THE GERMINATION OF CERTAIN INTRODUCED AFRICAN GRASSES AS INFLUENCED BY DIFFERENT TEMPERATURE AND MOISTURE STRESSES

by

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A Thesis Submitted to the Faculty of the

DEPARTMENT OF WATERSHED MANAGEMENT

In Partial Fulfillment of the Requirements

For the Degree of

MASTER OF SCIENCE

In the Graduate College

UNIVERSITY OF ARIZONA

1963

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Robert R. Humphrey — Apr. 29 1963

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ACKNOWLEDGMENT

The author wishes to express his sincere gratitude to his major professor and thesis director, Dr. Robert R. Humphrey, for his help and advice. He is also grateful to his wife for her help and encouragement throughout the course of the study.

Sincere thanks are due to Dr. E. B. Kurtz for his assistance during the initial and final stages of the laboratory work; to Mr. E. M. Schmutz for photographic assistance and technical advice; to Mr. M. J. Zwolinski for photographic assistance; to the Departments of Watershed Management, Bacteriology, and Botany for use of facilities; and to the Soil Conservation Service Plant Materials Center for providing the seeds used in the study.

The author is grateful to the United States Agency for International Development (U.S.A.I.D.), the Ghana Government, and the Agricultural Research Institute (Kumasi) for the Scholarship award which made study at the University of Arizona possible.

To all unnamed who offered help and kindness or were courteous the author is indebted.

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INTRODUCTION

The successful establishment of a grass stand depends initially on good germination; this in turn is influenced by temperature and moisture as well as by light. Different species usually differ in their requirements of these three factors for optimum germination. An intimate knowledge of the conditions under which the maximum number of seeds will germinate within a given period of time is therefore necessary. This knowledge serves as an aid in selecting locations where a species will germinate and may grow when seeded.

Many grasses indigenous to Africa have been introduced within recent years into the United States. Some of these have proven useful in various ways, including (1) reseeding of ranges, especially in overgrazed areas; (2) controlling of erosion and reclamation of several eroded areas; (3) improving soil structure; and (4) facilitating moisture conservation.

Most of the introduced species are being widely used in reseeding areas that differ climatically from areas where they are native. In some of these areas, as for example the Southwest, growth is hampered by high soil temperatures and low soil moisture. Grasses and other plants should not be introduced in areas where such conditions prevail without a knowledge of their temperature and moisture requirements. Energy and money may be wasted when unadapted species are used.

Little is known about either the temperature or moisture requirements of most of the introduced African grasses. The present study has been undertaken in an effort to determine the influence of various temperatures and moisture conditions on four of the most widely used grasses, namely, Eragrostis chloromelas Steud., Eragrostis curvula Schrad., Pennisetum ciliare (L.) Link., and Panicum maximum Jacq.

Eragrostis chloromelas and Eragrostis curvula are indigenous to South Africa. The latter grows also in Northern Nigeria (Foster and Mundy, 1961). Both species grow at elevations of 4,500-6,500 feet or lower in areas receiving from 18 to 30 inches of rainfall a year (Rattray, 1960). Pennisetum ciliare occurs in the Bush Veld of South Africa (Meredith, 1955) and in the West Indies. Panicum maximum is found in many places south of the Sahara in areas receiving an annual rainfall of 28 to 56 inches (Rattray, 1960). It is one of the pioneer grasses that invades overcultivated areas in parts of the northern limits of the High Forest Zone of Ghana (Asare, 1962).

The results of this study may be useful as a guide for those who wish to use these species in reseeding depleted ranges. Although the experimental conditions of this study can rarely be duplicated under field conditions, the information developed may be applied in the field by interpretation or extrapolation.

REVIEW OF LITERATURE

The effects of temperature and moisture on seed germination have been extensively studied by many workers. In general, the studies have shown that different species usually differ in their germination requirements for these two factors.

Temperature

Most of the physiological processes in plants normally take place at temperatures between 0 and 40°* (Went, 1953). Both very low and very high temperatures are injurious to plants. Seeds, which in reality are dormant embryonic plants, have minimum and maximum temperatures at which they will germinate. This range is narrow in many species and determines to a greater or lesser extent the geographical distribution of plants and the time of year when they normally will germinate.

Juhren, Hiesey, and Went (1953) reported that most grasses differ in their ability to germinate and grow under different temperatures. These workers found that *Poa compressa*, *P. ampla*, *Bromus*

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* All temperatures given in this thesis are in degrees centigrade unless otherwise stated.

carinatus and Agropyron dasystachyum germinated well at both warm and cool temperatures, but Poa scabrella and P. bulbosa germinated and developed well only at cool temperatures. They also found that the ability to germinate well at high temperatures usually indicated that the plant would subsequently grow well at high temperatures and vice versa. It may be concluded from this that, provided other conditions are favorable, the establishment of a stand of vegetation under field conditions may be indicated by the temperature under which optimum germination occurs.

Harrington (1923) noted that the most favorable germination temperature for many kinds of seeds corresponds closely with the field soil temperature that induces the most prompt and vigorous seed production of these same species.

As noted by Delouche (1953), investigations into the effect of temperature on germination have been directed mainly towards finding the maximum, optimum, and minimum temperatures necessary for germination of different kinds of seeds. The results of these studies suggest that the final percentage germination of a given species is more or less equal over a certain range of temperature, but that within this range higher temperatures result in an increased germination rate.

Different temperatures are sometimes reported by different workers as most suitable for the germination of a specific species.

According to Edwards (1934) these apparent discrepancies are due in part to the fact that different workers tend to define optimum temperatures differently. Optimum temperature is variously defined as (1) the temperature producing the first or last seedling in the shortest possible time, or (2) the temperature at which the greatest number of seeds germinate in a given period of time.

Germination test discrepancies also sometimes result from variations in the definition of germination. The 'Rules' (Anonymous, 1949) define germination as "the emergence and development from seed embryo of those essential structures which, for the kind of seed in question, are indicative of the ability to produce a normal plant under normal conditions." Discrepancies in germination tests may also be due in part to pretreatment of seeds, storage time or age of seeds before planting, and the medium in which the seeds are germinated. Although the 'Rules' specify that corn germinates best at a temperature alternating between 20 and 30°, Delouche (1953) reported that corn germination was completed two days sooner at the constant temperatures of 30 and 35° than at the temperature recommended by the 'Rules.'

Kotowski (1926) gave the optimum temperature for melon germination at 30°. Delouche (1953) has reported that the germination of melon (species not given) was most rapid at alternating 30°-20° temperatures. At this alternating temperature, Delouche found that germination was completed in three days as opposed to six days at the alternating 20-30° temperature recommended by the 'Rules.'

