AN ABSTRACT OF THE THESIS OF

Francisco Humberto Dübbern de Souza for the degree of Master of Science

in Crop Science presented on December 16, 1977

Title: GRASS SEED QUALITY IN RELATION TO TIME OF WINDROWING

Redacted for Privacy

Abstract approved: ______________________________
Don F. Grabe

This study was undertaken to obtain information on the quality of grass seed when windrowed at the high moisture levels necessary for obtaining maximum yields. A secondary goal was to monitor moisture and temperature fluctuations in the windrow and to relate their effects to development and deterioration of the seed.

Three species of perennial grasses were included in the study: tall fescue (*Festuca arundinacea* Schreb.) variety "Fawn", orchardgrass (*Dactylis glomerata* L.) variety "Potomac", and perennial ryegrass (*Lolium perenne* L.) variety "Linn".

The effect of heading date on seed development at the recommended windrowing time was evaluated with individually tagged panicles.

Tall fescue was windrowed on 28 June, 01 July and 06 July; orchardgrass on 28 June, 01 July and 06 July; and perennial ryegrass on 01 July, 06 July and 16 July. These dates were chosen to provide windrows mowed at moisture levels higher than, equal to, and lower than the optimum for maximum yields of pure live seed. Moisture and

temperature fluctuations in the windrow were monitored and changes in seed development and deterioration were evaluated.

Heading date influenced several seed quality characteristics at the recommended time for windrowing. Early inflorescences were lowest in seed moisture content. Tall fescue and perennial ryegrass seeds from the Late group, and orchardgrass seeds from the Intermediate and Late groups had not attained maximum seed weight. Seedlings of tall fescue and orchardgrass produced by seeds from the Late group had not attained maximum shoot weight. Seeds of all inflorescence age groups reached maximum viability several days before optimum windrowing date.

Seed moisture contents when windrowed were 51.6, 41.5, and 15.9% in tall fescue, 44.8, 41.4 and 30.7% in orchardgrass, and 49.8, 28.5 and 19.1% in perennial ryegrass. During periods without rainfall, seed moisture decreased rapidly during the day, increased during the night, and decreased to a new low the following day. Several rains occurred during this period, raising seed moisture levels above 40%. During the drying period, seed moisture in the lower part of the perenial ryegrass windrow was as much as 8% higher than seed in the upper part. The average maximum temperatures in the upper and lower portions of the perennial ryegrass windrow were 38.3 and 24.3$^{\circ}$C during July and 31.1 and 19.2$^{\circ}$C during August. The maximum temperature reached in the upper part was 47$^{\circ}$C on 28 and 29 July.

Each weeks' delay in windrowing resulted in improved seed quality, with the greatest improvement occurring between the first and second cutting, However, the data support Klein and Harmond's recommendations for windrowing tall fescue at 43% moisture, orchardgrass at 44% moisture, and perennial ryegrass at 35% moisture. Perennial ryegrass seed quality was not improved by delaying windrowing, while orchardgrass and tall fescue seeds increased somewhat in weight. Because of the risk of increased shattering losses, delaying windrowing to improve seed quality does not appear justified.

A small amount of seed development took place while the seeds were in the windrow. Seed weight of tall fescue harvested at 51.6% moisture increased from 250.6 to 279.6 mg/100 seeds. No increase in seed weight occurred in the other species or windrowing dates. After several days in the windrow, speed of germination increased in all three species. Germination percentage, seedling emergence, and shoot weight did not improve after windrowing.

Very little seed deterioration occurred during the first month in the windrow. A perceptible drop in germination of orchardgrass and perennial ryegrass occurred during the 2 weeks prior to the 19 August sampling date. Seed weight declined by the end of the experimental period in all three crops. Some germinated seeds were found in the perennial ryegras windrows by the end of August. No reduction in speed of germination or shoot weight occurred, while there was a trend toward reduced seedling emergence near the end of the experimental period. There were no indications that the stage of maturity when harvested influenced the rate of seed deterioration in the windrow.

The probability of seed deterioration occurring at a faster rate than in 1976 is not great since a total of 75.69 mm (2.98 in) of rain fell during the experimental period, compared to a normal rainfall of 27.43 mm (1.08 in).

# Grass Seed Quality in Relation to Time of Windrowing

by

Francisco Humberto Dübbern de Souza

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed December 1977

Commencement June 1978

APPROVED:

Redacted for Privacy

Professor of Agronomy
in charge of major

Redacted for Privacy

Head of Department of Crop Science

Redacted for Privacy

Dean of Graduate School

Date thesis is presented December 16, 1977

Typed by Brenda Oberson for Francisco Humberto Dübbern de Souza

ACKNOWLEDGMENTS

I want to express my sincere gratitude to several people I met during my graduate program at the Oregon State University:

Dr. Don F. Grabe for his advisory during the execution of this work and preparation of this thesis.

All the staff members of the Oregon State University Seed Laboratory, for their friendship and for the use of lab equipment;

Dr. H. D. Bunch, Director of International Programs at the Mississippi State University; to AGIPLAN, contract between Mississippi State University and Federative Republic of Brazil, and to EMBRAPA, for the financial support;

My fellow Crop Science graduate students, for their friendship and collaboration;

Dr. K. L. Chambers, Dr. R. Highsmith, and Dr. H. W. Youngberg, for serving as members of the graduate committee;

Janice Seibel for helping me with the correction of part of the manuscripts of this thesis.

I also am deeply grateful to Dr. F. F. Toledo and Dr. J. Marcos Filho, from the University of Sao Paulo for the guidance during the first steps of my career and for the opportunities they gave me.

TABLE OF CONTENTS

## LIST OF TABLES

LIST OF TABLES (continued)

## LIST OF FIGURES

# GRASS SEED QUALITY IN RELATION TO TIME OF WINDROWING

## INTRODUCTION

Harvesting seed at the proper time is of particular importance to grass seed growers since both the yield and quality of the seed are determined at that time. Because of the indeterminate growth habit of most grasses, the seeds do not mature and ripen uniformly. Early maturing seeds frequently shatter before the late developing seeds are mature. To prevent excessive seed shattering, most grass seed crops in the Willamette Valley are windrowed before combining. To obtain maximum yields, the crop usually must be windrowed before all the seeds have fully developed and before excessive shattering has occurred. Thus a grass seed lot at harvest normally contains seeds of varying stages of development and quality.

Several researchers have attempted to determine the best harvest time to obtain maximum seed yields. Klein and Harmond (1971) have demonstrated that maximum yields of pure live seed occur at specific moisture levels in each grass species. Most such studies do not give attention to the quality of the seed, other than viability, at the time maximum yields are attained.

While the practice of windrowing is effective in preventing excessive shattering, seed deterioration and sprouting may occur during periods of excessively wet weather. Little information is available concerning the environmental conditions within the windrow or of the effect of these conditions on seed development and deterioration.

This study was undertaken to obtain additional information on the relationships between optimum windrowing time, seed quality, and the developmental and deteriorative changes seeds undergo in the windrow. Specific objectives were to: (a) determine the quality of the seed at the harvest times recommended for maximum yield, (b) study the post-harvest development of the seed in the windrow, (c) monitor moisture and temperature fluctuations in the windrow, (d) observe the effect of environmental factors on deterioration of seed in the windrow, and (e) assess the effects of heading date on quality of the seed.

# LITERATURE REVIEW

## Effect of Inflorescence Age on Seed Development in Grasses

Seed development of cultivated grass species has been described in terms of dry weight, germination, moisture content, etc. on the basis of individual seed. Few authors have studied seed development in relation to the age of the inflorescence. This is of particular importance since continuous formation of new tillers and decay of old ones--characteristic of grass species--results in a state of continuous change in the plant (Langer, 1956) which is reflected in inflorescence formation and, ultimately, in seed development (Pegler, 1976). The quality of the seed lot as a whole may be affected as a consequence.

Langer (1956), studying the life history of individual tillers in timothy (Phleum pratense), attributed the difference in yield between tillers of different age groups or position to variation in the number of seeds per ear, since the 1,000-seed weight did not vary significantly. In 1959, Stoddart, attempting to determine the relative contribution to the total yield by different inflorescence age groups in a population of timothy, found a high negative correlation between head length and emergence date. He chose four head lengths, ranging from 4 to 13 cm in three varieties, and studied seed development on them. He noticed that seed setting in the shortest of the heads was low compared to the other head lengths. The weight of the seed decreased with the length of the head. In two of the varieties, seeds from the smallest heads were very low in germination by the time of harvest, which occurred 40 and 45 days after anthesis, depending on the variety. By delaying harvest to allow further development of those seeds, excessive loss by shattering would have occurred.

Lewis (1961) observed in S. 53 meadow fescue (Festuca pratensis), that the tillers which were formed by the end of the year produced a higher yield per tiller and seeds of better quality than the tillers formed later.

Anslow (1963) studied seed formation in S. 24 perennial ryegrass (Lolium perenne). The inflorescences were classified in three age groups according to their time of emergence. The groups were called Early, Intermediate, and Late, and the age difference between them was 1 week. The age groups contributed 17.5, 42.1, and 40.4%, respectively, to the total number of heads. In all groups, anther exsertion peaked on the same day, although it occurred in a reduced frequency in the Late group. The florets from the Late group were considerably less fertile than those from the other groups. Anslow further reported (1964) that the seeds in the Early heads dried faster than those in the Later heads. Maximum germination in seeds from the Early heads occurred about 18 days after anthesis, or 8 days ahead of the Later heads, which were also lower in germination.

Maximum germination value in the Early and Intermediate heads occurred 4 to 6 days before the maximum seed weight was reached. In the case of Late heads, maximum germination was not reached until 26 days after anthesis and this also was before maximum seed weight was reached. Seeds in the Late heads were 67% lighter than those from the Early heads.

Roberts (1971) collected random sheaves of seed heads of two varieties of tetraploid ryegrass at 3 to 4 day intervals, beginning midway through the ripening period. He observed that samples collected after the seeds had reached 45% moisture content showed a sudden depression in germination capacity, which was attributed to the contribution of physiologically unripe seeds from late formed tillers.

Hill and Watkin (1975) reported that in ryegrass, timothy, and prairie grass (*Bromus unioloides*), most seed head components were influenced by the time of ear emergence. The early inflorescences were longer, bore more spikelets and more florets per head and had a greater culm length than the late heads. The first two of the four emergence groups studied contributed between 75 and 85% of the total heads in the crop. In another paper (1975), the authors showed considerable variation in seed weight between heads of the different emergence groups. In the case of ryegrass and prairie grass, the seeds from the second emergence group were the heaviest, and for the other species the lowest seed weight occurred in heads from the last group.

## Effect of Time of Harvesting on Grass Seed Quality and Yield

Perhaps the biggest problem in the cultivation of a grass seed crop is the determination of the proper time for harvesting. The harvest would be best performed at the point where the maximum yield and the highest seed quality can be obtained. In grass crops, shattering is a major determinator of yield. The maturation stage of the seed can also influence the yield and it is closely related to seed quality.

Time of harvest has been studied by many authors. The highest yield of the best quality reed canary grass (Phalaris arundinacea) seeds was obtained by Wilkins and Hughes (1932) by harvesting them at the time 5% of the seeds had shattered. Harvesting consisted of hand-picking the heads and allowing the seeds to dry on them before threshing.

Hermann and Hermann (1939) observed high viability in hand harvested crested wheatgrass (Agropyron cristatum) seeds after the early dough stage of endosperm development; however vigorous seedlings were obtained only after the hard dough stage.

McAlister (1943) studied the viability and storability of eight grass species, among them Agropyron, Bromus, Elymus, and Stipa. Harvests were made at the pre-milk, milk, dough, and mature stages of development. Seeds from the pre-milk and milk stages were usually inferior in viability and longevity to seeds harvested at dough or mature stages. Dough stage seeds had similar viability and longevity as mature seeds in all species.

Lawrence (1960) concluded that Russian wild ryegrass (Elymus junceus) seeds of good quality (measured in terms of germination and emergence in greenhouse flats) can be obtained even from seeds harvested at an immature stage if the swath method of harvest is used. At those same stages of maturity however, straight combining followed by drying impaired the quality of the seed to a greater extent. He stated that combining or swathing earlier than 6 days before maturity can result in a smaller yield than if the crop is harvested just prior to the stage of excessive shattering, due mainly to low 100-kernel weight.

"Manchar" smooth bromegrass (Bromus inermis) and "Delta" Kentucky bluegrass (Poa pratensis) seeds harvested at various moisture content, starting as soon as the seeds could be threshed with a combine, did not show any difference in germination, when harvested by the simulated-windrow method. The average germination of those seeds was considerably higher than the average of the combine harvested ones. The authors, DeWitt et al. (1962) stated that the straight combine method of harvest must be done at a high moisture content to avoid shattering losses. As a consequence, bad quality seeds, resulting from early interruption of development, and heating problems during curing may occur.

Horning and Canode (1963) harvested smooth bromegrass seeds containing from 65 to 12.5% moisture by simulated straight-combining and simulated-windrowing. Windrow harvested seeds peaked in seed weight at 45.2% moisture, while the straight-combined ones did the same 2 days later at 34.1% moisture. No difference was found in the final weight attained by the seeds harvested by both methods. Peak germination was reached at 60.8% moisture by the windrow harvested seeds and 12 days later (at 24.1% moisture) by the straight-combine harvested ones. Average germination was 79.8% for the windrow harvested seeds and 65.4% for the straight-combine ones. Only small differences in germination were observed from seeds harvested at widely different moisture content. Seedlings produced by windrow harvested seeds were bigger than those from the straight combine harvested seeds.

Nellist and Rees (1963) obtained the maximum yield, germination, and highest speed of germination of S. 37 cocksfoot (*Dactylis glomerata*) seeds by swathing the crop 22 days after anthesis when the seeds had 44% moisture content and threshing them after 10 days in the swath. The quality of direct combined seeds was comparatively poor until 32 days after anthesis, although the yields were considered good. By the time their quality reached acceptable levels, the yields were low due to heavy shattering. The author recommended moisture testing as a good method to determine the best time for harvest.

Arnold and Lake (1965) concluded that the best way to harvest S. 48 timothy seeds is to cut the crop just before shattering starts and artificially dry them. In the case of S. 143 cocksfoot, the same authors (1966) reported that swathing should be done at 40% moisture content for maximum yield and germination. Direct harvesting should not be performed before 30% moisture content, but at this point the yield is reduced due to shattering losses.

Lawrence (1967), studying the effect of simulated straight combine and simulated windrow harvesting on Russian wild ryegrass seed, reported that after 5 years seeds harvested by the straight combine method germinated less than 60%, whereas those windrow harvested 3 to 4 days before excessive shattering occurred still germinated 75% or higher. Seeds harvested at earlier stages of maturity by either method deteriorated in germination at a similar rate.

Nellist and Rees (1968) obtained the highest yield and quality of S. 24 ryegrass seeds by swathing the crop at 40 to 50% moisture content and threshing when it fell to 30%. Direct harvesting at 35% moisture resulted in even higher yield and the seeds obtained were of reasonable quality.

Jensen and Jørgensen (1969) concluded that the degree of maturity greatly influenced the germination capacity, speed of germination, and storability of combine harvested Festuca pratensis seeds. The stage of development did not influence the germinability of the seeds dried in sheaves before threshing.

Roberts (1969), in an attempt to determine the best time for harvesting S. 352 timothy seed reported that 40% moisture content or 30 to 35 days after peak anthesis seems to be the point at which maximum seed weight and good germination can be obtained. If the seed is to be combine harvested it should not be done before 30% moisture but at this point shattering losses might be excessive.

Klein and Harmond (1971) surveyed harvesting operations for grass and small legume seeds and concluded that the optimum point for harvesting a crop is a result of a balance between seed weight, germination capacity, shattering losses, and combining losses. They observed that the optimum time for mowing often occurred before peak germination, and many times it occurred after some shattering had already taken place. They determined the best time for maximum yield of pure-live-seed of several crops by periodically windrowing the crop throughout the harvest season. They proposed the use of curves relating yield and moisture content of the seed in the standing crop for the determination of the proper mowing time.

Williams (1972) concluded that the best time to direct combine tetraploid hybrid ryegrass is when the seed reaches the 40% moisture content level. At this point maximum yield and germination capacity can be obtained.

McWilliam and Schroeder (1974) obtained light seeds with low viability and low seedling performance, by hand-harvesting Phalaris tuberosa earlier than 27 to 30 days after the onset of anthesis. By delaying the harvest, better quality seeds were obtained but a marked reduction in yield occurred because of shattering.

Hill and Watkin (1975), studying time and method of harvesting for maximum viable seed yield of perennial ryegrass, timothy, and prairie grass, concluded that the highest yield was obtained when the crops were mowed at or slightly prior to seed maturity, which occurred about 30 days after peak anthesis in all species. Drying curves, where yield and moisture content of the standing crop were associated, were drawn for each of the species studied, and their use for the prediction of the most adequate cutting time was proposed.

