THE UNIVERSITY OF MANITOBA

THE EFFECTS OF WATER POTENTIALS OF SOME MEDIA ON THE AFTER-RIPENING AND GERMINATION OF *Caragana arborescens* AND *Cytisus austriacus* SEED

by

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ABSTRACT

The mature seeds of *Caragana arborescens* Lam., common caragana and *Cytisus austriacus* L., Austrian broom are dormant. To overcome the dormant condition, caragana seeds may be stratified for 14 days and the Austrian broom seeds for 42 days in a moist medium prior to germination.

A moisture tension which is dependent on water content exists for each medium in which seeds may be after-ripened or germinated. Optimum germination in caragana seeds occurred when the water contents of the medias were adjusted to within the pF range of 1.0 to 4.0 whereas optimum seed germination for Austrian broom occurred in pF range of 1.5 to 3.5. As observed particularly in turface, the seed-water regime for seed after-ripening may differ from that required for seed germination. The water content of the turface of pF 4.0 was sufficient enough to promote after-ripening but was not sufficient to initiate germination in caragana seeds.

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INTRODUCTION

The plant propagator may experience some difficulty in the production of woody ornamental plants from seed. Many woody ornamental seeds, although viable, are dormant and this condition must be overcome prior to germination. The dormancy may be caused by mechanical means such as an impermeable seed coat, or physiological such as chemical inhibition of metabolic activities. Seed dormancy may be advantageous to plants growing in temperate zones, allowing the seed to germinate at a favorable time and place. In the natural habitat, several years may elapse before favorable conditions are attained to overcome the dormant conditions. The plant propagator may induce the seeds to maximum germination by creating the essential combination of natural conditions needed to overcome the dormant condition.

For dormant seeds to germinate, physiological changes of after-ripening, must occur within the seed. Generally, after-ripening is promoted by stratification or the practice of placing seeds in moist layers of a medium. The determination of environmental conditions of water, oxygen and temperature are important for effective after-ripening.

While considerable experimentation has occurred on the effect of water, air, temperature and chemicals for after-ripening and germination, little is known about the physical effect of the medium. The primary medium components used are mineral soils, including sand, peat and processed medium amendments such as perlite, turface and vermiculite. These are used individually or as mixtures. The medium may vary in particle size, composition, nutritive content and reaction. Because the composition of the medium may affect after-ripening and germination, it would be desirable to tailor the medium to obtain uniform results similar to those developed for rooting and container culture.

The objective of the study was to establish an optimum water potential range for some media and to compare the media for after-ripening and germination of two woody ornamental plant species, *Caragana arborescens* Lam. and *Cytisus austriacus* L.

LITERATURE REVIEW

The stratification and germination medium is a disperse, three-phase system consisting of mineral particles, water and air (29). According to Heydecker (27, 28), and Pollock and Manalo (40), the three phases must potentially interact to contribute to seed germination. The medium used must provide adequate pore space for air-water balance, optimum temperature for imbibition of water and to initiate physiological activity within the embryo, and to enable the seedling to emerge without mechanical obstruction. The importance of precision seeding to germination rate and percentage has made it necessary to develop and evaluate the capabilities of the medium to fulfill the necessary criteria (45).

Moisture

The germination of dormant or nondormant seeds is affected primarily by the moisture condition of the medium (7, 11, 12, 35, 43). Lyon, Buckman and Brady (35) describe two forces, adhesion and cohesion, as accounting for temporary fixation of water in the medium. Adhesion is an electrostatic force acting on both internal and external surfaces of the medium solid phase, holding water in a thin film. The adhesive force is prevalent in clay. Cohesion is the attractive force of water molecules for one another within the pore spaces.

A suction is exerted by the hydrophilic colloids within the seed to remove the water held within the medium by adhesion and cohesion (7, 10, 11, 12, 29, 35, 40). Availability of water to the seeds depends upon the moisture characteristics of the soil and the imbibition characteristics of the seed (11, 12). According to Collis-George and Sands (11, 12), the germination behavior of seeds is controlled by water suction and permeability. The water requirements for each species is specific in terms of energy required for suction and rate of water supply, thus it is possible to determine the water regime for each species.

The suction required to remove water from a medium is dependant upon the size of the initial pore spaces and the texture of the medium and the amount of water present in the pore spaces (43). A saturated or wet medium will give up water more readily than a dry or non-saturated medium. In a coarse textured medium such as sand, there are large initial pore space sizes and very little change in pore space size as water is withdrawn and air readily replaced the water. In a fine textured medium such as clay, the initial pore space sizes are smaller and the withdrawal of water results in shrinkage and reduces the pore size. The net result is that greater suction is required to remove water from the finely textured soils.

Many methods have been devised for measuring water potential gradient between the medium and the plants or seeds. Hillel (29), stated that there is no universally accepted method for measuring, computing or expressing the moisture regimes of various media. The relationship of soil water to seed germination can be expressed as a function of percentage moisture (4, 34, 46), water holding capacity (35), and available water (11, 12, 33). In the literature it is generally agreed that the availability of water is dependent on the soil moisture potential rather than the total soil moisture content. Soil moisture potential may be expressed as pF (19), or potential available water. The availability of water differs with each medium.

Medium

The natural soil amendments are sand and peat. Buckman and Brady (7), Hartmann and Kester (26), and Lindquist (34) define sand as particles of rock between 0.05 to 2.0 mm in diameter. Kuenan (32) states that the basic origin of sand is calcium carbonate, aluminum silicate or silicon dioxide. Sand is desirable as an individual medium in a mixture due to a wide range of pore sizes for aeration and drainage. The large particle size and rigid structure of sand make water readily available while maintaining large pore spaces.

Hartmann and Kester (26) define peat as the organic remains of plants which have accumulated in places where decomposition has been retarded by wet conditions. Peat may be classified as woody peat, fibrous peat or sedimentary peat (35). Fibrous peat, composed of sedges, sphagnum mosses and cattails is the most common type used by horticulturists (33, 35, 35). Although fibrous peats are heterogeneous in character, the gravimetric water content is very high, possibly ten times greater than that of mineral soils. A good quality peat is open, porous and supplies adequate aeration. A disadvantage of peat is the loss of fibrous qualities with repeated use (7, 35).

A 1:1 mixture of sand and peat could provide a good germination medium. The sand provides large pore spaces with readily available water whereas peat supplies fibrous bulk for water retention.

