TECHNOLOGY EVALUATION AND DEVELOPMENT SUB-PROGRAM

FIELD EMERGENCE PREDICTORS FOR GRAIN CORN UNDER NO-TILL MANAGEMENT

FINAL REPORT

May, 1992

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EXECUTIVE SUMMARY

A simplified screening test for field emergence of grain corn
under no-till management.

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September 1991

Rationale

It has been shown that when no-till (NT) management is practised with grain corn, plant residues on the soil surface can accumulate, shading as much as seventy percent of the soil from the warming effect of the sun. Springtime soil temperatures are 4-8ºC cooler than under conventional till (CT) causing reduced seedling emergence and economic losses to farmers.

Objectives

A rapid, efficient laboratory measurement of corn cold tolerance during germination and early growth is needed to identify hybrids which germinate and grow best under cool NT conditions.

Methods

Two series of low temperature experiments (I and II) were carried out to do a detailed study (I) (see Part I) of germination on a small number of hybrids and a less detailed study (II) (see Part II) on as many hybrids as time permitted using the germination parameters identified in Series I as being the most efficient predictors of NT emergence under cool conditions.

In Series I experiments, seven hybrids each from DeKalb and Pioneer plus an internal standard, Pride 5, were studied. Germination was measured under optimal conditions at 25ºC. Root and shoot germination and also 1 cm shoot production were studied in detail over a period of up to 45 days at 11ºC. Growth of seedlings at 12ºC during 4 weeks in a growth chamber was also investigated.

Series II work focused on a survey of 126 hybrids chosen from the Ontario Hybrid Corn Performance Trials. Germination under near optimal conditions was verified at 25^{0}C. Readings on days 5 and 6 of germination at 11ºC were done for root germination and on days 20 and 22 for 1 cm coleoptile production.

In addition to Series I and II, a brief report is included on a field emergence experiment performed by a farm group in 1988. It was possible to relate field emergence data on five DeKalb and five Pioneer hybrids to laboratory data on time to produce a 1 cm coleoptile at 11ºC.

Results

Germination at 25^{0}C was uniformly high, in most cases exceeding 90% in both Series I and II experiments. Of the 126 hybrids studied in Series II, only 4 were rejected for further study because of germination below 80%. The viability of hybrid seed from commercial sources was found to be generally very good.

In Series I, growth at 12ºC over 4 weeks in a controlled environment chamber showed considerable contrast between hybrids with no potential to grow at this temperature and those which grew steadily. Interestingly, the check (internal standard), Pride 5, had the best genetic potential to grow under these cool conditions. Leaf number, chlorophyll content, anthocyanin content, plant vigour and root vigour were also studied but found not to be as efficient predictors of cold tolerance over the four weeks of study as root and 1 cm coleoptile production.

A detailed study of germination at 11ºC over 45 days completed Series I work. Data was analyzed using the SAS statistical package and correcting germination curves for deviations from 100% viability using PROC PROBIT. Time for 50% production of root, coleoptile and 1 cm coleoptile as calculated by the probit routine was taken as the most representative measure of each physiological response. The relationships among time-to-50% responses were investigated statistically. A highly significant correlation of 1cm coleoptile production (r=0.814, p=0.0002) to coleoptile germination was found while those to other physiological responses were not significant. Published data (H.J. Hope et al, 1992. Can.J. Plant Sci 72: 83-91) on time to 50% 1 cm coleoptile for 30 short-season maritime hybrids demonstrated a significant correlation with field emergence. In addition, a significant correlation (p=0.05) was found between time-to-50% 1 cm coleoptile production and the difference between field emergence under NT and CT (1988 field experiment). Further field work is needed to extend this limited comparison of laboratory and field data on 10 hybridsto a larger more representative group.

In series II, laboratory germination at 11ºC for 122 hybridswas studied. Data on percent root germination after 5 and 6 days and 1 cm coleoptile production after 20 and 22 days were compiled.The widest distribution of data was found for roots on day 5 and for 1 cm coleoptiles on day 22. Using these 2 growth parameters, several predictors of cold tolerance were investigated. A weighting of three times as much for 1 cm coleoptile germination asfor root germination is predicted to be most efficient (see conclusion 5) pending field verification.

Conclusions

1) Time to production of a 1 cm coleoptile is the best of the predictors of cold tolerance under NT management practices considered in this study probably because it gives a measure of low temperature tolerance to both germination and early growth. Use of this predictor allows easy identification of the above averagehybrids.

2) CHU ratings do not correlate with cold tolerance.

3) Seedling growth at 12ºC does not predict good cold tolerance during germination.

4) Rapid 1 cm coleoptile production correlates with minimal reduction in emergence of hybrids under NT as compared to hybridsunder CT in the limited one year field trial from 1988.

5) Use of a cold tolerance rating is proposed as an efficient method of identifying corn hybrids that will emerge well under cold NT soil conditions. Field verification of this laboratory-derivedrating calculation must also be done on a subset of the hybrids tested in the laboratory to assure the general applicability of the rating to hybrids grown in Ontario. Based on a rating scale from1 to 100, hybrids would be grouped into three cold tolerance groups: 1 (very good), 2 (good) or 3 (average). A cold tolerance rating for a given hybrid, based on laboratory measurements wouldbe calculated as follows:

$$[(\text{Days \%-germination}) + (3 \times \text{Day}_{22}\text{\%-germination})] / 4$$

PART I

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PART II

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1.0 INTRODUCTION

Under no till (NT) management, crop residues are left on the soilsurface in a relatively undisturbed state (Hummel et al, 1985). This practise is increasing in popularity in corn growing regions for several reasons. In addition to reducing costs of fuel, equipment, labour, and time, NT is also an important means of improving soil quality by increasing its content of organic matter, and promoting its conservation through erosion control (Carter and Barnett, 1987).

Increasing the amount of soil surface plant residues , has been shown to increase the water content and decrease the temperature of the soil by as much as 5.9ºC during the early planting season(Johnson and Lowery, 1985). This in turn decreases the rate of germination and emergence of the corn from 78% (moldboard) to 67% (NT) in early plantings (Mock and Erbach, 1977). Other groups such as Carter and Barnett in 1987 have also reported a decrease (7-12%) in emergence under NT. Reduced emergence is not a very important problem in warm, well drained areas but it can be significant in northern corn growing regions which have poor soil drainage and a shorter growing season (Griffith et al, 1988). In these regions, NT will often increase the probability of having low yields in a corn-only rotation. Experimental evidences indicates that decreased yield from NT can be minimized or eliminated with an appropriate rotation such as corn-soy beans. Especially on low organic matter poorly structured soils Griffith et al (1988) have demonstrated that "no-till planting should lead to increased yield potential inrotation corn (corn-soy bean) and equal yield potential in continuous corn, compared to continuous moldboard plowing."

Studies have shown that corn hybrids can respond differently to various tillage practises (Carter and Barnett, 1987). In a study of the reaction of four hybrids to varying tillage procedures, Kaspar et al (1987) demonstrated that "response to tillage varied significantly among hybrids". It would be an advantage to be able to select cultivars which were less susceptible to the lower springsoil temperatures found under NT management. Cold tolerance is heritable (Pinnell, 1949; Mock and Eberhart, 1972) and genetic variation exists for emergence at low temperatures (Eagles and Brooking, 1981) therefore it is important to choose hybrids carefully for NT management.

In 1988, a field study of grain corn was done to evaluate the usefulness of ten cultivars from two seed suppliers for NT management in south western Ontario. The objectives of this studywere to measure emergence and yield of different corn hybrids currently available to Ontario corn producers, and identify the most productive ones for growing under NT management practises. For a variety of reasons including the time (4 or 5 years) necessary to get results in field plots it was decided after the 1988 experiment to look for a rapid laboratory-based procedure. This would reduce the time necessary to identify promising hybrids for NT to 3 or 4 months and would permit as many repetitions as the system needed to give statistically valid results. This report describes the development of a procedure for identifying grain corn hybrids with superior tolerance of cold conditions during germination and early growth. In addition, reference is made to data from the 1988 field experiments and a resume of the protocol and results are presented in Appendix B.

2.0 MATERIALS AND METHODS

2.1 Low temperature germination

For each cultivar tested, groups of 25 seeds were placed embryo up in a square disposable plastic petri dish (9.5 x 9.5 x 1.5 cm) lined with Whatman #1 filter paper. To initiate germination, 5 ml of sterile distilled water were added to each dish as needed. These were then placed on a metal tray in a germinator at either 11.0ºC, or 25.0ºC (controls). In both cases, relative humidity was kept at 98% or higher. Triplicate 25-seed lots were germinated at 11.0ºC, and quadruplicates at 25.0ºC.

Visual observations on three germination parameters were taken daily for material at 11.0ºC, and every 12 hr for that at 25.0ºC and entered directly into a Radio Shack laptop computer using software written for these experiments. Germination was followed until no more changes were observed (usually 45 days at 11.0ºC and seven days at 25ºC). The time taken by each seed to germinate a root, acoleoptile, and for the coleoptile to reach a length of 1 cm was recorded. Upon reaching a coleoptile length of 1 cm, the seed was removed from the dish and discarded.

At the termination of experiments, data files were transferred electronically to a Digital Equipment VAX minicomputer for analysis. Time for 50% of the seeds to reach each of the measured stages was calculated for every cultivar and every replicate using the PROC FREQUENCY and PROC PROBIT procedures from the SAS software package. Where necessary, germination at 11ºC was corrected for less than 100% germination at 25ºC using the appropriate routine in PROC PROBIT. Other statistical calculations noted later in the test were also done using the SAS package of routines.

2.2 Low temperature growth

Seeds were germinated in a controlled environment germinator at 25.0°C and 98 % relative humidity for 3 to 4 days. Seedlings were then transplanted when the coleoptile had a length of about 3 cm,into a hydroponic growth system with Hoagland's solution. Fifty seeds were placed in each tray, three trays being prepared for each cultivar. These were placed in a growth chamber at 12.0ºC day and 10.0ºC night temperature, with a 16/8 h day/night photoperiod, 85-90 % relative humidity, and a light intensity of 600 Ue.m^{-2}.s^{-1}.

Every 2-3 days, the trays were rotated within a given growth chamber in order to nullify the effect of temperature and light variation within the chamber.

After 2, 3 and 4 weeks of growth, readings were made on each seedling for leaf number, leaf length (cm), visual chlorophyll rating, visual anthocyanin rating, plant vigour, and root vigour. In addition, the number of whorled plants in each tray was recorded. Data was recorded directly into a laptop computer and later uploaded to a VAX minicomputer. Pigment and vigour ratings were visually given on a scale of 1 to 5, a value of 5 indicating greatest intensity.

3.0 RESULTS AND DISCUSSION

3.1 Low temperature germination

Low temperature germination was followed at 11ºC (51.8ºF) using samples of seven DeKalb and seven Pioneer grain corn hybrids kindly donated by the companies. Seed was observed daily for appearance of root, coleoptile and a 1 cm coleoptile during germination overa period of 45 days (Table 1).

To establish a sense of direction based on the large number of germination values which were of potential use, calculations (Table 2) were done for the degree of correlation between three stages of root germination (30%, 50% and 70%; 'R30, R50, R70'), the slope of the germination curve between 30 and 70% (SL3070'), time to produce a 1 cm coleoptile ('COLE50') and the respective Ontario CHU ratings for each hybrid. Time to 1 cm coleoptile (1-CM) correlates well with time to 50% germination (COLE50) of the coleoptile (r=0.81, P=0.0002). Unfortunately, lab experience shows that coleoptile germination is much slower and more tedious to observe than time to1 cm coleoptile. Time to 30% root germination (R30) correlates highly with time to 50 (r=0.98) and time to 70% root germination (r=0.94) both at P=0.0001. Since all three of these values seem tobe telling us the same thing, R50 is the best choice as it is easiest to approximate on a large scale. It would be very convenient if one could calculate back from the already published data on CHUs to predict cold tolerance but the correlations are not good enough on combined data (Table 2) and when DeKalb and Pioneerdata are separated (Table 3) the relationship breaks down completely. A marginal correlation exists between Dekalb CHUs and1-CM (r=0.78, P=0.04) but there is none with Pioneer hybrids (r=0.04, P=0.93) Data from two values: time to 50% root germination, and time to 50% production of a 1-cm coleoptile (shoot) at 11ºC were analyzed in greater detail.

Over a five year period, data has been collected on hybrid corn emergence in the maritime provinces. During the last year of thisstudy, measurements of low temperature germination at 11ºC were done in our lab on subsamples of the same 30 seed-lots used for the plot experiments. The hybrids used in the maritime study were short season types

(<2500 CHU) possessing variable amounts of adaptation to the cool east coast maritime growing season (Hope et al 1990). The data from the maritime experiments supports the hypothesis that a short time to production of a 1 cm coleoptile is a good predictor of high field emergence. A short time to root appearance was also judged to be of considerable importance to NT management as it has been demonstrated that the reduction of emergence caused by low temperature increases susceptibility to seed and seedling diseases thus reducing seedling vigour (Schulz and Bateman, 1968).

Interestingly, in Table 1 the extremes are all found in two hybrids, DK 331 having the shortest times to root, coleoptile and 1 cm coleoptile production and P3475 having the longest times to these three stages. The hybrids used in this study are not represented in the maritime field emergence data but one can get a good indication of the usefulness of time to 1 cm coleoptile as a predictor of high field emergence for the fifteen study hybrids from 1988 southwestern Ontario (SWO) field data (Appendix B). A copy of this SWO data file, gathered by another group, was kindly sent to us for purposes of comparison by Dr. W. Findlay from Agriculture Canada in Harrow.

A limited analysis of the SWO data has been done and is presented in Appendix B. This analysis permits us to get an overview of the SWO data and to assess how it relates to the present study. In Table B1, the relationship of field emergence (EM143 to EM153) to time to root production (Root) and time to production of a 1 cm coleoptile (1 cm

Coleoptile) in the lab is studied. In addition, field emergence from the first and last day of data collection is plotted against the Root and 1 cm shoot lab data (Fig 7 and 8 in Appendix B) to give an indication of data spread and the linear regressions which can be drawn based on the data. In resume, the field data is not surprisingly more variable than lab data but doessupport conclusions based on lab results. Also the field data is consistent within itself - for example the correlation coefficients in Table 1, Appendix B, all tell us that the longer the time to produce root and shoot at 11ºC, the poorer the field emergence. The relationship is more difficult to demonstrate (level of confidence drops) as the plants get older. However, it is not surprising that the longer in time one is from an event the more difficult it becomes to show cause and effect. The SWO field data shows very interesting trends. It is too bad that it is just a little bit too variable to merit scientific publication.

