# Effects of Soil Temperature, Soil Moisture Content and Seeding Depth on Germination and Emergence of Winter Wheat.

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A concern of many winter wheat producers in the fall is whether to plant in a dry seedbed at the optimum seeding date or else wait for some precipitation before seeding to ensure prompt emergence. This dilemma poses two problems. If seeding is delayed, this means that the plants will have to emerge and grow under lower soil and air temperatures. On the other hand, waiting for precipitation will ensure that germination and emergence can occur. But the question then becomes: how much precipitation is required to ensure proper emergence and growth? In order to shed light on this dilemma, one must determine the relative effects of temperature and moisture stress, within the limits expected under field conditions on germination and emergence.

A study was therefore initiated to determine the effects of temperature and moisture stress on seed water uptake and speed of germination, as well as the effects of temperature, moisture stress and seeding depth on speed of emergence.

## (A) Temperature and soil moisture content on seed water uptake.

The effects of temperature and soil moisture content on seed water uptake were studied using the winter wheat cultivar, 'Norstar'. Six temperatures (5,10,15,20,25 and 30 degrees C) along with four different water potentials (0,-2,-10 and -15 bars) were investigated. Seeds of uniform size and of the same seed lot were chosen. Twenty seeds were either put on two filter papers imbibed with distilled water or else buried in soil (Bradwell clay loam) of different water potentials. After various lengths of time, depending on the temperature, two twenty seed lots were removed from the filter papers and dug up from the soil of various water potential. Thirteen readings were done for each temperature and water potential. After each reading, the number of seeds germinated and the gravimetric moisture content of the seeds were determined. The seeds were dried for 24 hours in a forced air oven set at 100 degrees C. The seed water content of the seeds was expressed as kg of water per kg of dry seed.

The water uptake curves (water content (kg/kg) vs time (days)) were fitted to an equation of the form $y=a+b\sqrt{x}$ where y is the seed water content and x is the time. Good fits and high coefficients of determfination were obtained for each temperature and water potential studied. A list of all the equations is given in Table 1.

The effects of temperature on seed water uptake with seeds placed at various water potentials are shown in Figure 1. As temperature increases, the rate of water uptake increases regardless of water potential. The rate of water uptake was still increasing at 30 degrees C at all water potentials. Similar findings are reported by Fraser and Haley (1932), Campbell and Jones (1955), Becker (1960) and Asraf and Abu-Shakra (1978).

When the pattern of seed water uptake is compared between the various water potential used for each temperature, the rate of water uptake is much quicker with seeds placed on wet filter papers than in soil at all temperatures (Figure 2). When the rate of seed water uptake is examined between seeds placed in soil of various water contents, the differences are not very large. At 5 and 10 degrees C, there are virtually no differences. As temperature increases, the differences become more noticeable but still very small. Ward and Shaykewich (1972) working with the spring wheat variety 'Neepawa', found large differences in rate of water uptake with seeds buried in soil of various water potential. This is certainly not the case with the winter wheat variety 'Norstar'.

In summary, temperature has a strong effect on the rate of seed water uptake. When water uptake was compared between seeds placed at various water potentials, the seeds placed on wet filter papers absorbed water at a much faster rate than with seeds placed in soil of various water contents. When the differences in rates of water uptake were examined for seeds placed in soil at different water potentials, there were essentially no differences at 5 degrees C and 10 degrees C. Small differences showed up at the higher temperatures but not as large as those reported by Ward and Shaykewich (1972) for spring wheat.

**(B) The effects of temperature and moisture stress on germination.**

Seed germination was determined by recording the number of seeds germinated during the seed water uptake studies. The cumulative proportion of seeds germinated over time were fitted to the log-logistic function and the time to 50% germination (GT50) calculated from the fitted curve. The log-logistic function has the form $p=1/1+\exp-(a+b \ Ln(t))$. A seed was considered germinated when the radicle was approximately 2 - 3 mm long.