As stated previously, time of storage and treatment before planting also determine in part the temperature that is most favorable for germination. Barton (1936) studied germination in seeds of Lepidium lasiocarpum, Streptanthus arizonicus, and Daucus pusillus and found that with an increase in storage time after ripening, percentage germination increased and germination occurred over a wider range of temperature. Kerns and Toole (1934) found that seeds of six different species and varieties of fescue that had been prechilled at 5° for seven days showed an increase in germination at temperatures ordinarily too high for complete germination of fresh seeds. They also noted that seeds of each of the six species and varieties collected at different stages of maturity and germinated immediately after harvest required relatively low temperatures for germination. The need for low temperature was more pronounced in seeds collected when immature than in seeds collected when completely ripe. These workers also observed that the older the seeds, the wider the range of temperature over which they germinated. They found that a few months after harvest, maximum germination of fescue was obtained at an alternating temperature of 20-30°; also the rate of germination was reduced by alternating temperatures lower than 20-30°.

The results of germination tests to date indicate that some seeds germinate best at constant temperatures, others at alternating temperatures, while still others germinate equally well at either alternating or constant temperatures. Harrington (1923) conducted germination tests on various species under 15 constant and alternating temperatures. He found that Daucus carota, Petroselinum, Phleum pratense, Festuca elatior, and several other flowering plants germinated well at both alternating and constant temperatures. Seeds of Pastinaca sativa, Agrostis palustris and sometimes Celeri graveolens, Dactylis glomerata, and Poa pratensis germinated better at alternating than at constant temperatures. Different lots of the same kind of seeds differed widely in their temperature sensitivity; thus some kinds of seeds under certain conditions germinated better with alternating temperatures. Vicia sativa, Lactuca sativa, and Pisum sativum, on the other hand, germinate best at a constant temperature of 20° (Anonymous, 1949).

A number of hypotheses have been advanced to explain the effect of alternating temperatures upon germination. Haberlandt (1875) and Eidam (1883) suggested temperature effects upon water uptake as the possible cause of the effect of temperature alternations upon germination. As most seeds whose germination is favored by temperature alternations imbibe more water at any temperature than the minimum required for germination, this explanation does not seem tenable.

Liebenberg (1884) suggested that reserve materials made available at any given temperature tend to be used up in respiration, but that a slight surplus of these materials becomes soluble at higher temperatures. This surplus is available for growth when a reduction in temperature reduces respiration instantly.

Gassner (1910) postulated that the effect of alternating temperature on germination of Chloris ciliata is due entirely to oxygen relations. Vanha (1898) pointed out that differences in temperature among the different parts of the seed, the seed bed, and the outer air following a sudden temperature change result in different gas densities which set up lively gas movements leading to removal of carbon dioxide and renewal of oxygen. These conditions, he said, favor increased respiration and probably germination. Harrington (1923) suggested that a detailed study of respiration and internal changes of seeds at different temperatures might help to explain the effect of alternating temperatures. He noted that the respiratory quotient of dormant apple seeds decreased with decreasing temperature and vice versa and postulated that if this happened in all or most dormant seeds, oxygen may accumulate or even be metabolized at low temperatures in a form which becomes immediately available for the inception of growth processes when seeds are subjected to a higher temperature. This hypothesis is in some respects the opposite of that of Liebenberg but is not in opposition to those of Vanha and Gassner.

According to the 'Rules' high germination of Eragrostis curvula should be obtained at an alternating 20-35° temperature; light is essential for its germination and fresh and dormant seeds should be prechilled at 5° for two weeks prior to germination. Toole (1938) tested the seeds of Eragrostis curvula and reported that complete germination was not obtained with constant temperatures of 10°, 15°, 20°, and 25°; neither did alternating temperatures of 25-35° result in optimum germination. At alternating temperatures above 20-30°, seeds on filter papers moistened either with 0.2 percent nitric acid solution or with water gave equally high final germination percentages. At constant temperatures, however, seeds germinated in nitric acid solution had a higher germination percentage than those germinated in water.

According to the 'Rules' maximum germination of Panicum maximum should be obtained when the seeds are subjected to an alternating 15-35° temperature. The 'Rules' also stipulate that light is essential for the germination of this species. Cullinan (1941) removed the lemma and palea of Panicum maximum and germinated the seeds in Petri-dishes on cotton moistened with a 0.2 percent solution of potassium nitrate. On treating the seeds with one percent ethyl mercuric tartrate, fungal attack was considerably reduced. Maximum germination was obtained at an alternating 15-35° temperature.

The 'Rules' specify that Pennisetum ciliare is best germinated on sand at 30° after prechilling at 5° for seven days; fresh seeds should be prechilled at the above temperature for six weeks; light is necessary for germination. Akamine (1944) placed one-month-old seeds of Pennisetum ciliare in Petri-dishes at 25° and obtained the following germination results: untreated seeds 1.5 percent, seeds with husk 11 percent, and naked seeds 91.5 percent. When he planted acid-treated seeds in soil, he obtained a higher total germination than from seeds in Petri-dishes. He also reported that naked seeds germinated better than seeds with the lemma and palea attached and concluded that lemma, palea, and glumes contained an inhibitor that was absorbed by the soil. Brown (1952) reported 84 percent germination when Pennisetum ciliare seeds were stored at 65° for four weeks. The check samples gave five percent germination. When the seeds were stored at 80° for one week, 32 percent germination was obtained as contrasted with three percent for the check. Baker (1952) after removing the glumes, palea, and lemma from the seeds of Pennisetum ciliare, abraded and germinated them at an alternating 10-35° temperature in Petri-dishes on filter paper moistened with 0.2 percent potassium nitrate. The seeds were prechilled for five days prior to testing. Germination was between 80 and 90 percent as contrasted with 25 percent or less from seed similarly treated but not abraded and only 20 percent from seeds not prechilled or abraded. Anderson (1953) also conducted germination tests using Pennisetum ciliare and obtained complete germination of freshly harvested seeds both when the naked seeds were planted in Petri-dishes on a paper substratum moistened with 0.2 percent potassium nitrate solution and when they were prechilled at 5° for seven days and planted in soil. A high percentage of the seeds germinated when they were previously prechilled or abraded. A still higher percentage germinated when the seeds were both prechilled and abraded before planting.

Moisture Stress

Owing to the osmotic properties of solutions, they offer resistance to water absorption by plant roots. It appears that the same physical properties of solutions govern the imbibition of water by seeds. The absorption of water from solution by seeds has been studied by a number of investigators. Slosson (1899) immersed a large number of seeds in different salt solutions of varying osmotic pressures and found that absorption of water by seeds was hindered by salts in solution. He observed that the retardation of imbibition did not increase in proportion to an increase in osmotic pressure of the solution. He also observed that solutions of different salts with the same osmotic pressure produced the same effect. This, he pointed out, indicated essentially that osmotic pressure was more important than the kind of salt used.

Rudolfs (1921) reached the same conclusions as Slosson, i.e., that the retarding effect of strong salt solutions on germination was directly proportional to the osmotic pressure. It had been previously shown by Slosson and Buffum (1898) that living and dead seeds imbibed water equally well. Shive (1917) added single solutions of known concentrations to corn and bean seeds and incubated these for 48 to 72 hours at room temperatures. This study indicated that higher osmotic concentrations retarded but did not prevent germination. Shive concluded that retardation of germination was directly related to the amount of water imbibed by the seeds and this in turn was dependent on the osmotic concentration of the solution.

