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Title: Factors Affecting Stand Establishment and Yield of Meadowfoam (Limnanthes alba Benth.)

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Germination of meadowfoam (Limnanthes alba Benth.) seed is inhibited by warm soil temperatures. This has led to recommendations for planting from early to mid-October when soil temperatures are below about 15°C. Objective data on the effects of planting date on stand establishment and yield are not available. These studies were initiated to obtain information on the earliest safe planting date to obtain adequate plant populations and maximum yield. Specific objectives were to determine:

1. The effects of high temperature, light and reduced oxygen on induction of secondary dormancy.
2. The effects of soil moisture and temperature on seed germination and seedling emergence.
3. The effects of planting date, depth of planting and soil temperature on stand establishment.

4. The effects of planting dates on yield.

Imbibed seeds of dormant and non-dormant lots of 'Mermaid' meadowfoam were subjected to high temperature, light and reduced oxygen treatments for 0, 3, 6, 9, 12, and 15 days. Following treatment, the seeds were removed to optimum germination conditions to assess the degree of dormancy induced by the various environmental factors.

The effect of soil moisture on seed germination was determined at four alternating temperatures in seed germinators to simulate field conditions during August, September, October and November. Field plantings were made on several dates in 1984 and 1985 and soil temperatures were recorded during the emergence period. Yield trials with three lots of Mermaid meadowfoam were planted on six dates in 1985.

Exposure of imbibed seeds to 25°C was the most effective means of inducing dormancy, with significant increases in dormancy occurring in both lots after 3 days' exposure. Germination of the non-dormant lot decreased from over 90% to less than 30% after 15 days of warm temperature. Exposure to continuous light was effective in inducing dormancy after 6 days' treatment. Imbibition in an atmosphere of 2% oxygen decreased germination after 9 days' treatment. Reduction in germination by light and reduced oxygen was only moderate, but a greater degree of dormancy would be expected with longer exposure.

Optimum conditions for seedling emergence under simulated field conditions were a soil moisture content of 70% of field capacity and an alternating temperature of 10-15°C. In field trials, maximum seedling emergence occurred in the 24 September 1984 and 26 September 1985 plantings. Emergence was negatively and significantly correlated with the average minimum temperature for the 7 and 14-day periods after planting. There was less association with average maximum and daily temperatures. Seed yield increased from 665 kg ha^{-1} from the 29 August planting to 1276 kg ha^{-1} from the 10 October planting. The low yield from the earliest planting was largely due to lower plant density.

These experiments affirmed that exposure of meadowfoam seeds to factors that inhibit germination will induce secondary dormancy after a minimum exposure period. In the field, induction of dormancy and reduced seedling emergence would be expected if soils are warm or poorly aerated. While light would not be a factor in field emergence, it should be avoided to obtain maximum germination in laboratory germination tests.

These studies support advancing the recommended early planting date to 1 October if irrigation is available or soil moisture is adequate. Planting depths between 1.0 and 2.5 cm are equally satisfactory. Seed dormancy at this time is not a problem when planting 3-month-old seed

from the current years' harvest.

Factors Affecting Stand Establishment and Yield of Meadowfoam (*Limnanthes alba* Benth.)

by

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DEDICATION

This thesis is dedicated to my parents. U Ba Kyaing and Daw Than Nyunt, who had always provided love and guidance.

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INTRODUCTION

As with many new crops, meadowfoam (*Limnanthes alba* Benth.) has seed problems that must be overcome to facilitate commercialization of the crop. Among these problems is seed dormancy. The seed is notorious for germinating poorly in warm soils. For this reason, fall seeding is usually delayed to obtain the cool soil temperatures required for successful stand establishment. If seed dormancy problems can be overcome, seeding could be done earlier, resulting in more vigorous stands and larger plants going into the winter. Earlier seeding would reduce the risks of fall rains and cold weather which would delay planting and necessary fall growth.

No good information has been available concerning relationships between seed dormancy and stand establishment. Information is needed on the causes and extent of the seed dormancy problem and on methods of removing seed dormancy as a crop yield limitation. In the long run, it may be possible to reduce dormancy problems through breeding and selection. In the short run, however, faster progress can be made through application of physiological information. Even in the long run, the physiological information will be needed to aid in selection against dormancy. Findings

from these studies can then be applied to developing and recommending the best stand establishment methods.

The overall objective of this work is to reduce the temperature-related dormancy problems of meadowfoam to facilitate earlier fall planting, establishment of optimum stands, and maximum crop yields. Specific objectives were to:

1. Determine the effects of high temperature, light and reduced oxygen on induction of secondary dormancy.
2. Determine the effects of soil moisture and temperature on seed germination and seedling emergence.
3. Determine the effects of planting date and soil temperature on stand establishment.
4. Determine the effects of planting date on yield.

The results of this study are presented in the form of two manuscripts. The first manuscript reports on the environmental factors that induce secondary dormancy in imbibed seeds. The second reports on factors that affect stand establishment and yield of meadowfoam.

LITERATURE REVIEW

Development of Meadowfoam

Gentry and Miller (1965) observed that meadowfoam (Limnanthes alba Benth.) has a growing season and harvest period similar to winter grains and has shown adaptability to cultivation in a wide range of soils and climates. The unusual adaptation of the meadowfoam plant to very poorly drained soils was an important factor for agronomic researchers in the Willamette Valley of Oregon (Jolliff, 1981).

The major agronomic problems associated with the initial use of wild meadowfoam populations were poor seed retention, low yield, prostrate growth habit and short plants (Kanuika, 1969). In 1967, Calhoun began crop improvement and agronomic production research on these problems in order to increase seed yield. The first named meadowfoam cultivar was Foamore, which was developed from a single plant selection made in 1970 at Corvallis, Oregon, from plant introduction accession PI 283704 of L. alba variety alba. It is an upright growing plant with good seed retention that makes possible direct combine harvest of the seed. The climate of the Willamette Valley of Oregon seemed to be well suited for the production of this crop (Higgins et al., 1971). Johnson et al. (1978 and 1980) studied the influence of planting dates, seeding

rates, and date of harvest on yield and agronomic characteristics of meadowfoam. A 20 to 37% decrease in yield was observed when the harvest was delayed two weeks. Maturity was determined when the seeds became dark brown and shriveled and when the leaves lost their green pigment and turned brown. Harvesting one week before maturity resulted in the highest yield. Maximum seed yields resulted following early to mid-October planting and from a planting rate of at least 23 kg ha^{-1}.

Chemical Composition of Meadowfoam

Meadowfoam seed contains an oil of unique composition that is of interest (Jolliff, 1981). Smith et al. (1960) reported the fatty acid content of L. douglasii included two previously unknown components: cis-5-eicosenoic (65%) and cis-5-docosenoic acid (7%). The oil contains 13% erucic (cis-13-docosenoic) acid. This oil is highly unusual in that it contains over 95% of fatty acids with chain lenghts greater than C_{18} (Smith et al., 1960; Miller et al., 1964). Miwa and Wolff (1962) studied chemical and physical properties of oil, fatty acids, fatty alcohols, and wax esters derived from seed of L. douglasii. Because of their similarity a comparison of chemical composition and physical properties between the wax esters and jojoba oil is also presented. Jojoba oil is a liquid was ester of long chain fatty acids and fatty alcohols and is a

useful raw material for the chemical and allied industries in such fields as plastics, lubricants, pharmaceuticals and cosmetics. Jolliff et al. (1981) reported that L. alba is being domesticated at Oregon State University for production of an industrial oil with long chain C_{20} and C_{22} fatty acids. Crane et al. (1981) investigated the effect of nitrogen fertilization on meadowfoam seed protein content, oil content, and fatty acid composition. Their results demonstrate that fatty acid composition of meadowfoam oil can be reduced by the application of nitrogen fertilizer. Johnson et al. (1980) found that increasing nitrogen fertilization resulted in significant decrease in seed yield and oil content but an increase in protein content.

Effect of Temperature and Light on Germination of Meadowfoam

In a laboratory experiment, Toy and Willingham showed that optimum seed germination temperatures for 10 species or varieties of Limnanthes ranged from approximately 4.4 to 15.5°C. Seeds subjected to 21°C or higher germination temperatures not only germinated poorly, but also showed low germination when subsequently transferred to lower temperatures, which indicated that the seeds may have reverted to a secondary dormancy. Ten accessions of Limnanthes were moistened and placed in 26.6°C in a cabinet

for up to 14 days. Then they were transferred to 4.4, 10, 15.5°C temperatures for germination. In two accessions, 85% of the seeds became dormant after only 2 days at 26.6°C. In six accessions, up to 80% of the seeds became dormant after 14 days at 26.6°C. In two other accessions, there was little or no dormancy induced. After 16 months, one half of the ungerminated seeds in each treatment were dried under room conditions for 2 1/2 months. Then they were again moistened and placed under germination temperatures. Up to 78% of the seeds thus treated germinated, compared with few or none of those maintained continuously under germination conditions (Toy and Willingham, 1966 and 1967).

The effect of light and temperature on germination of two accessions of L. alba seed were determined by Cole (1974). Seeds were germinated on a two-way thermogradient plate and in plastic dishes. Temperatures ranged from 5 to 25°C and the temperature gradients were changed on 8-16 h cycles. Germination occurred over a range of constant temperatures from 5 to 17°C when averaged over all treatments and accessions. Maximum germination at constant temperature occurred at 9 to 13°C. Light suppressed germination on the thermogradient plate at temperatures which were not optimum for germination. Maximum germination and seedling growth were also observed at alternating temperature in continuous dark conditions.

