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Title: STIMULATION OF BLUEGRASS SEED GERMINATION BY SOAKING AND DRYING TREATMENTS

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The objective of this study was to develop a soaking and drying procedure to stimulate faster germination of Kentucky bluegrass (Poa pratensis L.) seed.

The seeds were soaked in cheesecloth bags in nine chemical solutions. The effects of temperature and time of soaking and of aeration of the solution were studied. The most beneficial results were obtained when the seeds were soaked at 5°C for 6 days in an aerated KNO_3 solution. Following the soaking period, the seeds were air-dried for 24 hours at room temperature to return them to a moisture content of approximately 10%.

The effects of presoaking were evaluated in terms of speed of germination, percent germination, maximum and minimum germination temperatures, alternating temperature requirements, drought resistance, soil emergence and storability.

Soaking in a complete nutrient solution, 200 ppm GA_3 and 2.3 ppm benzyl adenine also gave better results than unsoaked controls. Succinic acid, thiourea, hydrogen peroxide, sodium hypochlorite and water had no stimulating effects. Shorter and longer soaking periods and temperatures of 20° and 5-25°C were less beneficial.

Presoaked seeds started to germinate 1 to 2 days earlier, reached the peak of germination 2 to 3 days earlier and frequently had a higher germination percentage than the control. Presoaking allowed the seeds to germinate at a minimum temperature 3°C below and a maximum temperature 4°C above that of the control. The requirement for alternating temperatures was also reduced.

The beneficial effects of the treatments were more obvious under a stress germination temperature of 25°C than at the more optimum 15-25°C.

The ability to germinate under moisture stress conditions was improved by presoaking. The relative advantage in favor of the presoaked seeds increased as the osmotic pressure of the germination media increased.

Even though the difference was not statistically significant, presoaked seeds emerged faster and had higher percent germination 20 days after planting in greenhouse soil. When soil was used as the germination media, seeds presoaked in water performed better than

seeds presoaked in KNO_3.

Cultivars responded differently to the treatments. Merion, the cultivar which was hardest to germinate in the laboratory, was not affected by the treatments. Less dormant cultivars such as Cougar, Park and Newport were stimulated more than the more dormant Pennstar, Fylking and Windsor.

A germination test conducted after 4 months of storage indicated that the beneficial effects of the treatments were irreversible. Viability of the treated seeds was retained after 7 months of storage at room temperature.

Presoaking increased the germination speed to a greater degree than the after-ripening which took place during 7 months of storage at room temperature.

Humid storage accelerated germination but dry storage at 40° C did not.

Stimulation of Bluegrass Seed Germination by Soaking and Drying Treatments

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INTRODUCTION

Kentucky bluegrass (Poa pratensis L.) is the most commonly used turf-grass species in the U.S. One of its disadvantages as a lawn and turf grass, however, is its inherently long germination and establishment period.

Development of procedures for more rapid stand establishment would be a great boon to the turf industry and homeowners alike.

In addition, stimulation treatments would shorten the length of time required for laboratory germination testing, thus facilitating seed shipment and trade.

Evidence is accumulating that preplanting treatments can be developed to stimulate faster seed germination. These treatments include exposure to magnetic fields, irradiation, slight heating, a small amount of aging, increasing the protein content, and soaking in water, chemicals and growth regulators.

The major objective of this study was to develop a practical presoaking and drying treatment to stimulate faster germination of Kentucky bluegrass seed and to determine the effects of this treatment on seed performance. In addition, the effects of various storage conditions on the speed of germination of bluegrass seed were also studied.

LITERATURE REVIEW

Methods of Seed Stimulations

The earliest attempts to improve the performance of seeds through preplanting treatments were made in the nineteenth century. Two German scientists, Kraus in 1800 AD and Wollney in 1885 AD, investigated the effect of soaking seeds in water upon subsequent growth and yield and obtained remarkable results (Kidd and West, 1918a).

In the twentieth century, growth regulators, chemical solutions, radiation, ultrasonic treatments, radio frequency, glow discharge, magnetism, and increased protein content have also been investigated as preplanting treatments.

Radiation

Shull and Mitchell (1933) found that low doses of X-rays given to corn (Zea mays L.) seeds resulted in a stimulation of early growth of the seedlings. Long and Kersten (1936) obtained similar results by irradiating soybean (Glycine max L.) seeds. Breslavets and her colleagues (1946) reported remarkable increases in the growth and yield of rye (Secale cereale L.) by giving the seeds a dose of 250 r (roentgen units) of X-rays. Similar results are reported for peas (Pisum sativum L.) and ryegrass (Lolium spp.). Timofeev, Resovsky

and Poryadkova (1956) reported increased growth of many crop plants following irradiation of dry or soaked seeds with low doses of X-rays or by soaking the seeds in radioactive solutions. They attributed the effect to weak poisoning. Kuzin (1955) obtained increased yields of radish (Raphanus sativus L.), cabbage (Brassica oleracea var. capitata L.) and peas by 10-30% following irradiation of the seeds with X-rays. Two American scientists, Stein and Steffensen (1959) found some increase in length of both roots and shoots of corn seedlings following seed irradiation. Tedoradze (1961) claimed that seed irradiation not only increased yields of legumes but also promoted or delayed the time of flowering.

According to Sax (1963) who reviewed the stimulation of plant growth by ionizing radiation, the results of stimulation of plant growth at certain stages of development could be attributed to the effects of irradiation on auxin balance. He concluded that obtaining greater yields from crop plants by the use of radioactive fertilizers or by irradiation of seeds still lack critical confirmation.

Nuttal et al. (1968) observed earlier maturity and increased yields in several vegetable species by treating the seeds with low doses of gamma irradiation. Whelan (1970) found that eight cucumber (Cucumis sativus L.) cultivars treated with high levels of radiation differed markedly in seedling emergence.

Negative results from radiation treatments have also been

reported in literature. Kankis and Webster (1956) were not able to obtain any growth stimulation by irradiating sorghum (Sorghum vulgare Pers.) seeds with thermal neutrons at various doses. Osborne and Bacon (1960) and Skok and Charney (1962) have also reported negative results.

Ultrasonics

Findley and Campbel (1953) treated dormant hybrid seed sorn with 400 kilocycles of ultrasonic energy. However, they could not find any significant differences in emergence, plant height, silking or grain yield among hybrid corn plants.

Radiofrequency

Nelson, Nutile and Stetson (1970) exposed seeds of several vegetables including garden beans (Phaseolus vulgaris L.) cabbage, cantaloupe (Cucumis melo L.), cucumber, lettuce (Lactuca sativa L.), okra (Hibiscus esculentus L.), onion (Allium cepa L.), garden peas, pepper (Capsicum spp.), spinach (Spinacea oleracea L.), tomato (Lycopersicon esculentum Mill.) and Kentucky bluegrass to radiofrequency (RF) electric fields and tested to determine the influence of the electrical treatment on germination performance. They observed that germination was significantly increased by RF treatment through reduction of hard seed content in beans, okra and peas. Acceleration

of germination was evident in seeds of bluegrass, tomato and spinach.

Glow Discharge

Goodenough, Stone and McDow (1970) studied the effects of direct current glow discharge on the germination of cotton seed. They found that 3 minute glow discharge treatments at 30 to 150 miliamperes and 6 minute treatments at 30 to 95 miliamperes significantly improved early germination.

Magnetism

Puma (1952) prepared a magnetic field by using a solenoid. He placed broad bean (Vicia faba L.) seedlings in the magnetic field, root apexes facing North, South, East and West. He found that the roots with the apexes facing the South pole of the solenoid stopped growing. On the contrary, the apexes of the roots which were pointed towards the other three directions continued to grow without showing and differences from the control roots. Krylov's and Tarakanova's findings (1960) were different from Puma's in that corn seeds placed with the embryo roots towards the earth's South magnetic pole germinated one day earlier than seeds with the embryo roots facing the North magnetic pole. The growth of both the root and shoot was also increased by orienting the embryo root towards the South magnetic pole.

Pittman and Ormrod (1970) studied the physiological and

chemical features of magnetically treated winter wheat (Triticum aestivum L.) seeds and resultant seedlings. They found that seed treated before germination respired more slowly, released less heat energy and grew faster during the initial 16 hr than similar but untreated seed. They added oxygen and carbon dioxide to the seed environment and observed that O_2 repressed shoot growth and enhanced root growth of the treated seed but had no effect on untreated seed. Carbon dioxide suppressed the growth of shoots and roots of treated and untreated wheat seed equally. The same workers, Pittman and Ormrod (1971), investigated the growth responses of barley (Hordeum vulgare L.) seed which had been exposed to an introduced magnetic field. They reported that the treated seed produced visible sprouts 8 to 12 hr earlier than the control seed. The average length and dry matter content of the coleoptiles of the treated seeds were also greater.

Protein Content

Ries, Schweizer and Chmiel (1968) were able to increase the total crude protein of pea and bean seed per acre by field applications of simazine (2-chloro-4,6-bis(ethylamino)-S-triazine). Schweizer and Ries (1969) found that as a result of chemical applications, oat (Avena sativa L.) seed with a higher protein content yielded 21 to 42% more grain and wheat seed which contained more protein developed into larger seedlings. They were able to correlate the protein content

of the seed with subsequent growth and yield. Seedling growth was more closely associated with protein content of the seed when environmental nitrogen supply was low. Ries et al. (1970) applied simazine and terbacil (3-tert-butyl-5-chloro-6-methyl uracil) at sub-herbicidal rates as protein and growth regulators to wheat. Additional nitrogen was also applied. Increases in seed protein due to both herbicide and nitrogen applications were reflected to higher yields the next generation. They indicated that yield was directly correlated with seed protein content (mg protein/seed) but not with seed size.

Vergara, Miller and Avelino (1970), however, found that simazine application to flooded soil at the time of flowering decreased the grain yield in rice (Oryza sativa L.) which was attributed to increased sterility even though the percent protein in the grain was increased. They concluded that the decrease in grain yield consequently lowered the total grain protein production per crop.

Lopez (1972) obtained high and low protein seed of wheat and barley by field application of nitrogen. He found that high protein seed germinated faster, developed into larger seedlings and showed a higher rate of water absorbtion and oxygen consumption than did the low protein seed.

Soaking

Variable results have been reported in literature for presoaking

seeds. Even closely related species have shown different responses to the kind of solution used, its concentration, soaking time, temperature and method. While presoaking treatment increased the performance of seeds of certain species, some species have not been affected positively and adverse affects have been seen in others.

Soaking in Water. Soaking the seeds in water as a pre-planting treatment has been one of the most used methods to improve seed performance.

Kidd and West (1918b) in England soaked pea, bean, barley and sunflower (Helianthus annuus L.) seeds in distilled water at an average temperature of 17°C for periods varying from 8 to 72 hours. They planted the seeds wet on damp sand and found that the rate of germination declined when the seeds were soaked for periods exceeding 24 hr. They also soaked wheat, oat, broad bean and white mustard (Brassica hirta Moench.) seeds and planted them in soil. They observed that plants produced by the treated seeds were greater in dry weight than that of the controls. The same workers, Kidd and West (1919), studied the influence of temperature on the soaking of bean and pea seeds. Soaking was carried on at different temperatures ranging between 5 and 30°C. They found that at all temperatures, soaking the seeds in excess of water markedly decreased the number of plants produced and the amount of injury was more at both high and low temperatures than at medium temperatures.

Andrews and Beals (1919) investigated the effect of soaking in water and of aeration on the growth of corn seeds. They found that the best length of soaking was 12 hr and puncturing or removing a portion of the seed coat accelerated germination, while aerating the culture solution accelerated the growth. Kurbatov and Gluckmann (1930), after soaking the seeds of rice, wheat and peas, concluded that swelling of seeds proceeded most rapidly in pure water and it decreased in solutions with monovalent, bivalent and trivalent salts.

Chippindale (1933a) soaked seeds of orchardgrass (Dactylis glomerata L.) in water for 17 hr at 20°C and air dried them before sowing. He observed that the soaked seeds germinated earlier than the controls. This affect was atrributed to the faster absorbtion of water by the treated seeds, the paleas of which were at first impermeable. Besides orchardgrass, Chippindale studied the effect of soaking on other Graminae species. He (1934) found that when seeds were sown in soil not containing abundant moisture at an unfavorable temperature, they derived more benefit from previous soaking in water. Closely related species showed considerable differences of behavior and the acceleration produced by soaking was most pronounced in orchardgrass.

Linehan and Mercer (1936) in Ireland, however, were not able to observe any beneficial effects of presoaking the seeds of orchardgrass in water on germination. Eyster (1940) reported that not only

lack of oxygen, but bacterial activity, temperature of soaking, and loss of proteins, digestive enzymes and growth promoting substances were possible causes of decreased germination of bean seeds soaked in water.

Effects of presoaking in water on tree seeds have also been investigated by some workers. Rudolf (1952) obtained some beneficial results by soaking Jack pine (Pinus banksiana Lamb.) seeds in water prior to germination. He observed that the peak of the germination rate was reached in two days for the seed cold soaked 7 days at 40° F compared to 4 days for the untreated seed. Barton (1954) soaked several kinds of tree and shrub seeds in water for 1, 4, 7, and 14 days at two different temperatures, 5 and 20° C. She found that presoaking did not hasten the speed of germination or after-ripening. Hopkins (1960) studied germination stimulation in Pinus pinaster seed in Australia. He reported that by stratifying the seed for 7 to 9 weeks at 36° F after soaking for 8 days in water at room temperature, both the rate of germination and the total germination had been improved significantly. Drying the seed before sowing was not detrimental to the treatment effect.

Watanabe (1955), a Japanese scientist, soaked carrot seeds in water and sun dried them before planting. He stated that the effect of soaking and drying on the germination was not directly proportional to the time of soaking, but 3 to 4 hr of soaking seemed best. His

treatments had greater influence upon germination speed than on germination power. Milton (1955) reported that bluegrass could be made to sprout in 6 to 10 days by soaking the seeds in cheesecloth bags for 15 to 24 hr under water and sun drying them before planting in the soil. According to the author, soaking the seeds washes out ferulic and caffeic acids which are natural growth inhibitors.

May, Milthorpe and Milthorpe (1962) in England studied the drought resistance of various spring wheat varieties after presoaking the seeds. They found that the treatment gave best results if they subjected the grain to two or three cycles of wetting and drying. Their technique for presowing hardening was allowing the grain to take up an amount of water equivalent to about 30% of its air dry weight, leaving the grain for 24 hr at a temperature between 10 and 25°C and drying by spreading it out in a thin layer exposed to moving air. They observed that treated varieties were more resistant to drought and they yielded more grain than the controls. The beneficial results of hardening were more obvious when there was not ample water for plant use in the soil. They also observed that the degree of hardening was greater when the embryo was at a more advanced stage at the time of drying.

Evenari (1964), on the other hand, obtained negative results by soaking sorghum seeds in distilled water at room temperature until they absorbed 50% of their imbibition water and air drying them until they reached their initial weight. He found that height, fresh and dry

weights and grain yields of plants produced by the hardened seeds were significantly less than that of the plants produced by the non-hardened seeds.

Hafeez and Hudson (1967) found that plants produced from hardened seeds of radish had increased dry weight. They concluded that hardening seeds may confer a greater advantage in favorable than in adverse growing conditions. Salim and Todd (1968) studied the effects of soaking seeds as a pre-sowing and drought hardening treatment in three winter wheat and two barley varieties. Their conclusion was that no generalized statement could be made since the response was dependent on the treatment and variety used.

Orphanos and Heydecker (1968) in England investigated the soaking injury of bean seeds. They attributed the injury which was caused at a critical early stage of germination to a deficient oxygen supply to the interior of the soaked seed. The authors recommended four methods by which the ill effects of injury can be prevented. These were: removing the testa before or after soaking, completely or even partially drying the soaked seed, draining the seed after cutting off its end portion, and treatment of the seed with hydrogen peroxide before, during or after soaking. They also found that air bubbled through the soaking water could aggravate the injury.

Hull (1969) subjected sugar beet (Beta vulgaris L.) seeds to three cycles of wetting and drying. The treatment speeded up the

emergence but had no effect on the final emergence. Bleak and Keller (1969) soaked crested wheatgrass (Agropyron desertorum Fisch.) seeds to six different ages on moist blotter paper for periods ranging from 40 to 90 hr at 17.2° C, prior to greenhouse plantings in soil. They indicated that seeds planted wet after soaking emerged ahead of the controls and produced seedlings with longer roots and shoots, but drying before planting reduced the advantage. Older seeds required more time to produce seedlings; however, the advantage from the treatment was not altered by the age of the seed. The same workers, Bleak and Keller (1970), found that in field plantings, presoaked and dried seeds of crested wheatgrass had higher total emergence and revealed a better stand than controls as soil moisture decreased.

Berrie and Drennan (1971) studied the effect of hydration and dehydration on the germination of oat and tomato seeds. They observed that desiccation had little harmful effect if carried out before cell division and enlargement had commenced. According to the authors, some advancement of the onset of germination was apparent due probably to slight changes in the seed covering and also to the initiation of metabolic events which could withstand the dehydration. They concluded that the treatment could be repeated several times and the affects are only truly accumulative if the prior imbibitions are of substantial duration. Thomas and Christiansen (1971) investigated the effects of hydration and chilling treatments on germination and growth

of good and poor quality seed of cotton (Gossypium hirsutum L.). They reported that chilling adversely influenced the field plantings of both good and poor seed, hydration prevented chilling injury and also improved the performance of plantings of nonchilled poor quality seed. A combination of hydration and chilling treatment significantly increased yields of plantings from poor quality seed above the control.

Soaking in Growth Regulators. Bradford and Ewing (1958) treated cotton seed with dust formulations and solutions of gibberellic acid prior to planting. They observed significant reductions in stand but seedling height, length and width of cotyledons were significantly increased. Button (1959) soaked seeds of creeping red fescue (Festuca rubra L.) on blotters saturated with different concentrations of potassium salt of gibberellic acid. He reported that GA treatment was effective in hastening the germination up to the nineteenth day of count and the most promising concentrations of GA were in the range of 0.20 to 0.30 mg per 100 seeds in about 10 ml of water. Howell et al. (1960) treated soybean seeds with 2 and 8 gm of potassium gibberellate in one pint of water per bushel of seed. They found that stands and yields were reduced by the treatment, but maturity and oil and protein content of the seed were not affected.

Stickler and Pauli (1961) investigated the effects of GA on seedling vigor and yield of different seed sizes of winter wheat by using three seed sizes and three GA levels. They stated that in

experiments conducted in the greenhouse and in the field, GA seed treatment decreased emergence in all varieties and seed sizes. The same workers, Pauli and Stickler (1961), also studied the effects of seed treatment with GA on grain sorghum and found that laboratory germination rates were increased, particularly during the first 48 hr, but final emergence, maturity, plant height, grain yields and components of yield were not influenced in the field. Allan, Vogel and Craddock (1961) studied the effect of GA upon seedling emergence of eight slow and fast emerging wheat varieties. They soaked the seeds in 1, 10, and 100 ppm of GA solutions for 24 hr and planted them wet. The authors observed that the treatment stimulated slow emerging varieties to emerge at rates comparable to rapid emerging varieties under both greenhouse and field conditions, but rapid emerging varieties were adversely affected.

Delouche (1961) increased the germination of centipede grass (Eremochloa ophiuroides L.) seeds by presoaking them for 16 hr in a 1000 ppm aqueous solution of the potassium salt of gibberellic acid. Kahre, Kolk and Wiberg (1962) were able to shorten the germination test period of dormant cereals by planting the seeds in sand moistened with 100 ppm to 400 ppm of GA solutions. Kahre (1965) reported that the concentration of GA recommended to break dormancy and hasten the germination of freshly harvested cereal seed was 200 ppm. Popov (1962) reported the stimulating effect of treating bean seeds with

gibberellin on growth processes of the plants. Teare, Law and Wilson (1970) found that emergence of GA treated pea seedlings was 4 to 6 days earlier than nontreated seedlings under cool conditions, but at high temperatures treated seedlings emerged only one day earlier than the control. They also found that date of blooming and maturity were not enhanced and dry weight at maturity and seed yield were lowered by seed application of GA. The authors concluded that GA treatment of seed does not have any carry-over effects.

Thompson (1970) reported that both the speed of germination and final germination could be increased by treating the seeds of Primula species with a mixture of GA_4 and GA_7.

Soaking in Chemical Solutions. Tautphoeus in 1876, Kraus in 1880, Wollny in 1885 and Schleh in 1907 investigated the effect of soaking seeds in various nutrient salt solutions upon their germination and subsequent growth and yield. Their results obtained by the use of nutrient salt solutions were not much better than those obtained with pure water (Kidd and West, 1918b).

Chippindale (1933b) attempted to accelerate the germination of orchardgrass seeds by treating them with solutions of copper sulphate, mercuric compounds, magnesium chloride, lead nitrate, manganase and magnesium sulphate, sodium chloride, oxalic acid, ortho-phosphoric acid and Uspulun. Seeds were floated on the surface of the solutions for 16 hr at 22°C and air dried before planting. His

attempts with the chemical solutions were unsuccessful; however, he obtained positive results by using distilled water. Kotowsky (1926) in Poland soaked pepper, spinach and parsnip (Pastinaca sativa L.) seeds in different chemical solutions for 6 hr before planting. He found that $MgCl_2$, $NaNO_3$ and $MgSO_4$ increased the percentage of germination but the speed of germination was not affected.

Prill, Barton and Solt (1949) studied the effects of some organic acids on the growth of wheat roots and observed no stimulatory effects. Mart'yanova (1960) reported that barley seeds hardened with 110 mg/L of boric acid yielded more grain than the non-hardened ones, especially under drought conditions.

Ching (1959) reported that stimulation of Douglas fir (Pseudotsuga menziesii Mirb.) seed germination was obtained by soaking the seeds in 1% hydrogen peroxide for 36 to 48 hr at room temperature. She found that the time required to obtain 50% of the total germination potential was reduced from 8.5 days to 2 days by the treatment and treated seeds exhibited a higher respiration rate than water presoaked controls. Beet and spinach seed germination was also hastened by H_2O_2 treatments (Ching, 1961).

Mikkelsen and Sinah (1961) reported that soaking rice seed in 5% K_2HPO_4 and NaH_2PO_4 and .05% solutions of chlorine water and sodium hypochlorite did not alter the germination percentage. According to the authors, treatment of seed with sodium hypochlorite

solution, chlorine water or certain salt solutions appears to destroy or reduce the effectiveness of the inhibitor, increase the rate and uniformity of germination and stimulate seedling development. On the other hand, Frank and Larson (1970) found that by treating the seeds of green needlegrass (Stipa viridula Trin.) with 3.20% sodium hypochlorite for 5 hr, germination could be increased over untreated seed by 45%, suggesting a partial degredation of the lemma and palea by the chemical.

Ross and Kosar (1939) found that among the sulphur compounds tested to stimulate the germination of dormant lettuce seed, thiourea was the most effective. Mayer (1956) indicated that thiourea was an enzyme activator. Barton (1961) investigated the effects of antibiotics, thiourea and potassium 1-naphthalene acetate on the germination of some vegetable, grass and flower seeds. She found that the treatments failed to increase the speed or percentage of germination, but dormancy of freshly harvested lettuce seed was broken by soaking the seeds for 16 hr in 0.5 or 1.0% thiourea solutions. Harper (1970) obtained highest germination of dormant antelope bitterbrush (Purshia tridentata (Pursh) DC.) seeds by soaking them in 0.2% thiourea solution for 128 minutes.

Korneev (1962), a Russian worker, reported that presowing treatment of corn seeds with succinic and nicotinic acids and ten days of cooling of germinated seeds influenced the enzyme activity, the

photosynthetic intensity and yield or corn. Improved edibility, higher specific gravity of the cobs, and increased protein and decreased cellulose content were also noted.

Ells (1963) soaked tomato seeds on germination paper with K_3PO_4, KNO_3, NaCl and distilled water and he obtained faster emergence. According to Ells, the primary effect of the seed treatment is not due to the salts used in the solution nor to the amount of water retained by the seed by the treatment. Rather, it is due to certain enzymatic activities which take place within the seed while it is being held in a moist condition, and the major function of the salt in the solution appears to be that of maintaining an osmotic pressure sufficient to prevent the seed from germinating while permitting enough moisture to enter the seed to promote enzymatic activities. Oyer and Koehler (1966) modified Ells' method of seed treatment to hasten the germination of tomato seed. They incubated large quantities of seed in an aerated solution of KNO_3 and K_3PO_4 at equal concentrations of each salt ranging from 1 to 2% for 6 to 10 days at 24° C. After soaking, seeds were rinsed, dried and planted. They found that treated seeds germinated earlier and at a more rapid rate at lower temperatures (17 and 12° C) than they did at a moderate temperature (21° C). The response to the treatment was increased with temperature and time of incubation.

Haight (1972) soaked orchardgrass and bluegrass seeds in

distilled water, 200 ppm of GA_3 and 20,000 ppm of NaCl solutions on top of blotters and dried them prior to planting. He found that for all the treatments the best temperature for soaking the seeds was 5°C and the best length of soaking in water and GA_3 was 72 hr for orchardgrass and 96 hr for bluegrass, but 144 hr gave the best results for soaking the seeds of both orchardgrass and bluegrass in NaCl. He reported that both seed germination and seedling emergence were improved by the treatments, but that seedling growth rate was unchanged. Greater benefits were obtained when germination was conducted at a sub-optimal temperature. He noted that soaking and drying treatments also increased the imbibition and respiration rates of the seed and they were most effective on cultivars exhibiting higher levels of dormancy.

Factors Affecting Germination of Bluegrass

The effects of temperature, preconditioning, light, moistening agents, maturity at harvest, rate of drying, amount of after-ripening and storage conditions on bluegrass germination have been studied by many researchers. The effect of light, temperature and moistening agents have been investigated more extensively than others.

Temperature

Toole (1923) reported that the first requirement for the

germination of bluegrass species was the alternation of temperature. Nelson (1927) also found that the effect of alternating temperature was of great importance and not replacable by KNO_3 and light. Nakamura (1962) states that Kentucky bluegrass seed has a deep dormancy and germinates poorly at constant temperatures, even after a long period of dry storage. According to the author, the most effective treatment for overcoming this dormancy is the daily alternation of temperature.

