AN EVALUATION OF LABORATORY GERMINATION OF VARIOUS SMALL GRAIN SPECIES IN MANNITOL STRESS SOLUTIONS

By

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CHAPTER I

INTRODUCTION

Observation of small grain varieties during establishment has indicated that some varieties became established faster than others of the same crop. Interest is generated in the utilization of small grain species as a source of winter pasture since their use greatly reduces the cost of overwintering livestock in Oklahoma. The selection of a particular variety for this purpose in part depends on its ability to become established early. This statement is based on the conclusion that early fall establishment is needed for adequate forage to be available when range grasses have lost their productivity. In addition, those species that attain greater growth going into the winter months are generally the most desirable for winter grazing. Considering these needs and uses, the varieties selected for this study were chosen from those which appeared to be potentially suitable for forage production in Oklahoma, or which exhibited noticeable rapidity in germination and growth.

Seedling establishment may be limited by: 1) some physiological mechanism resulting in an inability to obtain enough water for rapid seed germination, and 2) seed morphological characteristics such as size and length of coleoptile. The latter are components of seedling vigor and, as such, varies between crops, varieties within crops and age of crop seed utilized.

Small grains and other forage crops, particularly range grasses, are known to differ in their ability to germinate and grow under less than optimum moisture conditions. A knowledge of which forage producing small grains has this ability is essential for a complete evaluation.

It is also generally recognized that all crops and many varieties have certain temperature ranges within which they germinate best. As a result, all species do not react the same to a given environment.

Consequently, the objectives of this study were: 1) to evaluate the ability of a select group of small grain crops and varieties to germinate under various stress conditions involving temperature and moisture, and 2) to observe seedling response by crop variety to conditions of stress.

CHAPTER II

LITERATURE REVIEW

An important characteristic of non-irrigated crops grown in the western and southwestern parts of the United States is that of being able to withstand periods of low moisture availability. The above characteristic cannot be overemphasized since plants must at times germinate and become established under drouthy conditions.

Temperature, gas, light, seed coat, maturity, dormancy, and genetically controlled metabolic effects, according to Barton (3), are all factors affecting the control of germination. Metabolic control is possibly the most involved in germination under drouth conditions although the other factors, particularly temperature, cause interactions. Variability is expected among and within species with regard to this characteristic.

If variability exists, the chances of obtaining genetic lines which will perform satisfactorily near the wilting coefficient is improbable. In fact, an osmotic tension of three to six atmospheres is sufficient to cause reduced germination and growth on some species. On the other hand, there is a good chance that genetic lines may be obtained that will contain better growth and production characteristics under those conditions in which water is held by a force of less than twelve atmospheres but greater than three.

Changes in soil moisture content below ten percent causes sharp increases in moisture tension according to Wadleigh and Ayers (51). They indicated a loam soil of six to seven percent moisture was near the fifteen-atmosphere-percentage, the wilting coefficient, which was in agreement with the findings of Richards and Weaver (38).

Ayers (2) stated that in order for the plant to obtain water from the soil, two main forces must be overcome: 1) the surface force action of the soil particles usually referred to as soil moisture tension and 2) the osmotic force action which is due to dissolved materials in the soil solution. The sum of these two factors is referred to as soil moisture stress, a measure of the availability of soil moisture.

Earlier work by Van Overbeek (32) indicated that uptake of water was made up of two components: 1) pressure of osmotic origin and 2) "active" pressure. The "active" pressure is unaccounted for and may involve other metabolic forces.

A rather thorough review of the physical and physiological aspects of water absorption was conducted by Kramer (24).

Numerous workers have shown that different species and varieties differ in water requirements for seed germination (8,9,12,17,18,37,44, 45,50). These researchers used various methods other than mannitol for their investigations. Wright and Streetman (56) made an extensive review of various laboratory methods for drouth evaluations.

The first germination experiments involving mannitol as a chemical for producing osmotic stress was conducted by Uhvits (49) in 1946. Using both sodium chloride and mannitol in comparative tests on alfalfa, she observed: 1) a reduced growth rate and lower average germination with higher concentrations of both chemicals; 2) practically no germination at twelve to fifteen atmospheres; 3) sodium chloride was more toxic than mannitol; and 4) mannitol seedlings had greater recovery and fewer deformities.

Wiggans and Gardner (54) also showed that mannitol has less effect on germination of radish and sorghum seeds than polyvinylpyrrollidone (PVP), sodium chloride, glucose, and sucrose.

Helmerick and Pfeifer (15) found differential varietal responses between Yogo and Cheyenne winter wheat when germinated under controlled moisture conditions in mannitol and in soil in a pressure-membrane apparatus.

A large-scale method for testing plants for drouth-tolerance was suggested by Powell (35) using mannitol. Later Powell and Pfeifer (36) found that seedlings selected for high total growth rate in mannitol solutions also have drouth hardiness as measured by comparing the results from two generations of the same parentage. They indicated that mannitol solutions gave a relative measure of the difference between selections for drouth hardiness.

Using mannitol solutions in germination tests on range grass seeds Kneebone (22) found improved strains known to have superior establishment characteristics germinate faster and produce larger seedlings when grown under an osmotic pressure of seven and one-half atmospheres.

Dotzenko and Dean (10) found highly significant differences between alfalfa varieties and osmotic pressures which indicated the ability to germinate in high osmotic pressures was heritable. Later Dotzenko and Haus (11) again reported the trait was heritable and showed that progeny from crosses which had been selected from various varieties at twelve atmospheres of osmotic tension also showed ability to germinate at this osmotic tension.

Work by Schwer et al. (40) indicated that the ability to germinate was heritable since progeny of plants selected for this characteristic did germinate better than check plants, but heat, cold and drouth tolerance tests under greenhouse conditions did not show significant differences.

In work with range grass species, McGinnies (29), Knipe and Herbel (23), and Wright and Hall (57) found reduced growth and germination with increases in osmotic pressure. McGinnies also concluded temperature influenced germination of range grass seed under moisture stress.

Mannitol has not been shown to be metabolizable in higher plants. However, certain bacteria are known to produce mannitol (33,43), and to metabolize mannitol (16,25,27,34,41). Recently, enzymes have been isolated from _Escherichia coli_ for catylyzing the reversible reaction for production and utilization of mannitol (55). Martinez et al. (28) recently isolated an enzyme essential for the biosynthesis of mannitol from fructose. Some investigators working with higher plants have shown evidence that mannitol is taken into the plant.

Collander and Bärlund (7) assessed the half saturation time of mannitol to be greater than thirty-five days in shoots of intact plants. Thimann (46,47) assumed that mannitol acts solely as an osmotic agent in preventing water uptake. Other workers who have used this chemical as an agent for producing osmotic stress have taken a similar view.

Bayley and Setterfield (4) concluded that if mannitol worked simply as an osmotic agent in preventing increase in wall area then it does not affect the synthesis and deposition of new wall material. They found no detectable deposition of wall material and offered explanations that mannitol may interfere with metabolism of new wall material or may merely inhibit uptake of water by the cell and this in turn prevents cell elongation. They suggested studies involving mannitol be interpreted with care since cell wall deposition is altered.

Later, investigations were conducted by Thimann (48) on the uptake of mannitol into potato disks. He found that the mannitol absorbed by potato disks was mostly in the apparent free space and very little in the cells.

The first direct evidence for mannitol absorption was shown by Groenewegen and Mills (14). They identified pure mannitol in water of guttation from intact plants but pointed out that the mannitol may have existed only in the xylem and may have been excluded from the vacuoles. They proposed mannitol is not a suitable substance to impose water stress on intact plants for any considerable time.

Slatyer (42) investigated the effects of mannitol on the internal osmotic potential and turgor pressure of tomatoes. He found that a water stress is induced in the plant but could not be considered analogous to the effect of soil water tension since osmotic potential and turgor pressure levels are displaced. Some mannitol was absorbed and the relative reduction in turgor pressure decreases proportionally with the amount absorbed and with the increase in internal osmotic potential. Hence, the growth inhibition observed with increases in osmotic tension seems not to be entirely due to direct osmotic effects when diffusible solutes are involved. Burström (5), and Ordin et al. (31) have also suspected some mannitol absorption into the plant.

More recently investigations have dealt with alteration of ribonucleic acid and protein content under induced moisture stress. Gates and Bonner (13) found an increase in ribonucleic acid level initially followed by a decrease and concluded that osmotically induced moisture stress increases the rate of destruction of ribonucleic acid. Similarly, Kessler (20) found the same effect. Later Chen and Kessler (6) found protein level to increase at the beginning of water stress, decrease at medium water stress, and increase at extreme water stress. Nieman and Poulsen (30) indicated ribonucleic acid, deoxyribonucleic acid and protein all were largely inhibited at one atmosphere osmotic pressure produced by mannitol. Investigations by West (52,53) indicate a shift in adenosine-5'-triphosphate, uridine-5'-triphosphate, and quanosine-5'-triphosphate which are precursers to ribonucleic acid. Adenosine-5'-diphosphate and adenosine-5'-triphosphate decreased and quanosine-5'-diphosphate, quanosine-5'-triphosphate, and uridine-5'-triphosphate increased when moisture was limited. Kessler and Frank-Tishel (21) postulated that the extent of the resistance of plants to drouth and low temperature is related to either a higher quanosine-cytidine content in the ribonucleic acid and/or its ability to synthesize quanosine-cytidine-rich ribonucleic acid molecules under the stimulus of slight stress conditions. Many investigations concerning ribonucleic acid involve mannitol as the chemical for producing the osmotic stress.

CHAPTER III

MATERIALS AND METHODS

Laboratory Germination Procedure

Tests were conducted in 1962, on twelve small grain varieties. Three Stults Da-lite germinators were used; one set for 20° C. constant, one for 30° C. constant and one for an alternate 20°-30° C. environment. Each environment was set for 8 hours of darkness and 16 hours of light, the dark period being concomitant with the 20° C. setting of the alternate environment. Seed were placed in covered plastic boxes 2 7/8 by 2 7/8 by 1 1/2 inch. Each box contained 6 layers of Kimpac with 8 ml of moistening agent measured with a burette. Osmotic stress solutions of 0, 3, 6, 9, 12, and 15 atmospheres were created with mannitol and used as moistening agents. The calculations of the osmotic pressure were made according to the formula given by Uhivts (49). One box containing 25 seed was considered as an experimental unit. Six replications were used in each germinate. One replicate consisted of 72 boxes randomly assigned to two tray levels in a randomized block design as suggested by Ahring et al. (1). Drafting tape was used to seal each box to prevent the drawing or loss of moisture during the study.

A single seed germination count was made on the 10th day after incubation as described by Justice et al. (19) for: 1) number of normal seedlings, 2) height of normal seedlings, and 3) number of seedlings with coleoptiles greater than 10 mm in length. A seedling was considered normal when the leaf-roll (plumule) had projected through the coleoptile and the coleoptile was at least 20 mm. in length.

The germination rate was estimated by the method proposed by Maquire (26). By this method germination rate equals

$$\frac{\text{number of normal seedlings}}{\text{days to first count}} + \ldots\ldots + \frac{\text{number of normal seedlings}}{\text{days to final count}}.$$

The speed of germination in the three environments was estimated for all varieties. Germination counts were made on the 4th, 6th, 7th, and 8th days after the initiation of the germination test.

Measurements on oat coleoptiles and determinations of the number and length of root radicals were made on the basis of 6 seedlings randomly selected from those used for measuring effects of the osmotic pressure substrates. Coleoptile width was measured under a 40 x binocular scope.

Seed sources, by varieties used in the experiments, are shown in Table I.