Effect of Temperature on Germination of Seeds

The beginning of the dormant condition in seeds is frequently accompanied by a narrowing of the range of temperature within which germination may occur (Vegis, 1964). David (1929 and 1930) made a very thorough study of the induction of dormancy in seeds of Ambrosia trifida L. and Xanthium. He was able to modify these embryos into and out of dormancy by varying the temperature and oxygen supply. He found that relatively high temperatures and restricted oxygen caused the seeds to develop a secondary dormancy which could be overcome by relatively low temperatures and increased oxygen pressure. Each of these changes took considerable time to develop.

Other investigations have shown that temperature is one of the most influential environmental factors affecting the induction of seed dormancy during seed formation and expression of dormancy during germination. Variations in temperature during seed development affect dormancy of seed in several species. Harrington and Thompson (1952) found that dormancy of lettuce (Lactuca sativa L.) seed was reduced when seeds matured at higher temperatures. Ryegrass (Lolium sp.) seed dormancy, according to Jensen and Pierpoint (1971), varies with season and area of production, as well as with species. Wiesner and Grabe (1972) concluded that dormancy of ryegrass seed was

expressed by differential sensitivity to germination temperatures. Non-dormant seeds germinated over a wider range of temperatures than dormant seeds. Germination did not occur in dormant seed lots at temperatures of 25 and 30°C, but upon after-ripening, germination occurred at these temperatures.

In rice (Oryza sativa L.), a high temperature induced dormancy has been reported (Takahashi, 1967). Horowitz and Givelberg (1982) studied the effect of high temperatures on germination and dormancy of Solanum nigrum seeds. These seeds did not germinate in the dark, but in light 98% of those seeds were germinated at optimum 25°C after five days. No germination occurred above 35°C, although seeds remained viable up to 50°C. The seeds were also subjected to heat treatments for given periods in a simulation of conditions occurring in solar sterilization, and then incubated at 25°C in light for germination. Their results showed that germination was reduced with high temperatures or longer heat treatment.

George (1967) investigated a high temperature seed dormancy in wheat (Triticum aestivum L.). Woodbury and Wiebe (1983) studied temperature-moisture interactions as a factor in germination and dormancy of wheat. Controlled environment studies were made on the effects of temperature on wheat germination with water uptake restricted by resistances outside the seed. At low temperature, the lag

in germination or emergence increased but growth rate was unaffected. The amount of water required for germination was decreased by low temperature when water supply was interrupted, Woodbury and Wiebe (1980), but was increased if water supply was continuous. Winter wheat required less water to germinate than spring wheat. Stand establishment in wheat requires minimum levels of grain dormancy, while the control of preharvest rain damage and sprouting requires higher levels of dormancy. Plants of five cultivars were grown from anthesis to maturity, under controlled temperatures of 15 or 26^{o}C or in the field. Grains were then germinated at 15, 20 and 26^{o}C and the degree of dormancy was measured using weighted germination percentage (WGP) to take account of the rate of germination and the number of grains germinated at each temperature. The results indicated that dormancy is induced by low temperatures (15^{o}C) during grains to development (Reddy et al., 1985).

Some experiments were reported which clarified the influence of temperature on dormancy of seed of Avena fatua (Sawhney and Naylor, 1980). Temperature treatments administered at two stages of the life cycle, during seed development (stage 1) and during the period immediately following seed maturation (stage 2), influence the duration of dormancy in all families (pure lines) so far investigated. There was evidence for induction of thermo-

dormancy by relatively high incubation temperature. This effect was most evident in seeds which are exposed to relatively low temperatures during maturation.

Freshly-collected mature mericarps of Aethusa cynapium were dormant, but some germinated at alternating (16h low/8h high) temperatures when the seed coverings were removed. Burial during winter increased percentage germination and the temperature ranges over which it took place. In late spring the range narrowed, first at low and then at higher temperatures, widening again in autumn. Moist storage at both low (4°C) and high (30°C) temperature overcame dormancy, but exposure to 30°C inhibited subsequent germination at low temperatures (Roberts and Boddrell, 1985). Totterdell and Roberts (1979) tried to remove the innate dormancy of seeds of Rumex crispus L. and Rumex obtusifolius L. by an initial period of low-temperature stratification. The optimum period for stratification depends on two separate processes which occur during the treatment, a rapid loss of innate or primary dormancy and a slower development of induced or secondary dormancy. The rate of induction of secondary dormancy increases with increase in temperature, and is more rapid in the dark than the light. The rate of induction of secondary dormancy during stratification is greater in R. crispus than in R. obtusifolius.

Lettuce seeds (achenes) may undergo to thermodormancy when they are imbibed at high temperatures, resulting in poor emergence and lack of uniformity in stand establishment. Seed priming can be an effective method of improving lettuce stand establishment under high temperature conditions. In field trials in the Imperial Valley of California, where the soil temperature exceeded 35°C for the first 11 h of imbibition under sprinkler irrigation, total emergency of untreated seeds after six days was between 10% and 21% and coated seeds ranged from 46% to 69% (Veronica et al., 1985). Germination of new seeds (1-6 months old) of Hypericum perforatum L. was restricted by high temperatures (16/8h, 20/30°C), darkness and a chemical inhibitor in exudate from the capsule, whereas germination of 9-year-old seeds was only restricted by the inhibitor. The effect of the chemical inhibitor and high temperature was overcome, respectively, by washing seeds in water and by reducing temperatures to constant 15°C (Campbell, 1985).

Effect of Soil Temperature on Field Emergence of Seeds

Lettuce seed planted when soil temperatures are between 25 and 30°C may fail to germinate, producing poor stands. The failure of lettuce seed to germinate well at temperatures above 25°C is not fully understood

could strongly influence seed germination in the field are light, alternating temperature and nitrate ions; all are environmental factors at or near the soil surface and could contribute to the well-known response of many weed species to germinate when near the surface (Vincent and Roberts, 1977). Laude et al. (1952) studied the effect of high soil temperatures on the seedling emergency of perennial grasses. This suggests that tolerance of high soil temperatures decreases from planting to emergence. Dubetz et al. (1962) also studied the effect of soil temperature on rate and percentage emergence of 19 native herbaceous species at the following soil temperatures: 6, 13, 18, and 24°C. The rate of emergency of all species was greater at 24°C than at 18°C.

It is difficult to predict the rate and extent of emergence of field plantings of winter wheat because it has a wide variability and interactive effects among soil temperature, moisture and deep planting to reach moisture sufficient for emergence (Lindstrom et al., 1976). Russelle (1978) investigated the effect of soil temperature on the rate of first emergence and 70% stand of winter wheat and winter barley in the field, and to develop a means of predicting the average last date of planting at one location in eastern Oregon after which stand establishment is delayed. The results indicated

that if a 70% stand within 14 days of planting wheat were desired, the average last date to plant in this area would be 25 September. Effects of temperature and moisture on stand establishment and seedling characteristics associated with stand establishment of seven wheat cultivars were studied by Conway (1977). His results indicated that minimum stands were attained under high soil temperature (22°C) and high moisture stress (-6 bars). Percent stand reached a maximum at 8°C and a minimum at 22°C. Nelson and Sharples (1986) found that the rate and total emergence of lettuce seedlings incubated at 33°C for 10 hr alternating with 23°C for 14 h was markedly increased by seed treatment with 0.5 mM fucicoccin (FC). Neither gibberellic acid (GA) nor kinetin (K) were effective in improving emergence when used alone. The combination of FC with GA or K appeared to give a synergistic enhancement of emergence rate. Radicle elongation of seedling was reduced by seed treatment with FC, K or combinations of FC, GA and K in tests at 20°C.

The Influence of Light on Dormancy and Germination of Seeds

The influence of light and potassium nitrate on the dormancy and germination of A. fatua seed buried under natural conditions was studied over a 13-month period. Natural emergence of seedlings from buried seed in

relation to rainfall and temperature regimes and fluctuation was also monitored. Their findings showed that potassium nitrate is stimulatory to germination only in light (Hilton, 1985). Seeds of six species of common weeds were imbibed in water or potassium nitrate and illuminated during or after chilling (1°C). All responded to chilling, but only to any marked extent when combined with light or nitrate, or both (Vincent and Roberts, 1979). Light can regulate the germination of seeds of wild oat. In a low volume of water, seeds are inhibited by white light and in high volumes they are promoted, when compared to seeds in darkness. Blue, red and far-red light also inhibited germination of seeds in low volumes of water; in high volumes of water there were no differences between these three bands of light and darkness (Hsiao and Simpson, 1971).

The germination of Typha latifolia L. seed required high temperatures, low oxygen concentration and relatively long exposure to light to induce high percentages of seed germination. A greater percentage of seeds germinated at 35°C than at lower temperatures. Less than 10% of the seeds germinated at 15°C and none at 10°C (Bonewell et al., 1983). Dormancy in seeds of the parasitic phanerogam (Aeginetia indica L.) can be broken by chemical treatment with sodium hypochlorite, which also helps to control contaminating microflora. A germination medium was

developed that suppressed microbial contamination and permitted long term observation of these slow-germinating seeds. Continuous light as low as 0.1 fc completely inhibited germination on this growth medium. Brief intermittent light exposures depressed germination (French and Sherman, 1976).

