SOME FACTORS AFFECTING GERMINATION IN SUGAR BEET SEEDS (BETA VULGARIS L.)

by

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I. INTRODUCTION

From an agronomic standpoint the rapid and uniform germination of sugar beets under field conditions is greatly to be desired. It has been shown (48) that there is a direct correlation between the date of emergence and the final yield and also between the final yield and the sugar content of the beets. Rapid and uniform germination makes for an earlier cultivation and spring mechanization program. This in turn helps to decrease the high labor costs of blocking and thinning (37% of the total cost of production according to studies by Wright (82).) Prompt blocking and thinning whether by hand labor or by mechanized equipment eliminates the detrimental competition for moisture, light and nutrients from weeds and excess beets. Experiments (1) have also shown that resistance of damping off organisms (i.e. block root, root rot, etc.) is enhanced by prompt emergence and rapid subsequent growth.

Attempts to achieve uniform stands and rapid emergence have tended to center around mechanical seed and soil treatments. These have included decortication, shearing and pelleting of the seed (78); breeding for single germed seed balls (49); and soil compaction experiments in which an attempt is made to provide better seed-soil moisture relationships.

The fundamental and basic problem of sugar beet emergence however, concerns itself with the physiological conditions inherent in the process of germination in relationship to the soil environment.

It is therefore the purpose of this thesis to present briefly, various facts concerned with the germination of seeds, particularly in relationship to the behavior of sugar beet seeds in field and laboratory.

II. BASIC PRINCIPLES CONCERNED WITH GERMINATION

The growth and development of sugar beet seeds is described by Artschwager (3,4). It follows closely the general pattern of seed development of cultivated crops including pollination and fertilization, embryo and endosperm development. Throughout this period the seed is in a dynamic condition. However, following abscission from the mother plant the seed goes into a resting stage, due to lack of nutrients and water, until environmental conditions are such that germination and a further dynamic growth is possible. While in the resting or dormant period, many seeds will not germinate until internal physiological changes have occurred to "after-ripen" the seed. Crocker (13) in his discussion of the general problem lists the environmental conditions of temperature, gaseous exchange, moisture and often light as being factors necessary to bring about after-ripening.

At present there is available no experimental data as to the length of the dormant period of the sugar beet. It is apparently not long. Thus there is no object in trying to break a dormancy which does not exist.

Although the seed is now in a condition where germination is possible, a number of environmental conditions must be in proper adjustment, however, before the seed can actually germinate. At least the conditions of proper moisture, temperature, aeration and often light are necessary for germination. (It may be noted that these are the same factors which were required to overcome dormancy.) Furthermore, these conditions must be in a proper adjustment or balance. For example, optimum temperature, aeration and light conditions will not initiate germination unless the moisture conditions are also satisfactory. The amounts or intensities of these factors vary with the species. In other words, the maximum and minimum amounts of any one factor, other factors being constant, are probably specific for any species, varying slightly with the conditions of development on the mother plant and the environment of the mother plant.

In order to understand the problem of germination more fully, these various factors as they are related to germination are discussed separately below.

a. Light.

Crocker (12) has indicated that a large number of different seeds require light for germination. In some cases without light, a seed (ie. Viscum album) may be killed in a few weeks. Other seeds are inhibited in the germination process by light. In some cases this light-induced or light-inhibited characteristic may be overcome with chemical treatment. The mechanism of this phenomenon is not well understood but it is presumed that certain regions of the spectra influence enzyme activity within the seed.

However, many seeds germinate equally well in either the presence of absence of light. Sugar beet seeds apparently fall within this category and therefore a more complete discussion of this important factor of germination may be concluded without logical detriment to the argument.

b. Aeration.

The best known example of work dealing with this phase of germination has probably been done with Xanthium seeds. Shull (58,59), Crocker (11) and Thornton (70) have all indicated that the failure of the upper intact seed of Xanthium to germinate is due to the low permeability of the seed coat to oxygen.

Schaible (57), germinating seeds of cultivated plants in one fourth of an atmosphere of pressure, found that seeds germinated a little better in the reduced pressure of oxygen enriched air than in a full atmosphere of air, but very much poorer in the reduced atmosphere without oxygen enrichment. He concluded that the oxygen content of the air is not much above that needed for the germination of seeds and that oxygen is necessary to induce germination.

The amount of oxygen required by different species naturally varies. Water plants would be expected to have a lower oxygen requirement than land plants. Takahashi (66) and Taylor (69) have found that rice can germinate in almost complete absence of oxygen but that wheat fails to germinate under similiar conditions. In oxygen concentration below 1% less than half of the wheat germinated. All of the rice germinated under similiar conditions.

Morinaga (43) found that out of 34 species of land plants, 25 germinated better on moist filter paper than under water, 18 germinated well under water and 21 species germinated under boiled water sealed with paraffin oil. He also indicated (45) that certain seeds were benefited as far as germination was concerned in environments of reduced oxygen supply.

Jones (31) in his work on rice concluded that the early seeding of rice is preferable to late seeding because the temperature of the atmosphere and water are lower in the spring and more oxygen is dissolved in the water at low than at high temperatures. The dissolved oxygen resulted in a higher percentage of seedlings.

The amount of CO_2 in the germinating environment also exerts an influence. Thornton (71) and Harrington (25) have both found that increased pressures of CO_2 decrease or lower the pressures of oxygen required for germination and also exert an influence upon the temperature requirements for germination. It should be noted in this connection that soil air contains approximately ten times as much CO_2 as atmospheric air.

Farnsworth (21) in soil aeration studies on sugar beets found that soils with an air capacity of less than 12 percent decreased the germination and growth of sugar beets due to lack of aeration.

Finding nothing in the literature specific to sugar beets on this point of minimum aeration requirements, a series of experiments was set up to determine some of the effects of the lack of oxygen upon the germination of sugar beet seeds.

Experiment I.

a. Two one liter flacks were filled about half full with quartz sand. In the first flask (A) water was added so that the sand was about 3/4 filled with water, thus making the upper layers of sand well moistened but not excessively wet. In the second flask (B), water was added so that it stood half an inch over the top of the sand. Fifty segmented sugar beet seeds (U.S. 215x216) were placed in the sand of each flask to a depth of ½ inch. Both flasks were corked to prevent evaporation. After 12 days 76% of the seeds in flask (A) had germinated whereas none of the seeds in flask (B) had germinated.

b. Another flask was made up similiar to (B) of the first experiment. However, in this case a glass tube was inserted through a cork at the mouth of the flask to the bottom of the flask through the sand. The other end of the tube was connected to an air supply. Another smaller tube was also placed through the cork to permit free passage of air, but to cut down on evaporation. (See Figure I)

This experiment as well as the one above were carried out under laboratory conditions with the temperature at approximately 25° C. The air supply connected to the tube was turned on so as to permit the escape of approximately 4 bubbles of air per second from the bottom of the tube. After 12 days 25% of the seeds had germinated.

As will be shown under the section on Temperature, twelve days time is sufficient to determine whether or not there will be any germination.

Discussion

In this experiment sugar beet seed balls failed to germinate under water at 25° C. unless an additional supply of oxygen was added to the water.

c. Temperature.

The effect of temperature upon the germination of seeds is intricate, complicated and not well known. Such factors as the interrelation between temperature and moisture as shown by Shull (60) as well as previously mentioned interrelations between temperature and gaseous supply make this a

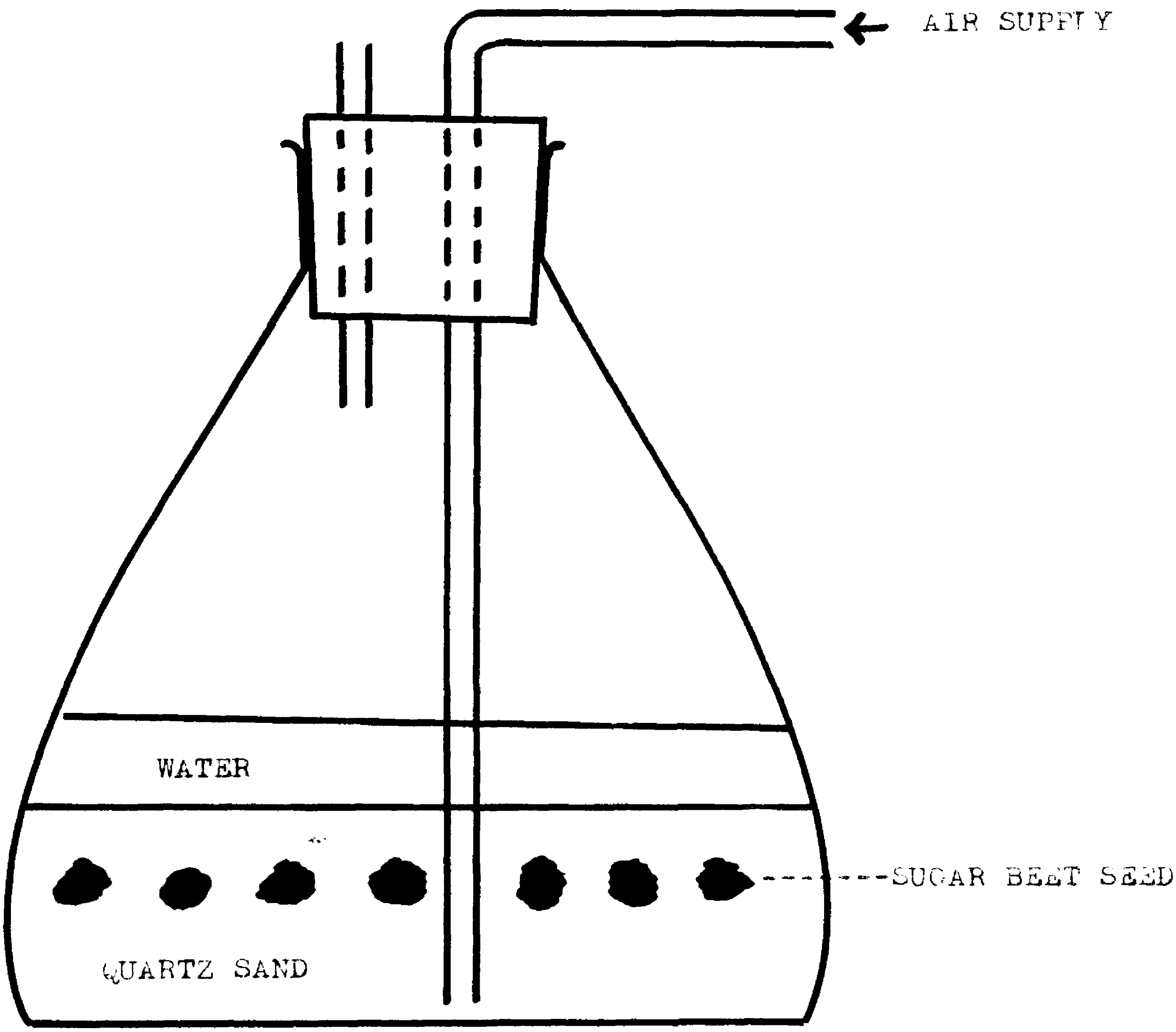


FIGURE I

difficult problem to fully understand. Germination, to a large degree, involves a series of chemical and physical reactions. Van't Hoff's law states that for every 10° C. rise in temperature the speed of reaction is increased two to three times. Thus, temperature undoubtedly influences the rates of reactions occurring within germinating seeds.

Wilson and Hottes (79) found that the rate of initial germination of wheat at varying temperatures follows in general the principal of van't Hoff's law. However, at higher temperatures of 20° - 30° C. the germination may have been more rapid but not as complete as at lower temperatures of 10° - 20° C. There was also a greater prevalence of molds at the higher temperatures.

Plants vary widely as to species in regard to their specific or optimum temperature requirements. A number of seeds have been observed (40) to be capable of germinating in blocks of ice. Other species are not capable of germinating at such low temperatures under otherwise normal conditions. Furthermore, although many seeds are capable of germinating at one fixed temperature, the germination of many other species is enhanced by an alternation of temperatures, often approximating the diurnal variation of temperatures occurring in the natural habitat of the plant at the time of normal germination. The range and degree of these alternating temperatures is dependent upon the particular species. In 1923, Harrington (26) found that the seeds of redtop, parship, celery, orchard grass, bluegrass and Johnson grass germinated much better with favorable alternations of temperatures than at constant temperatures. Much subsequent work has been done upon this particular problem with a variety of seeds (13, 44).