The results of these investigations suggested that retardation of absorption was accomplished through the osmotic resistance offered to the entrance of water into the seeds. Thus, the solutions created moisture stress, a different concentration of the same chemical creating a different moisture stress or different levels of moisture availability. As a consequence, solutions of different concentrations could be employed in studying the effect of different levels of moisture availability on seed germination and seedling growth.

Some chemicals are toxic to seeds; others are nontoxic. Wiggans and Gardner (1959) germinated seeds of scarlet globe radish and sorghum using different concentrations of various chemicals. They found that polyvinylpyrorollidone (a long chain polymer) and sodium chloride were somewhat toxic to the seeds. Glucose, sucrose, and D-mannitol were not toxic, but the first two reduced germination considerably more at comparable concentrations than did the latter.

Concentrations of glucose and sucrose at 10 atmospheres or more greatly or completely inhibited germination and elongation of radicle and plumule. Uhvits (1946) reported that at the same concentration, sodium chloride effected a greater reduction than D-mannitol in both rate and amount of germination in alfalfa. This was attributed to the toxicity of sodium chloride. It was also observed that as the osmotic pressure of the solution increased, the seeds absorbed less water and germination was reduced.

The effect of moisture stress on different varieties of wheat and alfalfa has been investigated by many workers. Helmerick and Pfeifer (1954) used various osmotic concentrations of D-mannitol solution to simulate drought. Their study showed a correlation between the germination of two wheat varieties (Yogo and Cheyenne) under field and laboratory conditions. The Yogo variety responded significantly better than Cheyenne when both were germinated under similar moisture stresses. Rodger, Williams, and Davis (1957) used various concentrations of D-mannitol solution in germination tests of several varieties of alfalfa and found that germination decreased with an increase in osmotic concentration of the germination solution. This study also indicated a greater decrease in winter-hardy varieties than in the vigorous non-hardy strains. Dotzenko and Dean (1959) germinated six varieties of alfalfa in solutions of various osmotic pressures. They found that the percentage of seeds that would germinate under extreme drought was heritable and that the germination percentage decreased as the osmotic pressure of the solution was increased. Delouche (1953) in tests on the germination of corn, watermelons, and soybeans found that at low moisture levels germination was delayed and percentage germination was depressed. When seeds were supplied with excessive moisture, germination was much more depressed than when moisture was insufficient. Evans and Stickler (1961) germinated four varieties of sorghum using three concentrations of water-mannitol solutions. They, like earlier workers, found that germination decreased with an increase in osmotic concentration; also the four varieties responded differently and the time required for germination increased with an increase in osmotic concentration. The effect of moisture tension on plumule and radicle development was not identical.

The effect of moisture stress on 22 garden vegetables has been investigated by Doneen and MacGillivray (1943). Their studies showed that emergence was delayed with an increase in osmotic tension. Of the 22 species tested, 17 emerged even though soil moisture was at the wilting point. Ayres (1952) made similar observations with relation to moisture stress noting that an increase delayed and reduced emergence. He found that when the moisture percentage in fine sand was reduced from 12.4 to 7.2 percent, time of emergence was increased more than 48 hours and total emergence was decreased about 40 percent. Hunter and Erickson (1952) also found that corn, rice, soybeans, and sugar-beet seeds were unable to absorb enough water for germination unless moisture stress was less than 12.5, 7.9, 6.6, and 3.5 atmospheres, respectively. McGinnies (1960) germinated six cool-season grasses under moisture stresses of 1/3, 5, 7 1/2, 10, 12 1/2, and 15 atmospheres at 10, 20, and 30° and found that germination was reduced and also delayed with increase in moisture stress. Under high moisture stress, all the species germinated better at 20° than at 10° and 30°.

Germination requirements of range grasses have been studied by a number of workers. Kneebone (1957) tested Panicum virgatum, Bouteloua curtipendula, and Andropogon hallii using mannitol solutions and reported that the higher the osmotic concentration of the solution the lower was early germination and total growth. He also reported that strains with superior establishment characteristics germinated faster and produced larger seedlings when grown at an osmotic concentration of 7.5 atmospheres. Knipe and Herbel (1960) tested germination of seven grass species at room temperature using water-mannitol solutions. This study indicated total germination of Eragrostis lehmanniana, Eragrostis chloromelas, and Sporobolus flexuosus decreased with increase in osmotic concentration from 0.3 to 7.0 atmospheres. Seedling growth rate was also generally reduced by an increase in osmotic concentration. Bouteloua eriopoda and Muhlenbergia porteri germinated well at osmotic concentrations of 15.0 to 20.0 atmospheres in contrast with the germination behavior of the other species tested.

The effect of moisture stress on water uptake and elongation of radicle and plumule has been studied by a number of workers. Borzini (1936) concluded that the development of seedlings was directly related to the osmotic pressure of the germination solution. Gingrich and Russel (1957) studied the growth response of corn roots under seven soil-moisture tensions and osmotic stresses using mannitol in combination with five oxygen concentrations. Small seedlings were grown for 24 hours at 25° in soil and in osmotic-pressure media. Both radicle elongation and rate of increase in fresh weight of excised seedlings decreased with an increase in soil-moisture tension and osmotic stress, over a range of 1/3 to 12 atmospheres. Increase in the dry weight of excised seedlings decreased with increasing soil-moisture tension but was not affected by osmotic stress. Root growth was usually greater in osmotic media than in soil at the same stress. It was concluded that growth was highly dependent on the moisture stress of the growth medium. The difference between growth in soil and in osmotic media led to the conclusion that a factor other than physico-chemical stress was operative, a factor that was assumed to be the water-transmitting properties of the two media. Helmerick and Pfeifer (1954) and Powell and Pfeifer (1956) showed that the marked differences in germination between varieties of sorghum probably represented inherent differences.

in drought resistance between varieties of the same species. According to Wiggans and Gardner (1959), although germination of radish was identical with the best results obtained for any of the sorghums, differences between these two dissimilar taxonomic groups in respect to drought resistance in the field was obvious. Wiggans and Gardner concluded that the use of germinating seeds for determining drought resistance, particularly between species, was open to considerable doubt and that the effect of osmotic-pressure solutions on germinating seeds was at best a test of physiological drought resistance and perhaps then only at the seedling stage. Osmotic solutions, therefore, might not provide a reliable measure of morphological drought resistance, even though they might reliably indicate physiological drought resistance.

METHOD OF STUDY

The germination of four grass species, Eragrostis chloromelas, Eragrostis curvula, Pennisetum ciliare, and Panicum maximum was tested under varying degrees of moisture stress and temperature. The seeds were obtained from the Soil Conservation Service Plant Materials Center in Tucson.