Nascimento et al. (1976) studied the effect of harvest date upon the vigor and germination of molasses grass (Melinis minutiflora) and jaragua grass (Hyparrhenia rufa) seeds. They found that for molasses grass the maximum vigor and percentage of germination was attained by the seeds between 41 and 48 days after flowering. The same stage was reached by jaragua grass at two times, at 34 and 55 days after flowering.

Pegler (1976) studied the harvest ripeness in ten varieties of forage grasses. He observed that maximum germination seed yield was usually obtained after shattering had already begun. The peaks of germinable seed yield and of individual seed weight did not coincide, maximum seed yield frequently occurring earlier. He found endosperm development to be a reliable guide for the assessment of the best time for windrowing, and suggested it be used together with moisture content for an even better assessment.

## Drying of Seed in the Windrow

The environmental conditions to which seeds are subjected in the windrow are known to influence the quality of those seeds. Actually, windrowing is somewhat equivalent to seed storage under field conditions. For this reason, farmers are always concerned about having a windrowed crop in the field, since thay have little control over the factors which make up the windrow environment, such as temperature, rainfall, etc. Few researchers have studied changes in seed quality in the windrow.

Robertson (1956) studied the rate of drying of oats (*Avena sativa*) in the windrow. He observed that under conditions where no wetting occurred, seed moisture content decreased during the day, remained constant during the night and decreased again on the following day. However, when the material was subjected to a series of wetting and drying periods, each succeeding drying period removed slightly more moisture than had been deposited in the preceding wetting period. From this, Robertson deduced that the increase in the moisture content of the material after a rainfall is mostly due to superficial water. He affirms that there is a minimum time required for a windrowed crop to reach equilibrium moisture content, and this time seems not to be severely affected by weather conditions. The same author (1957) observed the rate of drying of an oat crop cut in windrows of various sizes and arrangements. He concluded that a) the stubble height influences the rate of drying of the windrow and that the height should be determined by the crop, with a minimum of 6 and a maximum of 10 inches, b) the optimum density of the windrow should permit fast drying and at the same time protect as much of the crop from rainfall as possible, c) the smaller the windrow the faster the moisture losses associated either with the ripening of the crop or the evaporation of surface water from rainfall or condensation, d) the smaller the windrow the faster the rate of wetting by rainfall, due to a greater ratio of perimeter to cross-sectional area, e) the loss of moisture from inside of the material proceeds at a rate that is independent of the weather conditions, while the superficial moisture depends on the saturation deficit of the atmosphere and can change at very fast rates.

Blight (1962), comparing results obtained from roofed and unroofed windrows, confirmed the results obtained by Robertson in 1956. He went a little further, reporting that 1 day seems to be enough to bring the moisture level back to the original level before the wetting period, even after a heavy rain. Blight (1963) compared the drying rates of barley (Hordeum vulgare) windrows of various sizes, in an attempt to establish the most appropriate width of cut for a machine for windrowing barley. He concluded that, compared to oats, the width of the machine is much less important when windrowing barley. Even though more bulkey than an oat windrow, a double 11-ft windrow arrangement dried almost as fast as a double 5-1/2-ft arrangement.

Dodds and Pelton (1969) reported that weather factors can affect moisture fluctuation in a windrowed crop of what (Triticum aestivum). They observed that most of the moisture gained by the wheat kernels in the windrow was attributed to rainfall. Nevertheless, during periods of low vapor pressure deficits occurring either following a rain or under weather conditions which created it, condensation may maintain the existing moisture content or even increase it. The authors also observed that despite unfavorable weather conditions in some instances, the moisture content of the kernels kept decreasing, as indication that the maturing process was still occurring.

Hart and Burton (1967), studying the effect of weather upon the curing process in coastal bermudagrass (Cynodon dactylon) hay, observed that the moisture content of the windrowed crop after a day of curing was significantly influenced by the initial water content, vapor pressure deficit of air, solar radiation, and yield.

Germination of Kentucky bluegrass seeds harvested with 26 to 29% moisture and dried in the windrow was not influenced by any of the five drying conditions imposed by Canode et al. (1970). In the same study, the authors observed that seeds from 5 to 10 cm depths in the windrow dried more slowly than seeds on the surface under the three shading conditions applied. The temperature of the windrow was within a range that could have caused damage to the seed, but none occurred.

Hayhoe (1973), in a review of the effect of weather on the field drying of forages, concluded that little was known about moisture and temperature within the windrow, or how they are related to general weather conditions.

## Seed Development in the Windrow

Swathing is a crop procedure widely applied by grass seed growers. This practice, which causes the interruption of the functional contact between the roots and the aerial parts of the plant, results in several advantages to the growers such as reduction of shattering losses, elimination of artificial drying, possibility of handling large acreages, and others. Some of these advantages are related to the post-cutting development of the seeds, which occurs on the windrowed culm in the field. This aspect of seed development has been studied by several researchers.

As early as 1893, evidences of post-harvest changes in seeds on detached culms were reported. In that year Kedzie (1893) observed that wheat seeds dried on the cut straw were heavier than those shelled and weighed immediately. Davenport and Fraser (1896) reported that wheat kernels harvested at watery or milk stages of endosperm development had a higher weight when dried on the straw than when removed and dried separately. The weight difference was as large as 6% when the drying occurred in the sun and 11% when in the shade. For the crop harvested at dough stage, however, the differences were not significant.

Harlan and Pope (1926) studied the development of immature barley kernels under different circumstances. They observed that kernels kept moist on the culm after cutting continued growing in endosperm and embryo for at least 8 days after harvest. However, when the immature kernels were allowed to air dry on the culm, the embryo length was approximately 40% shorter than when the culm was kept moist. Embryos of detached kernels dried in the slumes grew as much as those dried on the culm. No growth was observed in the immature kernels when they were removed from the culm, separated from the palea and lemma, and air dried. By observing development, although limited, in kernels dehulled and kept moist, they concluded that differentiation can take place even without noticeable increase in the weight of the kernel. The observations led the authors to conclude that photosynthesis products are translocated after harvest from the culm to the kernel.

Other authors have not observed seed development after cutting the plant. Arny and Sun (1927), working with wheat and oats, observed a reduction in yield when the plants were cut before the seeds reached maturity and allowed to cure in the shock. No matter the date at which the culms were cut, weight of 1,000 kernels was as great when dried rapidly in the oven than when cured slowly in bags or shocks. They concluded that no materials were translocated from the straw to the grain after cutting.

Wilson and Raleigh (1929) observed that the weight per bushel and 1,000-kernel weight of wheat and oats were greater when the plants were allowed to mature before harvest. The plants cut at any time before 6 days previous to maturity produced lower grain weight. No significant differences were observed among seeds produced by plants submitted to different treatments such as drying in an oven immediately after cutting, drying in a shock, in a shock with the culm bases immersed in water, and in bags under the eaves of a shed. Different amounts of plant parts attached to the seeds did not influence the 1,000 kernel weight. The authors stated that no appreciable translocation of reserves from the vegetative portions of the plant to the caryopsis occurs with the severance from the roots, from the milk stage to maturity.

Pope (1935) detached culms of "Hannchen" barley just before anthesis and immersed their basal portions in distilled water. Seeds harvested 29 days later weighed 19 mg while the seeds from intact culms weighed 53 mg.

Culpepper and Moon (1941) reported that seeds from sweet corn (*Zea mays*) ears harvested at an early stage of development germinated better if allowed to dry on the cob than when removed from the cob before drying. The germination was even better if the ear was kept on the cut stalk during the drying process.

Green *et al.* (1975) observed accumulation of $^{32}P$ in the kernels or windrowed wheat containing more than 35% moisture. However, no accumulation occurred below this level of moisture. They suggested that the loss of yield observed by other authors in wheat windrowed at a seed moisture content higher than 35% could be attributed to: 1) cutting off the translocation of stored food, mainly carbohydrates, from the lower part of the plant to the developing seed, or 2) cessation of the water movement from the root to the head, causing a moisture stress and a consequent reduction of photosynthesis in the flag leaf and inflorescence, or 3) limitation of light incidence under windrow conditions, resulting in a reduction of photosynthesis.

No accumulation of stored food seems to occur in seeds after they have reached physiological maturity.

Keller (1943) observed that the eleven grass species included in his study set viable seeds when the culms were detached near flowering time and immersed in tap water. Compared with the seeds produced by intact plants, seeds from detached culms were lighter, germinated only slightly less, took a longer period of time to germinate, and were fewer in number.

McWilliam and Wardlaw (1965) studied seed development in detached culms and intact plants of Phalaris tuberosa. The culms were detached at several times from anthesis to seed maturation, and were kept with their basal portion immersed in tap water. The culms detached at anthesis produced seeds weighing 20% less than seeds matured on the intact plants. The earlier the culms were detached, the greater the reduction in the number and quality of the seeds set. The detachment of the culm during the last 6 days of development did not affect the quality of the seeds produced when evaluated in terms of seedling dry weight. Shortening of the stem resulted in reduction of seed set and seed weight, but the removal of all or some of the leaves did not. Shading of the inflorescence greatly reduced seed set. By using labeled $CO_2$ and intact culms, they showed that only the photosynthates produced by the inflorescence and the upper part of the stem are utilized for seed development.

The post-harvest chemical changes in seeds of two Lolium species were studied by Stoddart (1965). He concluded that the later stages of seed maturation, described in terms of carbohydrate and alpha-amino-nitrogen, are able to proceed to completion without the existence of a functional attachment of culm to the root system. Stoddart observed that during the latter half of the ripening period carbohydrate translocation between seed and parent plant serves primarily to compensate for losses due to respiration. If harvest is made anytime after this point has been reached, the carbohydrate quality of the seed will not be affected but the weight will be reduced by the amount of sugar used in respiration occurring during the period between detachment and full ripeness. For the two species he studied, root independence occurred in qualitative terms by the time the seed reached the Total Soluble Carbohydrate maximum 8 to 13 days after anthesis. In terms of seed weight this point was reached only when the final endosperm free sugar content was stabilized. In seeds matured on intact plants the connection with the parent plant exists until the late dough stage, which indicates that detrimental changes can occur if the seeds are harvested before this point. The same author (1966) placed detached culms in $C^{14}$ sucrose solution and showed that sugar was readily incorporated into polysaccharides. The degree of uptake was directly proportional to the developmental stage of the seed at the time of detachment.

Nellist and Rees (1968) harvested S.24 ryegrass seed by direct and windrow harvesting, at four cutting dates over a period of 14 days, starting at 53.2% seed moisture content. The culms were threshed twice. The results from the first threshing showed that the seeds harvested directly were lighter and germinated less than the windrow harvested ones. The differences were not as significant among the seeds from the second threshing. The improvement in quality over the harvest period was associated with the gradual increase in 1,000 seed dry weight within the uncut and the windrowed crop. The authors suggested that the amount of weight gained by the seeds in the windrow depends on the rate at which the seed dries.

Koshy (1968) planted partially dissected panicles of annual bluegrass (Poa annua) removed at 0, 4, 8, 12, 16 and more than 16 days after anthesis. Seedling emergence occurred occurred even from the panicles harvested on the day of anthesis. He concluded that since the panicles did not receive any light under such circumstances, no photosynthesis occurred and the formation of the embryos and endosperms was based entirely upon reserves stored in various parts of the inflorescence.

Rampton and Lee (1969) observed a slight decrease in the 1,000-seed weight of orchardgrass seeds while curing in the windrow. This loss in weight was attributed to continued and rapid respiratory activity after windrowing which caused losses of dry matter in the individual seeds. Germination of the windrow-cured seeds was considerably superior to the drier cured seeds at all five stages of maturity at which the culms were cut.

# MATERIALS AND METHODS

The experiments involved three species of perennial grasses: tall fescue (Festuca arundinacea Schreb.) variety "Fawn", orchardgrass (Dactylis glomerata L.) variety "Potomac", and perennial ryegrass (Lolium perenne L.) variety "Linn".

The field studies were conducted from May to September of 1976 at the Hyslop Crop Science Field Laboratory, and the laboratory studies at the Seed Technology Laboratory at Oregon State University.

The plots, two of each species, were 3 years old and established on a Woodburn silt loam soil with good drainage. Each plot consisted of 12 rows 48.2 m (158 ft) long and 0.3 m (1 ft) apart, with a 1.5 m (5 ft) wide aisle separating them. They were flail-chopped in the Fall of 1975 and the residues were removed. Nitrogen was applied as urea (46%) at a rate of 114 kg/ha (100 lb/A) on 16 April 1976. Weed control was accomplished with 80% Karmex, 3.85 kg/ha (3.5 lb/A), applied the previous Fall, and occasional hoeing. Field mice presented a problem in the plots, and control was attempted with poison bait.

Climatic conditions from May to September were characterized as being unusually wet. The total precipitation during this period was 149 mm (5.87 in) (Table 12).

## Effect of Heading Date on Seed Development

### Field Procedures

Three groups of fully emerged inflorescences (characterized by having the last spikelet emerged from the flag leaf sheath) were tagged in one plot of each species at weekly intervals. Paper tags 2.5 x 3.0 cm in size were hung on the inflorescences at the flag leaf auricle level. Different colored tags were used each week. No inflorescences were tagged in the two outermost rows. The tagging (heading) dates were called Early, Intermediate, and Late. The number of inflorescences tagged varied from 150 to 300, depending on species and age of the inflorescences. The tagging started as soon as the inflorescences were in sufficient number.

Peak anthesis was determined by daily observation of 30 inflorescences randomly chosen within each age group. The extent of anthesis, as indicated by the presence of extruded anthers, was recorded. These observations were made between 930 and 1100 hours. The date of peak anthesis was defined as the day after anthesis first occurred over 75% of the length of the inflorescence.

At 2-day intervals after peak anthesis, a number of inflorescences were cut, wrapped in aluminum foil to prevent drying, and taken to the laboratory for study. The size of the sample varied according to the species, age of the inflorescences, and shattering.

Laboratory Procedure

The samples were threshed by hand. For moisture tests, a subsample was taken and tested immediately. The remaining samples were cleaned with a laboratory seed blower and observed on a diaphanoscope where the empty glumes were removed. Only seed[1] with caryopses longer than the rachilla were included.

Test procedures were as follows:

Moisture content. Approximately 2 g of seeds were dried 24 hours at 100°C, reweighed, and moisture content determined on a wet-basis. Duplicate determinations were made.

Seed weight. Two replications of 100 seeds were dried 24 hours at 80°C and weighed.

Germination test. Four replications of 50 seeds were planted on top of blotters soaked with 0.2% $KNO_3$ in plastic boxes 12 x 12 x 3 cm in size. The seeds were prechilled 5 days at 5°C and transferred to germinators for the time period and at the temperature prescribed by the AOSA Rules for Testing Seeds (1970). Water was added when necessary. Seedlings were evaluated 7 days after the test started

---

[1] The word seed throughout this thesis is used in the agronomic sense, referring to a one-seeded fruit (caryopsis) with attached lemma and palea.

and again at the end of the test period.

Shoot weight. Forty-eight seeds from each sampling date were prechilled 5 days at $5^{0}$C. Four replications of 12 seeds each were then planted 1.5 cm deep in 6-in plastic pots filled with a sterilized mixture (4:1) of soil and peat moss. Lime and fertilizer (13-13-13) were added before planting at a rate of 1.68 and 0.57 kg/$m^3$ of soil, respectively. The pots were arranged on greenhouse benches in a completely randomized design. Greenhouse temperatures were $18.5^{o}$ C for 16 hours at night and $24^{o}$C for 8 hours during the day. Water was applied daily. Four weeks after planting, the shoots were cut at soil level, put in paper bags, dried 1 hour at $100^{o}$C and 23 hours at $80^{o}$C, and weighed.

The germination and shoot weight tests were performed from April to June of 1977.

## Seed Development and Deterioration in the Windrow

### Field Procedures

Windrowing. A 50-ft length of a plot of each species was windrowed with a commercial windrower at three stages of seed maturity. The cutter bar was 18 cm (7 in) high for tall fescue and orchardgrass, and 10 cm (4 in) high for ryegrass. The border rows were removed before cutting, leaving a plot width of 3.0 m (10 ft).

Windrowing dates were 28 June, 01 July, and 06 July for tall fescue, 28 June, 01 July, and 06 July for orchardgrass, and 01 July, 06 July, and 16 July for ryegrass. These dates were chosen to provide windrows mowed at moisture levels higher than, at, and lower than the optimum suggested by Klein and Harmond (1971) for maximum yield of pure live seeds of the windrow.

Temperature monitoring. Temperatures in one of the perennial ryegrass windrows was continuously monitored with sensors placed 2.5 and 10.0 cm below the surface.

Sampling. For seed quality tests, seed samples of about 15-25 g were collected at random from the windrow, threshed on a rubbing board, wrapped in aluminum foil and transported to the laboratory. Samples were collected daily for the first 5 days, and at 6-day intervals thereafter until September. Samples were obtained twice a day, between 900 and 1100 and between 1500 and 1700 hours.

Starting on 8 July and continuing for 10 days, another set of samples was collected each morning and afternoon to study moisture fluctuations in the upper and lower portions of the windrow.

## Laboratory Procedures

Subsamples were taken immediately for moisture tests and the remainder cleaned before testing. Seed quality was evaluated a year later as follows:

Moisture content. Moisture content was determined as previously described.