Osmotic Pressure Measurements of Substrate Moistening Agent

The osmotic pressures of the solutions in the germination boxes were determined at the beginning and at two intervals during the 10 day germination period. Checks were made on the osmotic pressures of the mannitol solutions at 0, 5, and 10 days to note any occurrence of change in atmospheres of tension. Duplicate boxes of each treatment were placed in the germinator. One was removed at 5 days, the seedlings were removed from the substrate and the moistening agent was hand extracted and osmotic tension determined. Aseptic conditions were maintained between each extraction. The remaining boxes were removed at 10 days and the same procedure repeated.

TABLE I

VARIETIES AND SOURCE OF SMALL GRAINS USED TO MEASURE EFFECTS OF MOISTURE TENSION ON GERMINATION AND MORPHOLOGICAL CHARACTERS ON SEEDLING EMERGENCE

Variety	Year Produced	Location	C.I. Number
Oat			
Arkwin	1960	Stillwater	5850
Forkedeer	1961	Cherokee	3170
Cimarron	1961	Cherokee	5106
Wintok	1961	Cherokee	
Bronco	1961	Cherokee	6571
Wheat			
Triumph	1961	Cherokee	12132
Concho	1961	Cherokee	
Kaw	1961	Cherokee	
Barley			
Rogers	1961	Cherokee	9174
Ward	1961	Cherokee	
Rye			
Elbon	1961	(J. Echols)	
Balbo	1961	OFEE	

Osmotic tensions were determined by use of a freezing point depression apparatus. The apparatus consisted of a thermistor sensing element stationed inside a stirring mechanism. The thermistor was connected through a constant voltage and amperage circuit to a Sargent Recorder. The change in freezing point, based on distilled water being equal to zero atmosphere of tension was readable from the recorder graph. The recorder could be read accurately to .01 degree centigrade. Conversion to osmotic pressure was calculated by the following formula given by Richards and Campbell (39).

$$\text{Osmotic Pressure} = 12.06\,\Delta - .021\,\Delta^2$$

where Δ equals the change in freezing point from 0° C.

CHAPTER IV

RESULTS AND DISCUSSION

Significant differences at the one percent level were found within and among all small grain varieties tested in total germination and total growth with respect to temperature and osmotic tension. Significant interactions existed among responses due to temperatures and osmotic tensions, temperatures and varieties, and osmotic tensions and varieties. Significant differences appeared to exist among responses due to temperatures, osmotic tensions, and varieties.

The mean squares for the analyses of variance for each character are presented in Appendix Tables I through VI. The average number of normal seedlings, average height of normal seedlings and average number of seedlings with coleoptiles greater than 10 mm in length for all varieties, at all osmotic tensions and at all temperatures studied, are recorded in Appendix Tables XI, XII, and XIII.

Population Study

A seed population study of four small grains was conducted to determine the optimum number of seed per unit area of germination container which would give maximum germination. Seed numbers per box from 10 to 100 did not influence significantly the germination percentages of the four small grain varieties tested (Bronco oat, Rogers barley, Triumph wheat, Bablo rye). Replications containing 200 seed per box did reduce significantly the percentage germination of rye seed from those replications containing 50 seed per box, Table II. Replications containing 400 seed per box always had percentage germination values significantly reduced from all other containers with fewer seed per box. On the basis of these data, the germination tests were made with 25 seed per box.

Speed of Germination Study

Speed of germination, Table III, was ranked according to the method outlined by Maquire (26). Ward and Rogers barley ranked 1 and 2 at all temperatures tested. Cimarron oat ranked third in both 20° constant and 20°-30° alternate environments. The remaining varieties generally were ranked inconsistently in the three environments studied. The germination rate was observed to be faster at 30° and slower at 20°. Differences in speed of germination among varieties were not as great at 20° (range 11.637 to 8.151) as at 30° (range 12.478 to 6.978). Speed of seed germination of all oat varieties was slower at 30° and 20°-30° as compared to 20°. Wheat varieties germinated more rapidly in the 30° constant as compared to the 20° constant and the 20°-30° alternate environments. The speed of germination of Ward barley was greatest at 30° while Rogers barley seemed to be indifferent to environment and germinated equally well at all temperatures. Rye seed germinated most readily at 30° and were slowest in the 20°-30° alternate environment.

Osmotic Tension Study

Osmotic tensions of moistening agents for barley, oat, and wheat varieties were checked after 5 and 10 days and the results recorded in Table IV. The osmotic tension of the moistening agent was found to

TABLE II

AVERAGE PERCENT GERMINATION OF SMALL GRAIN VARIETIES AS INFLUENCED BY THE NUMBER OF SEED PER BOX

Number of Seed/Box	Small Grain			
	Rye	Multiple Range*	Wheat	Multiple Range
10	90.00	bc	97.50	b
20	92.50	bc	98.75	b
25	90.00	bc	95.00	b
50	94.00	c	94.00	b
100	87.25	bc	92.00	b
200	81.25	b	91.87	b
400	4.75	a	27.93	a
	Barley	Multiple Range	Oat	Multiple Range
10	100.00	b	100.00	b
20	97.50	b	100.00	b
25	100.00	b	100.00	b
50	98.50	b	100.00	b
100	98.25	b	99.75	b
200	87.50	b	95.75	b
400	13.62	a	20.00	a

*Any two means in any one crop followed by the same letters are not different significantly at the .01 level of confidence. Duncan's new multiple range test.

TABLE III

TWELVE SMALL GRAIN VARIETIES RANKED IN ORDER OF SPEED OF GERMINATION AT 20° and 30° CONSTANT AND 20°-30° C ALTERNATING TEMPERATURES

	Temperature					
	20° C		30° C		20°-30° C	
Variety	Germ. Speed	Rank	Germ. Speed	Rank	Germ. Speed	Rank
Ward	11.637*	1	12.478	1	10.937	1
Rogers	10.683	2	10.562	2	10.267	2
Cimarron	9.904	3	8.531	8	8.868	3
Balbo	9.410	4	10.395	4	7.674	11
Triumph	9.278	5	10.562	3	7.933	8
Concho	8.887	6	10.009	5	8.037	6
Forkedeer	8.649	7	7.801	10	8.118	4
Kaw	8.640	8	9.781	6	7.719	10
Bronco	8.600	9	6.978	12	8.072	5
Arkwin	8.569	10	7.625	11	7.921	9
Elbon	8.471	11	8.937	7	6.826	12
Wintok	8.151	12	7.916	9	8.029	7

*Values determined from formula proposed by Maquire (26).

TABLE IV

OSMOTIC PRESSURE OF SUBSTRATE MOISTENING AGENT FOR TEN SMALL GRAIN VARIETIES MEASURED AT 5 AND 10 DAYS AFTER BEGINNING OF GERMINATION TEST

		Mannitol Stress (atm)					
Variety	Days	0	3	6	9	12	15
Barley							
Ward	5	0.13	3.07	6.69	10.55	13.41	16.49
	10	0.13	3.33	6.18	10.25	14.30	16.69
Rogers	5	0.06	3.47	6.95	9.50	12.08	16.18
	10	0.33	2.06	6.61	9.63	13.15	16.61
Oat							
Arkwin	5	0.00	3.14	6.61	9.66	12.93	16.83
	10	0.81	3.72	7.00	9.84	12.99	16.36
Wintok	5	0.13	3.27	6.41	9.16	12.35	16.18
	10	0.06	1.73	6.48	9.83	12.68	16.23
Forkedeer	5	0.00	3.31	6.43	9.30	12.48	16.09
	10	0.19	3.07	7.62	10.03	12.62	16.68
Bronco	5	0.00	3.00	6.61	9.76	12.35	15.41
	10	0.19	2.74	6.75	10.36	12.75	16.28
Cimarron	5	0.06	4.07	6.89	9.30	12.33	15.82
	10	0.26	2.94	7.02	10.23	13.67	16.41
Wheat							
Triumph	5	0.06	3.27	6.48	8.32	12.15	16.35
	10	1.13	2.50	6.61	9.36	13.28	16.55
Concho	5	0.04	3.40	6.12	9.76	12.08	15.35
	10	0.53	2.27	6.14	10.03	12.95	15.35
Kaw	5	0.13	3.67	6.76	9.91	13.41	17.17
	10	0.19	3.94	7.56	10.84	13.81	16.49
Original Mannitol Solutions	5	0.00	2.87	6.08	9.04	12.19	15.31
	10	0.00	3.08	5.95	8.96	11.42	14.96
Distilled water on Kimpac	5	0.13					
	10	0.00					

increase at 5 and 10 days in the presence of seedling germination. The increase was observed to be greater at 15 atmospheres osmotic tension than at lower osmotic tensions. The absorption of water in minute quantities by the seedling from the stress solution is probably the cause of the increase found in moisture tension. The increase found in osmotic tension would tend to indicate that large amounts of mannitol are not being absorbed and metabolized by germinating seedlings, although it does not indicate that such metabolism is absent.

Normal Seedling Germination

The response attributable to blocking of treatments in the germinator was highly significant in the constant 20° and the constant 30° environments. The individual analyses of variance conducted on germination values from each temperature environment showed the varieties within each crop, the tensions within each crop and the variety by tensions interaction within each crop to be significant. This analysis is shown in Appendix Table IV. Also, highly significant responses were attributable to temperature environment as is shown by the analysis of variance in Appendix Table I.

Oat varieties

In general, the constant 30° environment was optimum for total germination under all moisture stresses as shown by the comparison of data presented in Figures 1, 2, and 3.

Normal oat seed germination was highly variable under conditions of artificially produced moisture stresses. Arkwin showed the least ability

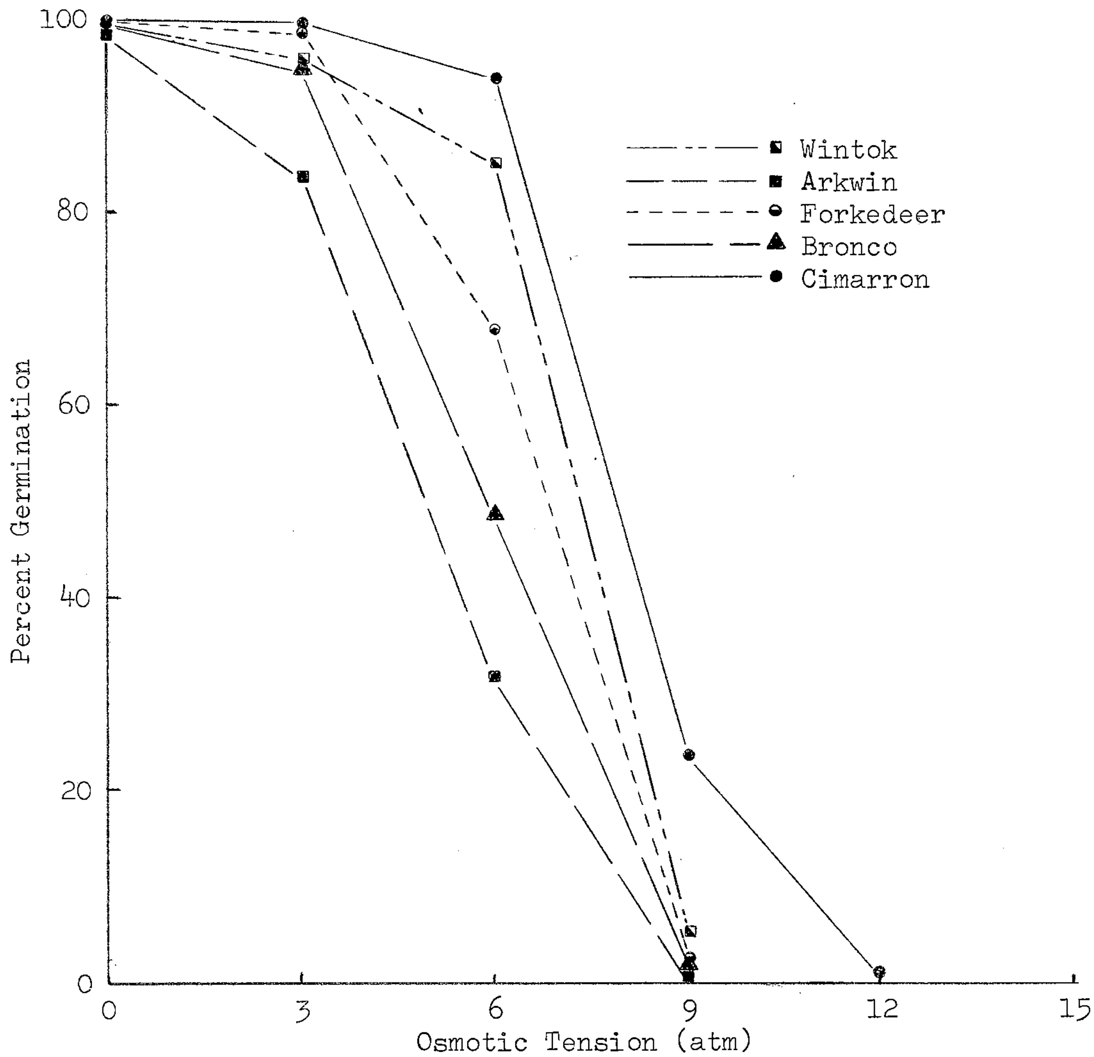

Figure 1. The Effect of Six Osmotic Tensions on the Germination Percentage of Five Oat Varieties at 20° C.