Preliminary testing indicated that satisfactory germination could be obtained with untreated naked seed of Eragrostis chloromelas and Eragrostis curvula, that Pennisetum ciliare had to be planted without removing the lemma and palea, while Panicum maximum had to be scarified in 90-percent sulphuric acid for 15 minutes before planting.

The tests were carried out by placing the seeds in Petri-dishes on three layers of filter paper saturated with distilled water or D-mannitol solution. Excess water or solution was removed with blotting paper. Water or D-mannitol solution was added whenever necessary to maintain the desired moisture level. Two species were planted in each dish. The topmost filter paper was divided into two equal parts and 50 seeds of a particular species were planted on each half. There were four replications of each species. The seeds were carefully selected and only those that appeared normal, mature, and undamaged were used.

Germination tests were carried out in one germinator and three ovens. The ovens were maintained within plus or minus 1° of the germination temperature specified; the germinator was maintained within plus or minus 5° F of the specified temperature. The Petri-dishes were placed in covered coffee cans lined with moistened blotting paper. Before being placed in the coffee cans, the seeds were exposed to light at room temperature for four hours. Germination counts were made at 36-hour intervals for 144 hours. A seed was considered germinated when it had produced a normal radicle and plumule and when it appeared that it would be able to continue growth under favorable conditions. Whenever germination of two or more of the four replications of a species was less than 75 percent of the average germination of the four replications at a particular temperature or moisture stress (as a result of fungi), the test was repeated. When only one of the replications was below this percentage, the average of the other three was used as the percentage germination of the species.

Temperature

The seeds were germinated at both constant and alternating temperatures. Five constant temperatures of 15°, 25°, 35°, 45°, and 55° and four alternating temperatures of 15-25°, 25-35°, 35-45°, and 45-55° were employed. With the alternating temperatures, the lower temperatures were maintained at night for 16 hours; the higher ones during the day for eight hours. The change in temperature was obtained by moving the coffee cans from one oven to another or from an oven to the germinator. For instance, to obtain the temperature change from 15-25°, the cans were removed from the germinator at 25° after eight hours to an oven at 15° for 16 hours.

<u>Moisture stress</u>

Solutions of D-mannitol*, a hexahydric alcohol, were prepared at concentrations equivalent to 5, 10, and 15 atmospheres. According to Uhvits (1946), this sugar alcohol is nontoxic to seeds. It is sufficiently soluble to develop stresses equivalent to 15 atmospheres. The amounts of water and mannitol required to give the above three tensions were calculated from the equation given by Helmerick and Pfeifer (1954) and also described by Wiggans and Gardner (1959). This is as follows:

$$g = \frac{PVm}{RT}$$

g = grams of mannitol

P = osmotic pressure in atmospheres

V = volume in liters

m = molecular weight of mannitol

R = 0.0825 liter atmospheres/degree/mol.

T = absolute temperature

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* E and A-Tested Purity reagent.

The filter papers were moistened with the appropriate concentration of the water-mannitol solution. The checks were moistened with distilled water. All excess solution was removed with blotting paper. Extra solution was added as necessary to keep the blotters moist. The inside of each Petri-dish cover was lined with filter paper to absorb water that would otherwise have condensed there. The seeds of each species were germinated at temperatures optimum for their germination. The effect of moisture stress on early growth was determined by measuring the average length of the plumule and radicle of 10 seedlings randomly selected 48 hours after planting from solutions of 5, 10, and 15 atmospheres. Investigations conducted to determine changes in osmotic pressure of the D-mannitol solution over a period of six hours indicated that at 25° the concentration of solutions at 5, 10, and 15 atmospheres increased to 5.9, 11.9, and 18.9 atmospheres, respectively. At 35° the concentration of solutions at 5, 10, and 15 atmospheres increased to 6.3, 12.5, and 19.3 atmospheres, respectively.

The results were tested for statistical reliability at the 5% level of significance using Duncan's new multiple-range test as outlined by Steel and Torrie (1960).

RESULTS AND CONCLUSIONS

Temperature

Eragrostis chloromelas

The highest total germination of *Eragrostis chloromelas* occurred at the alternating temperature of 25-35° (Table 1, Fig. 1). Germination was rapid during the first 36 hours, 86 percent of the seeds having germinated by the end of this period. Germination at the alternating temperatures of either 15-25° or 35-45° was not significantly different from that at the 25-35° alternating temperature; initial response at the alternating temperature of 15-25°, however, was slower and that at the alternating temperature of 35-45° higher than at 25-35°.

At constant temperatures, maximum germination (95 percent) was obtained at 35°. This however, was not significantly higher than germination at either 15 or 25° where total germination was 93 and 85 percent, respectively. Germination at 45° was significantly lower than at the alternating 25-35° temperature optimum for the germination of this species. At 15°, initial response was very slow, there being no germination at the first count (after 36 hours).

Table 1. Germination rate of Eragrostis chloromelas as affected by temperature.

Temperature (deg. C)	Germination time in hours				Total germination
	36	72	108	144	
	---------- percent germination ----------				
15	0	36.0	19.0	38.0	93.0
25	50.0	15.0	10.0	10.5	85.5
35	84.5	10.5	0	0	95.0
45	59.5	13.0	0	0	72.5 *
55	0	0	0	0	0
15-25	36.5	41.5	15.5	0	93.5
25-35	86.5	7.5	6.0	0	100.0
35-45	91.0	1.5	0	0	93.0
45-55	0	0	0	0	0

* Total germination significantly lower than at 25-35°.