Preparation. The samples were cleaned with a laboratory seed blower and observed on a diaphanoscope where the empty glumes were removed. Only seeds with caryopses longer than the rachilla were included.

Speed of germination index. Germination tests were conducted with four replications of 100 seeds as described previously. The boxes were rotated within ther germinator each day. Normal seedlings were removed daily and their number recorded. A normal seedling was considered to be one with a minimum shoot size of 1 cm for tall fescue and ryegrass, and 0.5 cm for orchardgrass, and whose plumule had extruded through the coleoptile. The speed of germination index was calculated according to Maguire (1962).

Germination. The final percent germination was obtained by summing the number of normal seedlings recorded daily for the speed of germination index.

Seed weight. Four replications of 100 seeds were weighed.

Shoot weight. Shoot weights were obtained as previously described, except that four replications of 13 seeds were planted 4 cm deep.

Seedling emergence. The number of normal seedlings emerged in the shoot weight test was recorded before harvest.

## Statistical Procedures

The data were evaluated by Analysis of Variance. The existence of significant differences was tested by the F test. The level of significance found among treatment means was determined by the L. S. D. test. Simple correlation was used to evaluate the degree of association among the means of the different seed quality tests (Steel and Torrie, 1960).

# RESULTS AND DISCUSSION

## Effects of Heading Date on Seed Development

The effects of heading date on seed development in the three grass species are shown in Figures 1-12. The important consideration here was to compare the quality of the seed from inflorescences of different ages at the time windrowing is recommended. The vertical line in each figure labeled "Windrowing date" indicates the date that seed moisture content of the entire plot was optimum for windrowing (Klein and Harmond, 1971). These moisture levels were 41.5% for tall fescue, 41.4% for orchardgrass, and 28.5% for perennial ryegrass.

The number of tagged inflorescences was considerably reduced before harvest by lodging and field mice. Also, as shattering became extremely heavy by the end of the maturation period, the number of inflorescences necessary to make up the required sample size had to be increased. All these factors contributed to the lack of inflorescences from the Early group at the end of the maturation period and sampling and testing could not be continued past the windrowing date.

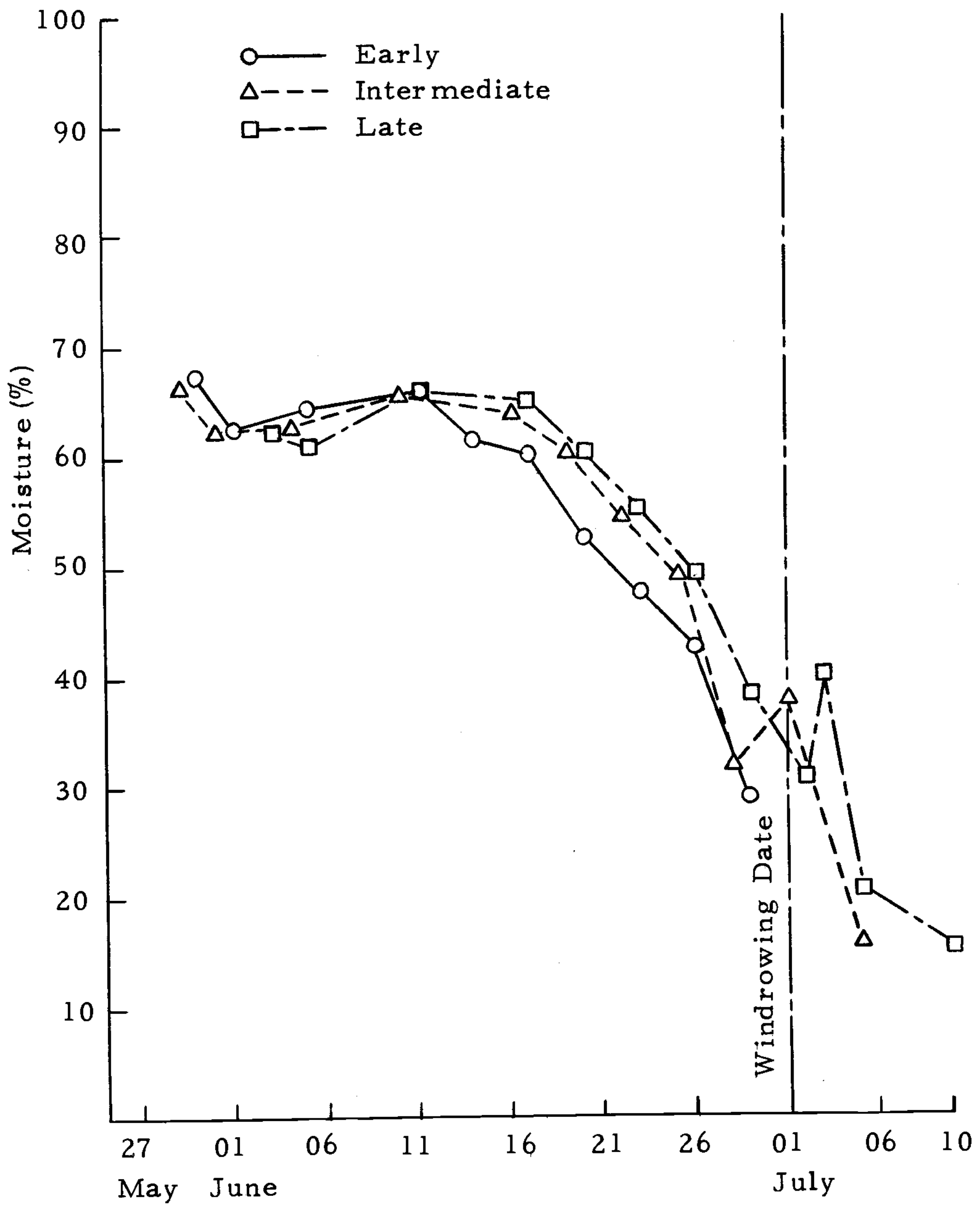


Figure 1. Effect of heading date on seed development in tall fescue: moisture content.

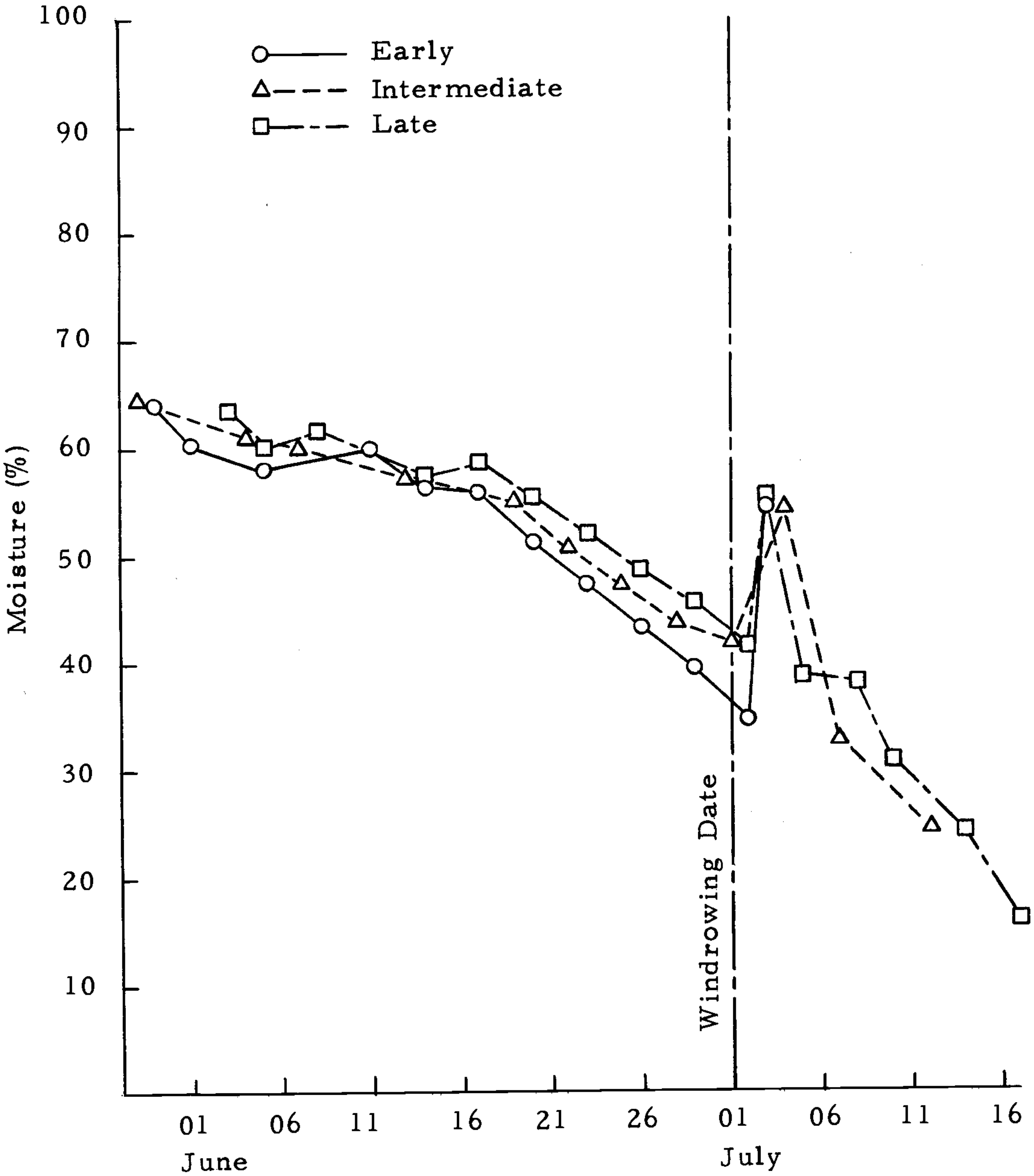


Figure 2. Effect of heading date on seed development in orchardgrass: moisture content.

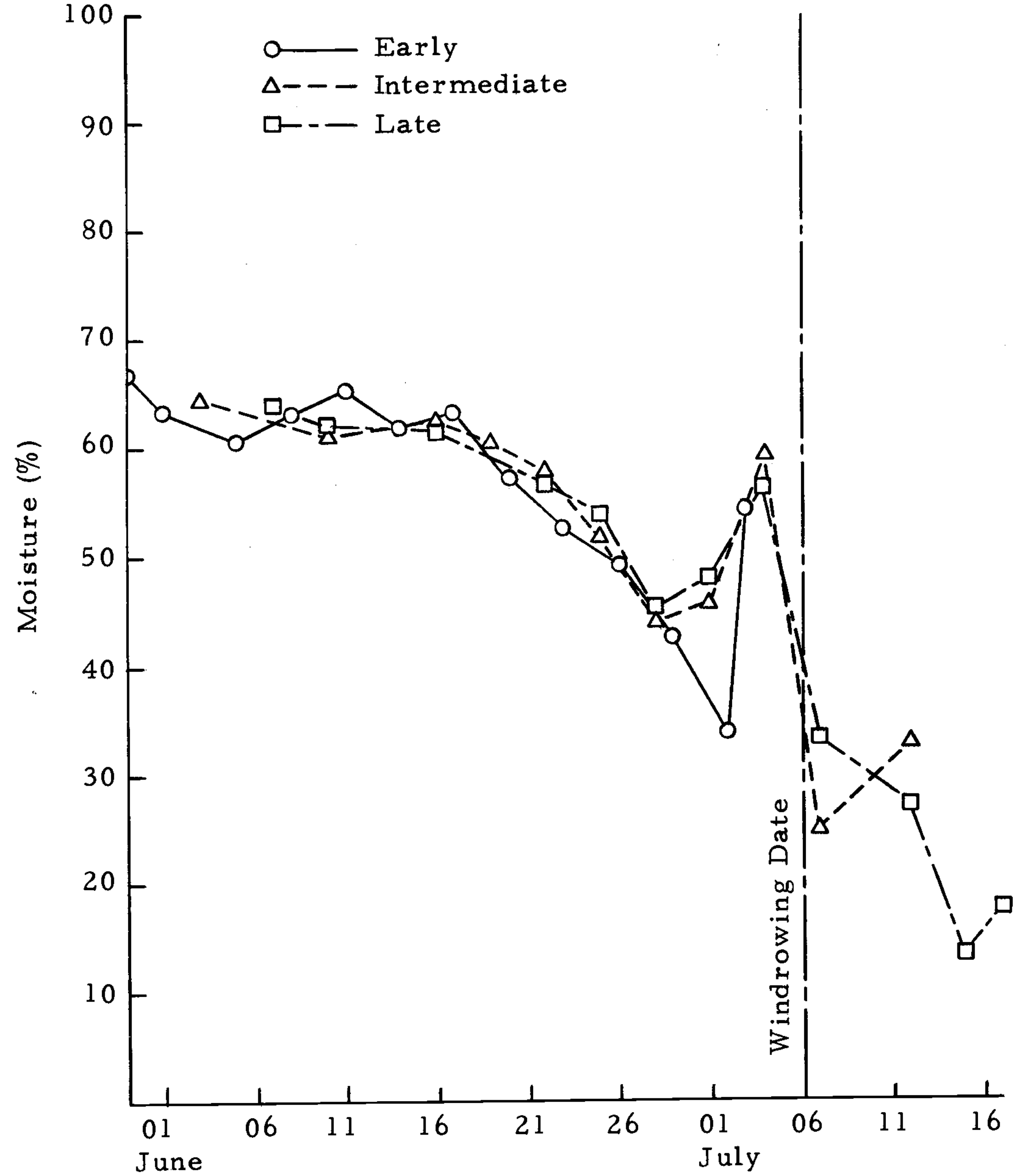


Figure 3. Effect of heading date on seed development in perennial ryegrass: moisture content.

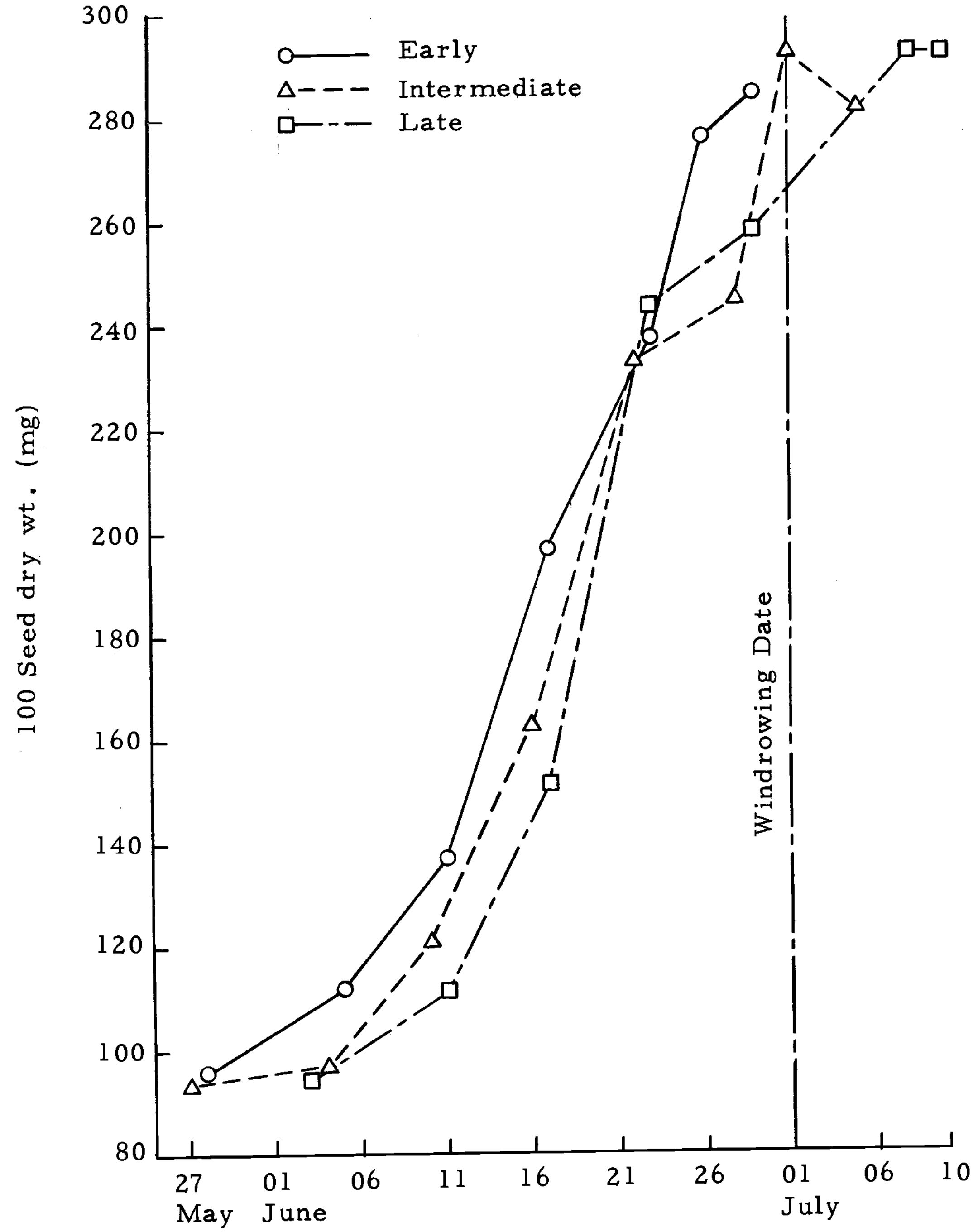


Figure 4. Effect of heading date on seed development in tall fescue: seed weight.