Intact, after-ripened seeds of channel millet (Echinochloa turnerana (Domin) J.M. Black) did not germinate in dark, but dehulled seeds achieved a high percentage of germination in the dark. Secondary dormancy was induced by imbibing intact seeds in the dark and was broken by subsequent dry storage or by disruption of enclosing structures. More intact after-ripened seeds that were subjected to wetting-drying cycles in the light germinated during the final wetting than did untreated seeds. High final germination percentage values were attained by both leached and unleached seeds (Conover and Geiger, 1984). Breaking of dormancy of saffron thistle seed can be achieved by leaching during imbibition in the presence of red light (600-680 nm). The results suggest a transient light sensitivity during the first 24 h of imbibition which, in non-leached seed, may be prevented by inhibitor present in the embryo (Wright et al., 1980). Froud-Williams et al. (1984) studied effects of light on germination and dormancy of various arable weeds. Germination of freshly collected seeds of some species was promoted by

short irradiation of red light. Dry storage did not affect germination of some species, but did affect dormancy and light requirement of Poa trivialis. Buried seeds of some species increased their sensitivity to far-red light.

Toole and Borthwick (1971) found that the germination of Kentucky bluegrass (Poa pratensis L.) seeds is influenced by two light interactions; one, the phytochrome reaction (P), is promotive, and the other, the so-called high-energy reaciton (HER), is inhibitory to germination. The level of germination of these two opposing reactions is influenced by temperature. Dormancy in seed of hazel (Corylus avellana L.) is naturally terminated by chilling. Freshly harvested seed of hazel, however, is only partially dormant. Embryo dormancy is induced during dry storage of intact fruits. Shannon et al. (1983) found that light broke the dormancy of hazel seeds when the testa is removed. Light, acting via phytochrome, also promotes the germination of hazel seeds when the embryonic axis is surgically uncovered. Black and Wareing (1960) studied the effect of temperature on light-hard and thermodormant dormant seed of Nemophila insignis. The seeds whose germination has been inhibited by light at 21^{o}C are transferred into darkness at the same temperature they do not germinate; these seeds are called light-hard. Similarly,

those seeds inhibited by high temperatures in darkness do not germinate when the temperature is afterwards lowered to 21°C. Seeds were rendered light-hard by exposure to white florescent light for three days at 21°C. Thermodormancy was induced by holding seeds in darkness for three days at 28-30°C.

The influence of light on the germination of A. fatua seed may be due to the use of seed of different types and differing dormancy status. To resolve these uncertainties, Hilton and Bitterli (1983) tested 30 stocks of seeds of known type and dormancy status. Their results indicated that light promoted the germination of three types of partially-dormant seed but had no effect on fully-dormant seed but had no effect on fully-dormant and fully-nondormant seed. Joubert and Small (1982) studied seed germination and dormancy of Stipa trichotoma (Nassella tussock). Caryopses of S. trichotoma are dormant when completely enclosed by a lemma and palea. Complete removal of these structures leads to high germination in both light and dark. Damaging the lemma and palea in a small area increases germination to some extent in the light. For a significant increase in dark germination the pericarp must also be damaged in addition to damaging the lemma and palea. Sulphuric acid sacrification for 7 min increases light germination.

The Influence of Oxygen on Germination and Emergence of Seeds

Oxygen concentration and oxygen diffusion rate can influence germination and emergence of wheat and mustard. Winter wheat did not germinate at concentrations below 1% yet only 10% oxygen gave maximum emergence (Kaack and Kristen, 1967). They found that the rate of emergence was reduced by reducing the oxygen content or by increasing water content. Horowitz and Givelberg (1982) studied the role of oxygen on germination of Solanum nigrum seeds. Oxygen at low (10%) or high (100%) concentration and carbon dioxide at high concentration (12%) did not affect germination markedly. In solar sterilization, high temperature appears to be the major factor reducing germination, while the level of oxygen or carbon dioxide in the soil atmosphere may play a secondary role.

Some workers reported that the breaking of seed dormancy in rice (Oryza sativa L.) is usually enhanced by higher oxygen tension, whereas others have shown that rice seed dormancy can be broken by incubation under anaerobic conditions. The results show that high oxygen tensions inhibit seed germination for a certain period after harvest in Japonica rice, whereas, Indica rice cultivars are not inhibited by oxygen at any stage (Takahashi, 1985). Germination of Strelitzia juncea seeds was increasingly stimulated by increasing the oxygen concentration in the

incubation atmosphere. Maximum stimulation was obtained with an initial oxygen concentration of 100%. Gibberellic acid did not affect germination. Oxygen, but not GA, caused an increase in alpha and beta amylase activities and reducing substance levels in embryos and endosperm. A continuous high oxygen concentration was required for maintenance of high amylase activity. Transferring seeds from a high oxygen concentration to air caused a drop in alpha amylase activity and no further increase in reducing substance levels. Embryos from oxygen treated seeds imbibed more water than air treated seeds (Ybema and Grobbelaar, 1984).

Types of Dormancy

Seeds which do not germinate when placed under conditions normally considered ideal for germination are said to be dormant. Primary dormancy is that with which a seed is shed. It is developed during maturation on the parent plant and persists for a variable length of time after the seed has been shed. This primary dormancy can later be lost, but if conditions are not then suitable--for example, during periods of drought or in a cold winter-- the seed will not germinate. Subsequently, during this period in which the seed remains ungerminated, dormancy can once again be induced in the seed. This is known as secondary dormancy. Whether the mechanism of secondary dormancy is

the same as that of primary dormancy is not known (Chancellor, 1982).

Evenari (1965) discussed secondary dormancy as being either thermo- (temperature), photo- (light), or skoto- (darkness) imposed, though other causes such as imposition by excess or adverse amounts of water, chemicals, and gases might also be added. He also said that sometimes nondormant seeds are subjected to conditions that subsequently caused them to become dormant. This may be caused by exposures of the seed to conditions that favor germination in all aspects except one.

Fellows et al. (1985) studied the characteristics of secondary dormant wild oat seed which have three types of dormancy; primary, secondary and enforced dormancy. Enforced dormancy occurs when the nondormant seed is placed under conditions that are unfavorable for germination. Enforced differs from secondary dormancy in that secondary dormant seed will not germinate when placed in favorable conditions.

Bewley (1980) has found that lettuce seeds imbibed in darkness at supra-optimal temperatures (23 + 1 or 23 -1^{o}C) develop a secondary dormancy, termed skotodormancy. A combination of red light and gibberellic acid will break secondary dormancy for longer than either alone, but red light and benzyladenine together are much more effective.

Desiccation of skotodormant seed does not diminish their dormancy.

According to the discussion of Bewley and Black (1982), the onset of primary or innate dormancy means the establishment of dormancy during seed development and maturation. Dormancy can also be induced in mature seeds after they have been shed from the mother plant. Non-dormant seeds can be rendered dormant, or the dormancy of partially dormant seeds can be deepened. These events occur when seeds are held under conditions unfavorable for their germination. Anaerobiosis, caused by excess water, by atmospheres low in oxygen, or by poorly permeable seed coat is one of the effective agents.

Secondary Dormancy

Seeds prevented from germinating when held in solutions of high osmotic strength may also enter secondary dormancy (Khan and Karssen, 1980). Seeds whose germination has been inhibited by light (e.g., Phacelia tanacetifolia and Nemophila insignis) do not germinate even when subsequently transferred to darkness; they are dormant and now require special, dormancy-breaking treatment. Many other examples of secondary dormancy are documented by Barton (1965). Davis (1930) found that isolated Xanthium pennsylvanicum embryos are made dormant by being embedded in wet clay at 30°C or when held in an atmosphere having a

low oxygen concentration. Similarly, imbibed, nondormant seeds of A. factua became dormant in an atmosphere of nitrogen, failing to germinate when transferred to air (Black, 1959).

Secondary dormancy of A. fatua seeds was induced by placing seeds in a flask kept in the dark at 20°C. Soaking for 4 days induced secondary dormancy in 80% of the seeds. Gibberellic acid at a level of 0.05 mM stimulated 95% of the secondary dormant seed to germinate, while sodium azide treatment resulted in 100% germination of the dormant seed after 3 weeks. Electrophoresis showed protein changes in the embryos of secondary dormant seed (Fellows, Fay and Foley, 1985).

Yield and Yield Components

Developmental processes determining yield potential and actual yield components of perennial ryegrass (Lolium perenne) seed crops were established by Hebblethwaite et al. (1977). The yield potential is defined as the number of florets per unit ground area of the crop at anthesis. It is dependent upon the number of fertile tillers and the number of florets per fertile tiller. Actual yield is defined as seed weight per unit ground area at harvest. This process determines the number of seeds per spikelet and mean weight per seed. In order to increase seed yield, one or more of the components of the final yield

must be increased. Very often, the increase in one component leads to the decrease in another component, resulting in final yield remaining constant. The phenomenon is known as yield component compensation.

