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Seed Dormancy

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SEED DORMANCY

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Dormancy of seed and other reproductive structures is one of the most ubiquitous phenomena in the plant kingdom. It is conditioned by endogenous, structural or chemical mechanisms which prevent the germination of otherwise viable seed when they are supplied with water, oxygen and temperature levels normally favorable for germination. Although dormancy in seed is most often characterized as a failure of live seed to germinate when favorable conditions are provided, it is also manifested - especially in cultivated species - as an increased specificity in the requirements for germination, e.g., the seed will germinate but only under a narrow range of constant or alternating temperatures.

Survival Value of Dormancy

Seed dormancy apparently evolved in plants as an adaptation of survival value to climatic conditions. By delaying the germination of the population of seed produced by a plant and distributing it (germination) over time, dormancy mechanisms increase the probability that some of the seed will germinate and develop at a time favorable for growth, development and reproduction. Survival of the species, therefore, is essentially ensured.

As an example of the survival value of seed dormancy, consider the life cycle of a summer annual species such as common weedy morningglory. The seed germinate in late spring or early summer (and throughout the summer), the plants develop, flower and produce seed in late summer or early fall. If the seed were not dormant, they would germinate during any period of warm temperatures and adequate moisture during the fall, and the seedlings would be killed by the first hard freeze. Morningglory seed, however, are dormant. A few seed might germinate during the fall and be killed by freezing weather, but most remain dormant. Conditions are not favorable for germination during winter - too cold - but do become favorable "periodically" as the season changes from winter to spring. A few more morningglory seed might germinate during these periods of good conditions and then succumb to a late freeze, but most still remain dormant. As the late spring and summer seasons become established, more of the seed germinate, develop into plants, flower and produce seed. But, some seed still remain dormant and do not germinate

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until the next spring, or the next, etc. In this way, "nature" guards not only against "expected" hazards to the survival of the species, i.e., freezes following germination in fall or early spring, but also against unexpected hazards during the normal growth cycle of the species such as summer floods or droughts which might prove fatal to growing morningglories.

The foregoing example suggests that the individual seeds of the population produced by a plant or species differ in degree of dormancy, and, thus, are "released" from dormancy at different times. This is true. In order for dormancy to be fully effective as a survival mechanism, two conditions must be met. First, the restriction on germination imposed by dormancy must be overcome by some natural and expected agency or condition, e.g., low temperature, hot dry weather, action of soil acids and microorganisms on seed coverings. Secondly, the intensity of dormancy must vary among the individual seeds so that they are not all released from the dormant state at the same time. If the first condition were not met, dormancy would obviously have no survival value - the seed would never be released from dormancy under "natural" conditions. On the other hand, if the second condition were not met and dormancy in all the seed was released at the same time, any unexpected hazard during the growing period such as flood or prolonged drought would wipe out the species. Dormancy, therefore, not only delays germination but distributes it over several years.

Dormancy in Cultivated Species

Seed dormancy is much more prevalent and profound - deep seated - in "wild" species than in cultivated species. Or, put another way, dormancy is less prevalent and intense in species which man has "improved" through selection and breeding than in species which have not been subjected to man's manipulations.

The seed of most varieties of crops long under domestication and improvement such as wheat, corn, rice, cotton and soybeans either have no "recognizable" dormancy or exhibit only a slight degree of very short-lived dormancy. Dormancy of the profound, persistent type is an inconvenience in crop production. Therefore, man has conciously and unconciously selected away from seed dormancy. Only a slight often "unrecognizeable" degree of dormancy has been preserved - enough to prevent germination in-the-ear, i.e., while the seed are still on the plant, which would, of course, be diastrous for seed production. It is of interest that a few lines of cultivated crops have been developed whose seed regularly germinate in-the-ear whenever rainfall is adequate. Such lines apparently have not retained sufficient dormancy to prevent germination in-the-ear and are termed viviparous lines.

The slight degrees of "residual" dormancy in most varieties of field crops persist after harvest and "drying" in only a small percentage of the seed, and even then for only a few weeks. It seldom persists long enough to be bothersome at planting time. For example, some varieties of rice exhibit 5-20% dormant seed when tested a few days after harvest and drying, but this dormancy is rapidly lost so that it is not evident when the seed are retested 3 or 5 weeks later.

Dormancy is much more of a problem in the forage and pasture species which have been subjected to relatively little of man's improvement efforts. And, of course, it is a major problem to the nurseryman, forester, and weed control specialist.