Sugar beets apparently germinate as well at an even temperature as under the influence of alternating temperatures. In the 1949 Proceedings of the Association of Official Seed Analysts, page 34, the official method for the laboratory germination of sugar beet seeds indicates the following:

a. Seeds should be placed between moist blotters.

b. Even temperatures should be maintained somewhere between 20° - 30° C.

c. First count after 3 days; final count after 14 days.

d. Seeds should be soaked in water (at least 250 cc. water per 100 seed balls) 2 hours before testing and should be washed after this treatment.

This apparently is the optimum germination temperature range for laboratory tests. However, these temperatures are seldom encountered, in Michigan soils at least, at planting dates for sugar beets.

Leach et al (36) found that at 50° F. in Yolo fine sandy loam soil the emergence periods for segmented, whole, pelleted and decorticated sugar beet seeds were more than twice as long as at 70° F. and that the differences between emergence rates for the various seed preparations were correspondingly increased.

Kotowski (35) investigated the relationship between temperature and germination for a variety of vegetable crop seeds. Seeds were planted in flats of quartz sand at various temperatures which were maintained and seedling counts recorded. Among the vegetables investigated was Crosby's Egyptian Beet; the results for which appear in the table below.

Table I.

Germination of Crosby's Egyptian Beet at a variety of temperatures.

	Temperature of Experiment					
	4°C.	8°C.	11°C.	18°C.	25°C.	30°C.
First seedling, days after sowing	0	20	12	6	4	3
Last seedling, days after sowing	0	42	24	15	12	12
Seedlings, in % of seed sown	0	110	131	120	122	101
Coefficient of velocity of germination	0	3.7	6.2	12.5	17.6	21.3

For all types of seeds used the time rate of the production of seedlings at the different temperature agreed well with the van't Hoff temperature coefficient.

The coefficient of velocity of germination is an indication of the rate of emergence of the seedlings.

In order to determine whether segmented sugar beet seeds would have the same specific temperature requirements as whole vegetable beet seed, the following experiment was conducted.

Experiment II.

Ten cc. of water was added to covered Petri dishes containing blotting paper. The dishes were then placed in a refrigerator and when the temperature had come to equilibrium, segmented sugar beet seed (U.S. 215x216) were added. The refrigerator was maintained at as nearly a constant temperature as possible. This type of procedure was conducted at 5, 8, 10, 15, and 20° C. One hundred seeds were used in each case. The results are shown as percent germination in the following table.

Table II.

Germination of sugar beet seed on moist blotters at a variety of temperatures.

	Temperature of Experiment				
Days after Planting	5°C.	8°C.	10°C.	15°C.	20°C.
5	0	0	0	12%	64%
10	0	0	8%	27%	78%
15	0	3%	43%	52%	82%
20	0	24%	68%	73%	82%

Discussion

The results here show agreement with the work of Kotowski (35) in that the rate of germination of sugar beet seeds is influenced by temperature. The experiment also indicated a minimum temperature requirement for segmented sugar beet seeds of this particular variety at somewhere between 5° and 8° C.

Because these particular sugar beet seeds failed to germinate at 5° C. and took at least 15 days before any appreciable germination was evident at 8° C. is, however, no criterion for assuming that all sugar beet seeds have this same minimum temperature rate and requirement.

Private conversation with Bion Tolman of the Utah-Idaho Sugar Company, indicates that there are hybrid sugar beet seeds which germinate readily at 35° F. (1.67° C.) and that the rate of germination is not slow even at this temperature.

d. Temperature and Storage Conditions prior to Germination.

Jacobs (30) found that soaking for 4 days in tap water and exposure to freezing for 48 hours is the most favorable condition to induce the early and complete sprouting of sugar pine seeds.

Barton (6) found that stratification for 2 months at 5° C. is of decided benefit in hastening the germination of shortleaf slash and loblolly pine seeds, while one month at 5° C. is more beneficial for longleaf pine seeds. There have been many other similiar investigations (14, 19) on other seeds. The benefit to improved germination of a period of low temperature stratification is again indicated. Some seeds appear to be benefitted by two periods of low temperature exposure while many others require none at all.

Park (50,51) lists a number of physical and chemical changes which occur in the seeds of Juniperus during low temperature after-ripening. These include: a. rapid and complete inbibition followed by a steady slow decrease in water content during after-ripening or until near germination; b. slight growth of embyro; c. rise in vigor of seeds as shown by their resistance to fungal attack.

The dormant period in sugar beet seeds is very short and it is doubtful whether low temperature stratification would have any significant beneficial effect upon subsequent germination. However, to determine this fact the following experiment was conducted.

Experiment III.

Segmented sugar beet seeds (U.S.215x216) were placed in moistened vermiculite in a series of mason jars and placed in a refrigerator set at 5° C. for a period of 15 days, one month and three months but in such an order that all could be removed simultaneously. Other seeds were made up to moisture contents of 15, 20, 25 and 30% and placed in separate closed mason jars in the same refrigerator for 3 months. At the end of the 3 months time all seeds were removed and germinated in lots of 100 between moistened blotting papers in a germinator set at 25° C. Dry untreated seed from the same original lot was germinated at the same time as a check. The results are presented as percent germination in the following table.

Table III.

Germination of sugar beet seeds after various periods of cold storage stratification at 5° C.

Days after Planting	Check	Treatments: Stratification in vermiculite: 15 days	1 mo.*	3 mo.*	Moisture contents of seeds in mason jars: 15%	20%*	25%*	30%*
3	42%	48%	28%	0	14%	0	0	0
6	68%	73%	44%	0	36%	0	0	0
9	78%	79%	47%	0	48%	0	0	0
12	82%	83%	51%	0	51%	0	0	0

* Seeds were very moldy at the end of three months cold storage.

Discussion

From this experiment it can be seen that low temperature stratification at 5° C. did not benefit the germination of sugar beet seeds when the moisture content of the seeds was above 15% or if they were left in moist stratification for periods of over 15 days. The germination of seeds stored at 5° C. in moistened vermiculite for 15 days was equal to and slightly better than check seed. This is probably due to the fact that when these seeds were placed in the germinator they were completely moistened and in a condition to start germinating. Furthermore, they were not under the influence of high moisture and temperature for a sufficient length of time to harm their viability.

This experiment tends to show why sugar beet seeds when planted under cold, moist soil conditions in the field germinate very slowly and with such low percentages of emergence.

The results are also in agreement with the findings of Toole et al (74) in regards to the effects of temperature and relative humidity of storage conditions upon a variety of vegetable seeds. Spinach seed, for example, was shown to deteriorate rapidly under storage conditions of high relative humidity, at higher temperatures the loss of viability being much more rapid than at low temperatures. The temperatures used by Toole et al varied from 50 to 80° F. and the relative humidities from 63% to 80%. The beet seeds in experiment III were all under the influence of approximately 100% relative humidity in the moistened vermiculite. At a moisture content of 15% the beet seeds, according to Hunter and Dexter (28), may be considered to be in atmospheres of 80% relative humidity.

e. Germination Stimulants and Chemical Dormancy Breakers.

For some period of time, numerous investigators have experimented upon a great variety of seeds using a large and growing selection of chemicals in an effort to bring about more rapid after-ripening and germination of seeds and to terminate dormancy. According to Crocker (13) few chemicals have proven successful in forcing dormant seeds. Some seeds have been forced by CO_2, H_2O_2 and mercury salts but none of these is generally effective as a forcing agent. Dexter (16, 17) attempted to stimulate germination and growth in sugar beets using indole acetic acid, indole butyric acid, phenyl acetic acid, naphthalene acetic acid, commercial hormone preparations, water soaked seeds planted dry and water soaked seeds planted wet. He found that in no case were beneficial results noted except when seeds were soaked in water and planted wet.

Gracanin (24) found that the speed of germination of the seeds of beet, rye, sunflower, Festuca and others was accelerated by treatment with O-phosphoric acid.

Garner and Sanders (23) believing the thickness of the pericarpal tissue to be the causal factor in the poor germination of sugar beet seeds, soaked some seed in sulphuric acid. They reported accelerated and increased germination with these treatments, but failed to show consistent benefit in the field.

Stout and Tolman (65) have questioned the beneficial effect of sulphuric acid in itself and indicate that the beneficial effects may be due to the increased moisture content of the seeds as a result of this treatment. These two investigators have also tried synthetic growth regulating substances on sugar beet seeds (73). Using dust applied to the seed and sprays on the foliage they found no significant benefit in either the greenhouse or field.

King (33) studied the changes of carbohydrates in germinating wheat seeds cultivated, respectively, in $MnSO_4$ solution, indoleacetic acid solution and redistilled water. He found that starch hydrolysis, respiration and translocation of foods were all accelerated by $MnSO_4$. Growth in $MnSO_4$ solution was better than that of the control which in turn was better than that in the indoleacetic acid medium.

Ni (47) found that $MnSO_4$ in low concentrations accelerated amylase activity of wheat seeds.

Tang and Loo (67) found that immersion of corn seeds in various concentrations of $MnSO_4$, $MnCl_2$ or $Mn(NO_3)_2$ increased the percent of germination and promoted the early growth of the seeds. The most effective concentration used was 10^{-3}M. Pre-treatments of corn seeds with a solution of manganese salts before germination also resulted in accelerated growth.

Becquerel and Rousseau (7) found that pea seeds soaked for 24 hours in a mixture of phenylacetic acid (10^{-5}M) and $MnSO_4$ (10^{-4}M) exerted a favoring action of 40% on the yield of the seeds.

In order to determine if chemicals mentioned as stimulators on other seeds and not yet tried on sugar beet seeds have any beneficial effect upon germination, the following experiment was conducted.

Experiment IV.

Separate lots of fifty segmented sugar beet seed (U.S. 215x216) were soaked for 2 hours in solutions of 0.125M, 0.2M and 0.5M of the following chemicals: $MgSO_4$, Oxalic acid, $NaNO_3$, starch, dextrose, thiourea, sucrose, tartaric acid, NaCl, K_2SO_4, KCl, KNO_3, NH_4Cl, $(NH_4)_2SO_4$, KH_2PO_4 and water. Seeds from each treatment, planted wet, together with dry check seed from the same original lot were planted in individual pots by means of pushing the seeds into the moistened quartz sand in the pots with the head of a nail to a depth of ½ inch and then covering with sand. The greenhouse temperature during this experiment was approximately 70° F. The results of those treatments which showed better than average results are presented in the following table, by number of sprouts.

Table IV.

Germination of sugar beet seed pre-treated with various chemicals.

Days after planting	Check	Water	0.125M $MgSO$	0.125M NaCl	0.125M Dextrose	0.125M Sucrose
			Treatments			
3	0	0	0	0	0	0
5	4	14	11	14	13	12
7	15	32	30	28	31	29
9	39	52	45	47	46	44
11	47	60	53	58	54	53
13	52	61	56	60	57	55

Discussion

The most beneficial chemical treatment was that of the 0.125M NaCl. This however, was slightly less than that of the water treatment and the other treatments were very close to that of water. Could it not be that the apparent beneficial action of the water rather than the chemicals in the water in which the seeds were soaked caused the seeds to have a more rapid germination than the check seeds? The results of a number of previously mentioned investigations have pointed to this fact. Satchell (56), for example, treated sugar beet seeds with NaCl in order to determine the effect on germination. His results showed a more rapid germination with the NaCl treated seeds than with the untreated check seeds. However, the NaCl treatments were not superior to treatment with water alone.

Ayers and Hayward (5) found that the percent germination of sugar beet seeds in soil decreased as the amount of NaCl added to the soil was increased. Even as little as 0.04% NaCl had a inhibiting effect upon germination. Corn, which is less tolerant than sugar beets during later stages of growth, gave satisfactory germination at approximately 10 atmospheres osmotic pressure with NaCl, and red kidney beans, which are very sensitive to salt, germinated slightly better than sugar beets. From these facts Hayward and Wadleigh (27) state that although sugar beets are regarded as salt tolerant crops they are relatively sensitive during germination. This indicates that there is not always a positive correlation between salt tolerance at germination and during later phases of growth.

f. Moisture.

The results of previously mentioned experimentation have tended again and again to point to the stimulatory effects of water upon the emergence and germination of sugar beet seeds. Moisture is indeed a factor of prime importance in the germination of seeds. However, to discuss this problem adequately the specific moisture requirements must be known.

Livingston (39) indicates that seed germination varies with the species of plant concerned as well as with the percentage of soil moisture.

Detmer (15) found that the quantity of water absorbed by different kinds of seeds, when thoroughly soaked, was by no means the same. For instance, wheat took up only 40 to 60% of its air dry weight while peas took up 100%. Thus the capacity for absorbing water is different in different seeds.