The average for time to 1 cm coleoptile is 22.4 days (Table 1). The most cold tolerant half of the study group can be chosen easily bytaking those which have a value equal to or less than 22.4 days (identified by asterisks in Table 1): DK331, DK358, DK397, P3790, P3925, P3794, P3979 and Pride 5. By adding a second condition, that time-to-root-appearance must be equal to or less than the group average of 6.4d, our list is narrowed down to DK331, P3925, P3794 and Pride 5. In this group of four hybrids are the two best ('best' for rapid emergence and minimum decrease in NT emergence) from the 1988 field trials: P3925 and P3794 (P3794 was identified as XC174in 1988 graphs p 29). Of the remaining two, data from other experiments in progress at PRC indicate that Pride 5 has superiorcold tolerance leaving only DK331, a new hybrid from DeKalb in 1990, on which we have no corroborating evidence. Since DK331 has both the shortest time to root production, 4.9d, and the shortesttime to 1 cm coleoptile, 19.2d, the evidence points strongly towards it having superior field emergence.

3.2 Low temperature growth

The growth of all fifteen corn hybrids was followed in growth chambers at 12/10ºC (day/night) with 16h days for a period of four wk post germination. Readings were taken at the end of 2, 3 and 4 wk growth. Those for week four are presented in Table 4. Data are the means and standard deviations for three repetitions of 50 plants giving data on a total population of 150 plants per hybrid. Means for each value presented have been calculated including Pride 5. As Pride 5 had a plant height (20.4 cm) completely out of the range of the other hybrids (10.2 - 14.7 cm) after 4 wk, a second mean for plant height was calculated excluding this hybrid.

Of the four elite-emergence hybrids identified: DK 331, P3925, P3794, and Pride 5 only one, P3794 does not have an average leaf number above 4.8, the group average. Similarly three of the four elite hybrids: P3925, P3794, Pride 5 have plant heights greater than the group average of 12.89 and DK 331 with a value of 12.7 is close to the average. Growth of elite hybrids at low temperature parallels the superior emergence of the material. Other values[1] were also observed for growth at 12ºC but are not presented here as the trends are similar to those for leaf number, plant height and chlorophyll rating. The most interesting observation to come out of the growth experiment is that Pride 5 grows much better at low temperature than any other entry in the test group. This hybrid is available only to researchers as it has been taken off the commercial market.

A summary of results on growth at 12ºC for 4 wk and also root germination and 1 cm coleoptile production are presented in a three-dimensional graph, Figure 1. Caps on top of the vertical 'posts' in this graph are coded to indicate the seed supplier. Tolocate hybrids that grow will at los temperature, one looks for tall posts, that is, for large values in the GROWTH-axis (Z-axis).A short tome to low temperature root germination is found in entries which have a low value on the ROOT-axis (Y-axis) and rapid 1 cm coleoptile production is found at low values of the SHOOT-axis (X-axis). Entries represented by tall posts in the front right ofthe graph would be predicted to have superior low temperature tolerance.

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[1] Also measured: anthocyanin rating, plant vigour, number of whorled plants, root vigour.

Work done on seed germination at 25ºC is summarized in Appendix A. Seed Germination was very good, varying between 95 and 100 percent.A very small interval separated the highest and lowest values for each of the other three germination parameters summarized in the appendix. It was concluded that such small differences among hybrids would be of no use as predictors.

4.0 CONCLUSIONS

1. Time to production of a 1 cm coleoptile is the best of the predictors of cold tolerance under NT management practices considered in this study probably because it gives a measure of low temperature tolerance to both germination and early growth. Use ofthis predictor allows easy identification of the above average hybrids.

2. The addition of time-to-root-germination as a second constraint serves to identify the elite members within a populationof above average hybrids.

5.0 FUTURE DIRECTIONS

1. A germination container must be chosen to minimize the workof: setting up, watering, and reading.

2. Readings should be done on roots after 6d and on coleoptiles after 22d. The best half or best third of the hybrids under studycan then be easily identified using the coleoptile data without recourse to time consuming, complex calculations. If a further reduction in numbers is needed, the early rooting criterion can then be applied to hybrids identified by the coleoptile measurement.

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TABLE 1

Summary of time to 50% occurrence of: root germination, coleoptile (shoot) germination, and production of a 1 cm coleoptile for 15 grain corn hybrids grown at 11ºC. An asterisk indicates => group average. A small 'c' indicates combined above average values forroot germination and 1 cm coleoptile.

Hybrid	Ontario CHU	Root germination	Coleoptile germination	1 cm coleoptile
DK 331 c	2475	S 4.9/0.1*	S 8.8/0.2	S 19.2/1.1*
DK 358	2600	7.5/0.3	11.3/1.1	21.7/1.2*
DK 397	2775	6.8/0.4	10.2/1.0	21.4/1.7*
DK 403	2850	5.4/0.2*	12.5/0.4	25.4/1.0
DK 415	2950	5.9/0.3*	11.1/0.2	22.8/0.7
DK 435	2925	4.7/1.3*	12.3/1.2	22.7/1.0
DK 485	3050	7.1/1.2	11.8/1.9	24.3/2.0
P3790	2850	6.5/1.2	10.0/1.0	21.2/1.3*
P3772	2900	7.6/1.2	10.6/0.6	22.6/0.6
P3902	2700	7.5/1.6	11.4/1.5	22.9/2.0
P3925 c	2750	5.8/0.4*	9.7/0.2	21.2/1.0*
P3794 c	2950	5.5/0.2*	10.3/1.0	22.1/2.3*
P3475	3300	L 7.8/0.1	L 13.3/0.2	L 26.8/1.2
P3979	2325	6.8/0.5	10.4/0.5	21.5/4.2*
Pride 5 C	2700	6.4/0.7*	12.0/1.2	20.8/1.6*

Average +/- SD		6.4	11.1	22.4
		1.0	1.2	1.9

TABLE 2

Low temperature germination of all hybrids. Correlation coefficients for 50% 1-cm coleoptile (1-CM), 30% root germination (R30), 50% root germination (R50), 70% root germination (R70) root germination rate between 30 and 70% (SL3070), 50% coleoptile germination (COLE50) and for Ontario corn heat units (CHU) are presented. Statistical significance, is given below each coefficient (Values =<0.05 are acceptable).

	1-CM	R30	R50	R70	SL3070	COLE50	CHU
1-CM	1.00000	0.25023	0.26345	0.26750	-0.16758	0.81496	0.40826
	0.0000	0.3684	0.3428	0.3351	0.5505	0.0002	0.1308
R30	0.25023	1.00000	0.98325	0.94370	-0.25271	0.17714	-0.14507
	0.3684	0.0000	0.0001	0.0001	0.3635	0.5277	0.6060
R50	0.26345	0.98325	1.00000	0.98818	-0.41290	0.20753	-0.12683
	0.3428	0.0001	0.0000	0.0001	0.1261	0.4580	0.6524
R70	0.26750	0.94370	0.98818	1.00000	-0.53750	0.22826	-0.10975
	0.3351	0.0001	0.0001	0.0000	0.0388	0.4132	0.6970
SL3070	-0.16758	-0.25271	-0.41290	-0.53750	1.00000	-0.28338	0.11000
	0.5505	0.3635	0.1261	0.0388	0.0000	0.3061	0.6963
COLE50	0.81496	0.17714	0.20753	0.22826	-0.28338	1.00000	0.30005
	0.0002	0.5277	0.4580	0.4132	0.3061	0.0000	0.2772
CHU	0.40826	-0.14507	-0.12683	-0.10975	0.11000	0.30005	1.00000
	0.1308	0.6060	0.6524	0.6970	0.6963	0.2772	0.0000

TABLE 3

Correlation coefficients based on DeKalb, Pioneer, and DeKalb plus Pioneer hybrids combined for the variables: time to 50% 1-cm coleoptile (1-CM) and Ontario corn heat units (CHU). Statistical significance, is given below each coefficient (Values =<0.05 are acceptable).

	Hybrids	1-CM	R30	R50	R70	SL3070	COLE50	CHU
1-CM	DeKalb +	1.00000	0.25023	0.26345	0.26750	-0.16758	0.81496	0.40826
	Pioneer	0.0000	0.3684	0.3428	0.3351	0.5505	0.0002	0.1308
CHU	DeKalb +	0.40826	-0.14507	-0.12683	-0.10975	0.11000	0.30005	1.00000
	Pioneer	0.1308	0.6060	0.6524	0.6970	0.6963	0.2772	0.0000
1-CM	DeKalb	1.00000	-0.00101	0.02733	0.05007	-0.23439	0.89059	0.77561
		0.0000	0.9983	0.9536	0.9151	0.6129	0.0072	0.0404
CHU	DeKalb	0.77561	-0.01925	0.05184	0.10743	-0.44558	0.71323	1.00000
		0.0404	0.9673	0.9121	0.8187	0.3164	0.0720	0.0000
1-CM	Pioneer	1.00000	0.71605	0.66374	0.60077	-0.16136	0.97547	0.04207
		0.0000	0.0703	0.1040	0.1537	0.7296	0.0002	0.9286
CHU	Pioneer	0.04207	-0.15846	-0.24889	-0.31303	0.53573	-0.12529	1.00000
		0.9286	0.7344	0.5904	0.4942	0.2152	0.7890	0.0000

TABLE 4

Growth of fifteen grain corn hybrids in a growth chamber at 12ºC. An asterisk or a '+' indicates an above average value.

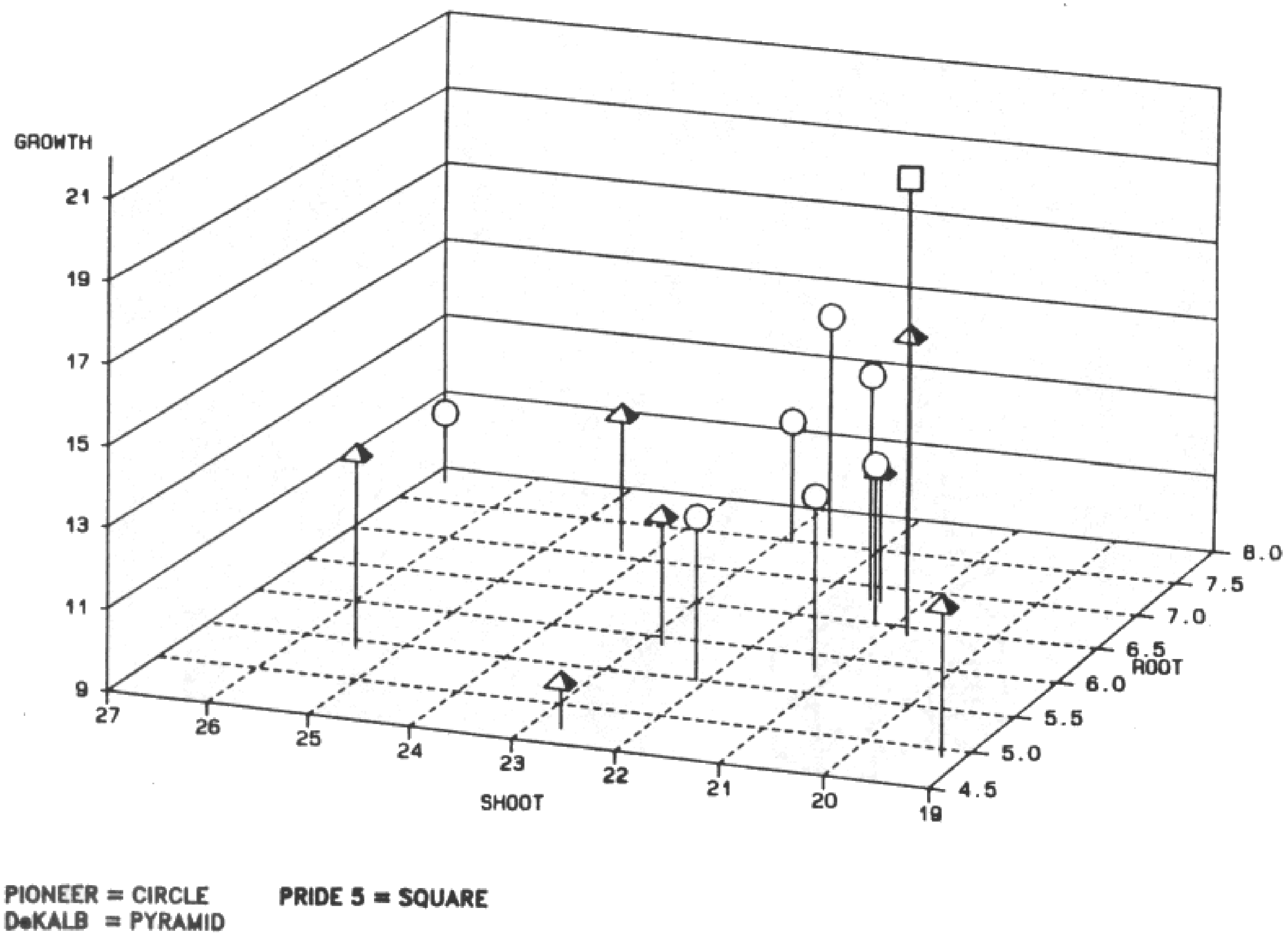
Hybrid	Ontario CHU	Leaf Number	Height cm	Chlorophyll Rating
DK 331	2475	5.1/0.4*	12.7/0.7	3.0/0.2
DK 358	2600	5.1/0.2*	14.7/0.5*+	3.4/0.1*
DK 397	2775	4.8/0.3*	12.4/1.1	3.3/0.4*
DK 403	2850	5.1/0.2*	13.9/0.1*+	3.7/0.1*
DK 415	2950	4.8/0.2*	12.3/0.4	3.2/0.3
DK 435	2925	4.7/0.2	10.2/0.2	2.7/0.2
DK 485	3050	4.5/0.1	12.6/0.5	3.4/0.1*
P3790	2850	4.3/0.4	13.0/0.6+	3.5/0.2*
P3772	2900	5.0/0.1*	14.7/0.8*+	3.8/0.1*
P3902	2700	3.9/0.4	12.1/0.1	3.2/0.1
P3925	2750	5.2/0.2*	13.3/1.0+	2.9/0.4
P3794	2950	4.3/0.2	13.0/1.2+	1.8/0.6
P3475	2700	4.7/0.2	10.8/0.6	3.2/0.2
P3979	2325	5.4/0.4*	14.7/1.8*+	3.6/0.1*
Pride 5	2700	5.1/0.1*	20.4/0.3*+	4.0/0.2*

Average +/- SD		4.80/0.41	13.39/2.34(*)	3.25/0.53

Notes: An average height, 12.89/1.36, excluding Pride 5 was calculated, values above it are indicated as '+'.