A summary of the GT50 values for each temperature and water potential is given in Table 2. The first observation is the strong influence of temperature on GT50. The time required for 50% germination almost doubles from 10 to 5 degrees C. The

Table 1. Regression coefficients[1] and coefficients of determination for seed water uptake at six temperatures and four water potentials.

| Temperature | Water potential (bars) | a | b | $R^2$ |
|---|---|---|---|---|
| 5 | distilled water | 0.144 | 0.259 | 99 |
| | -2 | 0.172 | 0.193 | 96 |
| | -10 | 0.165 | 0.190 | 96 |
| | -15 | 0.168 | 0.184 | 96 |
| 10 | distilled water | 0.051 | 0.376 | 99 |
| | -2 | 0.108 | 0.263 | 99 |
| | -10 | 0.109 | 0.257 | 99 |
| | -15 | 0.118 | 0.243 | 99 |
| 15 | distilled water | 0.096 | 0.433 | 97 |
| | -2 | 0.146 | 0.292 | 96 |
| | -10 | 0.143 | 0.279 | 96 |
| | -15 | 0.147 | 0.269 | 97 |
| 20 | distilled water | 0.094 | 0.481 | 99 |
| | -2 | 0.102 | 0.399 | 99 |
| | -10 | 0.109 | 0.378 | 99 |
| | -15 | 0.108 | 0.370 | 99 |
| 25 | distilled water | 0.067 | 0.631 | 99 |
| | -2 | 0.125 | 0.432 | 97 |
| | -10 | 0.122 | 0.420 | 99 |
| | -15 | 0.122 | 0.410 | 99 |
| 30 | distilled water | 0.086 | 0.664 | 98 |
| | -2 | 0.128 | 0.506 | 99 |
| | -10 | 0.137 | 0.463 | 98 |
| | -15 | 0.141 | 0.458 | 98 |

[1] The fitted equation as of the form $y = a+b\sqrt{x}$ where "y" is the water content (kg $H_2O$/kg dry seed), "x" is the time in days, and "a" and "b" are the estimated coefficients.