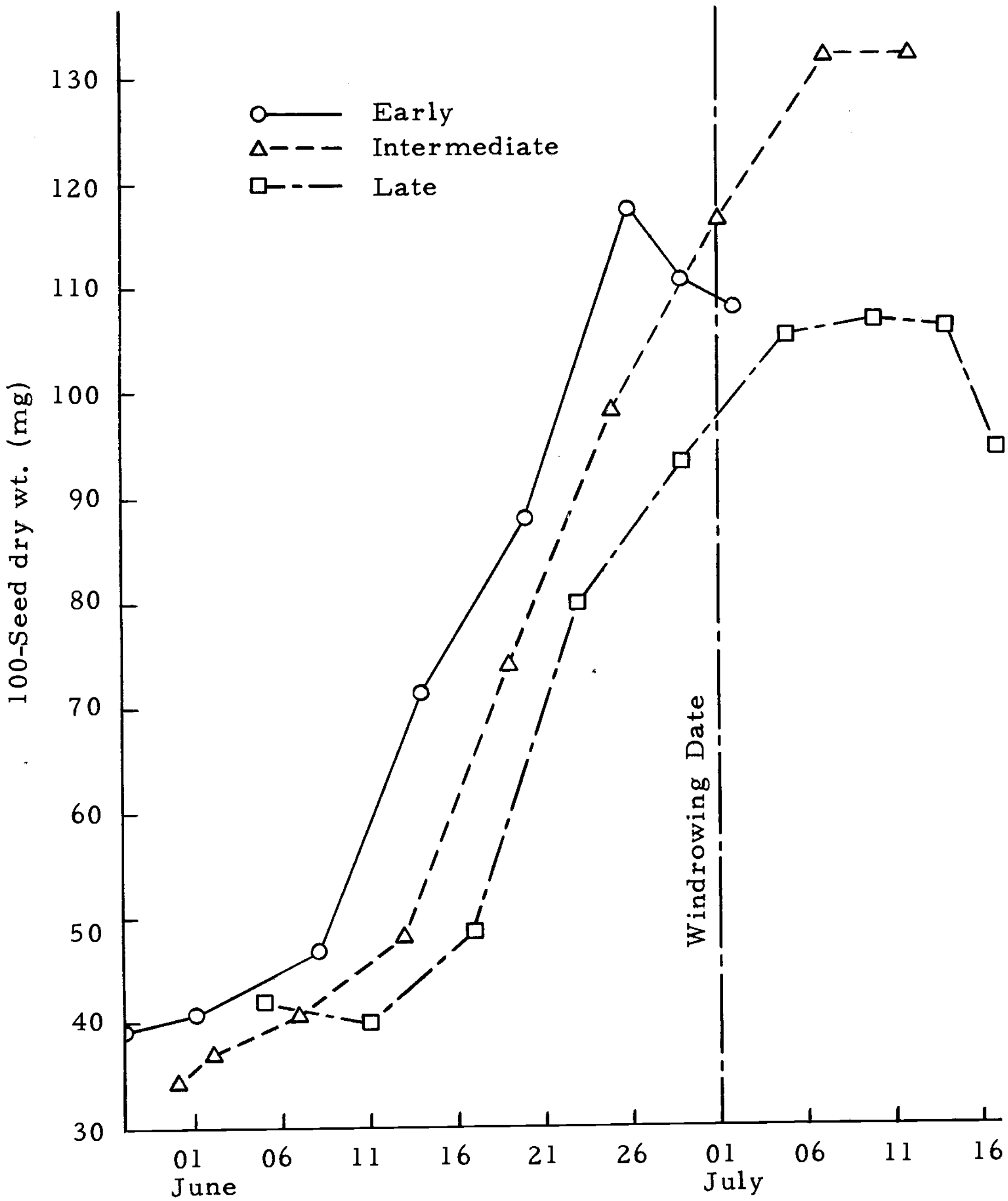


Figure 5. Effect of heading date on seed development in orchard-grass: seed weight.

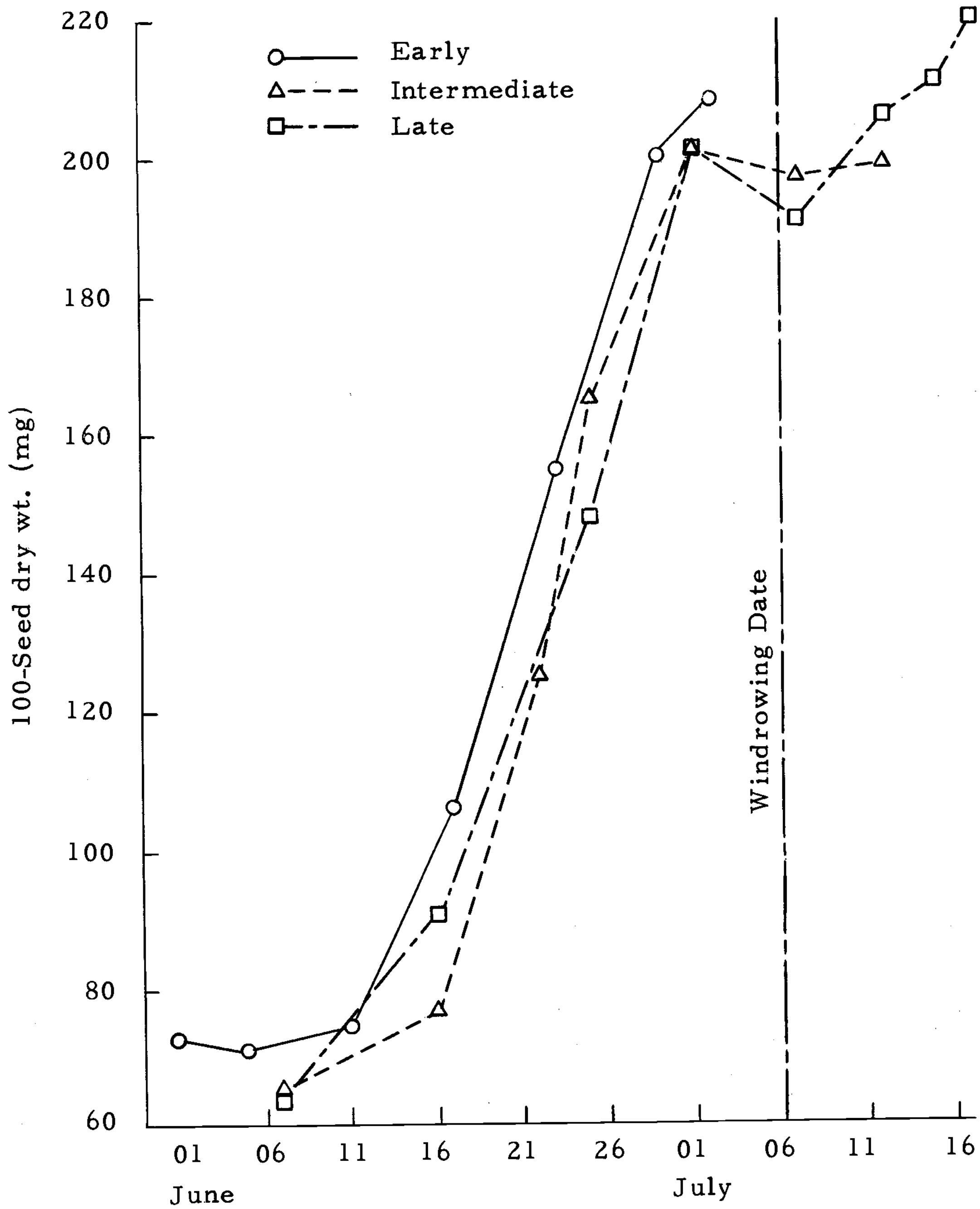


Figure 6. Effect of heading date on seed development in perennial ryegrass: seed weight.

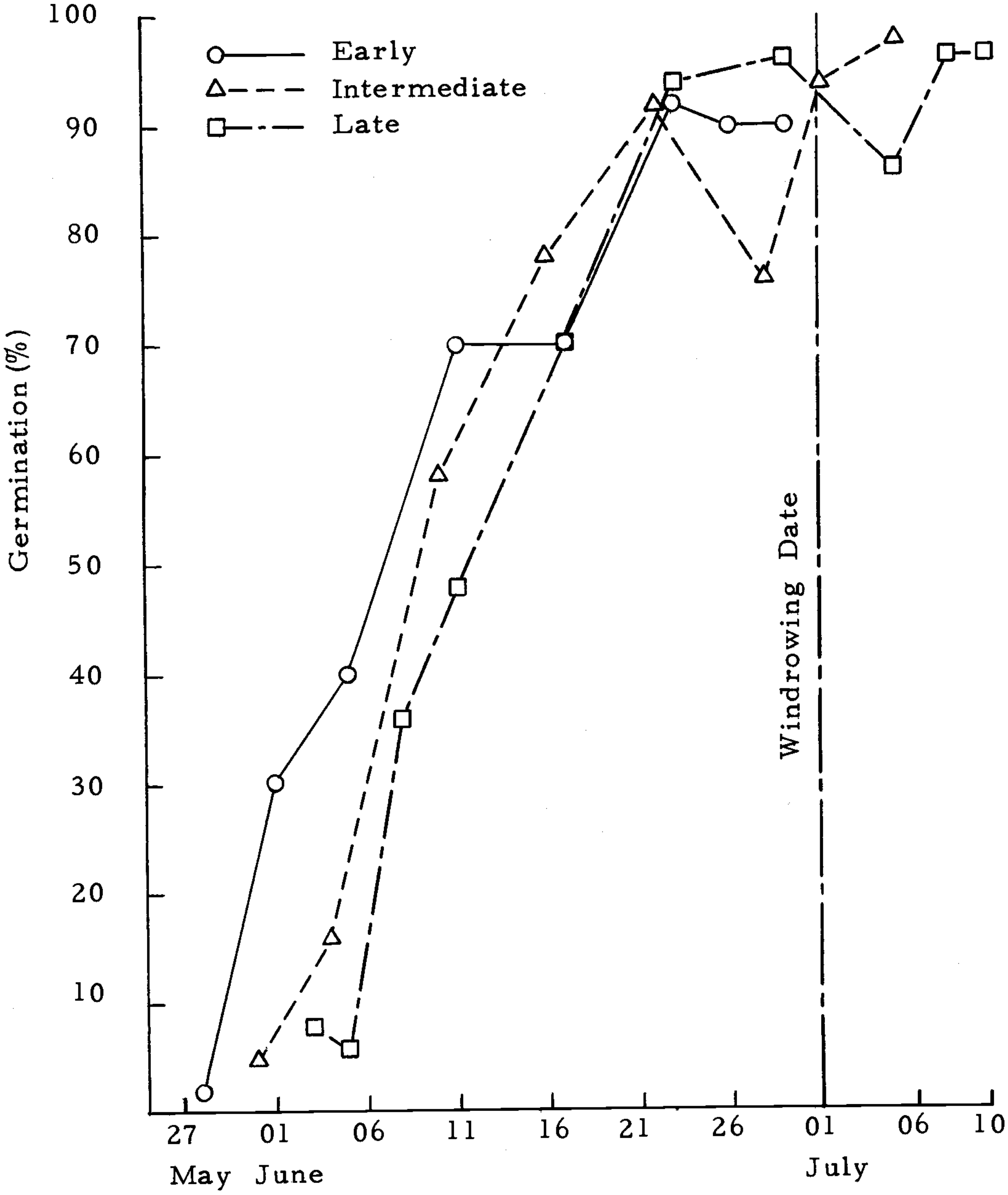


Figure 7. Effect of heading date on seed development in tall fescue: viability.

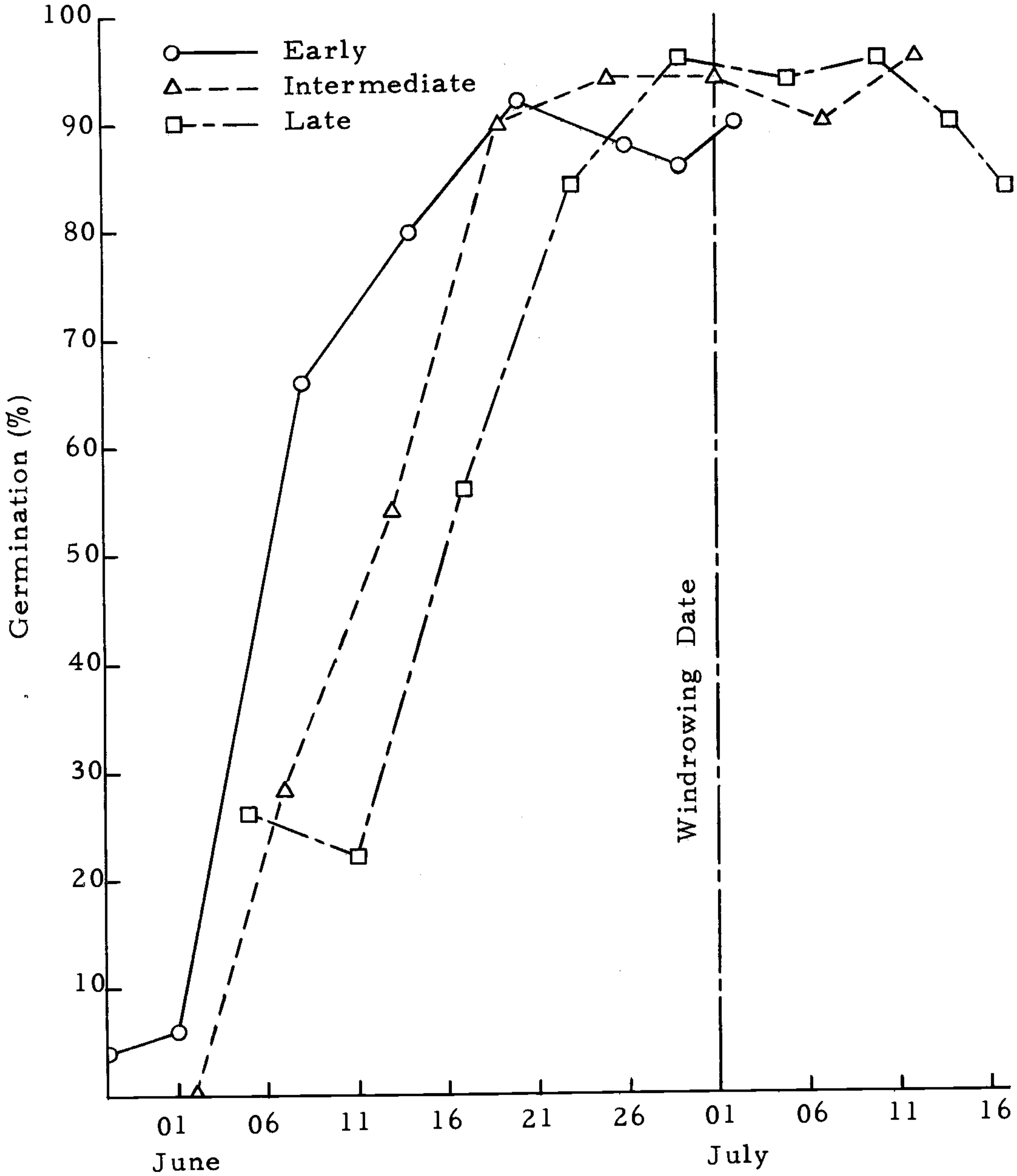


Figure 8. Effect of heading date on seed development in orchardgrass: viability.