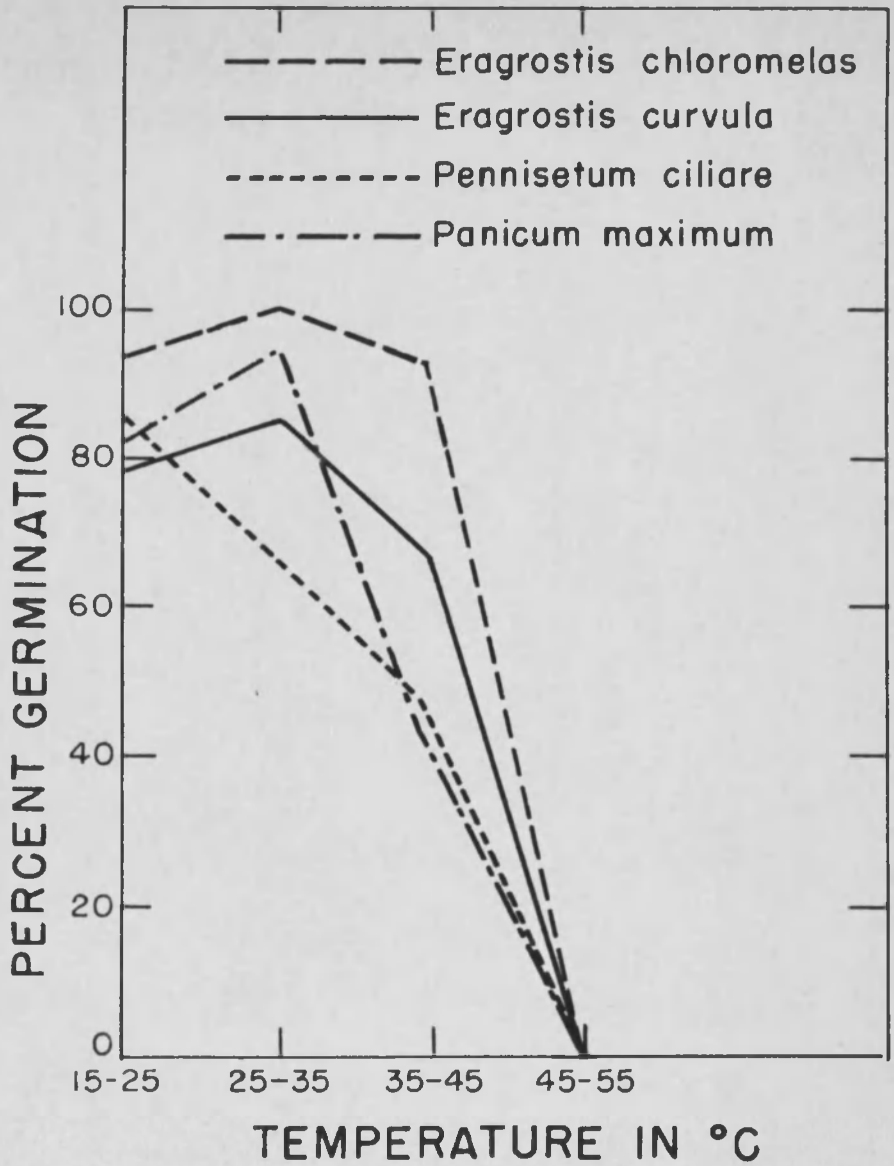

Fig. 1 - Percent Germination of Four Grasses at Alternating Temperatures.

It appears from the tests that, although an alternating 25-35° temperature offers the best condition for the germination of Eragrostis chloromelas, this species will also germinate well at alternating temperatures of 15-25° and 35-45° and at constant 15, 25, and 35° temperatures. Except for the lethal temperatures of 45° and above, the only temperature that significantly affected germination (adversely in this instance) was at the 45° constant level.

Eragrostis curvula

On a basis of initial response and total germination, constant temperature of 25° was optimum for Eragrostis curvula (Table 2, Fig. 2). Initial response was rapid and total germination was not significantly less than at the 25° constant-temperature level. At this latter level, on the other hand, initial response was slow, no seeds having germinated after 36 hours and only 36 percent after 72 hours.

Maximum germination with alternating temperatures was obtained by the 25-35° treatment. At this level, more than half the final germination (58 percent of the seeds) was recorded by the end of the initial 36 hours and most of the balance after 72 hours. Although the higher alternating temperature of 35-45° showed equally high germination during the first and second 36-hour intervals, total germination was significantly less than at 25°.

Insofar as the temperature intervals of this study permit, therefore, it may be concluded that (1) a constant temperature of about 25°

Table 2. Germination rate of Eragrostis curvula as affected by temperature.

Temperature (deg. C)	Germination time in hours				Total germination
	36	72	108	144	
	percent germination				
15	0	36.0	19.0	38.0	93.0
25	54.7	34.0	2.0	0.7	91.4
35	57.5	4.5	1.5	0	63.5*
45	38.5	9.0	0	0	77.5
55	0	0	0	0	0
15-25	29.0	39.0	6.0	4.0	78.0
25-35	58.5	19.0	7.5	0	85.0
35-45	59.5	18.0	0	0	67.5*
45-55	0	0	0	0	0

* Total germination significantly lower than that at 25°.

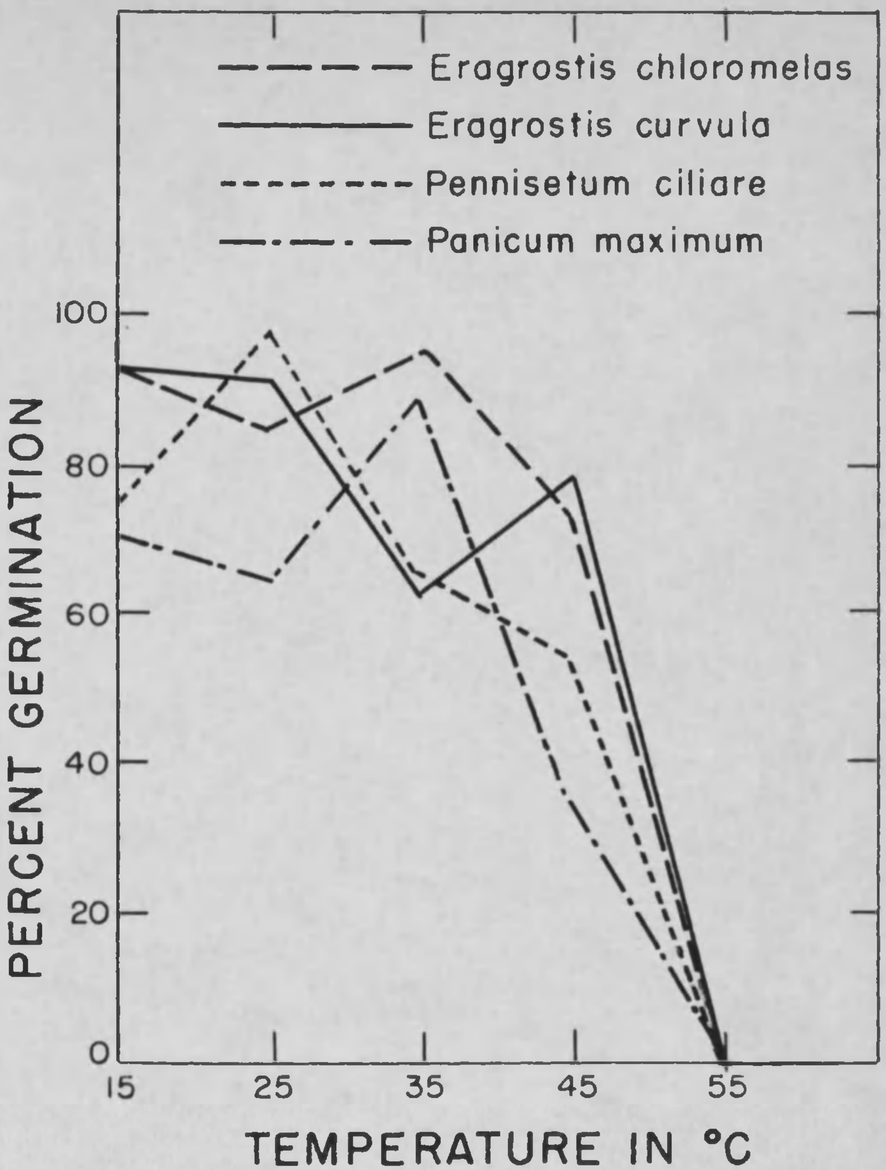

Fig. 2- Percent Germination of Four Grasses at Constant Temperatures.

provides better conditions for germination of Eragrostis curvula than the other temperatures tested, and (2) alternating temperatures of 25-35° provide a condition conducive to satisfactory germination but offer no apparent advantage, and perhaps a slight disadvantage, to the 25° constant temperature.