The processed media include vermiculite, perlite and turface. Raw vermiculite ore is a micaceous mineral, consisting of many thin layers which entrap air. Barshad (5), characterizes vermiculite chemically as hydrated magnesium-aluminum-iron-silicate. The oré is passed through furnaces at 1093°C converting water into steam thus expanding the layers. The end product is a small, porous, sponge-like, sterile "kernel" (particle). Vermiculite has a water holding capacity up to five times its weight due to the larger interface area. The recommended vermiculite for seed germination is grade No. 4 with a particle size range of 0.75 to 1.0 mm. Vermiculite provides for air and bulk when incorporated into a medium mixture.

A second processed medium is perlite. The grey white material of volcanic origin, is a chemical combination of silicon, aluminum, potassium and sodium oxide (26, 33). Perlite ore is heated in furnaces to approximately 982°C. As in the case of vermiculite, small amounts of water are changed to steam and thus expand the particles. The large particle size and rigid structure of the perlite provide for a wide range of pore sizes for aeration and ease of water removal. The porosity of the individual particles result in an entrapment of water and thus perlite has a greater water holding capacity than sand. Perlite is essentially neutral with a pH of 7.0 to 7.5.

Turface, a montmorillonite clay, is also a processed medium amendment. The raw clay is cut, crushed and ground to particles of uniform size. The particles are then fed to a calcinator at temperatures of 982°C where the careful control of the time and tumbling action produces a particle which allows for air movement and water absorption when used separately or as part of a medium mixture. Turface does not alter in particle size and shape when wetted and it can absorb water equal to its own weight. According to Technical Service Bulletin (2), turface provides a uniform supply of water to the growing plants.

Temperature

Collis-George and Sands (11, 12), stated that a water regime exists between seeds of different species of plants and the medium in which germination occurs. The regime reacts with other factors such as time, temperature and air-supply for after-ripening. Many woody ornamental plants such as *Caragana* (34), *Fraxinus* (51), *Elaeagnus* (13), *Acer* (17, 52), *Rosa* (48), and *Juniperus* (37) require temperatures for after-ripening of approximately 5°C. Giersbach (25), reported that cotoneaster seeds require treatment at two separate temperature ranges for germination to occur. Treatment at 15 to 25°C for three to four months overcomes the seed coat dormancy, followed by temperatures of 1 to 5°C for four months for after-ripening. *Viburnum* requires alternating temperatures between 10 and 30°C to overcome dormancies (22, 30).

Time

The length of after-ripening time varies with species. Linquist (34), stratified *Caragana arborescens* seeds for fifteen days. *Acer saccharum* and *Acer ginnala* (17, 52) require 30 days for after-ripening whereas *Viburnum* (22, 30) and cotoneaster (25) require two winters in natural habitat or over 110 days under laboratory conditions for germination to occur.

Physiological Changes

In a dormant or nongrowing condition, the metabolic rate of seeds is low (14, 31, 41, 42). As the after-ripening process begins, physiological changes requiring oxygen occur within the embryo. Eckerson (18), studying after-ripening of *Crataegus mollis* seeds, reported an increase in oxidase activity, reduction of fat content with an increase in soluble sugars and increased energy activity as measured in increased metabolic temperature. The increase in respiration in *Juniperus* seeds resulted in a doubling of catalase activity (37). Dumbroff and Webb (17, 52), stated that the respiratory rates of seeds of *Acer saccharum* and *Acer ginnala* are correlated to their water uptake. Dormant cereal seeds show a greater initial uptake of oxygen than nondormant seeds (36). Due to specific requirements of individual species, these scattered pieces of work still leave the propagator wondering if an optimum range of available water exists for the after-ripening and germination of seeds.

METHODS AND MATERIALS

The objective of the study was to establish a pF range for some media and to compare the media for after-ripening and germination of the two woody ornamental plant species, *Caragana arborescens* and *Cytisus austriacus*.

The experimental procedure was subdivided as follows:

I. Determination of water potential pF - water content relationship for each medium.

II. After-ripening and germination of common caragana, *Caragana arborescens*.

III. After-ripening and germination of Austrian broom, *Cytisus austriacus*.

The six natural and processed medium amendments used were:

1. Sand - local origin, 0.5 to 1.0 mm particle size.
2. Peat - Manitoba native fibrous peat moss, partly decomposed.
3. Sand-peat mixture - 1:1 mixture by volume.
4. Vermiculite - Terra-lite, commercial grade No. 3.
5. Perlite - Concrete aggregate.
6. Turface - Wyandotte Mulch.

Moisture Characteristics

The objective of this experiment was to determine the matrix potential of available water (pF) for each medium treatment. pF is the log moisture potential when moisture potential is given in equivalent cm of water, e.g., 1 atmosphere = 1033 cm of water ≃ pF 3.0. A treatment constitutes a definite volume of water (ml), added to a specific weight of medium (gm). Since the specific gravity of water is 1.0, the water to medium ratio is actually a weight of water to weight of medium ratio.

The procedure employed was similar to that outlined by Fawcett and Collis-George (19). The hydrophilic properties of filter paper were used to estimate the moisture potentials of soil media. Different grades of filter paper have different hydrophilic properties. This results in a definite pF-water content graph for each grade of filter paper. In this study, Whatman No. 42 filter paper was used. The filter paper was allowed sufficient time to equilibrate to the moisture in the medium and pF values were estimated from the standard graph for Whatman No. 42 filter paper (19).

A definite weight of medium was thoroughly mixed with a specific volume of water. One half of the medium was put into a plastic container and three pieces of Whatman No. 42 filter paper were placed on the medium. The air-dry weight of the innermost piece of filter paper was recorded immediately prior to being placed in the container. The remaining medium was pressed firmly on top of the filter papers and the containers closed and sealed with masking tape and placed in a cold room for fourteen days at a temperature of $1.6 \pm 0.5^{o}C$. After fourteen days, the containers were opened, the outer two filter papers were discarded and the innermost paper was weighed immediately. The increase in moisture percentage of air-dry weight was calculated and converted to a pF value by the Fawcett and Collis-George method (19).

The Soil Science Department, University of Manitoba, determined the pF-water content relationship of the Whatman No. 42 filter paper using a pressure membrane apparatus. The pF water content relationship was identical to that of Fawcett and Collis-George (19).

Several types of cardboard and plastic containers were tested for water retention. The eventual choice of container was a 10 oz plastic pack No. 6810, with a capacity of 300 ml.

Prior to experimentation, the sand was screened for particle size 0.5 to 1.0 mm, washed and leached with warm water to remove foreign debris. The pH of the sand was 7.1 as determined by a Fisher Accumet pH meter. Sand was oven dried at 200^{o}C for 24 hours prior to use. The peat was screened by using a 3.0 mm screen and was washed and leached. A filter paper lined Buckner Funnel was used to suction dry the peat. Prior to using the peat, the peat was further dried by spreading out to air dry for 24 hours. The pH of the peat was 6.9 as determined by a Fisher Accumet pH meter.