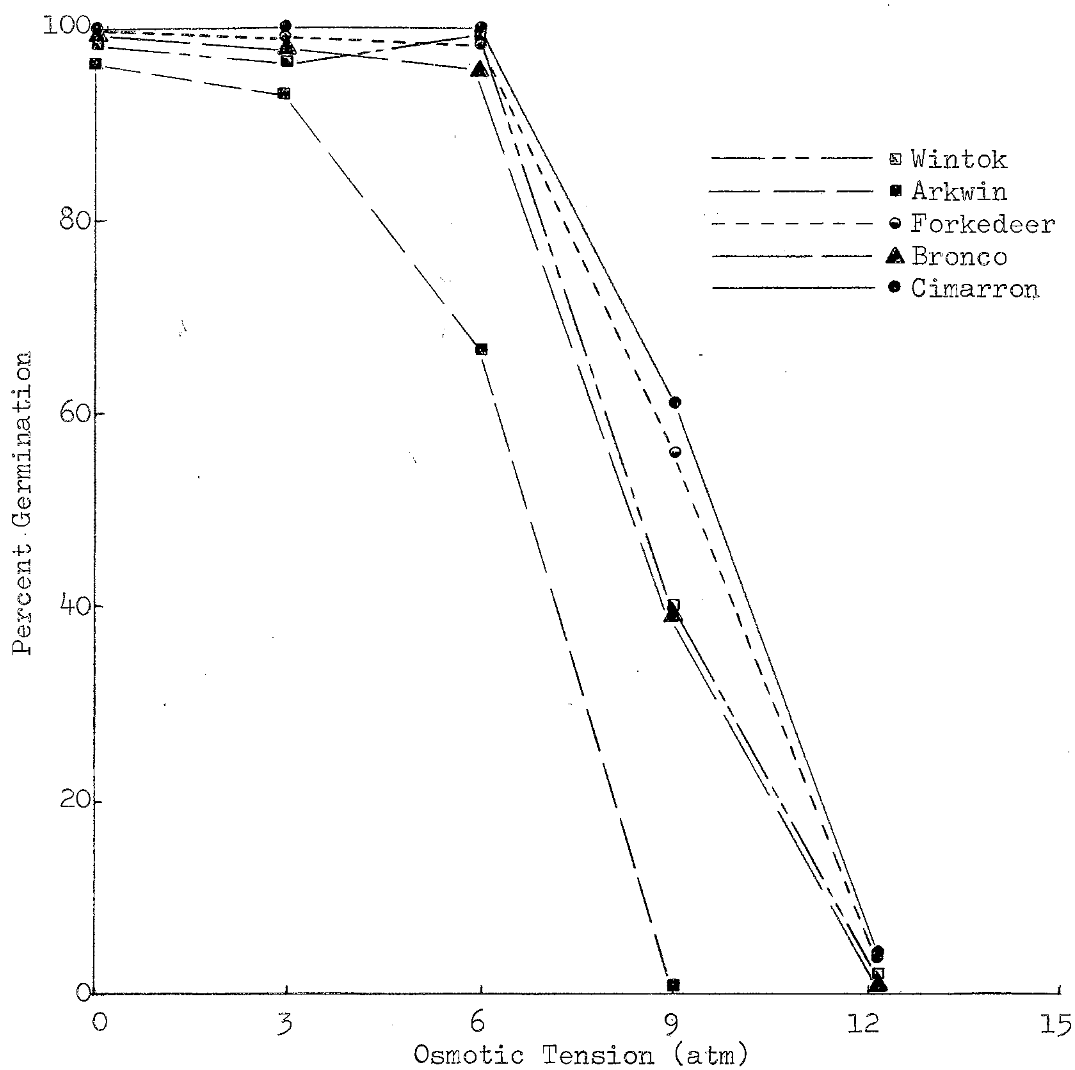

Figure 2. The Effect of Six Osmotic Tensions on the Germination Percentage of Five Oat Varieties at 20°-30° C.

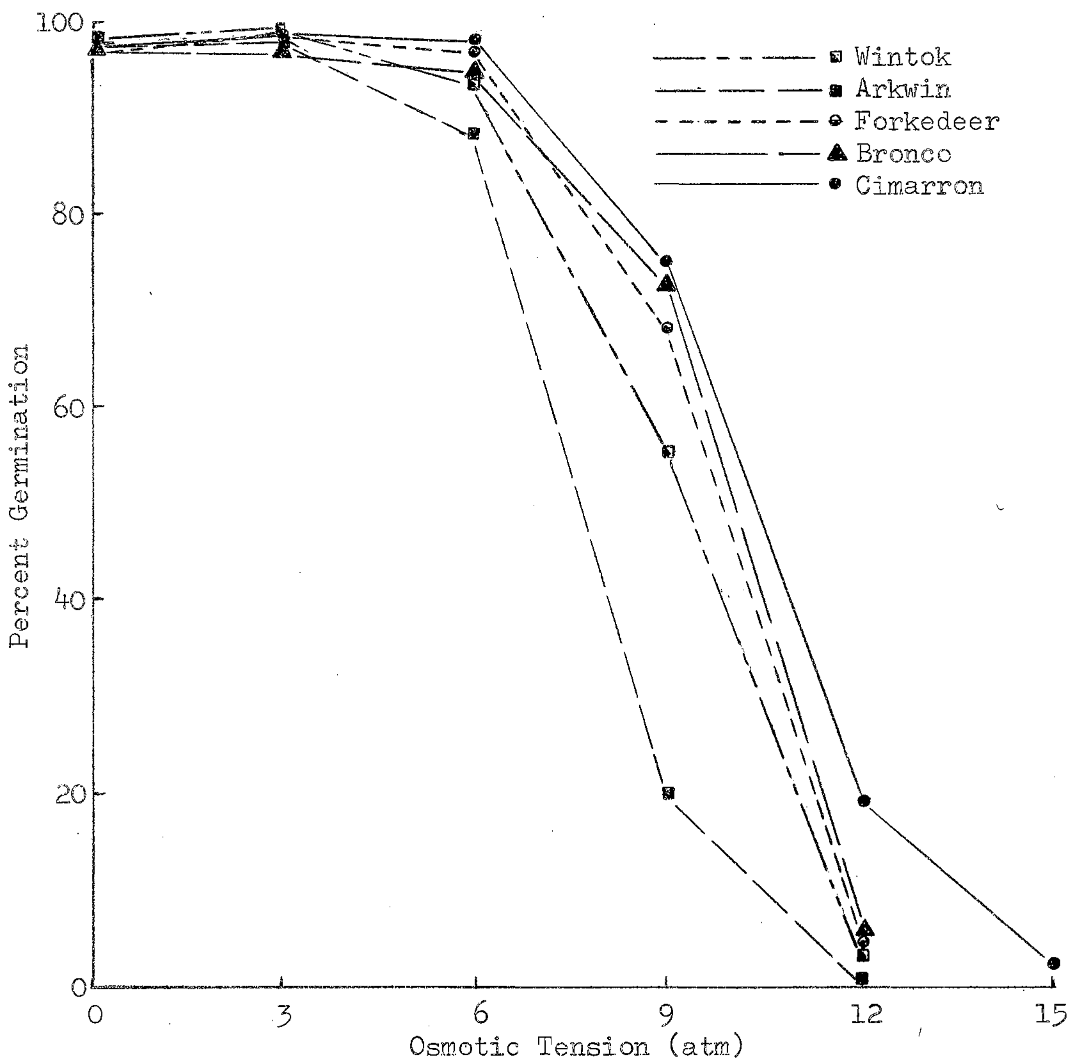

Figure 3. The Effect of Six Osmotic Tensions on the Germination Percentage of Five Oat Varieties at 30° C.

to germinate under these artificial conditions while Cimarron exhibited the greatest ability.

Total germination was not reduced at osmotic tensions below six atmospheres at 30° or at 20°-30°, except for Arkwin which was slightly reduced at 30° at six atmospheres and was greatly reduced at 20°-30°. The 20° environment reduced total germination of all oat varieties with the exception of Cimarron at six atmospheres. The total germination of Arkwin was affected most severely and appeared most sensitive to stress solutions at low temperatures. The greatest differences between germination of oat varieties occurred at six atmospheres in the 20° environment. Increases in germination temperatures seemed to delay the decrease in germination resulting from osmotic stress.

Wheat varieties

The average germination of all wheat varieties tested, as with oats, was best at the 30° temperature. This corresponded to the temperature which gave the fastest rate of germination in speed of germination experiments. Triumph was consistently superior in ability to germinate in mannitol stress solutions as is shown in Figures 4, 5, and 6. Kaw and Concho varieties germinated very similarly at all temperatures at all tensions.

The wheat varieties tested attained a higher total germination at 9 and 12 atmospheres than any oat variety at the same temperature. Thus, the wheat varieties showed greater ability to germinate in mannitol stress solutions than the oat varieties tested.