Many other researchers have studied the temperatures required for germination, with varying results. Several workers (Crosier, 1941; Hite, 1919; Toole, 1923) have indicated that alternating temperatures of 20 and 30°C (20°C night and 30°C day) gave best results, while others (Andersen, 1941, 1947; Bass, 1955a; Sprague, 1940; Crosier, 1941) thought that alternating temperatures of 15 and 30°C were as good as or better than 20-30°C. Cuddy (1962) found that 15-25°C was the best alternating temperature. Sprague (1940) reported that 10-30°C gave satisfactory results.

Light

A number of investigators (Andersen, 1941, 1947; Fryer, 1922; Waldron, 1921) consider light to be essential for best germination of bluegrass, while others (Brown, 1920; Goss, 1923; Nelson, 1927; Toole 1923) consider light to be non-essential.

The reason for some of the differences in response to light

obtained by these workers is explained by Hite (1923) who found the response of bluegrass seed to light to be closely related to after-ripening of the seed. Well after-ripened seed showed little response to light, while non-afterripened seed gave a higher germination with light. The same worker (Hite, 1919) found that a complete viability test of Kentucky bluegrass seed could be obtained in the dark with a 20-30° C alternation, but under constant temperature, light gave higher germination. Cieslar and Liebenberg considered that the only effect of light was its heating action, while Laschke concluded that light could not be replaced by high temperature (Bass, 1954).

Andersen (1947) found that, like Kentucky bluegrass seeds, Canada bluegrass (Poa compressa L.) seeds were also light sensitive and fluorescent light was more effective in promoting germination than daylight. Bass (1950) found that when light was filtered and used at a uniform 10 foot candles, some wavelengths were more effective than others in promoting germination of Kentucky bluegrass seed. He stated that the effectiveness of a given filter depended upon the maturity of the seed at harvest and/or the length of time after harvest before making the germination test. Immature non-afterripened seed germinated best with orange or green light and poorest with blue or red light. After-ripened and fully mature seed germinated almost equally well under all filters used. The same worker (Bass, 1951) found that no single light intensity gave the highest germination for all

samples of bluegrass seed tested. He also found that light may substitute at least in part for KNO_3, also that KNO_3 may substitute for light. He concluded that light sensitivity decreased with increased time after harvest and that completely after-ripened seed germinated almost as well in darkness as in light. His results agree with the results of Hite.

Delouche (1958) found that light was the most effective factor in bluegrass germination, KNO_3 was the next and prechilling was the least effective. Four weeks after harvest, both KNO_3 and light were necessary to bring about complete germination, while eight weeks after harvest either light or KNO_3 alone was sufficient to promote complete germination.

Moistening Agent

Another important factor in bluegrass germination is the moistening agent. Toole (1923) found 0.2% KNO_3 necessary for the germination of Canada bluegrass, but not for Kentucky bluegrass. However, Bass (1951) obtained highest germination of Kentucky bluegrass with 0.2% KNO_3. Bass (1953), compared 0.1% and 0.2% concentrations of KNO_3 as moistening agents for Kentucky bluegrass germination tests. He found that neither 0.1% nor 0.2% KNO_3 consistently gave higher results than the other.

Andersen (1941) obtained satisfactory germination of freshly

harvested Kentucky bluegrass seed with either 0.1% KNO_3 or water at 15-30°C and 15-25°C alternating temperatures when light was supplied during the high temperature period. Later, Justice and Andersen (1946) obtained similar results from after-ripened Kentucky bluegrass seed. Andersen (1947) also obtained highest germination from Canada bluegrass seed with 0.1% KNO_3 and light at 10-30°C or 15-30°C alternating temperatures.

Crosier and Cullinan (1941), on the other hand, found KNO_3 to be of little value in germinating the average sample of Kentucky bluegrass seed.

Some workers have investigated the effects of moistening agents when soil was used as a germination substratum instead of blotters. Nelson (1927) reported that salts, e.g., potassium nitrate, sodium nitrate, ammonium nitrate and calcium nitrate proved to be stimulating to the germination of Poa spp. in solution culture, while salts of lead were depressant, but in the soil all the salts proved to be depressant. Stewart (1938) found that as the seed of Canada bluegrass increased in age, the stimulatory effect of KNO_3 became less pronounced and when used with sand, the effect of KNO_3 seemed to dissipate. Stewart (1938) indicated that concentrations of KNO_3 greater than 0.2% accelerated mold and fungi growth. Andersen (1935) found that nitrate solution did not alter the percentage of germination of Canada bluegrass seed in soil, but it raised germination considerably

with filter paper. Later, Andersen (1955) reported that Merion Kentucky bluegrass seed gave higher germination on soil and sand mixture than on blotters moistened with 0.2% KNO_3.

Andersen (1938, 1947) found other methods of germinating Canada bluegrass seed which gave equal results to that obtained by moistening the substratum with KNO_3. These included removing the glume from the caryopsis, sowing the seeds on substratum moistened with H_2O and exposing them to CO_2 for 10 days, and daily moistening and drying of the seed for 2 or 3 weeks on top of blotters prior to testing for germination.

Effects of other moistening agents on bluegrass germination have also been investigated. Andersen (1931) found that nitric acid concentrations in the range of N/520 to N/1040 gave germination percentages of Canada bluegrass equal to N/50 KNO_3. The same worker (Andersen, 1957) found that 100 mg/L of gibberellin concentration was best for the germination of Merion Kentucky bluegrass and a combination of 100 mg/L of gibberellin and 1 g/L KNO_3 gave 1 or 2 percent higher germination than gibberellin alone.

Andersen (1960) attempted to eliminate the fungi on germination tests of Merion Kentucky bluegrass seed by planting the seeds with KNO_3 on blotters moistened with antibiotic solutions including gibberellin. Antibiotic solutions of 0.1% KNO_3 gave good average percentages of germination and low percentages of seedlings without

roots or with very short roots. Highest germination and best fungi control were obtained with 0.1% KNO_3 plus 25 ppm oligomycin.

Nakamura (1962) reported that among 0.2% KNO_3, 0.2% thiourea, 100 ppm gibberellin and concentrated sulphuric acid solutions, only KNO_3 and gibberellin were helpful but not entirely effective in promoting the germination of Kentucky bluegrass seed.

Maguire and Steen (1971) found that KNO_3 increased the germination of Kentucky bluegrass seed lots with considerable dormancy, but had no effect on less dormant lots. They concluded that KNO_3 does not overcome dormancy per se but may act in conjunction with dormancy breaking treatments such as light and alternating temperatures to increase germination rates.

Prechilling

Bass (1954, 1955a) considered prechilling especially beneficial for freshly harvested Kentucky bluegrass seed and found that a 5-day prechill at 10°C prior to germination at 15-30°C alternating temperature gave the highest germination of Merion Kentucky bluegrass. Andersen (1955) also found the same results for Merion Kentucky bluegrass.

Bass (1955b) compared 21- and 28-day germination percentages with and without prechilling. He reported that the average increase between the 21- and 28-day counts without chilling was 1.08%

compared to 1.21% with chilling.

Maturity

Hite (1923) found that maturity at harvest did not affect viability, but after-ripening on the plant was more rapid than after-ripening during storage. Berry in 1944 also found that bluegrass seed could be harvested when relatively immature and still germinate well if sufficient time was allowed for maturation. He stated that time between harvest and maximum germination varied with maturity, the more mature the seed, the shorter the period (Bass, 1954).

Bass (1954) reported that Kentucky bluegrass seed harvested while still immature was dormant and very sensitive to light, temperature and moistening agent when planted immediately after harvest, but as after-ripening progressed it lost its dormancy and sensitivity to these factors. Seed which was mature when harvested was less sensitive to germination conditions. This author obtained maximum germination 4 weeks after harvest with the immature seed and 1 week after harvest with the mature seed. Delouche (1958) found that the initial degree of dormancy in Kentucky bluegrass was influenced by the stage of maturity. The time interval after harvest was more important than the stage of maturity at harvest. However, when the seeds were hulled, maximum germination was obtained regardless of the stage of maturity at harvest. He also indicated that the greater the

moisture content at harvest, the greater the degree of dormancy.

Storage

Hite (1923) found that the first few weeks of storage at 40°C increased the germination rate of bluegrass seed, however final germination was not affected by the treatment. Steward (1938) also reported that subjecting the seeds of Canada bluegrass to a drying temperature of 40°C for 24 hrs did not markedly affect their ultimate germination.

MATERIALS AND METHODS

Seed Lots

Kentucky bluegrass seed lots chosen for experimentation were obtained from commercial seed companies. Cultivars and years of production were as follows:

Cultivars	Year harvested
MERION	1971
FYLKING	1971
PENNSTAR	1971
WINDSOR	1971
BARON	1971
NEWPORT	1971
PARK	1971
COUGAR	1971
DELTA	1968
9 GK 36 CODE 95	1969
NEWPORT	1970
PARK	1970
0 GK 33 CODE 95	1970

The seed lots were obtained in the fall of 1971 and stored at 5° C until needed for experiments.

Analytical Procedures

The general procedures followed in all the germination tests were as follows unless otherwise specified: Fifty seeds were planted for each treatment on top of blue germination blotters in 12 x 12 x 3 cm clear plastic boxes. The blotters were soaked with tap water. Each treatment was replicated three times. The three replications were

placed in a randomized complete block design within the germinators, with one box of each treatment appearing on each of the three shelves. When 15-25°C alternating temperature was used, low temperature was provided for 15 hr and high temperature for 9 hr. Temperatures within the germinators were maintained within ±0.5°C of the desired temperature. The experiments were made in complete darkness.

Germination percentages were determined by counting and removing the germinated seedlings daily. A seed was considered germinated when the radicle was 2 mm long. Tests were usually terminated on the 15th day after planting.

Speed of germination indexes were calculated to provide a measure of the overall speed of germination. The G.I. was calculated by summing the quotients of the daily germination counts divided by the number of days elapsed, for example:

$$\frac{0}{3} + \frac{5}{4} + \frac{10}{5} + \ldots + \frac{1}{15} = \text{G.I.}$$

The index was based on a 15-day germination period.

Seed moisture content was calculated on a dry weight basis as follows:

$$\% \text{ Moisture} = \frac{\text{Wet wt. - Dry wt.}}{\text{Dry wt.}} \times 100$$

Soaking and Drying Procedures

Soaking was carried out in 250 ml beakers containing 200 ml of water or chemical solution. Cheesecloth bags containing 1 gm seed and secured with a rubber band were suspended in the beakers.

Aeration, when desired, was provided by bubbling air through the solution with an "Oscar" aquarium air pump.

The pump and beaker assemblies were placed in germinators to maintain the proper temperatures.

After soaking was completed, the seeds were removed from the cheesecloth bags and spread in a thin layer on top of paper towels to air-dry on a laboratory bench at room temperature (approximately 22°C) for 24 hr.

Germination and Emergence Characteristics of the Seed Lots

When the seeds were obtained from the companies, a preliminary experiment was conducted in the greenhouse (approximately 15°C during night and 25°C during day) to observe the emergence and stand of each cultivar under simulated turf conditions. Seeds of the 13 cultivars were planted in 35 x 50 x 10 cm metal flats. In compliance with the recommended seeding rate for lawns, 2 gm seed of each cultivar were broadcast and covered with soil approximately 5 mm thick (USDA, 1968). Three flats were planted for each cultivar.

A factorial analysis of the germination characteristics of the 13 cultivars was made to observe their responses to light, moistening agent and germination temperature under laboratory conditions.

Three replications of 25 seeds of each cultivar were planted for each treatment. Treatments consisted of all combinations of prechill, light and dark, 15-25 and 25°C germination temperatures and 0.2% KNO_3 and water as moistening agents.

For prechilling, the boxes with seeds were placed at 5°C for 7 days before germinating at either 15-25 or 25°C. Light in the germinators was provided by fluorescent lights 9 hr per day. In the alternating temperature germinator, lights were on during the warm part of the temperature cycle. Darkness was provided by wrapping the boxes in aluminum foil. The KNO_3 concentration was 0.2%. Germination percentages were determined after 28 days (AOSA, 1970).

Establishment of Presoaking and Drying Procedures

Length of Presoaking

Seeds of Windsor and Fylking were soaked and aerated in tap water and 0.2% KNO_3 solution for 12, 48, 96, 144, 192 and 240 hr at 5°C to determine the optimum length of the presoaking period. One bag of each cultivar was taken out of the beakers at the end of each length of soaking and dried. Treated seeds and untreated controls

were germinated at 15-25°C. Percent and speed of germination were determined.

Another experiment was conducted to determine the optimum length of soaking more precisely. In this experiment, eight cultivars (Baron, Windsor, Fylking, Cougar, Merion, Park, Newport and Pennstar) of the 1971 crop were soaked in 0.2% KNO_3. One bag of each cultivar was removed after 120, 144, and 168 hr. After the seeds were dried, they and the untreated controls were germinated at 15-25°C. Percent and speed of germination were determined.

Length of Drying Period Required

The drying time required for soaked seeds to return to their original moisture content was determined. Seeds of the eight 1971 seed lots were soaked 6 days in water at 5°C. The moisture contents, dry weight basis, were determined immediately after soaking and after 16 and 24 hr of drying.

Temperature and Method of Presoaking

After the optimum length of soaking was established, five cultivars (1971 crop Windsor, Cougar, Fylking, Merion and Newport) were used to compare the effects of soaking on top of blotters with soaking while submerged in solutions. The effects of aeration were also studied. The soaks were performed at 5 and 20°C as follows:

1-144 hr at 5°C on top of blotters moistened with 0.2% KNO_3 solution.

2-144 hr at 5°C in bags suspended in 0.2% KNO_3 solution.

3-144 hr at 5°C in bags suspended in aerated 0.2% KNO_3 solution.

4-144 hr at 20°C on top of blotters moistened with 0.2% KNO_3 solution.

5-144 hr at 20°C in bags suspended in 0.2% KNO_3 solution.

6-144 hr at 20°C in bags suspended in aerated 0.2% KNO_3 solution.

After soaking, seeds were dried and germinated at 15-25 and 25°C. Percent and speed of germination were determined.

Soaking in Chemical Solutions

Seeds of eight cultivars of 1971 crop were soaked at 5°C in nine aerated chemical solutions. The solutions used and their concentrations were as follows:

Chemical Solution	Concentration
1-Tap water	
2-Potassium nitrate	0.2%
3-Gibberellic acid[1/]	200 ppm
4-Benzyl adenine[2/]	2.3 ppm
5-Thiourea	0.1%
6-Succinic acid	15 ppm
7-Hydrogen peroxide	0.1%
8-Sodium hypochlorite	3.2%
9-Nutrient solution[3/]	complete (FeEDTA) (Machlis and Torrey, 1956).

[1/] 10% K salt of gibberellic acid purchased from Nutritional Biochemicals Corp.

[2/] N-6-Benzyl adenine purchased from Nutritional Biochemicals Corp.

[3/] Hoagland's solution.

The length of soaking was 24 hr for benzyl adenine and H_2O_2, 5 hr for NaOCl and 144 hr for the other six solutions. Seeds were rinsed with running tap water for 4 minutes after being soaked in NaOCl. After the seeds were dried, they were planted with unsoaked controls and germinated at 15-25 and 25°C. The results were evaluated by determining the percent and speed of germination for each treatment.

Soaking at Alternating Temperatures

Seeds of 1971 crop Merion, Cougar Windsor, Fylking and Newport were soaked in aerated solutions of KNO_3, GA_3 and water for 144 hr at 5 and 5-25°C. Soaking in alternating temperatures was conducted by leaving the beakers for 12 hr at each temperature. After 6 days, seeds were dried and germinated at 15-25 and 25°C. Daily germination percentages were determined.

Cycles of Soaking and Drying

Seeds of Merion and Cougar were subjected to one to six cycles of soaking and drying treatments. Seed bags were placed in aerated water, KNO_3 and GA_3 solutions at 5°C. At the end of 24 hr, the bags were taken out and the seeds were air dried for 24 hr. This 24 hr of soaking and 24 hr of drying was called one cycle. The procedure was repeated for succeeding cycles. At the end of each cycle, seeds of

each treatment were germinated at 15-25 and 25°C. Percent and speed of germination were determined.

Effects of Presoaking on Seed Performance Besides Percent and Speed of Germination

Temperature Range Over Which Seeds Germinate

Seeds of Fylking and Windsor soaked for 6 days at 5°C in aerated KNO_3 and water were planted on a thermal gradient plate with untreated controls to observe their differential responses to germination temperatures. The plate was set at 5°C on the cold end and 40°C on the warm end. The temperature on half of the plate was alternated daily, providing an infinite number of temperatures between 5-40 and 40-5°C. The temperatures on the other half of the plate were held constant. Two rows of seeds were planted along the length of the plate for each treatment on both halves of the plate. Treatments were replicated three times. Data were obtained on the maximum and minimun constant temperatures at which treated and untreated seeds germinated. Determinations were also made of the wideness of temperature alternations necessary for germination to occur.

Germination Under Moisture Stress Conditions

The effect of presoaking and drying on the ability to germinate under moisture stress was determined by germinating the seeds in

solutions with different osmotic pressures.

Seeds of Merion and Cougar soaked in aerated KNO_3 and water for 6 days at 5° C were selected for these tests. They were planted on top of blue germination blotters moistened with three different concentrations of polyethylene glycol[4/] solutions and germinated at 15-25° C. The three concentrations of polyethylene glycol were prepared by dissolving 1, 10 and 20 gm of the substance in 100 ml of distilled water. The following table shows the relationship between concentration and osmotic pressure of the solutions of polyethylene glycol-1000 (Jackson, 1962):

Concentration gm/100 ml solution	Osmotic pressure in atmospheres
1	0.6
10	4.2
20	14.1

Percent and speed of germination were determined by making daily counts until the 15th day of germination.

Seedling Emergence Rate From Soil

Soil emergence trials were conducted in the greenhouse to compare the speed of emergence and total stand of treated versus untreated seeds. Seeds of 1971 crop Park, Newport, Merion and

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[4/] Polyethylene glycol-1000, manufactured by J. T. Baker Chemical Co.

Pennstar soaked in aerated water, KNO_3, GA_3 for 6 days at 5°C were planted with unsoaked controls in 35 x 50 x 10 cm metal flats. For each observation 100 seeds were planted 5 mm deep in a row. The rows were 7 cm apart and there were four rows per flat. There were four observations per treatment and the flats were arranged in a completely random design. Greenhouse temperatures were approximately 25°C at night and ranged as high as 35°C during the day. Emergence counts were made each day from the 10th through the 20th day after planting to determine the percent and speed of emergence. The data were analyzed as a factorial arrangement of treatments.

Storability of Presoaked Seeds

The effect of presoaking and drying upon the storability of the seed was determined by germination tests 4 months after the treatment. Seeds of 1971 crop Merion, Windsor, Cougar and Pennstar were soaked in aerated water, KNO_3 and GA_3 for 6 days at 5°C, dried and stored for 4 months. These seeds were planted at the same time as seeds receiving the same treatments without storage. Untreated controls were also planted. Seeds were germinated at 15-25 and 25°C and percent and speed of germination were determined.

Seeds of Merion, Cougar and Windsor in a second experiment, were soaked in aerated water and KNO_3 for 6 days at 5°C, dried, and stored for 4 months at room temperature. These seeds were

germinated with unsoaked controls at 20, 25, and 15-25°C and percent and speed of germination were determined.

Effects of Other Stimulation Procedures on Seed Performance

Storage at Room Temperature

Effects of storage of untreated seeds at room temperature on seed performance was determined by making three germination tests: (1) immediately after the seeds were obtained, (2) after 4 months of storage in paper bags and (3) after 7 months of storage in paper bags. Seeds of the 13 cultivars and lots were germinated at 15-25 and 25°C and percent and speed of germination were determined.

Accelerated Aging

Two accelerated aging experiments were conducted to attempt to hasten the after-ripening of seeds by subjecting them to dry heat and humid heat during storage. Seeds of Merion, Windsor and Cougar were used for both experiments.

Dry Heat Treatment. Approximately 2 gm seed of each cultivar were put in uncovered weighing bottles and placed in an oven at 40 ± 3°C for 30 days. Samples were taken at 5-day intervals. The percent and speed of germination of each sample at 15-25°C were compared with that of unheated seeds.

Humid Heat Treatment. Seeds were put in porous wire baskets and suspended into sealed humidity chambers containing distilled water and a saturated salt solution. The controlled humidity chambers were stored at two different temperatures, 25 and 40°C, for 30 days. The four combinations of storage conditions were as follows:

1- 75% Relative Humidity - Stored at 25°C.
2- 75% Relative Humidity - Stored at 40°C.
3-100% Relative Humidity - Stored at 25°C.
4-100% Relative Humidity - Stored at 40°C.

Distilled water was used to obtain 100% RH and salt (NaCl) solution to obtain 75% RH.

Samples were taken out at 5-day intervals and germinated at 15-25°C with untreated controls. Percent and speed of germination were determined for each treatment.

Statistical Analysis

Experimental design and computations were based on Steel and Torrie (1960). The least significant difference (LSD) at 5% and 1% levels of significance was used to test differences between treatment means. A Control Data Corporation 3300 computer was utilized in making the analyses.

RESULTS

Germination and Emergence Characteristics of the Seed Lots

When Kentucky bluegrass cultivars and lots were broadcast-planted in greenhouse flats to simulate turf-seeding methods, differences in rates of emergence were obvious. Among the new crop seed lots, Park was the first to emerge. Windsor, Newport, Cougar and Baron were next, followed by Pennstar and Fylking. Merion was last to emerge and did not produce as thick a stand as the other cultivars.

The seed lots represented in the older seed group emerged at the same rate except for Newport which was somewhat slower. However, old seeds were faster in emergence compared to the new seeds.

The germination characteristics of the cultivars and lots under laboratory conditions are shown in Table 1.

All the lots except Delta showed a requirement for alternating temperatures to achieve a high percentage of germination. Among the 1971 lots, Merion, Fylking, Pennstar and Windsor were mose specific in this requirement, while a relatively high percentage of Cougar and Newport were able to germinate at constant 25°C. The 1970 lots of Newport and Park germinated only slightly better at 25°C than the 1971 lots.

Responses to prechilling, light and KNO_3 were also evident, but were less than the response to alternating temperature. These effects

Table 1. Germination characteristics of 13 Kentucky bluegrass cultivars and lots under laboratory conditions. Final germination percentages recorded 28 days after planting.

Cultivar	Year of Production	Light				Dark			
		15-25°		25°		15-25°		25°	
		KNO_3	H_2O	KNO_3	H_2O	KNO_3	H_2O	KNO_3	H_2O
Chilled									
Merion	1971	87	83	23	12	82	80	28	10
Fylking	1971	100	91	71	16	85	88	31	6
Windsor	1971	92	96	85	64	97	97	61	33
Pennstar	1971	83	84	56	30	82	82	57	35
Baron	1971	90	95	90	83	86	93	80	61
Park	1971	83	76	80	73	81	84	85	77
Cougar	1971	100	93	90	91	89	95	89	86
Newport	1971	94	89	84	69	86	88	87	83
Newport	1970	80	95	76	76	83	87	36	17
0 GK 33	1970	93	91	93	81	89	91	81	44
Park	1970	90	89	94	80	94	91	76	49
9 GK 36	1969	87	92	87	88	87	94	55	25
Delta	1968	89	87	87	88	80	87	85	79
Average		90	89	82	65	86	89	65	47
Not chilled									
Merion	1971	85	92	1	1	70	75	0	0
Fylking	1971	91	83	5	0	92	86	0	0
Windsor	1971	95	96	5	0	94	98	0	0
Pennstar	1971	80	88	34	2	88	87	2	0
Baron	1971	87	94	44	11	89	91	5	12
Park	1971	86	80	28	31	77	77	14	17
Cougar	1971	97	94	80	70	96	85	20	33
Newport	1971	86	90	52	36	88	86	26	51
Newport	1970	94	90	37	10	94	90	44	9
0 GK 33	1970	92	95	87	45	91	92	43	16
Park	1970	95	95	87	61	94	93	38	17
9 GK 36	1969	92	97	84	76	88	93	58	23
Delta	1968	91	94	90	83	96	94	91	70
Average		90	91	49	33	89	88	26	19

are summarized in Table 2. The beneficial effects of prechilling, light and KNO_3 were most obvious at the constant temperature, but these factors did not replace the need for alternating temperatures.

Table 2. Average germination responses of 13 Kentucky bluegrass cultivars to the main effects of prechilling, light, temperature and moistening agent.

Treatment	Germination %	Difference %
Chilled	61	12
Not chilled	49	
Light	59	8
Dark	51	
15-25° C	71	32
25° C	39	
KNO_3	58	6
H_2O	52	

Establishment of Presoaking and Drying Procedures

Length of Presoaking

The effects of length of presoaking on germination of Fylking and Windsor are shown in Table 3. The analyses of variance of these data are shown in Appendix Tables 1 and 2.

The greatest stimulation to speed of germination occurred with 144 hours (6 days) of presoaking, as shown by the large germination indexes. Greater stimulation was obtained when KNO_3 was used as the presoaking medium.

Table 3. Effect of length of presoak on percent and speed of germination of Windsor and Fylking Kentucky bluegrass cultivars presoaked in KNO_3 and water. Seed germinated at 15-25° C for 15 days.

Cultivar	Treatment	Length of Presoak (hr) 0 GI[1/]	0 %	12 GI	12 %	48 GI	48 %	96 GI	96 %	144 GI	144 %	196 GI	196 %	240 GI	240 %
Fylking	H_2O	8.2	76	9.0	90	9.7	92	9.8	88	10.1	93	7.9	83	8.8	87
	KNO_3	8.2	76	10.3	91	8.5	77	11.0	87	13.1	94	9.6	82	9.3	84
Windsor	H_2O	10.0	86	11.4	89	13.2	98	13.4	97	13.5	95	12.3	92	13.2	99
	KNO_3	10.0	86	11.9	94	12.5	97	12.2	93	15.1	93	10.8	95	14.2	91

[1/] Speed of germination index, LSD .05 = 1.80, LSD .01 = 2.40.

Additional tests were conducted with eight cultivars at soaking periods of 5, 6 and 7 days in KNO_3. The cultivars responded differently to the soaking treatments as seen in Figures 1 to 8. Presoaked seeds of four cultivars started to germinate 1 day earlier than the controls, while Baron germinated two days earlier. Pennstar, Park and Newport began to germinate on the same day as the controls. The peak of germination was reached 3 days earlier in Fylking, 2 days earlier in Pennstar and Windsor and 1 day earlier in Merion and Cougar.

In five of the eight cultivars, the greatest increase in germination speed occurred with 6 days of soaking (Table 4). Merion had the highest speed of germination index with 5 days of presoaking, but the peak of germination was reached 3 days earlier with 6 days of presoaking. Baron and Cougar responded best to 7 days of presoaking.