The sand-peat, 1:1 mixture was prepared by mixing equal volumes of cleaned sand and peat. The turface, vermiculite and perlite were used directly from the manufacturers bags.

The individual pF water content relationship for each medium was determined by adding a definite volume (ml) or weight (gm) of water to either 300 gm of sand, 25 gm of peat, 50 gm of sand-peat mixture, 15 gm of perlite, 75 gm of turface or 15 gm of vermiculite. The specific weight of each treatment medium is approximately equivalent to 250 cc of volume. For each medium, a range from 0.0 water content to saturation was covered.

After-ripening and Germination of *Caragana arborescens*

The objective was to determine the effect on the after-ripening and germination of *Caragana arborescens* seed when stratified in sand, peat, 1:1 sand-peat mixture and turface and to determine the optimum pF range for seed after-ripening and germination in each medium.

The *Caragana arborescens* seeds were collected on the University of Manitoba campus during the summers of 1969 and 1970. Immature and damaged seeds were culled out by visual inspection and water flotation and discarded. The seeds were stored in a cold storage room at an approximate temperature of 5°C.

After the pF values were determined and a pF graph was constructed for each medium, eight levels of water (ml) were used for seed treatments for after-ripening. Each trial had two controls, one wet where the seeds were immersed in water and one dry where the seeds were placed in an air-dry medium for the duration of the stratification period. Each treatment was replicated 12 times.

The specific amounts of water added to each medium appear in Table I.

Table I. The amount of water (ml) added to each medium for after-ripening caragana seeds.

		Treatments									
	Media	1	2	3	4	5	6	7	8	9	10
I.	Sand	4	6	8	12	16	20	40	50	0	imm.
II.	Turface I	15	20	30	35	40	45	55	60	0	imm.
III.	Turface II	15	20	30	35	40	45	55	50	0	imm.
IV.	Peat	25	30	37.5	50	62.5	75	87.5	100	0	imm.
V.	Sand-peat	5	10	15	20	25	30	35	40	0	imm.

Turface I - no additional water added prior to germination.
Turface II - additional water was added prior to germination.
imm. - immersed - the seeds are completely immersed in water.

Preliminary studies have indicated that the amount of water required for stratification was not sufficient for germination at low moisture levels. Prior to germination, water was added to treatments with less than a mean level of water for sand, peat and sand-peat mixtures to attain the mean water level. Mean level was in the pF range of approximately 1.5 to 2.0 for the media. In the case of turface, a large proportion of the water was held at high suction (high pF). This meant that at the mean water level, the pF value was approximately 4, i.e., the dry end of the available water range. Therefore, for the turface II treatment, 45 ml of water was added. This gave a pF value of approximately 1.3.

The criteria for germination was the emergence of the radicle, and germination counts were based on the emergence over a two week period. The seeds were germinated in closed containers at a temperature of 20°C.

After-ripening and germination of *Cytisus austriacus*

The objective was to determine the optimum pF range needed to bring about after-ripening and germination of *Cytisus austriacus* seed when stratified in peat, sand-peat mixture, perlite and vermiculite.

The Austrian broom seeds were collected at the University of Manitoba Arboretum during the fall of 1969. The seed lot was variable and many seeds were discarded after visual inspection and water flotation, only ripe, plump seeds were used for experimentation. The seeds were stored in a cold room at an approximate temperature of 5°C until required for experiments.

As in the case of caragana after-ripening, pF graphs of peat, sand-peat mixture, perlite and vermiculite were used to choose eight treatment levels per medium. Wet and dry controls were used for each medium. The seeds were prepared for after-ripening and stored in a cold room for 42 days at a temperature of 1.6 ± 0.05^{o}C. Treatment water levels used for each medium are shown in Table II.

Table II. The amounts of water (ml) added to each medium for after-ripening of Austrian broom.

		Treatment (water in ml)									
	Media	1	2	3	4	5	6	7	8	9	10
I.	Vermiculite	1	3	10	20	30	40	50	60	0	immersed
II.	Peat	25	30	37.5	50	62.5	75	87.5	100	0	immersed
III.	Sand-peat	5	10	15	20	25	30	35	40	0	immersed
IV.	Perlite	1	2	3	4	10	20	30	40	0	immersed

As in the experiment with caragana seeds, water was added to some of the treatments prior to germination. The treatments with a water content below the mean amount for each medium, had sufficient water added to attain the average level.

The criteria for germination was the same for *Caragana arborescens*.

RESULTS AND DISCUSSION

Moisture Characteristics

Water availability of a medium is related to moisture potential. pF is a convenient method of expressing moisture potential. The pF range is 0 to 7.0 where 0 represents a totally saturated medium and 7 expresses a dry medium.

The pF values of each medium were estimated from a table of values and a graph (19, 43). The values are based on the moisture characteristics of Whatman No. 42 filter paper. The pF values were conversions from the moisture content of filter paper which was expressed as a percent of oven-dry weight as indicated in Figure 1. According to Fawcett and Collis-George (19), error due to calibration of the filter paper is approximately 1%. Because of the limited deviation from the normal curve for the filter paper, this method is a fairly simple, accurate method of determining water potential.

Data in Table III are examples of the relationship between moisture content and pF values in sand. The percentage of the weight increase of the centre filter paper as compared to the initial weight, constitutes the moisture content.

Moisture content - pF relationships of peat, sand-peat mixture, vermiculite, perlite and turface appear in the Appendix Tables 1 to 6. These values were used to construct a graph, Figure 2. The graph represents the pF values as a function of the treatment level of water, g water/g media (Dry weight) x 10.