In work on seed germination in media of low water content. Peters (53) found that seeds of peas, soybeans and grains of corn and wheat germinated at or below the wilting coefficient of 1.13% moisture in quartz sand of 0.1 mm. size.

Doneen and MacGillivray (18) using a wide variety of seeds of cultivated plants found that seeds of all crops germinated in a shorter time at high soil moistures than at low. Most seeds gave good germination over the entire range of available water and seemed to fall into four groups based upon their ability to germinate near the permanent wilting percentage, with garden beets in the group requiring next to the highest soil moisture. An example from each group, including seed balls of Detroit Dark Red Beets, is listed in the following table.

Table V.

Germination of vegetable seeds at different soil moistures, grouped with reference to germination near permanent wilting percentage. (Field capacity - 15.7%; Wilting point - 8.6%)

		Percent Soil Moisture							
Seeds Tested	Official Germination	7	8	9	10	11	12	14	16
		Germination							
	%	%	%	%	%	%	%	%	%
Group A Sweet Corn, Golden Bantam.	95	2	35	90	95	93	93	89	93
Group B Carrot, Imperator.	91	0	3	57	75	87	76	78	77
Group C Beets, Detroit Dark Red.	91	0	3	4	52	82	90	91	93
Group D Celery.	80	0	0	0	0	29	43	63	73

Discussion

The soil in which the seeds were germinated was a Yolo fine sandy loam. It can be seen that the beet seeds failed to show any appreciable germination until soil of 10% moisture was used (this is distinctly above the wilting percentage) and that full germination was not reached until the soil moisture had reached 12%.

In plantings ranging from near the permanent wilting percentage to near field capacity, Leach et al (36) found that decorticated sugar beet seed germinated faster and showed a higher percentage of potential emergence than whole seed at low soil moistures. At high soil moistures there were only slight differences in rates of emergence between whole, decorticated and segmented seed. Pelleted seed tested in the same manner showed a lower emergence and a longer emergence period than unpelleted seed from the same source. In low soil moistures the delay in emergence from pelleted seeds was pronounced.

These facts lead one to presume that the speed of germination is dependent upon the ability of the beet seeds themselves to absorb, adsorb and/or imbibe water from the surrounding media and the relative ease with which this can be done. The materials which cover the pelleted seed, having first to absorb water before the seed can get it, apparently slow down or impede this process of absorption. In addition the corky floral matter of the seed ball surrounding the true seeds themselves tends to impede the uptake of water.

Stiles (62,63) made a quantitative study of the course of water absorption by seeds during germination (a) to determine whether seeds actually differ in the total amount and rate of water untake; (b) to note the role played by the various parts of the seeds; (c) to determine whether there exist seeds with mesic (intermediate water), hydric (high water) or xeric (low water or desert) germination modifications; and (d) to determine whether there are varietial differences in the water absorption by seeds. Data on seeds studies include three varieties of Zea Mays, two varieties of Gossypium hirsutum, Phaseolus coccineus, P. lunatus, P. vulgaris and Glycine max. Her conclusions indicate that the various seeds differ in the total amount of water absorbed and in the rates of absorption; that seeds apparently possess slight degrees of adaptation to germination in mesic, hydric and xeric conditions; that varietal differences appear in the water absorbing capacity of seeds and in percentage moisture required for germination; and that different organs of the seed play one or more roles in the germination process. The seed coats all behaved similarly in that they absorbed water quickly until an approximate saturation was reached and this saturation level was approximately maintained thereafter. Seed coats served as transporting agents for water from the external water supply to the internal parts of the seed.

Hunter and Dexter (28) working with segmented sugar beet seed found (a) that the seeds failed to germinate in air at

100% relative humidity and that at this high humidity the seeds obtained a maximum of 29% moisture content. (b) In soil, germination did not occur unless the seed took up somewhat over 30% moisture; that germination took up somewhat over 24 hours, but water absorption was complete in about 4 hours. (c) Seeds immersed in water took up over 30% of water in one half hour. (d) Free water films appear to be necessary for germination.

In order to investigate this problem more specifically for sugar beets and to determine more exactly the minimum moisture requirements for beet seed germination the following series of experiments was performed.

Experiment V.

The seed used throughout this experiment was segmented sugar beet seed (variety U.S. 215x216). All experiments were carried out at a temperature of approximately 25°C. The soils chosen, all Michigan soils, were a Miami silt loam, a Brookston sandy clay loam, a Nappanee clay loam, and a Clyde clay. All lots of soils were first screened through 2mm mesh for uniformity.

In order to further categorize the soils, pF curves were determined for each by use of the following methods:

a. Vapor Pressure Method. The pF values were determined by suspending soil samples in air tight mason jars over sulphuric acid of proper concentration to give relative humidities of the atmosphere in the mason jars of 10, 50, 75, 93 and 98%

relative humidity or pF values of 6.5, 6.0, 5.6, 5.0 and 4.5 respectively. Two weeks was allowed for equilibrium to be attained and then the moisture content of the soil samples was determined by placing weighed samples in an oven at 103°C for 24 hours and reweighing.

b. Centrifuge Method. The moisture equivalent (pF of 2.7) method as described by Veihmeyer and Hendrickson (77) was determined by setting the centrifuge at 2440 r.p.m. By setting the centrifuge to 5300 r.p.m. and using the same procedure as above a pF of 3.31 was obtained.

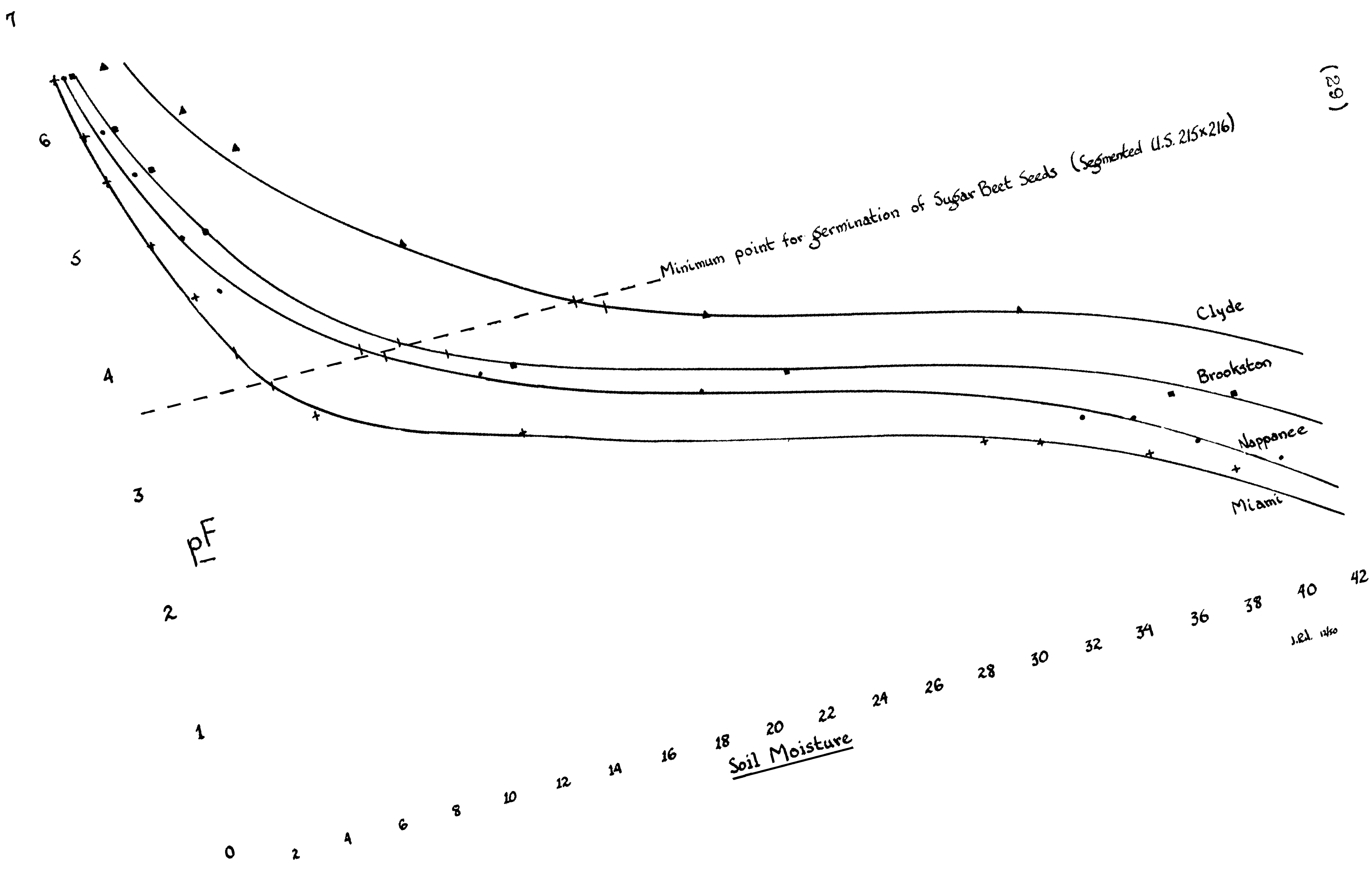
c. pF Table Method. By allowing moisture saturated soil samples to drain on a pF table set at 60 cm., 40 cm., 20cm., and 10 cm. pF values of 1.78, 1.60, 1.30 and 1.00 respectively were obtained.

The results of these pF determinations appear in Table VI and are summarized on Graph I.

Table VI

Soil pF Determinations

Method	pF	Results in Soil Moisture Percentage			
		Miami	Brookston	Nappanee	Clyde
		%	%	%	%
1. In Rel. Hum. of 10%	6.5	0.61	0.91	1.30	2.40
2. In Rel. Hum. of 50%	6.0	1.15	1.91	2.27	4.85
3. In Rel. Hum. of 75%	5.6	1.59	2.62	3.18	6.35
4. In Rel. Hum. of 93%	5.0	2.54	3.62	4.49	8.32
5. In Rel. Hum. of 98%	4.5	3.56	4.39	6.09	11.22
6. Centrifuge at 5300 RPM	3.31	6.51	11.89	12.30	21.35
7. Moisture Equivalent	2.7	12.58	20.41	23.65	32.75
8. 60 cm. H_2O	1.77	30.00	33.73	36.96	47.25
9. 40 cm. H_2O	1.6	32.05	35.45	39.19	
10. 20 cm. H_2O	1.3	35.73	37.52	43.50	
11. 10 cm. H_2O	1.0	38.64	40.33	46.39	


Minimum point for Germination of Sugar Beet Seeds (Segmented U.S. 215x216)
Clyde
Brookston
Nappanee
Miami
pF
7
6
5
4
3
2
1
Soil Moisture
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42

The bulk of the experiment centered around the determination of the minimum moisture required for sugar beet seeds to germinate.

Each of the soils was brought to a desired moisture content by adding an exact amount of water (based upon the air dry moisture content of the soil) to a measured amount of air dry soil. The water was then thoroughly mixed with the soil by means of stirring with a spoon and then placing the sample in a sealed mason jar which in turn was placed in an end-over-end rotator for a period of three days to allow for equilibrium. At the end of this time 50 segmented beet seed balls screened through 10/64" on 8/64" mesh for uniformity, were placed in each mason jar which contained approximately 150 grams of soil. Thère were six replications of each soil moisture for each soil type, these being as follows:

For Miami:	3%, 4%, 5%, 6%
For Brookston:	9%, 10%, 11%, 12%
For Nappanee:	8%, 9%, 10%, 11%
For Clyde:	15%, 16%, 17%, 18%

The jars containing the seed and soil were then placed in an insulated box. The temperature was maintained at as close to 25°C as possible in this box to prevent changes in the relative humidity within the jars themselves. At periods of from one to six days after planting the seed together with the soil, jars of each different soil, at each different soil moisture were removed and the moisture content of both the seed and the soil contained therein was determined. Soil moisture was determined on an oven dry basis and seed moistures were determined on an absolute basis. Seeds were carefully checked to see if any sprouting had occurred and if so this fact was recorded.

The data (all figures shown are averaged results of four trials) from these experiments is found in Tables VII, VIII, IX and X.

Table VII.

Moisture content in sugar beet seeds in Nappanee clay loam soil at various soil moisture contents.