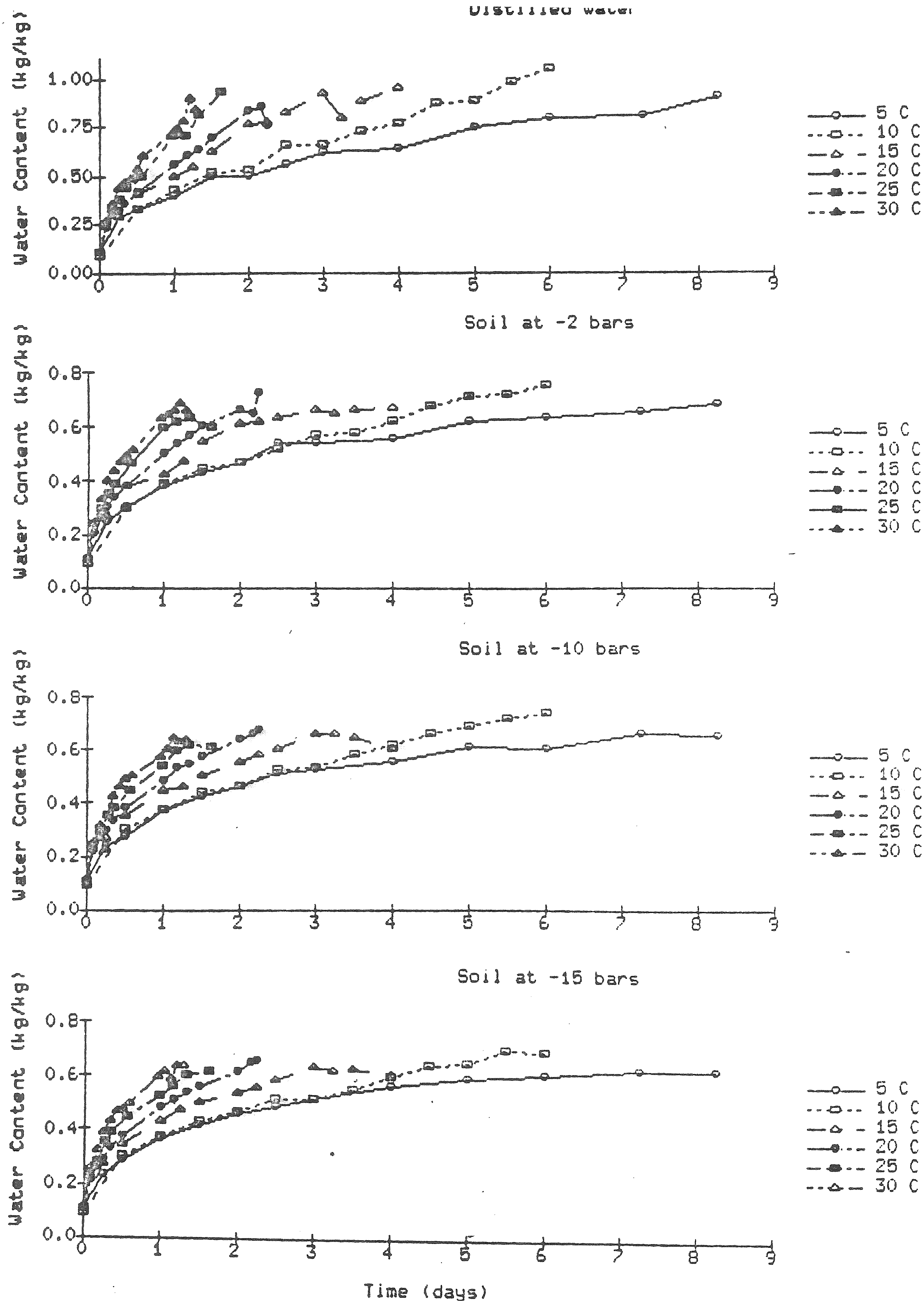


Figure 1. Seed water uptake at six temperatures for four different water potentials.

