem to agree with the laboratory emergence date.

Table 8. Heat units required by sugarbeets to reach 50% and 84% emergence for the stress germination, laboratory emergence, and field emergence tests.

Experiment	Moisture Tension (atm)	HU_{50}[†]	HU_{84}[††]
Stress Germination	.15	37	57
	5	49	65
	7	62	76
Average		49	66
Laboratory Emergence	.35	84	94
	2.7	108	130
	7.0	101	114
Average		92	105
Field Tests	[§]	81	104

[†] Heat units needed for 50% germination or emergence.
[††] Heat units needed for 84% germination or emergence.
[§] Moisture tenstion varied in the field from planting to final emergence.

Conclusions

From the results of this study it can be concluded that the emergence of sugarbeets is dependent on soil temperatures within the range of temperatures tested. When put on a heat unit basis the results indicate soil temperatures affects the rate of emergence but not the final number of plants emerged. As soil moisture tension increases, the emergence rate of sugarbeets is slowed. The linear relationship developed from the laboratory emergence model indicated that maintenance of soil .moisture tension less than about 6 atm would insure an emergence rate of 60% or more.

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