The relative change in pF per unit water addition to the medium

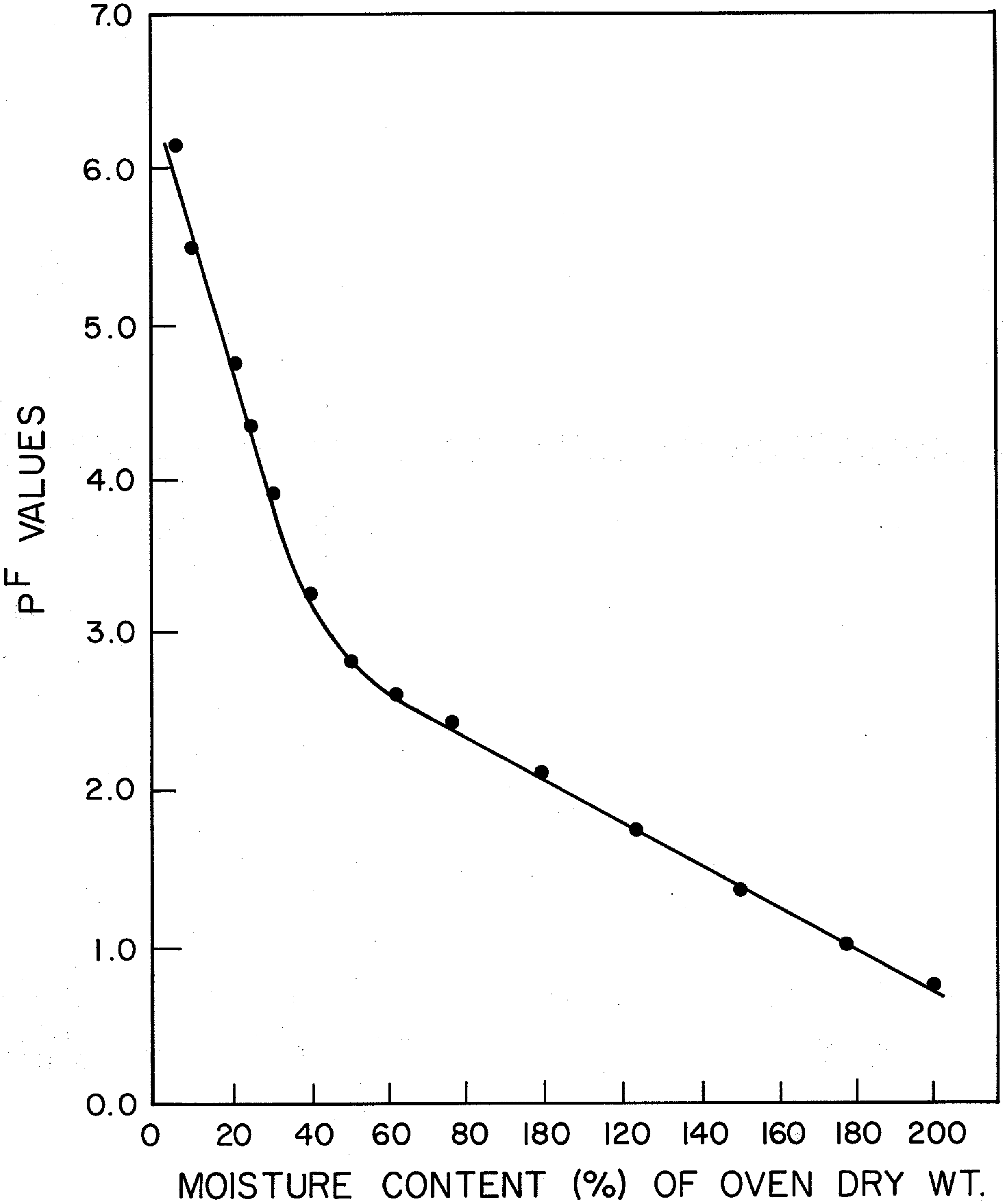

Fig. I The P^F as related to the moisture content (%) of oven dry weight of Whatman No. 42 filter paper as taken from Fawcett R.G. and N. Collis – George (19)

Table III. The relationship of the percentage moisture content to pF values in sand.

g water/g media (D.W.) x 10	Moisture content (%) of oven dry filter paper	pF value
.03	14.95	5.15
.07	20.31	4.75
.10	26.52	4.25
.13	34.03	3.70
.17	40.94	3.30
.20	69.87	2.52
.27	118.91	1.85
.33	136.59	1.60
.40	146.53	1.43
.47	149.06	1.39
.53	158.26	1.25
.60	164.21	1.16
.67	169.21	1.13
1.00	174.48	1.05
1.33	176.58	1.00
1.67	176.97	1.00
2.00	180.64	.98
2.33	182.54	.98
F.C. 3.00	187.91	.97