The influence of time of harvest on seed yield, seed weight, and oil content of meadowfoam was determined (Johnson et al., 1978). Paraquat was used as a harvest aid to hasten maturity and reduce shattering during direct combined harvest or swathering. Johnson et al. (1980) also studied the effect of planting dates and seeding rate of meadowfoam on seed yield. Maximum yield was obtained from October 5 planting at seeding rate of 23 kg ha^{-1}. Pearson and Jolliff (1986) studied irrigation effects on seed yield of meadowfoam. They evaluated flower phenology by counting and hand picking flowers in a 0.10 m^2 plot area. Flowers per stem were determined from 40 samples of unbranched stems randomly selected from each plot. Seeds per flower were evaluated from 0.10 m^2 yield sample. Seed yield and 1000-seed weight were determined after threshed samples were cleaned and seed oil content was determined by solvent extraction with hexane.

MANUSCRIPT I

INDUCTION OF SECONDARY DORMANCY IN SEED OF MEADOWFOAM (*LIMNANTHES ALBA* BENTH.)

ABSTRACT

Fall seedings of meadowfoam (Limnanthes alba Benth.) in Oregon are usually delayed until early to mid-October because of the possibility of inducing secondary dormancy from earlier planting in warm soils. This experiment was conducted under laboratory conditions to determine if secondary dormancy is induced by warm temperatures or other environmental conditions that are unfavorable to meadowfoam seed germination.

Imbibed seeds of dormant and non-dormant lots of 'Mermaid' meadowfoam were subjected to high temperature, light and reduced oxygen treatments for 0, 3, 6, 9, 12 and 15 days. Following treatment, the seeds were removed to optimum germination conditions to assess the degree of dormancy induced by various environmental factors.

Exposure of imbibed seeds to 25°C caused the most induced dormancy, with significant increases in both lots after 3 days exposure. Germination of the non-dormant lot decreased from over 90% to less than 30% after 15 days of warm temperature. Exposure to continuous light was effective in inducing dormancy after 6 days treatment. Imbibition in an atmosphere of 2% oxygen decreased germination after 9 days treatment. Reduction in germination by light and reduced oxygen was only moderate, but a greater degree of dormancy would be expected with longer exposure.

These experiments affirmed that exposure of meadowfoam seeds to factors that inhibit germination will induce secondary dormancy after a minimum exposure period. In the field, induction of dormancy and reduced seedling emergence would be expected if soils are warm or poorly aerated. While light would not be a factor in field emergence, it should be avoided to obtain maximum germination in laboratory germination tests.

Additional index words: Germination, Temperature, Light, Oxygen.

Induction of Secondary Dormancy in Seed of Meadowfoam (*Limnanthes alba* Benth.)

INTRODUCTION

Secondary dormancy may be induced in seeds that are exposed to environmental conditions otherwise favorable for germination but lacking in one or more conditions required for germination to occur. When returned to a favorable germination environment, such seeds fail to germinate (Bewley and Black, 1982; Chacellor, 1982; Fellows et al., 1985).

Most environmental factors that inhibit germination of a particular species may also induce secondary dormancy. Thus, prolonged exposure to high temperatures may induce secondary dormancy in seeds such as *Ambrosia trifida* L. (Davis, 1930) and *Chenopodium bonus-henricus* L. (Khan and Karssen, 1980). Imbibition in light may induce dormancy in light-inhibited seeds such as *Nemophila insignis* L. (Black and Wareing, 1960) and *Nigella damascena* L. (Isikawa, 1957), while dark imbibition may induce dormancy in light-requiring seeds of *Rumex crispus* L. (Taylorson and Hendricks, 1976). Imbibition under anaerobic conditions may cause dormancy in seeds of *Avena fatua* L. (Black, 1959), and imbibition under water stress may induce dormancy in *Lactuca sativa* L. (Khan, 1960). Additional examples of these and other causes of secondary dormancy are reviewed by Bewley and Black (1982).

Mechanisms of secondary dormancy (as well as primary dormancy) serve to prevent weed seeds from germinating under environmental conditions that are unfavorable for survival of the seedlings (Fellows et al., 1985). Such mechanisms would be a detriment in crop seeds however, since it is desirable that they germinate and emerge quickly under a variety of environmental conditions.

Germination of seeds of meadowfoam (Limnanthes alba Benth.), a new oil-seed crop, is inhibited by warm temperatures and light (Cole, 1974). Toy and Willingham (1967) showed that several species of Limnanthes went into secondary dormancy when imbibed seeds were held at 27°C for several days, and they indicated this would be an obstacle to development of these species into agricultural crops. Because of the possibility of induction of secondary dormancy in warm soils, fall seedings of meadowfoam in Oregon are usually delayed until early to mid-October when the soil temperatures are lower (Jolliff, 1981).

The objectives of this study were to determine if seeds of the improved cultivar "Mermaid" go into secondary dormancy at high temperatures, and to investigate other environmental conditions that may induce secondary dormancy in meadowfoam.

MATERIALS AND METHODS

Seedlots of Mermaid meadowfoam (Limnanthes alba Benth.) produced in 1984 and 1986 were used in these studies. Imbibed seeds were subjected to high temperature, light and reduced oxygen treatments for up to 15 days, following which they were removed to optimum germination conditions to determine the degree of dormancy induced by the treatments.

For the high temperature treatments, 50 seeds were placed on top of moist blotters in 11 x 11 x 3.5-cm clear plastic germination boxes. The boxes were placed in a dark germinator at 25°C.

For the light treatments, 50 seeds were placed on top of moist blotters in germination boxes. The boxes were placed in a germinator at 10°C with continuous light. Light was supplied by four cool-white fluorescent bulbs at a photosynthetic photon flux density of 48 u mol m^{-2} s^{-1} as measured with a Li-Cor Solar Monitor LI-1776 (Li-Cor, Ltd.).

For the reduced oxygen treatments, 50 seeds were placed on top of moist blotters in wide-mouth 473 ml (pint) jars. The lids were fitted with #7 two-hole rubber stoppers with 7-mm glass tubes. The tubes were sealed with rubber septa. The jars were flushed with a mixture of 2% oxygen and 98% nitrogen for approximately 3 min

through hypodermic needles inserted through the septa. The gas mixture was regulated with a Matheson Flowmeter Model 7351 H (Matheson Gas Products, Inc., N.J.) and monitored with a Percent Oxygen Monitor Model 74223 (Bio-Tek Instruments Inc., Burlington, VT.). The jars were also flushed with the gas mixture at 2-day intervals. The jars were placed in a dark germinator at 10°C.

After induction periods of 0, 3, 6, 9, 12 and 15 days, the seeds were placed in a dark germinator at 10°C and germination counts were made after 7 and 14 days. For the high temperature and light treatments, the seeds remained in the boxes in which they were treated. For the oxygen treatment, the seeds were transferred to germination boxes.

All experiments were replicated three times. Data were analyzed by analysis of variance and least significant differences were calculated for comparison of treatment means (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Exposure of imbibed meadowfoam seeds to 25°C, continuous light or an atmosphere of 2% oxygen induced secondary dormancy in both seed lots (Figs. 1, 2, 3). The proportion of seeds becoming dormant increased as the length of exposure to unfavorable conditions increased.

High temperature was the most effective means of inducing dormancy (Fig. I.1). Low temperatures are required for germination of meadowfoam seed, and no germination occurs at 25°C (Cole, 1974). Dormancy in both lots increased significantly after the first 3-day induction period and continued to increase rapidly. Toy and Willingham (1967) obtained similar results with Limnanthes alba in 1967, indicating that seed dormancy characteristics have apparently remained unchanged during the development of the cultivar Mermaid. The effect of high temperature on intensifying dormancy under controlled laboratory conditions affirms the importance of not planting meadowfoam in the field in early fall when soil temperatures are still warm. Not only do high temperatures prevent immediate germination (Cole, 1974), but the seeds become dormant and may not contribute to the stand even after the soil is cooler and temperatures are favorable for germination.

Exposure to continuous light was also effective in inducing dormancy (Fig. I.2). Differences in germination

were significant after 6 days treatment in 1986 seed and after 9 days in 1984 seed. Since light inhibits germination of meadowfoam (Cole, 1974), it would be expected to induce dormancy as well. Similarly, exposure to light induced secondary dormancy in other light-inhibited seeds such as Nemophila insignis L. (Black and Wareing, 1960) and Nigella damascena L. (Isikawa, 1957). While this phenomenon is biologically interesting, it does not appear to be of practical importance in relation to germination and emergence when meadowfoam stands are established by drilling. Light is important in laboratory germination testing, however, and should be excluded from meadowfoam seed to obtain maximum germination.

Exposure to atmospheres of reduced oxygen decreased germination percentages significantly in both seed lots after 9 days exposure (Fig. I.3). Reduction in germination was only moderate, but a greater degree of dormancy would be expected with longer exposure or subjection of the seeds to complete anaerobiosis (Black, 1959). Anaerobic conditions can occur in the soil, especially under waterlogged conditions. Although meadowfoam plants are reasonably well-adapted to growing in poorly drained soils (Calhoun and Crane, 1978; Jolliff, 1981), the seeds are probably no more tolerant of anaerobic germination conditions than are seeds of other species.