Mechanisms of Dormancy

Nature has been very inventive in evolving mechanisms to delay and distribute germination of seed over time - to achieve dormancy. Some of the mechanisms are so complex that even now they are poorly and incompletely understood, while others are much simpler and are "understood" quite clearly. In all cases, however, the mechanisms are marveleously ingenious.

The types or mechanisms of seed dormancy have been (and are) classified in various ways depending on the perspective, objectives, and background of the classifier. In general terms, however, seed dormancy mechanisms fall into two general types: mechanical - impermeability of the seed "coverings" to water, oxygen, "mechanical" restrictions imposed by the coverings, and physiological - inhibitors, hormonal imbalances, photosensitivity, etc. The mechanical types of dormancy are, of course, much easier to understand than the physiological.

Hardseededness

One of the most familiar mechanisms of dormancy is impermeability of the seed covering to water. Since absorption of water or rehydration is a requirement for germination, seed prevented from absorbing water by "waterproofing" of the seed coat cannot germinate. Seed with water impermeable seed coverings are commonly referred to as "hard" seed because they do not take up moisture and "soften" when planted.

Hardseededness is the common mechanism of seed dormancy in the legume, cotton, and morningglory families (and in others that are less familiar). In the legume family, hardseededness is most frequently encountered in the clovers, alfalfa, trefoils, vetches and other forage and pasture types most of which have relatively small seed. Hardseededness is present but less frequently encountered in peas, beans, and soybeans. The frequency of hardseededness varies not only among the species but also among varieties within a species. For example, Laredo soybean, a blackseeded forage type widely grown in the South in the 1940s and 1950s had a substantial percentage of hard seeds - as high as 50% in some lots. In modern "grain type" soybean varieties, on the other hand, hard seed are rather rare - usually much less than 1%. There has been some interest in the last few years in the potential of "hardseeded" lines of soybeans for minimizing weathering damage.

Modern cotton varieties have a low incidence of hard seed, but some of the wild relatives of cotton, and other members of the cotton family such as okra and the weedy species produce a high percentage of hard seed. Hardseededness is very common in the morningglory family, especially among the weedy species, and is a major factor contributing to their success as weeds.

Much of the work on the nature of hardseededness has been done in the small seeded legumes such as the clovers. The "water proofing" of the seed coat has been variously attributed to a waxy layer in the seed coat, a "hygroscopically" activated valve in the fissure or opening near the hilum, and pectic materials impregnated in the seed coat.

From the standpoint of a weedy morningglory or other weed, hardseededness is of great survival value. A few plants escaping weed control produce seed that infest the soil and ensure the continuity of the species for many years. Thus, to the farmer and weed control specialist hardseededness in weeds is, a nuisance, if not a curse.

Hardseededness does have a positive value in some of the forage and pasture legumes. Some varieties of crimson clover - an annual - have been deliberately selected for a high percentage of hard seed so as to insure volunteer "re-seeding". Some workers contend that a moderate percentage of hard seed in perennial crops such as alfalfa is beneficial in maintaining stands. On the other hand, the disadvantages of hard seed in an annual crop such as cotton are obvious.

In nature hardseededness is apparently overcome, i.e. the seed are rendered permeable to water, by the action of soil acids and microorganisms acting over time. More rapid methods for overcoming hardseededness have been devised by man. The most generally applicable method is scarification - a controlled scratching of the seed coat which cuts through the impermeable layer. Scarification can be as simple as rubbing a few hundred seed between the fingers and fine sandpaper, or as complex and critical as continuous-flow operations in a high capacity "huller-scarifier". Other methods for overcoming hardseededness include so-called acid acarification (soaking the seed in sulfuric acid), heating, rapid cooling to very low temperatures, brief soaks in hot water, soaks in solvents, and mechanical impaction. The sulfuric acid treatment erodes the seed coat while the heat and cooling treatments probably induce minute fractures in the seed coat by rapid expansion (heating) or contraction (cooling) of the seed.

All of the treatments for overcoming hardseededness - except solvents which are not very effective - have the common feature of "controlled damage". Improper and uncautious application of the methods or treatments can cause so much damage that the seed are rendered unfit for planting. Even when the treatments are applied properly, the seed should not be held in storage for too long because storage potential is decreased. The treatments, therefore, are best applied a short time before the planting season.