[1] - scale of 1(chlorotic) to 5 (dark green) was used.

Fig. 1. **RELATIONSHIP OF CORN ROOT GERMINATION AND SHOOT PRODUCTION TO GROWTH AT LOW TEMPERATURE - SUMMER 1990**



7.0 APPENDIX

7.1 APPENDIX A

Summary of time to 50% occurrence of: root germination, coleoptile (shoot) germination, and production of a 1 cm coleoptile for 15 grain corn hybrids grown at 25°C (77.0°F)

Hybrid	Germination %	Time to 50%		
		Root	Coleoptile	1 cm
DK 331	100	1.30/0.03	2.20/0.20	3.26/0.09
DK 358	95	1.77/0.09	2.54/0.13	3.92/0.20
DK 397	100	1.68/0.17	2.26/0.14	3.45/0.15
DK 403	100	1.51/0.13	2.68/0.25	3.65/0.18
DK 415	99	1.85/0.08	2.44/0.32	3.31/0.17
DK 435	99	1.33/0.06	2.63/0.08	3.43/0.21
DK 485	99	1.96/0.08	2.76/0.13	3.97/0.31
P3790	99	1.72/0.16	2.77/0.22	3.83/0.21
P3772	100	2.24/0.12	3.06/0.20	4.65/0.28
P3902	100	1.94/0.07	2.80/0.11	4.00/0.35
P3925	100	1.99/0.14	3.07/0.29	3.94/0.35
P3794 (XC174)	100	1.94/0.15	3.18/0.27	4.02/0.40
P3475	96	1.81/0.11	2.94/0.11	3.90/0.28
P3979	99	2.18/0.08	3.24/0.24	4.28/0.24
Pride 5	100	2.15/0.25	3.12/0.30	4.12/0.30

7.2 Appendix B: SUMMER 1988 PLOT EXPERIMENTS ON THE FARM OF MURRAY LOBB, GODERICH TWP., HURON CO., ONTARIO

CONTENTS

1. OBJECTIVES

The trials were designed to make a side by side comparison of conventional mouldboard plow tillage (CT) and no-till (NT) management practices for grain corn hybrids with respect to their influence on: 1) emergence, 2) growth rate, 3) dry matter accumulation, 4) flowering date; and 5) yield.

2. MATERIALS AND METHODS

2.1 Plant material

Two commercial seed suppliers provided seed which they believed would show a good range in potential for superior performance under NT management:

Test No	Hybrid	Test	Hybrid
1	DeKalb 358	6	Pioneer 3790
2	DeKalb 397	7	Pioneer 3772
3	DeKalb 403	8	Pioneer 3902
4	DeKalb 415	9	Pioneer 3925
5	DeKalb 435	10	Pioneer XC174

2.2 Soil, plot design, location

The field was set up in two strips under the Tillage 2000 design. Within each tillage treatment, hybrids were planted by randomly assigning them to a planter unit within blocks replicated five times down the field (Fig. B1). The blocks were 7m long and contained 12 rows, the two outside rows being buffers to eliminate border effects. The rows of corn were planted in a north-south direction on a Burford silt loam. The Burford series soils are well-drained and have been developed on loam or sandy loam overlying gravelly materials.

2.3 Planting and tillage equipment

A Kinze planter equipped with bubble coulters and Yetter furrow disks with notched blades was used to plant six rows at a time. Conventional plowing was done with an White model 548 mouldboard plow having 40.6 cm (16 inch) 619 general purpose bottoms. The cultivator used was an International Vibrashank with 20.3 cm (8 inch) sweeps, double pass, rear mounted harrow.

A planting rate of 27,000 plants per acre was planned at a depth of 1 3/4 inches. Fertilization was done at planting at a rate of 170 lb/acre of 5-26-30 and also on June 16 a side dressing of 28% nitrogen at the rate of 135 lb/acre was administered.

2.4 Herbicides

Herbicide was applied on May 14. A mixture of metolachlor (Dual, 0.8 L/acre) and 2,4-D amine, 0.5 L/acre (Korn oil concentrate) was used. On June 1, 2 lbs/acre active atrazine, 4.5 L/acre Korn oil was used followed by spot spraying with glyphosphate (Round-up) on June 5.

2.5 Sampling

Data was collected for the variables under observation (see OBJECTIVES above) in the following way:

Emergence counts were carried out from the date that 10% of the anticipated stand was visible until emergence was completed (May 23 to June 2, 1988). Counts were made at the Tillage 2000 benchmark sites for each replicate.

Growth rate was followed by measuring the heights of five randomly selected plants on a weekly basis beginning at the 3-leaf stage and continuing for the following 5 weeks.

Dry matter accumulation was measured 5 times during the growing season beginning at the 3-leaf stage and continuing at 2-week intervals untilmaturity. The final sample was at harvest. Above ground portions of five plants were removed at each sampling and dried at 80ºC to constant weight.

Flowering date was defined as the day when 50% of the silks had emerged. In practice, this was the day when the count fell between 40 and 60%. Observations were made on the same benchmark plants as were used for the emergence counts.

Yield was determined by hand harvesting a five-plant sample from eachhybrid plot and drying at 80°C. Observations made at harvest were: a) Dry matter on a 5-plant sample separated into 1. stalk + leaves + husk, 2. whole ear (dried),3. shelled dry grain; b) Grain yield estimated from the harvested hybrid row in each replicate using hand harvest from the bench mark sites.

2.6 Calendar

Planting was done May 10,1988.

Sample	1	2	3	4	5	Harvest
Stage	3-1f	5-1f	-	-	-	-
Date	May 24	June 7	June 21	July 1	July 15	Nov 2,3

3. RESULTS

3.1 Table

Table 1 Correlation coefficient and statistical significance (probability) of time to produce a root and a 1 cm coleoptile at 11C with 1988 field data on yield, moisture percentage, dry matter and percent emergence.

	Root	1 cm Coleoptile
Yield	-0.214	-0.005
	(0.032)	(0.960)
Moisture	-0.193	0.109
Percentage	(0.054)	(0.280)
DMC52	0.480	-0.223
	(0.0001)	(0.026)
DMC61	0.080	-0.003
	(0.430)	(0.980)
DMC74	0.153	0.080
	(0.128	(0.427)
DMC88	0.224	-0.024
	(0.025)	(0.813)
EM143	-0.212	-0.125
	(0.034	(0.217)
EM144	-0.148	-0.117
	(0.142)	(0.248)
EM145	-0.131	-0.100
	(0.194)	(0.324)
EM146	-0.167	-0.081
	(0.096	(0.421)
EM147	-0.148	-0.051
	(0.140)	(0.611)
EM153	-0.221	-0.034
	(0.027)	(0.734)

3.2 Figures

Figure 1. Plot plan for randomized placement of corn hybrids on Murray Lobb farm.

Figure 2. Field emergence for conventional and no-till management of DeKalb 358, 397 and 403.

Figure 3. Field emergence for conventional and no-till management of DeKalb 415 and 435.

Figure 4. Field emergence for conventional and no-till management of Pioneer 3772, 3790 and 3902.

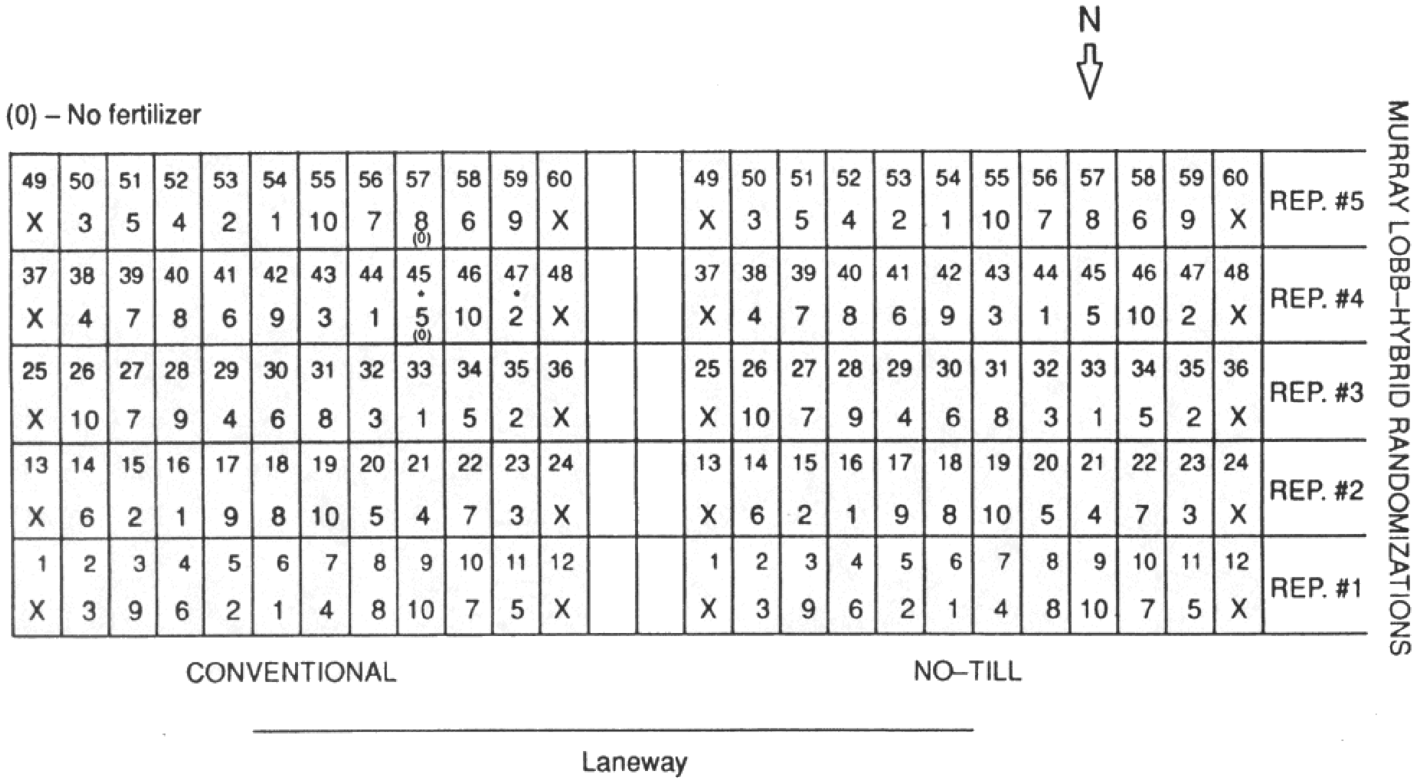
Figure 5. Field emergence for conventional and no-till management of Pioneer 3925 and XC174.

Figure 6. Yield means and coefficient of variation for 1988 field trials under conventional and no-till management systems.

Figure 7. Field emergence on May 22 1988 (Julian date 143) and June 1 (Julian date 153) plotted as a function of time to produce a 1 cm shoot at 11°C. Straight line represents a linear regression.

Figure 8. Field emergence on May 22 1988 (Julian date 143) and June 1 (Julian date 153) plotted as a function of time for the primary root to appear at 11°0. Straight line represents a linear regression.

Fig. 1



CONVENTIONAL

49 X	50 3	51 5	52 4	53 2	54 1	55 10	56 7	57 8 (0)	58 6	59 9	60 X		
37 X	38 4	39 7	40 8	41 6	42 9	43 3	44 1	45 • 5 (0)	46 10	47 • 2	48 X		
25 X	26 10	27 7	28 9	29 4	30 6	31 8	32 3	33 1	34 5	35 2	36 X		
13 X	14 6	15 2	16 1	17 9	18 8	19 10	20 5	21 4	22 7	23 3	24 X		
1 X	2 3	3 9	4 6	5 2	6 1	7 4	8 8	9 10	10 7	11 5	12 X		

NO–TILL

49 X	50 3	51 5	52 4	53 2	54 1	55 10	56 7	57 8	58 6	59 9	60 X	REP. #5
37 X	38 4	39 7	40 8	41 6	42 9	43 3	44 1	45 5	46 10	47 2	48 X	REP. #4
25 X	26 10	27 7	28 9	29 4	30 6	31 8	32 3	33 1	34 5	35 2	36 X	REP. #3
13 X	14 6	15 2	16 1	17 9	18 8	19 10	20 5	21 4	22 7	23 3	24 X	REP. #2
1 X	2 3	3 9	4 6	5 2	6 1	7 4	8 8	9 10	10 7	11 5	12 X	REP. #1