Days after planting seed	Percent soil moisture 7.88%	8.84%	9.47%	10.62%
	Percent moisture in seeds			
	%	%	%	%
0	6.13	6.13	6.13	6.13
1	28.46	28.02	33.14	33.58
2	27.49	29.98	30.62	32.80
3	27.01	29.16	32.20	34.79*
4	26.89	27.98	30.76*	31.01*
5.	27.45	29.62	32.84*	36.98*
6	26.85	28.89	34.81*	42.31*

* indicates sprouting of seeds.

Table VIII.

Moisture content in sugar beet seeds in Brookston sandy clay loam soil at various soil moisture contents.

Days after planting seed	Percent soil moisture			
	8.48%	9.57%	10.24%	12.01%
	Percent moisture in seeds			
	%	%	%	%
0	5.59	5.59	5.59	5.59
1	25.09	25.65	28.02	29.50
2	25.87	25.44	28.44	30.43
3	22.68	25.65	27.79	30.72
4	23.94	26.30	27.05	30.28
5	24.50	26.55	27.24	33.15*
6	24.50	25.46	28.35	36.48*

* indicates sprouting of seeds.

Table IX.

Moisture content in sugar beet seeds in Miami silt loam soil at various soil moisture contents.

Days after planting seed	Percent soil moisture 3.38%	4.41%	5.54%	6.08%
	Percent moisture in seeds			
	%	%	%	%
0	5.84	5.84	5.84	5.84
1	21.67	21.21	24.26	26.90
2	22.42	22.08	27.36	30.09
3	20.09	23.23	30.00	34.68*
4	20.61	22.89	31.89*	32.13*
5	21.11	22.56	31.25*	35.98*
6	20.98	23.31	32.68*	41.13*

* indicates sprouting of seeds.

Table X.

Moisture content in sugar beet seeds in Clyde clay soil at various soil moisture contents.

Days after planting seed	Percent soil moisture			
	14.88%	16.07%	16.76%	17.74%
	Percent moisture in seeds			
	%	%	%	%
0	5.92	5.92	5.92	5.92
1	27.04	27.11	28.40	30.62
2	24.53	27.49	27.95	30.43
3	26.71	27.83	29.57	31.28
4	24.32	24.98	28.87	31.99*
5	29.01	25.32	29.21	32.31*
6	26.32	27.81	28.43	35.08*

* indicates sprouting of seeds.

Observations

In each case it may be observed that in order to germinate, a sugar beet seed must attain a moisture content of 30% or over.

In the Miami silt loam soil this is possible somewhere between 4.41% and 5.45%; in the Brookston sandy clay loam, between 10.44% and 12.01%; in the Nappanee clay loam, between 8.84% and 9.47%; and in the Clyde clay soil, between 16.74% and 17.74% soil moisture.

If these various soil moisture percentages for each soil are placed on the pF curve of that particular soil as is shown on Graph I, page 29, it may be seen that they inclose a straight line which lies on pF 3.7.

Discussion

These results indicate that a soil should have a pF of at least 3.7 at 25°C. in order for segmented sugar beet seeds of this particular variety to germinate.

At a lower soil moisture, even though the soil air has a relative humidity of 100% and water films are present on the soil particles, the water is so strongly adsorbed on the surface of the soil particles that the seed is unable to remove sufficient amounts for germination even though in direct contact with the soil particles.

At a pF of 3.7 or below (i.e. lower pF or higher moisture content) the films of water surrounding the soil particles are sufficiently great that the seed may absorb enough for germination before the force of the soil-water interfaces becomes so strong that the seed is no longer able to absorb water. Once the seed has germinated, the value of pF 3.7 is no longer as critical and the pF may approach the wilting percentage without too much damage to the plant. This is due to the fact that the roots of the newly formed plant are able to draw water from a much larger soil area than the seed. When the seed itself must function as the absorbing organ in a soil slightly drier than pF 3.7, the seed "dries out" the soil surrounding it and still does not obtain enough moisture to germinate. Furthermore, soil water movement in soils at this pF is not sufficient or rapid enough to replenish the soil just surrounding the seed and thus it can never obtain enough moisture to germinate. When, however, the soil has a pF of 3.7, or has a little higher moisture content, the water from films surrounding the soil particles further from the seed is able to move to those soil particles immediately surrounding the seed which the seed is "drying out". Sufficient moisture is thus supplied to keep the interface tension between the soil and water films such that the seed is able to continue to absorb water until germination.

When it has been shown a number of times that a variety of seeds can germinate over the entire range of soil moisture from near (and according to Peters (53) below) the wilting percentage to field capacity, why, if the facts above are correct, do not the sugar beet seeds germinate at soil moistures drier than pF of 3.7? A number of methods of attack have been presented in an attempt to explain this fact.

Cox et al (9) found that the seed coats of certain varieties of cabbage seed contained a germination inhibitor which could be removed by treating the seed with cold concentrated H_2SO_4 and then thoroughly washing in tap water.

Mosheov (46) found that a water soluble extract from wheat seeds when used as the moisture supply for germination caused a delay in the germination of wheat seeds, but increased the rate of growth subsequent to germination. The inhibition effect but not the subsequent stimulation was destroyed by boiling the extract for a half an hour. In darkness the inhibition was much smaller or negligible.

Smith (61) has indicated that the hulls and chaff of cereals have an influence on the germination of the seeds of these crops. The removal of hulls tends to benefit more rapid germination but also makes the seeds more succeptable to molds.

Evenari et al (20) state that tomato juice contains both an inhibitory as well as a stimulatory substance. At high concentration the former overshadows the latter but the former could be dialized whereas the latter could not. The inhibitory substance effected the germination of cereals, the degree of decreasing effect being oats - barley - wheat - maize. The fruit of Poterium spinosum also contains a substance which is inhibitory to germination. Suitable adsorbents are capable of removing this substance.

Tolman and Stout (72,73) working with sugar beet seeds came to the conclusion that a water soluble inhibitory substance was present in the corky material of the seed balls. They concluded that the inhibiting effect was largely due to ammonia released by enzymatic hydrolysis, and that the removal of this water soluble nitrogen fraction from the pericarpal tissue affords an explanation of the beneficial effects of washing or soaking some seeds prior to germination tests. When experiments are carried out in petri dishes the effect of this germination inhibitor is significant but its influence disappears when the seeds are planted in soil. This obviously points to the fact that in the soil this inhibitory substance is removed from the seed by adsorption on the colloidal matter in the soil.

In this connection, Toole et al (75) indicate that better germination results are obtained in a mixture of sand and muck than on blotting paper. Anderson (3) concurs with this and further states that pre-soaking the seed is not necessary when sand, soil or Kimpak is used as a germination media. She states that pre-soaking appears to help when blotting paper is used and attributes the browning of the unsoaked seed to Rhizopus nigricans.

Patrick (52), in an attempt to justify the inclusion in the Official Seed Analysts Rules of the 2 hour pregermination soaking period for beet seeds carried out a number of experiments which indicate that presoaking was of no apparent benefit to total germination. The same percentage germination was found for both soaked and unsoaked seeds, but, no figures were given as to the relative speed of emergence. He states, however, that germinating seed balls which have been pre-soaked carry less fungi and give a considerably higher preliminary germination count, indicating that the pre-soaked seeds had a more rapid germination.

Taylor (68) working with celery seed found that seed extracts partially inhibited germination. However, of even greater influence on germination was treatment with NaOCl at various concentrations, the effect of which was apparently to cut down on mold and fungus growth. The best results were a combination of NaOCl treatment and presoaking of the seed prior to planting in the field. Seeds treated with NaOCl and presprouted for 5 days when planted at the same time as untreated seeds would not only emerge 9 to 10 days earlier than the untreated seeds but would have achieved almost complete emergence before any emergence had occurred from the untreated seeds. Twenty four hours drying of seed presprouted for four days reduced germination to 11%.

Ivanoff (29) found that soaking unshelled peanuts in water for 20-24 hours reduced fungus growth on the pods, decreased seed and seedling infection, and increased emergence in the field. It might appear from this that the benefit derived from pre-soaking was not solely one of removal of inhibitory matter. The removal of fungi from the seed coat as well as the direct stimulation of water upon the embryo itself also results from pre-soaking the seed.

In any case the conditions stated above are those in which there is a sufficiency of water. In the laboratory when large amounts of water were used, the effects of the extraction of inhibitory matter as well as the washing away of fungi could be observed. Under field conditions where there is by no means as much free water to wash the seeds, and where the adsorbing action of the soil colloidal matter is in effect, it was more difficult to observe any effect from the pre-soaking of seeds. Could it not be, though, that under more carefully controlled field conditions the effect of pre-soaking might be noted? Is it not possible that enough extra moisture is required to dissolve out and dilute the inhibitory matter from the seeds so as to change the minimum soil moisture from the wilting point (pF 4.15) to a pF of 3.7? If not, why do sugar beets need a soil with a higher moisture content in which to germinate satisfactorily than almost all other cultivated crops?

Another reason which might cause sugar beet seeds to require more water to germinate than most seeds is due to the osmotic effect mentioned previously (5). The germination of sugar beet seeds is readily inhibited even by low osmotic concentrations. It may be due to this fact that a higher soil moisture content benefits sugar beet seed germination.

At any rate, in the light of what has just been stated, the material surrounding the seed (i.e. hulls, chaff, pulp or juice of the tomato fruit, pericarpal material of sugar beet seed balls) appears to exert an influence of some kind in the process of germination. As has been mentioned by Stiles (62,62) seed coats serve as transporting agents for water from the external water supply to the internal parts of the seed. Water must pass through this material before the growing parts can obtain it and begin to function. The rate at which the internal parts obtain water is governed by the seed coat. This in turn affects the rate of the germination process. In order to determine the rates of absorption and the influence of the pericarpal material, the following experiment was performed.

Experiment VI

Segmented sugar beet seeds (U.S. 215x216) of known moisture content were immersed in a beaker of water at 75° F. Samples of seed were removed at appropriate time intervals. Seed balls were quickly dissected to remove the true seeds and moisture content determination both of the whole seed ball and of the true seed itself were made. Table XI shows the results of this experiment.

Table XI.

Moisture content of sugar beet seed balls and true seed after different periods of submersion in water.

	Length of time submerged in water, in hours.						
	0	½	1	1½	2	4	24
	%	%	%	%	%	%	%
Moisture content of seed ball	7.25	39.41	41.33	42.65	45.92	42.68	45.38
Moisture content of true seed		21.21	27.27	27.29	26.67	36.36	43.47

Discussion

The results indicate that the true seed takes about 24 hours to come to equilibrium as far as moisture content with the whole seed ball is concerned. During the first half hour of soaking, the seed ball had absorbed water very rapidly and to a percentage definitely higher than that required for germination. It has already been shown that a moisture content of 30% or above is necessary for germination (28). It is presumed that this holds for the true seed itself since it has also been shown that seeds will not germinate even after seven days although their moisture contents are as high as 28.82%, and after one day the true seed will be in equilibrium with the whole seed. However, at the end of the first half hour the true seed only had a moisture content of 21.21%. It is not until the whole seed has soaked for four hours that the true seed has reached a moisture content higher than 30%. This indicates a lag of about 4 hours between the time that the whole seed has attained a moisture content of over 30% and the time that the true seed has reached this point.

In order to find out more about the influence on water absorption of the pericarpal material, a comparison of the various absorption rates and moisture requirements of whole seed as against segmented seed was made in the following experiment.

Experiment VII

In a series of mason jars, air was maintained at a variety of relative humidities (25, 50, 65, 75, 89, 90 and 100%) by placing in them various concentrations of H_2SO_4 as indicated by Wilson (80). Suspended from the inside of the jar cap and above the liquid in the jar was a small perforated metal cup. Within this cup was placed a known number of air dry whole seed of a known moisture content. At varying intervals these seed were removed from each of the air tight jars, weighed and returned. When the weight became constant, indicating moisture equilibrium between the seeds and the surrounding atmosphere, the seeds were placed in an air-oven at 102°C. for 24 hours and reweighed so that their moisture contents could be calculated. Table XII shows the results of this experiment.

Table XII.

Moisture content of whole sugar beet seeds exposed for various periods of time to air at relative humidities shown (75° F.)

Time, in hours.	25%	50%	65%	75%	80%	90%	100%
	Relative Humidity of Atmosphere in Jars						
	Moisture content of whole seeds						
	%	%	%	%	%	%	%
0	6.98	6.98	6.98	6.98	6.98	6.98	6.98
24	7.03	8.23	9.74	11.50	12.68	20.45	30.65
48	6.95	8.31	10.36	12.02	13.13	21.21	34.73*
168	6.97	8.36	10.93	12.78	14.02	22.36*	34.75*

* indicates that the seeds were moldy.