Pennisetum ciliare

Maximum initial (first 36 hours) germination of Pennisetum ciliare was obtained using a constant and an alternating 25-35° temperature (Table 3, Fig. 2). A slightly lower germination percentage was obtained at 25°. By the end of the second 36-hour period, however, germination was significantly greater at 25° than at any other of the constant temperatures, an advantage that was maintained throughout the 144-hour test. It will be noted that at the end of this time (Table 3) 97 percent of the seeds at a constant 25° temperature had germinated, a significantly greater proportion than at the 45° and 35-45° temperatures. Lethal temperatures were reached somewhere in the range between 45° and 55°, no germination being recorded at the higher of these figures.

The employment of alternating temperatures yielded results somewhat similar to those obtained with constant levels. Maximum initial (first 36 hours) germination was obtained with 15-25° and 25-35° ranges. The lower of these, however, yielded the highest total germination, indicating, as had the constant temperature test, that a

Table 3. Germination rate of Pennisetum ciliare as affected by temperature.

Temperature (deg. C)	Germination time in hours				Total germination
	36	72	108	144	
	percent germination				
15	0	39.0	35.5	3.5	75.5
25	41.0	46.5	8.0	1.5	97.0
35	43.0	19.5	5.0	0	67.5*
45	33.0	20.0	1.5	0	54.5*
55	0	0	0	0	0
15-25	41.0	32.0	12.0	0	85.5
25-35	43.0	23.5	5.0	7.0	68.5
35-45	29.0	15.5	2.5	0	47.0*
45-55	0	0	0	0	0

* Total germination significantly lower than at 25°.

germination peak was reached at somewhere around the 25° level. As with the constant temperatures, an alternating series with 55° as a maximum proved lethal. Since the total germination at 35-45° (alternating) was roughly half as high as at the most favorable range, the lethal point was reached somewhere between 45 and 55°. This confirms the constant-temperature germination results.

Panicum maximum

The highest total germination of Panicum maximum occurred at the alternating 25-35° temperatures (Table 4, Fig. 1). Total germination at this temperature range was significantly higher than at the constant 25° and 45° or the alternating 35-45° levels. Initial germination was greater at a constant 35° than at any other temperature, either constant or alternating. Response to germination during the first 36 hours after planting at the alternating 25-35° temperatures was lower than at the constant 35°. At the latter temperature, however, germination during the second 36 hours was only about one-third of that at the alternating 25-35° temperatures. At 25° and below, germination at the first count was lower than at the second count. This was in contrast with temperatures of 35° and above where (except at lethal levels) germination at the first count was higher than at the second count. Thus it would seem that at the alternating 25-35° temperatures, the night

Table 4. Germination rate of Panicum maximum as affected by temperature.

Temperature (deg. C)	Germination time in hours				Total germination
	36	72	108	144	
	------------- percent germination -------------				
15	0	3.0	27.0	41.0	71.0
25	17.5	29.0	2.0	15.5	64.0*
35	75.5	10.5	1.5	2.0	89.5
45	30.5	25.5	0	0	56.0*
55	0	0	0	0	0
15-25	8.0	68.0	7.0	0	83.0
25-35	56.0	33.5	5.5	0.5	95.5
35-45	28.0	15.0	0	0	43.5*
45-55	0	0	0	0	0

* Total germination significantly lower than at 25-35°.

temperature of 25° was responsible for the relatively low germination of the first count.

At both the constant 45° and the alternating 45-55° temperatures there was no germination after the second count, i.e., 72 hours after planting, suggesting a cumulative unfavorable effect of these high temperatures. Total germination at the alternating temperatures seem to support the results obtained at the constant temperatures but the alternating temperatures do seem to provide slightly more favorable conditions for germination.

General Discussion

Constant temperatures as high as 35° were injurious to the seeds of all four species used in this study. At the alternating temperatures of 45-55° and a constant temperature of 55°, none of the seeds of the four species germinated, the seeds presumably being killed at these temperatures.* The effect of a constant 45° temperature was high initial response but a reduction of total germination. The high initial response was probably due to the acceleration of physico-chemical reactions in the seeds.

With all of the grasses the low temperature of 15° slowed down germination rate. It did not, however, adversely affect total percentage

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* No germination occurred when seeds tested at 55° were transferred to a temperature of 25° for ten days.

germination of the small-seeded Eragrostis chloromelas and Eragrostis curvula, but reduced total percentage germination of the comparatively large-seeded Panicum maximum and Pennisetum ciliare. At this low temperature, none of the seeds of the four species had germinated at the first count (after 36 hours). The slow rate of germination was presumably due to a slow physico-chemical reaction rate. Enzyme activation may also have been low. Reasons for the difference in total germination of the small- and large-seeded species was not apparent.

The optimum temperature for the germination of all four species was within the temperature range of 25° to 35°. Presumably, at the temperature that was optimum for the germination of each species, the effect of temperature was to accelerate physico-chemical reactions without enzyme inactivation or killing of the seeds.

Moisture Stress

The effect of moisture stress on total germination of Eragrostis chloromelas, Eragrostis curvula, Pennisetum ciliare and Panicum maximum was more or less similar. An increase in moisture stress obtained by varying the concentration of D-mannitol solution adversely affected total germination. Each species showed a reduction in total germination with every increase in the osmotic concentration of the germination solution (Table 5, Fig. 3).

Table 5. Germination of four grasses in various concentrations of D-mannitol solution at constant and alternating temperatures.

Osmotic concentration in atmospheres	Germination time in hours	Germination of species at temperatures indicated			
		Eragrostis chloromelas	Eragrostis curvula	Pennisetum ciliare	Panicum maximum
		25-35° C	25° C	25° C	25-35° C
		percent			
0	36	86.5	54.7	41.0	56.0
	72	7.5	34.0	46.5	33.5
	108	6.0	2.0	8.0	5.5
	144	0	0.7	1.5	0.5
	Total	100.0	91.4	97.0	95.5
5	36	54.7	22.7	63.3	43.3
	72	34.0	53.3	14.0	26.7
	108	4.0	13.3	6.7	2.0
	144	0	0	0	1.0
	Total	93.3	89.3	84.0	93.0
10	36	51.3	46.7	53.3	54.0
	72	26.7	18.0	14.7	11.3
	108	3.7	2.0	2.0	0.7
	144	0	0	0	0
	Total	82.6	66.7	70.0	66.0
15	36	37.3	43.3	42.0	37.0
	72	27.3	8.7	8.0	18.5
	108	0.7	0	1.0	2.5
	144	0	0	0	0
	Total	65.3*	51.0	51.0*	58.0

* Total germination significantly lower than at 0 atmosphere.