Length of Drying Period Required

After the soaking periods were completed, the seeds were spread out in thin layers to dry. The rates of moisture loss in one experiment are shown in Table 5. Drying for 24 hours was sufficient for the seeds to lose the water imbibed in the soaking treatments.

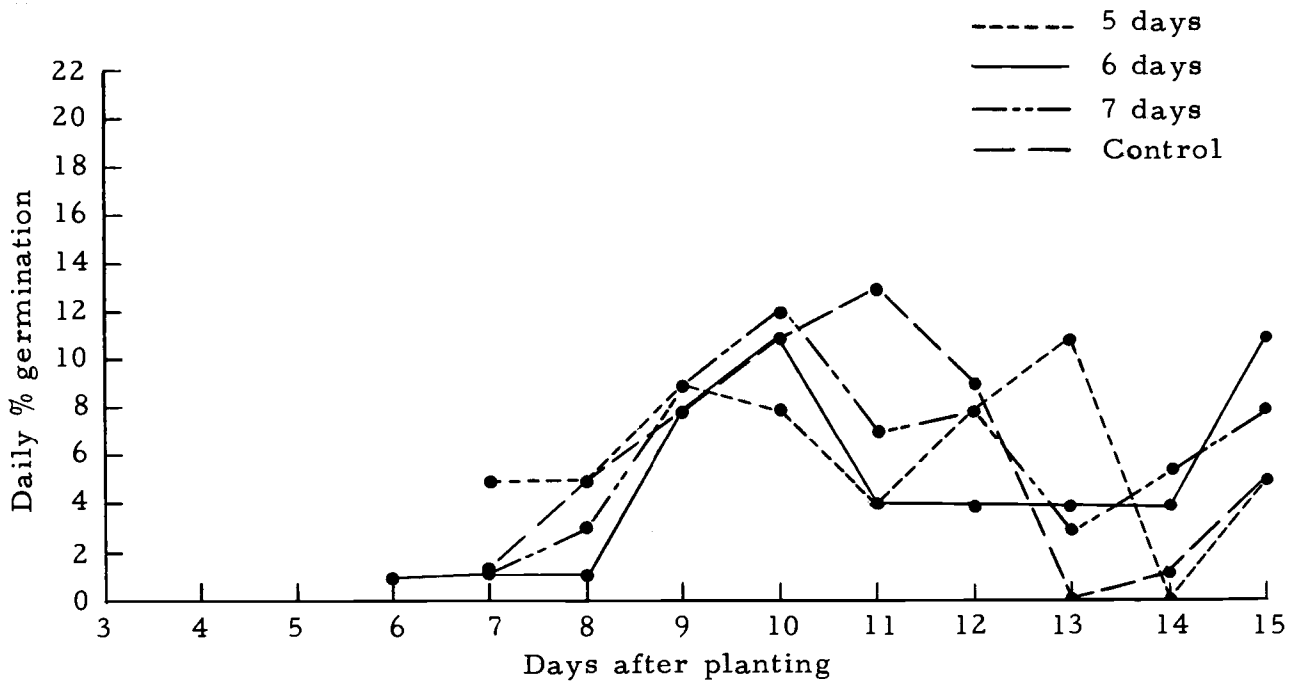

Figure 1. Daily germination percentages of Merion Kentucky bluegrass seed presoaked in KNO_3 for 5, 6 and 7 days. Seed germinated at 15-25° C.

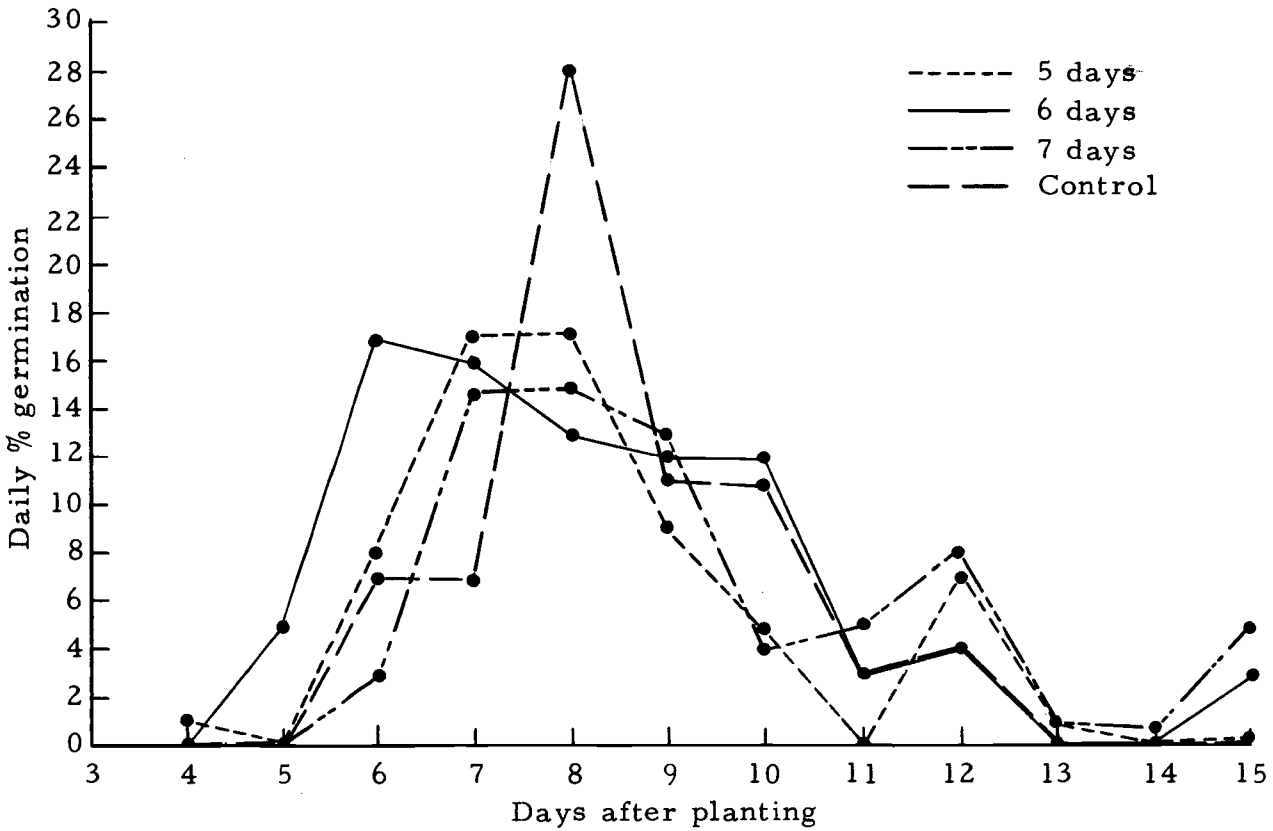

Figure 2. Daily germination percentages of Pennstar Kentucky bluegrass seed presoaked in KNO_3 for 5, 6 and 7 days. Seed germinated at 15-25°C.

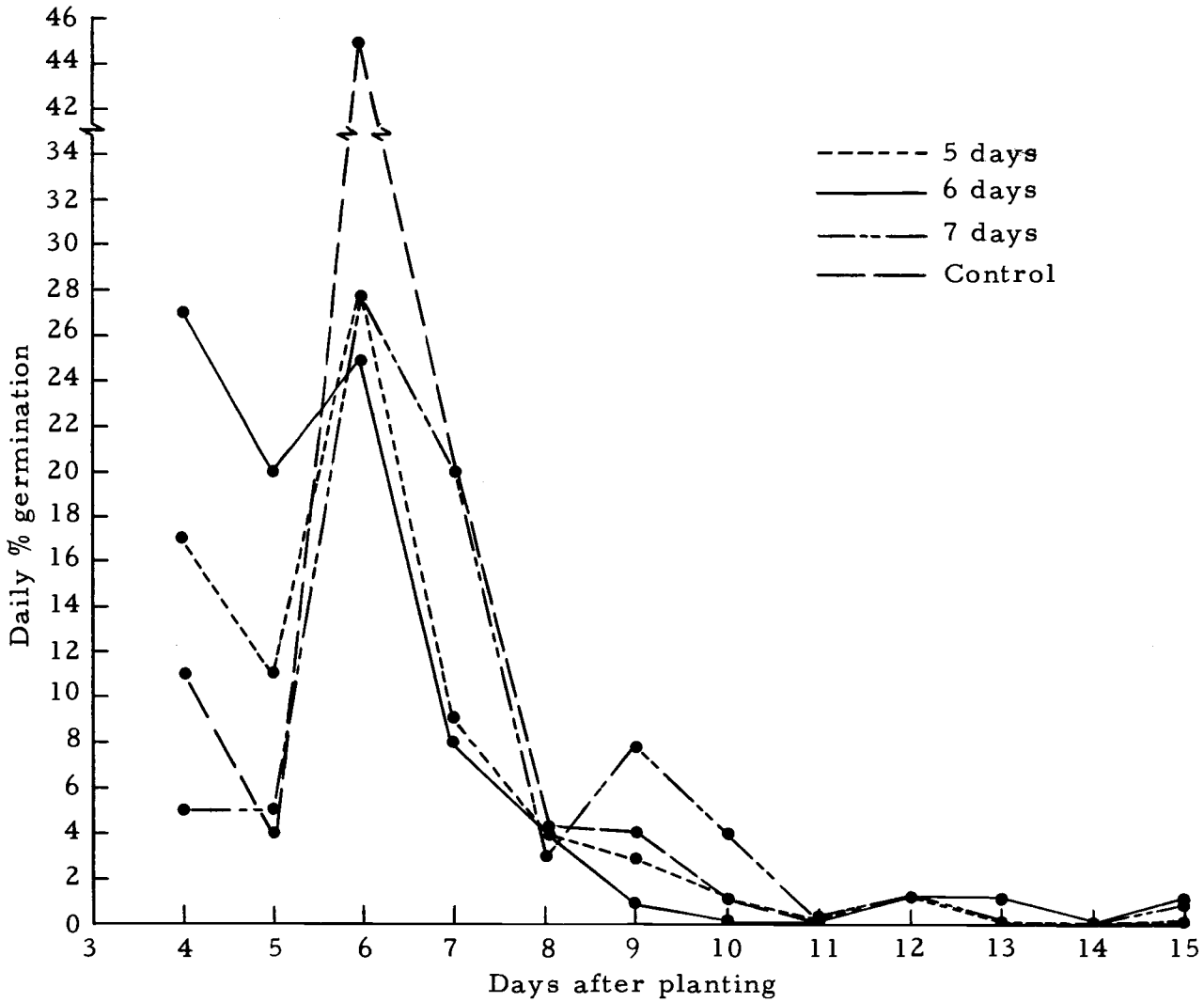

Figure 3. Daily germination percentages of 1971 Park Kentucky bluegrass seed presoaked in KNO_3 for 5, 6 and 7 days. Seed germinated at 15-25°C.

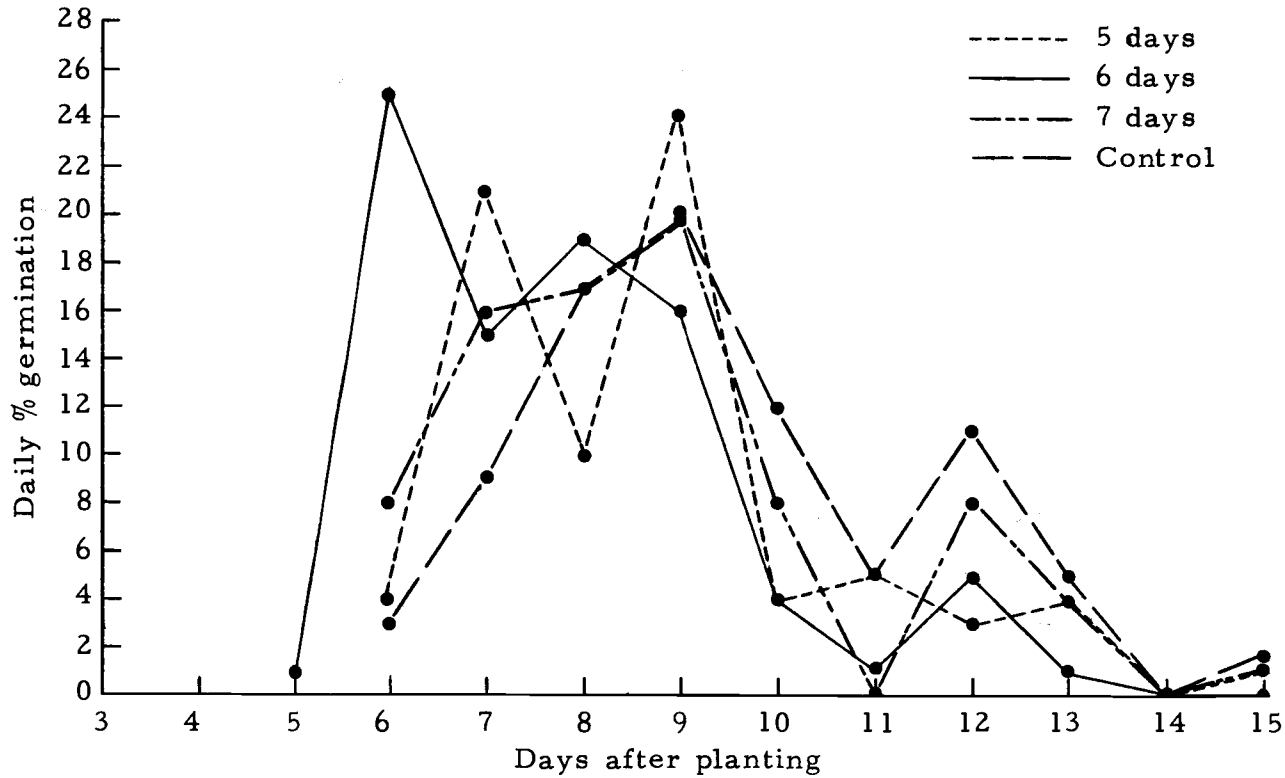

Figure 4. Daily germination percentages of Fylking Kentucky bluegrass seed presoaked in KNO_3 for 5, 6 and 7 days. Seed germinated at 15-25°C.

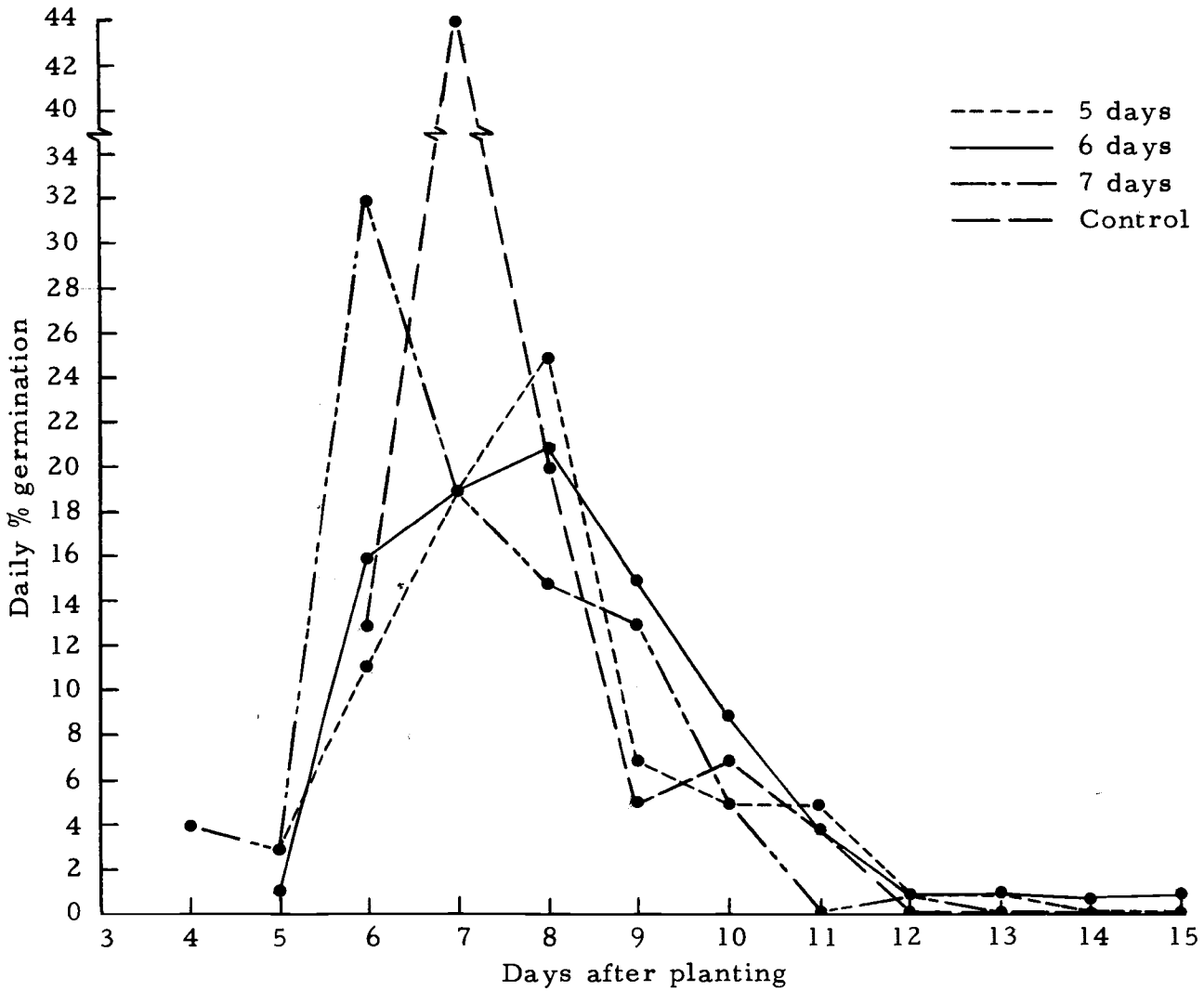

Figure 5. Daily germination percentages of Baron Kentucky bluegrass seed presoaked in KNO_3 for 5, 6 and 7 days. Seed germinated at 15-25°C.

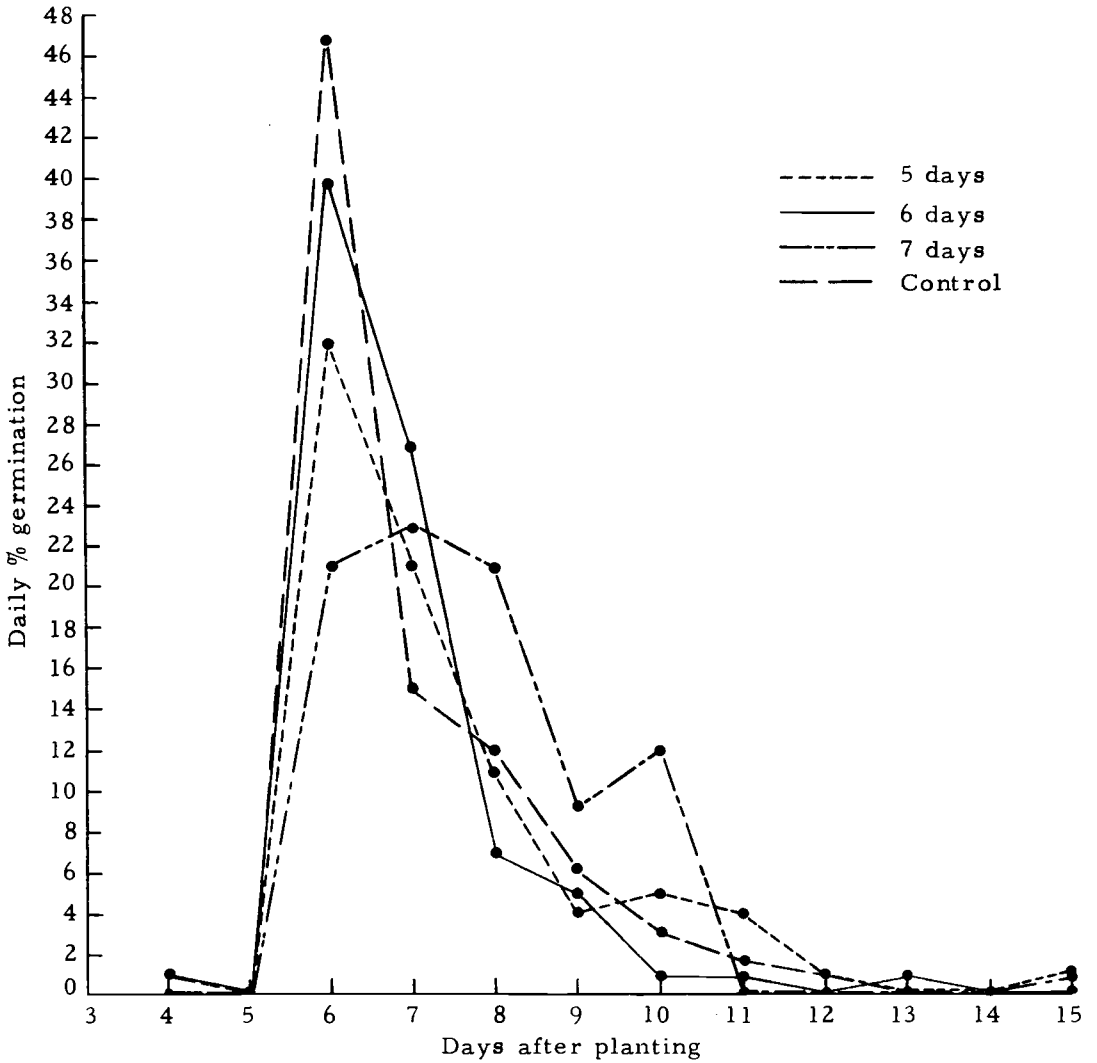

Figure 6. Daily germination percentages of 1971 Newport Kentucky bluegrass seed presoaked in KNO_3 for 5, 6 and 7 days. Seed germinated at 15-25°C.

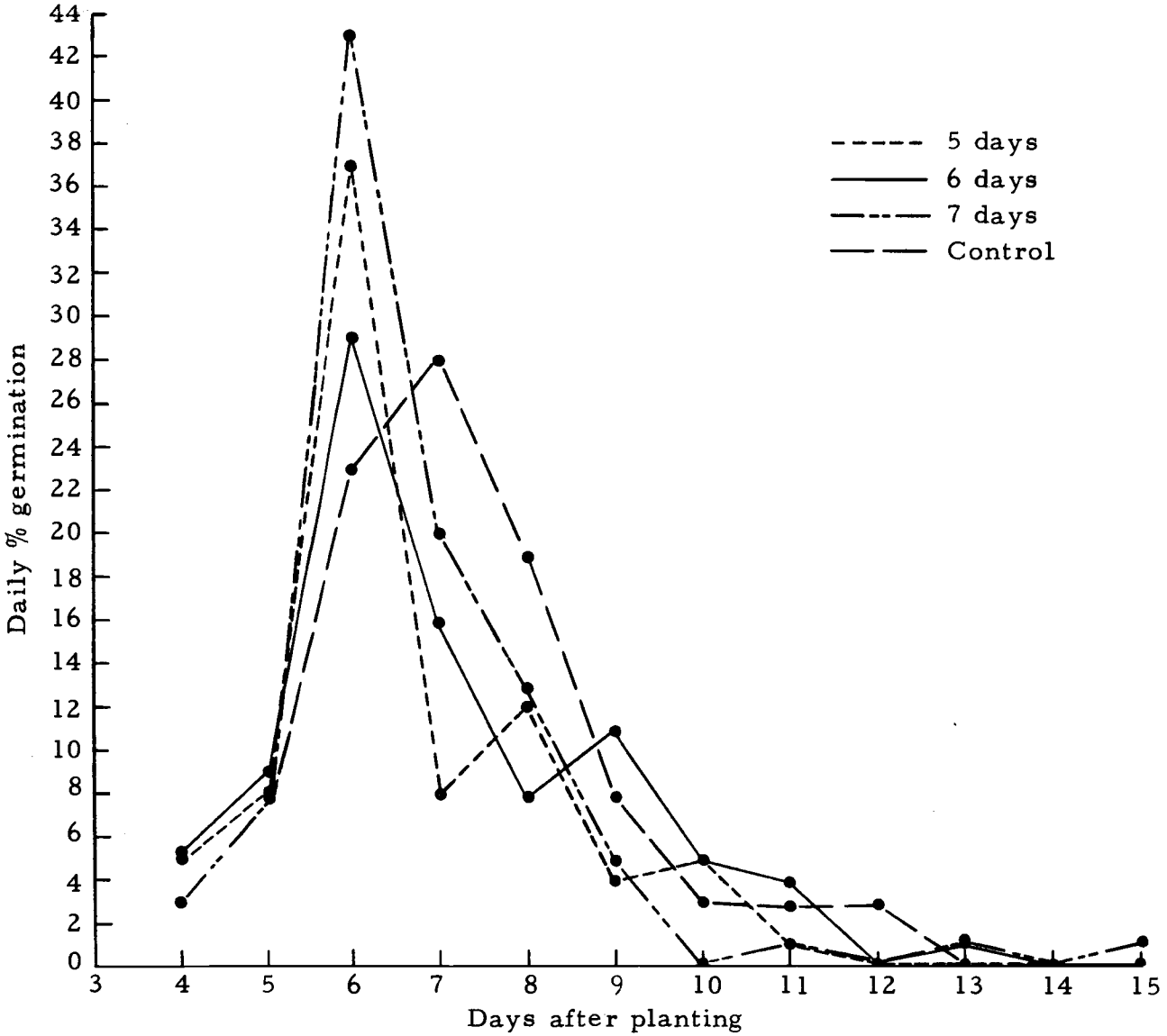

Figure 7. Daily germination percentages of Cougar Kentucky bluegrass seed presoaked in KNO_3 for 5, 6 and 7 days. Seed germinated at 15-25° C.