Fig. 2. EMERGENCE FOR CONVENTIONAL AND NO-TILL MANAGEMENT
PLOT DATA SUMMER 1988

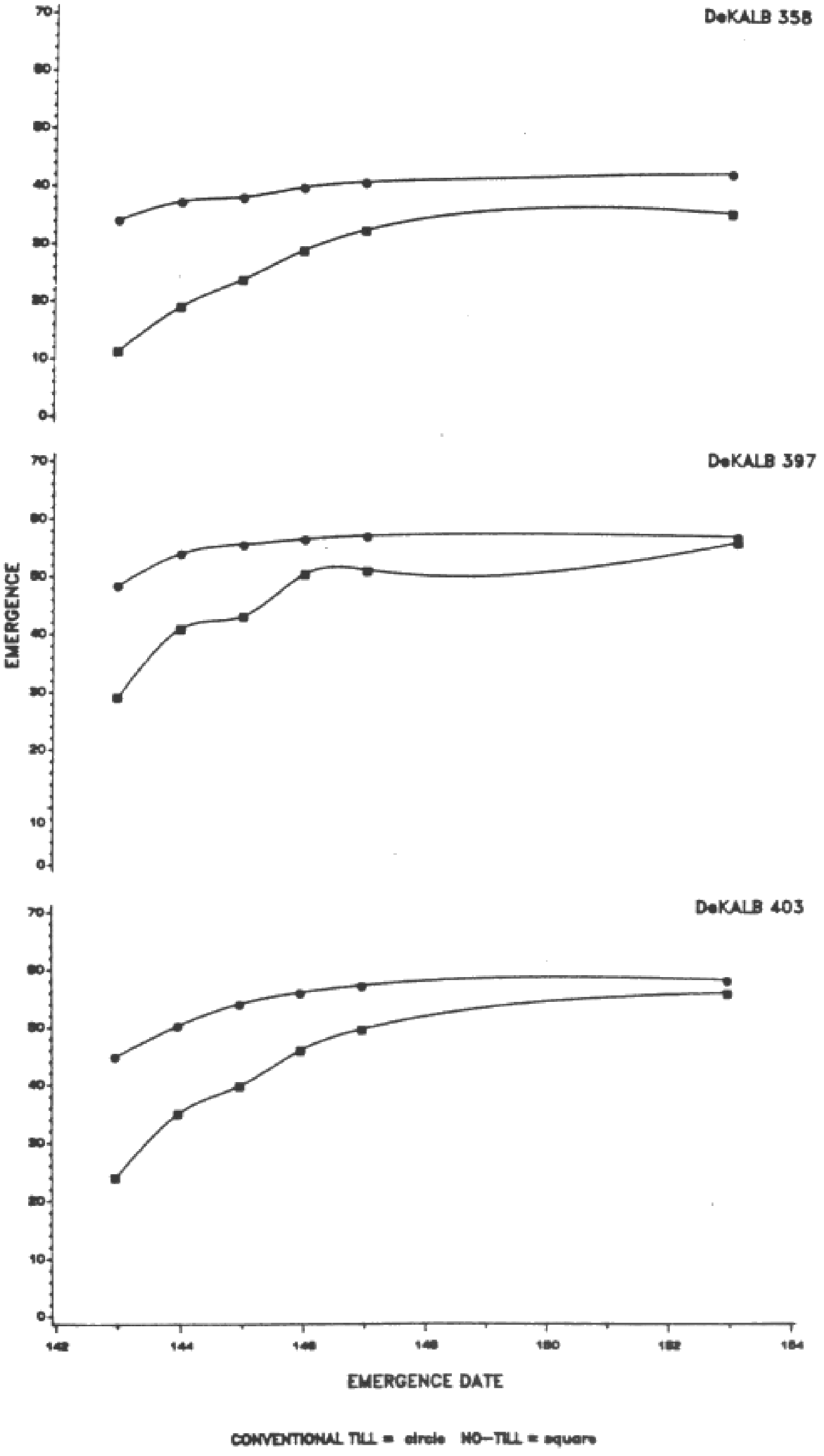


Fig. 3. EMERGENCE FOR CONVENTIONAL AND NO-TILL MANAGEMENT
PLOT DATA SUMMER 1988

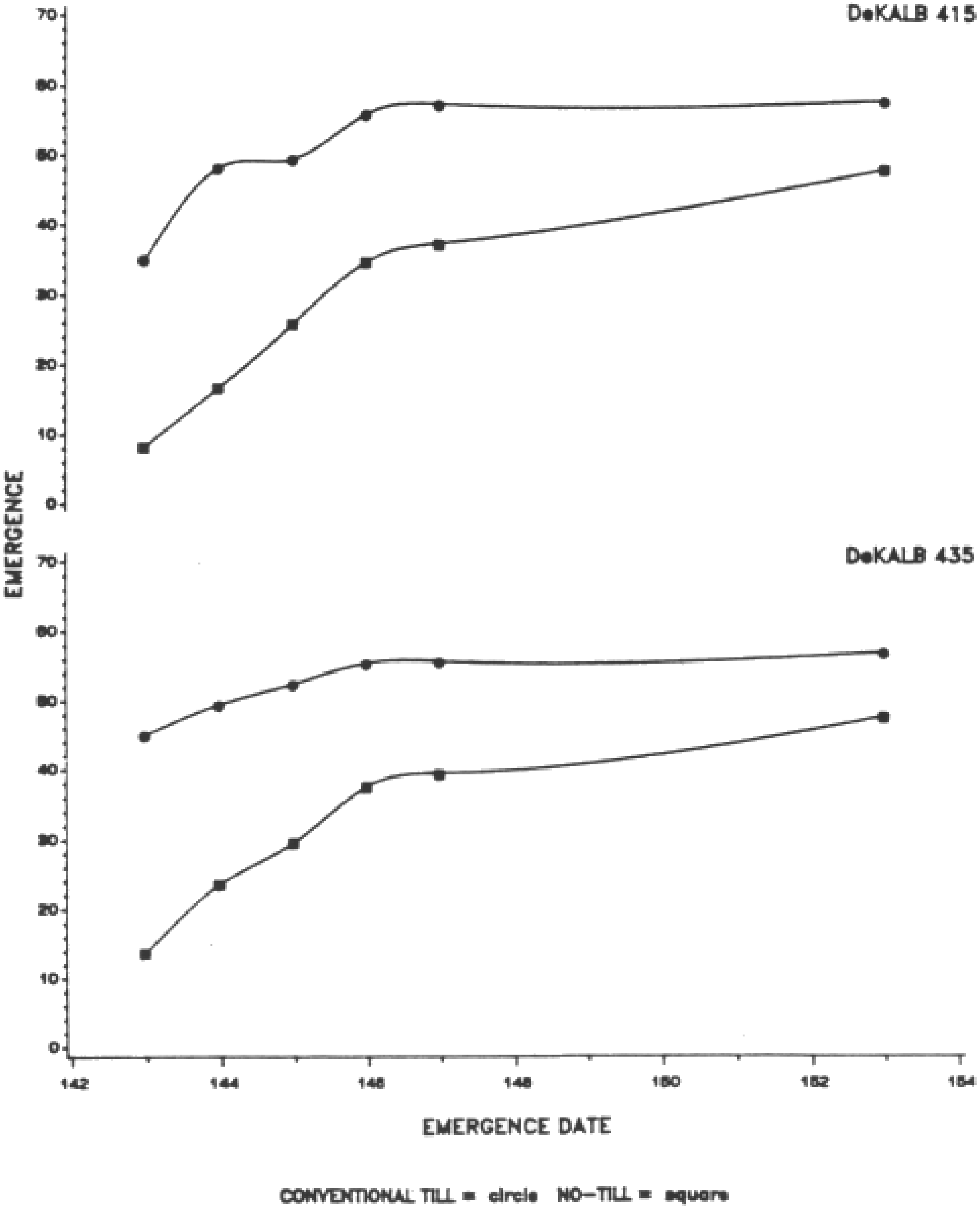


Fig. 4. EMERGENCE FOR CONVENTIONAL AND NO-TILL MANAGEMENT

PLOT DATA SUMMER 1988

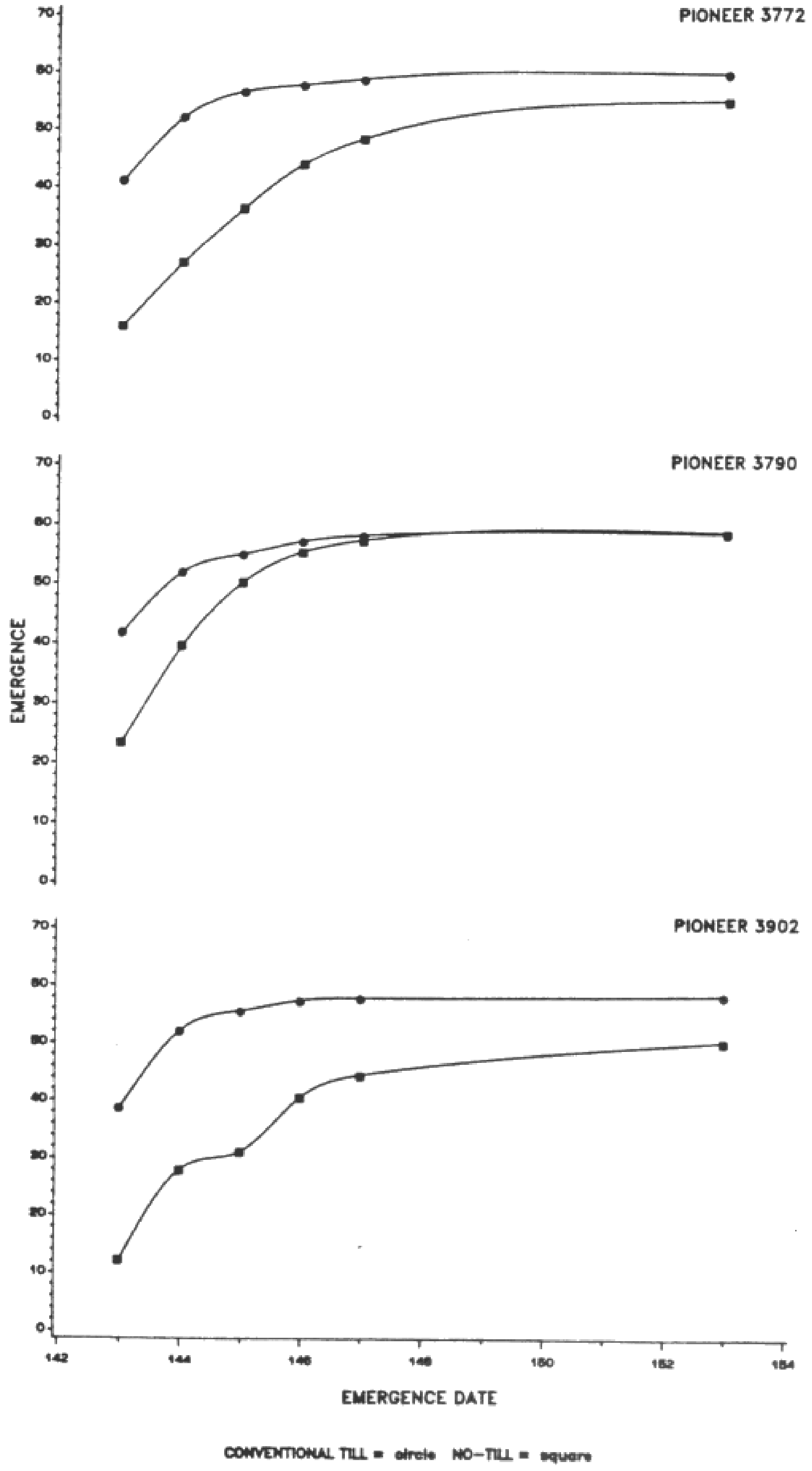


Fig. 5. **EMERGENCE FOR CONVENTIONAL AND NO-TILL MANAGEMENT**

PLOT DATA SUMMER 1988

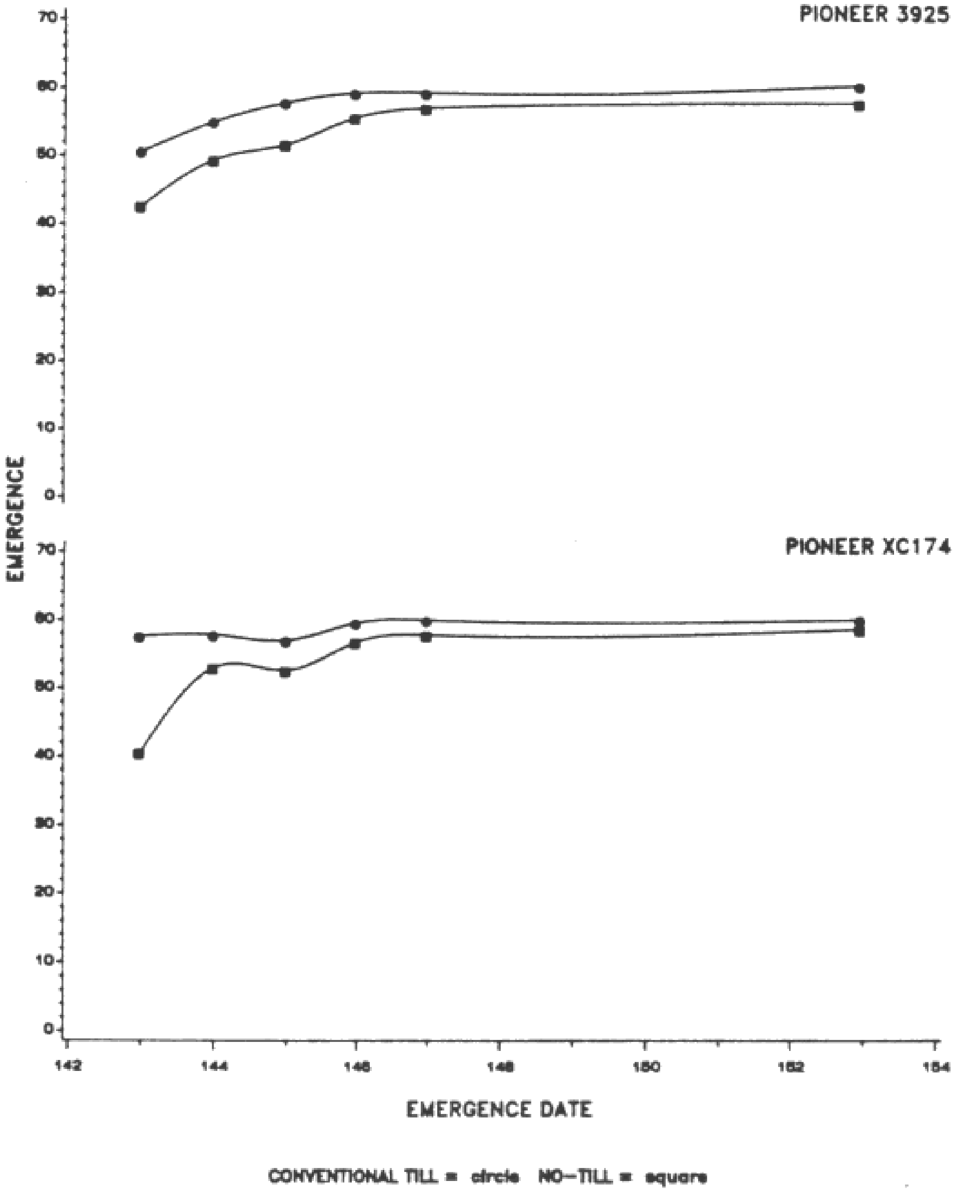


Fig. 6. YIELD MEANS AND COEFF OF VAR FOR 1988 CORN FIELD TRIALS UNDER CONVENTIONAL AND NO-TILL MANAGEMENT SYSTEMS

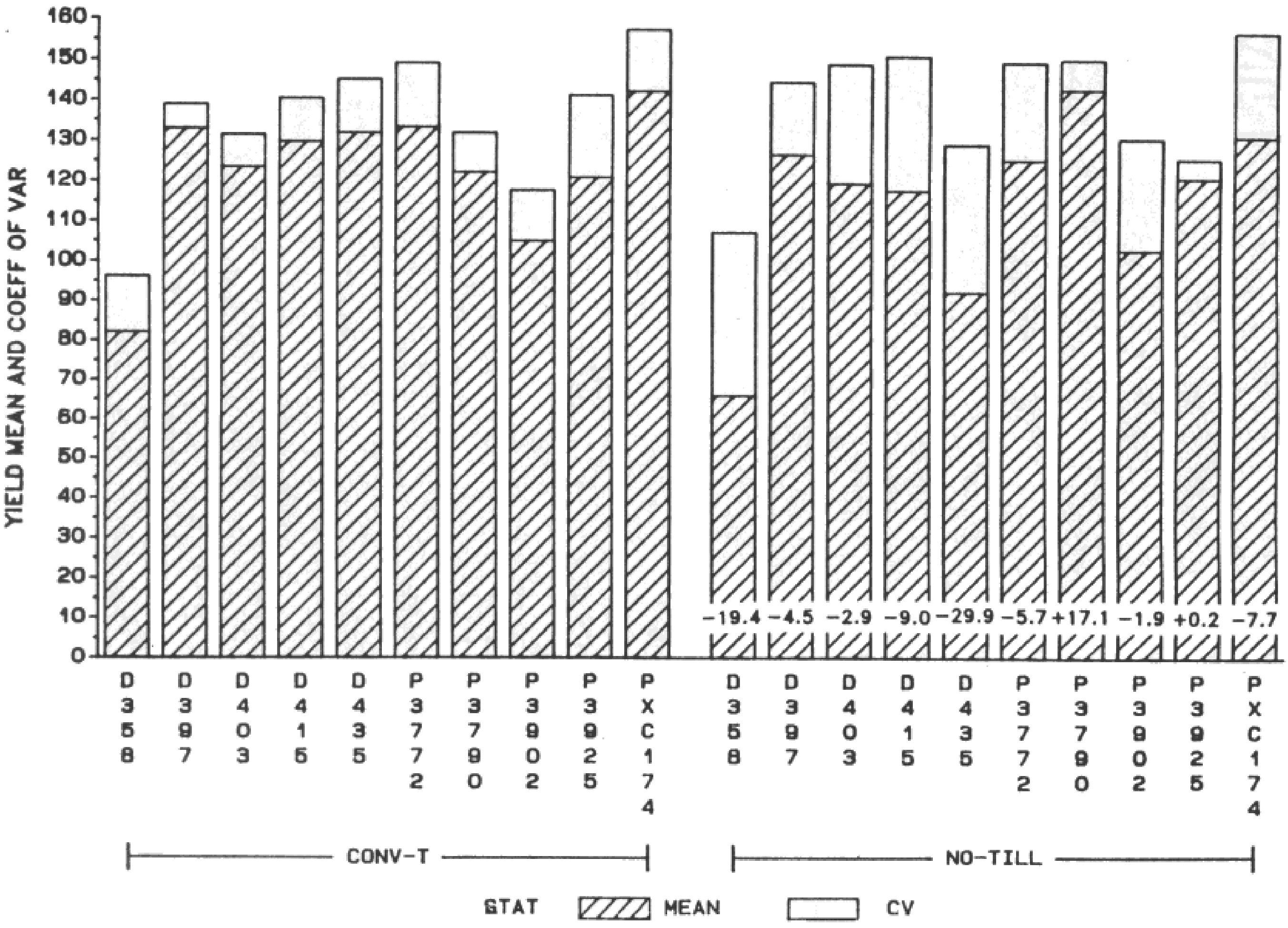


Fig. 7. DAYS TO 50% 1 CM SHOOT AT 11C vs 1988 FIELD EMERGENCE

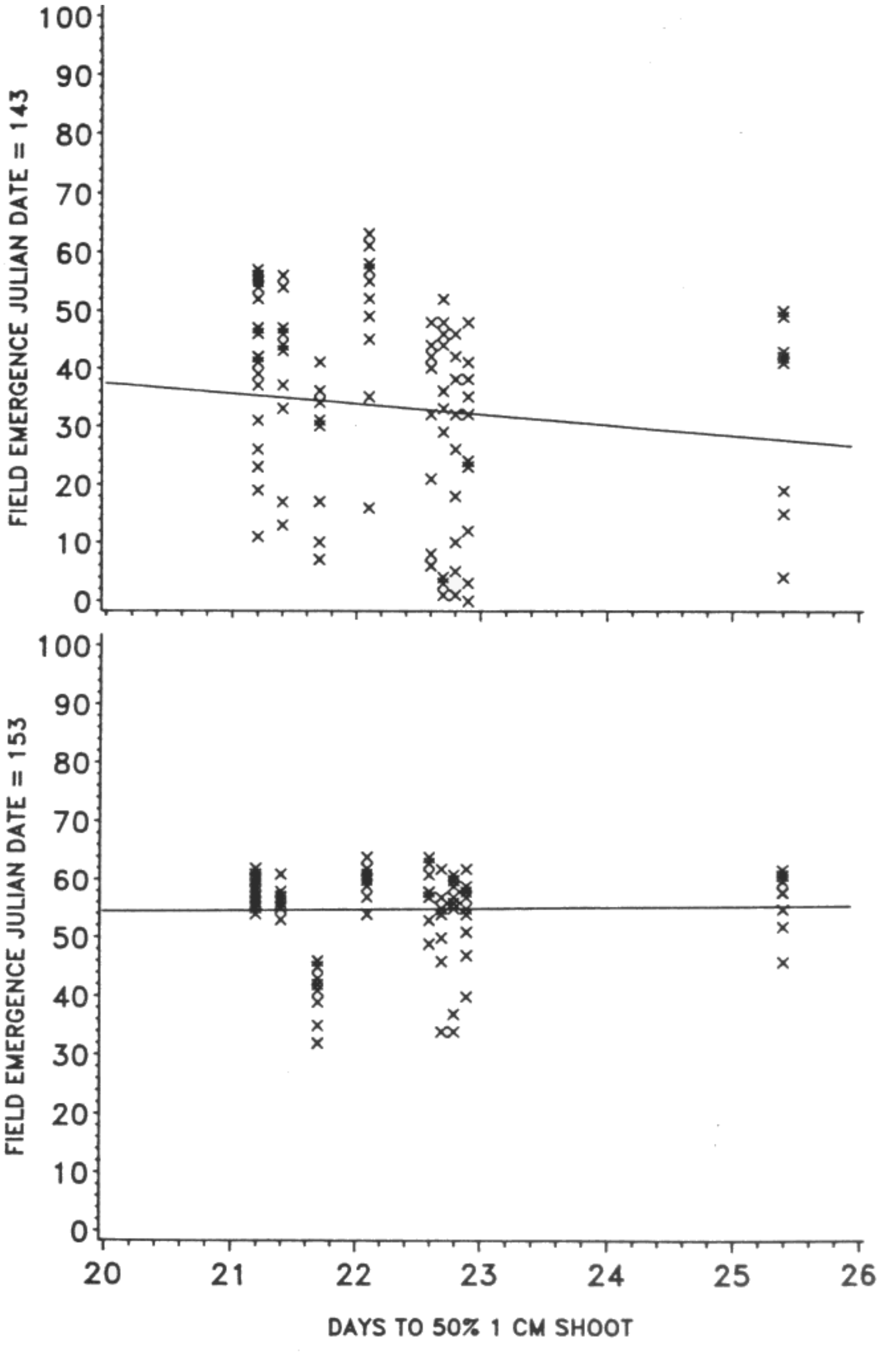
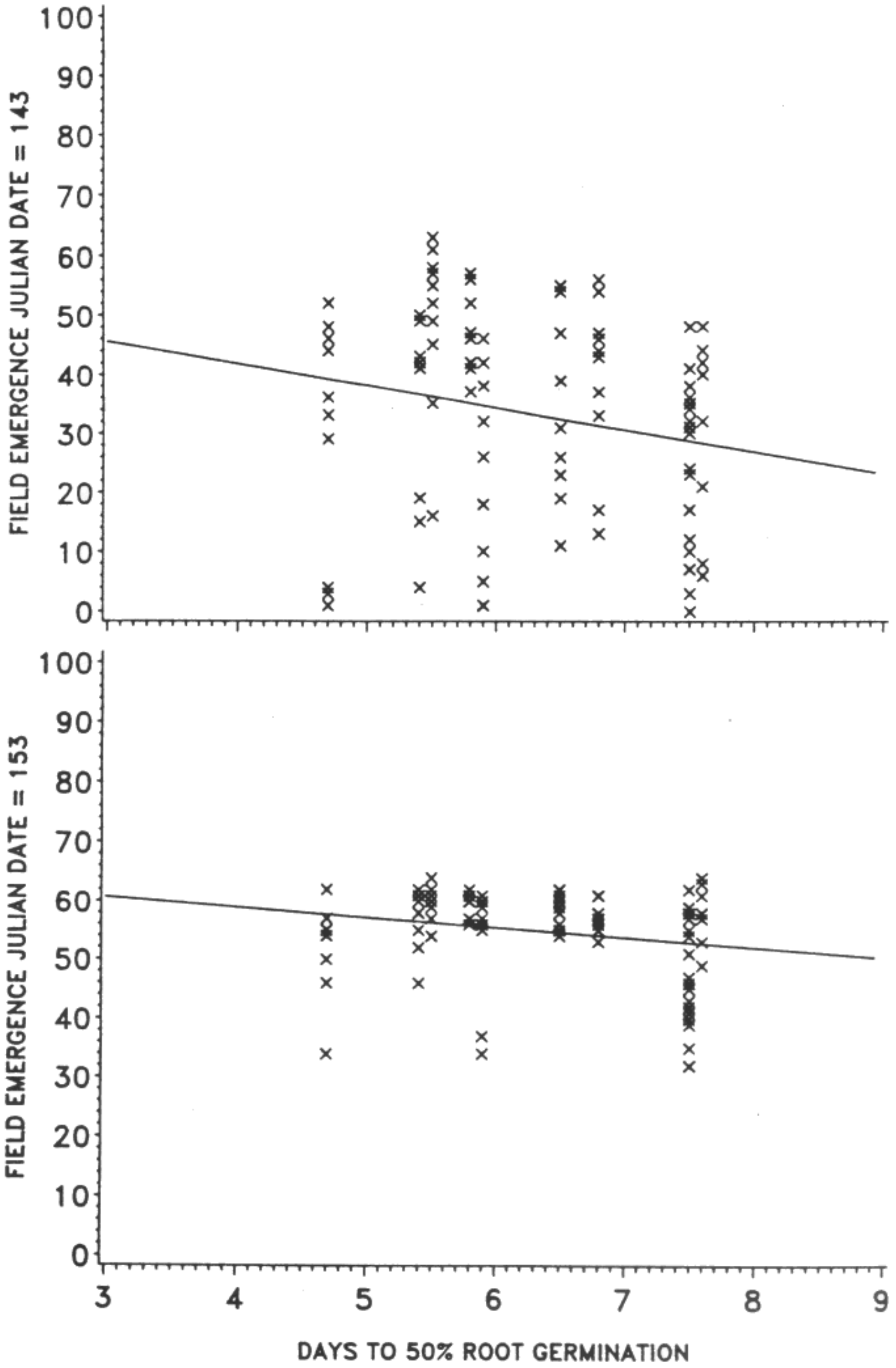


Fig. 8. 50% ROOT GERMINATION AT 11C vs 1988 FIELD EMERGENCE



1.0 INTRODUCTION

In southern and eastern Ontario, the introduction of grain corn adapted to the over 2500 CHU range concomitant with selective herbicides induced growers to abandon traditional crop rotation management. The selective herbicide atrazine gave effective chemical control of most weedy species but left residues in the soil precluding a following crop of a broad leaved species. This form of continuous-corn crop management was common in Ontario for over 20 years. When it became clear that continuous corn was mildly to severely deleterious to the physical, chemical and biological properties of soil, alternate management practices had to be developed. In addition, the run off of fertilizer and herbicide/pesticide residues from heavily cultivated fields into streams and ultimately into the Great Lakes-St Lawrence water system was of increasing concern to persons charged with maintaining acceptable water quality for human use in that water basin.

One of the more promising alternatives to continuous-corn was seen to be a return to crop rotation combined with a reduction in tillage using ridge-till (RT) or no-till (NT) management procedures. Initially, slightly lower corn yields (Carter and Barnett 1987) were achieved with these new procedures indicating the need for some fine-tuning to optimize planting technology, weed control and fertilizer application. It was soon found that spring soil temperatures under NT were cooler by as much as 5.9ºC (Johnson and Lowery 1985) compared to conventional-till (CT) because of the shading effect of plant residues from previous crops. This new cooler environment lead to reduced germination/emergence.