Discussion

In no case was there any germination of the seeds. From the table it can be seen that at every relative humidity the seeds approached equilibrium in about 48 hours. The important fact is that at 100% relative humidity whole seed attained a moisture content of 34.75% without germinating. As was shown by Hunter and Dexter (28) segmented seed from the same lot only attained a moisture content of 28.82% at 100% relative humidity. The difference may be attributed to the moisture contained in the pericarpal matter of the whole seed. This is undoubtedly the reason that whole seed, while it can germinate in soil of the same moisture content as segmented or decorticated seed, takes a longer time period to do it. It requires more moisture to saturate the seed and perhaps to dilute the inhibitor present.

In connection with the problem of moisture absorption it has been indicated in a number of cases above that soaking or wetting the seed prior to planting is beneficial to germination. Knott (34) experimenting with seed soaking came to the following conclusions (a) Soaking seed of beet, cabbage and tomato in shallow distilled water for 24 hours shows no definite influence on the later growth and yield, if the plants from the soaked and dry seed appear above ground at the same time. (b) The stimulating advantage claimed for soaking may be due simply to the initial head start of the soaked seed at a time when the plant is at its greatest efficiency.

Theoretically, how great a head start would a segmented sugar beet seed that has been soaked for 4 hours have over a dry one when both are planted at the same time in a soil with adequate moisture, aeration and temperature conditions? After 4 hours of soaking the embryo has absorbed sufficient moisture so that the germination processes have been initiated. Enzyme activity, hydrolysis, cell division and growth are all under way so that when this seed is planted in a soil conducive to germination it is already growing. Due to the fact that it is wet it probably makes contact with the films of water in the soil and absorbs moisture more readily than a dry seed. Now, the dry seed when placed in this soil reaches, as a whole, moisture equilibrium in the soil in about 4 hours. However, in Experiment VI we saw that there was a definite lag between the moisture content of the whole seed ball and the true seed itself. This means that although the seed ball as a whole has attained apparent equilibrium after 4 hours in the soil the true seed has probably not reached this point and at least another 4 hours will have to elapse before this has been reached. The dry seed can now begin to germinate 8 hours after the soaked one although both were planted at the same time. Thus an advantage of only from 4 to 8 hours may be gained, theoretically and under the conditions mentioned, by soaking the seed. This example was taken with a temperature of about 75° F. (that of experimental conditions concurrent with the facts) in mind. Now, if the seed were soaked at this temperature for 4 hours and placed with dry seed in a soil 10°C. cooler what would be the result? According to van't Hoff's rule the speed of the reaction would be halved. That is, the seeds would take twice as long to germinate at this temperature. The soaked seed, however, has already begun to germinate, although at this lower temperature the process will continue at only half the rate of 75° F. The dry seed will now take twice as long to reach the initial steps of germination and will then proceed at half its rate at 75° F. An advantage now of from 8 to 16 hours has been gained by the soaked seed. If the temperature of the soil is lower still, the difference could be expected to be proportionally greater. According to Shull (60), seed germination does not follow van't Hoff's rule this closely. Nevertheless, as has been shown above, temperature plays a very important role. Thus in the best of environmental conditions the maximum which can be expected in having treated seed germinate faster than untreated seed is about 24 hours.

In order to test the validity of this hypothesis the following experiment was conducted.

Experiment VIII

Two lots of 25 grams each of segmented sugar beet seed (U.S. 215x216) were placed in cheese-cloth bags. One bag was placed in a liter of water at 25° C. and soaked for 4 hours. The other bag was placed in a liter of ice water in the refrigerator and soaked four hours. At the end of this time 100 wet seeds from each treatment together with 100 dry untreated check seeds were placed between moist blotters in the germinator at 25° C. The results of this germination test as percent of seeds germinated is given in Table XIII.

Another lot of 100 wet seeds from each of the above treatments together with 100 dry untreated check seeds were placed between blotters moistened with water at 9° C. and placed in a refrigerator set at 9° C. The results of this germination test as percent of seeds germinated is also given in Table XIII.

Table XIII.

Germination of seed pre-soaked at two temperatures under two temperature conditions.

Days after planting	Seed treatments: Check seed (Planted dry)		Seed soaked 4 hours at 25°C. Planted wet		Seed soaked 4 hours at 8°C. Planted wet	
	at 9°C.	at 25°C.	at 9°C.	at 25°C.	at 9°C.	at 25°C.
1	0	0	0	18%	0	10%
2	0	2%	0	68%	0	56%
3	0	39%	0	83%	0	70%
4	0	74%	0	86%	0	70%
5	0	75%	0	88%	0	71%
6	0	77%*	0	90%	0	71%
7	0	77%*	0	90%	0	73%
8	0	77%*	1%	90%	0	73%
9	0	77%*	4%	90%	2%	73%*
10	0	77%*	6%	90%	3%	73%*

Table XIII. (con't.)

Days after planting	Seed treatments					
	Check seed (Planted dry)		Seed soaked 4 hours at 25°C. Planted wet		Seed soaked 4 hours at 8°C. Planted wet	
	at 9°C.	at 25°C.	at 9°C.	at 25°C.	at 9°C.	at 25°C.
11	2%	77%*	12%	90%	7%	73%*
12	4%	77%*	16%	90%*	10%	73%*
13	6%	77%*	19%	90%*	14%	73%*
14	13%	77%*	23%	90%*	19%	73%*
15	18%	77%*	29%	90%*	22%	73%*

* indicates large amounts of mold present.

Discussion

The results of this experiment have indicated that sugar beet seeds which have been soaked and are planted wet germinate more rapidly than unsoaked seeds planted dry. Furthermore the temperature of the soaking period influences the rate of germination. Those seeds which were soaked in water at 25°C. germinated more rapidly than those seeds soaked in water at 8°C. This is true at regular germination temperatures of 25°C. and even more pronounced at germination temperatures of 8°C.

These results further tend to support the previously stated contention that seeds soaked in water at 25°C. and planted wet in cold soils will emerge more rapidly than untreated seeds planted dry in the same soils.

Now, in many cases if a time advantage could be guaranteed, what would be some of the more practical aspects of treating the seeds by this soaking method and then planting them wet? If a farmer were to soak his seed prior to planting and then because of rain or some other reason were unable to plant, what would be the result? Would the seed thus started in the germination process be rendered worthless and useless?

Martin and Leonard (40) state in their book that wheat, barley, oats, corn and even peas have been sprouted, allowed to dry and resprouted three to seven times before germination was fully destroyed. Germination, however, was lower with each repeated sprouting. Levett and Hamer (37) have shown that the germination of kok-sazhyz seed was hastened by permitting the seeds to absorb water in quantity insufficient to induce germination, then drying the seed before sowing. The stimulation was obtained whether the uptake of water was controlled osmotically or by exposure to atmospheres of definite relative humidity.

McKee (41) testing the ability of crimson clover seeds to germinate after periods of wetting and drying found the following results.

Table XIV.

Germination of crimson clover seeds following various wetting and drying periods.

Treat-ment	No. hours seed in contact with water	Length of Radicle in mm.	No. of hours dried	Regermination	
				% cotyledons	% good plants
1	22	0	169	90	85
2	27	1	164	90	45
3	45	5	146	25	5
4	69	10	122	15	5
5	76	10	115	15	0

From this be concluded that where the radicle did not show as a result of the soaking there was no subsequent damage upon regermination.

Uttaman (76) conducted tests which showed that drying sprouted paddy (rice) seed or mutilation of the young plumule and radicle did not kill the germ of the seed. The same seed could be re-germinated and dried repeatedly a number of times without loss of viability, provided the sprouted seed was dried properly and stored out of contact with atmospheric moisture. Sprouted seed lost its viability rapidly when stored in cloth bags.

In order to determine the effect of wetting and drying upon sugar beet seed the following experiment was conducted.

Experiment IX

Five lots of 25 grams each of segmented sugar beet seeds (U.S. 215x216) were prepared. The first lot was soaked in a liter of water for six hours, then dried by placing the seeds on a blotting paper before a fan. The second lot was similar to the first except that after drying, it was again soaked for six hours and then dried again. The third lot received three wet and dry treatments; the fourth lot four and the fifth lot five. When all lots had been dry for at least 3 days four 50 seed samples from each lot together with untreated check seed were placed on moist blotting paper and placed in the germinator at 22° C. Table XV shows the germination counts for the first seven days in the germinator and Table XVI shows the results of planting these seeds in moist sand in the greenhouse. Figure II shows the seeds after the third day on one of the blotters.

Table XV.

Germination of sugar beet seeds on moist blotters after different periods of wetting and drying.

Days after planting	Check	6 hour soak	2x6 hour soak	3x6 hour soak	4x6 hour soak	5x6* hour soak
1	0	1	4	9	14	4
2	3	62	99	126	122	117
3	83	134	154	169	150	153
4	147	145	171	176	153	158
5	166	157	176	183	160	164
6	181	161	180	193	166	173
7	185	168	181	195	170	175

* The title 5x6, for example, indicates that the seeds had received five alternate wetting and drying periods - the wetting period being for six hours.

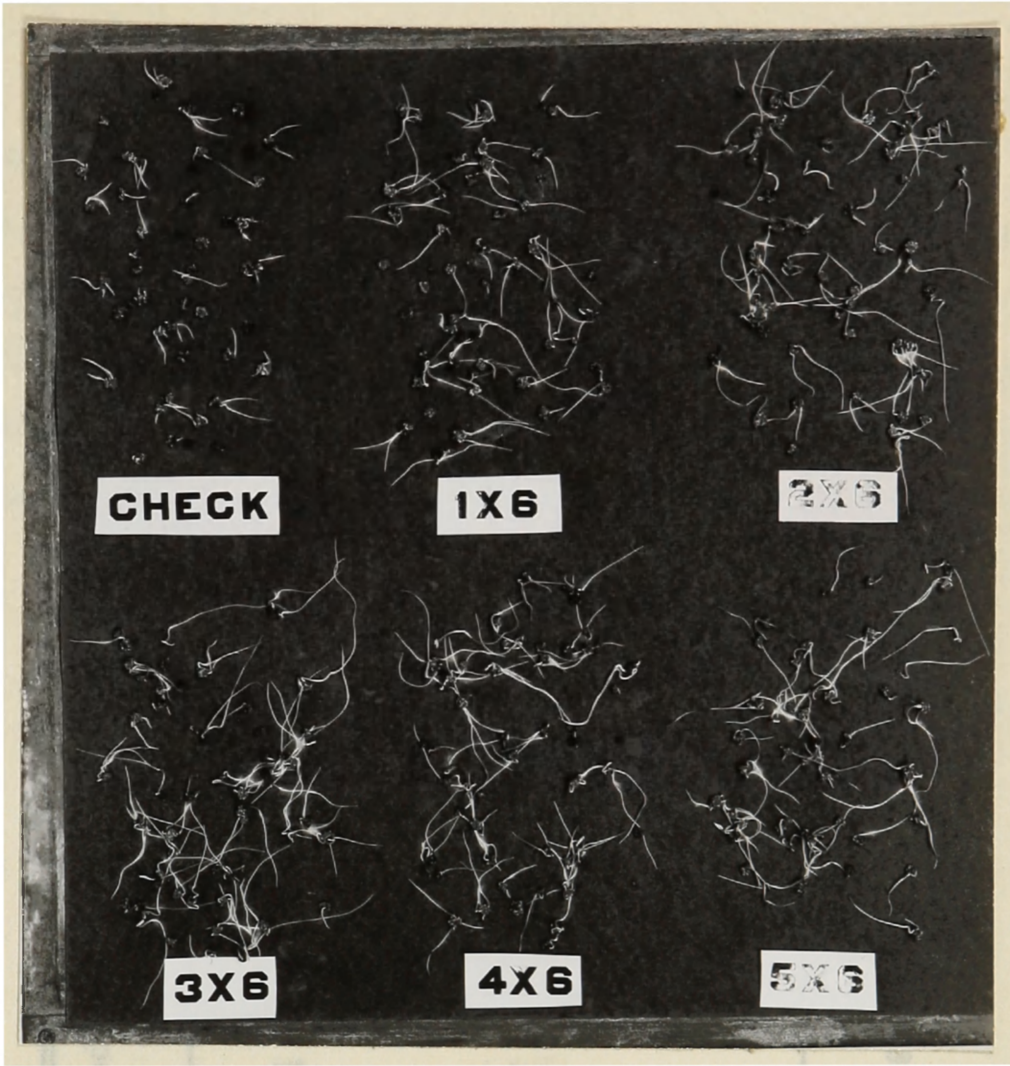


Figure II

Germination of sugar beet seeds on moist blotting paper at 22° C. three days after planting. Treatments include check seed; seeds soaked for six hours in water and dried (1x6); seeds soaked for six hours, dried, soaked again for six hours and dried (2x6); seeds treated with three (3x6), four (4x6), and five (5x6) alternate wet and dry periods.