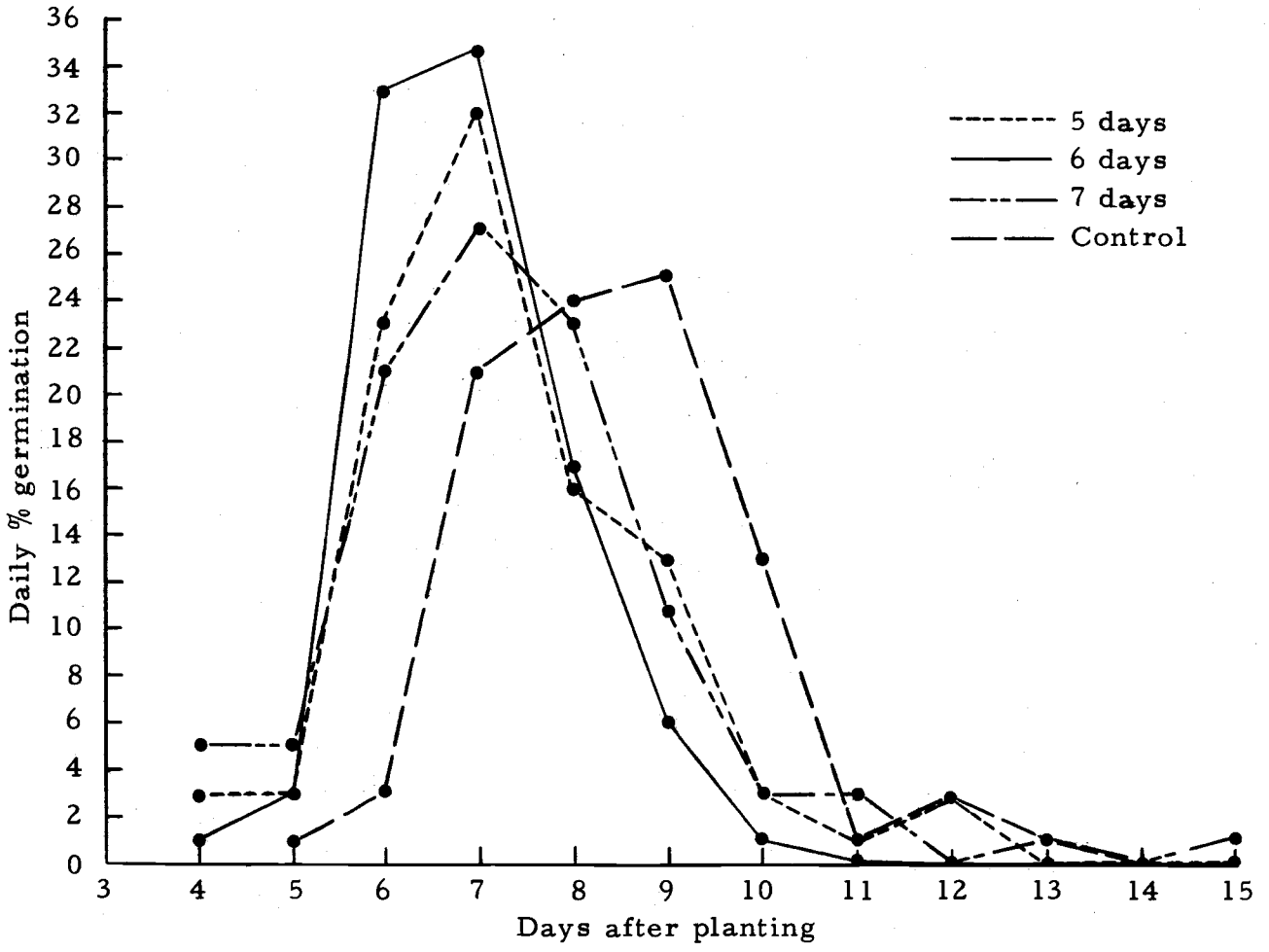

Figure 8. Daily germination percentages of Windsor Kentucky bluegrass seed presoaked in KNO_3 for 5, 6 and 7 days. Seed germinated at 15-25°C.

Table 4. Effect of length of presoak on percent and speed of germination of eight 1971 Kentucky bluegrass cultivars presoaked in KNO_3. Seed germinated at 15-25°C for 15 days.

	Length of Presoak (days)							
	0		5		6		7	
Cultivar	GI[1/]	%	GI	%	GI	%	GI	%
Merion	5.2	52	5.5	55	4.6	49	4.8	51
Pennstar	9.1	71	8.5	65	11.4	87	8.0	70
Fylking	9.2	85	9.1	76	11.8	87	9.9	82
Newport	12.5	84	11.3	79	12.6	83	12.2	89
Baron	12.6	93	10.1	77	11.6	90	13.5	92
Cougar	13.1	95	12.9	80	13.6	90	14.8	95
Windsor	13.7	92	13.6	97	14.6	96	14.5	99
Park	15.0	89	13.5	74	17.2	91	11.8	75
Average	11.3	83	10.6	75	12.2	84	11.2	81

[1/] Speed of germination index, LSD .05 = 2.76, LSD .01 = 3.67.

Table 5. Moisture changes in the seeds during presoaking and drying. Figures are percent moisture, dry weight basis.

Cultivar	Before Soaking	After Soaking	16 hr after Soaking	24 hr after Soaking
Fylking	9.8	101.8	9.9	10.0
Cougar	9.8	98.5	9.7	9.8
Windsor	9.9	101.5	9.8	9.9
Baron	10.2	104.7	9.7	9.9
Pennstar	10.9	107.7	9.5	9.8
Merion	11.4	119.8	9.8	9.8
1971 Park	13.4	121.6	9.6	9.8
1971 Newport	14.1	110.7	10.2	10.3
Average	11.2	108.3	9.8	9.9

Temperature of Presoaking

Significant differences were found between the two prosoaking temperatures when the seeds were germinated at either 15-25 or 25° C. A presoaking temperature of 5° C resulted in faster germination than a presoaking temperature of 20° C with each of the three presoaking methods. The results of this experiment are shown in Tables 6 and 7. The analyses of variance for these data are shown in Appendix Tables 3 and 4.

Method of Presoaking

The effects of soaking the seeds on top of blotters compared to submerging them in KNO_3 solutions, followed by germination at 15-25° C, are shown in Table 6.

For those seeds soaked at 5° C, the average speed of germination index was greater when soaked on top of blotters, but the difference was not significant. When presoaked at 20° C, however, speed of germination was greatest when submerged and aerated.

Aeration of the solution had only a slight beneficial, but non-significant affect when soaked at 5° C. When soaked at 20° C, aeration greatly improved the speed of germination, but not to the extent of any of the treatments at 5° C.

There was no difference among the three presoaking methods

Table 6. Effect of temperature and method of presoaking on percent and speed of germination of five Kentucky bluegrass cultivars. Germination recorded for 15 days after planting at 15-25° C.

Cultivars	5° C						20° C					
	On Blotter		In Water				On Blotter		In Water			
			Not-aereated		Aerated				Not-aerated		Aerated	
	GI[1/]	%	GI	%	GI	%	GI	%	GI	%	GI	%
Merion	9.8	81	6.8	61	7.4	66	10.4	84	4.4	40	9.0	82
Newport	13.4	90	13.8	85	13.9	88	9.3	66	8.4	64	12.2	84
Fylking	13.5	99	13.1	90	12.0	91	11.3	80	10.5	80	12.3	90
Windsor	14.5	92	13.6	85	15.2	97	8.5	95	11.6	93	13.6	94
Cougar	15.5	93	14.3	94	14.7	95	7.3	48	9.9	86	13.0	84
Average	13.3	91	12.3	83	12.6	87	9.4	75	9.0	73	12.0	87

[1/] Speed of germination index, LSD .05 = 2.26, LSD .01 = 3.01.

Table 7. Effect of temperature and method of presoaking on percent and speed of germination of five Kentucky bluegrass cultivars. Germination recorded for 15 days after planting at 25°C.

Cultivars	5°C						20°C					
	On Blotter		In Water				On Blotter		In Water			
			Not-aerated		Aerated				Not-aerated		Aerated	
	GI[1/]	%	GI	%	GI	%	GI	%	GI	%	GI	%
Merion	.6	4	.4	3	.1	1	.1	1	2.9	3	.1	1
Fylking	2.5	15	1.6	10	.9	5	.3	2	.3	1	.1	1
Windsor	4.2	19	2.3	14	3.1	16	.4	2	.6	4	.5	2
Newport	10.1	48	7.6	45	10.5	49	1.1	9	3.5	20	1.6	8
Cougar	17.5	78	15.5	79	16.7	86	3.2	19	8.8	57	7.8	48
Average	7.0	33	5.5	30	6.3	31	1.7	7	3.2	17	2.0	12

[1/] Speed of germination index, LSD .05 = 1.74, LSD .01 = 2.32.

when the treated seeds were germinated at 25°C (Table 7).

In summary, the foregoing experiments on procedure have shown the optimum presoaking conditions to be 6 days at 5°C, either on blotters or submerged in water. Because of the impracticability of soaking large quantities of seeds on blotters, subsequent experiments were conducted by soaking the seeds in aerated solutions. The seeds were allowed to dry at least 24 hours before being placed in germination tests.

Soaking in Chemical Solutions

The effects of soaking in nine chemical solutions on the germination percentage of eight 1971 Kentucky bluegrass cultivars are shown in Tables 8 and 9. There were significant differences among the effects of the chemicals on the speed of germination at both germination temperatures, but the differences were more obvious at 25°C, indicated by a higher mean square value.

The analyses of variance for the speed of germination of eight 1971 bluegrass cultivars are shown in Appendix Tables 5 and 6. LSD's indicated that at 15-25°C only KNO_3 and nutrient solution, among the nine chemicals tried differed significantly at the 1% level from the control (Appendix Table 5). The effects of these two solutions on germination speed are shown in Figures 9 to 16. Peak germination was reached one or two days earlier than in the controls, depending on the cultivar.

Table 8. Percent germination of eight 1971 Kentucky bluegrass cultivars presoaked in nine chemical solutions. Germination recorded 15 days after planting at 15-25° C.

Cultivars	KNO_3	NS[1/]	GA_3	BA[2/]	SA[3/]	TU[4/]	H_2O_2[5/]	NaOCl[6/]	Water	Control
Merion	67	62	68	77	65	49	66	77	58	84
Pennstar	91	89	74	79	81	76	61	70	87	74
Fylking	90	88	82	95	88	89	74	80	78	85
Windsor	95	96	94	94	92	92	96	93	92	98
Baron	88	93	91	85	84	98	95	82	87	88
Park	85	88	88	84	73	75	93	76	85	81
Newport	93	80	89	87	87	91	86	90	79	86
Cougar	93	91	96	79	92	85	91	87	83	87
Average	88	86	85	85	83	82	83	82	81	85

[1/] Nutrient solution

[2/] Benzyl adenine

[3/] Succinic acid

[4/] Thiourea

[5/] Hydrogen peroxide

[6/] Sodium hypochlorite

Table 9. Percent germination of eight 1971 Kentucky bluegrass cultivars presoaked in nine chemical solutions. Germination recorded 15 days after planting at 25°C.

Cultivars	KNO_3	NS[1/]	GA_3	BA[2/]	SA[3/]	TU[4/]	H_2O_2[5/]	NaOCl[6/]	Water	Control
Merion	0	1	1	1	0	0	0	0	0	0
Pennstar	3	9	0	0	2	0	2	0	4	0
Fylking	21	2	3	0	1	3	0	0	0	0
Windsor	30	16	2	1	2	8	1	0	3	0
Baron	38	28	27	4	14	7	4	6	10	9
Park	44	39	12	15	5	14	19	13	18	21
Newport	68	48	20	44	18	20	28	33	16	17
Cougar	91	85	89	80	77	68	70	70	73	67
Average	37	29	19	18	15	15	16	15	16	14

[1/] Nutrient solution

[2/] Benzyl adenine

[3/] Succinic acid

[4/] Thiourea

[5/] Hydrogen peroxide

[6/] Sodium hypochlorite

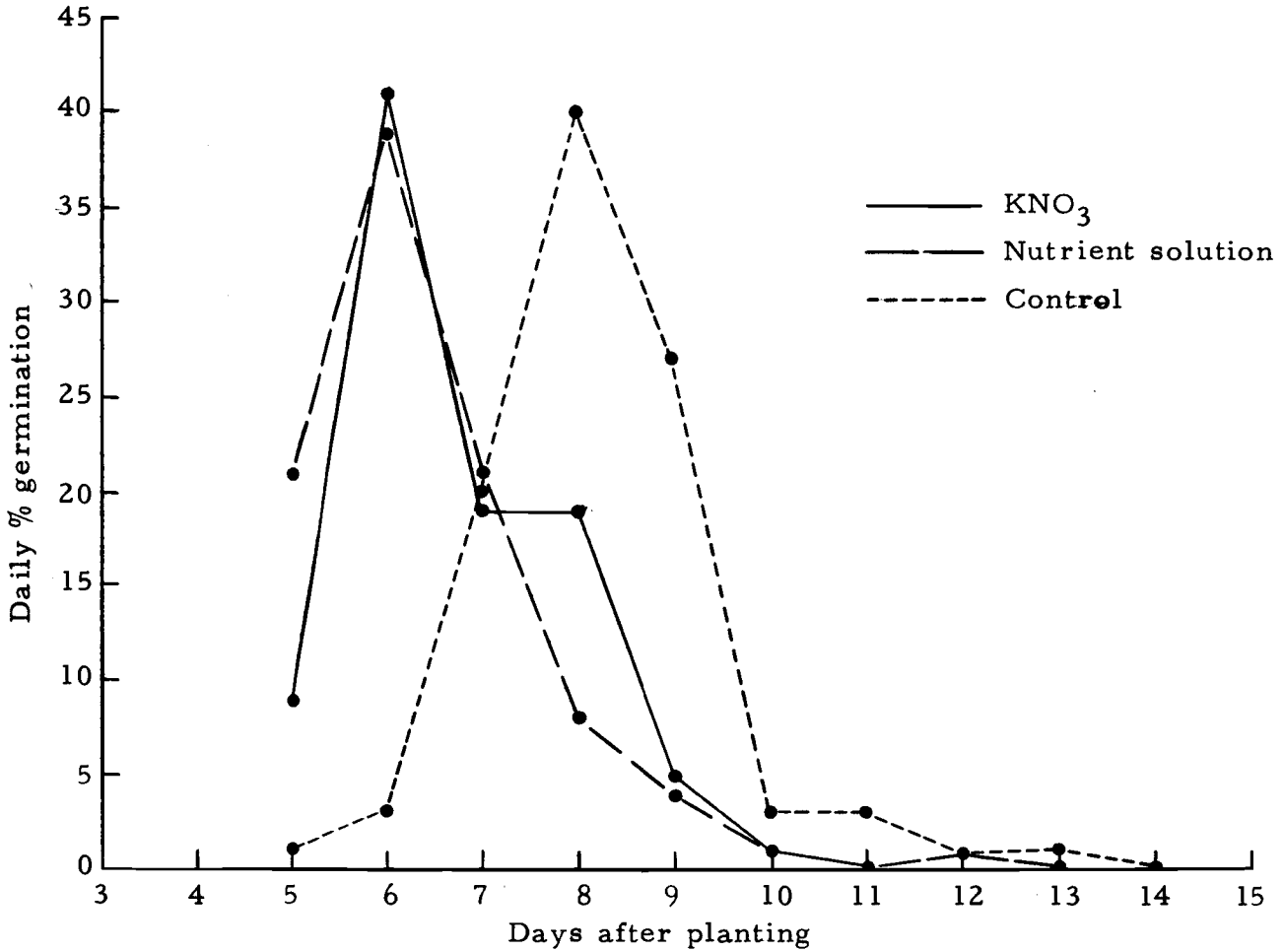

Figure 9. Daily germination percentages of Windsor Kentucky bluegrass seed presoaked in KNO_3 and nutrient solution. Seed germinated at 15-25° C.

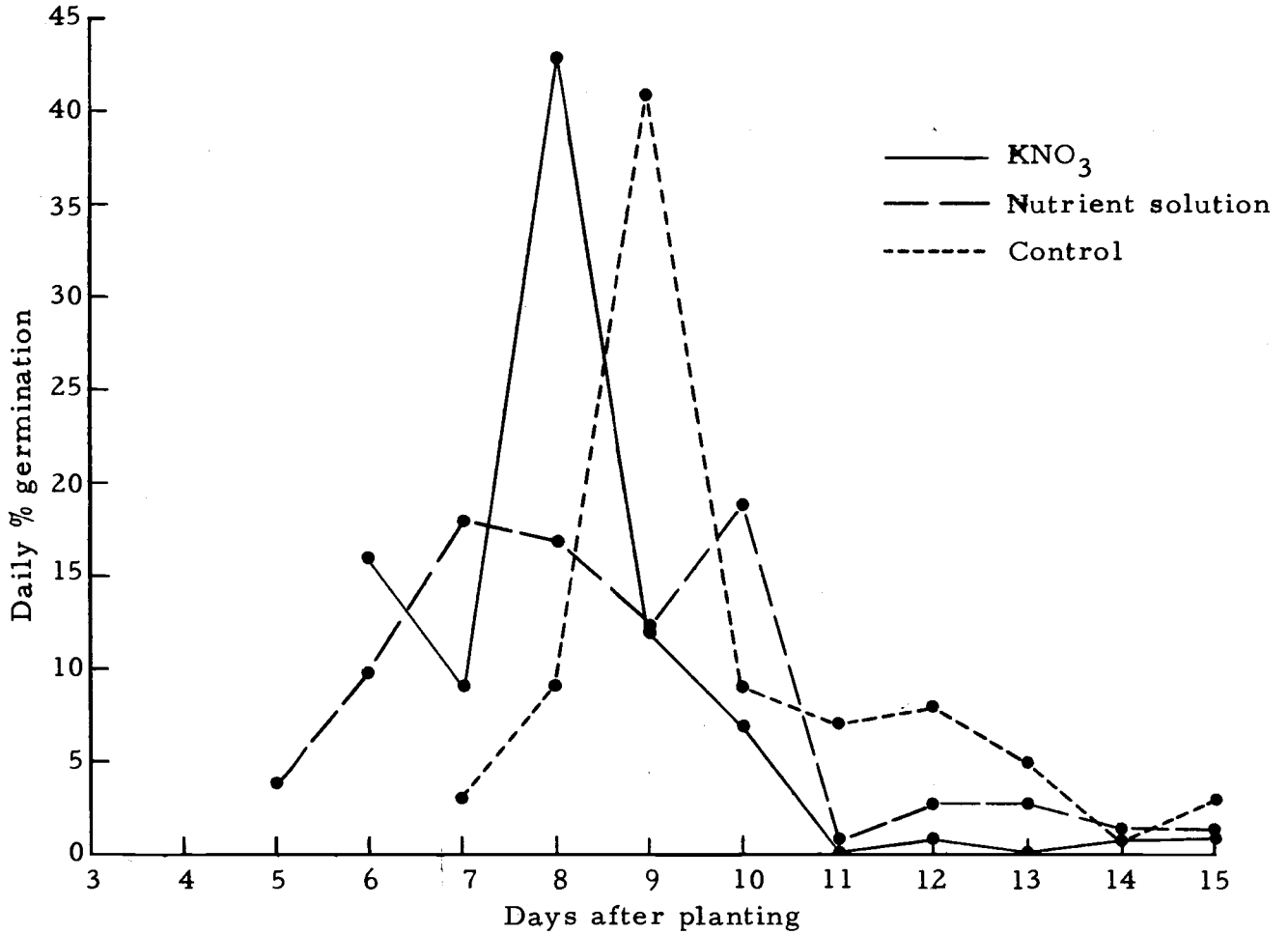

Figure 10. Daily germination percentages of Fylking Kentucky bluegrass seed presoaked in KNO_3 and nutrient solution. Seed germinated at 15-25° C.

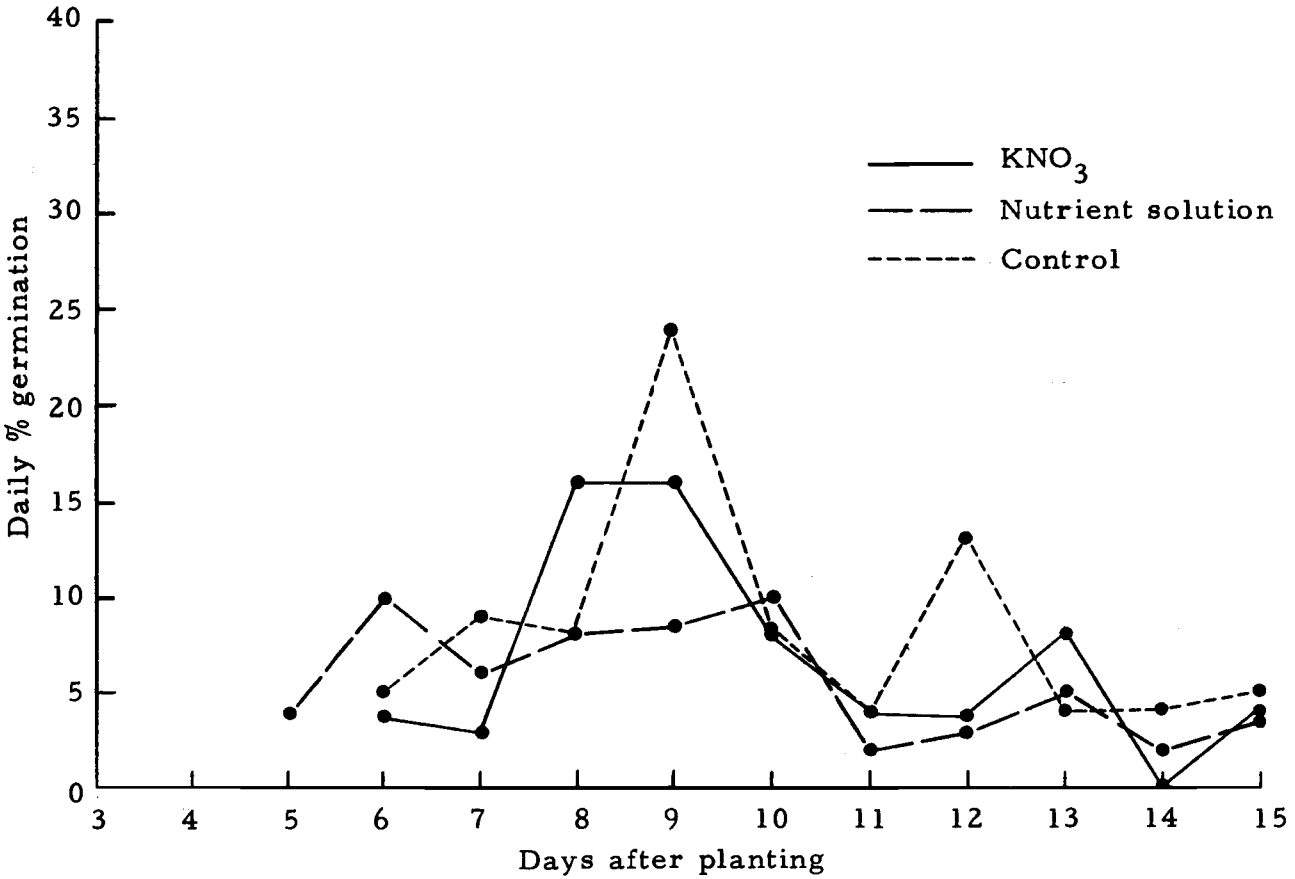

Figure 11. Daily germination percentages of Merion Kentucky bluegrass seed presoaked in nutrient solution and KNO_3. Seed germinated at 15-25° C.

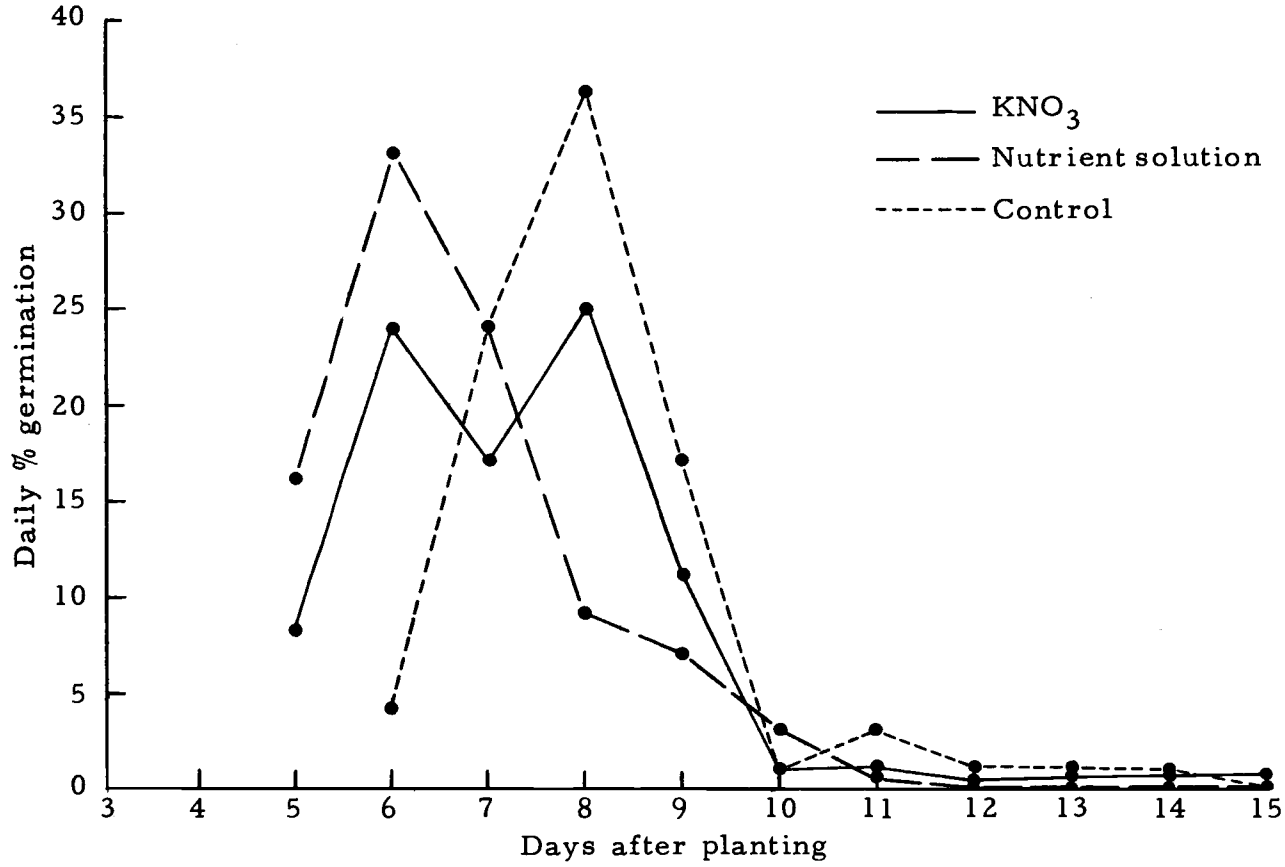

Figure 12. Daily germination percentages of Baron Kentucky bluegrass seed presoaked in nutrient solution and KNO_3. Seed germinated at 15-25° C.