This study has shown that Mermaid, an improved cultivar of meadowfoam, retains the propensity for going into secondary dormancy by exposure to temperatures that are unfavorable for germination. Secondary dormancy is also induced by exposure to other unfavorable germination conditions such as light and reduced oxygen levels, and it would be expected that other unfavorable conditions would act similarly. Secondary dormancy was induced in this study by maintaining all germination conditions at a favorable level except the single condition being evaluated. A combination of two or more unfavorable factors would be expected to result in either a more intense dormancy or a faster rate of induction. At the time of the experiment, the 1984 seed was non-dormant while a high proportion of the recently harvested 1986 seed was still in primary dormancy. Dormancy of both seed lots increased at about the same rate, regardless of the initial difference in intensity of dormancy. Of the three environmental factors studied, warm temperature would probably be the most important factor limiting germination in the field. Reduction of dormancy characteristics by breeding or by physiological means would greatly reduce the risks involved in stand establishment of meadowfoam.

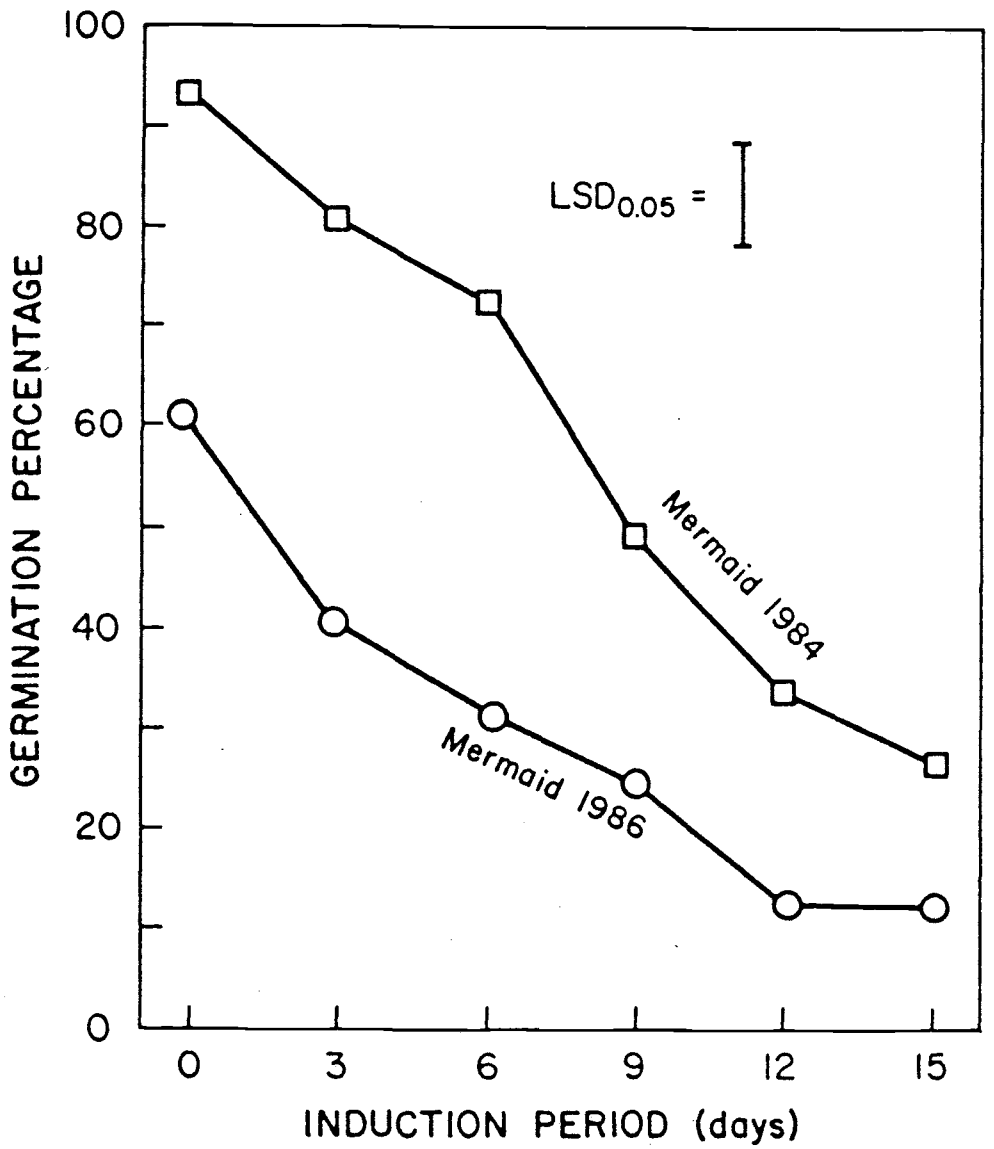

Figure I.1. Effect of high temperature on induction of secondary dormancy in imbibed seeds of Mermaid meadowfoam. Seeds held at 25°C in dark for 3 to 15 days.

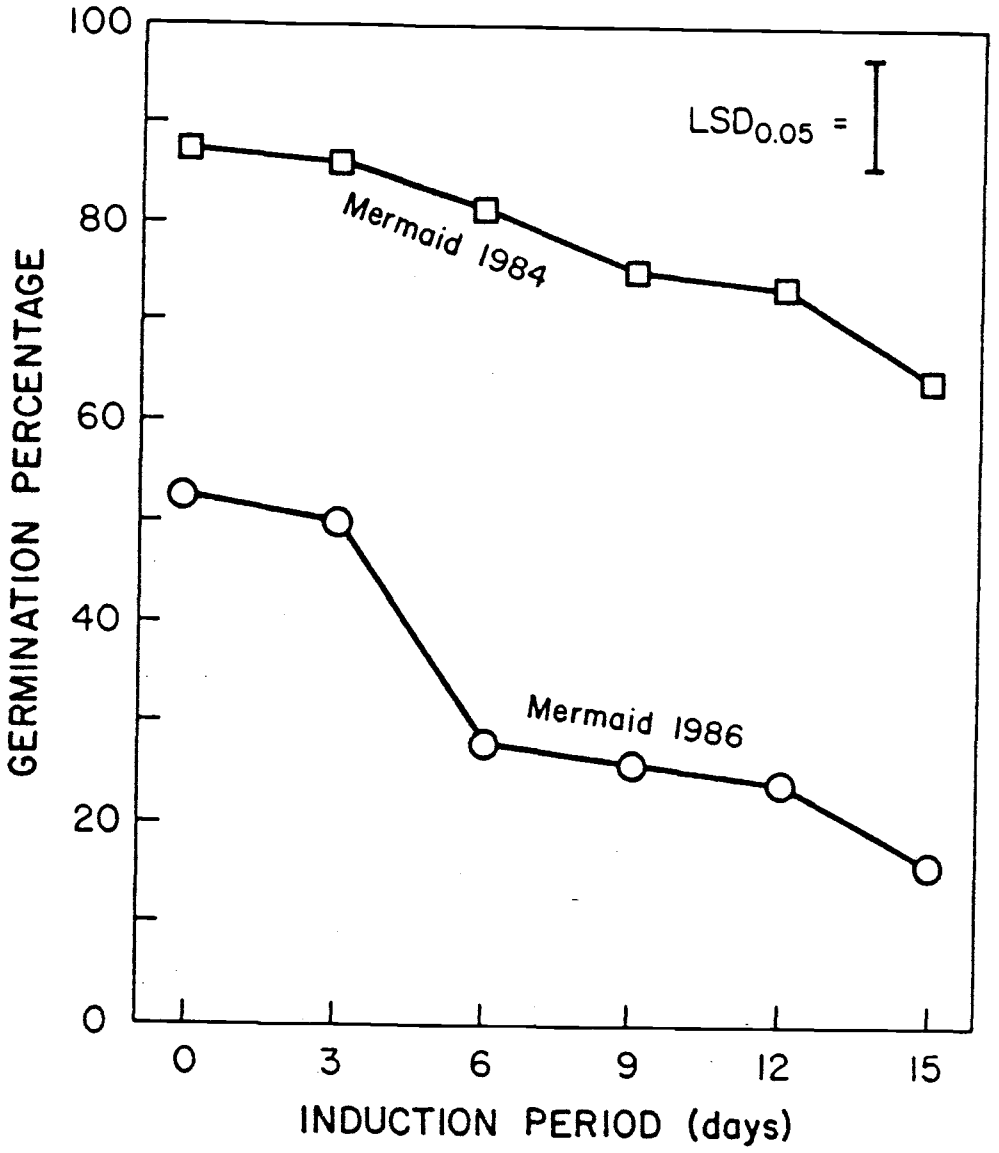

Figure I.2. Effect of light on induction of secondary dormancy in imbibed seeds of Mermaid meadowfoam. Seeds held in continuous light at 10°C for 3 to 15 days.