In the past, corn hybrids were not selected for high cold tolerance in the early stages of growth. As a result, random distribution of tolerance is found in currently available material from the seed trade. Because no corn cold tolerance ratings are available from industry or government agencies, it was decided that it would be desirable to investigate how cold tolerance might best be determined. The objective of doing these determinations was to make a predictor of successful field emergence available to growers who could then select the hybrids best adapted to their individual NT management system.

Seed suppliers often use one elite inbred as the female parent for several hybrids which they market under different names. However, information on hybrid parentage is a carefully guarded trade secret not available to the farmers.

A corn seed is a complex mixture of three types of tissues (Fig 1A) each with a different hereditary make up. As one might expect, the embryo ('germ') has equal contributions from both parents. The pericarp or seed coat is all derived from the female parent but the endosperm inherits two-thirds of its genetic material from the female and one-third from the male parent. Because maternal inheritance can sometimes play an important role in determining the characteristics of an F1 hybrid corn plant, a study has recently been done to investigate the use of inbred seedling cold tolerance to predict hybrid cold tolerance by Aidun, Migus and Hamilton (1991). A cold tolerant inbred, CO255, was crossed to 18 other inbreds. No maternal inheritance was observed in six reciprocal crosses involving the common parent CO255. The authors concluded that prediction of corn hybrid cold tolerance could not be based on that of the inbred parents. The implication of this conclusion for the grower is that hybrid cold tolerance cannot be predicted based on maternal inheritance from an inbred with superior cold tolerance.