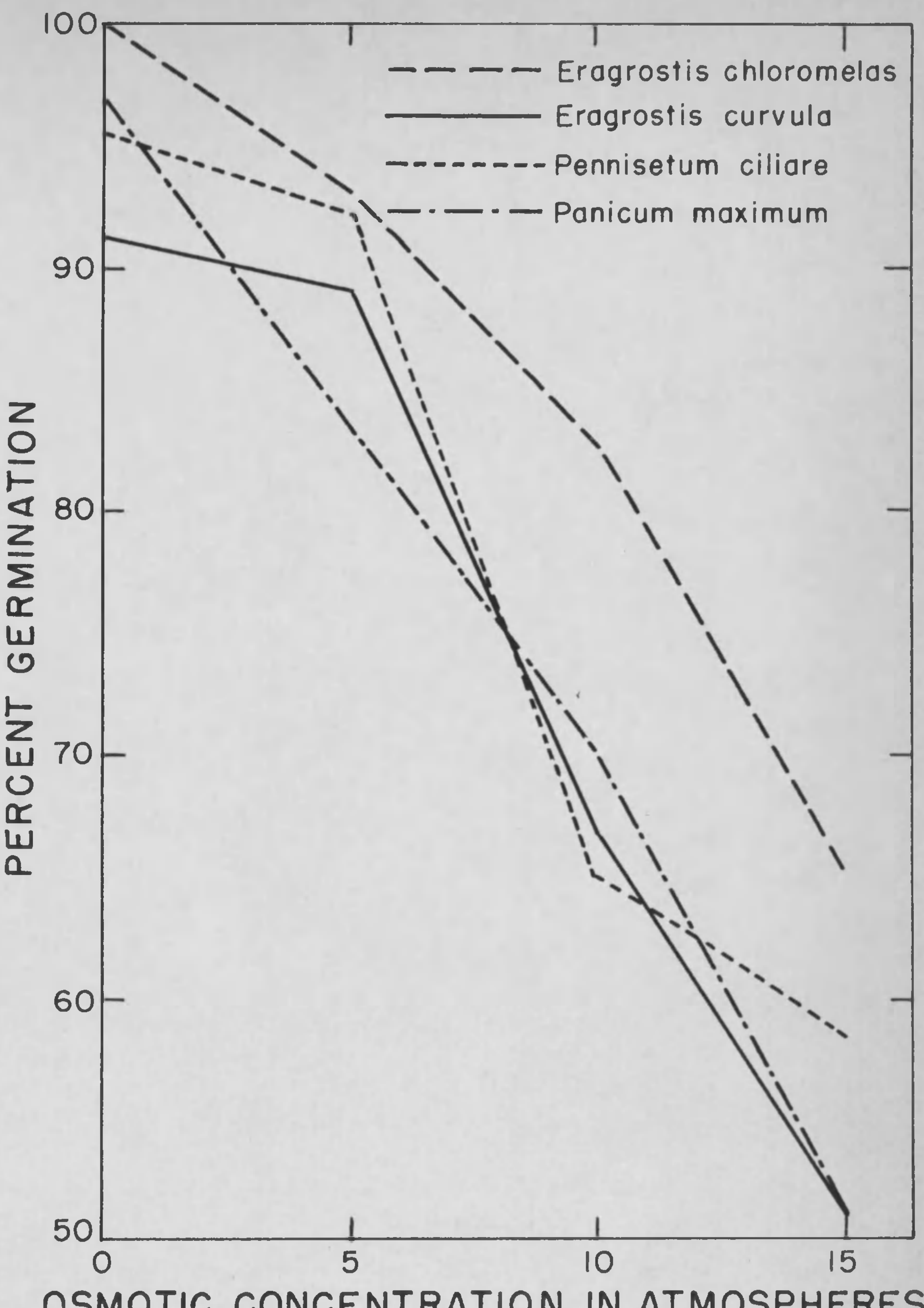

Fig. 3.- Total Germination of Four Grasses as Affected by Osmotic Concentration of Germination Solution.

Germination of all the species except Pennisetum ciliare at the three moisture-stress levels of 5, 10, and 15 atmospheres employed in the study was lower at the first count (after 36 hours) than at 0 atmosphere, i.e., when there was no moisture stress. Total germination of all four species under no stress was not significantly higher than at a stress of 5 and 10 atmospheres. Total germination of Eragrostis curvula and Panicum maximum at 15 atmospheres was not significantly different from germination under no stress. Germination of Eragrostis chloromelas and Pennisetum ciliare at no stress on the other hand was significantly higher than germination at 15 atmospheres.

It will be noted from Table 5 and Figure 4 that under moisture stress, germination of Eragrostis chloromelas was higher than that of the other three species. At a moisture stress equivalent to five atmospheres, germination of all four species was high. At the high moisture stress of 15 atmospheres, however, germination of all the grasses used in the study was at a minimum.

The effect of moisture stress on radicle and plumule elongation follows a pattern similar to that on germination (Tables 6 and 7; Figs. 4, 5, 6, and 7). The higher the osmotic concentration of the D-mannitol solution the less the elongation of both plumule and radicle, i.e., there was an inverse relationship between moisture stress and elongation of plumule and radicle.

Table 6. Average plumule length of four grass species in D-mannitol solution 48 hours after planting.

Species	Average plumule length at varying osmotic concentrations*		
	5 Atm.	10 Atm.	15 Atm.
	mm		
Eragrostis chloromelas	9.6	8.6	6.1
Eragrostis curvula	4.8	2.2	1.9
Pennisetum ciliare	6.6	5.7	3.2
Panicum maximum	14.0	10.8	6.4

* Average of 10 seedlings.

Table 7. Average radicle length of four grass species in D-mannitol solution 48 hours after planting.

Species	Average radicle length at varying osmotic concentrations*		
	5 Atm.	10 Atm.	15 Atm.
	----------------- mm -----------------		
Eragrostis chloromelas	11.6	8.1	6.1
Eragrostis curvula	7.7	4.2	3.1
Pennisetum ciliare	24.4	10.7	8.1
Panicum maximum	14.9	11.8	6.4

* Average of 10 seedlings.