Oxygen Impermeability

Seed dormancy in most species of the grass family appears to be conditioned - in part at least - by a restriction on oxygen absorption imposed by the pericarp (seed coat). The evidence for this "mechanical" type of dormancy in the grasses, however, is not as conclusive as for the water impermeability type of dormancy previously discussed.

The lines of evidence for an oxygen restriction or impermeability type of dormancy in many kinds of grass seed are two-fold: (1) rupturing the pericarp near the embryo (or germ) overcomes dormancy; and (2) increasing the partial pressure of oxygen partially overcomes dormancy in a few kinds of grass seed. The former line of evidence is the most persuasive.

Rupture of the pericarp near the embryo by pricking with a fine needle is the most effective means of breaking seed dormancy in grass species. The treatment is equally effective for temperate climate range grasses such as western wheatgrass or tropical grasses such as bahiagrass. Since rupturing of the pericarp with a needle is very tedious, acid "scarification" procedures similar to those used for "hard seed" have been used to overcome dormancy in some grass species. It is also likely that some of the benefits of hulling grass seed, e.g., bermudagrass, are related to an elimination of dormancy by mechanical scarification of the pericarp.

A variety of other treatments are used to overcome dormancy in grass seed. None of these, however, are as generally applicable and effective as rupturing or scratching the pericarp, or even acid scarification.

In seed testing practice the use of alternating temperatures, a 0.2% potassium nitrate solution as moistening agent, light and "prechilling" are prescribed singlely and in various combinations for overcoming seed dormancy in such temperate climate forage and range grasses as orchardgrass, fescues, smooth bromegrass, the ryegrasses and many range grasses. The prechill treatment involves subjecting the seed (after planting for germination test) to a 5 to 10C temperature for 5 to 10 days before transferring to an alternating temperature such as 15-25C for germination. While these treatments are generally effective, individual species often respond in different ways. For example, germination of western wheatgrass is inhibited rather than promoted by light.

In the temperate cereals such as wheat, barley, rye and oats, dormant seed are relatively insensitive to light and potassium nitrate treatment but respond well to pre-chilling, pre-drying and to treatment with gibberellin, a hormone.

Dormant seed of subtropical of tropical forage species usually respond quite well to pre-drying treatments, only slightly to light and

KNO_3, and not at all to pre-chilling. Light, potassium nitrate and pre-chilling have no effect on dormant rice seed. Dormancy in rice, however, can usually be overcome completely by pre-drying or a 24 to 48 hour soak in warm water (40C).

In addition to the treatments mentioned above, the literature contains many reports on the use of exotic chemicals - ranging from citric acid to ethylene chlorohydrin - for overcoming dormancy in selected grass species. These chemical treatments appear to be very specific in application.

The varying responses of different kinds of grass seed to the array of treatments used (and tried) suggests that dormancy is probably much more complex than indicated by the general applicability of the "pericarp rupture" treatment. A relative impermeability of the pericarp to oxygen is probably only one of a delicate balance of factors conditioning dormancy. Competitive oxygen requiring reactions, inhibitors, hormone-inhibitor disbalances and other yet-to-be uncovered factors also appear to be involved.

If time can be considered as a "treatment" then it is even more effective than rupture of the pericarp in release of the dormant condition. In all grass species, the percentage of dormant seed in the population diminishes with time. The rate of release appears to increase with storage temperature - up to a point.

The incidence of seed dormancy in the cereals and small grains varies among varieties. Some varieties have a relatively high percentage of dormant seed, while in other varieties dormancy is hardly recognizeable. In any event, dormancy is short lived and seldom persists longer than a month or two after harvest. Dormancy "problems", therefore, are mostly confined to the testing laboratory. There is no effect on field emergence at normal planting times except in cases of a dormancy induced in some kinds of sorghum seed by over-drying, and second crop rice planted a few weeks after harvest as practiced in some parts of Asia.

Dormancy in most temperate forage species is usually released by planting time. In the range grasses and some tropical forage grasses, dormancy persists for one to several years and has an adverse effect on field emergence. Some kinds of range grass seed are held in storage for 18-24 months before marketing to allow for a substantial reduction in the percentage of dormant seed before marketing.

Light

Light plays a vital role in the growth and reproduction of plants. It is not surprising, therefore, that it is also involved in the mechanisms of dormancy in some kinds of seed.