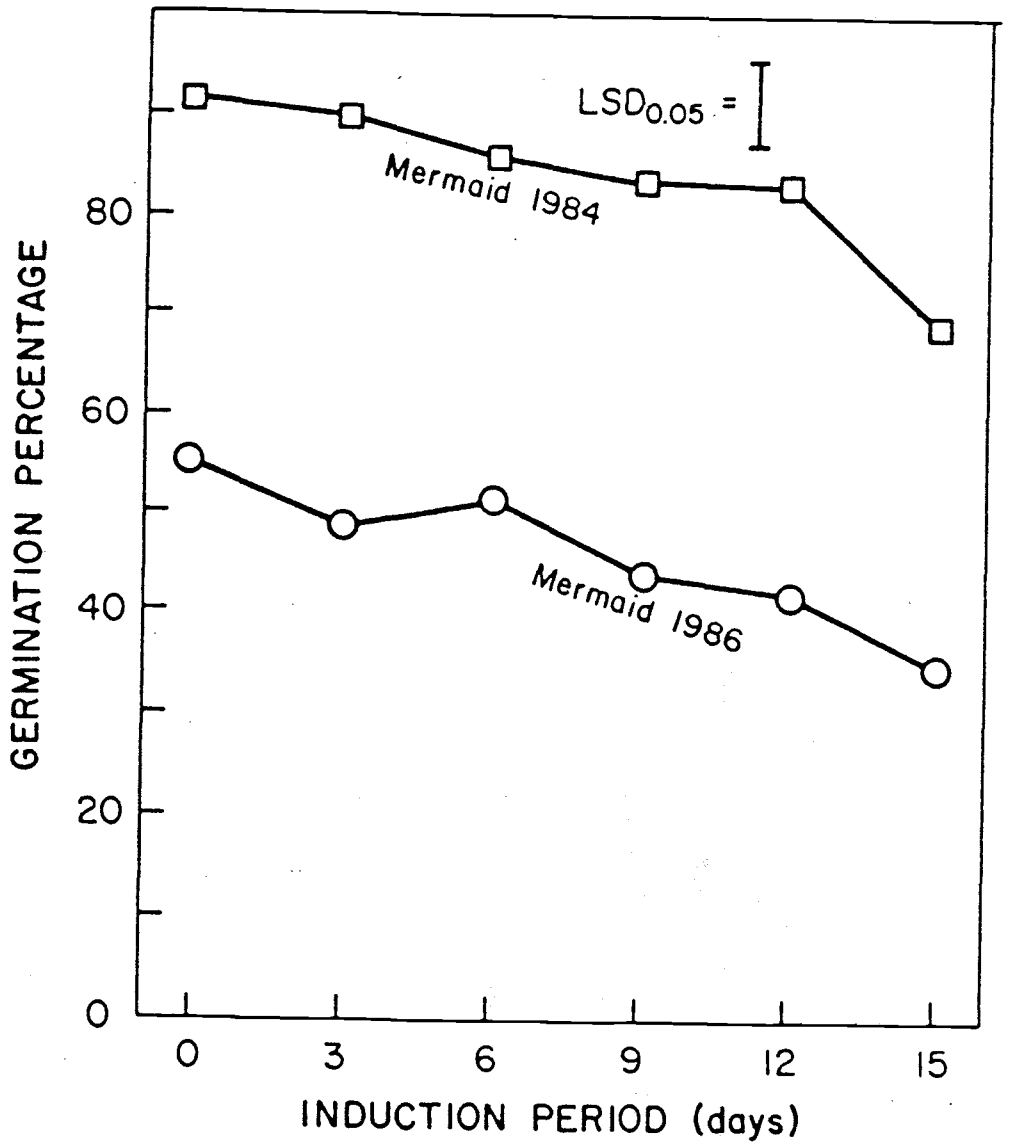

Figure I.3. Effect of low oxygen on induction of secondary dormancy in imbibed seeds of Mermaid meadowfoam. Seeds held at 2% oxygen at 10°C in dark for 3 to 15 days.

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MANUSCRIPT II

STAND ESTABLISHMENT AND YIELD OF MEADOWFOAM IN RELATION TO PLANTING DATE AND SOIL TEMPERATURE

ABSTRACT

Germination of meadowfoam (Limnanthes alba Benth.) seed is inhibited by warm soil temperatures. This has led to recommendations for planting from early to mid-October when soil temperatures are below about 15°C. Objective data on the effects of planting date on stand establishment and yield are not available. These studies were initiated to obtain information on the earliest safe planting date to obtain adequate plant populations and maximum yield. Specific objectives were to determine the effects of soil moisture on seed germination; the effects of planting date, depth of planting and soil temperature on stand establishment; and the effects of planting date on yield.

The effects of soil moisture on seed germination were determined at four alternating temperatures in seed germinators to simulate field conditions during August, September, October and November. Field plantings were made on several dates in 1984 and 1985 and soil temperatures were recorded during the emergence period. Yield trials with three lots of 'Mermaid' meadowfoam were planted on six dates in 1985.

Optimum conditions for seedling emergence under simulated field conditions were a soil moisture content of 70% of field capacity and an alternating temperature of 10-15°C. In field trials, maximum seedling emergence

occurred in the 24 September 1984 and 26 September 1985 plantings.

Emergence was negatively and significantly correlated with the average minimum temperature for the 7 and 14-day periods after planting. There was less association with average maximum and daily temperatures. Seed yield increased from 665 kg ha^{-1} from the 29 August planting to 1276 kg ha^{-1} from the 10 October planting. The low yield from the earliest planting was largely due to lower plant density.

These studies support advancing the recommended early planting date to 1 October if irrigation is available or soil moisture is adequate. Planting depths between 1.0 and 2.5 cm are equally satisfactory. Seed dormancy at this time is not a problem when planting 3-month-old seed from the current year's harvest.

Additional index words: *Limnanthes alba* Benth., Depth of planting, Soil moisture, Seedling emergence, Seed.

Stand Establishment and Yield of Meadowfoam in Relation to Planting Date and Soil Temperatures

INTRODUCTION

Development of cultural practices for meadowfoam (Limnanthes alba Benth.), a new oilseed crop, began in the 1960s. Meadowfoam is normally handled as a winter annual and planted in the fall (Higgins et al., 1971). Highest yields were obtained in Maryland from early to mid-October planting dates (Johnson et al., 1980). Planting rates giving maximum yields have ranged from 23 kg ha^{-1} in 10-cm rows to 33.6 kg ha^{-1} in 15-cm rows (Johnson et al., 1980; Calhoun and Crane, 1978). Seeding depths below 1 cm are not recommended (Jolliff et al., 1981).

Response to nitrogen (N) fertilization has not been consistent. Nitrogen did not increase the amount of seed produced, but resulted in more harvested seed because of more upright plant growth (Calhoun and Crane, 1978). Nitrogen application resulted in a decrease in seed yield in Maryland (Johnson et al., 1980) and in seed oil content in Oregon (Crane et al., 1981). McGahuey (1986) did not obtain a yield increase from N fertilization in 1981, but more than doubled seed yield in 1982 with spring application of 50 kg N ha^{-1}. Meadowfoam requires a high plant water potential (Pearson and Jolliff, 1985), and yield is not reduced by waterlogged soils (Calhoun and Crane,

1978). Pearson and Jolliff (1986) found that the benefits of irrigation depended on available soil moisture, with no seed yield increase from irrigation in 1981, but a 32% increase in 1982. Weed control was achieved with pre-emergence applications of propachlor (Jolliff et al., 1981). Meadowfoam is subject to seed shattering if harvest is delayed (Higgins et al., 1971; Johnson et al., 1978). Current production practices recommended in Oregon are described by Karow et al. (1986).

This research was conducted to examine additional factors affecting stand establishment and yield of meadowfoam. Specific objectives were to:

1. Determine the effects of soil moisture on seed germination and seedling emergence.
2. Determine the effects of planting date, depth of planting and soil temperature on stand establishment.
3. Determine the effect of planting date on yield.

MATERIALS AND METHODS

Soil Moisture Studies

Soil moisture and temperature conditions typically encountered in the field at Corvallis, Oregon were reproduced in seed germinators. One thousand g field soil was placed in 24 x 16.5 x 3.8 cm plastic boxes. One hundred 19-month-old seeds of non-dormant Mermaid meadowfoam were planted at a depth of 1.3 cm in each box. Water was added to the boxes to bring the soil to 50, 60, 70, 80 or 90% of field capacity. Field capacity of the soil was determined by the method described in the Seed Vigor Testing Handbook (Association of Official Seed Analysts, 1983). The boxes were enclosed in polyethylene bags to maintain a constant moisture level. The boxes were weighed weekly and the slight amount of water lost was replaced. The boxes were placed in dark germinators maintained at 16-8 h temperature cycles of 20-30, 15-25, 10-15 or 5-10^{o}C, controlled to $\pm$ 1.0^{o}C. Final germination counts were made 21 days after planting. The experimental design was a completely randomized design with three replications.

Date of Planting Studies

Stand Establishment

Stand establishment trials were conducted in 1984 and 1985 at the Hyslop Crop Science Field Laboratory near

Corvallis, Oregon on a Woodburn silt loam (fine-silty, mixed, mesic Aquultic Argixeroll) soil. In 1984, the species and selections planted were: L. alba Mermaid produced in 1983 and 1984; L. floccosa Selection OLC-2 produced in 1983; L. floccosa x L. alba Selection 83-557 produced in 1984; L. floccosa x L. alba Selections ORL 83-526 and ORL 83-446 produced in 1984. In 1985, the seed lots were: L. alba Mermaid produced in 1983, 1984 and 1985; L. floccosa produced in 1983; and L. floccosa x L. alba Selection 83-557 produced in 1984.