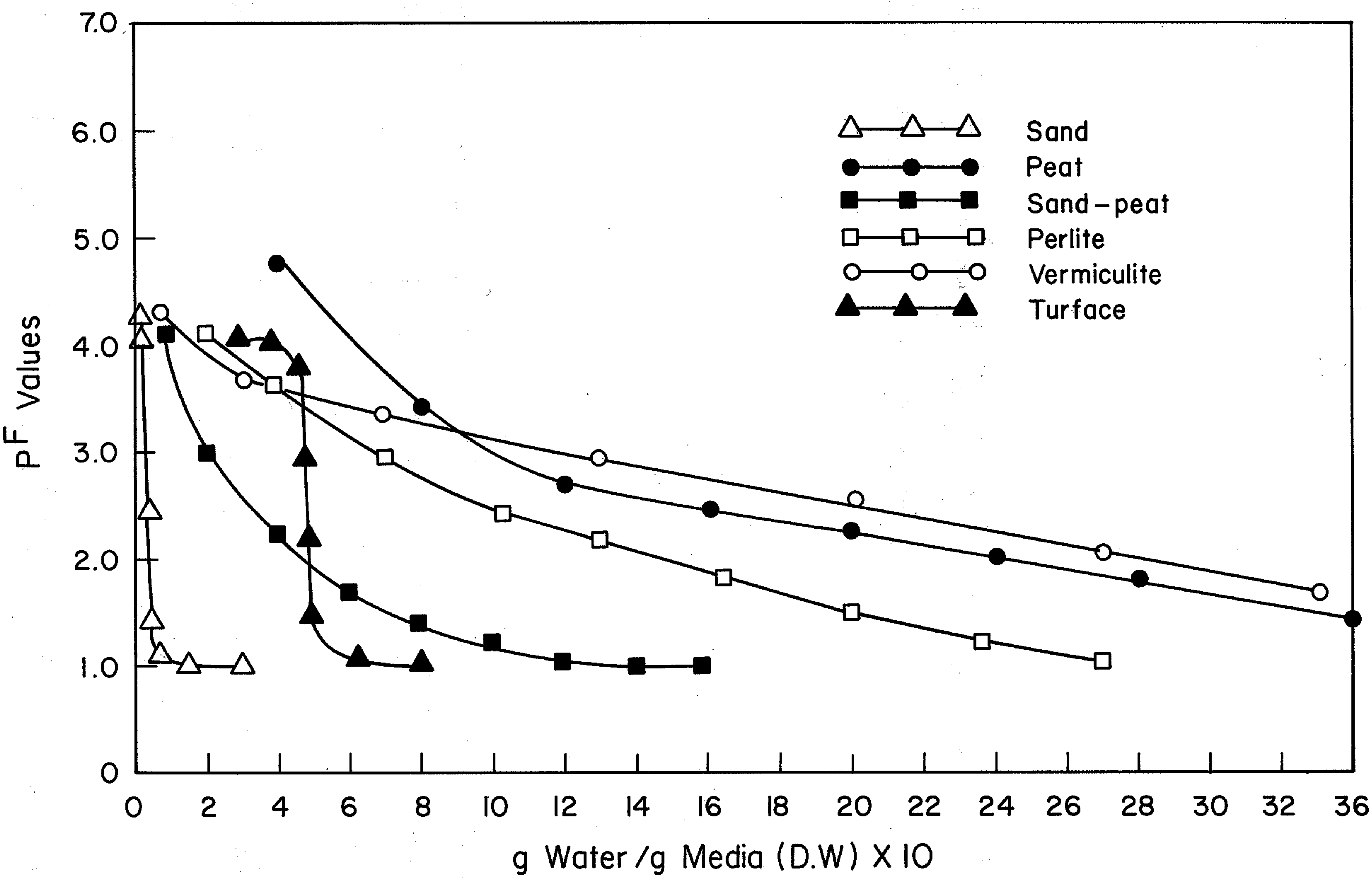

Fig. 2 The relationship between unit of water additions to dry weight of media X 10 and the P^F of the media

is indicative of water availability of the medium, Figure 2. A large change in pF related to a small change in unit water addition to the medium indicated that the medium released water readily. There was minimal water retention and little force would be required to remove the water from the medium. A small change in pF related to a large change in unit water addition indicated a greater water retention and less water availability in the medium.

Two forces account for the temporary fixation of water in the medium. Adhesion is the attraction of solid surfaces for water molecules and is only operative at solid-liquid interfaces. The greater the interface area, the greater the water retention. A second force is an electrostatic attraction of water molecules for charged media particles. As a result of electrostatic charge on media particles and the dipole nature of water molecules, water becomes more organized even at a distance from the media particle. Water molecules are electrostatically bound to other water molecules within pore spaces. Water held by these forces not only can keep the smaller capillary pores within the medium entirely full but also maintains thick films of water in the pores. When the medium is near saturation, it would be easy to remove water but as the moisture content decreases, greater force would be necessary to remove water.

There was a large change in pF in sand, pF 4.1 to 1.0, as related to a small change in unit water addition, 0.03 to 3.00 g water/10 g (D.W.) sand. Water was readily available from the sand and there was little water retention. The large initial pore space size and minimum change in pore space size as water is withdrawn could account for the readily available water in sand. Sand particles have little electrostatic attraction for water molecules. The low water retention in sand was evidenced by the relatively small amount of water which was required to reach field capacity in sand as compared to the other media. An advantage of using sand is that water is readily available to seeds, seedlings and plants, whereas a disadvantage is the low retention of water in sand which would require repeated additions of water to maintain a near constant pF.

There was a relatively small change in pF as related to a large change in unit water addition for peat, vermiculite and perlite. The water retention curves approach linearity and it would be relatively simple to achieve desired pF values based on the curves. Each of the three media has great water retention as was evidenced by the total amount of water required to reach field capacity, 28.0 g water/10 g (D.W.) perlite, 34.0 g water/10 g (D.W.) vermiculite and 36.0 g water/10 g (D.W.) peat. Water was more readily available from perlite than from peat or vermiculite. Water retention was greatest in the vermiculite as was evidenced by higher pF values at given moisture content.

Peat, vermiculite and perlite have great water retention due to large interface surface areas which contribute to adhesive binding of water and charged media particles which result in electrostatic water binding. Vermiculite and perlite have been heat processed to produce expanded, porous particles. Water is absorbed and trapped within the particles which results in greater water retention. The large particle size, rigid particle structure and large pore space size of perlite would make water more available from perlite than from peat or vermiculite as evidenced by lower pF values at given moisture content. Peat has large interface surface area, perhaps two to four times that of a montmorillonite clay and a high cation exchange capacity indicative of potentially large electrostatic water binding forces (7).

The water retention curve for the 1:1 sand-peat mixture is a composite of the sand and peat curves. At lower units of water addition, the mixture resembled sand as a relatively small change in water resulted in a large change in pF. As the total moisture content increased, the pF changed very little and the curve resembled that of peat. The high water holding capacity of peat was evidenced in the mixture as approximately five times more water was required to reach field capacity in the mixture as was required for sand.

Turface has a unique water retention curve. A possible explanation of the unique reaction of water in the turface could be the particle composition of the heat processed montmorillonite clay. Unlike perlite and vermiculite, the heat processing does not appreciably expand the particles of turface and there is minimum swelling of the turface when wetted. At low moisture content, a fairly large range of unit water additions, 2.0 to 4.7 g/10 g (D.W.) turface, resulted in a small change in pF, 4.0 to 3.5. Water would be tightly bound in the turface as the interlattice spaces or capillaries would be filled. Once the internal spaces of the turface particle were filled, any subsequent additions of water would become available to the seed. This was evidenced in turface as a very small amount of added water, from 4.7 to 5.0 g/10 g (D.W.) turface, resulted in a large change in pF, 3.5 to 1.3. At this point, water becomes readily available. The third region of the graph has a relatively small change in pF, 1.5 to 1.0 as related to a large change in unit water additions, 5.0 to 8.0 g/10 g (D.W.) turface. A weak adhesive force could account for the water retention in turface at the low pF values.

Each species of plants appears to have a critical water or pF range for seed germination (11, 12). Optimum seed germination would occur if constant pF could be maintained within this range. The water retention curves of peat, perlite and vermiculite approach linearity and it would be relatively simple to achieve and maintain the desired pF in these media. Peat, perlite and vermiculite have great water retention and would not require repeated additions of water to maintain a fairly constant pF. Water is readily available from sand but a disadvantage of using sand is low water retention. Water would have to be added repeatedly to maintain a constant pF. It would be relatively easy to maintain a constant pF in fairly dry or saturated turface. However, it would be difficult to achieve and maintain a constant pF in the range of pF 1.5 to 3.5 as a small amount of water would result in a large pF change.

After-ripening and Germination of *Caragana arborescens*

The caragana seeds were stratified for 14 days at 1.6°C after which time the seeds were germinated for 14 days at 21°C in a growth chamber. The total number of seeds germinated was recorded for each medium treatment. The mean germination values for each medium treatment are shown in Table IV.

A factorial analysis of variance on fixed variables was used to determine if differences occurred between the media and between the treatments within the medium. There are significant differences between the treatment levels, the media and the interaction between medium and treatments as shown in Table V.

Table IV. The mean germination of caragana seed in each of the media.