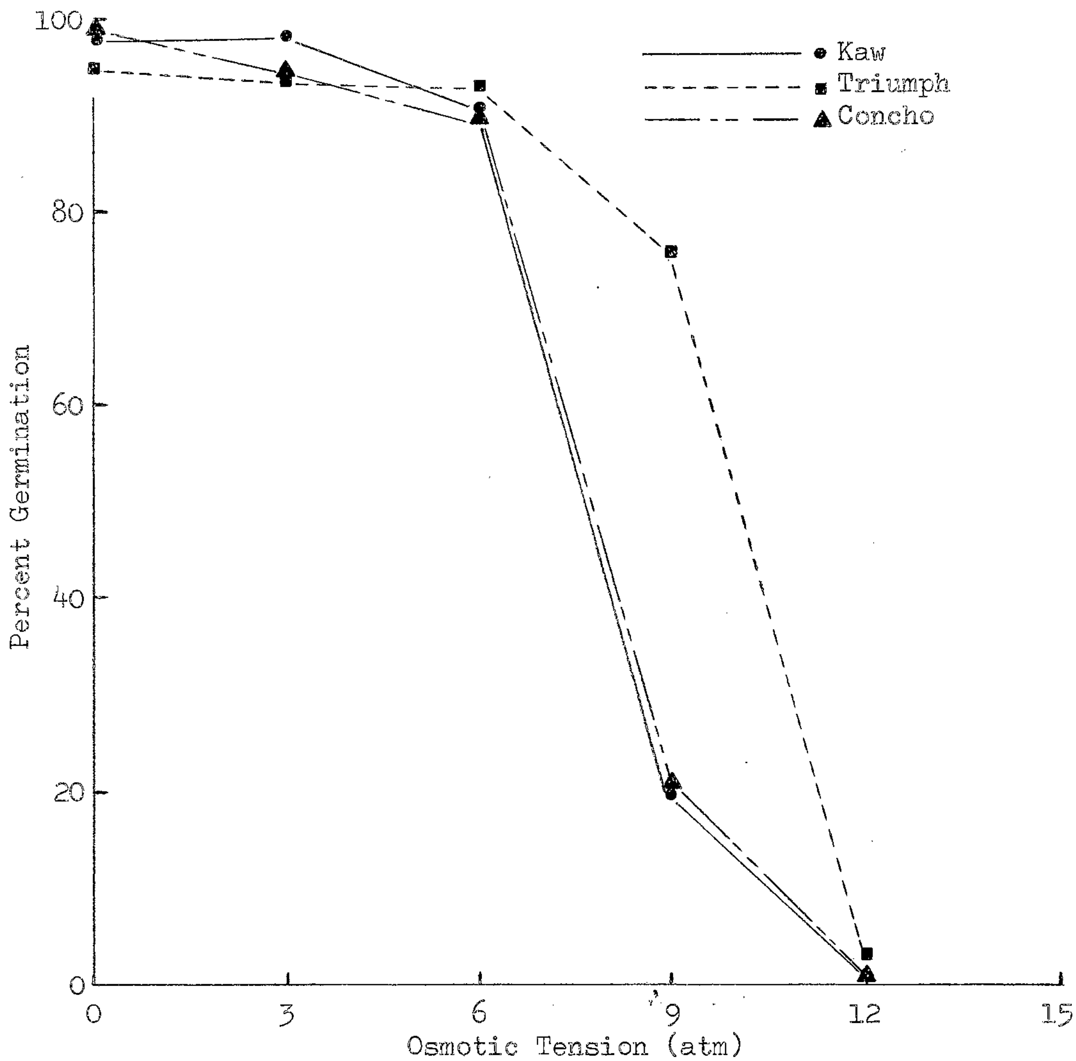

Figure 4. The Effect of Six Osmotic Tensions on the Germination Percentage of Three Wheat Varieties at 20° C.

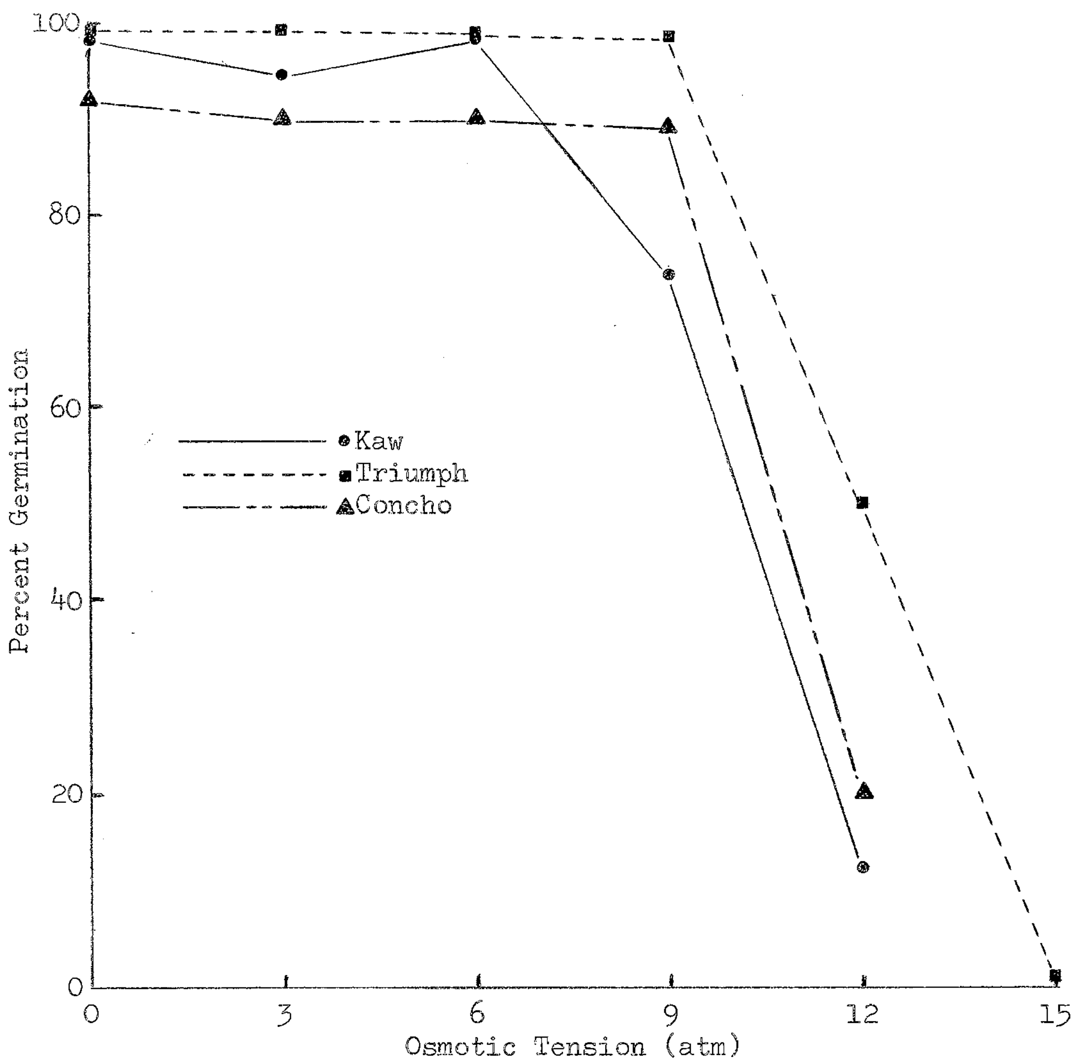

Figure 5. The Effect of Six Osmotic Tensions on the Germination Percentage of Three Wheat Varieties at 20°-30° C.

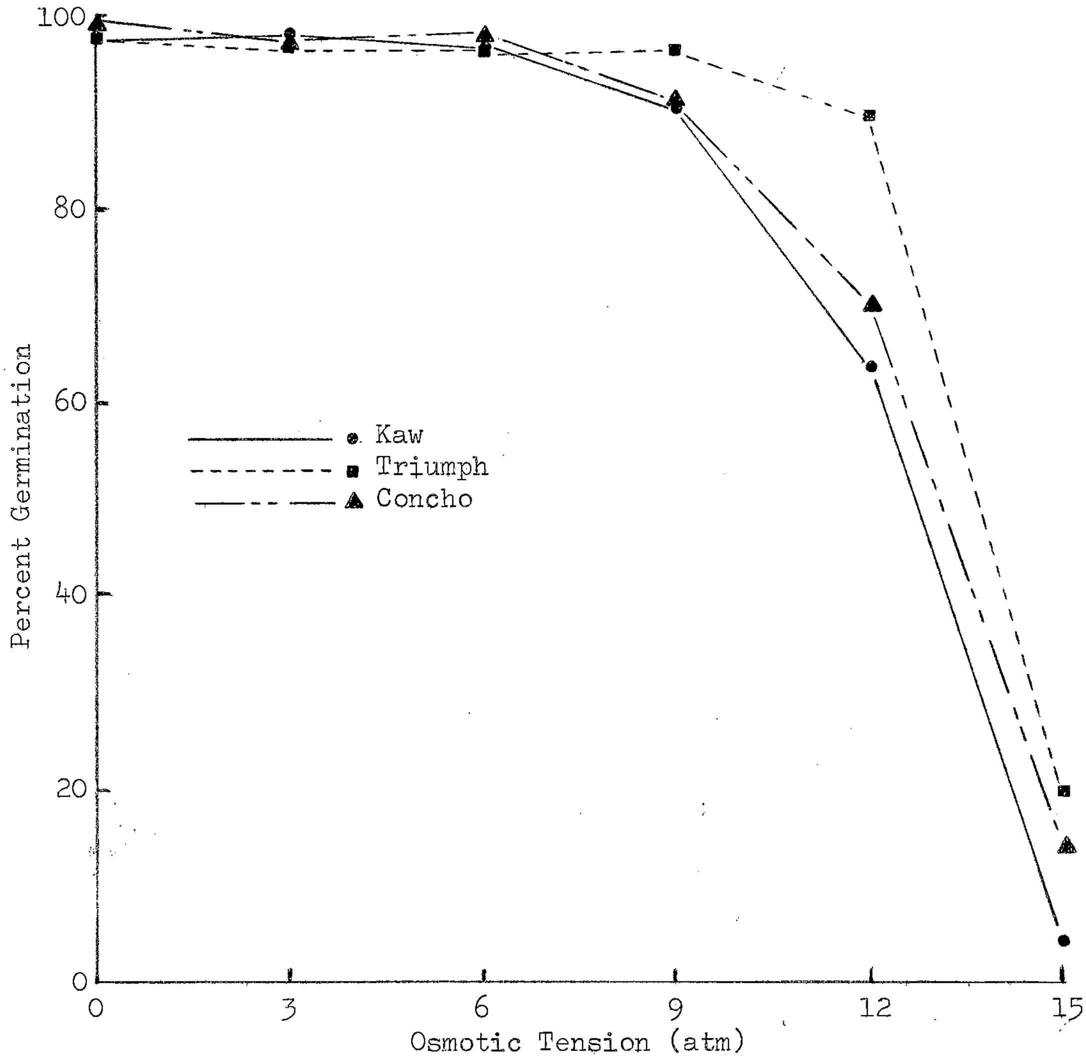

Figure 6. The Effect of Six Osmotic Tensions on the Germination Percentage of Three Wheat Varieties at 30° C.

Barley varieties

Ward barley, as shown in Figures 7, 8, and 9, had the highest germination of all small grain varieties tested at 9, 12, and 15 atmospheres osmotic tension and showed the greatest ability to germinate in mannitol stress solutions. Again, maximum germination occurred in the 30° environment and minimum germination occurred in the 20° environment. Ward germinated significantly higher than Rogers in all environments at all tensions except at 15 atmospheres in the 20° temperature. At 30° Ward germinated 71 percent at 15 atmospheres and 94 percent at 12 atmospheres. Rogers barley seemed to decline in viability during the three tests but showed an ability to germinate to a lesser extent than Ward.

Rye varieties

Balbo rye exhibited the greatest amount of germination at 30° as did all small grains. Compared to other small grains tested at the 30° temperature seed of Balbo rye germinated higher than all wheat or oat varieties but lower than Ward barley at the 12 and 15 atmosphere tensions. Elbon rye showed a lesser ability to germinate at all tensions than Balbo but Elbon was badly infected by fungus during germination at 30° which may have affected its ability to germinate.

Germination--Seedlings with Coleoptiles Greater Than 10 MM

One of the primary effects of artificially induced moisture stress was the reduction in size of the germinated seedling. As the osmotic tension of the moistening agent increased there were larger numbers of sprouted seedlings in the boxes that did not qualify as normal seedlings.