In the late 1930s Flint and McAlister demonstrated that the different colors or wavelengths of light had entirely different effects on the germination of lettuce seed. Red light (wavelength, 6500 Angstrom units) promoted germination of lettuce seed while far-red light (radiation with wavelength of 7500 Angstrom units) inhibited germination. The mechanism for these peculiar responses of lettuce seed to light was not uncovered until the early 1950s. Borthwick and co-workers showed that the germination promoting effects of red light and the germination inhibiting effects of far-red radiation were immediately and repeatedly reversible. Imbibed lettuce seed exposed to short periods of alternating red and far-red radiation germinated or were inhibited in germination depending on the wave-length of the last radiation in the sequence, i.e., germination was promoted when red light was last in the sequence, while a last exposure to far-red radiation inhibited germination. These and other responses suggested to Borthwick and his co-workers that the effects of light on germination of lettuce seed could be interpreted in terms of changes in a light-receptive pigment. The pigment was later identified, characterized and called phytochrome. The pigment exists in two inter-convertible energy states: P-730 which promotes germination, and P-660 which inhibits germination. When lettuce seed (or other light sensitive seeds) are exposed to red light, P-660 is converted to P-730 and germination proceeds. Conversely, exposure of the seed to far-red radiation converts P-730 back to P-660, which inhibits germination.

Control of germination by the red-far red photoreaction has been demonstrated in a variety of seed kinds ranging from lettuce through tobacco and peppergrass (a weed), and including some of the pines.

The light requirement for germination is usually most binding in freshly, harvested seed. The seed become increasingly insensitive to light with time under air-dry storage conditions. Imbibition (water absorption) and germination temperature also affect the sensitivity of seed to light. Lettuce seed which have "lost" their light sensitivity during storage become light sensitive again when imbibed at high temperatures (i.e., 35C). Other "stress" conditions such as continuous far-red radiation during imbibition and high osmotic pressure moistening agents, also increase or re-instate light-sensitivity.

On the other hand, proper manipulation of the imbibition-germination environment and other treatments can "substitute" for light, or by-pass the light requirement. Seed of some varieties of tobacco require light for germination at constant temperatures but germinate quite well in total darkness at alternating temperatures. Lettuce seed often germinates quite well at temperatures of 15C or lower, but require light for complete germination at higher temperatures. Low temperature stratification of sufficient duration by-passes the light requirement in some kinds of pine seed. The plant hormone gibberellic acid eliminates the light requirement in many kinds of light-sensitive seed.

As mentioned above, the photocontrol of germination is often coupled with thermodormancy, i.e., temperature control of germination. The action of photo - and thermo-dormancy mechanisms in controlling the germination and growth period of a plant species is dramatically evident in bracted plantain, a common weed. Bracted plantain is a winter annual. Seedlings of bracted plantain can be observed in infested areas in October. The seedlings develop into a typical rosette plant form during the fall and winter. In late spring a flowering stalk develops and seed are borne, maturing in June. After maturation the seed shatter and fall to the ground where they remain until October at which time they germinate and the cycle begins again. Why don't the seed of bracted plantain germinate in the period June - October?

Germination of bracted plantain seed is rigidly controlled by temperature and light. The seed are light sensitive and only a few (usually less than 10%) will germinate in darkness at a temperature of 20C or lower and only an occasional seed germinates above 20C. When exposed to light, the seed germinate very well up to about 26C. Above this temperature germination percentage decreases sharply. At 30C none of the seed germinate even in light.

These responses suggest at least several of the reasons why bracted plantain is a winter annual rather than a summer annual, and a successful weed. At the time seed mature and shatter in June, the temperature is generally too high for germination. During this high temperature period some of the seed become covered with soil or plant residue, thus, establishing a dark condition. In October when the soil temperature decreases to a favorable level for germination i.e., 25C or lower, seed exposed to light germinate and seedlings are established. However, only a small percentage of the seed covered with soil or plant debris sufficiently to exclude light germinate and develop into plants. The rest remain dormant until something "uncovers" them or until light sensitivity is lost with time. Thus, germination is distributed over time.

Dormancy in bracted plantain appears to be related in some way to a deficiency in gibberellin, the hormone believed to be involved in the initiation of the germination process. Application of gibberellin to bracted plantain seed induces complete germination up to about 32C in light or darkness, and even promotes germination in about 50% of the seed at 35C when exposed to light. In field studies a few years ago we were able to induce germination in some bracted plantain seed buried 1/4th inch in soil in August, when soil temperatures averaged above 30C, by a drench with a gibberillen solution.