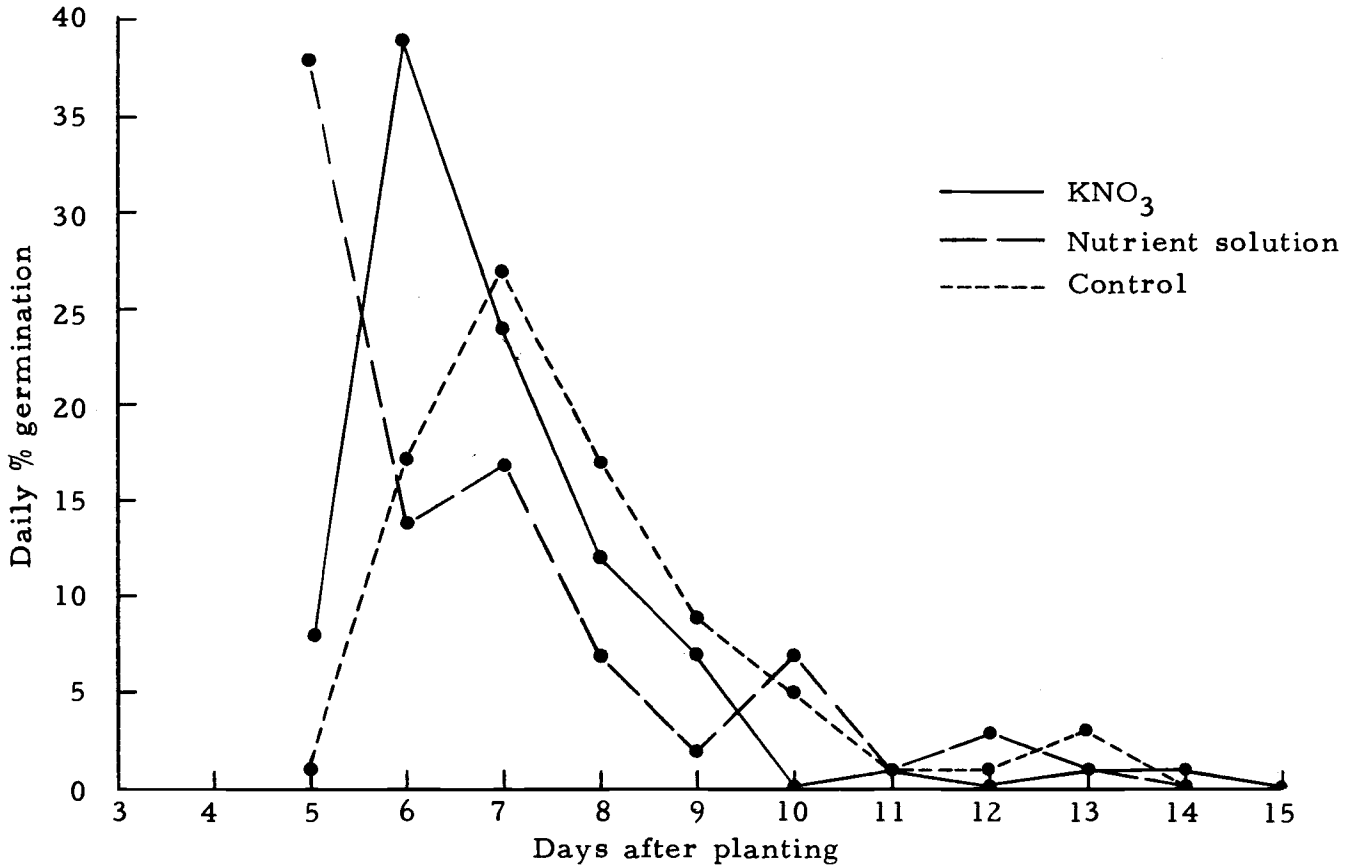

Figure 13. Daily germination percentages of Cougar Kentucky bluegrass seed presoaked in KNO_3 and nutrient solution. Seed germinated at 15-25°C.

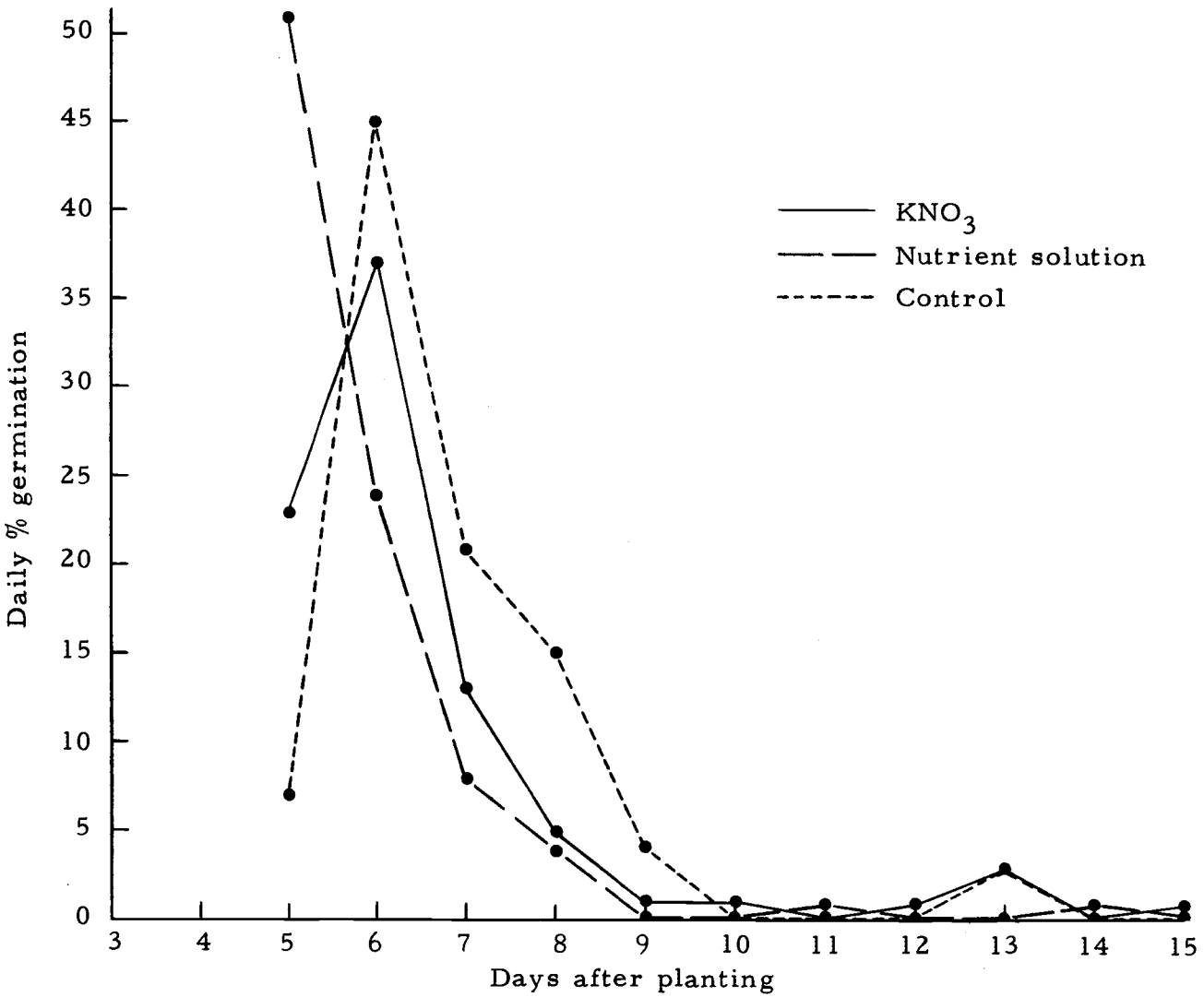

Figure 14. Daily germination percentages of 1971 Park Kentucky bluegrass seed presoaked in KNO_3 and nutrient solution. Seed germinated at 15-25° C.

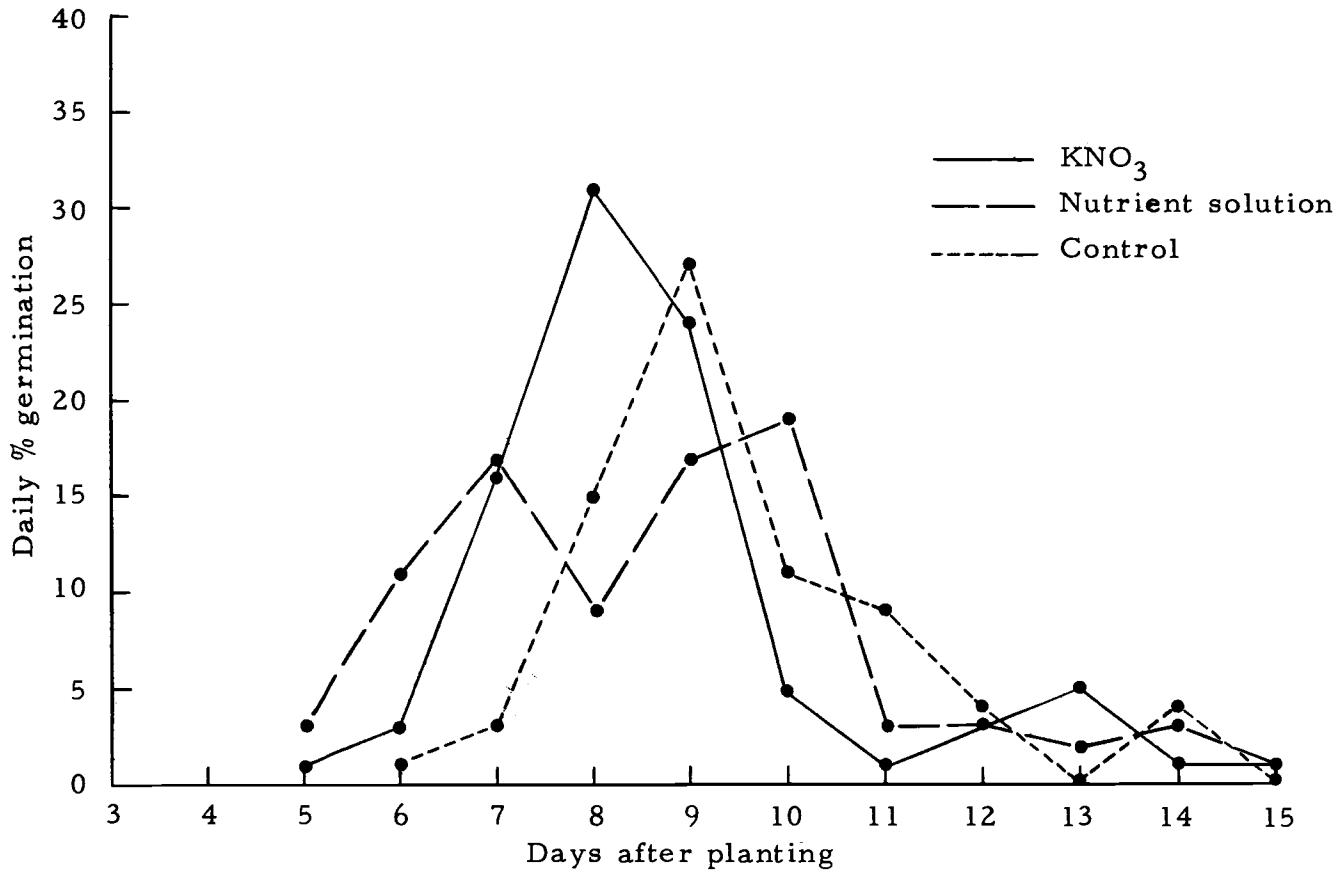

Figure 15. Daily germination percentages of Pennstar Kentucky bluegrass seed pre-soaked in KNO_3 and nutrient solution. Seed germinated at 15-25° C.

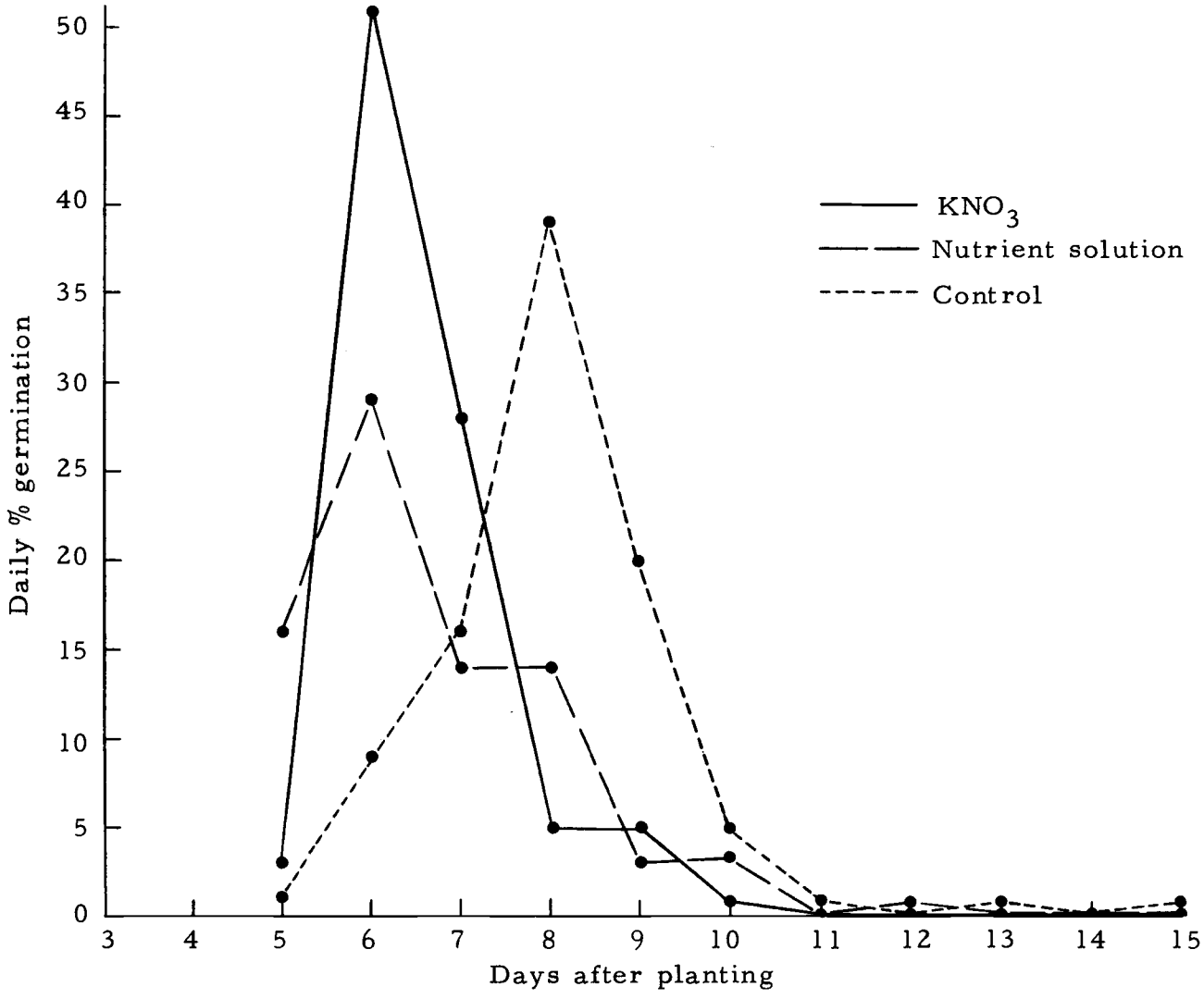

Figure 16. Daily germination percentages of 1971 Newport Kentucky bluegrass seed pre-soaked in KNO_3 and nutrient solution. Seed germinated at 15-25° C.

At 25°C, seeds presoaked in KNO_3, GA_3, benzyl adenine and nutrient solution differed from the untreated controls at the 1% level of probability (Appendix Table 6). When averaged over all cultivars, KNO_3 treatment gave fastest and highest germination. The next best treatment was nutrient solution, followed by gibberellic acid and benzyl adenine. Figures 17 to 24 show the daily percentage germination of the presoaked seeds at 25°C until the 15th day of germination. In these figures, only the germination obtained from the three best treatments for each cultivar are shown with the controls. Although the germination percentage was quite low at 25°C, peak germination again occurred earlier in the treated lots.

Cultivars varied in their responses to soaking in the chemical solutions. When speed of germination and final germination were considered at both germination temperatures, Merion did not benefit from any of the chemicals, while Cougar and Newport were stimulated by most of the solutions. The chemical solutions resulting in significant increases in the speed of germination at 25°C are listed for each cultivar in Table 10.

At 15-25°C, the 5-day germination percentages of seeds soaked in nutrient solution were consistently higher than that of seeds soaked in KNO_3, while at 25°C, highest 5-day germination was obtained from KNO_3 soaks. This was particularly true of Park, Cougar and Newport, relatively non-dormant and fast germinating cultivars (Figures 13, 14, 16).

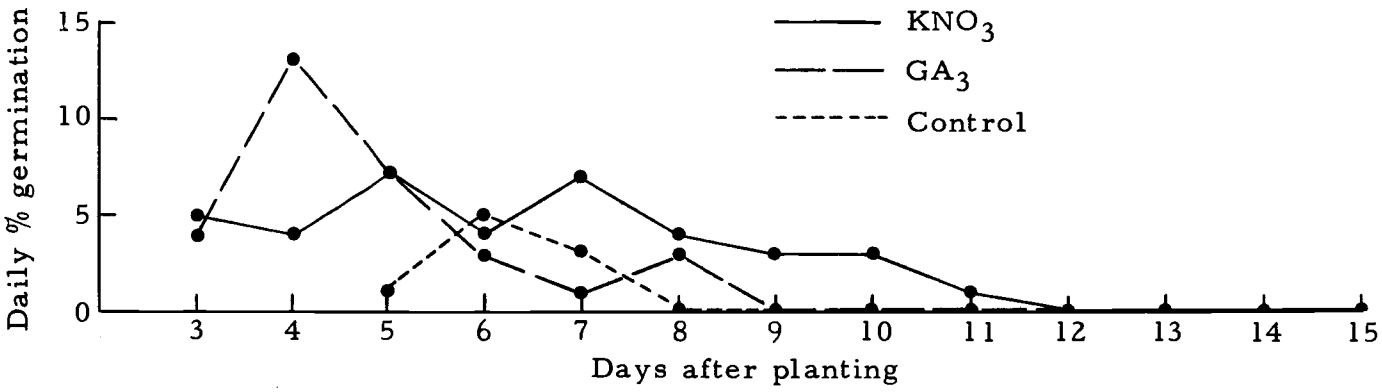

Figure 17. Daily germination percentages of Baron Kentucky bluegrass seed presoaked in KNO_3, and GA_3. Seed germinated at 25° C.

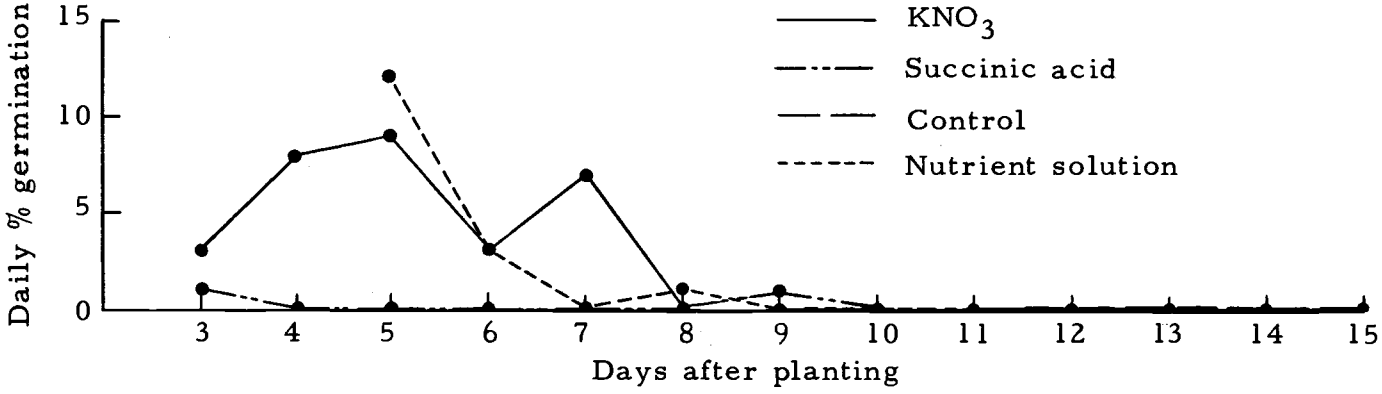

Figure 18. Daily germination percentages of Windsor Kentucky bluegrass seed presoaked in KNO_3, succinic acid and nutrient solution. Seed germinated at 25° C.

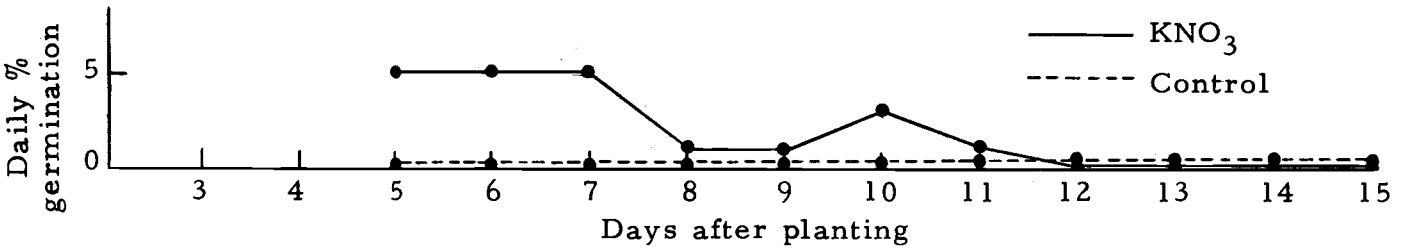

Figure 19. Daily germination percentages of Fylking Kentucky bluegrass seed presoaked in KNO_3. Seed germinated at 25° C.

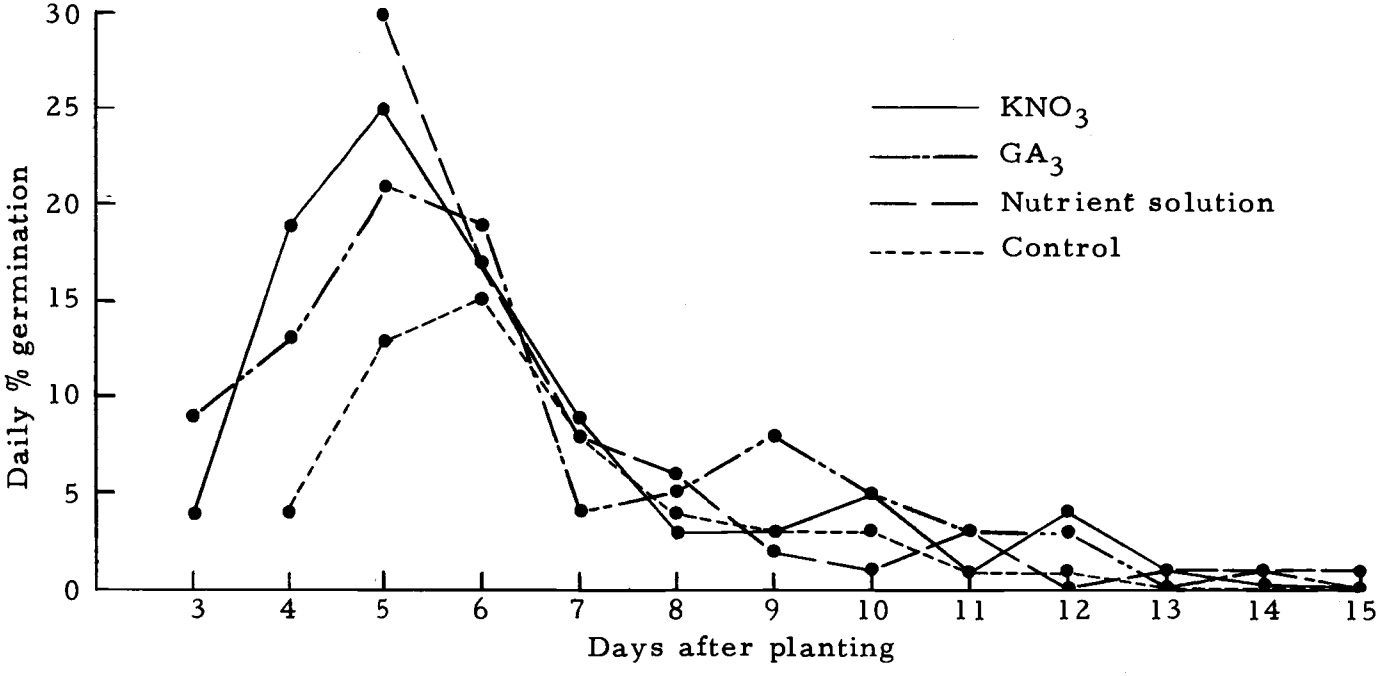

Figure 20. Daily germination percentages of Cougar Kentucky bluegrass seed presoaked in KNO_3, GA_3 and nutrient solution. Seed germinated at 25° C.

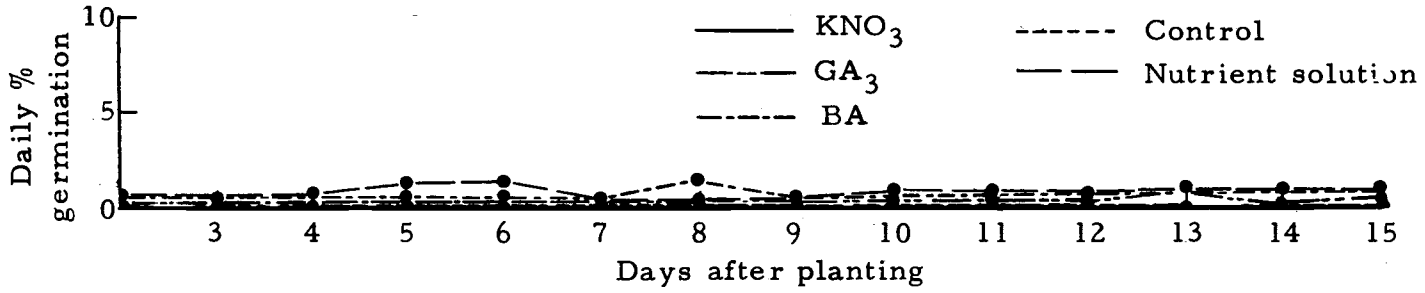

Figure 21. Daily germination percentages of Merion Kentucky bluegrass seed presoaked in KNO_3, GA_3, BA and nutrient solution. Seed germinated at 25° C.