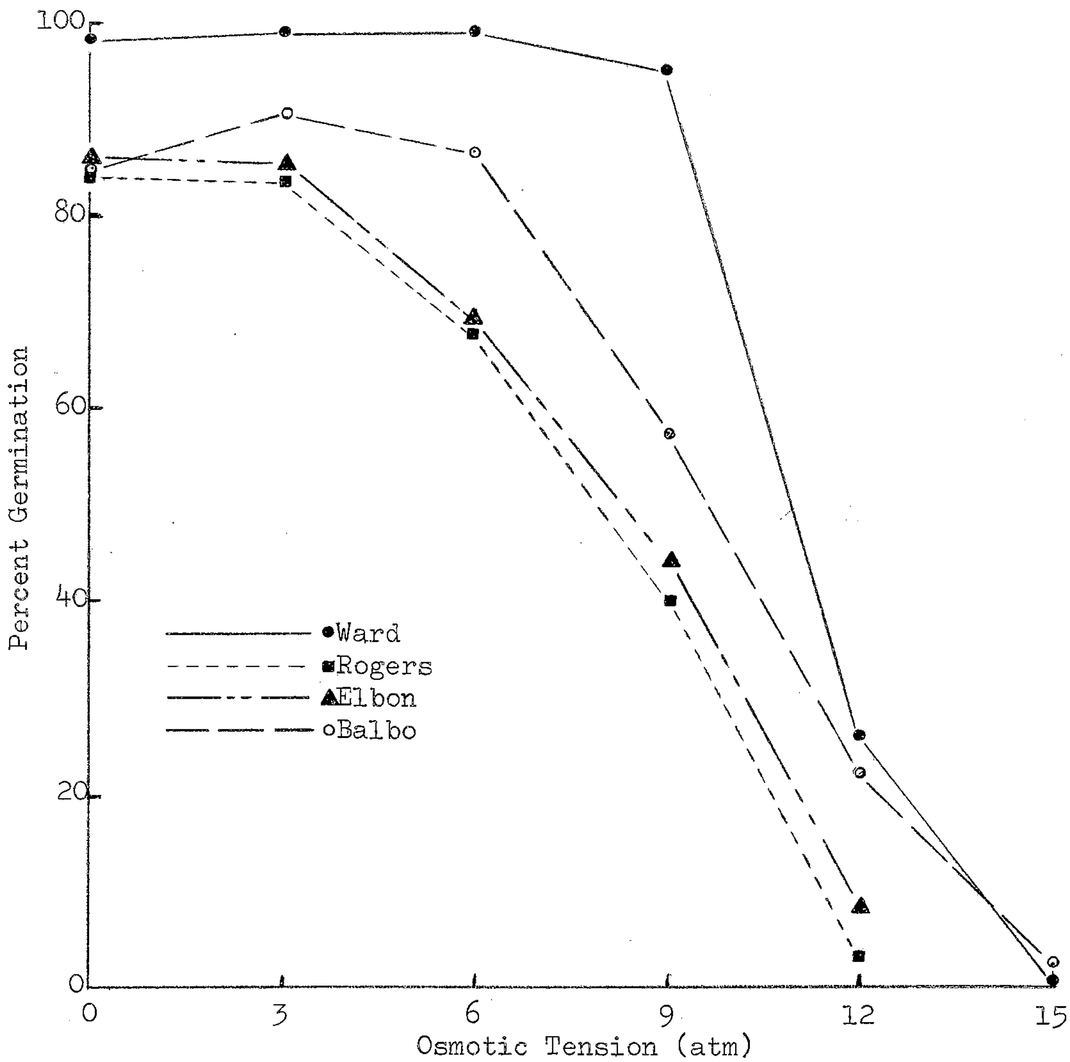

Figure 7. The Effect of Six Osmotic Tensions on the Germination Percentage of Two Barley and Two Rye Varieties at 20° C.

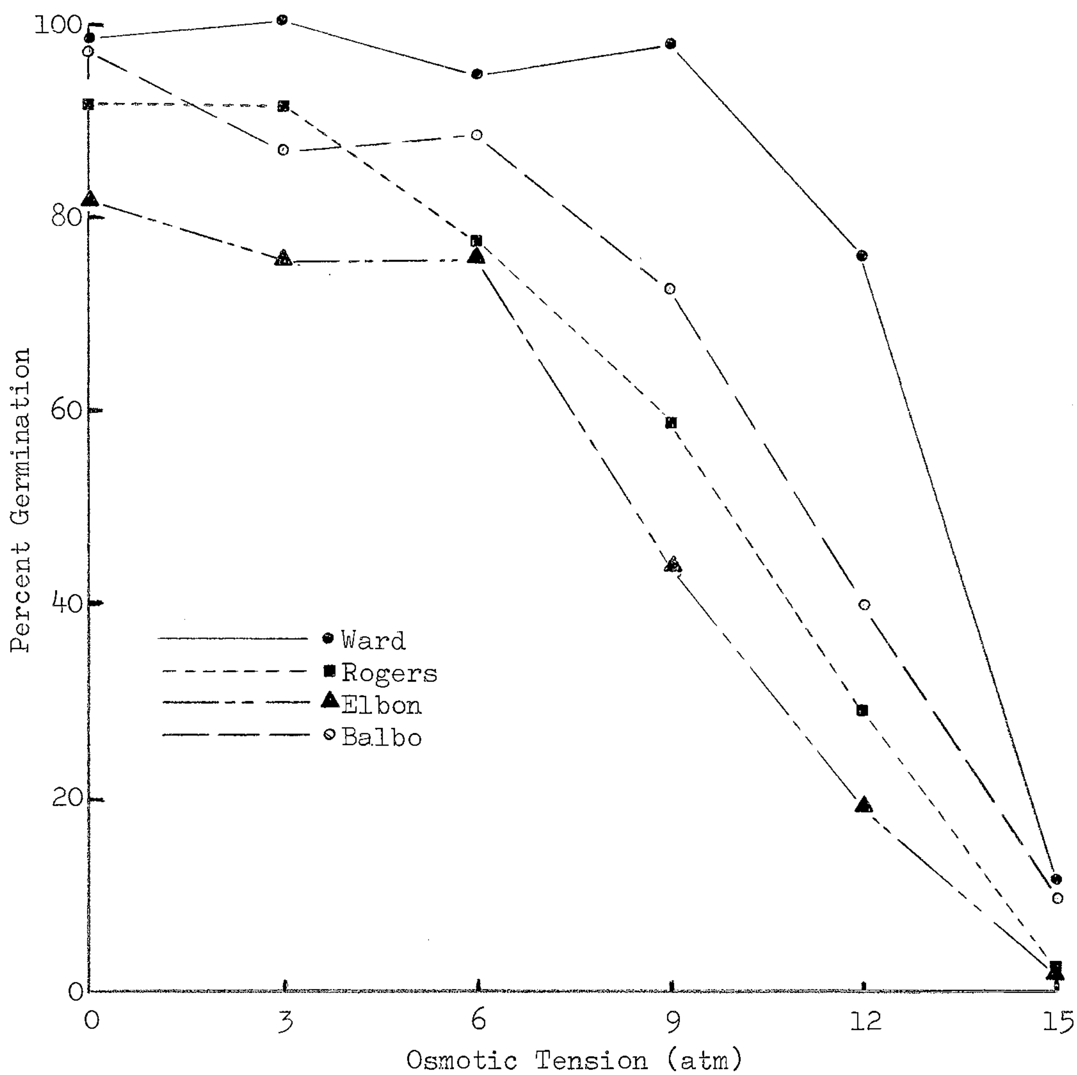

Figure 8. The Effect of Six Osmotic Tensions on the Germination Percentage of Two Barley and Two Rye Varieties at 20°-30° C.

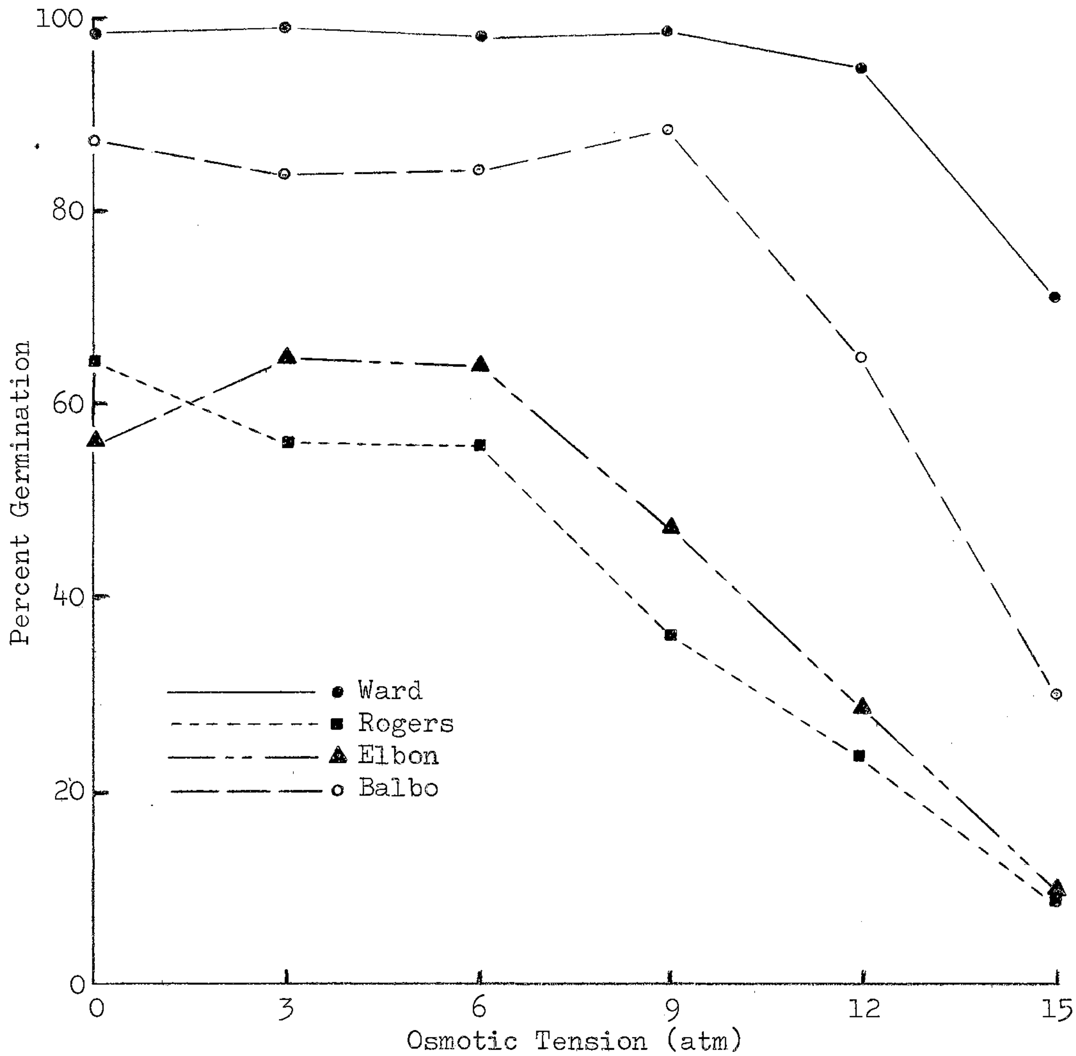

Figure 9. The Effect of Six Osmotic Tensions on the Germination Percentage of Two Barley and Two Rye Varieties at 30° C.

Thus counts were made of those seedlings which possessed a coleoptile 10 mm long and a primary root 5 mm in length. The analyses of variances are presented in Appendix Tables III and V and the average data are presented in Appendix Table XII.

In general, this criterion of germination did not change the percentage of germination appreciably at 0, 3, and 6 atmospheres. The major exception to this was with Arkwin oat in which the germination percentage in the 20° temperature at 3, 6, and 9 atmospheres was greater with this criterion than with the normal seedling method of determining germination. A comparison of the two methods of expressing germination is shown in Figure 10.