Other Mechanisms

Some of the most interesting and intricate mechanisms of seed dormancy are found in the shrubs and trees. It has been estimated that nearly 70% of the American tree species exhibit "deep seated" seed dormancy. The percentage of species exhibiting "deep-seated" seed dormancy is probably even higher among the shrubs.

Hardseededness is the usual type of dromancy in seed of members of the legume family such as honey locust and black locust. This type of dormancy is also found in some of the huckleberries and sumacs. In other species such as the basswoods, dogwoods, hawthorns, and snowberries, seed dormancy is conditioned by both an impermeable seed covering aand "embryo" dormancy. Hardseededness in tree and shrub species is usually overcome by a warm temperature pre-treatment of imbibed seed and/or by soaks in concentrated sulfuric acid.

The most common type of seed dormancy in some of the more economically important tree species such as the pines, firs, Douglas fir, and black oaks is so-called embryo dormancy. Germination is not initiated until certain physiological changes occur in the embryonic axis or supporting tissues such as the endosperm and cotyledons. In nature the changes that result in loss of the dormant condition are induced by low temperatures during the winter time. The early foresters and nurserymen observed that the low winter temperatures broke dormancy only when the seed were fully imbibed. Seed in air dry storage were not affected by the low temperatures. A treatment was then developed for breaking dormancy which consisted of layering seed between moist sand or peat and exposing the set-up to winter temperatures for 1-3 months. Following treatment the seed were separated from the sand or peat and planted in the nursery. Later as mechanical refrigeration became available, the refrigerator or cold storeroom was used to produce an "artificial" winter which was just as effective as the natural one in overcoming dormancy. Although the seed and moist substrata are no longer neatly positioned in layers, the treatment is still known as "stratification" - or more precisely, low temperature stratification.

The species mentioned above require only one period of low temperature stratification to release dormancy sufficiently for planting. In other species multiple stratification treatments are required to overcome dormancy. The combination hard seed covering and embryo dormancy mechanisms in some of the dogwoods, hawthorns and snowberries have already been mentioned. Singe low temperature stratification is effective only when the seed are fully imbibed with water, the hard seed condition has to be overcome first. In nature the seed covering softens the first summer after seed dispersal while the embryo dormancy is released during the second winter. Two years, therefore, are required for seedling production. In nursery practice, the use of sulfuric acid or a high temperature stratification treatment (25 to 30C) to soften the seed followed by low temperature stratification permits nursery seedling and seedling production the first spring after harvest.

In the ornamental genus <u>Viburnum</u> the shoot bud (epicotyl) of the embryo is dormant in some of the northern species. The epicotyl dormancy can be overcome by low temperature stratification but only when the roots are developed. In nature the roots develop during the first spring or summer after seed ripening while dormancy of the epicotyl is overcome the following winter. Nursery practice usually involves a warm temperature treatment to initiate root growth and permit their development followed by an artificial winter in the cold room. This type of dormancy is also exhibited by some species of *Lilium* and *Paeonia*.

In some herbaceous genera such as *Trillium*, *Convallaria*, and *Smilacina*, dormancy specialization is carried to extremes - the root and shoot buds are both dormant and shoot dormancy cannot be broken until the roots are developed. Treatments used to overcome this type of dormancy are complicated. First, the seed are given a low temperature stratification treatment for 3-6 months to release the root dormancy. This is then followed by a warm temperature treatment for 1-5 months to permit initiation and development of roots. After the roots are developed, a second low temperature stratification treatment is required to overcome the shoot dormancy. Following this treatment, the seed are finally "ready" to produce seedlings.

Some species exhibit even more peculiar types of dormancy. The embryos of peach, apple and some of the hawthorns (all members of the "Rose Family") are sort of partially dormant. The embryos can be forced to germinate by removal of the seed covering but the seedling produced are drawfed. This physiological drawfism can be overcome by exposing the seedlings to low temperatures for 2-3 months, or - in some cases - by removal of the cotyledons or treatment with gibberellin. Apparently, some type of inhibitor is present in the cotyledons which inhibits growth.

Many seed of the *Ginkgo* tree are dispersed before the embryo is fully mature. The seed will not germinate until the embryo matures 2 to 3 months after dispersal.

The deep seated dormancy mechanisms and combinations in tree and shrub seeds are a continuing challenge to the forester and nurseryman. Compared to this challenge, that confronting the agronomist is rather minor.