Medium	Treatments									
	1	2	3	4	5	6	7	8	9	10
Sand	19.73	19.87	19.87	19.87	19.87	19.73	19.53	19.40	14.00	3.00
Turface I	0.0	0.14	1.0	1.71	19.29	19.71	19.50	19.07	1.46	1.14
Turface II	17.9	17.9	19.5	19.9	19.9	19.4	19.8	18.9	14.9	1.1
Peat	19.93	19.5	19.95	19.64	19.71	19.64	19.71	19.71	14.57	1.36
Sand-peat	18.38	19.88	19.63	19.75	19.88	19.88	19.88	19.75	14.63	1.38

Table V. Analysis of the variance of the after-ripening and germination results of caragana seeds in media.

Source	Df	S.S.	M.S.	F
Media	4	228.49	57.12	671.89 *
Treatment	9	584.01	64.89	763.24 *
Media-Treatment	36	333.88	9.27	109.09 *
Within cells	560	47.61	0.085	
TOTAL	609	1288.41		

Coefficient of variance = 7.97%.

* 5% level of significance.

The media means are shown in Table VI. The t-test was used to determine the difference between the media means and the results of the comparisons of means are indicated in Table VII.

There was no significant differences between the germination values of peat, sand and sand-peat mixture and turface II. However, a difference did occur in the actual length of time required for germination. This was a slower germination rate in turface II. Seeds in peat and sand-peat mixture attain maximum germination after 7 days whereas turface II took 14 days. The greater length of time for germination in turface II could be due to a slower rate of imbibition, particularly at the lower levels of water.

The similarity of germination values of peat and sand-peat mixture may be attributed to the similarities of water availability as indicated in the pF graph. The additional water which was added to the lower levels in turface II, resulted in water availability for germination occurring within 1.0 to 1.5, as indicated in Figure 2. This is approximately the same pF range in which the seeds germinate in peat and sand-peat mixture.

According to the data in Table IV, the highest mean germination value occurred in sand. A comparison of the mean germination value of sand to the other media, indicates no significant difference between sand and sand-peat mixture. A significant difference occurred between sand and the two turface treatments. The superiority of the mean germination values for sand may be attributed to the low level of water retention and water availability as indicated in sand and pF graph.

The Duncan Multiple Range Test (47) was used to determine if significant differences did occur between the treatments for each medium.

Table VI. The effect of the media on the mean germination counts of caragana.

Media	Mean germination count
Sand	17.48
Turface I	9.61
Turface II	16.92
Peat	17.38
Sand-Peat Mixture	17.30

Reference - Turface I and Turface II see Table I.

Table VII. The comparison of mean in each medium by using t-tests.

Media Means Paired	t-values
Sand - turface I	47.39 **
Sand - turface II	3.21 **
Sand - peat	2.02 n.s.
Sand - sand-peat mixture	1.75 **
Turface I - turface II	39.27 **
Turface I - peat	45.38 **
Turface I - sand-peat mixture	38.11 **
Turface II - peat	1.29 n.s.
Turface II - sand-peat mixture	1.15 n.s.
Peat - sand-peat mixture	0.00 n.s.

**1% level of significant. * 5% level of significance.
n.s. = Not significant.

In sand, peat, sand-peat mixture and turface II, a significant difference occurred between the two controls, wet and dry, and the other treatments. There was no significant difference between the mean germination values for treatments 1 to 8. Since the mean germination was the lowest in the controls, this would support research cited in the literature, that air and water are essential for after-ripening process in seeds. It would appear, that caragana seeds after-ripen if stratified within the range of available water for each medium of pF 1.0 to 4.0.

The results obtained from turface I, indicate that when no water was added to turface between after-ripening and germination, turface reacted in a predictable manner to the moisture content - pF graph constructed for this medium. The mean germination was very low at the lower moisture-content levels, 3.0 - 4.5 g water/g turface (D.W.) x 10 or pF 3.5 to 5.2. A slight increase in germination counts was evidenced in this moisture content range as the amount of water increased. There was no significant difference between the medium treatment in the water content range of 5.0 to 8.0 g water/g turface (D.W.) x 10, pF 1.0 to 1.5. Approximately 95% of the total seeds had germinated in this range.

The pF graph for turface and the Duncan Multiple Range Test reveal two distinct ranges of water availability within the turface as indicated by Figure 2. At low levels of total water, there is a retention of water. Within this range very little water is available to the seeds and germination is reduced. In the second range, water is readily available. However, a small amount of water added can change the