Table XVI.

Germination of sugar beet seeds in moist sand after different periods of wetting and drying.

Days after planting	Check	6 hour soak	2x6 hour soak	3x6 hour soak	4x6 hour soak	5x6* hour soak
2	0	0	0	0	0	0
3	0	0	0	6	1	0
4	1	8	20	37	20	18
5	114	141	150	185	153	130
6	155	172	181	199	169	143
7	162	180	184	202	173	146

* The title 5x6, for example, indicates that the seeds had received five alternate wetting and drying periods - the wetting period being for six hours.

In order to further determine the effect of wetting and drying all seeds which were treated above were stored in paper bags in the laboratory for one year. At the end of this time the seeds were again tested by germinating on blotting paper in the germinator. The results appear in Table XVII as number of seeds which germinated from 100 seeds from each treatment.

Table XVII.

Germination of sugar beet seeds stored for one year after a variety of different wetting and drying periods.

Days after planting	Check	Wetting and drying treatments				
		6 hour soak	2x6 hour soak	3x6 hour soak	4x6 hour soak	5x6* hour soak
1	0	0	0	0	0	0
2	47	48	62	62	47	50
3	64	62	67	74	57	55
4	66	66	72	77	59	58
5	67	67	72	78	59	59
6	67	68	73	79	60	60
7	68	68	74	80	60	60

* The title 5x6, for example, indicates that the seeds had received five alternate wetting and drying periods - the wetting period being for six hours.

Discussion

From these results it can be seen that this wetting and drying process in some manner stimulated germination. Perhaps the alternating wetting and drying tends to extract any germination inhibitor present or in some manner primes the germination mechanism so that once in a favorable environment the seed germinates rapidly. At any rate, the important point is that an alternation of wetting and drying did not harm the germination porential of the segmented sugar beet seed unless it was done at least 5 times, and in some instances appeared to be a beneficial treatment in inducing more rapid germination. It must also be remembered that complete and rapid drying was insured after each soaking process. Without this complete drying the pattern would undoubtedly be different.

From these results one is led to ask what the effect of a more prolonged soaking treatment would be upon the subsequent germination. In order to determine this another experiment was performed as follows.

Experiment X

Four lots of 25 grams each of segmented sugar beet seeds (U.S. 215x216) were placed in cheese-cloth bags and placed in separate beakers each containing a liter of water. Care was taken to keep the bags below the surface of the water so that germination could not occur. The first lot was soaked for 24 hours, the second for 48 hours, the third for 72 hours and the fourth for 96 hours. The soaking periods were so arranged that all lots were removed simultaneously. Seeds were then dried for three days. Four lots of 50 seeds each from each treatment were then placed, together with 200 dry check seeds, between moist blotters in the germinator at 25° C. Germination counts are recorded in Table XVIII as to seeds germinated under year 1949.

As in the preceeding experiment these treated seeds were stored in paper sacks in the laboratory for one year and then 200 seeds from each lot were tested in the germinator. The results of this test is given in Table XVIII as to seeds germinated under year 1950.

Table XVIII.

Germination of sugar beet seeds soaked for various time periods in water.

Days after planting	Check		Length of soaking period: 24 hours		48 hours		72 hours		96 hours	
	1949	1950*	1949	1950	1949	1950	1949	1950	1949	1950
1	0	0	2	0	3	0	12	0	10	0
2	4	3	21	5	34	7	80	12	80	9
3	81	90	140	90	145	102	155	112	157	100
4	156	142	160	108	195	118	166	122	160	122
5	163	152	168	110	207	120	180	122	163	122
6	178	157	175	111	209	122	186	122	164	122
7	180	159	179	113	210	123	189	122	164	122

* Same seeds as under 1949 but tested after one year's storage.

Discussion

Soaking seed in water for varying periods of time apparently did not harm the vitality of the seed until the soaking period reached 96 hours. As was true in the case of the seeds which were soaked for alternate periods of 6 hours these seed which were soaked for 24, 48, and 72 hours were observed to germinate more rapidly and with a greater percentage of germination than the check seed.

The viability and vitality of the seed when treated by soaking decreased somewhat more than check seed after storage under laboratory conditions for one year.

The results of this experiment would lead one to believe that a farmer could soak his seed for as long as 72 hours without any subsequent damage providing that he either planted them soon after removing from the water or dried them before storing them. Furthermore seeds soaked in any particular year should, if possible, be used that year.

g. Further environmental conditions conducive to germination.

Sugar beets have been grown as a cultivated crop for less than 200 years. The center of origin of the genus Beta was probably in eastern Asia and this crop is extremely resistant to drought, tolerant of high salt concentrations as evidenced by their growth in situations exposed to ocean spray, and capable of persistant and fair growth even in pauperized soils. According to Brandes and Coons (8) the sugar beet makes its best and most efficient growth as a crop plant within a zone lying between the summer-temperature isotherms of 67^{o} and 72^{o} F. However, at the present time the area used for the production of sugar beet seed is located in southern California, New Mexico and Arizona. It is in these areas that the proper winter temperatures for the vernalization and over wintering of the mother beets is possible in the field. Thus we have the situation where seed produced for commercial use throughout the United States is raised in the southwestern area of this country. This is an area which also may be thought of as having soils with a general high salt concentration as well as a higher average temperature than those areas (especially Michigan) in which sugar beets are grown.

Keeping these facts in mind let us now turn to a field first brought to prominence by Kidd and West (32). In a series of experiments these two investigators soaked seeds in water for varying periods of time; determined differences of performance by seeds of the same genetic species harvested from different locations, at different dates of harvest, under different weather conditions at harvest time; determined differences in performance by seeds of the same plant but different in size and position; treated seeds with a variety of physical and chemical stimuli and arrived at the following conclusions: a. Factors which affect the plant during its earliest stages of development (plant in embryo state in seed) have a more or less pronounced effect upon the whole of its subsequent life history. b. External (i.e. weather conditions at harvest time) as well as internal (effect of nutrient quality and quantity from mother plant) conditions have a pronounced effect upon the plants subsequent development. c. Growth and yield of resulting plants are proportional to their initial "food-capital" and thus provide a demonstration of the so called "compound-interest" law.

In this connection Reed (55) has found that the nitrogen-carbohydrate composition of the seed has a measurable effect upon the subsequent growth of the seedling in speed and vigor. The growth of the seedling is influenced by the nature and relative amounts of the food reserves of the seed, as well as by the differences in the external environment.

Crescini (10) working with the seeds of hemp concludes that environmental as well as genetic factors cause variations in seed viability, germination and readiness to germinate.

Pinnell (54) working with corn found that environmental factors during ear development influenced germination so that individual selfed ears within relatively homozygous frequently differed widely in stand performance.

The environment of the seed itself determines its ability to germinate. It is known that in many cases the seeds of certain species of plants will not germinate unless placed in an environment which includes some of the leaf litter which is prevalent in the area of that particular species natural habitat. For example, Lihnell (38) working with the seeds of Pyrola rotundifolia, P. secunda and P. uniflora found that the first two species would germinate in sterile cultures but that the seeds of P. uniflora would only germinate in the presence of a mycorrhizal fungi.

Although no attempt was made to carry out experiments dealing with the environmental influence on the germination of sugar beets and although nothing can be found in the present literature which is particularly concerned with this fact, this is a point which should not be overlooked in connection with the problem of germination. The environment of the southwestern part of the U.S. upon the mother beet plants and its subsequent effect upon the seeds developed there together with the time and conditions of harvest may well have an important influence upon the germination capabilities of these seed when they are planted in other parts of the country under quite different conditions.

III. Agronomic Manipulation of Basic Principles - Field Experiments.

Taking together the few facts known about field germination in general and the germination of sugar beets in particular, a series of field experiments were performed under a variety of conditions. In these experiments the attempt was made to utilize the best known methods of beet germination as found by laboratory and greenhouse experimentation or in the literature to determine which would be the most satisfactory under field conditions in Michigan.

Experiment XI.

In this experiment three different seed treatments together with check seed (segmented U.S. 215x216) were planted on twelve different farms in Bay and Saginaw counties in Michigan. The procedure adopted was to contact a farmer who was in the process of seeding sugar beets and have him continue in his operation but to raise the seed buckets for a distance of from 50 to 100 feet. Following the lines made by the presswheel over the fertilizer already drilled in, the three seed treatments and check seed were drilled into the field with a hand drill. For all dry seed the drill opening was set to "radish seed". For the wet soaked seed the opening was set to "beet seed". This gave the most satisfactory and uniform numbers of seed drilled per unit distance so that a fair comparison could later be made.

The three treatments were _a_, seed soaked for 72 hours in running tap water and dried on a blotter under a fan; _b_, seed soaked and dried twice in running water for a period of 6 hours each time; _c_, seed alternately soaked and dried as in _b_ with a further soaking of 4 hours just prior to planting in a solution of $M^{-3}MnSO_4$ at 25° C.

The plantings were made on May 3rd, 1950. Soil temperature readings were made at a depth of 2 inches in each field. No soil moisture determinations were made since the soil in each field was well within the range of wilting percentage to field capacity. Counts of seedlings were made on

May 11th and May 17th, each count representing the number of seedlings per 50 feet of row.

The soil type for each particular farm was determined from the maps contained in the U.S. Department of Agriculture Soil Survey Bulletins of Bay County (81) and Saginaw County (42).

Seedling counts per 50 feet of row are shown in Table XIX.

Table XIX.

Germination of sugar beet seed, with four different treatments in a variety of soil types under Michigan field conditions.

Seeds planted on May 3, 1950

Farm and Soil Type	Temp. of Soil in °C. at depth of 2"	Seed Treatments: Check planted dry		2x6 hour soak planted dry		2x6 $MnSO_4$ soaked planted wet		72 hour soaked planted dry	
		May 11	May 17	May 11	May 17	May 11	May 17	May 11	May 17
A. Holzei Bros. Wisner clay loam	16°	45	270	54	280	82	340	66	215
B. Herman Reif Burnt muck over clay	16°	26	80	53	92	73	200	8	51
C. Johnson Farm Wisner clay loam	15°	55	295	52	260	74	380	55	205
D. Ernst Krabbe Brookston loam	14.5°	31	280	93	400	103	440	48	220
E. Leo Eigner Wisner clay loam	16°	68	250	103	197	150	340	75	100
F. Clarence Barbour Wisner loam	16.5°	37	235	55	285	65	306	19	198

Table XIX (con't.)

Farm and Soil Type	Temp. of Soil in °C. at depth of 2"	Seed Treatments: Check planted dry		2x6 hour soak planted dry		2x6 $MnSO_4$ soaked planted wet		72 hour soaked planted dry	
		May 11	May 17	May 11	May 17	May 11	May 17	May 11	May 17
G. Lawrence Eigner Wisner loam	17°	32	325	33	400	60	410	55	320
H. Janes Farm Wisner clay loam	17°	50	290	75	330	98	420	32	225
I. Raeder Farm Kaukawlin loam	16°	68	310	87	260	115	345	71	245
J. Humpert Farm Burnt muck over clay	14.5°	55	295	61	220	90	310	43	215
K. Alvin Krabbe Brookston loam	14.5°	58	340	62	450	80	480	49	290
L. Indiantown Farm Wisner loam	15°	17	205	24	185	49	265	2	160
Mean		45.2	264.1	62.7	279.9	86.5	353.0	43.6	203.6

Discussion

The results from this experiment showed that germination was benefited only slightly in the case of the two alternate soaking periods of seed treatment and was of no benefit in the case of the 72 hour soaking seed treatment, when the seeds in both cases were planted dry.

When the seeds were planted in a wet condition, as in the case of the $MnSO_4$ treated seed which had previously been treated to two alternate wet and dry treatments, the benefit to germination was appreciable and the results were quite consistent over all soil types.

Whether the difference in germination between the seed which was soaked twice for six hours and planted dry and the same seed which was soaked in M^{-3} $MnSO_4$ solution and planted wet was due to the $MnSO_4$ or to the fact that the seed was wet can not actually be stated. Therefore further field experiments were conducted to ascertain this fact.

The photographs on pages 71 and 72 give a visible indication of the differences in the rates of germination between the various seed treatments.