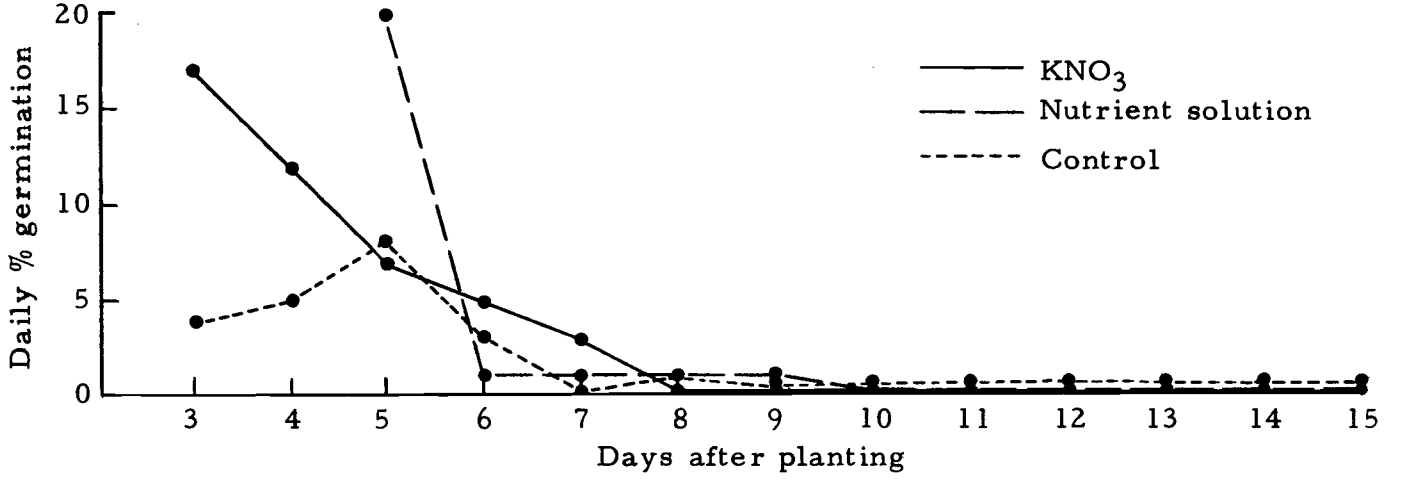

Figure 22. Daily germination percentages of 1971 Park Kentucky bluegrass seed presoaked in KNO_3 and nutrient solution. Seed germinated at 25° C.

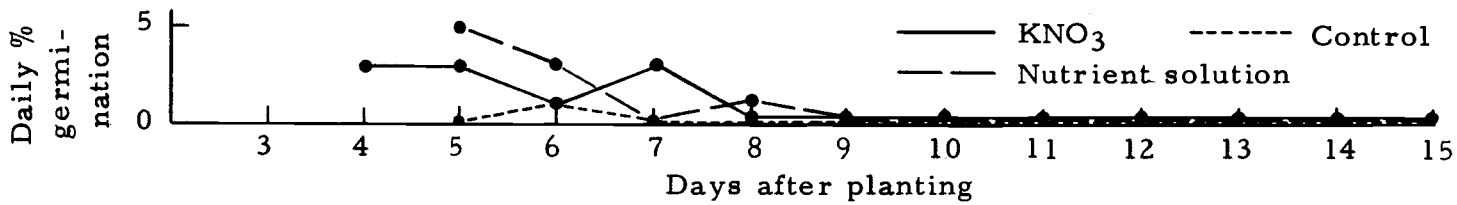

Figure 23. Daily germination percentages of Pennstar Kentucky bluegrass seed presoaked in KNO_3 and nutrient solution. Seed germination at 25°C.

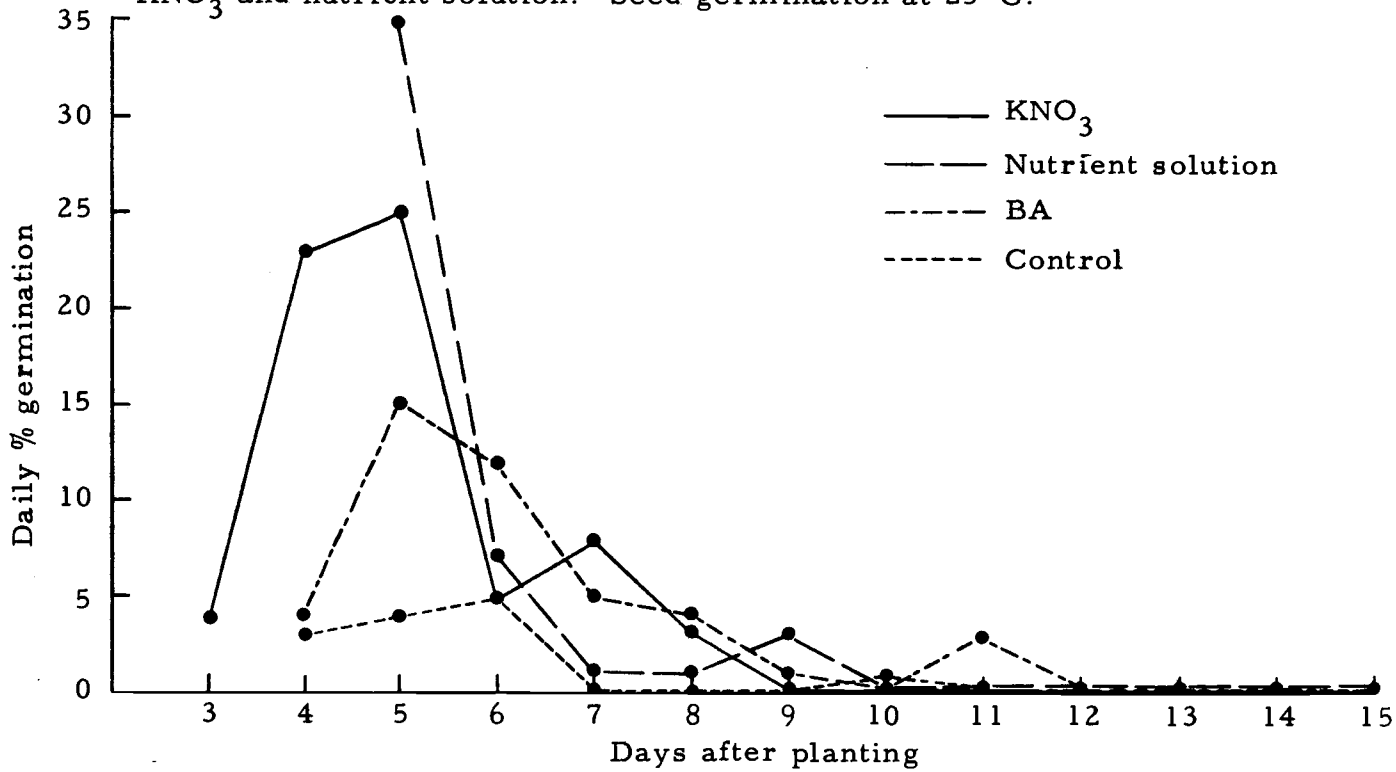

Figure 24. Daily germination percentages of 1971 Newport Kentucky bluegrass seed presoaked in KNO_3, benzyl adenine and nutrient solution. Seed germinated at 25°C.

Table 10. Chemical solutions resulting in significant increases in the speed of germination at 25° C.

Cultivar	Chemical Treatment
Merion	
Fylking	KNO_3
Pennstar	KNO_3
	Nutrient solution
Baron	KNO_3
	GA_3
Park	KNO_3
	Nutrient solution
Windsor	KNO_3
	Succinic acid
	Nutrient solution
	Thiourea
Newport	KNO_3
	Nutrient solution
	Benzyl adenine
	NaOCl
	H_2O_2
	Thiourea
	GA_3
Cougar	GA_3
	KNO_3
	Nutrient solution
	Benzyl adenine
	H_2O
	Succinic acid
	Thiourea
	H_2O_2
	NaOCl

Soaking at Alternating Temperatures

The comparative effects on speed of germination from presoaking in constant and alternating temperatures are shown in Figures 25 to 29, with the analyses of variance of the data shown in Appendix Tables 7 and 8.

When germinated at 25°C, Merion was the only cultivar to benefit slightly from the alternating presoaking temperature. Cougar, Fylking and Newport performed better at a constant presoaking temperature. There was no difference in the performance of Windsor at either presoaking temperature.

When the results were averaged over cultivars, the increased speed of germination after soaking at 5°C was significant at the 1% level.

When germinated at 15-25°C, the soaking temperature did not affect the speed of germination.

Among the chemicals used, KNO_3 was more beneficial than GA_3 and water, but there was no difference between the affects of GA_3 and water.

Cycles of Soaking and Drying

The effects of repeated cycles of soaking and drying on speed of germination are shown in Tables 11 and 12. A substantial increase in

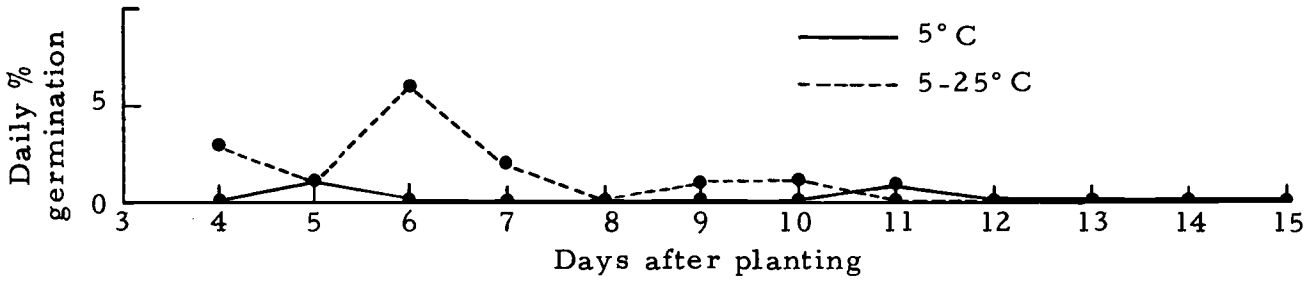

Figure 25. Daily germination percentages of Merion Kentucky bluegrass seed presoaked in KNO_3 at 5 and 5-25°C. Seed germinated at 25°C.

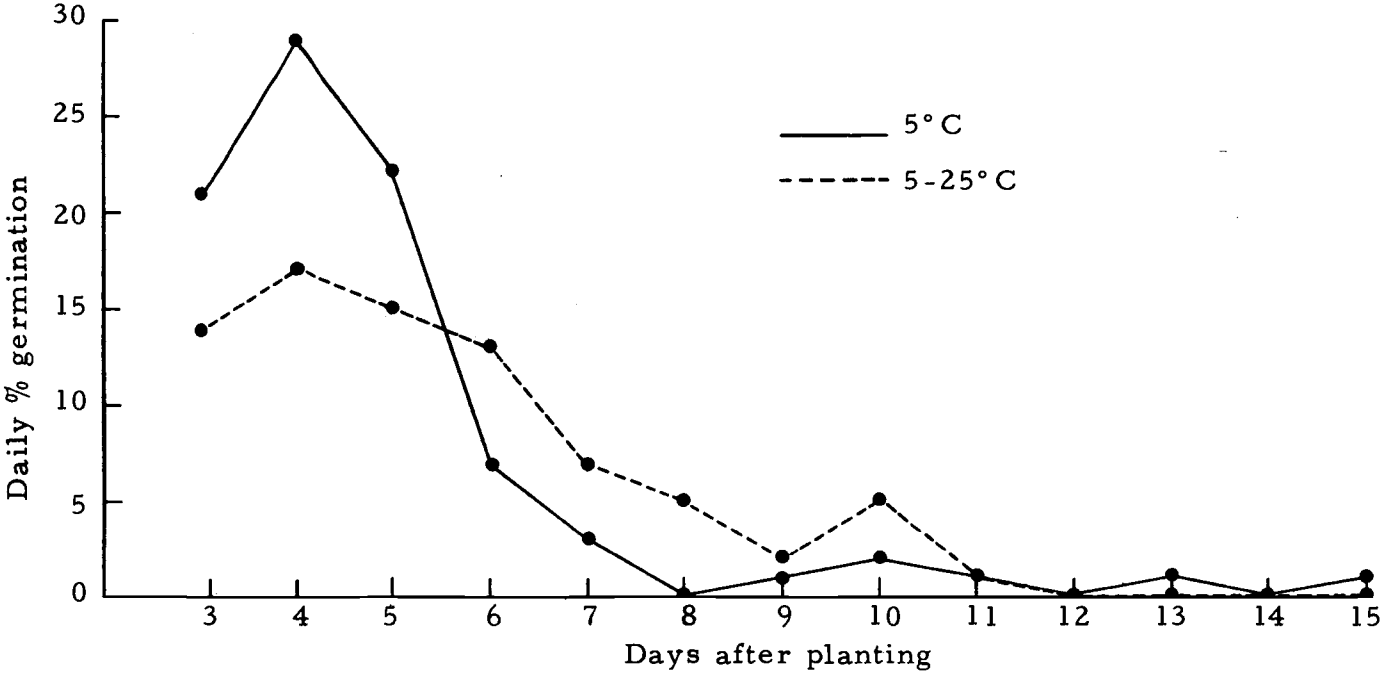

Figure 26. Daily germination percentages of Cougar Kentucky bluegrass seed presoaked in KNO_3 at 5 and 5-25°C. Seed germinated at 25°C.

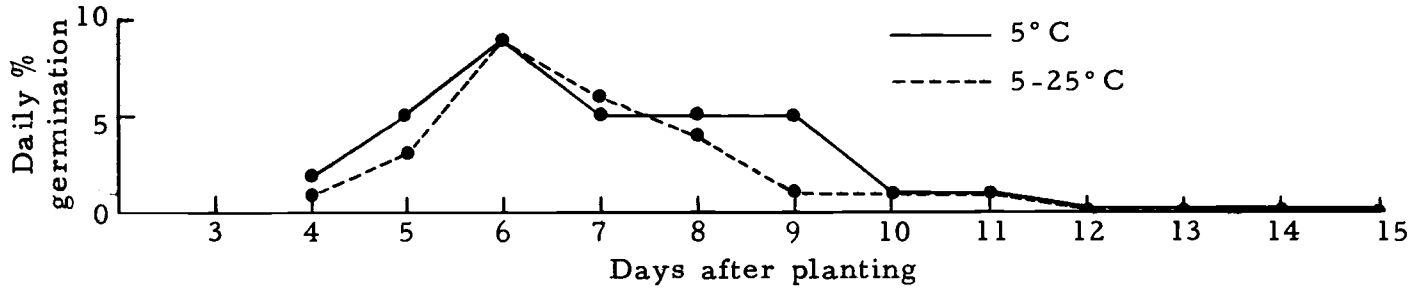

Figure 27. Daily germination percentages of Fylking Kentucky bluegrass seed presoaked in KNO_3 at 5 and 5-25° C. Seed germinated at 25° C.

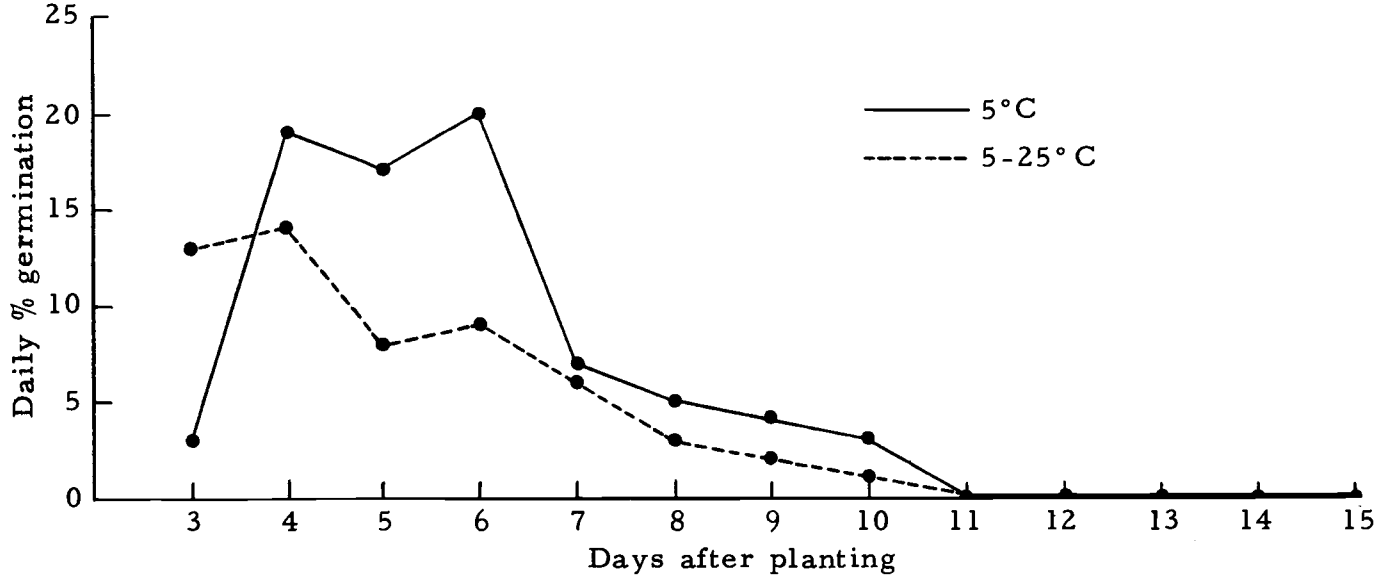

Figure 28. Daily germination percentages of 1971 Newport Kentucky bluegrass seed presoaked in KNO_3 at 5 and 5-25° C. Seed germinated at 25° C.

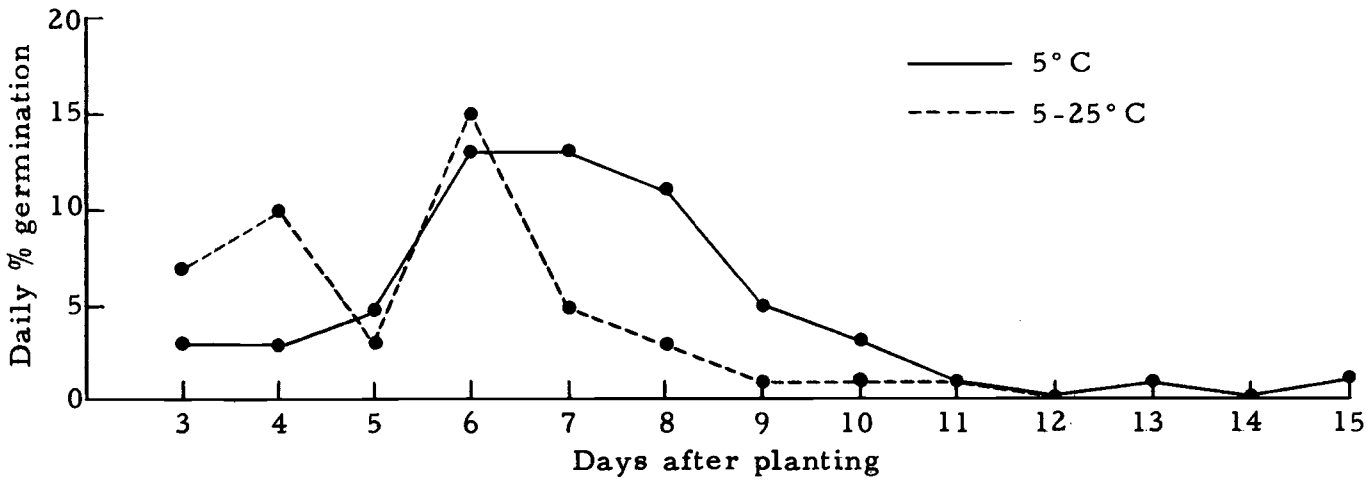

Figure 29. Daily germination percentages of Windsor Kentucky bluegrass seed presoaked in KNO_3 at 5 and 5-25° C. Seed germinated at 25° C.

Table 11. Percent and speed of germination of Merion and Cougar Kentucky bluegrass cultivars subjected to 6 cycles of soaking and drying. Seed germinated at 15-25°C.

Cycles of Soaking and Drying	Merion						Cougar					
	KNO_3		GA_3		H_2O		KNO_3		GA_3		H_2O	
	GI[1/]	%	GI	%	GI	%	GI	%	GI	%	GI	%
1	9.5	80	8.7	72	8.9	80	14.0	92	15.0	96	15.0	92
2	8.6	74	9.6	80	8.7	79	14.8	95	15.2	97	13.4	90
3	8.3	74	8.2	73	8.0	73	16.0	92	13.9	94	13.9	93
4	7.9	67	9.1	73	8.2	75	13.7	96	13.7	94	13.2	91
5	8.7	72	7.7	71	8.5	72	13.2	89	13.3	93	13.5	94
6	8.2	69	9.3	78	9.8	76	13.4	92	14.4	96	14.0	92
Control		GI: 7.5,		%: 64				GI: 11.7,		%: 81		

[1/] Speed of germination index.

Table 12. Percent and speed of germination of Merion and Cougar Kentucky bluegrass cultivars subjected to 6 cycles of soaking and drying. Seed germinated at 25° C.

Cycles of Soaking and Drying	Merion						Cougar					
	KNO_3		GA_3		H_2O		KNO_3		GA_3		H_2O	
	GI[1/]	%	GI	%	GI	%	GI	%	GI	%	GI	%
1	.4	1	.3	2	0	0	14.3	84	13.3	79	13.1	84
2	.2	2	.5	3	0	0	13.0	80	13.8	81	12.4	82
3	.5	3	.4	3	.1	1	14.3	84	14.0	85	12.7	76
4	.5	3	.4	3	.6	4	14.1	84	12.8	77	13.6	78
5	.9	7	.3	3	.4	3	14.2	84	12.1	71	13.8	81
6	.3	3	.3	2	.3	2	14.2	86	13.6	82	12.8	77
Control		GI: 0,		%: 0				GI: 8.1,		%: 65		

[1/] Speed of germination index.

Speed of germination occurred after one cycle, especially in Cougar. However, no benefits were obtained from additional cycles, either at 15-25 or 25°C germination temperatures. Likewise, no harmful effects were observed from as many as six cycles of soaking and drying. Soaking in water, KNO_3 and GA_3 resulted in equal degrees of stimulation. The analyses of variance for these data are shown in Appendix Tables 9 and 10.

Effects of Presoaking on Seed Performance Besides Percent and Speed of Germination

Temperature Range Over Which Seeds Germinate

Presoaking and drying extended the temperature range over which Windsor and Fylking bluegrass seeds germinated when planted on a thermal gradient plate. When the temperatures were held constant, untreated Windsor seeds germinated between 16 and 25°C, while KNO_3 soaked seeds germinated between 13 and 29°C--an increased range of 7°C. Untreated Fylking did not germinate at any constant temperature, but KNO_3 treated seeds germinated at constant temperatures between 18 and 27°C.

At alternating temperatures, no increase in the high or low germination temperature range resulted from presoaking. All treatments germinated between 10-30 and 30-10°C. Untreated seeds of both cultivars did not germinate, however, at the narrow temperature

alternation between 19 and 22°C, while the treated seeds did, especially when soaked in KNO_3.

Germination Under Moisture Stress Conditions

When seeds of Merion and Cougar presoaked in KNO_3 and water were planted on blotters moistened with three concentrations of polyethylene glycol with unsoaked controls, significant differences were found among the speeds of germination. LSD's indicated that seeds of Cougar presoaked in KNO_3 had a faster speed of germination than the seeds presoaked in water at 1% level. However, there was no difference between water and controls. The analysis of variance for these data are shown in Appendix Table 11.

The relative ability of KNO_3 presoaked seeds to germinate under moisture stress conditions is shown in Figures 30 through 32. When seeds of Cougar were germinated in water, germination of presoaked seeds was 12% higher than the untreated controls. When germinated in 20% polyethylene glycol solution (14.1 atmospheres), germination of the untreated seeds was depressed to a much greater extent than that of the presoaked seeds, producing a 50% germination differential after 15 days. Presoaked seeds also began to germinate 3 days earlier than the controls in 20% polyethylene glycol.