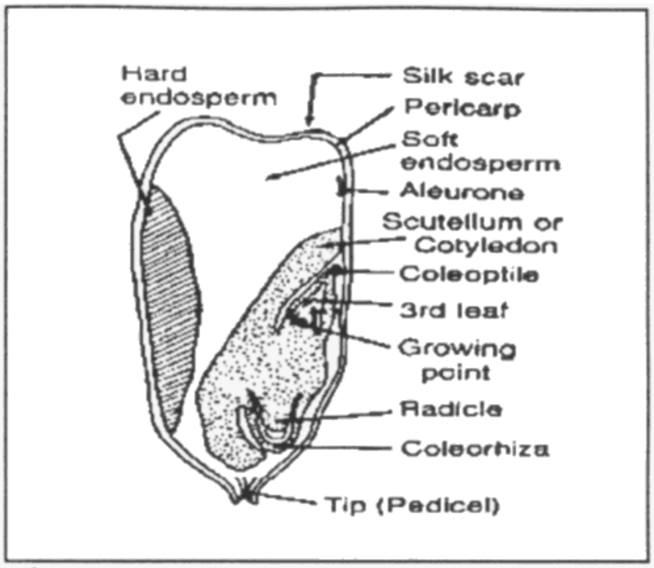


Figure 1A

Trends in cold tolerance inheritance similar to those in corn have already been observed in other cereal species. Limin and Fowler (1983) working with winter wheat and Maksimovic (1981) using winter barley found that F1 plants from crosses between cold tolerant and cold susceptible parents displayed incomplete dominance of tolerance. Maternal inheritance was not observed.

A plot experiment was run in 1988 and reported in an appendix to a report prepared by Hope and Maamari (1991, Part I) to investigate yield and other agronomic characteristics of 5 Pioneer and 5 DeKalb hybrids under NT and CT management. It was concluded from this work that the best hybrids under CT were not always the best hybrids under NT. Also, it became clear that a rapid laboratory predictor of superior cold tolerance was needed if the over 200 hybrids on the market were to be assessed quickly enough so that the assessment would be of use to growers.

A series of laboratory experiments (Part I) was conducted on the 10 hybrids used for field studies in 1988 plus 2 more from each of Pioneer and DeKalb and an internal control, Pride 5. Analysis of data from detailed studies of low temperature germination at 11°C indicated that the time to produce a 1 cm coleoptile was a promising predictor of successful field emergence under NT management. The detailed study on 14 hybrids from two suppliers indicated that it might be possible to do a more rapid measurement with only two sets of readings per hybrid thus permitting a larger, more representative group to be studied during four months in the summer when university students are available to assist in the work. The data which follow summarize a study done on 122 grain corn hybrids during the summer of 1991.

2.0 MATERIALS AND METHODS

2.1 Seed

Subsamples from seed used by the Ontario Corn Committee for yearly hybrid performance trials were obtained from the Ridgetown College of Agricultural Technology. This seed was furnished by the seed industry and can be considered representative of the seed available to growers in 1991.

2.2 Germination and early growth

2.2.1 At 25ºC

For each hybrid, groups of 25 seeds were placed randomly in a sterile disposable plastic plant tissue culture dish (8.9 x 7.5 x 6.3 cm) lined with Whatman #1 filter paper. Germination was initiated by adding 2.5 ml of sterile distilled water to each dish. The seed was then placed in a germinator at 25.0ºC and 98% or higher relative humidity. Quadruplicate 25-seed lots of each hybrid were tested.

Observations on germination and early growth at 25.0ºC were done once, 10 days after imbibition, when all seed with the potential to germinate had germinated and grown a coleoptile over 1 cm long. Germination, for the purposes of this work, is defined as growth of seed root or coleoptile through the seed coat. The number of seeds that germinated and the number of seeds that produced a 1 cm long coleoptile were recorded.

2.2.2 At 11ºC

For each cultivar tested, sets of 25 seeds were placed with the embryo facing up in a disposable square plastic petri dish (9.5 x 9.5 x 1.5 cm) lined with Whatman #1 filter paper. These were then placed on metal trays in a germinator at 11.0ºC and 98% or higher relative humidity. Germination of quadruplicate 25-seed lots at 11.0ºC was initiated as in the case of the 25ºC controls by addition of 2.5 ml of sterile distilled water.

Visual observations on two germination parameters were taken after 5, 6, 20 and 22 days at 11.0ºC and entered directly into a lap top computer using software written for these experiments. The number of seeds that produced a root was recorded on each sampling day while the number of seeds that had grown a coleoptile 1 cm long was recorded on days 20 and 22. Seeds that had produced a 1 cm coleoptile by day 20 were removed from the dish and discarded.

At the end of experiments, data files were transferred electronically to a Digital Equipment VAX minicomputer for analysis. Cumulative frequencies for each cultivar and replicate were first calculated and then mean values of the four replicates for each cultivar. Several procedures including PROC FREQ, PROC MEANS and PROC SORT from a SAS software package were used for data analysis.

3.0 RESULTS AND DISCUSSION

3.1 Germination at 25ºC

All but 4 of the 122 hybrids tested showed germination over 80 percent during a period of 10 days (Table 1; column G25C). Hybrids 14, 49, 66 and 93, with 25ºC germination values of 62-78 percent were not included in the cold tolerance ratings presented in Appendix A because of their considerably lower values compared to the mean of 91.9. It was considered prudent not to include these hybrids with low germination since our seed samples might not have been representative of the true genetic potential of the crosses. The distribution of germination values is highly skewed towards high values (Fig 1) indicating that a high number (78 of 122) of the corn hybrids had germination even higher than the arithmetic mean of 91.9% (92.6% with the below-80% values removed) would indicate. Most hybrids germinated quickly and evenly at 25ºC. Readings were taken at 10 days but many hybrids had completed germination within 4 to 7 days.

3.2 Root germination at 11ºC

Readings were taken at 5 and 6 days (Table 1; columns D5, D6) following imbibition in order to avoid missing the time at which the optimum spread in values would be apparent. A detailed study from the previous year (Part I) had been done on 15 hybrids from two companies. It was not certain that the predicted optimum of day 6 based on the small population of 15 would still be optimum for the larger group of 122 hybrids. Early analysis of data indicated that two readings should be taken and that probably day 5 would be the more useful. Later analysis of the complete data indicated that the widest spread of values was found on day 5 (Fig 3). Day 6 data (not illustrated) had too many high-percent values which would reduce our ability to separate out hybrids with high cold tolerance from those with average tolerance.

3.3 Coleoptile growth at 11ºC

Counts of seedlings with a 1 cm coleoptile were done on days 20 and 22 (Table 1; column D22) following imbibition to avoid missing the widest spread of data as was done for root germination. Data published by Hope et al (1992) has shown that production of a 1 cm coleoptile at 11ºC is an efficient predictor of good emergence for short season (under 2400 CHU) corn lines. In their publication, Hope et al correlated laboratory data with that from test plots in the maritime provinces observed over a period of five years. An objective of the present study was to verify that a similar relationship holds true for corn hybrids in the 2400-3500 range grown in Ontario.

A collaborative field study begun at Ridgetown College of Agricultural Technology in the spring of 1991 by G. Scheifele used 58 of the 122 hybrids from our study. Unfortunately, these plantings under no-till, ridge-till and conventional till management gave no useable data on early emergence because of the extremely warm spring. It is projected that the field experiment will be repeated in 1992 and 1993.

3.4 Development of a field emergence predictor

An efficient field emergence predictor must meet four important requirements: 1) Close correlation with emergence under low soil temperatures in the field, 2) Rapid, low cost determination, 3) Adaptability to the addition/subtraction of data from year to year as new hybrids come on the market and older ones are withdrawn, 4)Easy explanation to the seed growers, retail suppliers and farm groups. The best single predictor is coleoptile growth. However, experience during the taking of many thousands of readings has shown that some hybrids have tardy development of a primary root. We believe that slow root development leaves a seedling open to attack by seed pathogens in the soil. This leads us to propose a predictor that would include both a factor for coleoptile growth and one for root growth. The highly significant correlation (r=0.70564, p=0.0001) demonstrated in this work between root (D5) and 1 cm coleoptile (D22) production (Table 2) under cold stress indicates that inclusion of a root factor will not weaken the predictor and may well serve to weed out some questionable material.

The following cold tolerance (CT) rating systems were considered for use as a predictor of field emergence:

$$CT = Day_5 \times Day_{22} \qquad RTO$$

$$CT = [(1 \times Day_5) + (1 \times Day_{22})] /2 \qquad RT1$$

$$CT = [(1 \times Day_5) + (2 \times Day_{22})] /3 \qquad RT2$$

$$CT = [(1 \times Day_5) + (3 \times Day_{22})] /4 \qquad RT3$$

where: Day_5 is the percent root germination five days following imbibition and Day_{22} is the percent of 1 cm coleoptiles found at the end of 22 days.

Predictor RTO and others in which one factor is multiplied by another were rejected because they gave a large awkward (0 to 10,000 in the example) scale. Predictor RT1 places as much emphasis on root as coleoptile data which is probably not justified.

Predictors RT2 and RT3 are the most useful of the series. It was concluded that predictor RT3, giving three times as much weight to coleoptile as to root data, would be the best choice pending confirmation based on field data from Ontario. Predictor RT3 has the advantage of putting primary emphasis on coleoptile data but yet incorporating some root germination weighting. In the case of a hybrid with very tardy root germination, the inclusion of a root factor might move the hybrid from a level of very good cold tolerance to one of good cold tolerance. The choice of predictor RT3 over RT2 is based solely on the experience of the authors working with germinating corn and remains to be confirmed by field data.

Predictor RT3 gives a scale of 0 (no root or coleoptile germination) to 100 (100% germination of both root and coleoptile). A range of 0 to 100 is easy to understand and explain and also mathematically convenient to use. In addition, the cold tolerance rating list can have hybrids added/subtracted as the need arises. Hybrids with a 25ºC germination of over 80% were ranked by descending order based on emergence predictor RT3. In Appendices A and B, the hybrids have been grouped by cold tolerance where group 1 is most cold tolerant and in Appendix C statistical measures of dispersion done on the 4 reps for each hybrid are presented. In Appendix A, hybrids are listed by CHU grouping following the province of Ontario system. At the present time, the cutoff point between very good (rating 1) and good (rating 2) is near 68 and for the group 2-3 demarcation it is near 41. Experience may show that new hybrids coming on the market will nearly all fall in group 1 with high cold tolerance ratings. It might then be appropriate to consider fixed cutoff points rather than the present moveable ones thus increasing the relative proportion of hybrids rated 1 (very good). This strategy would recognize the fact that an increasing percentage of the available hybrids was very well adapted to cold stress during germination and early growth.

Because of the yearly and supplier-related variation in seed quality, it is not possible to obtain seed samples which all have the same percent germination at 25ºC. A detailed study over approximately 45 days of germination at 11ºC which would permit correction of 11ºC data for less than 100% germination at 25ºC using probit calculations would be very expensive if applied to all the commercial hybrids. Concern has been expressed that this recognized variation in seed viability invalidates any rating system for cold tolerance. If such were the case, then one should easily be able to demonstrate a correlation between low 25ºC germination and a weak (average) 11ºC cold stress rating. That is, a bias introduced in the cold stress readings should reflect the source of the bias - low viability at 25ºC. Calculation of a correlation coefficient between 25ºC germination and RT3 gave no significant correlation (r=-0.00123, p=0.9893). In Fig 5, cold tolerance ratings using calculation RT3 have been plotted against germination at 25ºC and the linear regression line added. In agreement with the lack of a significant correlation, the plot shows no visible relationship between low 25ºC germination and a low cold tolerance rating. Clearly, the small differences in seed viability in the 118 market place samples having 25ºC germination over 80% are not enough to compromise the validity of the cold rating system as proposed. This is fortunate since the seed from the market place used in our study should be representative of whata farmer can purchase.

Note added in editing: At the request of the TAP review committee, the authors have replaced the names of hybrids appearing in the data tables with code numbers and added a table (Appendix D) to show the names of the hybrids used in the testing.

4.0 CONCLUSIONS

1. Of the 122 hybrids tested, the great majority germinate very well under average to better than average conditions of temperature. At 25ºC, an average germination of 92 percent was observed.

2. During germination at 11ºC, a broad genetic range is found in the response of root and coleoptile to cold stress.

3. Pending field verification, we propose that hybrids be rated for cold tolerance as 1 (very good), 2 (good) or 3 (average) based on an objective rating calculated as:

$$[(1 \times \%\ \text{Day}_5\ \text{germination}) + (3 \times \%\ \text{Day}_{22}\ \text{germination})] / 4$$

5.0 REFERENCES

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6.0 TABLES AND GRAPHS

Table 1. Root germination on days 5 (D5) and day 6 (D6) as well as 1 cm coleoptile production on days 20 (D20) and 22 (D22) are presented with seed germination (G25C) for hybrids identified by hybrid code number (HYBR#).