This method of expressing germination characteristically produced higher germination values at 9, 12, and 15 atmospheres of moisture tension. Although germination percentages were higher with this criterion than with the normal seedling method, the relative comparisons of small grains to one another and varieties within small grains to one another were the same as when the normal seedling criterion was used to express germination. This method also tended to deemphasize the differences in germination between temperature environments. This was true because the method did not measure equivalent increases in germination in all temperature environments but measured much greater increases in germination in the 20° environment as compared to germination in the 30° environment.

Height of Seedlings

The analyses of variance are presented in Appendix Tables II and VI and the average data are presented in Appendix Table XIII. Normal

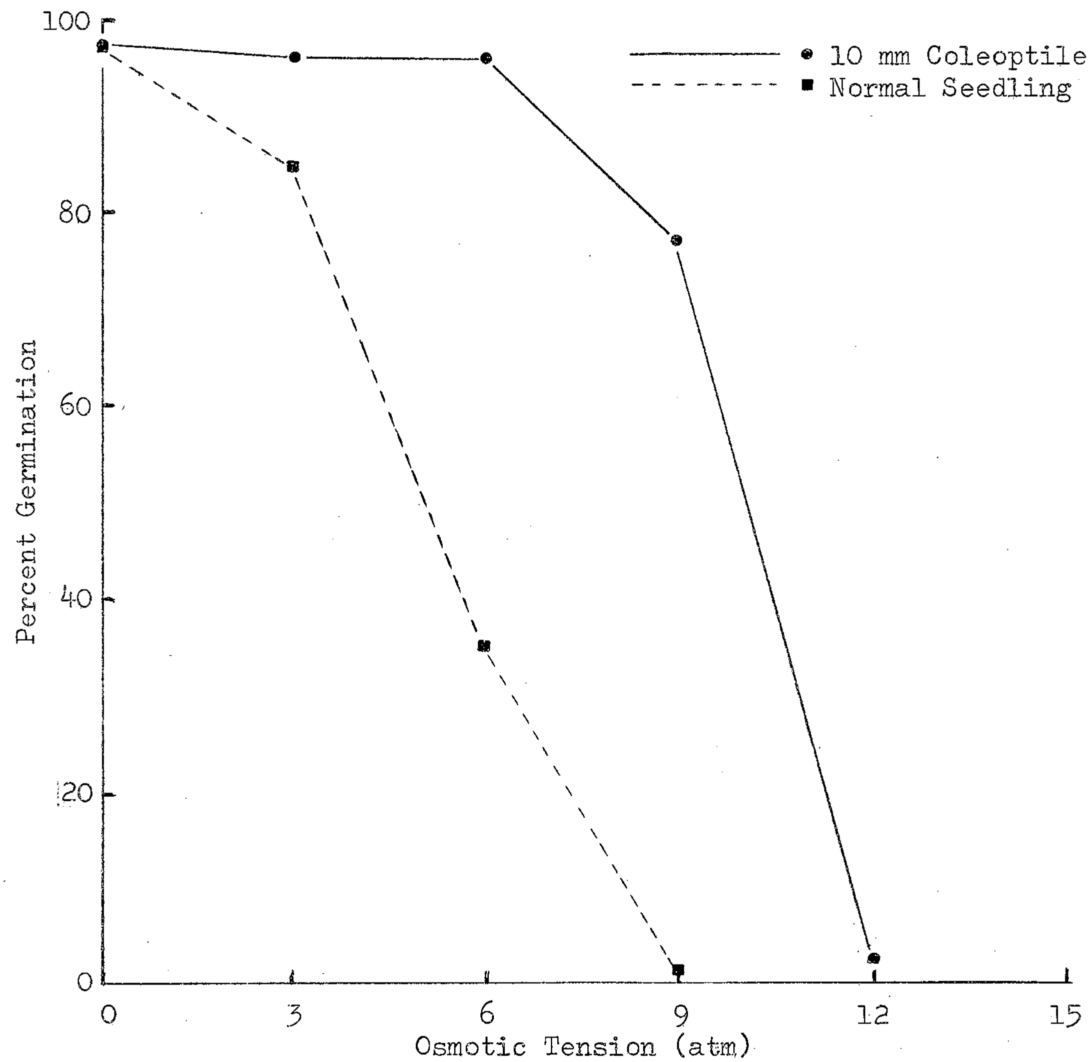

Figure 10. Comparison of Two Methods of Recording Germination Data of Arkwin Oat at 20° C. Normal Seedling Germination Versus Seedlings With Coleoptiles Greater Than 10 MM.

seedling height appeared to decrease linearly with increase in osmotic tension as shown in Figure 11. High germination temperature had the effect of producing seedlings of greater height than seedlings germinated at low temperatures. Balbo rye and Ward barley were the only varieties that produced normal seedlings at 20°. At the 30° temperature all varieties but four oat varieties produced normal seedlings. Thus, at higher temperatures there were greater numbers of normal seedling germinated at higher osmotic tensions and also these seedlings acquired greater height.

Seedling Morphology Study

This study of morphological character of oat varieties was not intended to be complete but obvious seedling morphological differences were noted during stress germination. The average coleoptile width and length measurements by variety taken at 20°-30° are presented in Table V. A study of the data indicates that the coleoptiles of Arkwin oat were wider particularly until 9 atmospheres of tension were reached and longer at 0 and 3 atmospheres. In addition Arkwin had a greater average number of root radicals with the exception of Wintok at 6 atmospheres as shown in Table VI. Root length measurements, as shown in Table VII, indicated Bronco and Cimarron attained greater root lengths under 6 atmospheres moisture stress. These differences suggest that the ability of some small grains to germinate under dry conditions may partially involve its morphological development at an early age.

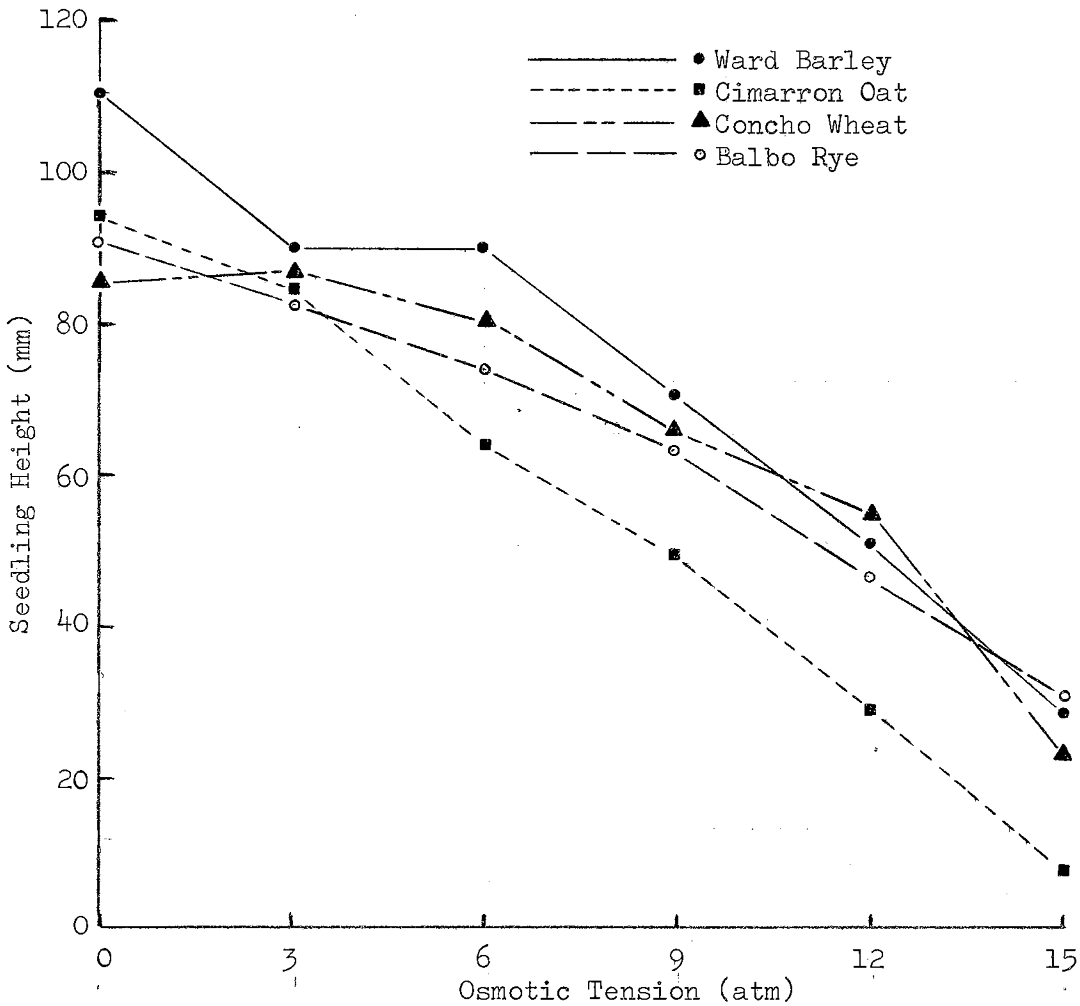

Figure 11. The Effect of Six Osmotic Tensions on the Seedling Height of Four Small Grain Varieties at 30° C.

TABLE V

MEAN COLEOPTILE LENGTH AND WIDTH OF 5 OAT VARIETIES AFTER 10 DAYS GERMINATION

AT 5 OSMOTIC TENSIONS AT 20°-30° C

	Osmotic Tension									
	0		3		6		9		12	
	Coleoptile		Coleoptile		Coleoptile		Coleoptile		Coleoptile	
Variety	Length	Width	Length	Width	Length	Width	Length	Width	Length	Width
Wintok	28.5	2.56	27.5	2.48	24.6	2.26	19.8	2.03	7.1	1.13
Arkwin	35.3	3.53	33.3	2.95	28.0	2.68	18.8	2.43	6.0	2.05
Forkedeer	30.6	3.68	29.0	2.60	27.3	2.45	24.0	2.05	12.2	2.04
Bronco	30.8	2.86	28.6	2.58	29.6	2.50	27.1	2.31	15.3	2.38
Cimarron	26.0	2.60	27.3	2.63	23.6	2.08	20.5	2.23	14.5	2.00

TABLE VI

AVERAGE NUMBER OF ROOT RADICALS ON 5 OAT VARIETIES AFTER

10 DAYS GERMINATION AT 5 OSMOTIC TENSIONS

	Average Number of Root Radicals				
	Osmotic Tensions				
Variety	0	3	6	9	12
Wintok	5.0	5.0	5.0	3.6	3.6
Arkwin	6.0	5.8	4.8	4.6	3.8
Forkedeer	3.5	3.3	3.6	3.5	3.8
Bronco	3.5	3.8	3.1	3.5	2.8
Cimarron	4.8	4.5	4.1	3.6	3.8

TABLE VII

AVERAGE ROOT LENGTH (MM) OF 5 OAT VARIETIES AFTER 10 DAYS GERMINATION AT 5 OSMOTIC TENSIONS

	Average Root Length (MM)				
	Osmotic Tensions				
Variety	0	3	6	9	12
Wintok	50.0	51.7	29.1	21.0	12.3
Arkwin	54.3	43.2	23.0	9.8	10.8
Forkedeer	44.7	48.5	42.8	29.5	9.5
Bronco	48.3	50.1	47.3	27.7	12.0
Cimarron	41.1	44.0	35.5	20.8	12.6

Discussion

Oat varieties, Arkwin and Cimarron, and to some degree, Forkedeer, have been observed to germinate and develop early at a more rapid rate than other small grain varieties during dry years. This study was conducted to determine if similar results could be obtained under laboratory conditions with the use of mannitol stress solutions.