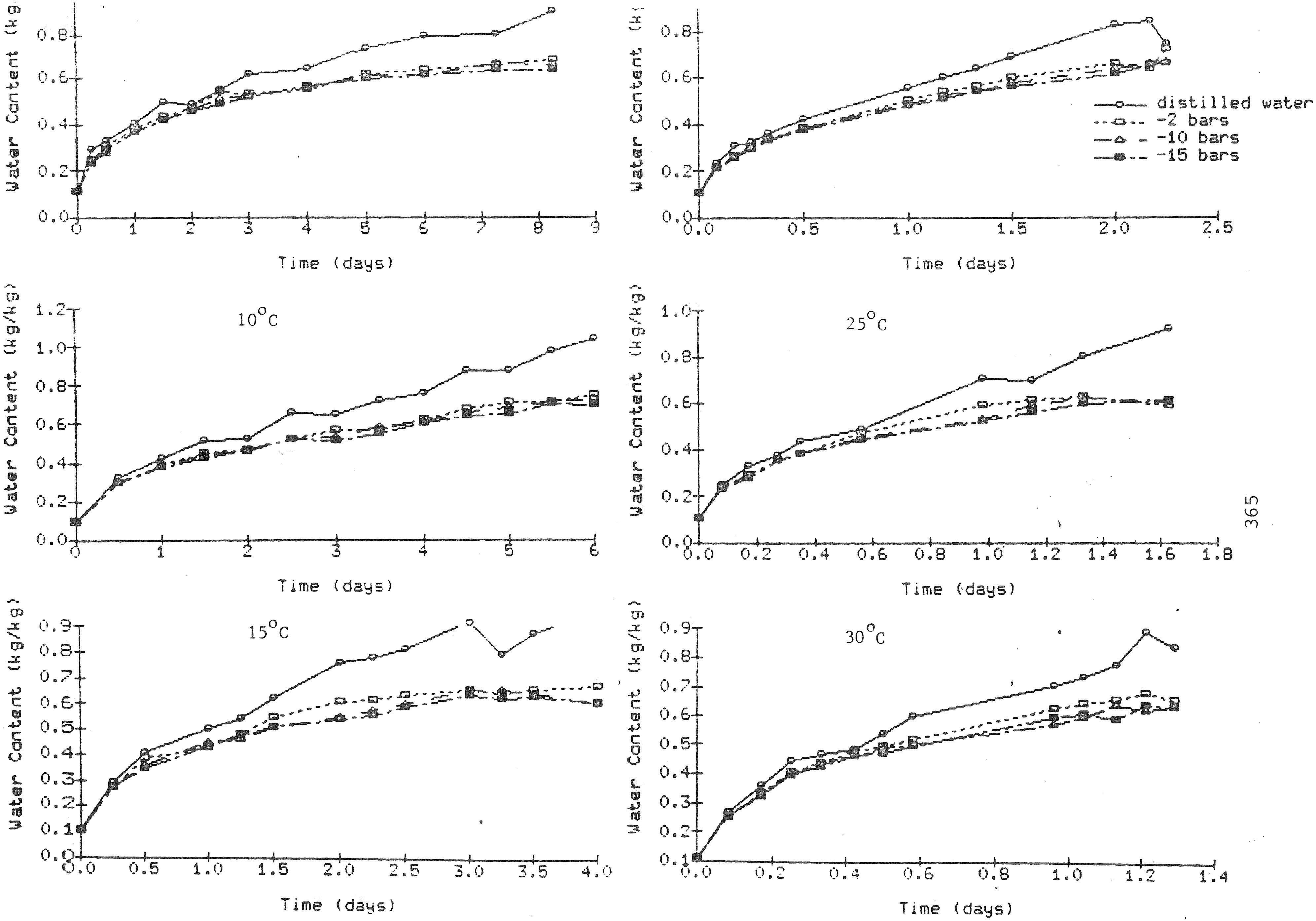


Figure 2. The effects of water potential on seed water uptake at six different temperatures.

minimum time required for germination occurred at 25 degrees C. Percent germination exceeded 90% in all cases. The effects of temperature on seed germination have been documented for a long time (Coffuran (1932); Wilson and Hottes (1927).

Examination of the effects of water potential on seed germination shows a different picture. The difference in time between germination on filter papers and germination at -15 bars was essentially non-existent regardless of temperature (Table 2). This is in sharp contract with the results of the seed water uptake studies where strong differences in rates of seed water uptake were observed between seeds placed on filter papers and seeds placed in soil at -15 bars. It would appear that the rate of seed water uptake does not ncessarily determine the rate of germination. These results are in sharp contrast with those of Pawloski and Shaykewich (1972). They observed a strong influence of soil water potential on speed of germination. However, a close examination of their methods reveals that germination was recorded with the seeds plaed on the surface of the soil. This means that ensuring good seed-soil contact greatly improves the rate of germination, even in soils at -15 bars, virtually eliminating the differences between soils at -2 and -15 bars.

Another question of interest is how much water must the seed imbibe in order for germination to occur. Given the times to 50% germination, it was possible to calculate the water content of the seeds at GT50 from the fitted seed water uptake curves (Table 3). As temperature increases, the seed water content at GT decreases up to 25 degrees C. At 30 degrees C, the water content increased. This is because the minimum GT50 values occurred at 25 degrees C and since the rate of water uptake was still increasing at 30 degrees C, it follows that the seed water content at GT50 should be higher at 30 degrees C. At -2 and -10 bars, the water content decreases from 5 to 15 degrees C, but increases at 20 degrees C and decreases again at 25 degrees C to increase again at 30 degrees C. There is no explanation for these results. The water content of the seed at GT50 is therefore dependent on the temperature and water potential to which the seed is exposed.

**(C) The effects of temperature, soil moisture content and seeding depth on the emergence of winter wheat.**

The relative effects of temperature and soil moisture have to be studied together in order to get a better appreciation of what to expect under field situations when seeding is delayed due to insufficient soil moisture compared to seeding at the optimum date in a dry seedbed. Another question of interest is: What is the optimum seeding depth of winter wheat?

Five soil moisture potentials (-0.3, -2, -4, -10, -15 bars) and three seeding depths (0.50, 1.0 and 2.0 ") were examined for their effects on emergence at six constant temperatures (5, 10, 15, 20, 25 and 30 degrees C). Air dry soil (Bradwell clay loam) was brought up to the desired water potential and placed in small

Table 2. Median germination times ($GT_{50}$) for six temperatures and four water potentials.

| Temperature (°C) | Water Potentials (bars) distilled water | -2.0 | -10.0 | -15.0 | Mean |
|---|---|---|---|---|---|
| 5 | 7.3 | 6.7 | 6.7 | 6.9 | 6.9 |
| 10 | 3.9 | 3.5 | 3.5 | 3.9 | 3.7 |
| 15 | 2.0 | 1.7 | 2.2 | 2.3 | 2.1 |
| 20 | 1.5 | 1.4 | 1.5 | 1.4 | 1.5 |
| 25 | 0.9 | 0.8 | 1.0 | 1.0 | 0.9 |
| 30 | 1.0 | 0.9 | 0.8 | 0.9 | 0.9 |
| Mean | 2.8 | 2.5 | 2.6 | 2.7 | |

Table 3. Seed water content (kg $H_2O$/kg dry seed) at $GT_{50}$ for six temperatures and four water potentials.