HYBR#	D5	D6	D2	D2	G25C	HYBR#	D5	D6	D20	D22	G25C
1	59	98	63	83	97	21	84	92	62	92	93
2	55	91	72	88	97	22	95	97	74	85	83
3	12	20	1	2	97	23	55	72	39	64	91
4	59	98	48	71	96	24	28	55	16	38	93
5	47	78	10	20	93	25	7	28	2	8	93
6	52	87	63	84	97	26	92	98	55	72	84
7	58	96	80	89	95	27	79	87	59	79	86
8	55	91	82	90	98	28	16	51	16	56	93
9	58	97	66	89	97	29	34	61	67	88	96
10	48	80	9	32	99	30	77	89	28	60	88
11	50	83	32	54	88	31	92	95	72	82	88
12	41	68	26	53	95	32	71	83	54	75	98
13	58	97	80	91	97	33	81	88	82	85	94
14	0	0	2	6	69	34	72	97	77	94	94
15	55	92	47	77	89	35	87	94	87	94	86
16	24	47	5	15	89	36	14	37	45	68	94
17	45	67	52	85	83	37	9	41	45	74	95
18	81	88	63	73	84	38	20	57	32	62	95
19	17	46	29	50	94	39	12	28	10	30	95
20	87	93	50	79	86	40	53	65	57	67	94

Table 1(Cont'd)

HYBR#	D5	D6	D20	D22	G25C	HYBR#	D5	D6	D20	D22	G25C
41	3	8	3	10	94	61	90	95	78	97	98
42	44	70	20	45	89	62	30	63	6	42	84
43	29	64	29	55	98	63	34	50	5	28	89
44	56	78	41	69	96	64	42	66	46	68	94
45	10	29	11	34	86	65	30	56	52	90	98
46	0	5	33	55	94	66	76	93	90	95	73
47	29	48	32	60	95	67	32	49	34	53	94
48	53	79	28	64	81	68	82	94	21	50	90
49	2	14	30	57	78	69	59	76	60	79	89
50	0	0	4	14	94	70	79	88	8	27	93
51	31	66	56	79	98	71	10	35	14	36	96
52	67	89	82	92	98	72	53	88	58	75	96
53	73	86	61	74	93	73	52	79	51	69	90
54	24	37	30	42	92	74	51	81	64	84	96
55	42	59	48	69	97	75	54	80	36	51	95
56	80	92	12	29	93	76	5	18	23	48	93
57	90	94	13	33	91	77	23	54	9	28	98
58	2	14	2	16	97	78	74	98	85	95	98
59	30	47	17	32	95	79	7	26	11	27	93
60	6	43	44	63	91						

Table 1(Cont'd)

HYBR#	D5	D6	D20	D22	G25	HYBR#	D5	D6	D20	D22	G2
80	46	80	38	64	99	102	19	53	7	38	81
81	9	26	19	45	99	103	14	53	20	77	80
82	19	50	43	65	99	104	8	24	44	95	91
83	28	50	10	30	96	105	1	3	3	9	89
84	56	82	28	51	96	106	47	83	18	44	93
85	93	100	14	3	95	107	10	18	4	15	92
86	81	86	67	79	91	108	34	70	44	65	85
87	27	66	15	31	96	109	9	26	7	24	93
88	4	20	5	8	94	110	14	43	3	5	82
89	83	98	40	64	87	111	10	21	28	60	93
90	81	99	65	93	88	112	33	68	42	65	94
91	40	70	9	62	92	113	1	10	36	60	98
92	77	91	57	84	93	114	17	42	3	3	97
93	3	12	5	36	62	115	41	72	50	81	98
94	15	54	50	91	92	116	10	43	8	20	94
95	44	73	34	82	98	117	60	77	5	19	90
96	23	62	59	79	92	118	30	65	43	67	97
97	39	74	9	42	87	119	76	90	1	1	98
98	24	62	3	11	90	120	92	100	57	78	87
99	30	69	7	55	91	121	15	37	20	41	88
100	1	15	2	15	89	122	2	8	12	35	94
101	2	9	5	15	91						

Table 2. Correlation coefficients for corn germination parameters. For each combination the coefficient, the probability and the number of data points are presented in descending order. Data from 11ºC experiments are presented for root germination on day 5 (D5) and day 6 (D6) and for 1 cm coleoptile production on day 20 (D20)and day 22 (D22) as well as germination predictors RT2 and RT3. Values for percent seed germination at 25ºC are indicated by G25C.

	D5	D6	D20	D22	G25C	RT2	RT3
D5	1.00000	0.91871	0.58829	0.51757	-0.00597	0.71132	0.70564
	0.0000	0.0001	0.00001	0.0001	0.9479	0.0001	0.000
	122	122	122	122	122	121	121
D6		1.00000	0.61232	0.59135	0.09746	0.74630	0.74196
		0.0000	0.0001	0.0001	0.2856	0.0001	0.0001
		122	122	122	122	121	121
D20			1.00000	0.91775	0.10629	0.92578	0.92265
			0.0000	0.0001	0.2439	0.0001	0.0001
			122	122	122	121	121
D22				1.00000	0.07091	0.96549	0.96852
				0.0000	0.4376	0.0001	0.0001
				122	122	121	121
G25C					1.00000	-0.00297	-0.00123
					0.0000	0.9742	0.9893
					122	121	121
RT2						1.00000	0.99917
						0.0000	0.0001
						121	121
RT3							1.00000
							0.0000
							121

Table 3 Comparison of emergence predictors RT2 and RT3 with 1 cm coleoptile production on day 22 (D22) and 25ºC seed germination.

HYBR#	RT3	RT2	D22	G25
61	95.3	94.7	97	98
35	92.3	91.7	94	86
66	90.3	89.3	95	73
21	90.0	89.0	92	93
90	90.0	88.7	93	88
78	89.8	88.3	95	98
34	88.5	88.0	94	94
22	87.5	86.7	85	83
52	85.8	85.4	92	98
31	84.5	83.7	82	88
33	84.0	83.7	85	94
13	83.8	82.7	91	97
9	82.3	81.7	89	97
92	82.3	81.7	84	93
7	82.1	81.3	89	95
8	82.1	80.0	90	98
120	81.5	79.8	78	87
20	81.0	79.7	79	86
2	80.6	79.4	88	97
86	79.5	79.0	79	91
27	79.0	78.7	79	86
1	77.9	78.1	83	97
26	77.0	76.2	72	84
6	76.9	75.7	84	97
74	75.8	74.5	84	96
17	75.0	73.7	85	83
18	75.0	73.7	73	84
65	75.0	73.0	90	98
29	74.5	72.3	88	96
32	74.0	71.7	75	98
69	74.0	71.0	79	89
53	73.8	70.4	74	93
104	73.3	70.0	95	91
15	72.6	70.0	77	89
95	72.5	69.3	82	98
94	72.0	68.2	91	92
115	71.0	67.7	81	98
72	69.5	67.7	75	96
4	68.9	66.0	71	96
89	68.8	65.7	64	87
51	67.0	65.7	79	98
44	65.8	64.7	69	96

Table 3 (Cont'd)

HYBR#	RT3	RT2	D22	G25
96	65.0	63.4	79	92
73	64.8	63.0	69	90
30	64.3	62.4	60	88
40	63.5	61.0	67	94
55	62.3	60.7	69	97
23	61.8	60.3	64	91
64	61.5	60.3	68	94
48	61.3	60.0	64	81
103	61.3	59.4	77	80
80	59.5	58.0	64	99
68	58.0	56.0	50	90
37	57.8	54.7	74	95
118	57.8	54.7	67	97
108	57.3	54.7	65	85
112	57.0	54.3	65	94
91	56.5	53.7	62	92
36	54.5	53.0	68	94
11	53.8	52.7	54	88
82	53.5	52.4	65	99
47	52.3	52.0	60	95
84	52.3	52.0	51	96
75	51.8	50.0	51	95
38	51.5	49.7	62	95
12	50.5	49.7	53	95
60	48.8	48.0	63	91
99	48.8	49.7	55	91
43	48.5	46.7	55	98
85	48.0	46.4	33	95
67	47.8	46.0	53	94
111	47.5	46.0	60	93
57	47.3	45.0	33	91
28	46.0	44.7	56	93
113	45.3	44.3	60	98
42	44.8	43.3	45	89
106	44.8	44.0	44	93
49	43.3	42.7	57	78
19	41.8	40.4	50	94
56	41.8	41.0	29	93
46	41.3	38.7	55	94
97	41.3	39.0	42	87
70	40.0	38.4	27	93
62	39.0	38.0	42	84

Table 3 (Cont'd)

HYBR#	RT3	RT2	D22	G25
54	37.5	36.7	42	92
76	37.3	36.0	48	93
10	36.8	34.7	32	99
81	36.0	33.7	45	99
24	35.5	33.0	38	93
121	34.5	32.7	41	88
102	33.3	32.4	38	81
59	31.5	31.7	32	95
87	30.0	31.4	31	96
63	29.5	30.0	28	89
71	29.5	29.7	36	96
83	29.5	29.8	30	96
117	29.3	29.4	19	90
45	28.0	27.3	34	86
93	27.8	26.3	36	62
5	27.3	26.0	20	93
77	26.7	26.0	28	98
122	26.8	25.0	35	94
39	25.5	24.0	30	95
79	22.0	24.0	27	93
109	20.3	20.3	24	93
119	19.8	19.0	1	98
116	17.5	18.0	20	94
16	17.3	16.7	15	89
98	14.3	15.4	11	90
107	13.8	13.4	15	92
58	12.5	11.4	16	97
101	11.8	10.7	15	91
100	11.5	10.4	15	89
50	10.5	9.4	14	94
41	8.3	8.0	10	94
25	7.8	7.7	8	93
110	7.3	7.7	5	82
88	7.0	7.7	8	94
105	7.0	6.7	9	89
114	6.5	6.4	3	97
3	4.8	5.7	2	97

6.1 List of figures

Figure 1

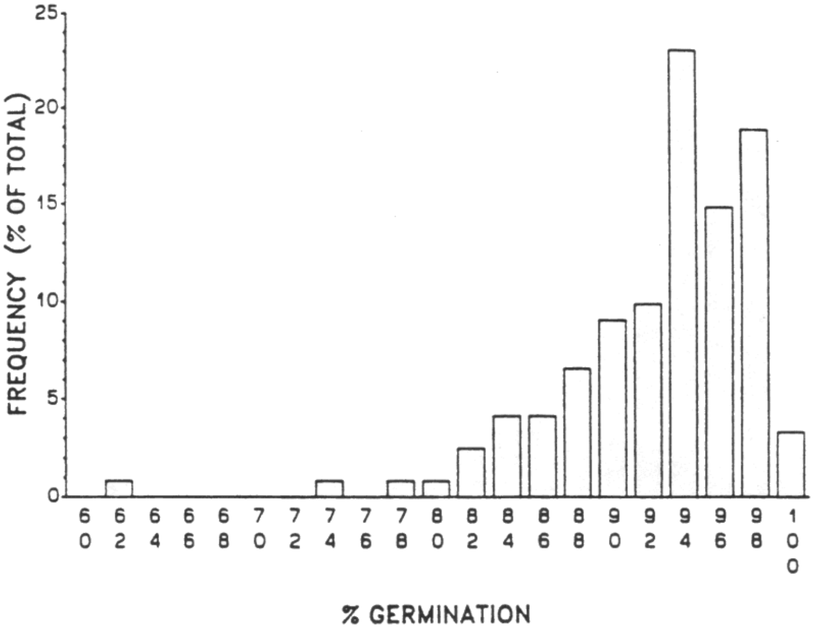


Figure 2

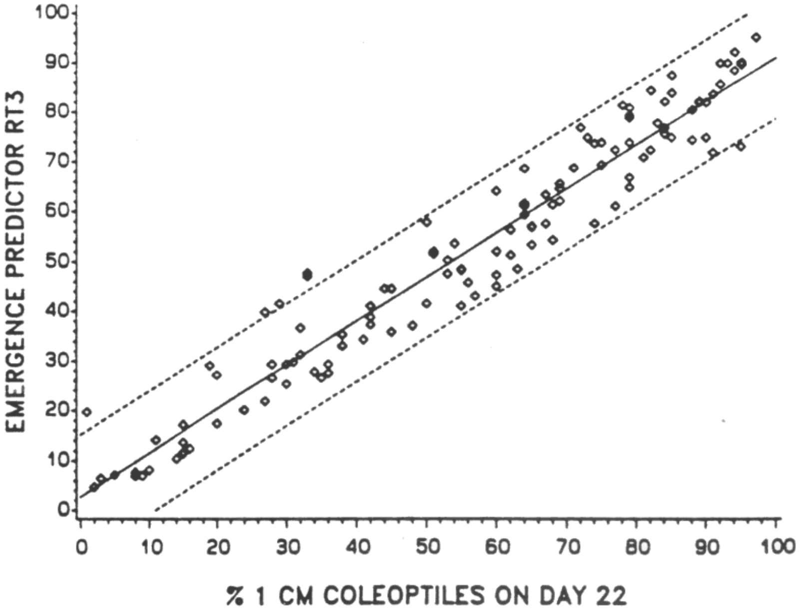


Figure 3

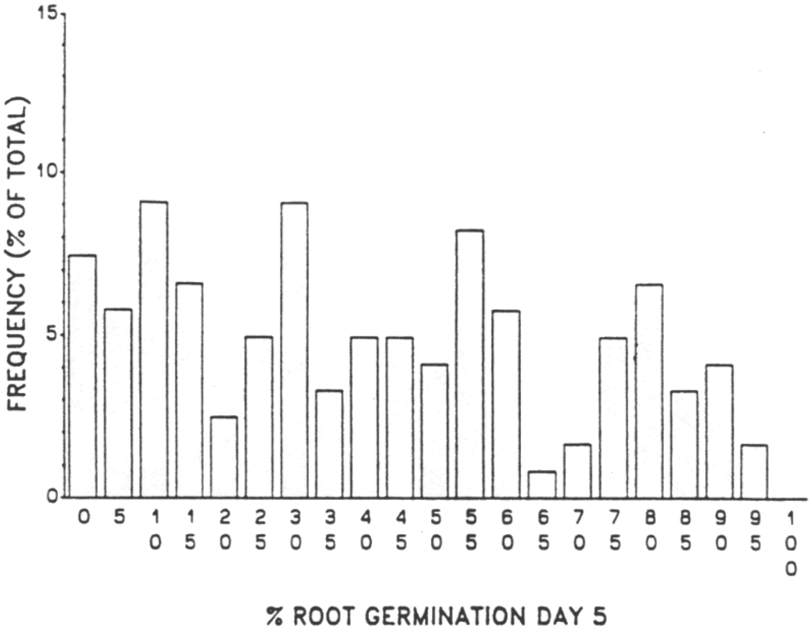


Figure 4

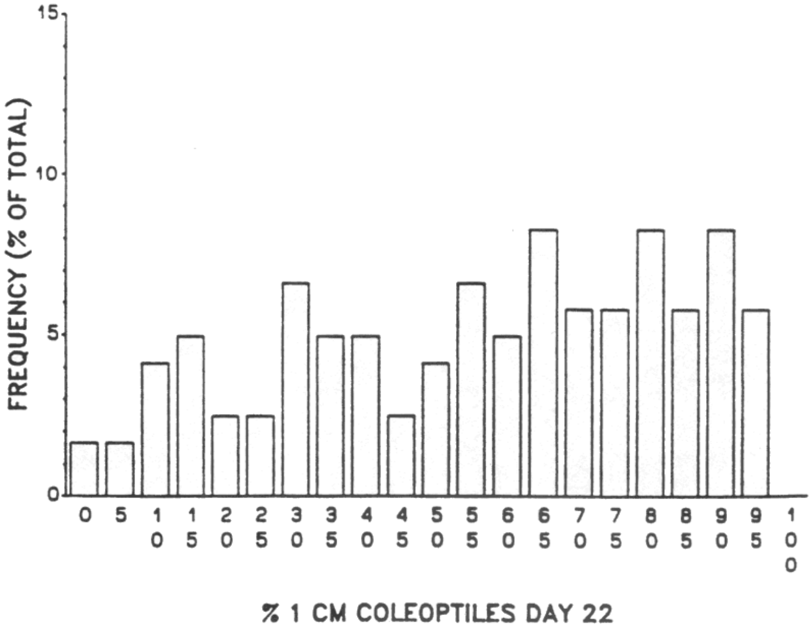
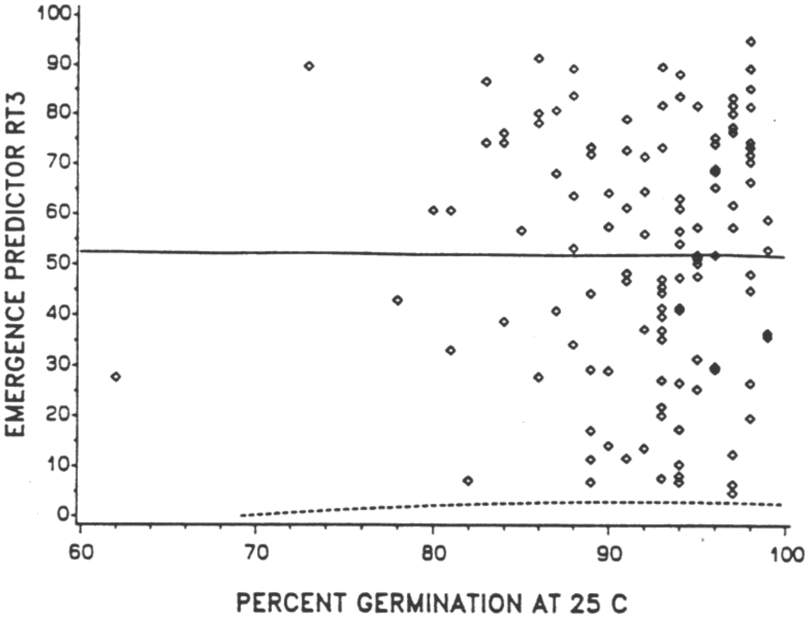