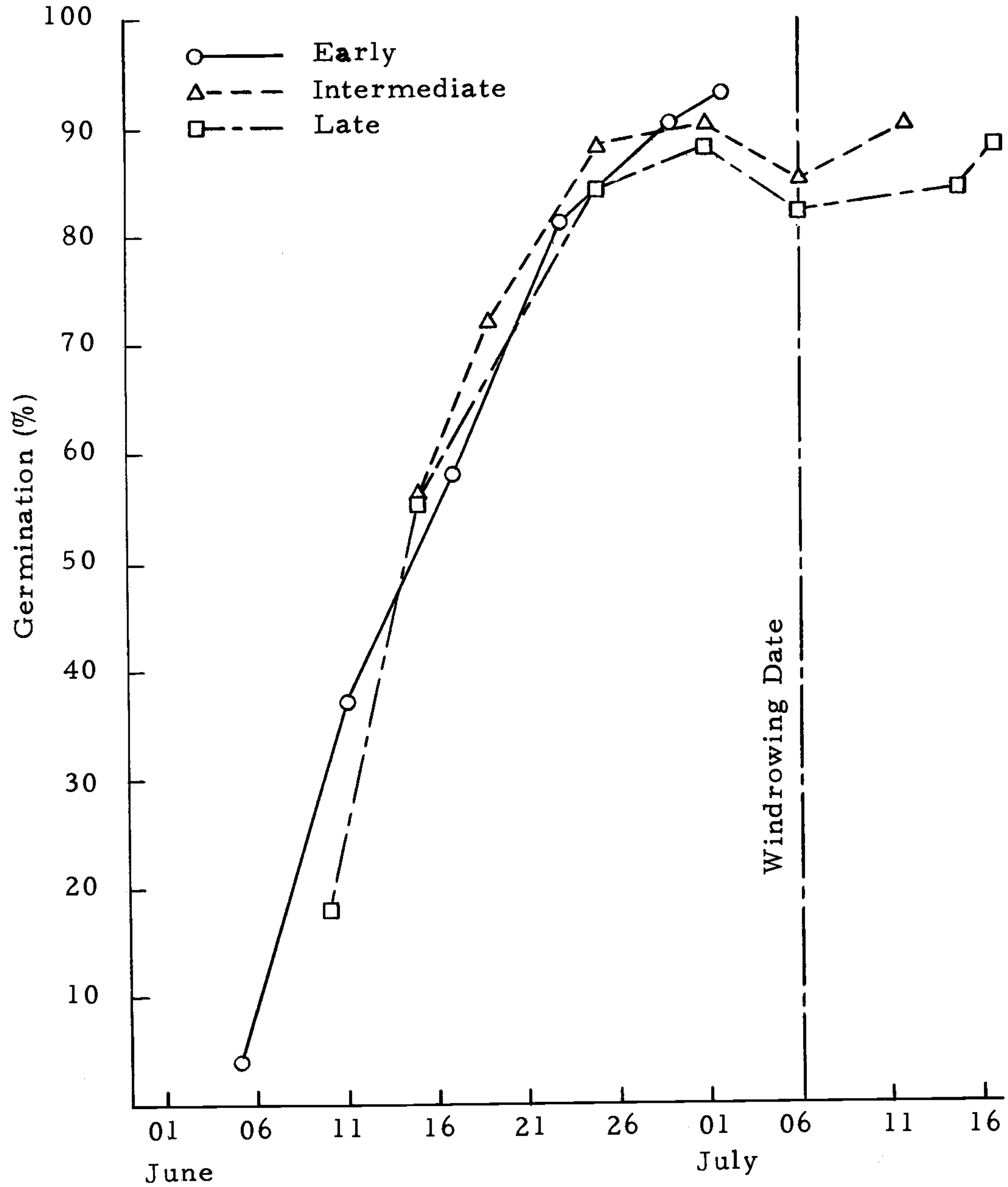


Figure 9. Effect of heading date on seed development in perennial ryegrass: viability.

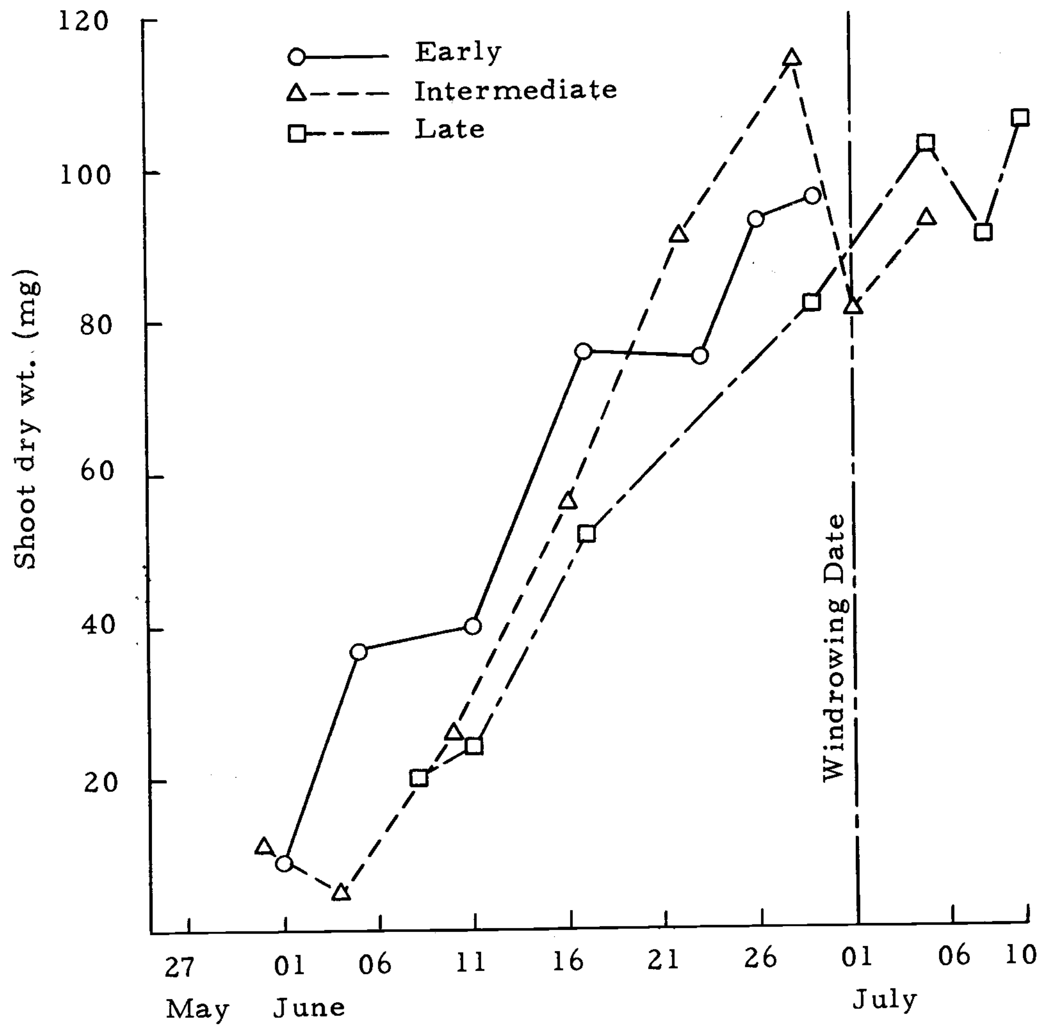


Figure 10. Effect of heading date on seed development in tall fescue: seedling weight.

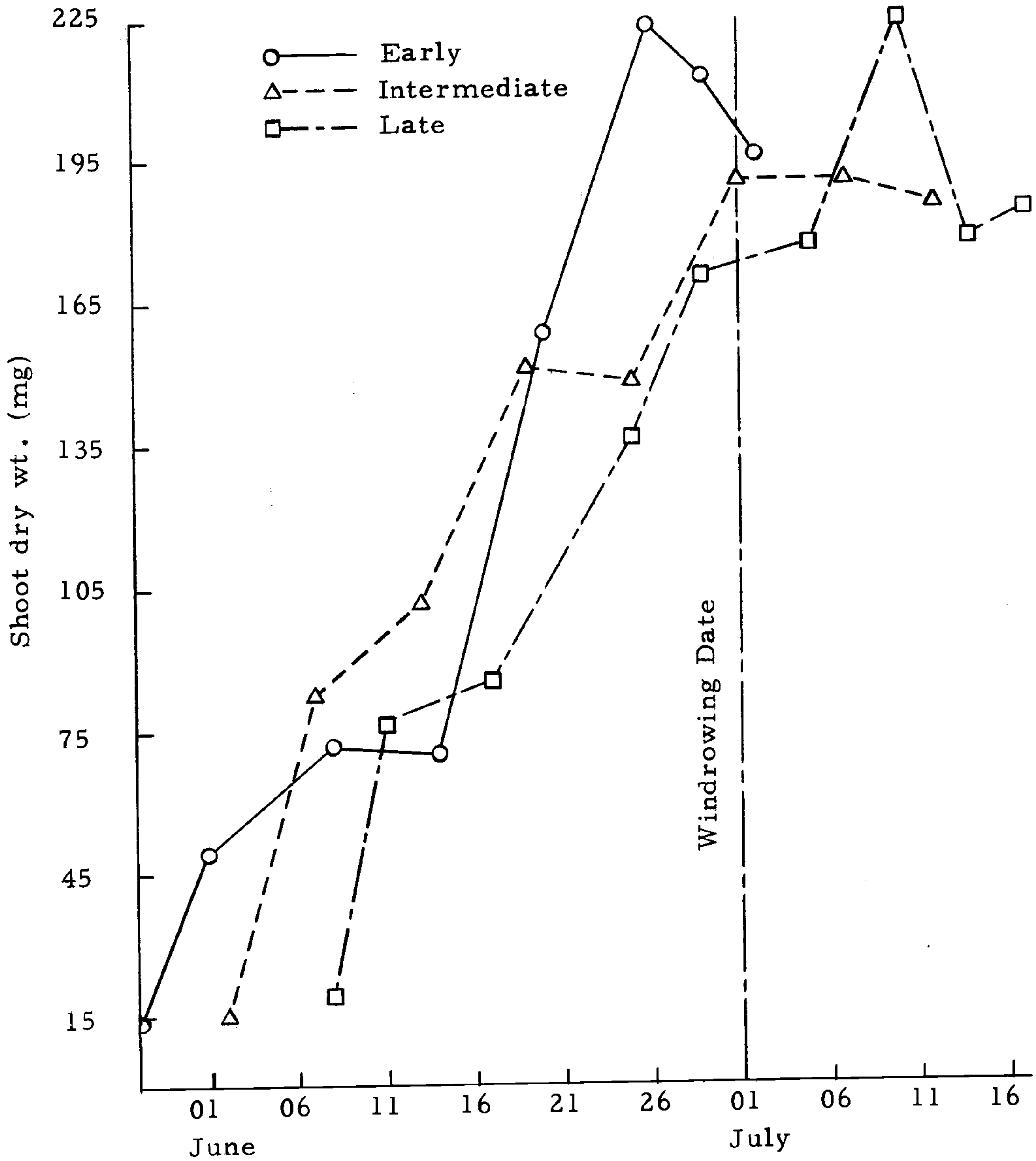


Figure 11. Effect of heading date on seed development in orchard-grass: seedling weight.

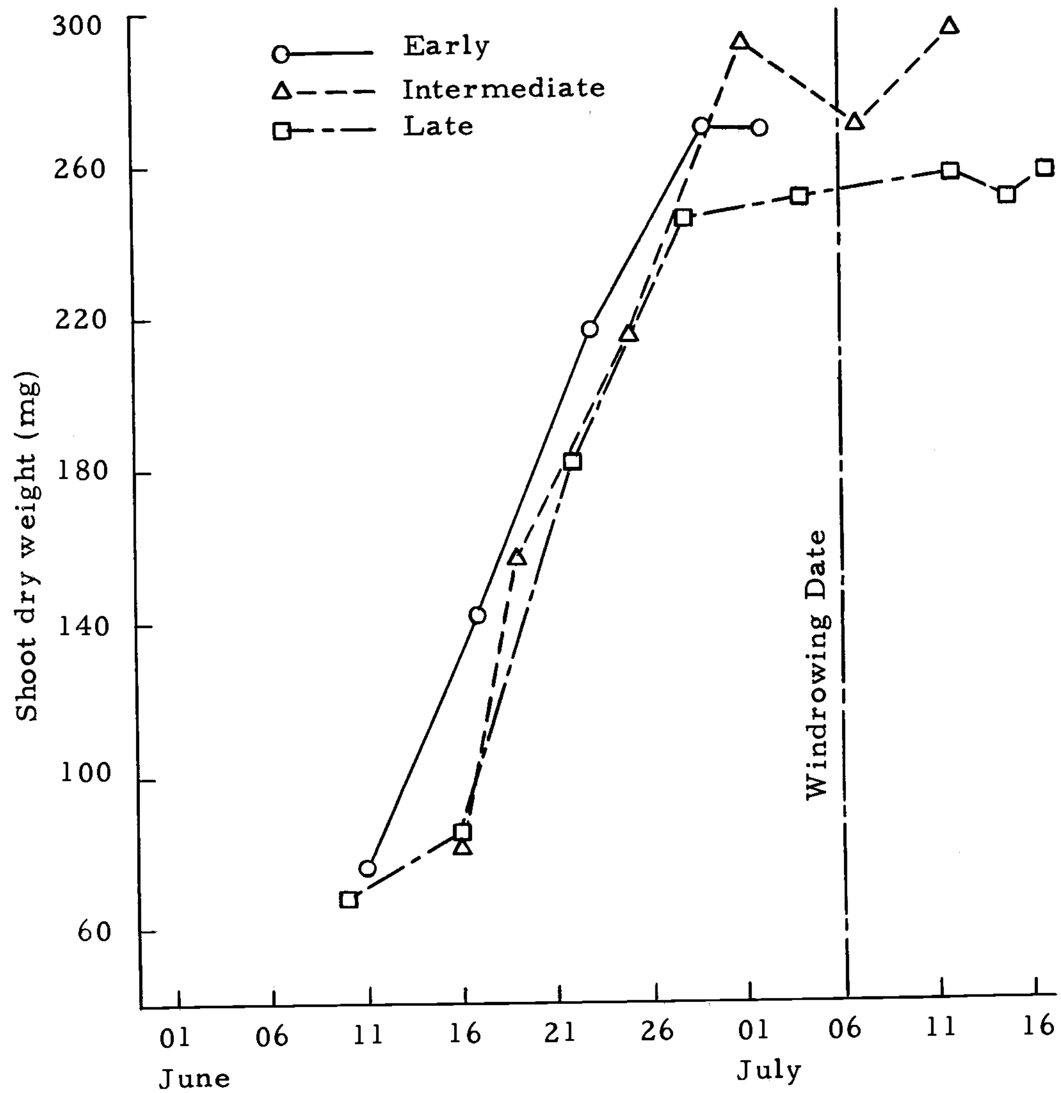


Figure 12. Effect of heading date on seed development in perennial ryegrass: seedling weight.

Time of Anthesis

The number of days from inflorescence extrusion to peak anthesis varied with each species as shown in Table 1. This time period ranged from 3 to 9 days in perennial ryegrass to 20 to 25 days in tall fescue.

In all species, Late inflorescences required the least time to reach peak anthesis. This would tend to cause the period during which anthesis occurs in a field to be considerably shorter than the period over which heading occurs.

Although Late perennial ryegrass inflorescences reached anthesis later than Early inflorescences, Anslow (1963) observed that three age groups of inflorescences reached peak anthesis simultaneously. These differences in reported anthesis dates may have been caused by different weather conditions during the developmental period. Jones and Brown (1951) reported that high temperatures, dew, rain, lack of wind, and cloudiness could delay or even inhibit anthesis in several grass species. Emecz (1962) concluded that anthesis in various grass species was positively related to temperature and light, and that wind and precipitation could inhibit it.

Seed Moisture

Moisture content was originally between 60 and 70% and gradually declined as is characteristic of developing seeds. In each

Table 1. Effect of heading date of three perennial grasses on rate of development in three seed quality characteristics.

| Crop | Inflorescence group | Heading date | Peak anthesis | Maximum germi-nation | Maximum seed weight | Maximum shoot weight |
|---|---|---|---|---|---|---|
| | | | days from heading | ------ days from peak anthesis------ | | |
| Tall fescue | Early | 04/30 | 25 | 29 | 35 | 32 |
| | Intermediate | 05/06 | 21 | 26 | 35 | 26 |
| | Late | 05/13 | 20 | 21 | 36 | 33 |
| Orchardgrass | Early | 05/08 | 18 | 25 | 30 | 30 |
| | Intermediate | 05/15 | 12 | 29 | 41 | 35 |
| | Late | 04/24 | 9 | 27 | 33 | 36 |
| Perennial ryegrass | Early | 05/23 | 9 | 28 | 31 | 28 |
| | Intermediate | 05/29 | 7 | 23 | 26 | 26 |
| | Late | 06/04 | 3 | 24 | 40 | 29 |

species, the drying rates of the three groups of inflorescences were similar, with the Early heads at the lowest moisture levels at windrowing time. As indicated by Figures 1-3, individual seeds at windrowing time vary widely in moisture because of differences in heading dates.

Rainfall caused an abrupt increase in moisture but the declining trend was rapidly resumed, indicating that the added moisture remained mostly on the exterior of the seed.

## Seed Weight

The heaviest final seed weights were produced in the Intermediate group in orchardgrass, and by the Late group in perennial ryegrass. In tall fescue the seeds had similar weight (Figures 4-6).

The three ages of tall fescue inflorescences required the same period of time to reach maximum seed weight. In orchardgrass, the Intermediate inflorescences required 10 days longer than the Early and Late groups, while the Late group required the longest amount of time in perennial ryegrass.

At the recommended time for windrowing, tall fescue seeds from the Late group, orchardgrass seeds from the Intermediate and Late groups, and ryegrass seeds from the Late group had not attained maximum seed weight. For all the seeds to reach their maximum stage of development, windrowing would have to be delayed 6 days in tall fescue, 7 days in orchardgrass, and 10 days in perennial ryegrass. This delay would not be commercially feasible since shattering losses would be too great.