| Temperature (°C) | Water Potentials (bars) | | | | Mean |
|---|---|---|---|---|---|
| | distilled water | -2.0 | -10.0 | -15.0 | |
| 5 | 0.844 | 0.671 | 0.658 | 0.651 | 0.706 |
| 10 | 0.794 | 0.600 | 0.590 | 0.598 | 0.646 |
| 15 | 0.708 | 0.527 | 0.557 | 0.555 | 0.587 |
| 20 | 0.683 | 0.574 | 0.572 | 0.546 | 0.594 |
| 25 | 0.666 | 0.512 | 0.542 | 0.532 | 0.563 |
| 30 | 0.752 | 0.608 | 0.551 | 0.575 | 0.622 |
| Mean | 0.741 | 0.582 | 0.578 | 0.576 | |

plastic pots lined with a plastic bag. Fifty seeds were planted at three depths and the pot enclosed in a plastic bag to minimize soil water evaporation. Each treatment was replicated six times.

Emergence was estimated by periodically recording the cumulative proportion of coleoptiles appearing at the soil surface. These results were then fitted to the log-logistic curve (p=1/1+exp-(a+b Ln(t)) and the time to 50% emergence (ET50) determined for each pot. The soil moisture content was determined at the beginning and end of each experiment. Each pot was unearthed and examined for seeds that had germinated but not emerged at the end of each experiment. This provided an accurate measurement of seed viability. A separate analysis of variance for ET50 was done for each temperature (Table 4). The factors, soil water potential and seeding dpeth, had a highly significant effect on ET50 at all temperatures. None of the soil water potential by seeding depth interactions were significant.

The ET50 values for each temperature, water potential and seeding depth are given in Table 5. It takes on average 24 days for winter wheat seeds to germinate and emerge at 5 degrees C, 10 days at 10 degrees C, 5.9 days at 15 degrees C and 4 days at 25 degrees C. In the range from 5 to 15 degrees C, every 5 degree measurement results in a 50% reduction in time to emergence with very little change occurring from 20 to 30 degrees C. The minimum time required for emergence was reached at 25 degrees C. At low temperatures (5 to 15 degrees C), small changes in soil temperatures resulted in large effects on ET50.

When soil water potential is considered, the effect was highly significant at all temperatures but the absolute differences were small. At 5 degrees C, going from soil at field capacity to soil at permanent wilt point only delayed emergence by 2 days (from 24 to 26.1 days). At 10 degrees C, the delay was less than 1 day, at 15 degrees there were essentially no differences. At the higher temperatures, the delay was proportionately greater. At 25 degrees C, ET50 went from 3.3 to 5.6 days and at 30 degrees C, from 3.5 to 4.1 days. There was less than 1 days difference at 20 degrees C. Dejong and Best (1979) found that different soil types at equivalent water potentials showed little differences in ET50 regardless of temperature and moisture potential. Their soil water potentials ranged from -0.33 to -10 bars and had negligible effects on delaying emergence. Lindstron et al (1976) report small differences in ET50 between -0.4 and -4 bars. We found the differences to be very small even down to -15 bars, especially at the lower temperatures.

Seeding depth is another factor that has a strong effect on emergence. At 5 degrees C, increasing the depth from 0.50" to 2.0" delayed emergence by 5 days and at 10 degrees C by 3 days (Table 5). As the temperature increased, the percent differences increased. Seeding depth delayed emergence regardless of temperature and moisture stress.

Table 4. Analysis of variance of $ET_{50}$ for six temperatures.

| | | MS (Temperature) | | | | | |
|---|---|---|---|---|---|---|---|
| Source | df | 5 | 10 | 15 | 20 | 25 | 30 |
| Block (B) | 1 | 21.65** | 4.53** | 0.33ns | 0.26ns | 1.28ns | 0.1 |
| Water Regime (W) | 4 | 21.22** | 4.23** | 1.58** | 3.28** | 18.66** | 1.8 |
| Seeding Depth (S) | 2 | 190.42** | 53.66** | 21.21** | 17.13** | 13.17** | 23.6 |
| B X W | 4 | 3.01ns | 0.15ns | 0.03ns | 0.13ns | 0.30ns | 0.C |
| B X S | 2 | 2.69ns | 0.54ns | 0.11ns | 0.03ns | 0.46ns | 0 |
| W X S | 8 | 0.78ns | 0.15nx | 0.19nx | 0.17nx | 0.29nx | 0 |
| B X W X S | 8 | 2.84* | 0.14ns | 0.12ns | 0.11ns | 0.43ns | 0 |
| Error | 60 | 1.42 | 0.19 | 0.11 | 0.13 | 0.48 | 0. |