Experiment XII.

In this particular field experiment, fourteen different seed treatments were used and plantings were made on three different dates. All experiments were carried out on the Michigan State College Farm on a field which had the following past history:

Figure 2.
Photo taken May 11th of seeds treated with two alternate soaking and drying treatments (2x6) planted dry.

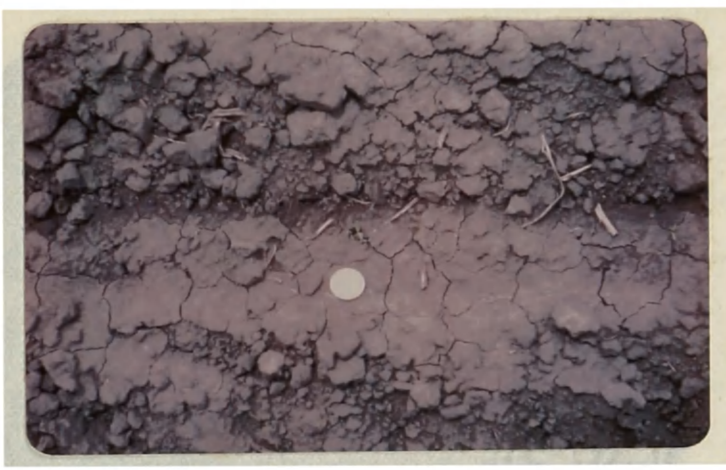


Figure 3.
Photo taken May 11th of check seeds.

Figure 4.
Photo taken May 11th of seeds treated with two alternate soaking and drying treatments (2x6) with an additional 4 hr. soak in M^{-3} $MnSO_4$ prior to planting.

Figure 5.
Photo taken May 11th showing difference in emergence rates between 2x6 hour treated seed (top row) and the same seed planted wet after 4 hours soak in $M^{-3}MnSO_4$ (bottom row).

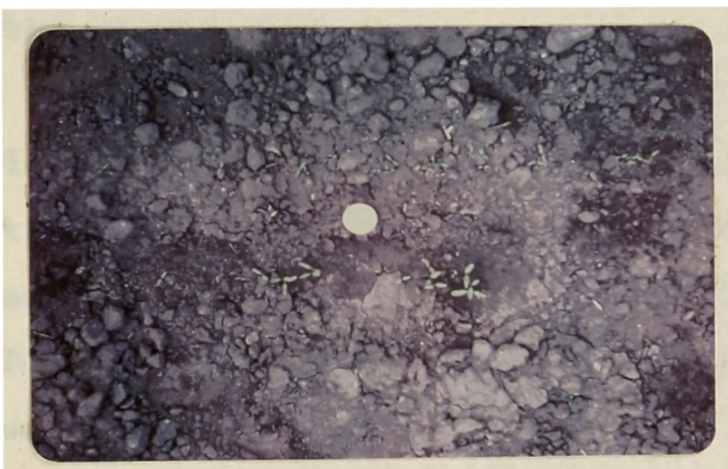


Figure 6.
Photo taken May 11th showing difference between check seed (top row) and 2x6 hour treated seed planted wet after 4 hours soak in $M^{-3}MnSO_4$ (bottom row).

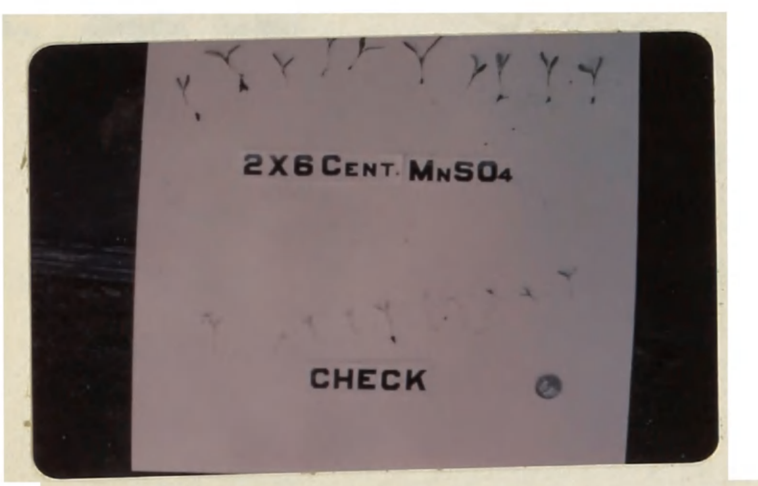


Figure 7.
Photo taken May 11th showing difference between same treatments as in Fig. 6 with the plants, however, removed from the soil for greater emphasis.

1947 - - - - wheat

1948 - - - - fallow

1949 - - - - popcorn

The soil type was a mixture of Brookston and Conover sandy clay loam.

In the spring of 1950 the one and one half acre plot was treated with 400 pounds of 3-18-9 to the acre and the land fitted in the normal manner for sugar beet plantings. A John Deere Bean and Beet Drill with no beets in the buckets was then driven over the plot to space mark rows for the plantings.

All plantings were made with separate, double, triple lattice designs with border strips. The length of each treatment in each block was 60 feet. Segmented sugar beet seed (U.S. 215x216) was used in all cases. The drill was a Planet Junior hand drill set to "radish seed" when dry seed was used and to "beet seed" when wet seed was used. These openings had been previously ascertained to give equal rates of seeding. The various seed treatments used are as follows:

A. Check Seed

1. and 12. planted dry.
2. soaked for 6 hours in water prior to planting and planted wet.
3. soaked for 6 hours in M^{-3} $MnSO_4$ prior to planting and planted wet.

B. Seed soaked for 72 hours in water and dried for 3 days before planting date

4. planted dry.
5. soaked for 6 hours in water prior to planting and planted wet.
6. soaked for 6 hours in M^{-3} $MnSO_4$ prior to planting and planted wet.

C. Seed soaked two 6 hour periods in water with complete drying after each soaking, and with 3 days drying before planting date

7. planted dry.
8. soaked for 6 hours in water prior to planting and planted wet.
9. soaked for 6 hours in M^{-3} $MnSO_4$ prior to planting and planted wet.

D. Seed soaked for three 6 hour periods in water with complete drying after each soaking, and with 3 days drying before planting date

10. planted dry.
11. soaked for 6 hours in water prior to planting and planted wet.
13. soaked for 6 hours in M^{-3} $MnSO_4$ prior to planting and planted wet.

E. Seed soaked for 24 hours in water and dried for 3 days before planting date

14. planted dry.
15. soaked for 6 hours in water prior to planting and

planted wet.

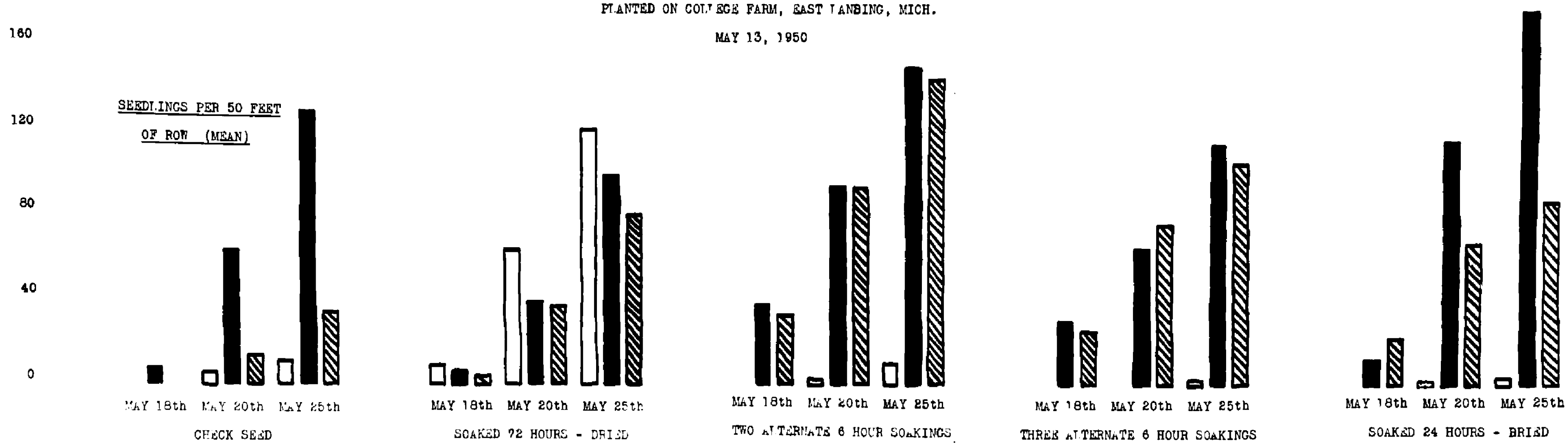
16. soaked for 6 hours in M^{-3} $MnSO_4$ prior to planting and planted wet.

Three different plantings were made. The first was on May 13, the second was on May 19, and the third was on May 30, 1950. The first planting was carried through to harvest to determine whether or not there would be any effect upon the final yield of the various treatments used to stimulate germination. These yield results together with the seedling counts for the first planting appear on Table XX. The seedling counts for the last two plantings also appear together in Table XX. Counts of the seedlings were made in 50 feet of row in each block. The figures in the tables are the means of the total values of the six different blocks in each design.

The results of this experiment are also presented on Graph II (page 76).

GRAPH II

GERMINATION OF SUGAR BEET SEEDS AFTER A VARIETY OF SEED TREATMENTS
PLANTED ON COLLEGE FARM, EAST LANSING, MICH.
MAY 13, 1950



KEY: PLANTED DRY — SOAKED 6 HOURS IN WATER PRIOR TO PLANTING AND PLANTED WET — SOAKED 6 HOURS IN M^{-3} $MnSO_4$ PRIOR TO PLANTING AND PLANTED WET

GERMINATION OF SUGAR BEET SEEDS AFTER A VARIETY OF SEED TREATMENTS
PLANTED ON COLLEGE FARM, EAST LANSING, MICH.
MAY 19, 1950

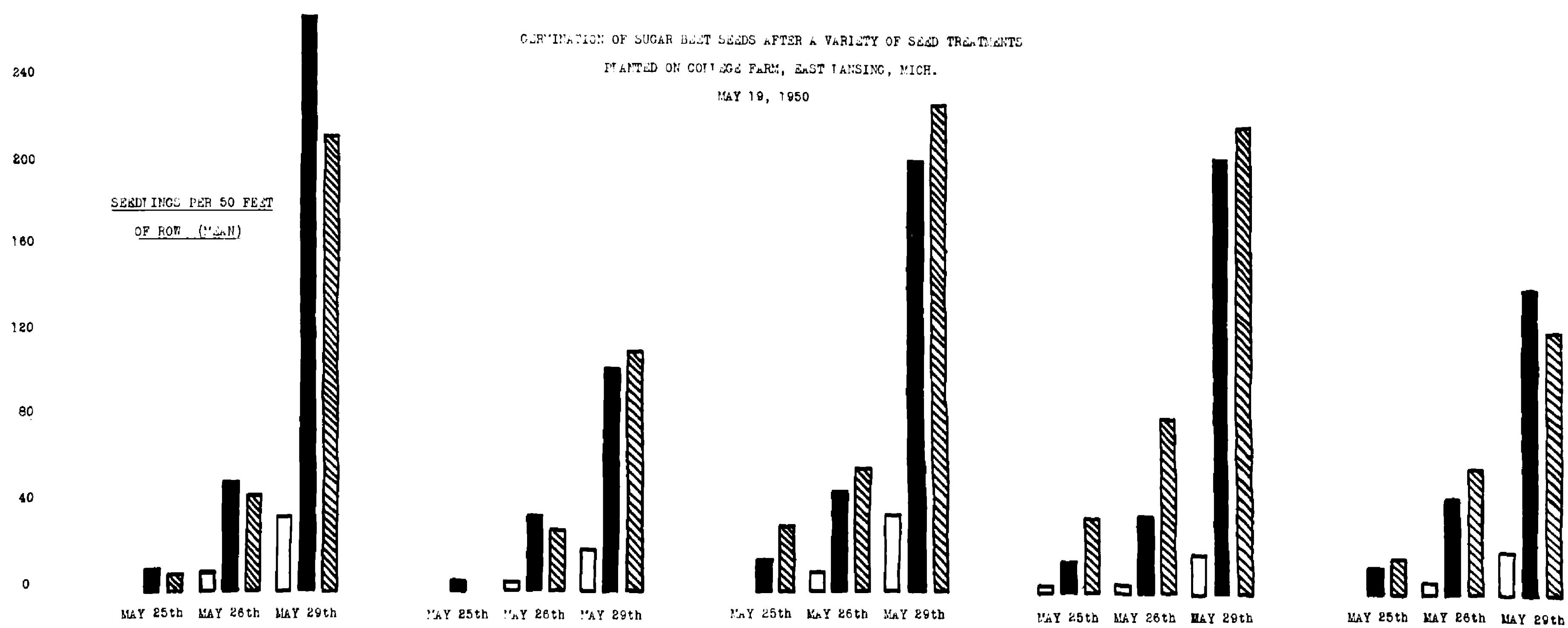


Table XX.