Plots were planted with a plot seeder with 100 seeds row^{-1} in 2.75-m rows spaced 0.3 m apart. Planting depth were 0.64, 1.3 and 1.9 cm in 1984 and 1.3, 1.9 and 2.54 cm in 1985. Planting dates were 17 August; 10, 17 and 24 September; and 1 October 1984 and 29 August; 12, 19, and 26 September; and 3 and 10 October 1985. Irrigation was applied after the first four plantings, while natural rainfall was sufficient for emergence of later plantings. Ramrod (2-chloro-N-isopropylacetanilide) at 2.24 kg ha^{-1} a.i. was applied for preemergence weed control. Emergence counts were made at near-weekly intervals until 19 November 1984 and 26 November 1985.

In 1984, soil temperatures at the 5-cm depth were obtained from the nearby Hyslop Crop Science Field Laboratory weather station. In 1985, soil temperatures in the plots were recorded at 1.27 and 2.54 cm depths.

The experimental design was a split-split plot with four replications.

Yield

Yield trials were established at Hyslop Crop Science Field Laboratory in 1985 with three seed lots of Mermaid meadowfoam produced in 1983, 1984 and 1985. Planting dates were 25 August; 12, 19 and 26 September and 3 and 10 October. Planting was done with an Ojyord planter at a seeding rate of 33.6 kg ha^{-1} and a depth of 1.3 cm. Plots were 6.09 x 1.52 m with 0.15-m row spacings. The experimental design was a split-plot with five replications.

An application of 336 kg ha^{-1} of 16-20-0 fertilizer was made during seedbed preparation. Urea was applied in the spring at a rate of 60 kg ha^{-1} of N. Ramrod was applied at 2.24 kg ha^{-1} a.i. for preemergence weed control. Irrigation was applied after the first four plantings and as needed thereafter in the fall. No additional water was applied in the spring and summer. Rovral 50WP [(Iprodione) 3-(3, 5-dichlorophenyl)-N-(1-methyl-ethyl)-2,4-dioxo-limidazolidine carboxamide] at 1.68 kg ha^{-1} was applied prior to peak bloom for Botrytis control. Flowering began in early May. Two colonies of honey bees were placed near the plots when the first planting was at 50% bloom.

The number of flowering branches plant^{-1}, flowers branch^{-1}, and seeds flower^{-1} were determined 15 June 1986 for each of the plots planted with 1984 seed. The number of plants 0.1 m^{-2} was determined by counting the stalks after harvest. A 4.5 m^{2} area was harvested from each plot with a Carter flail chopper (Carter Mfg., Brookston, IN). Plots from the first three planting dates were harvested 16 June and plots from the last three planting dates were harvested 19 June.

The harvested material was placed in burlap bags, dried in a heated-air drier, threshed, and cleaned with an M 2-B seed cleaner. Seed yield, 1000-seed weight and seed oil content were evaluated on the cleaned seed. Oil content was measured by the hexane extraction method of Comstock and Culbertson (1958).

RESULTS AND DISCUSSION

Effect of Soil Moisture and Temperature on Seedling Emergence

Seedling emergence of meadowfoam under 20 soil moisture-temperature regimes in seed germinators is shown in Table II.1. The four alternating temperatures approximated the 15-year average daily minimum and maximum soil temperatures for August (20-30°C), September (15-25°C), October (15-15°C) and November (5-10°C) at Corvallis (Hyslop Field Laboratory Microstation Climatic Survey Special Report 516. 1977. Oregon Agric. Exp. Stn.). Seedling emergence percentage was highest at the simulated October temperatures of 10-15°C. The optimum moisture level was 70% of field capacity, but wetter soils were only slightly detrimental to seedling emergence. The maximum emergence of 85% occurred at a temperature of 10-15°C and a soil moisture level of 70% of field capacity.

The benefit of cooler temperatures on meadowfoam seed germination was demonstrated previously by Toy and Willingham (1967) and Cole (1974). Although water relations of the growing crop have been studied (Calhoun and Crane, 1978; Pearson and Jolliff, 1986), the influence of soil moisture during germination and stand establishment has not. Satisfactory germination under high soil moisture conditions would be expected in view of meadowfoam's

natural habit of germinating on the edge of vernal pools and moist depressions in California and Oregon (Calhoun and Crane, 1978).

Effect of Planting Date on Seedling Emergence

The effect of planting date and depth of planting on seedling emergence of seed lots representing two species, two lines from an interspecific cross, and different ages of Mermaid seed are shown in Tables II.2 and II.3. The results from the two years were very consistent. Average emergence was low from the early plantings and increased to 69 and 68% in the 24 September 1984 and 26 September 1985 plantings, respectively. Emergence from later plantings remained at that level. Depths of planting between 0.64 and 2.54 cm had no effect on emergence. Emergence of all lots was reduced similarly by early plantings and the associated warm temperatures. Seeds from recent harvests had lost enough dormancy to produce stands equal to those from older seed lots. Differences in emergence percentages between the species and ages of seed were not large.

The average minimum, maximum and daily soil temperatures for the 7 and 14-day periods following planting are shown in Tables II.4 and II.5. Successful stand establishment was more closely related to minimum temperatures than to maximum or average daily temperatures (Table

II.6). Seedling emergence was negatively and significantly associated with the average minimum temperatures in both years. The 14-day minimum was more highly correlated with emergence than was the 7-day minimum. The negative correlation of emergence with the maximum and daily temperatures was usually not significant.

These results substantiate earlier recommendations of delaying planting of meadowfoam until temperatures are cooler. Toy and Willingham (1967) reported that, in laboratory studies, secondary dormancy was induced when imbibed meadowfoam seeds were exposed to temperatures over 27°C. The adverse effects of daily high soil temperatures of near 25°C were apparently offset by the cool night temperatures, preventing the onset of secondary dormancy and poor germination. High temperatures can also be partially avoided by slightly deeper planting. These studies showed that meadowfoam has the ability to emerge from 2.5-cm depths in fairly heavy soils.

Effect of Planting Date on Yield

Plants from the 29 August planting fully covered the ground by 15 November, while plants from later plantings were very small. Visual estimates of stand density indicated that percentage emergence of the 1983, 1984 and 1985 seed lots was equal, although the emergence rate of the 3-month-old 1985 seed was slower. Considerable plant growth

occurred throughout the winter. Although there was a spread of 6 weeks in planting dates, all the plantings reached harvest maturity within a 4-day period in June.

The average yield of the 29 August planting was only 665 kg ha^{-1}, compared to 1276 kg ha^{-1} from the last planting date (Table II.7). All plantings established after 12 September made satisfactory yields, however. Yields of the three seed lots were nearly equal, although the 1983 seed lot yielded significantly lower. There was concern that the 3-month-old 1985 seed lot might retain enough residual dormancy to prevent adequate stand establishment, but this did not occur at the seeding rates utilized.

The yield component with the greatest influence on yield was the low number of plants from the 29 August planting (Table II.8). Plant density was nearly equal in all the other dates of planting. Plants from the first planting produced more flowers $branch^{-1}$, but not enough to compensate for the fewer plants in the stand. Planting dates did not have a significant effect on number of branches $plant^{-1}$, seeds $flower^{-1}$, or 1000-seed weight. Seed oil content did not show a consistent trend in relation to planting date.

These studies support advancing the recommended early planting date for Mermaid meadowfoam in the Willamette Valley to 1 October if irrigation is available or soil moisture is adequate. By then the minimum soil tempera-

tures are cool enough for maximum germination and seedling emergence. Other factors being equal, maximum yields would be expected from this planting date, and there appears to be no advantage in delaying planting later than this time. Planting depths between 1 and 2.5 cm were equally satisfactory. Seed dormancy at this time is not a problem when planting 3-month-old seed from the current year's harvest.

Table II.1. Seedling emergence of Mermaid meadowfoam from seed planted 1.3 cm deep in soil at different temperature and moisture levels under simulated field conditions in the laboratory.

Moisture Levels	Temperature (°C)				Average for moisture
	5-10	10-15	15-25	20-30	
% F.C.†	----------% emergence----------				
50	68	58	43	1	42.5
60	63	67	55	1	46.5
70	71	85	52	4	53.0
80	64	78	46	5	48.3
90	71	73	48	12	51.0
Average for temp.	67.4	72.2	48.8	4.6	

$LSD_{0.05}$

Temperature = 3.81
Moisture = 4.26
Temp. x moisture = 8.53

†F.C. = Field capacity

Table II.2. Effect of planting date and depth of planting on field emergence of six meadowfoam seed lots in 1984.

Seed lots	Year seed produced	Planting dates: 17 August				10 Setpember				17 September				24 September				1 October				Average for lots
		Planting depths (cm): .6	1.3	1.9	Avg.	.6	1.3	1.9	Avg.	.6	1.3	1.9	Avg.	.6	1.3	1.9	Avg.	.6	1.3	1.9	Avg.	
		% emergence																				
A†	1983	32	37	37	35	58	58	47	54	57	58	57	57	74	78	70	64	54	62	66	61	56
B	1984	12	16	14	14	17	13	13	14	49	49	52	50	65	70	65	67	51	54	59	55	40
C	1983	35	38	34	36	45	54	34	44	50	56	46	51	61	65	64	63	53	59	60	57	50
D	1984	20	9	14	14	10	12	8	10	53	58	60	57	69	71	76	72	62	65	61	63	43
E	1984	14	15	19	16	14	19	11	11	53	59	59	57	70	72	70	71	60	67	61	63	44
F	1984	11	15	11	12	10	16	9	12	56	54	59	56	69	72	72	71	60	66	61	62	43
Avg. for depth		20	22	21		25	29	20		53	56	56		68	71	69		57	62	61		
Avg. for date					21				25				55				69				60	

$LSD_{0.05}$

Planting dates = 4.69
Seed lots = 2.38
Depths = 2.03
Dates x lots = 5.33
Dates x depths = 3.21

†Lot A = L. alba variety Mermaid
Lot B = L. alba variety Mermaid
Lot C = L. floccosa OLC-2
Lot D = L. floccosa x L. alba Selection 83-557
Lot E = L. floccosa x L. alba Selection ORL 83-526
Lot F = L. floccosa x L. alba Selection ORl 83-446

Table II.3. Effect of planting date and depth of planting on field emergence of fine meadowfoam seed lots in 1985.