At lower concentrations of polyethylene glycol, the advantage

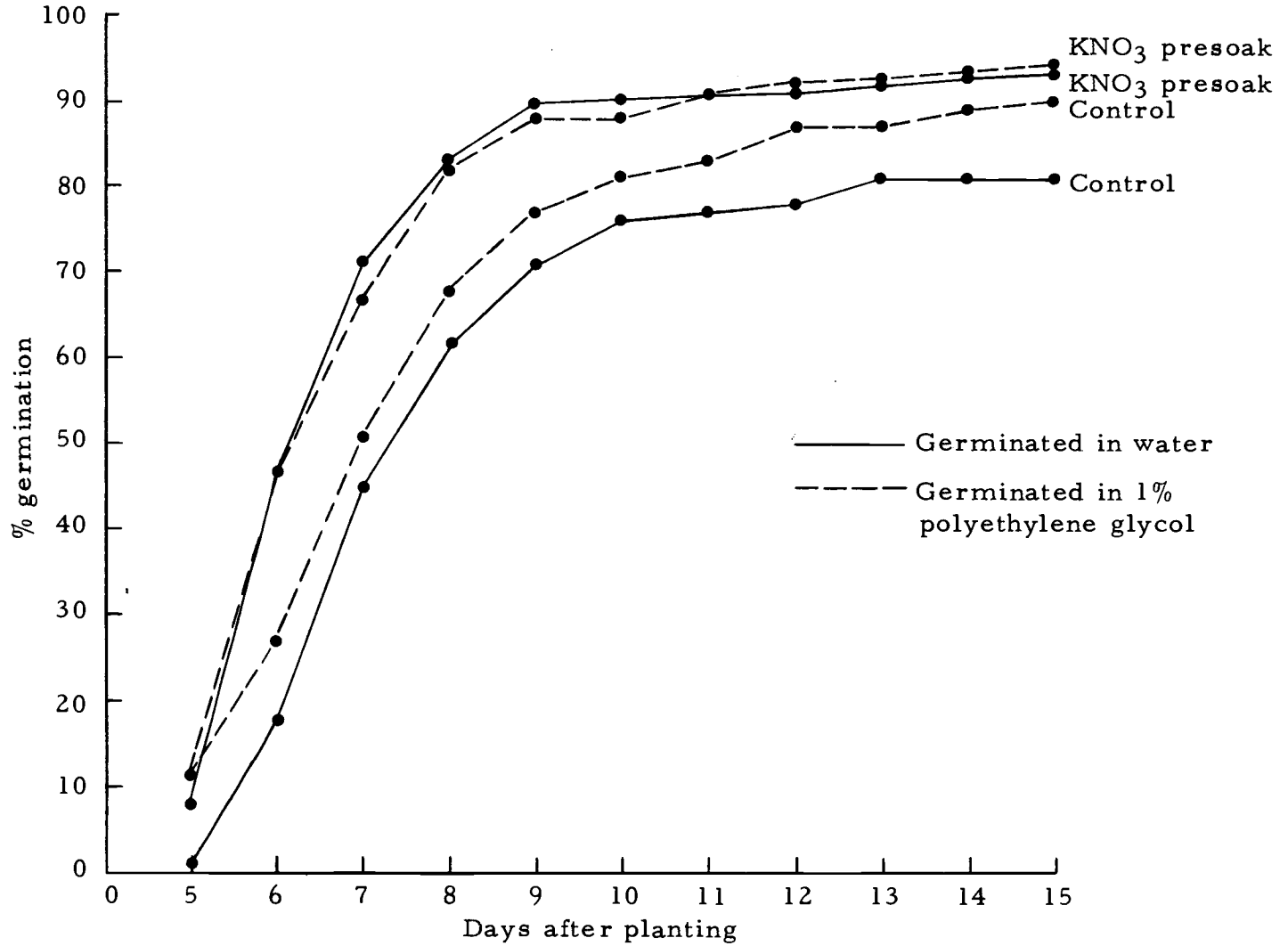

Figure 30. Percentage germination of KNO_3 presoaked Cougar Kentucky bluegrass seed in water and 1% polyethylene glycol. Seed germinated at 15-25°C.

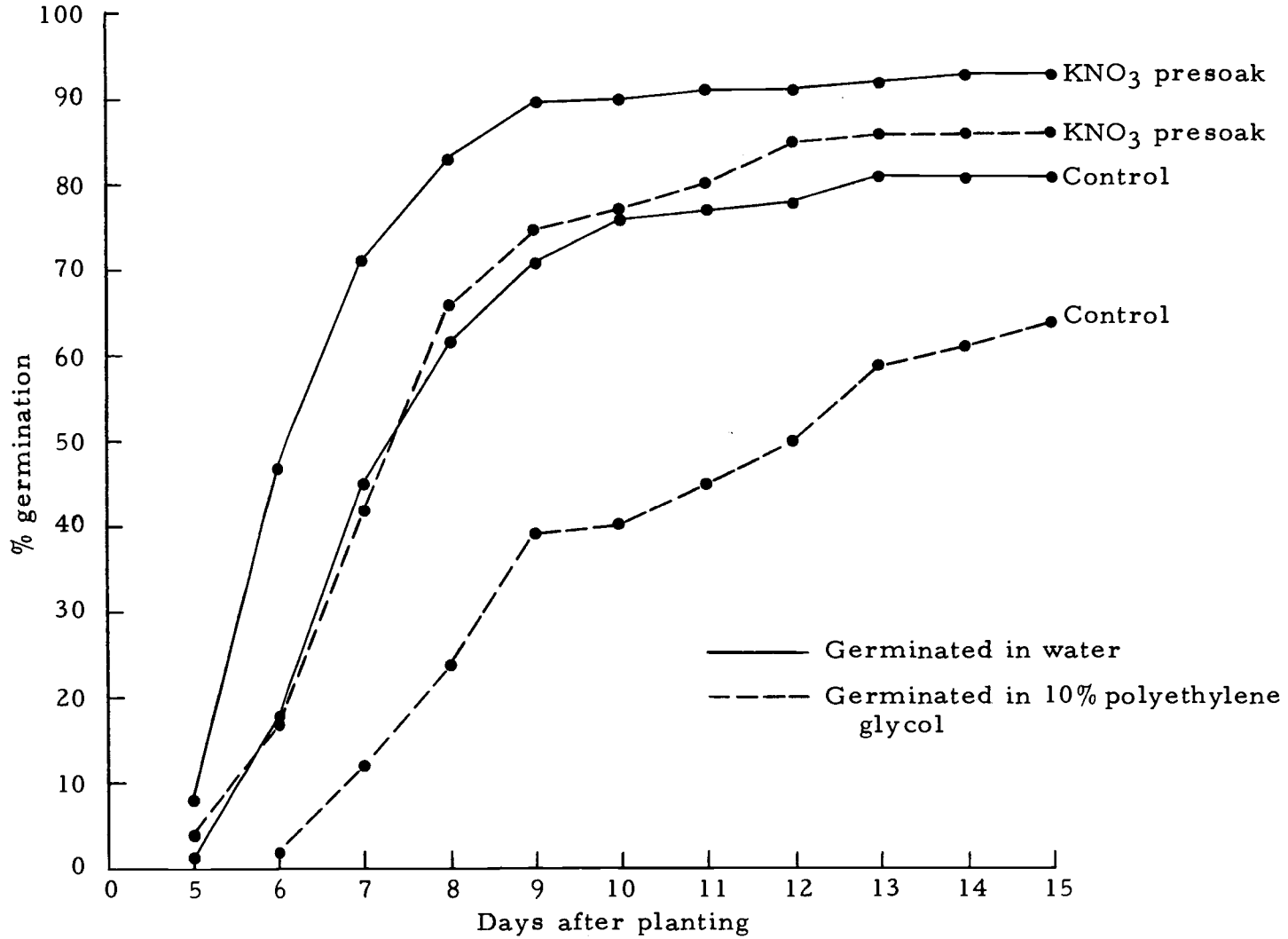

Figure 31. Percentage germination of KNO_3 presoaked Cougar Kentucky bluegrass seed in water and 10% polyethylene glycol. Seed germinated at 15-25°C.

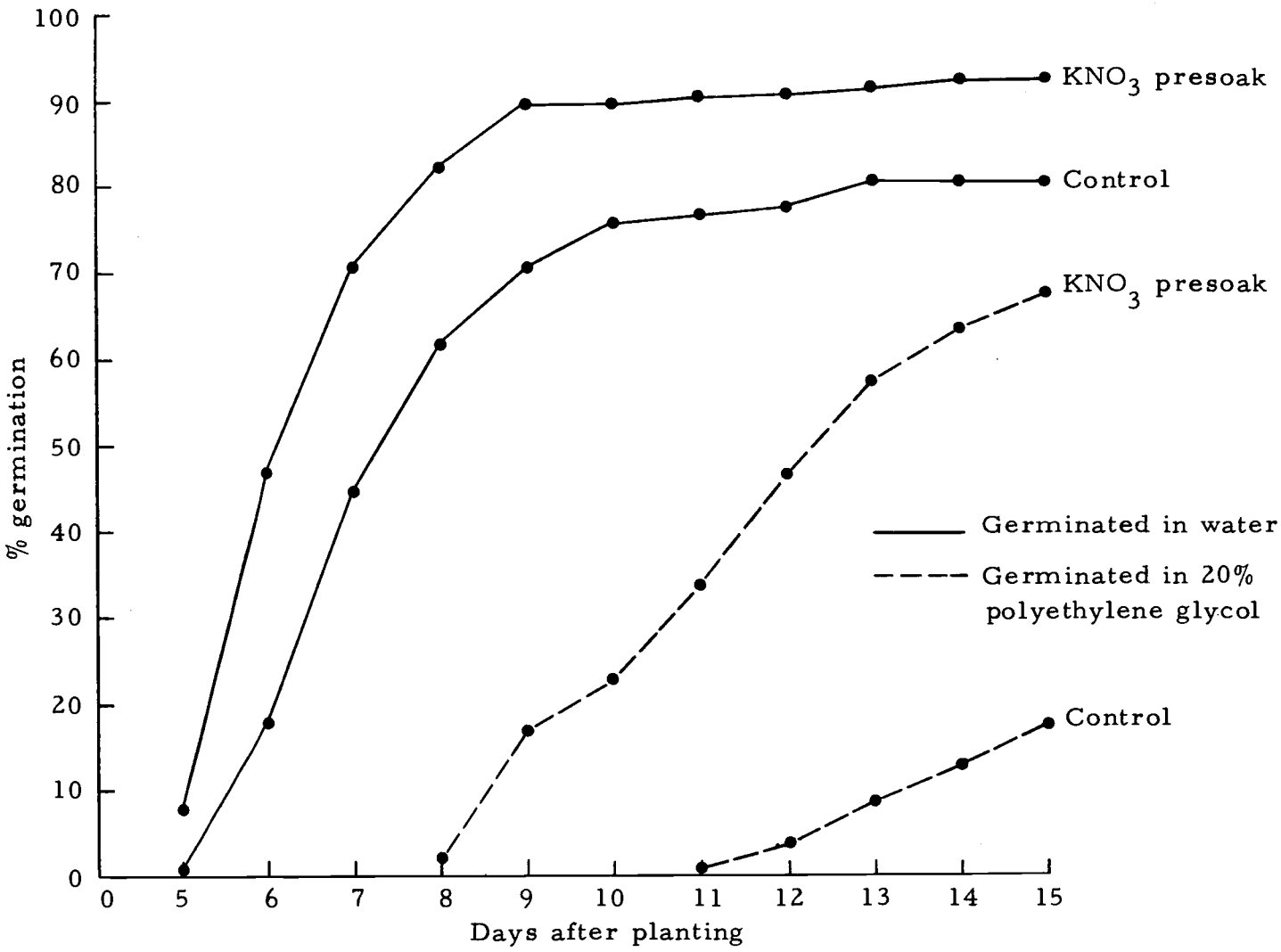

Figure 32. Percentage germination of KNO_3 presoaked Cougar Kentucky bluegrass seed in water and 20% polyethylene glycol. Seed germinated at 15-25°C.

from presoaking was proportional to the osmotic pressure of the solution (Figures 30 and 31).

Seedling Emergence Rate From Soil

The rates of emergence of presoaked seeds of four cultivars from soil in greenhouse plantings are shown in Figures 33 through 36. The percent and speed of emergence of the cultivars and treatments are shown in Table 13.

Table 13. Percent and speed of emergence of four Kentucky bluegrass cultivars presoaked in water, GA_3 and KNO_3. Germination recorded 20 days after planting in greenhouse soil.

	Control		H_2O Soak		KNO_3 Soak		GA_3 Soak	
Cultivar	EI[1/]	%	EI	%	EI	%	EI	%
Newport	1.3	21	3.1	45	.5	8	1.9	29
Merion	1.4	21	.8	15	.1	2	.2	3
Park	1.7	24	2.3	36	3.5	45	1.3	21
Pennstar	2.5	39	4.5	66	3.8	46	4.3	62
Average	1.7	26	2.7	41	2.0	25	1.9	29

[1/] Speed of emergence index.

Cultivar differences in speed of emergence were apparent with Park and Pennstar emerging first, followed by Newport, and Merion last.

Presoaking in water improved the emergence rate and total emergence of Newport and Pennstar, while presoaking in KNO_3 was

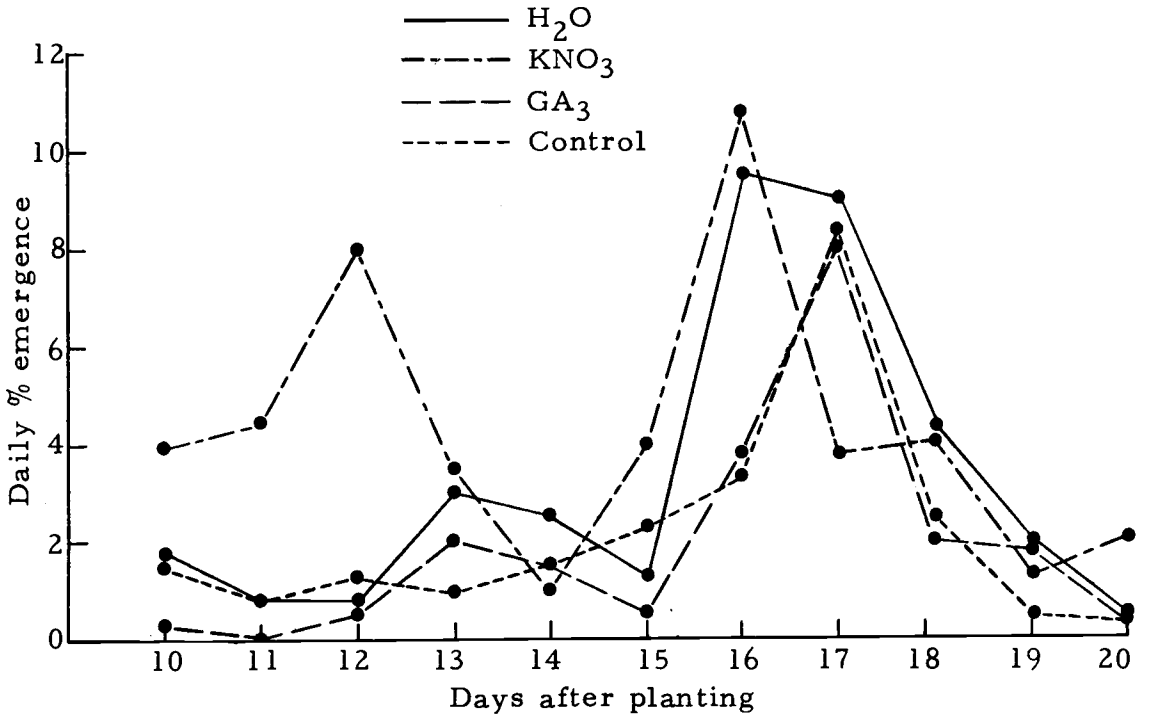

Figure 33. Daily emergence percentages of 1971 Park Kentucky bluegrass seed from soil after soaking and drying treatments.

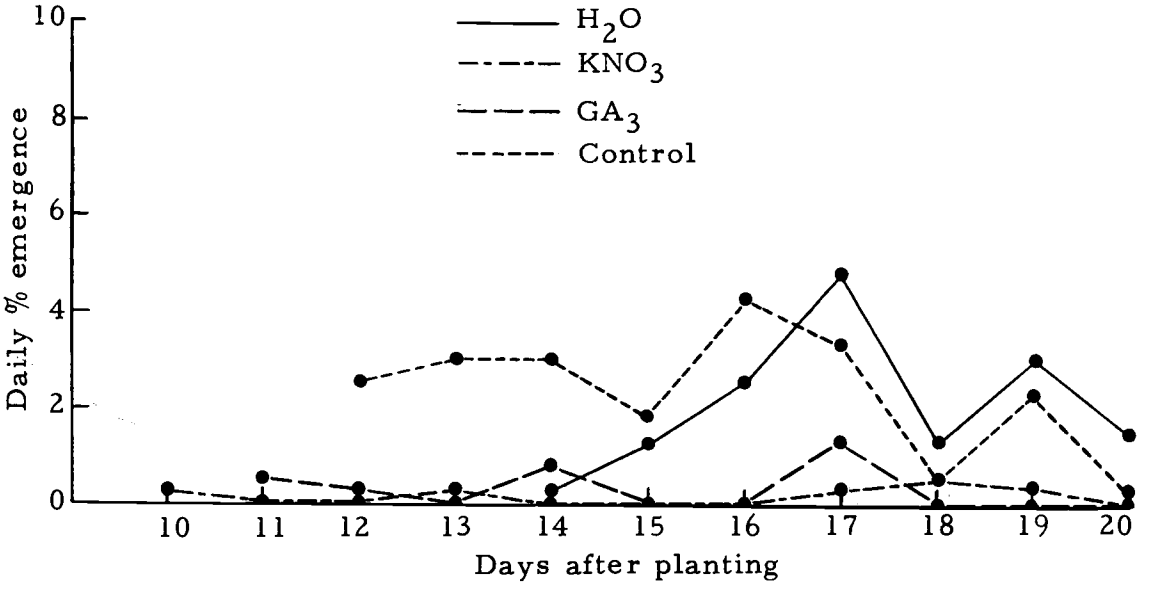

Figure 34. Daily emergence percentages of Merion Kentucky bluegrass seed from soil after soaking and drying treatments.

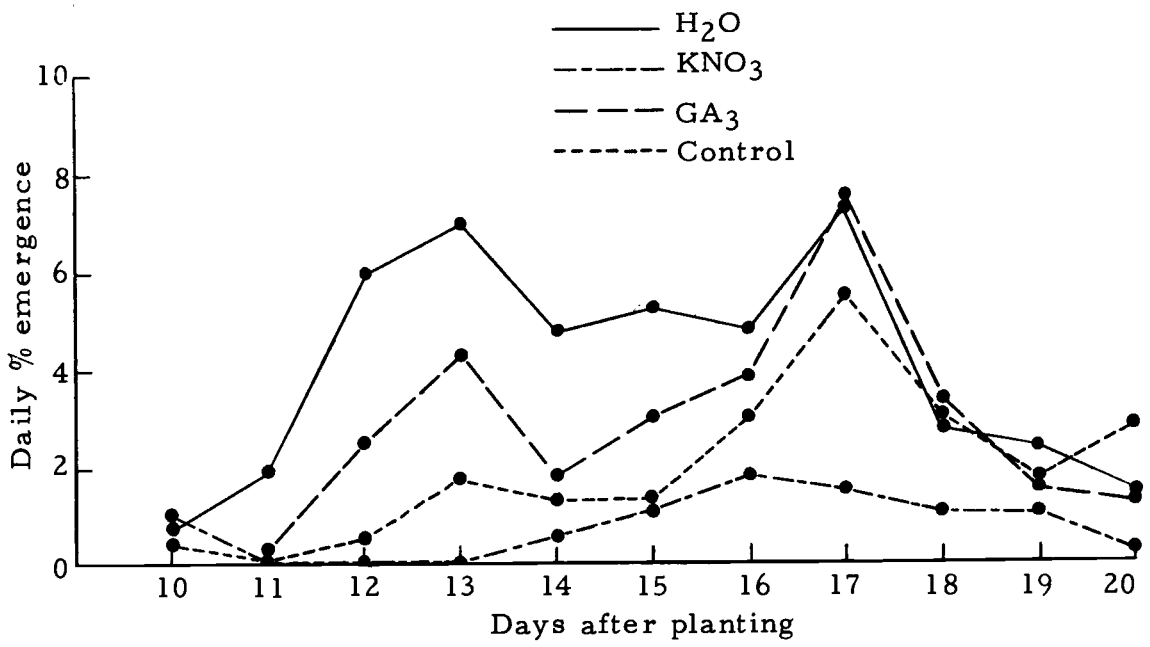

Figure 35. Daily emergence percentages of 1971 Newport Kentucky bluegrass seed from soil after soaking and drying treatments.

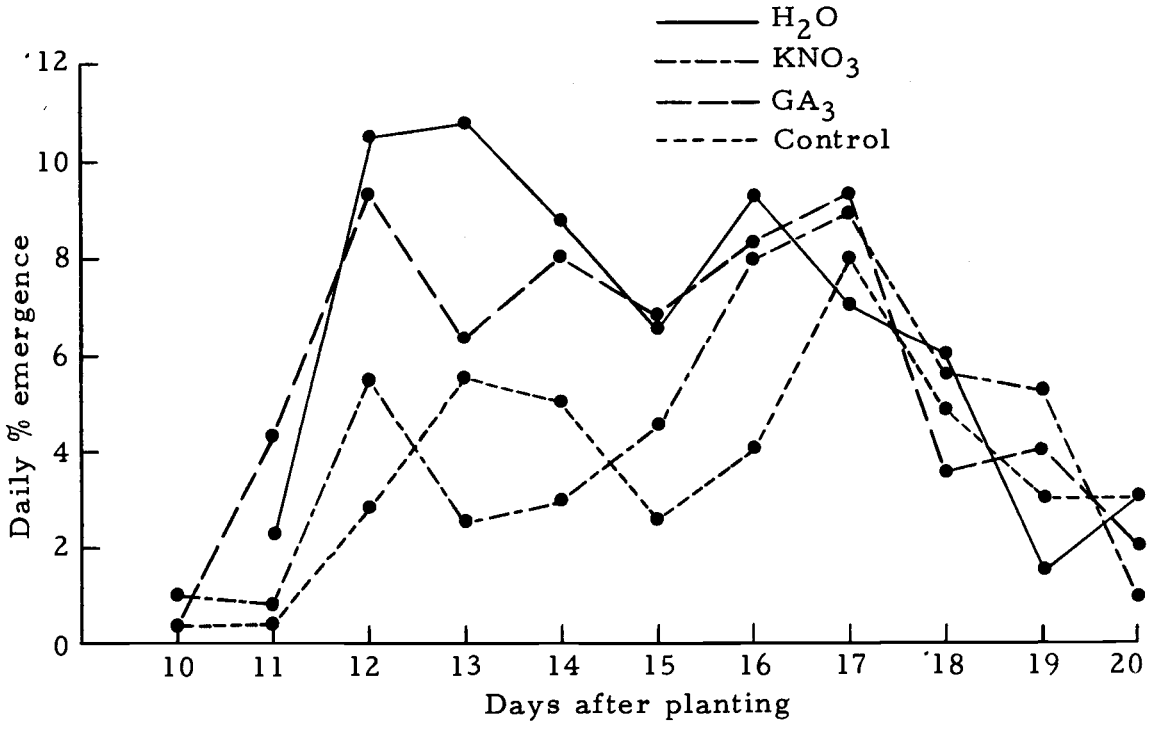

Figure 36. Daily emergence percentages of Pennstar Kentucky bluegrass seed from soil after soaking and drying treatments

more effective for Park. All presoaking treatments had adverse effects on Merion. These differences in the speed of emergence, however, were not significant. The analysis of variance for these data are shown in Appendix Table 12.

Storability of Presoaked Seeds

Presoaking and drying had no adverse effect on the storage life of the seed. On the contrary, stored seeds germinated faster and had higher germination percentages than the non-stored seeds when germination took place at a stress (25°C) temperature (Table 14). At a germination temperature of 15-25°C, there was no difference between the two treatments (Table 15).

At both germination temperatures, whether they were stored or not, treated seeds performed better than the controls as indicated by LSD's at the 1% level.

Again, seeds presoaked in KNO_3 germinated faster than those treated with water and GA_3, with no difference between water and GA_3 treatments. The analyses of variance for these data are shown in Appendix Tables 13 and 14.

In a second experiment with stored seeds, speed and germination percentages of Merion, Cougar and Windsor were determined at three temperatures. For each cultivar, the effects of the treatments varied according to the temperature of germination (Table 16). In

Table 14. Effect of four months storage on percent and speed of germination of presoaked Merion, Cougar, Pennstar and Windsor Kentucky bluegrass cultivars. Seed germinated at 25° C.

	H_2O Soak				KNO_3 Soak				GA_3 Soak					
	Not Stored		Stored		Not Stored		Stored		Not Stored		Stored		Control	
Cultivar	GI[1/]	%	GI	%	GI	%	GI	%	GI	%	GI	%	GI	%
Pennstar	.3	2	4.9	30	1.3	7	2.2	14	1.1	8	1.1	6	.3	2
Merion	.5	3	.1	15	1.0	5	.1	1	.1	1	.0	0	.0	1
Windsor	2.6	12	2.3	13	4.5	26	5.8	33	2.3	11	2.9	15	.0	0
Cougar	12.8	82	15.4	89	13.8	83	16.2	87	13.5	81	15.1	88	7.4	52
Average	4.1	25	5.7	37	5.2	30	6.1	34	4.3	25	4.8	27	1.9	14

[1/] Speed of germination index.

Table 15. Effect of four months storage on percent and speed of germination of presoaked Merion, Cougar, Pennstar and Windsor Kentucky bluegrass cultivars. Seed germinated at 15-25°C.

	H_2O Soak				KNO_3 Soak				GA_3 Soak					
	Not Stored		Stored		Not Stored		Stored		Not Stored		Stored		Control	
Cultivar	GI[1/]	%	GI	%	GI	%	GI	%	GI	%	GI	%	GI	%
Merion	7.5	70	7.3	69	9.0	71	7.9	68	8.4	77	7.0	65	8.1	74
Pennstar	8.9	81	10.0	81	11.3	91	11.4	84	9.9	84	9.9	87	8.8	80
Windsor	13.8	97	13.6	96	14.6	95	15.1	96	10.3	95	13.8	98	11.4	93
Cougar	14.0	91	13.9	94	14.8	94	12.4	80	13.7	92	13.8	93	12.2	92
Average	11.1	85	11.2	85	12.4	88	11.7	82	10.6	87	11.1	86	10.1	85

[1/] Speed of germination index.

Table 16. Percent and speed of germination of Merion, Cougar and Windsor Kentucky bluegrass seeds presoaked in water and KNO_3 and germinated at 20, 25 and 15-25° C.

	20° C						25° C						15-25° C					
	Cont		H_2O		KNO_3		Cont		H_2O		KNO_3		Cont		H_2O		KNO_3	
Cultivar	GI[1/]	%	GI	%	GI	%	GI	%	GI	%	GI	%	GI	%	GI	%	GI	%
Merion	.3	3	.2	2	.2	2	0	0	0	0	.1	0	7.9	84	5.9	58	6.8	67
Windsor	.5	5	4.0	39	9.5	82	0	0	.9	3	5.6	30	11.6	99	13.4	92	14.9	95
Cougar	9.1	65	12.5	85	15.5	97	7.8	53	14.9	73	15.7	91	11.8	81	12.9	83	13.1	93
Average	3.3	24	5.6	42	8.4	60	2.6	18	5.3	25	7.1	40	10.4	88	10.7	78	11.6	85

[1/] Speed of germination index.

Cougar, the greatest advantage from presoaking (38%) occurred at 25°C, while in Windsor, the greatest advantage (77%) occurred at 20°C. Presoaking lowered the germination of Merion.

Effects of Other Stimulation Procedures on Seed Performance

Storage at Room Temperature

The effects on speed of germination of natural after-ripening during 7 months of storage at room temperature are shown in Tables 17 and 18.

Compared with the control seeds which were stored at 5°C, seeds stored at room temperature after-ripened to a degree that germination was more rapid at both 15-25 and 25°C.