Germination of sugar beet seed planted at East Lansing, Michigan after a variety of pre-planting seed treatments.

Seed Treatments	Planted May 13, 1950: Seedling counts (Means)		Planted May 13, 1950: Final root wt. in pounds (Means)		Planted May 19, 1950: Seedling counts		Planted May 30, 1950: Seedling counts	
	May 18	May 20	May 25	Oct.15	May 25	May 26	May 29	June 6
A. Check seed								
1. Planted dry	0	1.5	5.2	7.3	0.5	3.7	24.5	4.5
12. Planted dry	0	5.5	11.7	6.9	3.2	9.5	35.2	3.5
2. 6 hour water soak, planted wet	8.3	65.5	130.5	23.4	11.5	51.2	271.5	29.2
3. 6 hour $M^{-3}MnSO_4$ soak, planted wet	0.3	14.3	34.2	11.4	8.7	45.2	215.0	22.9
B. Seed soaked for 72 hours in water and dried for 3 days before planting date								
4. Planted dry	8.9	65.2	122.9	22.5	0.2	4.7	19.7	1.9
5. 6 hour water soak, planted wet	6.7	39.9	100.0	25.1	5.5	35.9	104.9	52.5
6. 6 hour $M^{-3}MnSO_4$ soak, planted wet	4.0	37.0	80.7	20.7	0.5	29.2	112.2	30.0

Table XX. (con't.)

Seed Treatments	Planted May 13, 1950 — Seedling counts (Means)		Final root wt. in pounds (Means)		Planted May 19, 1950 — Seedling counts		Planted May 30, 1950 — Seedling counts	
	May 18	May 20	May 25	Oct. 15	May 25	May 26	May 29	June 6
C. Seed soaked for two 6 hour periods in water with complete drying after each soaking and with 3 days drying before planting date								
7. Planted dry	0.7	2.5	9.7	4.7	2.9	8.9	36.2	3.9
8. 6 hour water soak, planted wet	38.3	93.3	149.3	21.2	15.5	47.5	203.7	65.2
9. 6 hour $M^{-3}MnSO_4$ soak, planted wet	33.0	93.3	144.8	24.8	31.3	57.2	230.3	68.0
D. Seed soaked for three 6 hour periods in water with complete drying after each soaking and with 3 days drying before planting date								
10. Planted dry	0.2	0.8	2.0	0.5	0.3	4.3	18.9	8.5
11. 6 hour water soak, planted wet	31.0	64.9	114.5	21.7	15.0	35.9	205.5	72.2
13. 6 hour $M^{-3}MnSO_4$ soak, planted wet	26.2	76.2	105.3	21.3	34.9	81.0	220.3	52.5

Table XX. (con't.)

Seed Treatments	Planted May 13, 1950 — Seedling counts (Means)		Final root wt. in pounds (Means)		Planted May 19, 1950 — Seedling counts		Planted May 30, 1950 — Seedling counts	
	May 18	May 20	May 25	Oct. 15	May 25	May 26	May 29	June 6
E. Seed soaked for 24 hours in water and dried for 3 days prior to planting date								
14. Planted dry	0.3	1.0	3.5	7.4	0.7	6.3	20.3	2.5
15. 6 hour water soak, planted wet	12.0	115.5	175.3	24.2	13.9	45.8	143.7	39.5
16. 6 hour M^{-3} $MnSO_4$ soak, planted wet	23.0	67.2	87.2	20.2	17.7	59.7	123.5	36.0

Discussion

The results from this experiment indicate that when the sugar beet seeds were planted wet their rate of germination was superior to that of seeds planted dry. There is a further indication that this is due to the fact that the seeds are wet and have been soaked rather than to any stimulation by the $MnSO_4$. This is shown by the fact that the overall results show a higher emergence rate with water treatment alone than with the $MnSO_4$ treatment.

Although in some instances seeds which were extracted with various treatments prior to the pre-planting soaking showed superior results to the check seed which was soaked prior to planting and planted wet, these latter seeds, in general, tended to give the best results. It might be further stated that even though other treatments did give better results in some instances these results do not seem sufficiently superior to soaking the check seed in water prior to planting and planting them wet to warrant the additional time, trouble and expense involved.

The initial advantage of pre-planting soaking to seed germination carried over and may be seen from the results of the final yields of the beets of the May 13th trials. Here too, the check seed soaked in water prior to planting and planted wet shows up as well as all other treatments.

At the time of the plantings, the ground for the most part was cold and wet. The average temperature at a 3 inch depth for the various planting dates was as follows:

May 13, 1950 - - 10° C.

May 19, 1950 - - 15° C.

May 30, 1950 - - 17° C.

This temperature difference may be noted in the germination results for the three different plantings. The emergence on June 6th, 7 days after the May 30th planting are in general superior to the emergence of seedlings seven days after either the May 13th or the May 19th plantings.

A considerable amount of damping off was in evidence. Although there had been no beets planted in this particular field for at least three years, the adjacent field has been used for beet trials, including beet disease work. Plants which did not come up rapidly as well as seeds which did not germinate quickly might be presumed to have been destroyed by disease.

Private conversation with Bion Tolman indicates that results from several years work with soaked sugar beet seeds showed a definite advantage from the standpoint of uniformity of stands and rapidity of emergence of the soaked seeds over untreated seeds. Seeds which were soaked in water to the point where sprouts were beginning to show and were then dried, when later planted, also showed more rapid germination than untreated seeds but final yields were not significantly superior to the check. These results, appearing in annual reports, were unpublished.

From the point of view taken in this study, however, as long as the final yields are not significantly less than those given by check seeds the problems involved in soaking seeds are warranted. This is due to the fact that the entire spring mechanization program is dependent upon uniform stands which are in evidence before weed growth has become too heavy. If soaked seeds are able to germinate more uniformly and rapidly so as to give every advantage to this mechanization program the soaking is justified.

Drilling Wet Seed

One serious disadvantage was noted in handling the soaked seed. When attempts were made to drill the soaked seed using a John Deere Bean and Beet Drill, unless a very small amount was used, there was a considerable amount of bridging of the seed with the result that stands were vacant or very spotty.

In order to overcome this difficulty the seeds when ready for planting were removed from their water bath and as much water as possible removed by shaking. The seeds were then mixed with powdered vermiculite "Zonolite" which readily absorbed the excess moisture from the surface of the seed. The vermiculite was then screened off of the seeds which were then placed in the drill in a condition suitable for drilling without abnormal bridging.

To determine the exact effect of the vermiculite the following experiment was carried out.

Experiment XII

Seed was soaked for four hours in cheese-cloth sacks and then hung for 10 minutes in the shade at 28.5° C. While this was in process a standard John Deere Beet Drill equipped with standard segmented seed plates was mounted on blocks so that the wheels could be turned freely. 500 grams of segmented seed was introduced into each bucket and the wheels turned to simulate a distance of 50 feet at a rate of 2½ miles per hour. The spouts were covered with paper sacks and the seed contained in these sacks were counted and the average taken. 500 grams of the soaked seed was then placed in each bucket and the process repeated. Soaked seed was then mixed with various amounts of fine vermiculite, the vermiculite screened off, and the process repeated. Table XXI shows the results of these various treatments.

Table XXI.

Drill rates of sugar beet seed after various moisture treatments.

Treatment	Trials: Results for each bucket 1	2	3	4	Average
Dry segmented seed	525	550	556	515	536.5
Soaked segmented seed	270	410	295	376	338
Soaked segmented seed treated with 300 grams of fine vermiculite per 500 grams of seed	537	503	519	527	521.5
Soaked segmented seed treated with 200 grams of fine vermiculite per 500 grams of seed	480	505	480	507	493
Soaked segmented seed treated with 100 grams of fine vermiculite per 500 grams of seed	432	441	448	442	441

In field trials using an experimental drill equipped with a Cobley drill plate, soaked seed treated with vermiculite gave seeding rates of 96% as compared with dry, untreated check seed.

Discussion of Field Experiments in Light of Basic Principles Reviewed.

Two notable results of the field experiments were (a) the influence of moisture in the seed when it was planted and (b) the temperature of the soil. This is to be expected from the evidence presented by other investigators and by the laboratory experiments upon seeds. Seed which has been soaked for a sufficient period to permit the beginnings of the germination process and placed in a soil with at least a pF of 3.7 and a temperature of at least 8° C. will germinate more rapidly and emerge from the soil more rapidly than a dry seed under the same condition. As the temperature of the soil increases the speed of germination and emergence increases for both soaked and dry seed. The soaked seed still maintains an advantage but this advantage diminishes with an increase in temperature.

It should be noted, as well, that the longer a seed remains in cold, moist soil without germinating the less the chance of its ultimate germination. This may be attributed to low temperatures, high humidity conditions and the action of disease organisms. It is probably due to this fact that many seeds which were viable when planted failed to germinate and emerge even when germination conditions became more nearly optimum. This was especially evident from the results of the trials on the College Farm. Furthermore, this also substantiated evidence of laboratory experiments upon the cold moist stratification of seeds.

Summary and Conclusions

The following summary and conclusions concerning germination in sugar beet seeds are derived from the literature on the subject and especially from the results of experiments conducted on this problem in the field and laboratory.

1. Processed sugar beet seeds (U.S. 215x216) were found to require a moisture content of at least 30%, at a temperature of approximately 25° C., and whole sugar beet seeds (U.S. 215x216) were found to require a moisture content of somewhat over 35%, at the same temperature, before germination was possible. The difference in moisture requirements was attributed to the additional pericarpal material on the whole seeds.

2. It was found that it was not possible for segmented sugar beet seeds (U.S. 215x216) to absorb sufficient moisture from air even at 100% relative humidity to attain moisture contents high enough for germination.

3. Laboratory work on four Michigan soils showed that in order for segmented sugar beet seeds (U.S. 215x216) to absorb sufficient moisture from the soil environment they should be in contact with some water film and the soil pF should be at least 3.7 or lower (i.e. higher moisture content) at 20 - 25° C.

4. It was found that with other germination factors near optimum conditions, sugar beet seeds (U.S. 215x216) failed to germinate at 5° C. It was further observed, however, that as the temperature of the seeds environment

increased up to 30° C. the rate of germination increased according to van't Hoff's rule.

5. No treatment was discovered, chemical or otherwise which helped to speed up the emergence of sugar beet seeds as much as soaking the seed in water for at least 4 hours prior to planting and planting the seed wet. The water appeared to benefit the seed in a number of ways; a, by washing off disease organisms; b, by dissolving out and washing away inhibitory substances; c, by permitting the true seed to obtain sufficient water to stimulate enzyme activity and initiate germination prior to placement in the soil environment and d, by giving the seed coat a moisture film which helps in making contact with soil moisture films and thus aids in the absorbing process.

6. Sugar beet seeds, whole or segmented, were found to have their germination efficiency unimpaired after as many as five alternate periods of wetting and drying when the wetting periods were for 6 hours in water followed by immediate drying upon blotting papers under a fan. The results of experiments actually indicated that two and three alternate wet and dry periods benefited germination. Germination was slightly impaired after 7 such treatments. It appears from this that if proper precautions are taken to assure rapid drying following the soaking periods that soaked seeds may be dried and reused without loss to the germinating efficiency of the seeds.

7. It was found that seeds may also be soaked for as

long as 72 hours in water without damaging their germinating power if they are dried immediately upon removal from the water and provided that there is not a high quantity of oxygen in the water for under these conditions the seeds may germinate. A 96 hour soaking period was found to slightly impair the germination of sugar beet seeds.

8. When stored for at least three months under high moisture as well as low temperature conditions it was found that the viability of sugar beet seeds is quickly diminished. A moisture content of 15% or higher in sugar beet seeds under storage conditions was also found to reduce the viability of the seeds when stored at least one month.

9. Damp soaked seeds are handled poorly by a drill. Surface drying with vermiculite gives a damp seed which will drill without trouble.

Review of Literature

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