Seed lots	Year seed produced	Planting dates: 29 August — Planting depths (cm) 1.3	1.9	2.5	Avg.	12 Setpember 1.3	1.9	2.5	Avg.	19 September 1.3	1.9	2.5	Avg.	26 September 1.3	1.9	2.5	Avg.	3 October 1.3	1.9	2.5	Avg.	10 October 1.3	1.9	2.5	Avg.	Average for lots
		% emergence																								
A†	1983	42	41	43	42	55	52	53	53	60	62	61	61	65	71	71	69	50	70	73	64	65	67	65	66	59
B	1984	44	48	42	45	42	59	57	53	64	62	65	64	79	76	70	75	45	75	79	66	73	80	74	76	63
C	1985	44	45	38	42	56	58	58	57	58	63	66	62	72	75	71	73	56	69	74	66	73	73	74	73	62
D	1983	39	40	34	38	35	51	42	43	53	52	55	53	59	54	57	57	38	68	70	59	65	72	64	67	53
E	1984	50	41	42	44	46	48	49	48	57	62	62	60	69	70	66	68	63	69	74	69	69	72	71	71	60
Avg. for depth		44	43	40		47	54	52		58	60	62		69	69	70		50	70	74		69	73	70		
Avg. for date					42				51				60				68				65				70	

$LSD_{0.05}$

Planting dates	= 6.9
Seed lots	= 3.0
Depths	= 2.46
Dates x lots	= NS
Dates x depths	= 6.4

† Lot A = L. alba variety Mermaid
Lot B = L. alba variety Mermaid
Lot C = L. alba variety Mermaid
Lot D = L. floccosa
Lot E = L. floccosa x L. alba Selection 83-557

Table II.4. Average maximum, minimum, and daily soil temperatures in 1984. Temperatures at a 50-mm depth averaged over the 7 and 14-day periods following planting.

Planting date	7-day average			14-day average		
	Max.	Min.	Daily	Max.	Min.	Daily
	---------- °C ----------					
9-17-84	32	18	25	34	18	26
9-10-84	25	14	20	25	14	19
9-17-84	24	14	19	24	13	18
9-24-84	24	11	18	23	11	17
10-01-84	21	11	16	19	11	15

Table II.5. Average maximum, minimum, and daily soil temperatures in 1985. Temperatures at a 13-mm depth averaged over the 7 and 14-day periods following planting.

Planting date	7-day average			14-day average		
	Max.	Min.	Daily	Max.	Min.	Daily
	°C					
9-29-85	23	10	16	21	10	15
9-12-85	19	9	14	22	9	15
9-19-85	25	10	17	24	8	16
9-26-85	23	7	15	20	7	13
10-03-85	17	7	12	18	6	12
10-10-85	18	6	12	17	7	12

Table II.6. Correlation coefficients between seedling emergence of meadowfoam and average maximum, minimum, and daily soil temperatures. Temperatures averaged over the 7 and 14-day periods following planting.

Year	Temperature	r
	7-day average	
1984	Maximum	-0.74
	Minimum	-0.82*
	Daily	-0.79
1985	Maximum	-0.31
	Minimum	-0.82*
	Daily	-0.52
	14-day average	
1984	Maximum	-0.76
	Minimum	-0.90*
	Daily	-0.82*
1985	Maximum	-0.56
	Minimum	-0.92**
	Daily	-0.78

*, ** Significant at the 0.05 and 0.01 probability levels, respectively. N = 6.

Table II.7. Effect of planting date on seed yield of three meadowfoam seed lots.

Planting date	Seed lots and year produced			
	Mermaid 1983	Mermaid 1984	Mermaid 1985	Average for date
	----------kg ha^{-1}----------			
8-29-85	628	693	674	665
9-12-85	1012	1077	1055	1055
9-19-85	1059	1077	1110	1082
9-26-85	1047	1161	1104	1104
10-03-85	1170	1190	1279	1213
10-10-85	1190	1323	1314	1276
Average for lot	1018	1087	1089	

$LSD_{0.05}$

Planting dates	= 106
Seed lots	= 56
Dates x lots	= NS

Table II.8. Effect of planting date on meadowfoam yield components and oil content.

Planting date	Plants .10 m^{-2}	Branches $plant^{-1}$	Flowers $branch^{-1}$	Seeds $flower^{-1}$	1000-seed wt.	Oil content
	----------no.----------				g	%
8-29-85	17	8.5	7.0	2.8	5.81	26.83
9-12-85	26	9.5	5.0	3.0	5.65	26.85
9-19-85	28	10.5	4.7	2.8	5.55	27.90
9-26-85	29	9.7	4.7	2.6	5.27	27.05
10-03-85	27	10.0	4.5	2.8	5.31	26.57
10-10-85	25	10.3	4.7	3.0	5.87	26.43
$LSD_{0.05}$	3.16	NS	1.0	NS	NS	0.68

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APPENDIX

Appendix Table 1. Weekly mean soil temperatures for Hyslop Crop Science Field Laboratory. Temperatures are averaged over 15 year period (1961 to 1968 and 1970 to 1978).

Month	Week	Temperature (°C) Average maximum	Average minimum
August	1	32.35	19.20
	2	31.46	18.98
	3	30.30	18.31
	4	28.47	17.20
Avg. for month		30.64	18.42
September	1	27.26	16.15
	2	22.92	14.70
	3	23.75	14.09
	4	23.14	13.54
Avg. for month		24.26	14.62
October	1	20.64	11.93
	2	17.42	10.54
	3	16.15	9.04
	4	13.37	9.37
Avg. for month		16.89	10.22
November	1	11.71	6.93
	2	10.60	6.77
	3	8.93	5.60
	4	8.10	4.88
Avg. for month		9.83	6.04

Source: Hyslop Field Laboratory Microstation Climatic Survey Special Report 516 (1979) Agric. Exp. Stn.

Appendix Table 2. Measurements used to calculate the amount of water needed to achieve specific percentages of field capacity. 1000 g of soil at 39.39% F.C. used as the base. Moisture lost over the germination period as a percentage of initial weight.

Temp.	Desired moisture level	Initial moisture level	Added water	Germination box Initial weight	Germination box Final weight	Moisture losses
°C	% F.C.	%	ml	------ g ------		%
5-10	50	6.15	166	1434	1431	0.21
	60	6.15	205	1480	1474	0.41
	70	6.15	244	1502	1494	0.54
	80	6.15	284	1551	1546	0.32
	90	6.15	323	1591	1487	0.25
10-15	50	3.12	135	1481	1478	0.20
	60	3.12	175	1520	1517	0.20
	70	3.12	214	1557	1553	0.26
	80	3.12	254	1599	1595	0.27
	90	3.12	292	1637	1633	0.24
15-25	50	1.68	180	1514	1507	0.46
	60	1.68	219	1554	1554	0.00
	70	1.68	258	1648	1638	0.61
	80	1.68	298	1634	1622	0.74
	90	1.68	337	1672	1661	0.66
20-30	50	4.76	151	1451	1448	0.21
	60	4.76	189	1460	1455	0.34
	70	4.76	227	1498	1491	0.47
	80	4.76	267	1531	1525	0.39
	90	4.76	307	1572	1563	0.58

Appendix Table 3. Weekly mean soil temperature for Hyslop Farm at 2-inch depth in 1984 and 1985.

Month		Soil Temperature					
		1984 average			1985 average		
		maximum	minimum	daily	maximum	minimum	daily
		----------°C----------					
August	1	26.17	19.82	23.34	31.08	17.44	24.26
	2	28.38	20.37	24.37	30.28	17.12	23.70
	3	28.05	20.29	24.17	30.48	18.47	24.47
	4	26.41	19.81	23.11	30.57	16.59	23.52
Average		27.43	20.07	23.75	30.57	17.40	23.98
Septem-	1	26.79	15.38	21.08	26.79	15.69	21.24
ber	2	24.26	14.43	19.34	21.24	13.55	17.39
	3	26.24	15.30	20.77	20.77	11.41	16.09
	4	23.61	10.79	17.20	25.83	13.44	19.63
Average		25.22	13.97	19.59	23.65	13.52	18.58
October	1	21.09	11.10	16.09	23.86	12.76	18.83
	2	17.52	11.41	14.46	17.68	8.32	13.00
	3	12.05	7.21	9.63	17.44	8.80	13.12
	4	11.98	7.82	9.9	13.54	8.76	11.15
Average		15.66	9.38	12.52	18.13	9.66	13.89