There was considerable variation among small grains and among varieties of small grains for ability to germinate in artificial drouth conditions. As classified by the normal seedling method of measuring germination, the barley varieties showed the greatest ability to germinate in the higher osmotic solutions followed by rye, wheat, and oat varieties. Among varieties, Ward barley was far superior to all varieties tested while Triumph wheat consistently was superior among wheat varieties tested. The oat varieties exhibited the least ability to germinate at high osmotic tensions but also they exhibited wide variability. Among oat varieties, Cimarron was far superior to Arkwin while the other varieties ranked intermediate.

Seedlings with coleoptiles greater than 10 mm in length was a second criterion for measuring seed germination. This method did not alter the ranking of varieties relative to one another but it did measure higher germination percentages at the higher osmotic tensions. Basically, this was because many of the seedlings that were present at the higher tensions did not have the leaf role extended through the tip of the coleoptile. It seemed that this fact was not too important in delineating the ability of the varieties to germinate under artificial moisture stress.

Increases in osmotic tensions caused linear decreases in growth of seedlings. This reduction in growth with increases in osmotic tensions was greater with the oat varieties than with other small grain varieties.

One effect of temperature was to increase percentage germination as temperature increased. Thus, germination was less under high stress conditions at 20° than at 30° with the exception of Elbon rye and Rogers barley. In these instances it was assumed that the slight reductions in germination that occurred was due to reduction in seed viability. The basis for this conclusion is that these same varieties did not have reduced germination in the speed of germination trials conducted earlier and thus should have had similar germination in these later trials. A second effect of temperature was to increase total growth of seedlings as the temperature increased.

In order that stress conditions, created by mannitol solutions, be of value as a method of delineating drouth tolerant species, it must first be able to delineate a group of species which have known seed performance under dry conditions. Arkwin and Cimarron are two varieties of oats which are known to have the ability to germinate and grow at a rather rapid rate in dry years and should show this ability in the laboratory when subjected to stress solutions. The normal means of determination of a variety's superiority in mannitol tests has been to make germination counts according to some pre-set standard of germination and including the assumption that those which have high germinability are those which possess drouth tolerance.

Some workers have indicated that mannitol-produced osmotic stress stimulates drouth conditions. It has also been found by Kneebone (22) that the seed of those plants which were known to have superior establishment characteristics germinated faster and produced larger seedlings when grown under conditions of moisture stress. As is indicated by the results of this study, total germination of small grain varieties under stress does not delineate the species according to the expected gradation. Thus, total germination in mannitol stress solutions by itself seems an invalid estimation of a variety's ability to germinate under dry conditions. Therefore, can we state that mannitol is not useful in selecting drouth tolerant species?

In comparison to some of the other compounds used for producing osmotic stress, which either are metabolized more readily or are increasingly more inhibitive to total growth or are simply taken into the plant more readily, mannitol still ranks among the better compounds for this proposed purpose.

Perhaps then, the inadequacy of mannitol to produce the desired results was not in the use of mannitol itself but in the method of its use and the type of data collected.

If seeds were planted in soil at the permanent wilting percentage, little sprouting would occur. Yet, in mannitol produced osmotic solutions almost all seeds sprout but growth is limited from 1 to 4 mm at 15 atmospheres. It is suggested that although the two conditions are theoretically the same, that is, the availability of the water molecules to the seed or plant are withheld by a force of the same magnitude, the two conditions are not the same. In laboratory tests, the seeds lay in direct contact with the aqueous solution; but in dry soil, direct contact may not exist. Consequently, equivalent conditions are not approximated. Further, mechanical stress is not applied to the emerging seedlings in laboratory tests. It may further be noted that a considerable difference in pH may exist in mannitol solutions since the pH is lowered considerably with increases in mannitol concentration. It is suggested that further studies may include a solution causing osmotic tension with controlled pH and applied to or associated with a substrate which will cause mechanical stress to emerging seedlings.

CHAPTER V

SUMMARY AND CONCLUSIONS

Laboratory germination tests were conducted on 12 small grain varieties; 5 oat, 3 wheat, 2 barley, and 2 rye, at 6 osmotic tensions produced by mannitol. Total germination counts were made after 10 days using two seedling classifications of germination. These were: 1) number of normal seedlings, and 2) number of seedlings with coleoptiles greater than 10 mm in length. Average total growth measurements were also collected on normal seedlings. The tests were conducted in three temperature environments.

Osmotic tensions of all solutions were checked in a preliminary test at 5 and 10 days with a freezing point depression apparatus. At higher osmotic tensions very slight increases were observed in the osmotic tensions of the solutions in which seedlings had germinated and grown in comparison to original solutions.

Small grains which emerge rapidly and uniformly under dry field conditions have been recorded in tests at this station. Total germination data obtained in the mannitol stress experiments did not correlate with known field performances of these varieties. This suggests that total average germination by itself from mannitol stress solutions can not be depended on as a means to rank species, varieties, or strains according to their field response.

Varieties were observed to vary greatly in their ability to germinate and grow under osmotic stress. Varietal differences were observed also in coleoptile and root length, root number and germination rate.

The use of mannitol to induce osmotic stress in germination solutions as used in this research is not recommended.

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APPENDIX

APPENDIX TABLE I

ANALYSIS OF VARIANCE OF THE NUMBER OF NORMAL SEEDLINGS GERMINATED OF 12 VARIETIES OF SMALL GRAINS AFTER TEN DAYS AT SIX OSMOTIC TENSIONS AND THREE TEMPERATURE ENVIRONMENTS

Source	df	MS
Total	1295	101.73
Temperature	2	1534.08**
Blocks in Temp.	15	20.46
Tensions	5	19912.27**
Variety	11	826.31**
Temp. x Tens.	10	389.51**
Tens. x Var.	55	161.42**
Temp. x Var.	22	79.60**
Temp. x Tens. x Var.	110	50.01**
Error	1065	5.50

**Significant at the .01 level of confidence.

APPENDIX TABLE II

ANALYSIS OF VARIANCE OF THE HEIGHT IN MM OF SEEDLINGS GERMINATED OF 12 VARIETIES OF SMALL GRAINS AFTER TEN DAYS AT SIX OSMOTIC TENSIONS AND THREE TEMPERATURE ENVIRONMENTS

Source	df	MS
Total	1295	976.44
Temperature	2	26720.10**
Blocks in Temp.	15	248.94
Tensions	5	207068.52**
Varieties	11	7192.58**
Temp. x Tens.	10	1045.86**
Tens. x Var.	55	1007.29**
Temp. x Var.	22	362.27**
Temp. x Tens. x Var.	110	206.94**
Error	1065	58.01

**Significant at the .01 level of confidence.

APPENDIX TABLE III

ANALYSIS OF VARIANCE OF THE NUMBER OF SEEDLINGS WITH COLEOPTILES GREATER THAN 10 MM IN LENGTH GERMINATED OF 12 VARIETIES OF SMALL GRAINS AFTER TEN DAYS AT SIX OSMOTIC TENSIONS AND THREE TEMPERATURE ENVIRONMENTS

Source	df	MS
Total	1295	75.19
Temperature	2	83.37**
Blocks in Temp.	15	11.59
Tensions	5	14551.78**
Varieties	11	718.47**
Temp. x Tens.	10	47.63**
Tens. x Var.	55	222.89**
Temp. x Var.	22	93.02**
Temp. x Var. x Tens.	110	16.04**
Error	1065	4.84

**Significant at the .01 level of confidence.

APPENDIX TABLE IV

ANALYSES OF VARIANCE OF THE NUMBER OF NORMAL SEEDLINGS GERMINATED OF 12 VARIETIES OF SMALL GRAINS AFTER TEN DAYS AT SIX OSMOTIC TENSIONS AT 20°, 30°, AND ALTERNATE 20°-30° C.

		Mean Squares		
		Temperature (C)		
Source	df	20°	30°	20°-30°
Total	431	118.98	89.55	104.35
Block	5	30.78**	23.15**	7.43
Crop	3	278.19**	648.18**	339.25**
Varieties in Oats	4	86.51**	59.98**	111.58**
Tensions in Oats	5	4231.53**	3959.54**	4226.90**
Var. x Tens. in Oats	20	32.37**	33.46**	36.56**
Varieties in Wheat	2	68.51**	38.78**	69.62**
Tensions in Wheat	5	2440.96**	1265.29**	1984.86**
Var. x Tens. in Wheat	10	62.60**	12.73*	25.96**
Varieties in Barley	1	660.06**	3094.22**	512.00**
Tensions in Barley	5	1233.82**	190.02**	886.46**
Var. x Tens. in Barley	5	68.22**	39.32**	56.30**
Varieties in Rye	1	98.00**	1050.35**	253.13**
Tensions in Rye	5	1060.98**	369.93**	900.18**
Var. x Tens. in Rye	5	13.87	17.41*	9.49*
Error	355	7.13	5.82	3.54

*Significant at the .05 level of confidence.
**Significant at the .01 level of confidence.

APPENDIX TABLE V

ANALYSES OF VARIANCE OF THE NUMBER OF SEEDLINGS WITH COLEOPTILES GREATER THAN 10 MM IN LENGTH GERMINATED OF 12 VARIETIES OF SMALL GRAINS AFTER TEN DAYS AT SIX OSMOTIC TENSIONS AT 20°, 30°, AND ALTERNATE 20°-30° C.

		Mean Squares		
		Temperature (C)		
Source	df	20°	30°	20°-30°
Total	431	84.26	78.04	75.64
Block	5	13.55**	15.71**	5.54
Crop	3	96.11**	566.13**	203.03**
Varieties in Oats	4	102.35**	31.89**	119.39**
Tensions in Oats	5	3606.92**	3465.76**	3579.73**
Var. x Tens. in Oats	20	45.78**	15.82**	39.47**
Varieties in Wheat	2	11.03	19.51*	40.90**
Tens. in Wheat	5	1765.78**	992.48**	1398.08**
Var. x Tens. in Wheat	10	8.71*	8.01	25.33**
Varieties in Barley	1	767.01**	3029.01**	618.35**
Tens. in Barley	5	666.21**	140.85**	296.89**
Var. x Tens. in Barley	5	41.21**	39.78**	41.25**
Varieties in Rye	1	304.22**	1012.50**	465.13**
Tensions in Rye	5	264.22**	352.72**	237.09**
Var. x Tens. in Rye	5	21.66**	21.13**	11.76**
Error	355	4.56	6.17	3.81

*Significant at the .05 level of confidence.
**Significant at the .01 level of confidence.

APPENDIX TABLE VI

ANALYSES OF VARIANCE OF THE HEIGHT IN MM OF NORMAL SEEDLINGS GERMINATED OF 12 VARIETIES OF SMALL GRAINS AFTER TEN DAYS AT SIX OSMOTIC TENSIONS AT 20°, 30°, AND ALTERNATE 20°-30° C.

		Mean Squares		
		Temperature (C)		
Source	df	20°	30°	20°-30°
Total	431	1121.71	922.46	917.70
Block	5	232.04**	352.43**	162.34**
Crop	3	6113.94**	12210.27**	7494.95**
Varieties in Oats	4	731.31**	405.94**	377.85**
Tensions in Oats	5	40325.63**	37459.28**	37749.42**
Var. x Tens. in Oats	20	224.04**	133.46**	218.98**
Varieties in Wheat	2	369.44**	152.90**	19.79
Tensions in Wheat	5	21372.08**	9489.68**	14908.48**
Var. x Tens. in Wheat	10	206.95**	63.29	56.12
Varieties in Barley	1	220.50**	64.22	1334.72**
Tensions in Barley	5	15311.67**	12182.22**	11236.12**
Var. x Tens. in Barley	5	177.83*	58.72	27.86
Varieties in Rye	1	227.56**	1050.35**	186.89**
Tensions in Rye	5	8834.56**	6520.01**	5813.42**
Var. x Tens. in Rye	5	153.89*	42.01	173.52**
Error	355	64.86	67.83	41.34

*Significant at the .05 level of confidence.
**Significant at the .01 level of confidence.