Table 5. Median emergence time ($ET_{50}$) for six temperatures, five water potentials and three seeding depths.

| Temperature (°C) | Depth (inches) | Water Potential (bars) -0.3 | -2 | -4 | -10 | -15 | x̄ |
|---|---|---|---|---|---|---|---|
| 5 | 0.5 | 21.8 | 21.8 | 21.5 | 22.2 | 24.4 | 22.3 |
| | 1 | 22.9 | 22.7 | 22.8 | 23.9 | 25.1 | 23.5 |
| | 2 | 27.4 | 25.6 | 26.3 | 27.3 | 28.8 | 27.2 |
| | x̄ | 24.0 | 23.4 | 23.6 | 24.5 | 26.1 | 24.3 |
| 10 | 0.5 | 8.6 | 8.4 | 8.5 | 9.0 | 9.5 | 8.8 |
| | 1 | 9.7 | 9.0 | 9.6 | 9.9 | 10.5 | 9.7 |
| | 2 | 11.6 | 10.9 | 11.0 | 11.6 | 12.1 | 11.4 |
| | x̄ | 9.9 | 9.4 | 9.7 | 10.2 | 10.7 | 10.0 |
| 15 | 0.5 | 5.9 | 5.4 | 5.6 | 5.6 | 5.6 | 5.6 |
| | 1 | 6.3 | 5.5 | 5.6 | 6.0 | 6.3 | 6.0 |
| | 2 | 7.8 | 6.9 | 6.7 | 7.3 | 7.4 | 7.2 |
| | x̄ | 6.7 | 5.9 | 6.0 | 6.3 | 6.4 | 5.9 |
| 20 | 0.5 | 3.4 | 2.8 | 3.4 | 3.5 | 3.9 | 3.4 |
| | 1 | 3.8 | 3.5 | 3.9 | 3.9 | 4.6 | 3.9 |
| | 2 | 4.7 | 4.5 | 4.5 | 5.1 | 5.7 | 4.9 |
| | x̄ | 3.9 | 3.6 | 3.9 | 4.2 | 4.7 | 4.1 |
| 25 | 0.5 | 3.0 | 2.8 | 3.2 | 3.8 | 5.1 | 3.6 |
| | 1 | 2.9 | 3.0 | 3.4 | 4.2 | 5.1 | 3.7 |
| | 2 | 3.9 | 3.7 | 4.4 | 5.4 | 6.7 | 4.8 |
| | x̄ | 3.3 | 3.2 | 3.7 | 4.6 | 5.6 | 4.0 |
| 30 | 0.5 | 2.9 | 2.8 | 2.8 | 2.9 | 3.2 | 2.9 |
| | 1 | 3.3 | 3.1 | 3.2 | 3.4 | 3.8 | 3.4 |
| | 2 | 4.3 | 4.1 | 4.3 | 4.0 | 5.4 | 4.6 |
| | x̄ | 3.5 | 3.3 | 3.4 | 3.7 | 4.1 | 3.6 |

Another important question is whether or not any of these factors affect the numbers of seedlings emerging. High percent emergence were observed at 5 degrees C regardless of seeding depth and soil water potential (Table 6). The percent emergence decreased at the 5 cm depth with increasing temperature. This is because maximum coleoptile elongation occurs between 10 and 15 degrees C (Sunderman, 1964; Burleigh et al. 1965). At 25 and 30 degrees C, % emergence was the lowest. This is due in part to greater damping-off by the seedlings and a greater percentage of seedlings having coleoptiles that elongate very little.

When percent germination is examined (Table 7), high seed viability was obtained between 5 and 20 degrees C. As temperature inceased above 20 degrees C, the viability dropped, mainly because the seeds were more susceptible to attack by pathogens. This was more prominent at -15 bars than at higher soil water potentials. This agrees with the findings of Owen (1952).

Based on these findings, it is preferable for producers to seed in a dry seed bed at the optimum date rather than wait for some precipitation before seeding. Very little precipitation would be required to get germination occurring, given the above results. Also, the strong influence of temperature on emergence is a strong argument in favor of seeding at the optimum date.