## Viability

Seeds of all inflorescence age groups reached maximum viability several days before optimum windrowing time.

Heading date did not influence the final germination percentage in any of the species (Figures 7-9), although it did influence the date on which maximum levels were reached. This difference between Early and Late groups was 4 days in orchardgrass, 5 days in perennial ryegrass, and 8 days in tall fescue (Table 1).

## Shoot Weight

The maximum shoot weights of the tall fescue seed groups were essentially equal. In orchardgrass, the Early group produced the heaviest shoots, despite the fact that the Intermediate group produced the heaviest seeds. In perennial ryegrass, the heaviest shoots were produced by seeds from the Intermediate group, with the lightest shoots produced by the seeds from the Late group (Figures 10-12).

At windrowing time tall fescue and orchardgrass seeds from the Late group had not attained maximum shoot weight. As a consequence, depending on the contribution of these heads to the total number of heads of the crop, the quality of the seed lot could be impaired.

While the date of heading experiment covered a 2-week time span, the period of heading of the orchardgrass and tall fescue plots extended 10 more days. Therefore, seed in the windrow would be expected to represent a wider range of seed development than those from the tagged inflorescences.

## Temperature and Moisture Conditions in the Windrow

### Moisture Fluctuations

The moisture contents of the seeds when windrowed were 51.6, 41.5 and 15.9% for tall fescue, 44.8, 41.4 and 30.7% for orchardgrass, and 49.8, 28.5 and 19.1% for perennial ryegrass. The windrowings were timed so that the moisture levels at the second cutting would be near 43, 44 and 35%, the moisture levels recommended by Klein and Harmond (1971) for tall fescue, orchardgrass and perennial ryegrass. Weather conditions and non-availability of the windrower made it impossible to meet this objective entirely.

Drying rates and daily moisture fluctuation in the windrow are shown in Tables 2-4. During periods of no rainfall, seed moisture decreased rapidly during the day, increased during the night, and decreased to a new low the following day. This cycle was generally repeated until seed moisture reached an equilibrium with the relative

Table 2 . Daily moisture fluctuations of seeds in tall fescue windrows.

| 1st Maturity stage | | | 2nd Maturity stage | | | 3rd Maturity stage | | |
|---|---|---|---|---|---|---|---|---|
| Sampling date | Morning | Afternoon | Sampling date | Morning | Afternoon | Sampling date | Morning | Afternoon |
| | --------%-------- | | | --------%-------- | | | --------%-------- | |
| Jun 28 | 51.60 § | --- | Jul 01 | 41.54 § | --- | Jul 06 | 15.89 § | --- |
| 29 | 34.67 | 35.18 | 02 | 27.71 | 21.40 | 07 | 27.83 | 17.00 |
| 30 | 31.07 | 44.56 | 03 | 41.13 | --- | 08 | 54.82 | 21.89 |
| Jul 01 | 34.66 | 28.86 | 04 | 44.05 | --- | 09 | 18.68 | 7.61 |
| 02 | 38.69 | 16.29 | 05 | 18.01 | 9.34 | 10 | 14.01 | --- |
| 04 | 47.20 | --- | 06 | 14.45 | 12.66 | 11 | 37.27 | --- |
| 05 | 20.47 | 7.80 | 07 | 24.47 | 14.38 | 12 | 32.36 | 10.86 |
| 06 | 15.63 | 11.09 | 08 | 50.87 | 30.84 | 13 | 16.36 | 8.66 |
| 07 | 25.92 | 14.55 | 09 | 15.62 | 9.95 | 14 | 11.21 | --- |
| 08 | 50.38 | 18.38 | 10 | 14.00 | --- | 15 | 11.77 | 6.63 |
| 09 | 17.99 | 9.59 | 11 | 36.90 | --- | 16 | 12.40 | 8.09 |
| 10 | 15.00 | --- | 12 | 32.18 | 12.10 | | | |
| 11 | 35.47 | --- | 13 | 14.95 | --- | | | |
| 12 | 35.81 | 15.06 | 14 | 10.79 | --- | | | |

§ Moisture content at harvest

Table 3 . Daily moisture fluctuations of seed in orchardgrass windrows.

| 1st maturity stage | | | 2nd maturity stage | | | 3rd maturity stage | | |
|---|---|---|---|---|---|---|---|---|
| Sampling date | Morning | Afternoon | Sampling date | Morning | Afternoon | Sampling date | Morning | Afternoon |
| | --------%-------- | | | --------%-------- | | | --------%-------- | |
| Jun 28 | 44.82 § | --- | Jul 01 | 41.38 § | --- | Jul 06 | 30.74 § | --- |
| 29 | 37.44 | 33.89 | 02 | 33.67 | 29.56 | 07 | 34.65 | 25.26 |
| 30 | 37.35 | 49.39 | 03 | 47.07 | --- | 08 | 55.05 | 34.48 |
| Jun 01 | 38.03 | 32.67 | 04 | 53.55 | --- | 09 | 28.52 | 20.10 |
| 02 | 36.73 | 33.01 | 05 | 28.64 | 27.21 | 10 | 25.28 | --- |
| 03 | 48.58 | --- | 06 | 27.05 | 21.87 | 11 | 41.20 | --- |
| 04 | 51.56 | --- | 07 | 28.36 | 20.00 | 12 | 29.54 | 16.02 |
| 05 | 27.17 | 23.34 | 08 | 55.92 | 22.58 | 13 | 18.59 | 12.21 |
| 06 | 25.91 | 26.33 | 09 | 20.42 | 17.99 | 14 | 13.07 | 9.46 |
| 07 | 26.59 | 12.68 | 10 | 15.05 | --- | 15 | 10.93 | 5.62 |
| 08 | 53.98 | 23.01 | 12 | 24.62 | 10.14 | 16 | 10.96 | 7.74 |
| 09 | 16.46 | 14.55 | 14 | 10.61 | 8.11 | 22 | 10.76 | 7.56 |
| 12 | 26.75 | 11.50 | Aug 04 | 12.58 | 12.45 | Aug 04 | 12.83 | 7.39 |
| 15 | 10.39 | 5.63 | 06 | 15.23 | 11.09 | 06 | 15.11 | 11.89 |
| 18 | 9.42 | 6.02 | 09 | 15.77 | 9.98 | 09 | 15.02 | 10.49 |

§ Moisture content at harvest

Table 4 . Daily moisture fluctuations of seeds in perennial ryegrass windrows.

| 1st Maturity stage | | | 2nd Maturity stage | | | 3rd Maturity stage | | |
|---|---|---|---|---|---|---|---|---|
| Sampling Date | Morning | Afternoon | Sampling Date | Morning | Afternoon | Sampling Date | Morning | Afternoon |
| | --------%-------- | | | --------%-------- | | | --------%-------- | |
| Jul 01 | 49.78 § | | Jul 06 | 28.47 § | | Jul 16 | 19.15 § | |
| 02 | 41.86 | 29.56 | 07 | 35.81 | 27.60 | 17 | 12.66 | 7.98 |
| 03 | 48.96 | --- | 08 | 47.97 | 34.60 | 18 | 10.70 | 5.89 |
| 04 | 51.14 | --- | 09 | 26.42 | 14.46 | 19 | 10.78 | 7.19 |
| 05 | 28.56 | 19.27 | 10 | 19.32 | --- | 20 | --- | 9.03 |
| 06 | 21.01 | 22.06 | 11 | 46.63 | --- | 21 | 12.76 | 7.73 |
| 07 | 24.55 | 17.03 | 12 | 31.48 | 16.63 | 22 | 12.49 | 7.38 |
| 08 | --- | 25.72 | 13 | 20.96 | --- | 23 | 14.39 | 6.57 |
| 09 | 18.65 | 12.56 | 14 | 15.42 | 9.15 | 24 | 12.62 | 6.73 |
| 10 | 16.65 | --- | 15 | 13.70 | 6.92 | 27 | 12.83 | 7.76 |
| 11 | 44.90 | --- | 16 | 12.11 | 8.34 | | | |
| 12 | 32.79 | 14.36 | 17 | 11.13 | 7.94 | | | |
| 13 | 16.46 | --- | 18 | 9.87 | 5.54 | | | |
| 14 | 12.24 | 7.46 | 19 | 11.02 | 7.36 | | | |
| 15 | 13.33 | 8.76 | 20 | --- | 9.43 | | | |

§ Moisture content at harvest

humidity of the surrounding air.

Several rains occurred during this period (Table 5) raising seed moisture levels above 40%. With favorable conditions, moisture contents returned to original levels in a short period of time. In some cases, a drop of about 35% in moisture occurred in a period of 6 hours (Table 6).

During periods of no rainfall, seed moisture content was higher in the lower portion of the windrow (Table 6). These differences were sometimes as much as 8% in the morning and 4% in the afternoon. The rate of drying was about the same for seeds in both locations. The moisture differences observed do not appear great enough to cause faster deterioration of seeds in the lower portion of these windrows.

The windrows were relatively small (Table 7) allowing rapid drying. The stubble was tall enough to allow good air circulation. It would be expected that drying rates in heavier windrows would be slower than observed here. Robertson (1957) concluded that stubble height, density and width of windrow all influence the rate of drying.

Table 5 . Daily precipitation and maximum and minimum temperatures recorded from May to September of 1976 at Hyslop Crop Science Field Laboratory, Corvallis, OR.

| | May | | | June | | | July | | | August | | | September | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Temperature °F | | Precip | Temperature °F | | Precip | Temperature °F | | Precip | Temperature °F | | Precip | Temperature °F | | Precip |
| Day | max | min | in | max | min | in | max | min | in | max | min | in | max | min | in |
| 1 | 77 | 42 | 0 | 59 | 36 | .19 | 63 | 49 | .23 | 82 | 55 | 0 | 90 | 50 | 0 |
| 2 | 75 | 46 | .12 | 57 | 34 | .04 | 68 | 39 | .01 | 75 | 58 | 0 | 80 | 45 | 0 |
| 3 | 62 | 40 | T § | 62 | 35 | T | 78 | 53 | 0 | 80 | 55 | 0 | 77 | 51 | 0 |
| 4 | 64 | 47 | 0 | 62 | 39 | 0 | 72 | 55 | .23 | 81 | 57 | 0 | 83 | 48 | 0 |
| 5 | 62 | 43 | .03 | 65 | 40 | 0 | 77 | 53 | 0 | 66 | 57 | 0 | 83 | 50 | 0 |
| 6 | 59 | 36 | .05 | 66 | 47 | .08 | 84 | 50 | 0 | 70 | 56 | T | 74 | 42 | .46 |
| 7 | 69 | 43 | 0 | 66 | 46 | T | 80 | 56 | T | 68 | 57 | .23 | 69 | 43 | 0 |
| 8 | 77 | 50 | 0 | 62 | 47 | 0 | 71 | 54 | .35 | 66 | 52 | .05 | 71 | 48 | 0 |
| 9 | 79 | 45 | 0 | 67 | 46 | 0 | 74 | 54 | 0 | 74 | 49 | 0 | 82 | 54 | 0 |
| 10 | 83 | 51 | 0 | 75 | 49 | 0 | 73 | 48 | 0 | 77 | 53 | 0 | 87 | 46 | 0 |
| 11 | 61 | 40 | .10 | 64 | 51 | .01 | 73 | 55 | .05 | 82 | 54 | 0 | 87 | 48 | 0 |
| 12 | 66 | 44 | 0 | 58 | 50 | .12 | 68 | 53 | .03 | 87 | 51 | 0 | 69 | 53 | T |
| 13 | 77 | 44 | 0 | 63 | 33 | T | 72 | 47 | 0 | 82 | 56 | T | 72 | 42 | 0 |
| 14 | 72 | 36 | 0 | 66 | 41 | 0 | 79 | 49 | 0 | 61 | 55 | .25 | 76 | 46 | .74 |
| 15 | 62 | 40 | 0 | 77 | 45 | 0 | 82 | 53 | 0 | 70 | 52 | .38 | 69 | 49 | .01 |
| 16 | 79 | 42 | 0 | 70 | 53 | .03 | 92 | 50 | 0 | 64 | 50 | .13 | 76 | 55 | 0 |
| 17 | 62 | 34 | 0 | 68 | 47 | 0 | 88 | 46 | 0 | 62 | 48 | .57 | 66 | 56 | .06 |
| 18 | 60 | 33 | 0 | 82 | 56 | 0 | 80 | 47 | 0 | 74 | 48 | 0 | 65 | 53 | 0 |
| 19 | 66 | 42 | .01 | 88 | 52 | 0 | 80 | 42 | 0 | 79 | 47 | 0 | 72 | 45 | 0 |
| 20 | 60 | 33 | .02 | 75 | 45 | 0 | 82 | 54 | 0 | 75 | 52 | 0 | 87 | 54 | 0 |
| 21 | 67 | 37 | 0 | 70 | 42 | 0 | 74 | 45 | 0 | 80 | 51 | 0 | 85 | 55 | 0 |
| 22 | 73 | 41 | 0 | 68 | 42 | 0 | 76 | 46 | 0 | 83 | 47 | 0 | 65 | 55 | T |
| 23 | 65 | 48 | .08 | 68 | 40 | 0 | 85 | 52 | 0 | 77 | 44 | 0 | 72 | 51 | 0 |
| 24 | 64 | 46 | .03 | 74 | 49 | 0 | 90 | 53 | 0 | 79 | 54 | 0 | 74 | 49 | 0 |
| 25 | 64 | 35 | .01 | 74 | 40 | 0 | 57 | 59 | 0 | 79 | 54 | .41 | 75 | 45 | 0 |
| 26 | 67 | 34 | 0 | 67 | 45 | 0 | 89 | 49 | 0 | 69 | 43 | .06 | 81 | 47 | 0 |
| 27 | 82 | 49 | .15 | 78 | 41 | 0 | 80 | 46 | 0 | 73 | 45 | 0 | 73 | 46 | 0 |
| 28 | 62 | 35 | .04 | 89 | 45 | 0 | 85 | 50 | 0 | 82 | 53 | 0 | 78 | 46 | 0 |
| 29 | 55 | 34 | .08 | 88 | 54 | 0 | 92 | 52 | 0 | 84 | 56 | 0 | 78 | 54 | 0 |
| 30 | 55 | 43 | .13 | 74 | 43 | 0 | 83 | 59 | 0 | 89 | 53 | 0 | 80 | 54 | 0 |
| 31 | 53 | 44 | .29 | | | | 76 | 44 | 0 | 89 | 55 | 0 | | | |

§T = trace

Table 6 . Daily moisture fluctuations in seeds from the upper and lower portions of grass windrows.

| | Perennial ryegrass | | | | | Tall Fescue | | | | | Orchardgrass | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Morning | | Afternoon | | | Morning | | Afternoon | | | Morning | | Afternoon | |
| Sampling date | Upper | Lower | Upper | Lower | Sampling date | Upper | Lower | Upper | Lower | Sampling date | Upper | Lower | Upper | Lower |
| | --------------%-------------- | | | | | --------------%-------------- | | | | | --------------%-------------- | | | |
| Jul 13 | 17.46 | 22.06 | 8.21 | 11.75 | Jul 08 | --- | --- | 19.22 | 33.27 | Jul 08 | --- | --- | 22.18 | 27.34 |
| 14 | 11.81 | 13.72 | 6.80 | 9.42 | 09 | 14.02 | 22.02 | 8.63 | 12.22 | 09 | 20.47 | 24.37 | 13.13 | 14.51 |
| 15 | 11.91 | 12.50 | 5.49 | 6.17 | 10 | 15.20 | 14.86 | --- | --- | 10 | 15.32 | 16.17 | --- | --- |
| 16 | 10.84 | 13.88 | 6.43 | 13.16 | 11 | --- | 32.24 | --- | --- | 11 | 31.88 | 34.67 | --- | --- |
| 17 | 11.00 | 13.40 | 8.76 | 8.48 | 12 | 28.14 | 26.78 | 8.79 | 13.16 | 12 | 23.89 | 22.49 | 11.82 | 13.72 |
| 18 | 9.43 | 14.18 | 6.59 | 8.32 | 13 | 15.60 | 15.72 | 8.16 | 9.79 | 13 | 14.46 | 15.31 | 8.37 | 10.10 |
| 19 | 11.53 | 11.66 | 6.58 | 7.79 | 14 | 11.38 | 12.70 | 8.81 | 8.90 | 14 | 10.34 | 12.27 | 7.11 | 8.48 |
| 20 | 13.44 | 13.50 | 7.97 | 9.20 | 15 | 11.78 | 12.18 | 6.19 | 6.99 | 15 | 9.80 | 10.25 | 4.80 | 5.27 |
| 21 | 12.40 | 13.95 | 6.90 | 7.95 | 16 | 12.50 | 14.14 | 7.35 | 8.65 | 16 | 10.54 | 11.98 | 7.50 | 7.50 |
| 22 | 12.36 | 13.56 | 6.00 | 6.84 | | | | | | | | | | |

Table 7. Characteristics of windrows from three perennial grass crops.

| Crop | Stubble height | Windrow width | Windrow thickness |
|---|---|---|---|
| | -------- | cm | -------- |
| Tall fescue | 18 | 63 | 15 |
| Orchardgrass | 18 | 100 | 12 |
| Perennial ryegrass | 10 | 120 | 15 |

Temperature Fluctuations

The average maximum temperatures in the upper and lower portions of perennial ryegrass windrow were 38.3 and 24.3°C during July, and 31.1 and 19.2°C during August (Table 8). The maximum temperature reached in the upper part of the windrow was 47°C on July 28 and 29 (Table 8). But increase in temperature was always associated to a drop in seed moisture content (Tables 2-4).