Some Implications of Dormancy

The review of seed dormancy in the previous sections is not, by any means, exhaustive. Germination inhibitors which have an important role in delaying germination and distributing it over time were mentioned more or less parenthetically, and only a few times. The fascinating balances between dormancy mechanisms and components of the environment so beautifully domonstrated in some of the arid and semi-arid species were ignored.

As a sort of summation of this discussion of seed dormancy, I thought a bit of speculation on the practical implications and potential applications of dormancy phenomena in seed might be in order. A few of the implications and potential applications have already been mentioned, but I believe they can bear repeating.

Weed Control - Seed dormancy is an important characteristic that contributes to the weedy habit in plant species. Weeds produce an abundance of seed which vary widely in degree of dormancy. Some of the seed germinate as soon as environmental conditions become favorable. Other don't germinate until the following season, year, or years. Most weed control practices kill germinating or germinated seed, or seedlings, or growing plants, thus the dormant non-germinating weed seed in the soil are not affected. Since these do germinate later in the season or in the following seasons, weed control has to be almost continuous. Even with the best of weed control, a few weeds escape, grow and produce seed which then re-infest the soil.

Weed control would be greatly simplified if methods could be developed for breaking the dormancy of weed seed in the soil. One can envision, for example, incorporation of a chemical in the soil that would stimulate germination of weed seed - at least those in the surface layer. The germinating weed seed could be killed by application of appropriate chemicals or by mechanical methods, and the reservoir of weed seed in the soil would be significantly depleted. Additional weed seed could then be brought up to the germination zone and the procedures repeated. In time, the fields would be virtually weed free.

Field Deterioration of Seed - Weathering is a major cause of low seed quality. Rain, heavy dews, even fogs, combined with warm temperatures after seed are mature but before harvest are very detrimental to seed quality. There is good evidence, however, that the detrimental effects of weathering decrease as the intensity of dormancy of seed increases. We have demonstrated, for example, that "hard-seeded" lines of soybeans maintain germination under adverse climatic conditions during the harvest period much longer than released varieties. Other have demonstrated similar effects for hardseeded lines of cotton. Sorghum lines with a higher degree of seed dormancy than "normal" are also resistant to weathering.

Following this line of reasoning and the bits of evidence that have accumulated, breeding crops for higher degrees of seed dormancy might be one avenue for increasing resistance to weathering and improving seed and grain quality. There would, of course, be many side issues such as getting rid of the dormancy before planting, but these could probably be resolved.

Improving Storability - In the early 1960s one of our graduate students removed dormant rice seed from germination media after 30 days or so, placed them in a small sealed bottle, and stored the bottle on the table top in the lab. The seed had absorbed moisture and were at about 33% moisture content. The temperature in the room was about 75F. Every month the bottle was opened, seed were removed, treated to break dormancy, and tested for germination. When the seed "ran out" after 6 months they were still germinating above 95%. This is the point: the mechanism(s) that prevented the fully imbibed rice seed from germinating in some way also prevented or reduced the normal processes of deterioration. Non-dormant rice seed imbibed up to about 30% moisture and stored at 75F were dead within two weeks.

The development of "treatments" for harvested seed that would induce dormancy might permit the storage of high moisture seed or grain for considerable periods of time without deterioration. The treatments would have to be chemicals of some sort that inhibit germination (or selected metabolic processes) but whose action could be "reversed" by drying or other chemicals before planting.

Control of Germination - Consider the advantages that could be gained from rigorous control of the germination process after crop seed are planted. It is conceivable - even probable - that as our knowledge of the physiological processes involved in germination and dormancy advances, it will become possible to program seed for germination at pre-selected times, in response to the development of certain desirable combinations of environmental conditions in the seed bed, or on the application of triggering stimuli. A warm season crop could be planted anytime during the winter when soil conditions were mechanically suitable for planting but the seed would not germinate until the programmed time when climatic and soil conditions become favorable for germination and emergence. Some progress has already been made with wheat seed. If a triggering stimulus was required to release the germination control mechanism it could be flown on like an herbicide or insecticide.

Dormancy controls and regulates the germination of seed. In some cases, dormancy is released in response to specific triggering stimuli. Thus, the basic mechanisms for the control of the germination process already exist. As we gain a better understanding of these dormancy mechanisms and how they are released, some degree of germination control should be possible.

Some of my speculations might seem rather far-fetched - pipe dreams. None are original, however, so others have the same sorts of visions. Perhaps, just perhaps, these visions will begin to materialize in the 1980s.