## (D) Conclusions

(1) The strong effects of temperature. In the range of 5 to 15 degrees C., small changes in temperature resulted in large differences for water uptake, germination and emergence. Percent emergence and percent germination were higher at the low temperatures.

(2) Soil water potential had a small but significant effect. Seed water uptake was slower with seeds placed in soil than with seeds placed on wet filter papers, regardless of the temperature studied. At the lower temperatures (5 and 10 degrees C), there were essentially no differences in rate of water uptake between the seeds buried in soil of different water potentials (-2, -10 and -15 bars). The differences increased somewhat above 15 degrees C. Soil water potential had no effect on median germination time. Regardless of whether the seeds were placed on wet filter papers or buried in soil of various moisture contents, the median germination time was the same, regardless of temperature. This implies that under certain conditions, a faster rate of seed water uptake does not necessarily imply a faster rate of germination. Soil water potential had a significant effect on emergence regardless of temperature and seeding depth. However, the resultant differences were small in the range of -0.3 to -15 bars.

(3) Depth of planting had a strong delaying effect on emergence. An increase from 0.50" to 2.0" resulted in consistently greater times to emergence regardless of temperature

Table 6. Percent emergence for six temperatures, five water potentials and three seeding depths.

| | SOIL WATER POTENTIAL (bars) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | -0.3 | | | -2.0 | | | -4.0 | | | -10.0 | | | -15.0 | | |
| Temp (°C) | 0.5" | 1.0" | 2.0" | 0.5" | 1.0" | 2.0" | 0.5" | 1.0" | 2.0" | 0.5" | 1.0" | 2.0" | 0.5" | 1.0" | 2.0 |
| 5 | 94 | 93 | 88 | 94 | 93 | 91 | 94 | 95 | 92 | 93 | 95 | 93 | 91 | 95 | 93 |
| 10 | 92 | 89 | 82 | 93 | 90 | 92 | 93 | 89 | 87 | 94 | 92 | 91 | 95 | 93 | 81 |
| 15 | 87 | 86 | 79 | 95 | 94 | 88 | 93 | 93 | 92 | 94 | 94 | 93 | 92 | 94 | 93 |
| 20 | 90 | 85 | 78 | 94 | 87 | 89 | 92 | 94 | 87 | 94 | 93 | 90 | 92 | 93 | 89 |
| 25 | 82 | 86 | 73 | 88 | 88 | 84 | 92 | 90 | 84 | 84 | 83 | 83 | 56 | 62 | 70 |
| 30 | 86 | 83 | 73 | 90 | 88 | 80 | 87 | 86 | 81 | 87 | 90 | 87 | 76 | 76 | 76 |

Table 7. Percent germination for six temperatures, five water potentials and three seeding depths.

| | SOIL WATER POTENTIAL (bars) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | -0.3 | | | -2.0 | | | -4.0 | | | -10.0 | | | -15.0 | | |
| Temp($^{o}$C) | 0.5" | 1.0" | 2.0" | 0.5" | 1.0" | 2.0" | 0.5" | 1.0" | 2.0" | 0.5" | 1.0" | 2.0" | 0.5" | 1.0" | 2.0" |
| 5 | 96 | 97 | 95 | 98 | 96 | 96 | 98 | 97 | 96 | 96 | 96 | 96 | 95 | 97 | 97 |
| 10 | 98 | 97 | 94 | 97 | 95 | 97 | 96 | 96 | 92 | 97 | 96 | 95 | 97 | 94 | 95 |
| 15 | 95 | 96 | 94 | 96 | 98 | 94 | 95 | 95 | 96 | 95 | 96 | 96 | 95 | 96 | 97 |
| 20 | 98 | 98 | 95 | 96 | 95 | 94 | 96 | 98 | 94 | 96 | 94 | 95 | 94 | 94 | 94 |
| 25 | 93 | 95 | 86 | 93 | 92 | 90 | 96 | 92 | 88 | 88 | 89 | 88 | 89 | 70 | 77 |
| 30 | 98 | 96 | 90 | 97 | 94 | 91 | 95 | 92 | 90 | 90 | 94 | 93 | 84 | 81 | 81 |

and moislture stress.

(4) It is therefore recommended that farmers plant as shallow as possible and as close to the optimum seeding depth regardless of how dry the soil is.

## E) References

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