## Stage of Seed Development at Windrowing Time

Seed quality characteristic on the three windrowing dates are shown in Tables 9-11. In general, seed quality improved each week's delay in time of cutting, with the greatest improvement occurring between the first and second cutting.

Maximum seed weights in perennial ryegrass and tall fescue were reached by the second cutting date, while seed weight continued to increase until the third date in orchardgrass.

Maximum germinability of all three species was attained by the first cutting date, with no further improvement occurring. Speed of germination, however, was faster when cutting was delayed until

Table 8. Daily maximum temperatures 2.5 and 10.0 cm below the surface of a perennial ryegrass windrow.

| Date | 2.5 cm | 10.0 cm | Date | 2.5 cm | 10.0 cm | Date | 2.5 cm | 10.0 cm |
|---|---|---|---|---|---|---|---|---|
| | Distance below the surface | | | | | | | |
| | ----°C---- | | | ----°C---- | | | ----°C---- | |
| Jul 09 | 28 | 23 | Jul 28 | 47 | 27 | Aug 16 | 18 | 16 |
| 10 | 34 | 26 | 29 | 47 | 24 | 17 | 22 | 17 |
| 11 | 23 | 20 | 30 | 38 | 22 | 18 | 19 | 17 |
| 12 | 31 | 19 | 31 | 38 | 21 | 19 | 30 | 16 |
| 13 | 40 | 23 | Aug 01 | 33 | 21 | 20 | 38 | 19 |
| 14 | 39 | 25 | 02 | 41 | 23 | 21 | 39 | 20 |
| 15 | 46 | 26 | 03 | 42 | 23 | 22 | 37 | 19 |
| 16 | 43 | 27 | 04 | 23 | 18 | 23 | 35 | 19 |
| 17 | 39 | 25 | 05 | 28 | 19 | 24 | 37 | 19 |
| 18 | 39 | 24 | 06 | 25 | 17 | 25 | 26 | 17 |
| 19 | 37 | 27 | 07 | 20 | 17 | 26 | 30 | 17 |
| 20 | 36 | 21 | 08 | 30 | 19 | 27 | 30 | 17 |
| 21 | 35 | 23 | 09 | 37 | 21 | 28 | 37 | 19 |
| 22 | 38 | 26 | 10 | 41 | 23 | 29 | 30 | 20 |
| 23 | 40 | 27 | 11 | 44 | 23 | 30 | 41 | 21 |
| 24 | 42 | 27 | 12 | 42 | 23 | 31 | 32 | 22 |
| 25 | 43 | 26 | 13 | 16 | 18 | Sep 01 | 41 | 22 |
| 26 | 39 | 25 | 14 | 21 | 18 | 02 | 37 | 19 |
| 27 | 40 | 26 | 15 | 20 | 16 | 03 | 37 | 20 |

Table 9. Effect of time in windrow on quality of tall fescue seeds windrowed at three stages of seed maturity.

| Maturity stage | Sampling date | 100-Seed weight | Germi-nation | Speed of germination index | Seedling emergence | Shoot weight |
|---|---|---|---|---|---|---|
| | | mg | % | | % | mg |
| 1st | Jun 28 | 250.6 | 92 | 16.51 | 62 | 22 |
| | 29 | 257.6 | | | | |
| | Jul 01 | 265.2 | | | | |
| | 02 | 268.9 | | | | |
| | 03 | 279.6 | 90 | 16.84 | 66 | 26 |
| | 08 | 273.7 | 97 | 19.52 | 87 | 35 |
| | 15 | 273.3 | 94 | 18.26 | 68 | 25 |
| | 23 | 264.0 | 98 | 19.40 | 62 | 34 |
| | 30 | 274.9 | 94 | 17.92 | 71 | 31 |
| | Aug 19 | 261.8 | 90 | 18.58 | 74 | 31 |
| 2nd | Jul 01 | 271.6 | 93 | 16.48 | 62 | 26 |
| | 02 | 282.9 | | | | |
| | 03 | 269.5 | | | | |
| | 04 | 250.6 | | | | |
| | 09 | 277.4 | 98 | 19.09 | 70 | 30 |
| | 14 | 268.4 | 97 | 19.57 | 52 | 29 |
| | 23 | 273.9 | 97 | 19.47 | 64 | 31 |
| | 29 | 269.9 | 97 | 19.19 | 70 | 25 |
| | Aug 19 | 274.1 | 93 | 18.68 | 81 | 36 |
| | Sep 04 | 253.0 | 91 | 18.03 | 62 | 26 |
| 3rd | Jul 06 | 277.3 | 98 | 18.96 | 69 | 29 |
| | 07 | 272.6 | | | | |
| | 08 | 266.8 | | | | |
| | 09 | 283.4 | | | | |
| | 10 | 283.3 | 95 | 18.69 | 69 | 36 |
| | 16 | 282.0 | 96 | 19.88 | 77 | 34 |
| | 23 | 286.1 | 97 | 19.31 | 65 | 32 |
| | 31 | 279.2 | 97 | 19.05 | 79 | 30 |
| | Aug 19 | 272.5 | 93 | 19.41 | 83 | 34 |
| | Sep 04 | 270.5 | 94 | 18.02 | 73 | 33 |
| | L.S.D.$_{.05}$ | 11.7 | 4.1 | 1.0 | 16.9 | 11.8 |
| | L.S.D.$_{.01}$ | 15.4 | 5.5 | 1.4 | 22.6 | 11.7 |

Table 10. Effect of time in windrow on quality of orchardgrass seeds windrowed at three stages of seed maturity

| Maturity Stage | Sampling date | 100-Seed weight | Germi-nation | Speed of germination index | Seedling emergence | Shoot weight |
|---|---|---|---|---|---|---|
| | | mg | % | | % | mg |
| 1st | Jun 28 | 98.4 | 93 | 15.03 | 58 | 36 |
| | 29 | 102.5 | | | | |
| | 30 | 97.4 | | | | |
| | Jul 01 | 91.8 | | | | |
| | 02 | 91.6 | | | | |
| | 04 | 97.1 | 78 | 15.79 | 29 | 48 |
| | 08 | 95.8 | 88 | 21.00 | 48 | 36 |
| | 15 | 91.9 | 87 | 20.27 | 39 | 37 |
| | 24 | 92.8 | 87 | 21.54 | 46 | 50 |
| | 30 | 89.5 | 87 | 20.91 | 35 | 44 |
| | Aug 19 | 87.0 | 77 | 22.40 | 46 | 39 |
| | Sep 04 | 83.1 | 66 | 19.43 | 45 | 43 |
| 2nd | Jul 01 | 105.2 | 90 | 19.26 | 79 | 49 |
| | 02 | 103.8 | | | | |
| | 03 | 105.6 | | | | |
| | 04 | 106.3 | | | | |
| | 05 | 98.6 | | | | |
| | 06 | 100.2 | 86 | 19.41 | 52 | 47 |
| | 11 | 109.9 | 92 | 22.69 | 52 | 53 |
| | 29 | 103.8 | 76 | 19.01 | 29 | 62 |
| | Aug 04 | 93.5 | 85 | 20.46 | 50 | 51 |
| | 09 | 94.5 | 84 | 21.57 | 42 | 45 |
| | 19 | 95.8 | 75 | 22.23 | 44 | 41 |
| | Sep 04 | 90.2 | 79 | 21.43 | 27 | 53 |
| 3rd | Jul 06 | 110.4 | 91 | 18.78 | 71 | 50 |
| | 07 | 118.4 | | | | |
| | 08 | 114.2 | | | | |
| | 09 | 114.3 | | | | |
| | 10 | 113.7 | | | | |
| | 11 | 117.3 | 93 | 21.83 | 50 | 57 |
| | 22 | 113.7 | 86 | 21.06 | 48 | 69 |
| | 28 | 101.8 | 80 | 19.20 | 38 | 49 |
| | Aug 04 | 108.0 | 79 | 19.04 | 37 | 45 |
| | 09 | 106.9 | 83 | 22.68 | 71 | 65 |
| | 19 | 106.0 | 79 | 21.14 | 46 | 56 |
| | Sep 04 | 106.9 | 74 | 21.52 | 58 | 50 |
| $L.S.D._{.05}$ | | 7.2 | 7.6 | 2.2 | 20.5 | 22.4 |
| $L.S.D._{.01}$ | | 9.5 | 10.2 | 2.9 | 27.2 | 29.8 |

Table 11. Effect of time in the windrow on quality of perennial ryegrass seeds windrowed at three stages of seed maturity.

| Maturity stage | Sampling date | 100-seed weight | Germi-nation | Speed of germination index | Seedling emergence | Shoot weight |
|---|---|---|---|---|---|---|
| | | mg | % | | % | mg |
| 1st | Jul 01 | 183.1 | 85 | 16.40 | 79 | 110 |
| | 02 | 187.7 | | | | |
| | 03 | 184.6 | | | | |
| | 04 | 182.0 | | | | |
| | 05 | 183.4 | | | | |
| | 06 | 180.5 | 85 | 19.32 | 75 | 124 |
| | 11 | 191.9 | 92 | 19.48 | 70 | 117 |
| | 21 | 180.6 | 87 | 21.26 | 77 | 123 |
| | 28 | 184.0 | 90 | 21.62 | 66 | 123 |
| | Aug 04 | 175.2 | 91 | 21.48 | 75 | 117 |
| | 19 | 186.5 | 78 | 17.50 | 70 | 87 |
| 2nd | Jul 06 | 192.2 | 86 | 19.43 | 75 | 94 |
| | 07 | 193.2 | | | | |
| | 08 | 189.6 | | | | |
| | 09 | 181.7 | | | | |
| | 10 | 210.4 | | | | |
| | 11 | 214.6 | 91 | 21.92 | 87 | 139 |
| | 18 | 196.6 | 90 | 21.71 | 77 | 95 |
| | 28 | 185.6 | 89 | 21.51 | 77 | 115 |
| | 31 | 190.1 | 90 | 23.85 | 71 | 128 |
| | Aug 19 | 196.7 | 81 | 23.22 | 48 | 132 |
| | Sep 04 | 184.6 | 82 | 19.80 | 50 | 134 |
| 3rd | Jul 16 | 192.5 | 88 | 24.14 | 67 | 119 |
| | 17 | 197.5 | | | | |
| | 18 | 198.4 | | | | |
| | 19 | 189.8 | | | | |
| | 20 | 201.5 | | | | |
| | 23 | 206.0 | 89 | 23.81 | 73 | 134 |
| | 28 | 189.4 | 86 | 23.47 | 81 | 114 |
| | Aug 04 | 210.8 | 86 | 22.46 | 75 | 100 |
| | 08 | 201.6 | 87 | 23.99 | 70 | 111 |
| | 26 | 194.0 | 86 | 23.06 | 52 | 107 |
| | Sep 04 | 194.3 | 84 | 23.72 | 54 | 122 |
| | $L.S.D._{.05}$ | 12.9 | 4.9 | 1.7 | 17.1 | 42.4 |
| | $L.S.D._{.01}$ | 17.1 | 6.5 | 2.3 | 22.7 | 56.5 |

the second or third date.

Seedling emergence and shoot weight of orchardgrass improved between the first and second dates, while they were essentially equal at all three dates in perennial ryegrass and tall fescue.

## Seed Development in the Windrow

Increases in seed weight after windrowing, if they are to occur, would be expected during the first few days while moisture levels are still high. As shown in Table 9, this occurred in tall fescue harvested at the first maturity stage. Weight of seeds harvested at 51.6% moisture increased from 250.6 to 249.6 mg/100 seeds in the windrow. No increase in seed weight occurred in the other species or at the other cutting dates (Tables 9-11).

In terms of speed of germination, a post-cutting period in the windrow was beneficial for the seeds of all three species at first and second windrowing dates, suggesting that physiological changes still occurred in the seeds after the severance of the culm. Seeds from the third cutting of orchardgrass also increase in speed germination after windrowing.

Germination percentage, seedling emergence, and shoot weight did not improve during the post-windrowing period.

## Seed Deterioration in the Windrow

The germinability of all three species was maintained throughout the month of July (Tables 9-11). A perceptible drop in germination or orchardgrass and perennial ryegrass occurred during the 2 weeks prior to the 19 August sampling date. This deterioration coincided with a period of relatively low temperature and considerable rainfall (Table 5), which slowed the drying of the crop. The compact panicles of orchardgrass and denser windrows of perennial ryegrass probably slowed the drying rate of the seeds. In tall fescue, the only drop in germination occurred in windrow harvested at the second maturity stage.

Seed weight declined by the end of the experimental period in all three crops. This loss in weight is attributed to high respiration activity in seeds with high moisture.

Germinated seeds with protruding radicles were found in the perennial ryegrass windrows by the end of August. Some of these seeds produced normal seedlings in germination tests by the protrusion of seminal roots.

Speed of germination remained constant during the time seeds remained in the windrow. The lower germination rate index at the end of the experiment was due to lower germination percentage and not to speed of germination.

Some trends toward reduced seedling emergence occurred near the end of the experimental period, but due to excessive variability of the data, the difference in emergence was not statistically significant.

Shoot weight did not decrease with time in the windrow, although shoot weight was correlated with seed weight in orchardgrass and tall fescue (Table 12). Large variation in results (C. V. = 24, 28%, App. Table 1) probably masked effects due to deterioration, had they been present.

Table 12. Correlation coefficients between changes in seed weight in the windrow and other quality aspects of seeds of three perennial grasses.

| | Tall fescue | Orchard-grass | Rye-grass |
|---|---|---|---|
| | --------- Seed weight------------- | | |
| Shoot wt. | .508* | .616** | .074 |
| Speed germ. | .379 | .039 | .449* |
| Emergence | .330 | .406* | .039 |

*, ** Significant at 5 and 1% levels, respectively.

There were no indications that the stage of maturity when harvested influenced the rate or amount of deterioration of the seeds, despite the fact that they were subjected to different amounts of rainfall while in the windrow.

# GENERAL DISCUSSION

A primary objective of this research was to obtain information on relative seed quality at recommended windrowing times for grass seed crops. Klein and Harmond (1971) recommended windrowing at high moisture levels to obtain maximum yields. Germination was used as their index of seed quality. Maximum germination, however, occurs several days before seeds have reached a maximum stage of development and vigor. Thus their work left unanswered the question of whether maximum yields are attained at some sacrifice of individual seed quality.

The data support Klein and Harmond's recommendations for windrowing tall fescue at 43% moisture, orchardgrass at 44% moisture, and perennial ryegrass at 35% moisture. Perennial ryegrass seed quality was not improved by delaying windrowing, while orchardgrass and tall fescue seeds increased somewhat in weight. Because of the risk of increased shattering losses, delaying windrowing to improve seed quality does not appear justified.

Rather than by delaying windrowing, another approach toward improving seed quality would be to modify management practices to reduce the time span over which heading occurs. The time of heading was shown by Langer (1956) to be related to the age of the tiller. Tiller formation, in turn, is known to be influenced by genotype

(Bean, 1957), grazing (Hill and Watkin, 1975), burning (Stanwood, 1974), time and amount of nitrogen application (Wilson, 1959) as well as temperature, light intensity, water supply, and photoperiod (Langer, 1963). The relative importance of these factors in regulating the period of time over which heading occurs has not been sufficiently studied.

A second major objective was to monitor moisture and temperature fluctuations in the windrow in relation to seed deterioration. The probability of seed deterioration occurring at a faster rate than in 1976 is not great since a total of 75.69 mm (2.98 in) of rain fell during the experimental period, compared to a normal of 27.43 mm (1.08 in) (Table 13). Therefore the likelihood of seed deterioration occurring at a faster rate than in 1976 is not great. The experimental windrows were probably thinner than those in most production fields, however, and this may have promoted faster drying and less deterioration than normal during rainy weather. Prolonged cloudy and humid conditions following rain could also accelerate deterioration, even with lesser amounts of rain.