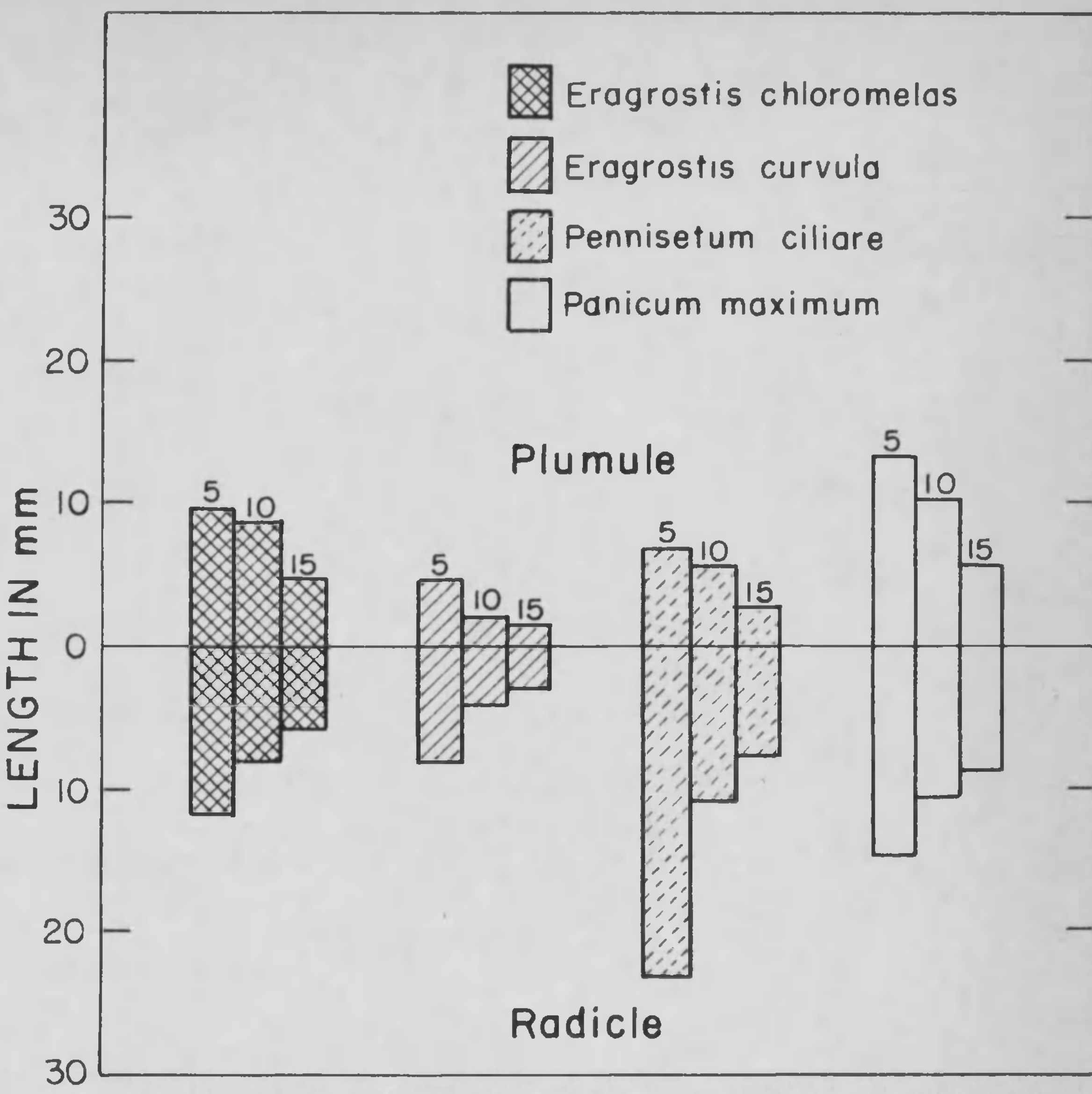

Fig. 4-Plumule and Radicle Elongation of Four Grasses in D-mannitol Solutions at 5, 10 and 15 Atmospheres.

Figure 5. Initial growth of Eragrostis chloromelas at 5, 10, and 15 atmospheres.

Figure 6. Initial growth of Pennisetum ciliare at 5, 10 , and 15 atmospheres.

Figure 7. Initial growth of Panicum maximum at 5, 10, and 15 atmospheres.

Discussion

Although it is recognized that moisture stress resulting from inadequate soil moisture and that resulting from solutions of different osmotic concentrations are not physically--and may not be physiologically--identical, both conditions presumably do result in a moisture-deficient environment for germinating seeds. The germination results obtained by subjecting seeds of the four grasses used in this study to varying concentrations of D-mannitol solution indicated a correlation between germination and osmotic concentration of the germination medium. Although it is possible that factors other than moisture availability may have been involved in part and correlated with the various osmotic pressures obtained, it appears significant to the moisture-stress thesis that every species showed a reduction in total germination with every increase in osmotic concentration of the solution. Thus, distilled water, which was used as a check, provided the best moisture-stress condition for all of the grasses, while an osmotic concentration equivalent to 15 atmospheres provided the poorest conditions. Even at this concentration, however, the final germination of none of the species fell below 50 percent.

Although a concentration of 15 atmospheres is equivalent to a wilting-point moisture stress, the seeds obviously were able to imbibe enough water even at this level to germinate. However, germination is one thing; establishment another. And, although the study was not continued long enough to determine whether the seedlings would survive at any of the concentrations tested, the marked reduction in both plumule and radicle length at the 15-atmosphere level appears to be critical. Little more than this can be said from this limited study, but longer time tests should provide additional information on survival.

SUMMARY

The germination of four introduced African grasses, Boer lovegrass (Eragrostis chloromelas), weeping lovegrass (Eragrostis curvula), buffel grass (Pennisetum ciliare), and Guinea grass (Panicum maximum) was tested under a variety of temperature and moisture-stress levels. Preliminary tests indicated that satisfactory germination could be obtained with untreated caryopses of Eragrostis chloromelas and Eragrostis curvula. Pennisetum ciliare would not germinate satisfactorily unless both the lemma and palea were left on the seed, the Panicum maximum required scarification (without removing the husk) in 90-percent sulphuric acid for 15 minutes before planting.

The effects of temperature on germination were studied employing five constant temperatures of 15°, 25°, 35°, 45°, and 55° and four alternating temperatures of 15-25°, 25-35°, 35-45°, and 45-55°. With the latter, the lower temperature represented night temperatures and the higher temperatures day temperatures. Night temperatures were maintained for 16 hours and day temperatures for eight hours.

The effect of moisture stress on rate of germination and growth measured by the rate of plumule and radicle elongation was studied

using three concentrations of D-mannitol solution at 5, 10, and 15 atmospheres.

The results of the tests on the effects of various temperatures on germination indicated that high temperatures prevented germination. At the alternating temperatures of 45-55° and the constant temperature of 55°, none of the four grass species germinated. This presumably was due to the fact that the seeds were killed at these two temperatures. The low temperature of 15° slowed down initial response to germination in all the four species and adversely affected total germination in Pennisetum ciliare and Panicum maximum. Enzyme activation was presumably lower and the rate of physico-chemical reactions were slower at this temperature than at the other temperatures used in the tests.

Optimum temperatures for germination of all species were between the range of 25 and 35°. Eragrostis chloromelas and Panicum maximum germinated best at the alternating temperature of 25-35°; Eragrostis curvula and Pennisetum ciliare at the constant temperature of 25°. At these temperatures it would seem that there was a maximum acceleration of physico-chemical reactions without enzyme inactivation or killing of the seeds.

The study of germination and early growth at the three moisture-stress levels employed in the study indicated that there was an inverse relationship between moisture stress and rate of germination and growth. The higher the moisture stress the lower the rate of germination and elongation of the plumule and radicle.

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