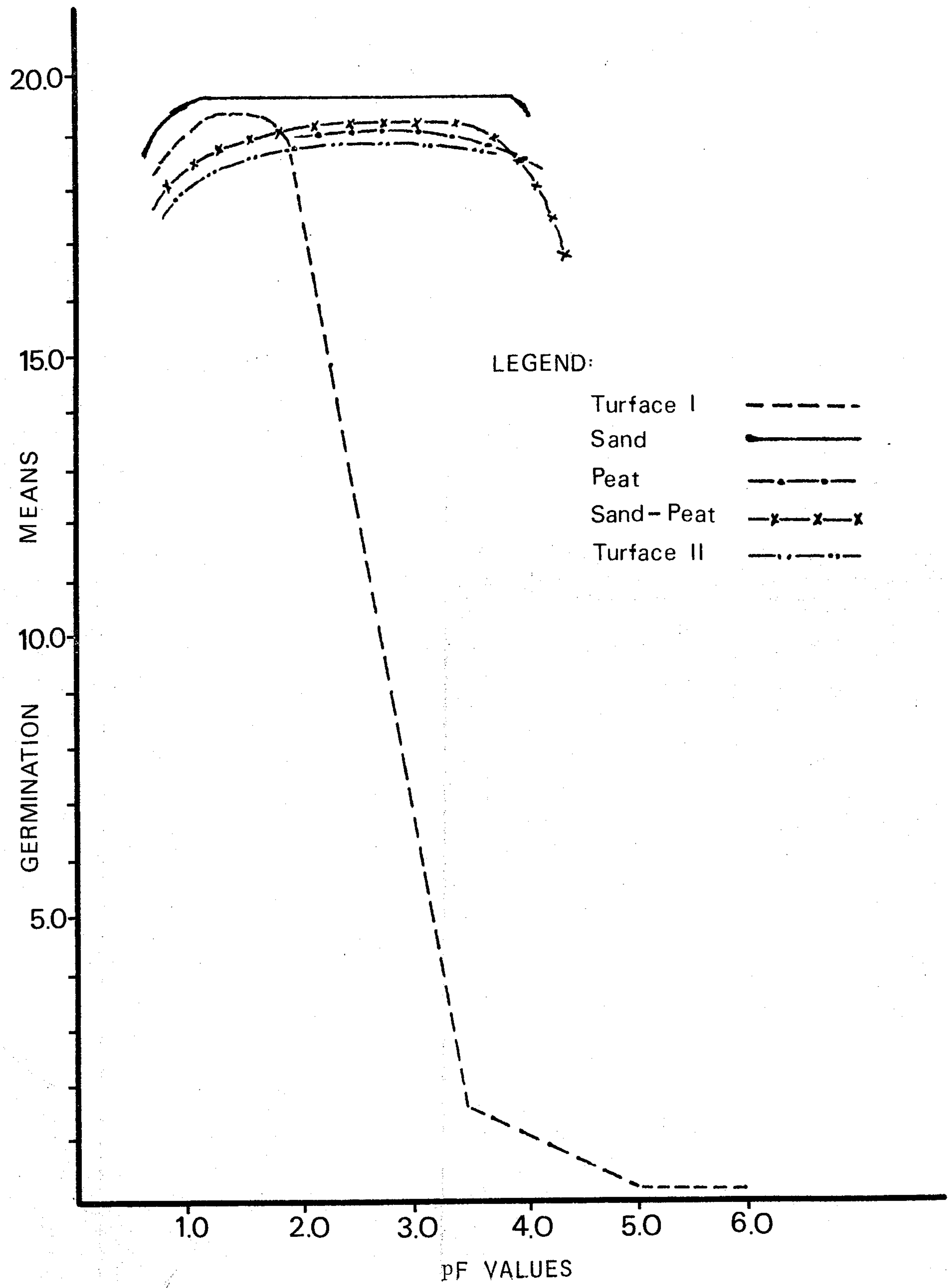

Fig. 3. The water regime of caragana seeds as a comparison of the germination rate to the pF values of the medias.

character of turface from one of water retention to one of water availability. In this experiment, at approximately 4.7 to 5.0 g water/g turface (D.W.) x 10, the addition of .33 of water in 10 gm of turface changed the character of the turface. As indicated in Table V, both turface I and turface II were given the same amount of water during after-ripening, therefore germination is dependent upon the additional water at the lower levels. Thus, the amount of water needed for after-ripening differs from the amount of water needed for germination.

Collis-George and Sands (11, 12) have stated that each plant species possesses a water regime with the medium. According to Fawcett and Collis-George (19), Whatman No. 42 filter paper has the same suction as plant seeds or approximately pF 6.0. As indicated in Figure 3, the water regime of caragana seeds is expressed as a function of the germination compared to the medium pF value. The satisfactory after-ripening and germination of caragana will occur within the range of pF 1.0 to 4.0 in sand, peat, sand-peat mixture and turface II. At a pF value greater than 4.0 the germination decreased sharply because of lack of water. Similarly at the value of 1.0, germination decreases due to lack of air. The results with turface I indicate that the water regime for after-ripening is not necessarily the same for germination.

The caragana will germinate if the amount of water added to the medium falls within the water availability range for the medium. The careful manipulation of the amount of water added to the medium will enable the propagator to use the available medium to obtain a satisfactory after-ripening and germination of seed.

After-ripening and Germination of *Cytisus austriacus*

The seeds of *Cytisus austriacus*, Austrian broom, were stratified in sealed containers for 42 days at a temperature of 1.6°C. The containers were kept at temperatures of 21°C for germination. The germination means data appears in Table VIII.

As in the case of caragana seeds, analysis of variance was used to analyze the mean germination values. Highly significant values were found to exist between the media; treatment levels and for the interaction between media and treatments.

With the exception of peat and sand-peat mixture the t-tests indicate significant differences between the media. Perlite had the highest germination while vermiculite had the lowest. There is greater water retention in vermiculite compared to either peat, sand-peat mixture or perlite as evidenced by the pF determination. Because of the greater water retention of vermiculite, the seeds exert more suction force to remove the water. At low levels of total water this would result in lower germination rates.

The Duncan Multiple Range Test was used to compare the treatment means. The uniformity which was present between the treatment means for caragana definitely did not occur for the broom. A possible explanation could be due to overall poor seed quality.

As was the case for caragana, a significant difference occurred between the wet and dry controls and the other treatments. Similarly, no significant differences occurred between the treatments 1 to 8 for peat, sand-peat mixture or perlite. Perlite had a more uniform range of means than either peat or sand-peat mixture. The mean germination

Table VIII. The mean germination of Austrian broom seed in each of the media.

Medium	Treatments									
	1	2	3	4	5	6	7	8	9	10
Vermiculite	2.63	4.63	8.50	9.88	8.63	10.25	12.13	13.50	0.38	0.63
Peat	10.50	9.63	12.00	12.25	11.63	13.50	10.13	8.75	0.38	0.63
Sand-peat	8.11	10.89	13.11	12.11	13.11	11.33	9.56	7.44	0.38	1.10
Perlite	8.8	9.9	11.6	12.2	12.2	12.0	11.3	13.0	5.9	1.2

Table IX. Analysis of variance of the after-ripening and germination results of Austrian broom in media.

Source	Df	S.S.	M.S.	F
Media	3	16.12	5.37	37.53 *
Treatment	9	353.29	39.25	274.20 *
Media-treatment	27	44.28	1.87	13.04 *
Within cells	310	456.83	0.14	
TOTAL	349			

* 5% level of significance.
Coefficient of variance = 13.91%.

The difference between the medium means were determined by t-tests. The results of the t-tests are in Table X.

Table X. The germination means of Austrian broom seeds stratified in several media.

Media	Germination means (total = 20)
Vermiculite	7.12
Peat	8.94
Sand-peat	8.68
Perlite	9.81

Table XI. The comparison of treatment media means as carried out by t-tests.

Paired Media Means	t-score
Vermiculite - peat	5.83 *
Vermiculite - sand-peat mixture	5.15 *
Vermiculite - perlite	10.61 *
Peat - sand-peat mixture	0.86 n.s.
Peat - perlite	4.52 *
Perlite - sand-peat mixture	5.57 *

* 5% level of significance.
n.s. = Not significant.

is the lowest in the controls, indicating that water and air are essential when stratifying Austrian broom.

The Duncan Multiple Range Test does show two ranges of means in vermiculite. In the moisture content range of 13.0 to 36 g water/g verminculite (D.W.) x 10, pF 2.1 to 2.9, there is no significant difference between the means. The range represents the available water region for vermiculite. At pF 3.0 to 4.5, a significant difference occurred between the means. As the pF value increased and a drier state was being reached, the mean germination count decreased.

As in the case of caragana seeds, Austrian broom prossesses a water regime with the media. Figure 4 expresses the water regime of Austrian broom as a function of the germination compared to the medium pF value. The optimum germination for the Austrian broom occurred within the range of pF 1.5 to 3.5. The water regime of Austrian broom is narrower than that of caragana. The careful manipulation of the amount of water added to the after-ripening and germination medium will lead to satisfactory germination of the Austrian broom.