Table 13. Precipitation: mean total and percent probability§ of selected amounts by weekly periods, 1931-1960, and 1976 data.

| Period begins | | Mean pcpn. | 1976 pcpn. | 0.06 | 0.10 | 0.20 | 0.40 | 0.60 | 0.80 | 1.00 | 1.40 | 2.00 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | in | | | | | | | | | | |
| | | % | | | | | | | | | | |
| May | 03 | 0.53 | 0.08 | 76 | 71 | 62 | 45 | 32 | 24 | 19 | 9 | 4 |
| | 10 | 0.48 | 0.10 | 70 | 66 | 56 | 41 | 29 | 21 | 15 | 8 | 3 |
| | 17 | 0.43 | 0.11 | 70 | 66 | 55 | 39 | 27 | 19 | 13 | 7 | 2 |
| | 24 | 0.42 | 0.44 | 71 | 66 | 55 | 37 | 24 | 16 | 10 | 5 | 2 |
| | 31 | 0.34 | 0.60 | 70 | 65 | 53 | 33 | 21 | 13 | 8 | 4 | 1 |
| Jun | 07 | 0.34 | 0.13 | 65 | 60 | 50 | 33 | 22 | 15 | 10 | 5 | 1 |
| | 14 | 0.44 | 0.03 | 58 | 54 | 46 | 32 | 23 | 16 | 11 | 5 | 2 |
| | 21 | 0.24 | | 52 | 48 | 39 | 26 | 16 | 11 | 7 | 3 | 1 |
| | 28 | 0.19 | 0.47 | 46 | 41 | 30 | 16 | 9 | 5 | 3 | 1 | |
| Jul | 05 | 0.10 | 0.40 | 35 | 30 | 20 | 9 | 4 | 2 | 1 | | |
| | 12 | 0.04 | 0.03 | 23 | 18 | 9 | 3 | 1 | 1 | | | |
| | 19 | 0.04 | | 19 | 15 | 9 | 4 | 2 | 1 | 1 | | |
| | 26 | 0.10 | | 23 | 19 | 13 | 6 | 4 | 2 | 1 | 1 | |
| Aug | 02 | 0.08 | 0.28 | 24 | 20 | 13 | 5 | 2 | 1 | 1 | | |
| | 09 | 0.04 | 0.63 | 20 | 16 | 9 | 3 | 1 | | | | |
| | 16 | 0.05 | 0.70 | 27 | 22 | 14 | 6 | 3 | 2 | 1 | | |
| | 23 | 0.21 | 0.47 | 43 | 37 | 26 | 15 | 8 | 4 | 3 | 1 | |
| | 30 | 0.23 | | 49 | 45 | 35 | 21 | 13 | 8 | 3 | 2 | |
| Sep | 06 | 0.25 | 0.46 | 52 | 49 | 40 | 26 | 17 | 11 | 4 | 3 | 1 |
| | 13 | 0.42 | 0.81 | 56 | 52 | 43 | 29 | 20 | 14 | 5 | 5 | 2 |
| | 20 | 0.27 | | 55 | 50 | 41 | 29 | 20 | 15 | 11 | 7 | 3 |
| | 27 | 0.51 | | 61 | 56 | 47 | 35 | 26 | 21 | 16 | 11 | 6 |

§ Average of data for Eugene and Salem, OR.

# SUMMARY AND CONCLUSIONS

Heading date influenced several seed quality characteristics at the recommended time for windrowing. Early inflorescences were lowest in seed moisture content. Tall fescue and perennial ryegrass seeds from the Late group, and orchardgrass seeds from the Intermediate and Late groups had not attained maximum seed weight. Seedlings of tall fescue and orchardgrass produced by seeds from the Late group had not attained maximum shoot weight. Seeds of all inflorescence age groups reached maximum viability several days before optimum windrowing date.

Seed moisture contents when windorwed were 51.6, 41.5 and 15.9% in tall fescue, 44.8, 41.4 and 30.7% in orchardgrass, and 49.8, 28.5 and 19.1% in perennial ryegrass. During periods without rainfall, seed moisture decreased rapidly during the day, increased during the night, and decreased to a new low the following day. Several rains occurred during this period, raising seed moisture levels above 40%. During the drying period, seed moisture in the lower part of the perennial ryegrass windrow was as much as 8% higher than seed in the upper part. The average maximum temperatures in the upper and lower portions of the perennial ryegrass windrow were 38.3 and 24.3°C during July and 31.1 and 19.2°C during August. The maximum temperature reached in the upper part was

was $47^{\circ}C$ on 28 and 29 July.

Each weekk of delay in windrowing resulted in improved seed quality, with the greatest improvement occurring between the first and second cutting. However, the data support Klein and Harmond's (1971) recommendations for windrowing tall fescue at 43% moisture, orchardgrass at 44% moisture, and perennial ryegrass at 35% moisture. Perennial ryegrass seed quality was not improved by delaying windrowing, while orchardgrass and tall fescue seeds increased somewhat in weight and speed of germination. Because of the risk of increased shattering losses, delaying windrowing to improve seed quality does not appear justified.

A small amount of seed development took place while the seeds were in the windrow. Seed weight of tall fescue harvested at 51.6% moisture increased from 250.6 to 279.6 mg/100 seeds. No increase in seed weight occurred in the other species or windrowing dates. After several days in the windrow, speed of germination increased in all three species. Germination percentage, seedling emergence, and shoot weight did not improve after windrowing.

Very little seed deterioration occurred during the first month in the windrow. A perceptible drop in germination of orchardgrass and perennial ryegrass occurred during the 2 weeks prior to the 19 August sampling date. Seed weight declined by the end of the experimental period in all three crops. Some germinated seeds were found in the perennial ryegrass windrows by the end of August. No reduction in speed of germination or shoot weight occurred, while there was a trend toward reduced seedling emergence near the end of the experimental period. There were no indications that the stage of maturity when harvested influenced the rate of seed deterioration in the windrow.

The probability of seed deterioration occurring at a faster rate than in 1976 is not great since a total of 75.69 mm (2.98 in) of rain fell during the experimental period, compared to a normal rainfall of 27.43 mm (1.08 in).

# BIBLIOGRAPHY


Anslow, R. C. 1963. Seed formation in perennial ryegrass. I - Anther exsertion and seed set. J. Br. Grassl. Soc. 18: 90-96.

Anslow, R. C. 1964. Seed formation in perennial ryegrass. II - Maturation of seed. J. Br. Grassl. Soc. 19: 349-357.

Arnold, R. E., and J. R. Lake. 1965. Direct, indirect, and double threshing in herbage seed production. I - S. 48 timothy. J. Agric. Engng. Res. 10: 204-211.

Arnold, R. E., and J. R. Lake. 1966. Direct, indirect, and double threshing in herbage seed production. II - S. 143 cocksfoot. J. Agric. Engng. Res. 11: 276-281.

Arny, A. C., and C. P. Sun. 1927. Time of cutting wheat and oats in relation to yield and composition. J. Am. Soc. Agron. 19: 410-439.

Association of Official Seed Analysts. 1970. Rules for testing seeds. Proc. Assoc. Off. Seed Anal. 60(2): 1-116.

Bean, E. W. 1967. Developmental analysis of inflorescence length in Phleum pratense. Rep. Welsh Pl. Breed. Sta. p. 79.

Blight, D. P. 1962. Swath harvesting: the rate of drying of oats in the swath. J. Agric. Engng. Res. 7: 8-11.

Blight, D. P. 1963. Swath harvesting: the barley swath. J. Agric. Engng. Res. 8: 202-204.

Canode, C. L., A. G. Law and J. D. Maguire. 1970. Post-harvest drying rate and germination of Kentucky bluegrass seed. Crop Sci. 10: 316-317.

Culpepper, C. W., and H. H. Moon. 1941. Effect of maturity at time of harvest on germination of sweet corn. J. Agric. Res. 63: 335-343.

Davenport, E., and W. J. Frasier. 1896. Experiments with wheat. Ill. Agric. Exp. Sta. Bull. 41.

DeWitt, J. L., C. L. Canode, and J. K. Patterson. 1962. Effects of heating and storage on the viability of grass seed harvested with high moisture content. Agron. J. 54:126-129.

Dodds, M. E., and W. L. Pelton. 1969. Weather factors affecting the change of kernel moisture in windrowed wheat. Agron. J. 61: 98-101.

Emecz, T. L. 1962. The effect of meteorological conditions on anthesis in agricultural grasses. Ann. Bot. 26: 159-172.

Green, D. G., M. E. Dodds, and F. G. Warder. 1975. Relationship between kernel moisture and translocation of phosphorus into the kernels of windrowed wheat. Can. J. Pl. Sci. 55: 319-320.

Harlan, H. V., and M. N. Pope. 1926. Development of immature barley kernels removed from the plant. J. Agric. Res. 32: 669-678.

Hart, R. H., and G. W. Burton. 1967. Curing coastal bermudagrass hay: effects of weather, yield, and quality of fresh herbage on drying rates. Agron. J. 59: 367-371.

Hayhoe, H. N. 1973. Weather effects on field drying of forages. A review. Natur. Can. 100: 395-405.

Hermann, E. M., and W. Hermann. 1939. The effect of maturity at time of harvest on certain responses of seed of crested wheatgrass, Agropyron cristatum (L.) Gaertn. J. Am. Soc. Agron. 31: 876-885.

Hill, M. J., and B. R. Watkin. 1975. Seed production studies on perennial ryegrass, timothy, and prairie grass. 1 - Effect of tiller age on tiller survival, ear emergence and seed head components. J. Br. Grassl. Soc. 30: 63-71.

Hill, M. J., and B. R. Watkin. 1975. Seed production studies on perennial ryegrass, timothy, and prairie grass. 2 - Changes in physiological components during seed development and time and method of harvesting for maximum seed yield. J. Br. Grassl. Soc. 30: 131-140.

Horning, E. V., and C. L. Canode. 1963. Effects of harvest method and moisture content on seed quality of smooth bromegrass. Agron. J. 55: 337-340.

Jensen, H. A., and J. Jørgensen. 1969. The influence of the degree of maturity and drying on the germinating capacity of Festuca pratensis Huds. Acta Agric. Scand. 19: 258-264.

Jones, M. D., and J. G. Brown. 1951. Pollination cycles of some grasses in Oklahoma. Agron. J. 43: 218-222.

Kedzie, R. C. 1893. The composition of wheat at various periods of ripening. Mich. Agric. Exp. Sta. Bull. 101.

Keller, W. 1943. Seed production of grass culms detached prior to pollination. J. Am. Soc. Agron. 35: 617-624.

Klein, L. M., and J. E. Harmond. 1971. Seed moisture - A harvest timing index for maximum yields. Trans. Am. Soc. Agric. Eng. 14: 124-126.

Koshy, T. W. 1969. Breeding systems in annual bluegrass, Poa annua L. Crop Sci. 9: 40-43.

Langer, R. H. M. 1956. Growth and nutrition of timothy (Phleum pratense). I - The life history of individual tillers. Ann. Appl. Biol. 44: 166-187.

Langer, R. H. M. 1963. Tillering in herbage grasses. Her. Abstr. 33: 141-148.

Lawrence, T. 1960. Quality of Russian wild ryegrass seed as influenced by time and method of harvesting. Can. J. Pl. Sci. 40: 474-481.

Lawrence, T. 1967. Effect of age on the germination and emergence of Russian wild ryegrass (Elymus junceus) seeds harvested by two methods at progressive stages of maturity. Can. J. Pl. Sci. 47: 181-185.

Lewis, J. 1961. Seed production studies with S. 53 meadow fescue. Rep. Welsh Pl. Breed. Sta. p. 129-136.

Maguire, J. D. 1962. Speed of germination: aid in selection and evaluation for seedling emergence and vigor. Crop Sci. 2: 176-177.

McAlister, D. F. 1943. The effect of maturity on the viability and longevity of the seeds of Western range and pasture grasses. J. Am. Soc. Agron. 35: 442-453.

McWilliam, J. R., and I. F. Wardlaw. 1965. Effect of detaching culms on seed development in Phalaris. Aust. J. Biol. Sci. 18: 283-294.

McWilliam, J. R., and H. E. Schroeder. 1974. The yield and quality of phalaris seed harvested prior to maturity. Aust. J. Agric. Res. 25: 259-264.

Nascimento, D. Jr., C. M. da Silva, and K. Euclides Filho. 1976. Efeito da epoca de colheita sobre o vigor e a germinacao de sementes de capim gordura e jaragua. Rev. Soc. Bras. Zoot. 5: 41-47.

Nellist, M. E., and D. V. H. Rees. 1963. A comparison of two methods of harvesting cocksfoot seed. J. Agric. Engng. Res. 8: 136-146.

Nellist, M. E., and D. V. H. Rees. 1968. A comparison of direct and swath-harvesting of S.24 ryegrass seed. J. Br. Grassl. Soc. 23: 336-342.

Pacific Northwest River Basins Commission. Meteorology Committee. 1969. Climatological Handbook. Columbia Basin States. Precipitation. Vol. 2, 262 p.

Pegler, R. A. D. 1976. Harvest ripeness in grass seed crop. J. Br. Grassl. Soc. 31: 7-13.

Pope, M. N. 1935. The production of barley by post-harvest pollination. J. Hered. 26: 411-413.

Ramptom, H. H., and W. O. Lee. 1969. Effects of windrow curing vs. quick drying on post-harvest development of orchardgrass (Dactylis glomerata L.) seeds. Agron. J. 61: 483-484.

Roberts, H. M. 1969. Harvesting S. 352 timothy for seed. J. Br. Grassl. Soc. 24: 14-16.

Roberts, H. M. 1971. Harvesting tetraploid ryegrass for seed. J. Br. Grassl. Soc. 26: 59-62.

Robertson, I. M. 1956. Swath harvesting: the process of drying. J. Agric. Engng. Res. 1: 125-131.

Robertson, I. M. 1957. Swath harvesting: II - The swath. J. Agric. Engng. Res. 2: 49-55.

Rogler, C. A. 1954. Seed size and seedling vigor in crested wheatgrass. Agron. J. 46: 216-220.

Stanwood, P. C. 1974. Influence of post-harvest management practices on plant growth and seed yield of cool season grasses. M. S. Thesis. Oregon State University, Corvallis, Or. 71 numbered pages.

Steel, R. G. D., and J. H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill Book Company, Inc., New York. 481 p.

Stoddart, J. L. 1959. A study of seed development and yield in timothy as related to the date of harvest. J. Br. Grassl. Soc. 14: 256-261.

Stoddart, J. L. 1965. Post-harvest changes in seed of *Lolium* species. J. Agric. Sci. 65: 365-370.

Stoddart, J. L. 1966. Changes in the molecular-size distribution of carbohydrates during ripening in attached and detached seeds of *Lolium temulentum* L. Ann. Bot. 30: 311-319.

Wilkins, F. S. and H. D. Hughes. 1932. Agronomic trials with reed canary grass. J. Am. Soc. Agron. 24: 18-28.

Williams, S. 1972. The effect of harvest date on the yield and quality of seed of tetraploid hybrid ryegrass. J. Br. Grassl. Soc. 27: 221-227.

Wilson, H. K. and S. M. Raleigh. 1929. Effect of harvesting wheat and oats at different stages of maturity. J. Am. Soc. Agron. 21: 1057-1078.

Wilson, J. R. 1959. The influence of time of tiller origin and nitrogen level on the floral initiation and ear emergence of four pasture grasses. N. Z. J. Agric. Res. 2: 915-932.

# APPENDIX

Appendix Table 1. Mean squares and degrees of freedom from the analysis of variance for quality tests of seeds from three windrowed perennial grass species.

| Crop | Source | df | Seed weight | df | Shoot weight | Speed of germination index | Germination | Emergence |
|---|---|---|---|---|---|---|---|---|
| Tall Fescue | Sampling (S) | 9 | 274.90** | 6 | 81.05 | 7.21** | 47.60** | 262.44* |
| | Harvest (H) | 2 | 965.17** | 2 | 115.73 | 5.57** | 29.87** | 472.37** |
| | S x H | 18 | 324.19** | 12 | 45.67 | 2.13* | 15.87* | 259.53* |
| | Error | 90 | 515.91 | 63 | 52.06 | 3.93 | 6.47 | 108.25 |
| | Total | 119 | | 83 | | | | |
| | Coef. variation (%) | | 2.64 | | 24.01 | 3.36 | 2.69 | 14.94 |
| Orchard-grass | Sampling (S) | 11 | 269.94** | 7 | 89.16 | 26.88** | 436.05** | 1163.94** |
| | Harvest (H) | 2 | 3798.67** | 2 | 1457.17** | 14.55** | 3.38 | 715.13** |
| | S x H | 22 | 48.00** | 14 | 229.75 | 9.49** | 93.73** | 458.88** |
| | Error | 108 | 19.83 | 72 | 189.89 | 1.76 | 22.12 | 158.52 |
| | Total | 143 | | 95 | | | | |
| | Coef. variation (%) | | 4.38 | | 28.18 | 6.53 | 5.66 | 26.55 |
| Perennial ryegrass | Sampling (S) | 10 | 241.41** | 6 | 869.72 | 15.20** | 88.66** | 882.41** |
| | Harvest (H) | 2 | 2410.81** | 2 | 221.87 | 108.77** | 2.30 | 219.80 |
| | S x H | 20 | 218.33** | 12 | 855.51 | 6.71** | 42.03** | 264.06 |
| | Error | 99 | 63.88 | 63 | 677.50 | 1.08 | 9.00 | 109.60 |
| | Total | 131 | | 83 | | | | |
| | Coef. variation (%) | | 4.17 | | 22.37 | 4.84 | 3.46 | 14.98 |

*, ** Significant at 5 and 1% level, respectively.