At 15-25°C, there were significant differences among the storage lengths. LSD's at 1% level showed that seeds stored for 4 and 7 months germinated faster than the control did. The average germination speed at 4 months, however, was faster than at 7 months. The analysis of variance for these data is shown in Appendix Table 15.

When cultivar X storage interactions were observed, 4 and 7 months of storage were equally beneficial for Baron, Windsor, Merion, Pennstar and Cougar. However, 1971 Park and 1971 Newport performed better after 4 months, and Fylking performed better after 7 months of storage.

Table 17. Percent and speed of germination of 13 Kentuckly bluegrass cultivars stored for four and seven months at room temperature. Seed germinated at 15-25°C.

Cultivar	Year of Production	Control[1]		4 Months Storage		7 Months Storage	
		GI[2]	%	GI	%	GI	%
Merion	1971	4.0	49	8.1	80	8.5	74
Pennstar	1971	8.0	78	9.5	81	9.4	84
Fylking	1971	8.3	81	9.9	88	11.6	89
Baron	1971	9.8	87	13.3	94	13.5	82
Windsor	1971	10.3	94	13.5	99	13.5	97
Park	1971	10.5	74	14.1	79	11.9	83
Newport	1971	11.6	85	13.7	98	11.8	92
Cougar	1971	12.5	97	14.1	94	13.3	98
Newport	1970	10.2	90	11.2	93	11.2	95
Delta	1968	10.7	85	12.4	89	11.7	89
9 GK 36	1969	12.8	94	13.3	91	12.1	92
Park	1970	13.7	92	15.7	95	13.5	91
0 GK 33	1970	14.2	98	15.4	95	13.3	95
Average		10.5	85	12.6	90	11.9	89

[1] Stored at 5°C.

[2] Speed of germination index.

Table 18. Percent and speed of germination of 13 Kentucky bluegrass cultivars stored for four and seven months at room temperature. Seed germinated at 25° C.

Cultivar	Year of Production	Control[1]		4 Months Storage		7 Months Storage	
		GI[2]	%	GI	%	GI	%
Merion	1971	.0	0	.0	0	.2	1
Fylking	1971	.0	0	.5	3	.5	3
Windsor	1971	.0	0	.5	3	1.2	8
Pennstar	1971	.4	1	.7	7	1.3	9
Baron	1971	.4	2	2.5	20	4.0	27
Park	1971	3.9	16	5.1	26	3.2	16
Newport	1971	3.9	25	6.1	40	5.8	34
Cougar	1971	11.6	73	12.9	83	15.1	85
Newport	1970	.4	4	2.0	13	2.1	14
9 GK 36	1969	2.9	16	5.1	30	5.8	33
Park	1970	6.7	39	9.9	55	11.6	61
0 GK 33	1970	7.8	40	5.3	34	9.6	51
Delta	1968	11.4	72	10.2	75	11.7	71
Average		3.8	29	4.7	30	5.5	32

[1] Stored at 5° C.

[2] Speed of germination index.

When 25°C was used as the germination temperature, again 4 and 7 months of storage stimulated the speed of germination significantly but, in general, seeds stored for 7 months performed better than the seeds stored for 4 months as indicated by LSD's at 1% level. The analysis of variance for these data is shown in Appendix Table 16.

When cultivar X storage interactions were observed, only Baron and Cougar performed better after 7 months of storage; the others did not show any significant difference.

In Table 19, germination after 7 months of storage at room temperature is compared with germination after presoaking in KNO_3. The KNO_3 data are taken from Table 9.

The presoaking treatment was more beneficial in terms of percent and speed of germination than was after-ripening for 7 months at room temperature.

Accelerated Aging

Dry Heat Treatment. Storing Kentucky bluegrass seeds at 40 ± 3°C for short periods of time did not substitute for natural after-ripening in increasing their speed or percentage of germination. The results of this experiment are shown in Table 20. The differences among the lengths of storage were not significant (Appendix Table 17).

Humid Heat Treatment. The effects of humid storage conditions

Table 19. Percent and speed of germination of seeds of eight Kentucky bluegrass cultivars stored at room temperature for seven months compared with seeds presoaked in KNO_3. Germination recorded for 15 days after planting at 25°C.

Cultivar	Control[1]		7 Months Storage		KNO_3 Presoak	
	GI[2]	%	GI	%	GI	%
Merion	.0	0	.2	1	.0	0
Fylking	.0	0	.5	3	3.4	21
Windsor	.0	0	1.2	8	6.1	30
Pennstar	.4	1	1.3	9	1.8	3
Baron	.4	2	4.0	27	1.5	38
Park	3.9	16	3.2	16	11.4	44
Newport	3.9	25	5.8	34	14.4	68
Cougar	11.6	73	15.1	85	17.0	91
Average	2.5	15	3.9	23	7.0	37

[1] Stored at 5°C.

[2] Speed of germination index.

Table 20. Percent and speed of germination of Merion, Windsor and Cougar Kentucky bluegrass cultivars stored at 40 ± 3°C. Germination recorded for 15 days after planting at 15-25°C.

Days Storage	Merion		Windsor		Cougar	
	GI[1]	%	GI	%	GI	%
0	7.8	80	11.9	95	12.5	91
5	7.9	83	10.8	98	11.4	97
10	9.1	95	9.9	88	11.5	90
15	8.7	93	11.2	98	11.9	95
20	7.1	80	11.1	94	11.9	90
25	7.9	81	10.8	95	11.2	92
30	7.9	84	10.6	99	11.2	86

[1] Speed of germination index.

on the speed of germination and percentage germination are shown in Table 21.

There were significant differences among the lengths of storage and among the storage conditions (Appendix Table 18). LSD's at the 1% level indicated that storing the seeds of Merion at either 75% or 100% RH at 25°C for 5 days improved both the speed of germination and the final germination over that of the control.

Seeds of Windsor and Cougar stored at 75% RH and 25°C showed increased speed of germination over the controls after 15 and 20 days of storage with no adverse effects on viability.

In general, seeds started to deteriorate in the first 5 days of storage at 100% RH at 40°C and in 10 days of storage at 75% RH at 40°C. Seeds stored at both humidities at 25°C however, still performed as well as the controls did until the end of the storage period.

Table 21. Percent and speed of germination of Merion, Windsor and Cougar Kentucky bluegrass cultivars stored at four combinations of temperature and relative humidity. Germination recorded for 15 days after planting at 15-25°C.

Days Storage	75%, 25°		75%, 40°		100%, 25°		100%, 40°	
	GI[1/]	%	GI	%	GI	%	GI	%
Merion								
0	7.4	73	7.4	73	7.4	73	7.4	73
5	8.9	82	6.0	60	9.0	86	3.4	46
10	7.4	69	5.3	53	5.6	60	2.8	37
15	7.4	68	2.8	31	5.7	64	.4	6
20	8.2	75	4.1	43	7.7	82	.0	0
25	7.7	75	.9	11	7.3	79	.0	0
30	7.6	74	.3	3	6.5	71	.0	0
Windsor								
0	10.8	95	10.8	95	10.8	95	10.8	95
5	10.1	88	9.0	86	9.4	88	7.3	81
10	11.3	89	7.8	80	10.4	92	7.2	85
15	12.4	99	6.3	72	10.8	94	5.1	67
20	12.6	99	3.6	40	9.6	88	.5	7
25	10.8	91	2.4	29	10.3	90	.0	0
30	10.9	94	.7	9	10.7	93	.0	0
Cougar								
0	11.5	91	11.5	91	11.5	91	11.5	91
5	12.0	96	9.6	85	10.7	88	7.9	74
10	12.3	91	8.5	78	12.5	91	8.2	79
15	13.0	93	7.8	75	11.0	85	1.7	20
20	12.6	92	5.2	52	10.8	92	.0	0
25	11.6	93	2.7	32	9.9	79	.0	0
30	11.4	95	.7	9	11.8	92	.0	0

[1/] Speed of germination index, LSD .05 = 1.09, LSD .01 = 1.45.

DISCUSSION

These experiments indicated that the speed of germination and emergence of Kentucky bluegrass seed can be increased by presoaking and drying treatments. In many cases, treated seeds began to germinate earlier and the period of peak germination occurred earlier as well.

Cultivars varied strikingly in their responses to the stimulation treatments. It was expected that the most dormant cultivars would be benefited the most as Haight (1972) found in orchardgrass. The opposite was true for Kentucky bluegrass, however. Merion, the cultivar most difficult to germinate under laboratory conditions, did not benefit from soaking and drying and frequently had a lower germination percent after treatment. Cougar and Newport, cultivars with the least specific germination requirements, were stimulated most by the treatments. The results show the importance of including several cultivars in experiments of this type where conclusions regarding the physiological responses of seeds are to be made.

The responses to soaking and drying differed under the different environmental conditions in which the seeds were germinated. Most of the germination tests were conducted at 15-25°C, representing a favorable temperature, and at 25°C, representing a temperature unfavorable to germination. The effects on percent and speed of

germination were generally more apparent at the less favorable constant temperature of 25° C. In one experiment where treated seeds of Windsor was germinated at 20° C as well as 25° C, the treated seeds exhibited a 77% advantage in total germination at 15 days. This indicates the need for additional testing of treated seeds at other temperatures to fully evaluate the stimulatory affects.

Limited testing of treated seeds on a thermal gradient plate indicated that treatment extended the temperature range over which the seeds germinated. At constant temperatures, treated seeds were able to germinate at temperatures 3 degrees cooler and 4 degrees warmer than was possible for untreated seeds.

Germination on the thermal gradient plate also indicated that treatment lessened the need for alternating temperatures which untreated seeds require for germination.

Oyer and Koehler (1966) and Haight (1972) also reported that more pronounced benefits from soaking occurred when seeds were germinated at stress temperatures.

One of the most striking effects of the soaking and drying treatments was the increased ability of the seeds to germinate under moisture stress conditions. Under the simulated drought conditions provided by the polyethylene glycol solutions, germination differences between treated and untreated seeds increased as the osmotic pressure increased. This feature should be of a distinct advantage in

establishing stands in home lawns which often are not maintained at optimum soil moisture levels. Since laboratory experiments showed promising results, drought resistance of presoaked Kentucky bluegrass seeds should be investigated further under moisture stress conditions in the soil.

Chippindale (1934), Marty'anova (1960) and May, Milthorpe and Milthorpe (1962) reported that drought hardiness of wheat and barley seeds also were increased by wetting and drying treatments.

Of the many soaking procedures investigated, presoaking the seeds for 6 days at 5°C in aerated KNO_3 solution was determined to be the most desirable. Haight (1972) also found that 5°C was the best presoaking temperature for Kentucky bluegrass, but did not include soaks beyond 4 days in his experiments.

Since soaking the seeds for 6 days at 5°C is similar to the cold, moist prechilling treatment used to break dormancy in seeds, the reduced level of dormancy is probably accounted for by this prechilling effect.

Observation of the germination characteristics of the cultivars indicated that alternation of germination temperature was the most important factor in Kentucky bluegrass germination. The same conclusions have been reported by Toole (1923), Nelson (1927), Nakamura (1962) and others. Considering this fact, the seeds were soaked at alternating temperatures of 5-25°C, but they did not perform

better than the seeds soaked at constant 5°C, when germinated at stress temperature (25°C). The requirement of Kentucky bluegrass seeds for alternating temperatures to germinate was best fulfilled during the germination period, rather than during presoaking. When optimum temperature (15-25°C) was used for germination however, there was no difference between presoaking at 5° and 5-25°C. Haight (1972) also found that 5-30°C promoted germination as well as 5°C.

Aeration was of questionable value when soaking at 5°C, but was more beneficial at 20°C, possibly because of a higher respiration rate of the seeds at the higher temperature. The findings of Andrews and Beals (1919) and Oyer and Koehler (1966) tend to agree with the beneficial results of aerating Kentucky bluegrass seeds.

Among the chemicals used, KNO_3 was the most stimulating one. However, when soil was used as the germination substratum, the beneficial effects of KNO_3 were not seen, possibly because of nitrates already present in the soil. GA_3 was also beneficial for certain cultivars like Baron and Cougar.

Non-dormant cultivars such as 1971 Park, Cougar and 1971 Newport presoaked in nutrient solutions had a faster start in germination than the other cultivars. This could be due to the nutrients which were absorbed by the seeds during presoaking and were ready to be used in the first few days of germination. The effects of presoaking the seeds in nutrient solutions needs further study before any more

speculations can be made.

May, Milthorpe and Milthorpe (1962), Hall (1969), Austin, Longden and Hutchinson (1969), Longden (1971) and Berrie and Drennan (1971) have reported beneficial results from three or four cycles of wetting and drying of wheat, carrot, tomato and sugar beet seeds. Repeated cycles of soaking and drying were no better than one cycle for Kentucky bluegrass seeds, however.

The soaking treatments were more effective than ordinary storage for after-ripening of the seeds. The soaking and drying treatments did more in 1 week to increase germination speed than for 7 months at room temperature.

Although Hite (1923) reported that the first few weeks of storage at 40° C increased the rate of germination of Kentucky bluegrass seed, little practical benefit was obtained from short exposure to dry or humid heat.

Throughout the conduct of this study, applicability of the treatments to commercial practice was regarded as an important objective. The methods and materials chosen for study were those that could also be applied to soaking seeds in bulk quantities.

Soaking treatments are feasible since the seeds can be dried and stored without losing the beneficial effects of the treatments. In this regard, the results agree with those of Hopkins (1960) and Haight (1972). Attempts have been made in the past to establish turf seedings

by planting soaked seeds in the wet condition, but this proved very difficult. By drying the seeds, plantability is not impaired and the stimulation effects are retained. It was encouraging to find that the soaking and drying treatments did not reduce the viability of the seeds over a 7-month storage period.

Field plantings are now required to determine if the effects of soaking and drying observed in the laboratory will be of practical benefit in obtaining more rapid stand establishment of grass seedings.

SUMMARY AND CONCLUSIONS

Of themany soaking procedures investigated, a presoaking length of 6 days and a temperature of 5°C was found to be the most desirable. Soaking the seeds in submerged cheesecloth bags and aerating the solution resulted in stimulation of germination almost equal to that from soaking them on blotters.

Drying the presoaked seeds for 24 hours was sufficient for them to return to their original moisture contents.

Soaking at alternating temperatures of 5-25°C was no better than soaking at continuous 5°C. Repeated cycles of soaking and drying did not give greater stimulation than one cycle.

Among the chemical solutions used, 0.2% KNO_3 promoted germination the most. Complete nutrient solution (Hoagland's), gibberellic acid and benzyl adenine were also beneficial.

The effects of presoaking treatments were evaluated in terms of speed of germination, percent germination, maximum and minimum germination temperatures, alternating germination requirements, germination under moisture stress conditions, soil emergence and storability.

The beneficial effects of the treatments were more pronounced when seeds were germinated at a stress temperature (25°C) than at a more optimum one (15-25°C).

Presoaked seeds started to germinate 1 to 2 days earlier, reached the peak of germination 1 to 3 days earlier, and frequently had a higher germination percentage than the control.

Treated seeds germinated at temperatures 3°C lower and 4°C higher than the unsoaked seeds.

The ability to germinate under moisture stress conditions was improved by soaking. Seeds of Cougar presoaked in KNO_3 had 50% more germination than the unsoaked controls at the end of 15 days when germinated in 20% polyethylene glycol.

Presoaked seeds emerged faster in soil, but the difference was not statistically significant. Seeds presoaked in water performed better than seeds presoaked in KNO_3 when they were planted in soil.

During storage for 4 months at room temperature, the positive effects of the treatments were not reversed and viability was not reduced.

Presoaking increased the germination speed to a greater degree than the after-ripening which took place during 7 months of storage at room temperature.

Moist storage (75% RH at 25°C) hastened the after-ripening process, but dry storage did not.

Cultivars responded differently to the treatments. Merion, the cultivar which was hardest to germinate in the laboratory, was not

affected by the treatments. Less dormant cultivars such as Cougar, Park and Newport were stimulated more than the more dormant Pennstar, Fylking and Windsor.

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APPENDIX

Appendix Table 1. Analysis of variance for time of presoaking in H_2O and KNO_3 on the speed of germination of Fylking and Windsor Kentucky bluegrass seed. Germination recorded until the 15th day after planting at 15-25°C.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares
Length	30.53	5	6.11**
Chemical	120.53	2	60.27**
Cultivar	179.62	1	179.62**
L x chem	47.88	10	4.79**
L x cult	11.84	5	2.37
Chem x cult	17.76	2	8.88**
L x chem x cult	21.88	10	2.19
Replication	.71	2	.36
Pooled error	85.53	70	1.22
Total	516.28	107	

** Significant difference at 1% level.

Appendix Table 2. Analysis of variance for time of presoaking in KNO_3 on the speed of germination of 1971 Kentucky bluegrass cultivars. Germination recorded until the 15th day after planting at 15-25°C.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares
Length	32.66	3	10.89*
Cultivar	789.60	7	112.80**
L x C	98.05	21	4.67
Replication	11.66	2	5.83
Pooled error	177.82	62	2.87
Total	1109.80	95	

*Significant difference at 5% level.
**Significant difference at 1% level.

Appendix Table 3. Analysis of variance for the speed of germination of five Kentucky bluegrass cultivars presoaked by using three different methods and two different temperatures. Germination recorded until the 15th day after planting at 15-25°C.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares
Method	45.98	2	22.99**
Temperature	138.16	1	138.16**
Cultivar	301.23	4	75.31**
M x T	37.70	2	18.85**
M x C	68.63	8	8.58**
T x C	48.17	4	12.04**
M x T x C	19.80	8	2.47
Replication	5.24	2	2.62
Pooled error	112.61	58	1.94
Total	777.53	89	

**Significant difference at 1% level.

Appendix Table 4. Analysis of variance for the speed of germination of five Kentucky bluegrass cultivars presoaked by using three methods and two temperatures. Germination recorded until the 15th day after planting at 25°C.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares
Method	.40	2	.20
Temperature	420.38	1	420.38**
Cultivar	1588.57	4	397.14**
M x T	38.11	2	19.06**
M x C	18.52	8	2.32
T x C	310.41	4	77.60**
M x T x C	37.63	8	4.70**
Replication	8.23	2	4.12*
Pooled error	66.09	58	1.14
Total	2488.35	89	

*Significant difference at 5% level.
**Significant difference at 1% level.

Appendix Table 5. Analysis of variance for the speed of germination of eight 1971 Kentucky bluegrass cultivars pre-soaked in nine chemical solutions. Germination recorded until the 15th day after planting at 15-25°C.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares
Chemical	195.92	9	21.77**
Cultivar	1098.23	7	156.89**
Chem x cult	233.61	63	3.71**
Replication	3.12	2	1.56
Pooled error	211.47	158	1.34
Total	1742.35	239	

**Significant difference at 1% level.
LSD .05 = .66
LSD .01 = .87

Appendix Table 6. Analysis of variance for the speed of germination of eight 1971 Kentucky bluegrass cultivars pre-soaked in nine chemical solutions. Germination recorded until the 15th day after planting at 25°C.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares
Chemical	562.06	9	62.45**
Cultivar	3891.70	7	555.96**
Chem x cult	566.86	63	9.00**
Replication	4.90	2	2.45
Pooled error	308.84	158	1.95
Total	5334.34	239	

**Significant difference at 1% level.
LSD .05 = .80
LSD .01 = 1.06

Appendix Table 7. Analysis of variance for the speed of germination of five Kentucky bluegrass cultivars presoaked at 5-25 and 5°C in three chemical solutions. Germination recorded until the 15th day after planting at 15-25°C.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares
Soaking temperature	.10	1	.10
Chemical	72.48	2	36.24**
Cultivar	437.83	4	109.46**
Temp x chem	11.83	2	5.91**
Temp x cult	7.09	4	1.77
Chem x cult	8.72	8	1.09
Temp x chem x cult	11.14	8	1.39
Replication	1.91	2	.96
Pooled error	67.31	58	1.16
Total	618.42	89	

**Significant difference at 1% level.

Appendix Table 8. Analysis of variance for the speed of germination of five Kentucky bluegrass cultivars presoaked at 5-25 and 5°C in three chemical solutions. Germination recorded until the 15th day after planting at 25°C.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares
Soaking temperature	73.55	1	73.55**
Chemical	324.30	2	162.15**
Cultivar	2232.24	4	558.06**
Temp x chem	33.01	2	16.51**
Temp x cult	171.46	4	42.87**
Chem x cult	90.85	8	11.36**
Temp x chem x cult	18.25	8	2.28
Replication	.96	2	.48
Pooled error	111.52	58	1.92
Total	3056.15	89	

**Significant difference at 1% level.
LSD .05 = .58
LSD .01 = .78

Appendix Table 9. Analysis of variance for the speed of germination of two Kentucky bluegrass cultivars subjected to six cycles of presoaking and drying. Germination recorded until the15th day after planting at 15-25°C.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares
Cycle	15.12	5	3.02
Chemical	1.13	2	.57
Cultivar	800.99	1	800.99**
Cycle x chem	17.07	10	1.71
Cycle x cult	6.96	5	1.39
Chem x cult	1.25	2	.62
Cycle x chem x cult	10.52	10	1.05
Replication	2.77	2	1.38
Pooled error	90.80	70	1.30
Total	946.58	107	

**Significant difference at 1% level.

Appendix Table 10. Analysis of variance for the speed of germination of two Kentucky bluegrass cultivars subjected to six cycles of presoaking and drying. Germination recorded until the 15th day after planting at 25°C.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares
Cycle	1.52	5	.30
Chemical	6.84	2	3.42
Cultivar	4627.18	1	4627.18**
Cycle x chem	9.88	10	.99
Cycle x cult	1.33	5	.27
Chem x cult	2.76	2	1.38
Cycle x chem x cult	4.87	10	.49
Replication	4.28	2	2.14
Pooled error	93.90	70	1.34
Total	4752.55	107	

**Significant difference at 1% level.

Appendix Table 11. Analysis of variance for the speed of germination of two Kentucky bluegrass cultivars presoaked and planted with three concentrations of polyethylene glycol. Germination recorded until the 15th day after planting at 15-25°C.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares
Chemical	14.53	2	7.26**
Concentration	556.28	2	278.14**
Cultivar	205.33	1	205.33**
Chem x conc	7.30	4	1.83*
Chem x cult	64.19	2	32.09**
Conc x cult	10.12	2	5.06**
Chem x conc x cult	7.60	4	1.90*
Replication	.17	2	.09
Pooled error	20.48	34	.60
Total	866.01	53	

*Significant difference at 5% level.
**Significant difference at 1% level.
LSD .05 = .53
LSD .01 = .71

Appendix Table 12. Analysis of variance for the speed of emergence of four presoaked Kentucky bluegrass cultivars.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares
Chemical	9.50	3	3.17
Cultivar	71.54	3	23.85**
Chem x cult	31.84	9	3.54
Pooled error	108.57	48	2.26
Total	221.45	63	

**Significant difference at 1% level.

Appendix Table 13. Analysis of variance for the data comparing speed of germination of four Kentucky bluegrass cultivars presoaked and planted with four cultivars presoaked and stored for four months. Germination recorded until the 15th day after planting at 15-25°C.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares
Treatment	.56	1	.56
Chemical	47.48	3	15.83**
Cultivar	490.97	3	163.66**
Treat x chem	7.03	3	2.34*
Treat x cult	7.33	3	2.44*
Chem x cult	35.28	9	3.92**
Treat x chem x cult	22.81	9	2.53**
Replication	2.06	2	1.03
Pooled error	48.26	62	.78
Total	661.79	95	

*Significant difference at 5% level.
**Significant difference at 1% level.
LSD .05 = .51
LSD .01 = .68

Appendix Table 14. Analysis of variance for the data comparing speed of germination of four Kentucky bluegrass cultivars presoaked and planted with four cultivars presoaked and stored for four months. Germination recorded until the 15th day after planting at 25° C.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares
Treatment	12.79	1	12.79**
Chemical	179.87	3	59.96**
Cultivar	2345.66	3	781.89**
Treat x chem	10.40	3	3.47**
Treat x cult	10.76	3	3.59**
Chem x cult	147.55	9	16.39**
Treat x chem x cult	29.00	9	3.22**
Replication	.70	2	.35
Pooled error	34.07	62	.55
Total	2770.81	95	

**Significant difference at 1% level.
LSD .05 = .43
LSD .01 = .60

Appendix Table 15. Analysis of variance for the speed of germination of 13 Kentucky bluegrass cultivars stored at room temperature for four and seven months. Germination recorded until the 15th day after planting at 15-25°C.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares
Storage	90.77	2	45.38**
Cultivar	483.78	12	40.32**
Storage x cultivar	67.12	24	2.80**
Replication	2.25	2	1.12
Pooled error	36.86	76	.49
Total	680.78	116	

**Significant difference at 1% level.
LSD .05 = .32
LSD .01 = .42

Appendix Table 16. Analysis of variance for the speed of germination of 13 Kentucky bluegrass cultivars stored at room temperature for four and seven months. Germination recorded until the 15th day after planting at 25°C.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares
Storage	60.67	2	30.34**
Cultivar	2105.74	12	175.48**
Storage x cultivar	85.01	24	3.54**
Replication	1.97	2	.99
Pooled error	47.74	76	.63
Total	2301.13	116	

**Significant difference at 1% level.
LSD .05 = .36
LSD .01 = .48

Appendix Table 17. Analysis of variance for the speed of germination of three Kentucky bluegrass cultivars treated with dry heat. Germination recorded until the 15th day after planting at 15-25°C.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares
Length	2.74	5	.55
Cultivar	340.29	2	170.14**
Treatment	10.70	1	10.70**
L x C	17.04	10	1.70
L x T	3.75	5	.75
C x T	11.02	2	5.51**
L x C x T	15.88	10	1.59
Replication	2.45	2	1.23
Pooled error	64.50	70	.92
Total	468.37	107	

**Significant difference at 1% level.

Appendix Table 18. Analysis of variance for the speed of germination of three Kentucky bluegrass cultivars treated with humid heat. Germination recorded until the 15th day after planting at 15-25°C.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares
Length	329.38	5	65.88**
Treatment	2783.24	4	695.81**
Cultivar	579.66	2	289.83**
L x T	485.17	20	24.26**
L x C	57.18	10	5.72**
T x C	47.41	8	5.93**
L x T x C	115.36	40	2.88**
Replication	.29	2	.15
Pooled error	82.13	178	.46
Total	4479.83	269	

**Significant difference at 1% level.