APPENDIX TABLE VII

ANALYSIS OF VARIANCE OF PERCENT GERMINATION OF BRONCO OAT

WITH 10, 20, 25, 50, 100, 200, 400 SEED PER BOX

Source	df	MS
Total	27	804.94
Block	3	4.33
Seed Number	6	3598.75**
Error	18	7.10

**Significant at the .01 level of confidence.

APPENDIX TABLE VIII

ANALYSIS OF VARIANCE OF PERCENT GERMINATION OF ROGERS BARLEY

WITH 10, 20, 25, 50, 100, 200, 400 SEED PER BOX

Source	df	MS
Total	27	922.74
Block	3	17.00
Seed Number	6	4047.00**
Error	18	32.2

**Significant at the .01 level of confidence.

APPENDIX TABLE IX

ANALYSIS OF VARIANCE OF PERCENT GERMINATION OF TRIUMPH WHEAT

WITH 10, 20, 25, 50, 100, 200, 400 SEED PER BOX

Source	df	MS
Total	27	596.00
Block	3	27.00
Seed Number	6	2585.33**
Error	18	27.72

**Significant at the .01 level of confidence.

APPENDIX TABLE X

ANALYSIS OF VARIANCE OF PERCENT GERMINATION OF BALBO RYE

WITH 10, 20, 25, 50, 100, 200, 400 SEED PER BOX

Source	df	MS
Total	27	941.37
Block	3	19.66
Seed Number	6	4140.16**
Error	18	28.72

**Significant at the .01 level of confidence.

APPENDIX TABLE XI

AVERAGE NUMBER OF NORMAL SEEDLINGS GERMINATED OF 12 VARIETIES OF SMALL GRAINS AFTER TEN DAYS AT SIX OSMOTIC TENSIONS AND THREE TEMPERATURE ENVIRONMENTS

Temperature	Variety	Atmospheres of Osmotic Tension 0	3	6	9	12	15
20°-30°	Wintok	24.66	24.50	24.83	10.00	0.33	0.00
	Arkwin	24.00	23.16	17.00	0.16	0.00	0.00
	Forkedeer	24.83	24.83	24.66	14.33	0.66	0.00
	Bronco	24.83	24.50	24.00	8.83	0.00	0.00
	Cimarron	24.83	25.00	24.83	15.50	0.50	0.00
	Kaw	24.33	23.66	24.50	19.16	3.16	0.00
	Triumph	24.83	24.33	24.66	24.33	12.50	0.16
	Concho	23.33	22.83	22.66	22.16	5.00	0.00
	Ward	24.66	25.00	23.66	24.33	19.16	2.83
	Rogers	23.00	22.66	19.50	14.66	7.33	0.50
	Elbon	20.66	18.83	19.00	11.00	4.83	0.33
	Balbo	24.00	21.83	22.83	18.16	8.00	2.33
20°	Wintok	25.00	23.83	17.83	1.00	0.00	0.00
	Arkwin	24.50	21.33	8.50	0.00	0.00	0.00
	Forkedeer	24.83	24.83	17.33	0.83	0.00	0.00
	Bronco	24.83	23.83	12.66	0.50	0.00	0.00
	Cimarron	24.66	25.00	23.66	6.16	0.16	0.00
	Kaw	24.33	24.00	22.83	5.16	0.00	0.00
	Triumph	23.83	23.50	23.33	19.00	0.83	0.00
	Concho	24.50	23.50	22.66	5.33	0.00	0.00
	Ward	25.00	24.83	24.83	23.66	7.00	0.00
	Rogers	21.00	20.83	17.16	9.50	0.50	0.00
	Elbon	21.50	21.50	17.33	10.50	1.83	0.16
	Balbo	21.16	22.83	22.00	14.50	5.83	0.50
30°	Wintok	24.50	24.66	23.33	13.66	0.66	0.00
	Arkwin	24.66	24.50	22.33	4.83	0.00	0.00
	Forkedeer	24.33	24.50	24.00	17.00	0.66	0.00
	Bronco	24.33	24.33	23.66	18.16	0.66	0.00
	Cimarron	24.66	24.33	24.16	18.83	5.00	0.33
	Kaw	24.33	24.33	24.33	22.83	15.83	1.00
	Triumph	24.33	24.50	24.33	24.00	22.50	5.33
	Concho	24.66	24.33	24.50	22.83	17.66	3.33
	Ward	24.83	24.83	24.66	24.66	23.33	17.83
	Rogers	16.33	14.00	14.16	9.00	5.83	2.16
	Elbon	14.00	15.66	15.33	11.83	5.50	2.00
	Balbo	22.00	21.00	21.16	22.16	16.16	7.66

APPENDIX TABLE XII

AVERAGE NUMBER OF SEEDLINGS WITH COLEOPTILES GREATER THAN 10 MM IN LENGTH GERMINATED OF 12 VARIETIES OF SMALL GRAINS AFTER TEN DAYS AT SIX OSMOTIC TENSIONS AND THREE TEMPERATURE ENVIRONMENTS

Temperature	Variety	Atmospheres of Osmotic Tension 0	3	6	9	12	15
	Wintok	24.66	24.50	24.83	19.83	1.83	0.00
	Arkwin	24.00	23.16	23.00	15.66	0.33	0.00
	Forkedeer	24.83	24.83	24.83	24.16	6.00	0.00
	Bronco	24.83	24.50	24.83	23.33	5.83	0.00
	Cimarron	24.83	25.00	24.83	24.50	16.00	0.33
20°-30°	Kaw	24.33	23.66	24.50	22.50	11.66	0.16
	Triumph	23.83	24.33	24.66	24.33	19.50	2.33
	Concho	23.33	22.83	23.16	23.50	20.50	3.00
	Ward	24.66	25.00	23.66	24.50	24.16	14.33
	Rogers	23.00	22.83	19.50	15.50	13.66	6.66
	Elbon	20.83	18.83	19.33	18.16	14.66	5.66
	Balbo	24.00	23.00	23.33	22.33	21.33	14.00
	Wintok	25.00	25.00	24.66	19.16	1.66	0.00
	Arkwin	24.50	24.16	24.00	19.00	0.33	0.16
	Forkedeer	25.00	25.00	24.66	24.16	8.50	0.16
	Bronco	24.83	24.16	24.83	19.33	2.83	0.00
	Cimarron	24.83	25.00	25.00	24.33	17.00	0.16
20°	Kaw	24.33	24.50	24.00	22.66	9.16	0.16
	Triumph	23.83	23.50	23.83	22.83	10.16	0.50
	Concho	24.50	23.83	23.33	24.00	14.50	0.33
	Ward	25.00	24.83	24.83	24.83	23.83	5.33
	Rogers	21.16	20.83	18.00	17.00	10.66	1.83
	Elbon	21.16	21.83	19.66	19.50	14.33	6.33
	Balbo	23.00	23.00	23.50	22.66	21.16	14.16
	Wintok	24.50	24.66	24.00	16.50	4.00	0.00
	Arkwin	24.66	24.66	23.66	16.83	0.00	0.00
	Forkedeer	24.50	24.50	24.00	18.33	8.66	0.00
	Bronco	24.33	24.50	23.66	20.16	3.50	0.33
	Cimarron	24.66	24.33	24.50	20.16	9.16	1.66
30°	Kaw	24.33	24.33	24.33	24.00	20.16	3.50
	Triumph	24.50	24.50	24.33	24.00	23.00	8.50
	Concho	24.83	24.50	24.50	23.00	19.83	5.16
	Ward	24.83	24.66	24.83	24.66	24.33	19.00
	Rogers	16.33	14.33	14.16	9.33	6.50	3.83
	Elbon	17.00	16.33	15.33	12.16	7.00	2.00
	Balbo	22.66	21.00	21.33	22.50	18.16	9.16

APPENDIX TABLE XIII

AVERAGE HEIGHT IN MM OF NORMAL SEEDLINGS GERMINATED OF 12 VARIETIES OF SMALL GRAINS AFTER TEN DAYS AT SIX OSMOTIC TENSIONS AND THREE TEMPERATURE ENVIRONMENTS

		Atmospheres of Osmotic Tension					
Temperature	Variety	0	3	6	9	12	15
	Wintok	80.83	70.00	53.00	29.33	5.83	0.00
	Arkwin	91.66	69.16	45.83	5.16	0.00	0.00
	Forkedeer	85.83	70.00	53.33	34.50	14.16	0.00
	Bronco	91.66	75.00	49.16	32.33	0.00	0.00
	Cimarron	87.50	73.33	52.50	38.33	8.00	0.00
20°-30°	Kaw	75.00	72.50	66.66	46.66	33.83	0.00
	Triumph	71.66	69.16	69.16	50.83	34.00	3.33
	Concho	80.00	77.50	66.66	45.00	34.33	0.00
	Ward	100.00	90.83	77.50	60.00	40.33	23.00
	Rogers	93.33	83.33	68.33	50.50	35.33	9.16
	Elbon	73.33	72.50	58.33	37.16	35.33	7.83
	Balbo	65.83	70.83	61.66	45.16	38.00	22.33
	Wintok	80.00	65.00	44.16	19.16	0.00	0.00
	Arkwin	92.50	61.66	35.83	0.00	0.00	0.00
	Forkedeer	89.16	62.50	48.83	7.50	0.00	0.00
	Bronco	91.66	60.83	44.16	12.83	0.00	0.00
	Cimarron	96.66	68.33	54.16	38.33	4.16	0.00
20°	Kaw	73.33	75.00	61.66	29.16	0.00	0.00
	Triumph	79.16	73.33	60.00	48.33	15.00	0.00
	Concho	77.50	85.00	59.16	45.83	0.00	0.00
	Ward	90.83	79.16	67.50	50.00	28.00	0.00
	Rogers	98.33	76.66	61.66	45.83	12.00	0.00
	Elbon	85.83	71.66	56.66	44.16	31.16	4.16
	Balbo	76.66	71.66	66.66	53.33	36.66	10.00
	Wintok	85.83	75.00	57.50	42.50	18.66	0.00
	Arkwin	94.16	83.33	52.50	40.83	0.00	0.00
	Forkedeer	93.33	75.83	53.33	40.83	17.50	0.00
	Bronco	95.00	80.00	57.50	38.33	20.00	0.00
	Cimarron	95.00	80.83	64.16	49.16	28.50	5.00
30°	Kaw	82.50	73.33	74.16	66.66	52.50	20.50
	Triumph	87.50	80.00	72.50	65.00	55.83	26.00
	Concho	85.83	86.66	80.00	65.00	54.16	22.00
	Ward	111.66	90.00	89.16	69.16	52.50	28.00
	Rogers	116.66	87.50	87.50	70.00	45.83	21.66
	Elbon	80.00	80.00	68.33	51.66	38.33	20.16
	Balbo	90.00	81.66	73.33	63.33	45.83	30.16

APPENDIX TABLE XIV

ESTIMATED NUMBER OF SEED PER POUND OF

12 SMALL GRAIN VARIETIES

Variety	Weight of 500 seed (g)	Calculated weight/seed (mg)	Estimated seed/pound
Oat			
Wintok	17.4395	34.880	13,004
Arkwin	18.5927	37.185	12,198
Forkedeer	16.9363	33.872	13,391
Bronco	16.9248	33.849	13,400
Cimarron	16.0170	32.034	14,159
Wheat			
Kaw	16.9079	33.815	13,413
Triumph	16.4512	32.902	13,786
Concho	13.8525	27.705	16,375
Barley			
Rogers	14.9475	29.895	15,172
Ward	12.1855	24.371	18,611
Rye			
Elbon	9.1790	18.358	24,708
Balbo	11.8360	23.672	19,161

VITA

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