Figure 5


EMERGENCE PREDICTOR RT3
100
90
80
70
60
50
40
30
20
10
0
60
70
80
90
100
PERCENT GERMINATION AT 25 C

7.0 APPENDIX

7.1 Appendix A

Corn hybrid cold tolerance based on predictor RT3. Cold tolerance is rated as 1 (very good), 2 (good) or 3 (average). Hybrids are listed in the same groups as are found in the 1992 Ontario Corn Committee report on performance trials

2400-2500 CHU

HYBR#	COLD TOLERANCE
72	1
94	1
67	2
111	2
112	2
122	3
110	3
121	3

2500-2600 CHU

HYBR#	COLD TOLERANCE
74	1
78	1
94	1
95	1
115	1
67	2
75	2
91	2
96	2
106	2
113	2
62	3
63	3
71	3
87	3
88	3
122	3
105	3
116	3
107	3
109	3
110	3

2500-2700 CHU

HYBR#	COLD TOLERANCE
69	1
78	1
95	1
115	1
60	2
68	2
73	2
75	2
91	2
36	2
96	2
106	2
113	2
118	2
62	3
63	3
71	3
87	3
88	3
105	3
116	3
107	3
109	3
114	3
119	3

2700-2900 CHU

HYBR#	COLD TOLERANCE
61	1
4	1
7	1
65	1
69	1
18	1
29	1
86	1
89	1
104	1
52	1
60	2
64	2
68	2
56	2
57	2
73	2
80	2
85	2
36	2
38	2
103	2
47	2
48	2
108	2
118	2
3	3
58	3
70	3
76	3
77	3
79	3
81	3
83	3
46	3
114	3
117	3
119	3

2800-3000 CHU

HYBR#	COLD TOLERANCE
61	1
4	1
7	1
69	1
13	1
18	1
29	1
86	1
89	1
34	1
104	1
52	1
64	2
56	2
57	2
80	2
82	2
19	2
28	2
85	2
38	2
44	2
103	2
47	2
48	2
108	2
51	2
3	3
58	3
10	3
59	3
70	3
77	3
79	3
81	3
25	3
83	3
97	3
45	3
46	3
50	3
117	3
119	3

2900-3100 CHU

HYBR#	COLD TOLERANCE
4	1
7	1
8	1
13	1
18	1
29	1
26	1
32	1
34	1
92	1
120	1
52	1
64	2
57	2
11	2
80	2
82	2
19	2
28	2
37	2
38	2
43	2
44	2
103	2
47	2
48	2
51	2
5	3
58	3
10	3
59	3
79	3
25	3
24	3
97	3
45	3
46	3
50	3

3100-3400 CHU

HYBR#	COLD TOLERANCE
1	1
2	1
6	1
8	1
9	1
15	1
17	1
20	1
21	1
22	1
27	1
32	1
33	1
31	1
90	1
35	1
92	1
120	1
53	1
11	2
12	2
82	2
19	2
23	2
84	2
30	2
37	2
40	2
99	2
42	2
43	2
55	2
5	3
16	3
25	3
24	3
39	3
98	3
41	3
100	3
101	3
102	3
54	3

3300-3500 CHU

HYBR#	COLD TOLERANCE
1	1
2	1
6	1
9	1
15	1
17	1
20	1
21	1
22	1
27	1
33	1
31	1
90	1
35	1
120	1
53	1
11	2
12	2
23	2
84	2
30	2
40	2
99	2
42	2
55	2
16	3
39	3
41	3
100	3
102	3
54	3

7.2 Appendix B

Corn hybrid cold tolerance based on predictor RT3.Cold tolerance is rated as 1 (very good), 2 (good) or 3 (average).

HYBR#	COLD TOLERANCE	HYBR#	COLD TOLERANCE
1	1	68	2
2	1	56	2
61	1	57	2
4	1	11	2
6	1	12	2
7	1	73	2
8	1	75	2
9	1	80	2
65	1	82	2
69	1	19	2
13	1	28	2
15	1	23	2
17	1	84	2
72	1	30	2
74	1	85	2
78	1	91	2
18	1	36	2
20	1	37	2
21	1	38	2
22	1	96	2
27	1	40	2
29	1	99	2
26	1	42	2
86	1	43	2
32	1	44	2
33	1	103	2
31	1	47	2
89	1	48	2
34	1	106	2
90	1	108	2
35	1	111	2
92	1	112	2
94	1	113	2
95	1	118	2
104	1	51	2
115	1	55	2
120	1		
52	1	3	3
53	1	5	3
		62	3
60	2	63	3
64	2	58	3
67	2		

Appendix B (Cont'd)

HYBRID	COLD TOLERANCE
10	3
59	3
16	3
70	3
71	3
76	3
77	3
79	3
81	3
25	3
24	3
83	3
87	3
88	3
122	3
97	3
39	3
98	3
41	3
100	3
101	3
102	3
45	3
46	3
105	3
50	3
116	3
107	3
109	3
110	3
121	3
114	3
117	3
119	3
54	3

7.3 Appendix C

Mean (MNRT3), standard deviation (SDRT3) and coefficient of variation for the emergence predictor RT3. Calculations based on 4 repetitions (N=4) are shown for hybrids identified by hybrid number (HYBR#).

HYBR#	RT3	MNRT3	SDRT3	CVRT3
61	95.3	95.3	4.9	5.1
35	92.3	92.3	7.9	8.6
21	90.0	90.0	7.0	7.8
90	90.0	90.0	5.6	6.2
78	89.8	89.8	4.3	4.8
34	88.5	88.5	4.1	4.7
22	87.5	87.5	6.7	7.6
52	85.8	85.8	3.3	3.9
31	84.5	84.5	7.8	9.2
33	84.0	84.0	4.8	5.8
13	83.8	82.8	5.7	6.9
9	82.3	81.3	8.6	10.6
92	82.3	82.3	7.1	8.7
7	82.1	81.3	5.1	6.3
8	82.1	81.3	7.1	8.8
120	81.5	81.5	6.0	7.4
20	81.0	81.0	11.0	13.6
2	80.6	79.8	6.5	8.1
86	79.5	79.5	8.3	10.5
27	79.0	79.0	8.1	10.3
1	77.9	77.1	5.1	6.6
26	77.0	77.0	14.2	18.5
6	76.9	76.0	6.0	7.9
74	75.8	75.8	4.6	6.0
17	75.0	75.0	9.4	12.6
18	75.0	75.0	16.4	21.8
65	75.0	75.0	4.9	6.5
29	74.5	74.5	8.6	11.5
32	74.0	74.0	13.5	18.2
69	74.0	74.0	3.7	5.1
53	73.8	73.8	17.0	23.1
104	73.3	73.3	2.6	3.6
15	72.5	71.6	17.2	24.1
95	72.5	72.5	10.1	14.0
94	72.0	72.0	3.6	4.9
115	71.0	71.0	7.3	10.3
72	69.5	69.5	4.5	6.5
4	68.9	68.1	20.0	29.3
89	68.8	68.8	21.3	31.0

Appendix C (Cont'd)

HYBR#	RT3	MNRT3	SDRT3	CVRT3
51	67.0	67.0	9.9	14.8
44	65.8	65.8	4.9	7.5
96	65.0	65.0	15.4	23.7
73	64.8	64.8	8.1	12.4
30	64.3	64.3	3.0	4.6
40	63.5	63.5	9.9	15.7
55	62.3	62.3	2.4	3.8
23	61.8	61.8	13.8	22.4
64	61.5	61.5	20.1	32.6
48	61.3	61.3	8.3	13.5
103	61.3	61.3	14.6	23.8
80	59.5	59.5	20.4	34.3
68	58.0	58.0	13.5	23.3
37	57.8	57.8	12.7	22.0
118	57.8	57.8	16.7	28.9
108	57.3	57.3	9.0	15.7
112	57.0	57.0	13.2	23.1
91	56.5	56.5	13.3	23.5
36	54.5	54.5	15.9	29.2
11	53.8	53.0	15.2	28.7
82	53.5	53.5	22.2	41.4
47	52.3	52.3	6.8	13.1
84	52.3	52.3	18.4	35.2
75	51.8	51.8	21.5	41.5
38	51.5	51.5	19.2	37.3
12	50.5	50.1	18.9	37.7
60	48.8	48.8	14.5	29.8
99	48.8	48.8	7.9	16.2
43	48.5	48.5	5.1	10.4
85	48.0	48.0	4.5	9.5
67	47.8	47.8	10.2	21.3
111	47.5	47.5	10.8	22.6
57	47.3	47.3	14.9	31.5
28	46.0	46.0	6.2	13.5
113	45.3	45.3	10.6	23.4
42	44.8	44.8	11.4	25.4
106	44.8	44.8	8.1	18.0
19	41.8	41.8	16.5	39.5
56	41.8	41.8	8.9	21.3
46	41.3	41.3	11.3	27.5
97	41.3	41.3	8.2	19.8
70	40.0	40.0	15.9	39.8
62	39.0	39.0	19.7	50.5
54	37.5	37.5	12.2	32.5

Appendix C (Cont'd)

HYBR#	RT3	MNRT3	SDRT3	CVRT3
76	37.3	37.3	14.7	39.5
10	36.8	36.0	11.5	31.9
81	36.0	36.0	6.4	17.7
24	35.5	35.5	9.1	25.7
121	34.5	34.5	5.7	16.7
102	33.3	33.3	19.1	57.4
59	31.5	31.5	11.6	36.7
87	30.0	30.0	21.3	71.0
63	29.5	29.5	6.1	20.8
71	29.5	29.5	4.8	16.3
83	29.5	29.5	12.7	42.9
117	29.3	29.3	11.1	38.1
45	28.0	28.0	5.5	19.6
5	27.3	26.8	13.2	49.2
77	26.8	26.8	10.0	37.3
122	26.8	26.8	8.8	32.9
39	25.5	25.5	9.9	38.8
79	22.0	22.0	13.3	60.4
109	20.3	20.3	11.4	56.1
119	19.8	19.8	3.3	16.7
116	17.5	17.5	4.9	28.2
16	17.3	17.3	3.9	22.4
98	14.3	14.3	9.9	69.3
107	13.8	13.8	4.8	34.8
58	12.5	12.5	8.7	69.9
101	11.8	11.8	10.6	89.9
100	11.5	11.5	10.3	89.9
50	10.5	10.5	10.5	100.3
41	8.3	8.3	3.5	42.4
25	7.8	7.8	5.0	64.4
110	7.3	7.3	1.7	23.6
88	7.0	7.0	10.0	143.3
105	7.0	7.0	7.1	101.0
114	6.5	6.5	3.7	56.9
3	4.8	4.5	1.7	38.5

7.4 Appendix D

Alphabetical list of hybrids used in the study.

AGRI-502
AGRI-501
AS-RX339
AS-RX370
AS-RX406
AS-RX409
CA-MX320
CA-MX335
CAR-3427
CAR-1927
CAR-3477
CAR-2127
CAR-3637
CAR-4327
CAR-SX123
DK-524
DK-415
DK-535
DK-403
DK-445
DK-397
DK-435
D-331
DK-485
DK-371
FER-8965
FER-8969
FER-8758
FL-1783
FL-1656
FU-G4010
FU-G4017
FU-G4018
FU-G4021
FU-G4022
FU-G4023
FU-G4027
FU-G4030
FU-G4106
FU-G4140
FU-G4153
FU-G4160
FU-G4211
FU-G4299
FU-G4309
FU-G4385
FU-G4447
GAR-8555
GAR-8808
GAR-8882
GH-H2331
GH-H2343
GH-H2404
GH-H2410
GL-220
GL-509
GL-582
HE-HSI340
HYL-2803
HYL-2260
HYL-2570
HYL-2729
HYL-2275
JAC-4900
JAC-2750
JAC-4170
JAC-7700
JAC-6770
LI-24.90
LI-22.73
N-N2001
N-N4350
N-PX9060
N-PX9214
OS-OS822
PIC-2700
PIC-5575
PIC-8898
PIC-8877
PIC-2600
PIO-3902
PIO-3901
PIO-3921
PIO-3929
PIO-3979
PIO-3953
PIO-3897
PIO-3772
PIO-3576
PIO-3704
PIO-3527
PIO-3475
PIO-3417
PIO-3751
PIO-3845
PIO-3790
PIO-3787
PIO-3954
PIO-3917
PIO-3967
PIO-3925
PIO-3737
PIO-3794
PIO-3733
PIO-3503
PIO-3573
PR-K1124
PR-K1184
PR-K127
PR-K2203
PR-K249
PR-K299
PR-K337
PR-K448
RE-RK602
RE-RK64
SC-2989
SC-2277