General Discussion

The germination of dormant and non-dormant seeds is affected primarily by the moisture condition of the medium (7, 35, 43). According to Collis-George and Sands (12), each species has a given water regime for optimum seed germination. The water regime is defined by a soil moisture suction (pF) range and is dependant upon the moisture absorption characteristic of the seed and the moisture characteristic of the medium. Each species would have its own distinctive pF range for seed germination (11, 12). For some species the range could be very small

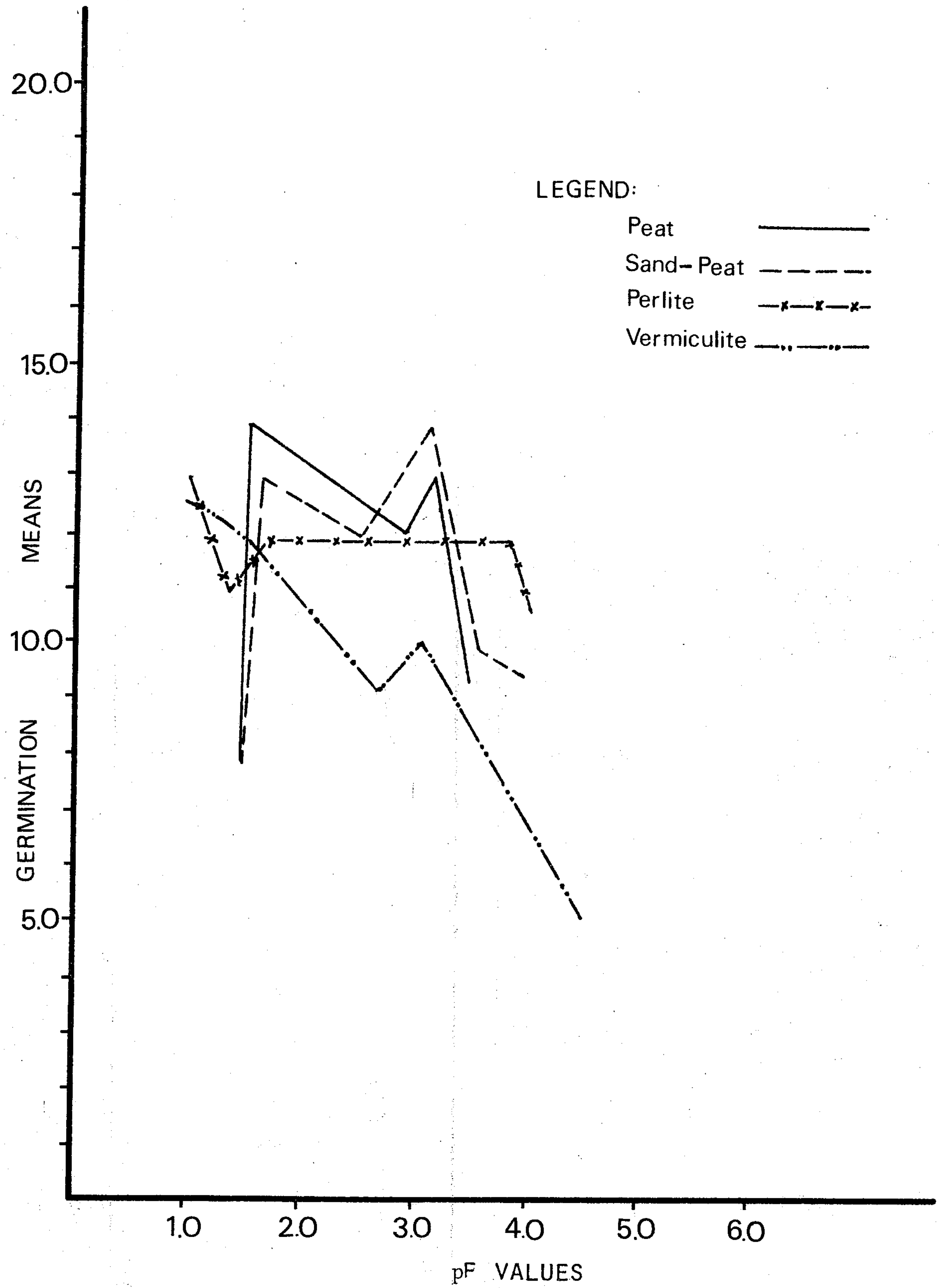

Fig. 4. The water regime of Austrian broom seeds as a comparison of the germination rate to the pF values of the media.

whereas the seed of other species could germinate over a large range of pF. Optimum seed germination would occur if the seed was placed in a medium with water available in the moisture regime range. For example, optimum caragana seed germination occurred following after-ripening at pF of 1.0 to 4.0 whereas optimum Austrian broom germination occurred at pF 1.5 to 3.5. If the seeds are placed in media with pF values which lie outside of the optimum range, germination decreases.

The choice of media for after-ripening and germination would depend upon the species of plants and the ease of attaining and maintaining a desired pF. A relatively constant pF would have to be maintained for those species which have a small pF range for germination. The media chosen would have a small change in pF as related to a large change in unit water additions, such as perlite, peat, and vermiculite. Sand, sand-peat and turface could be used for these species, but there would be greater difficulty in maintaining a constant pF in these media. A large change in pF related to small changes in unit water occur for sand, sand-peat and turface and repeated, small additions of unit water would be necessary to maintain the constant pF. The choice of media would not be as critical if germination occurred over a large pF range, as was evidenced for caragana seeds. In enclosed containers, the percentage of germination was equally high for sand, sand-peat and peat. The results might have varied if the experiments were conducted in open containers. Turface is not recommended for use because of the difficulty in attaining and maintaining a constant pF in the range of 1.5 to 3.5. The pF of turface changes very quickly with the slightest addition of water and turface would not be recommended for those species which germinate in a very small pF range, specifically if the range is within the proximity of 1.5 to 3.5.

SUMMARY

The freshly harvested seed of common caragana and Austrian broom are dormant and the dormancy may be overcome by stratifying the seed in moist medium for 14 and 42 days, respectively. After-ripening and subsequent germination is dependent on available water in the medium.

The pF-moisture content relationships were established for sand, peat, sand-peat mixture, turface, perlite and vermiculite. At low pF, water is readily available in the medium and little suction is required to remove the water. As the pF increased, a greater suction is exerted to remove the water. The amount of available water is predictable in sand, peat, sand-peat mixture, perlite and vermiculite, to the moisture content of the medium. Turface has two distinct available water ranges.

Each plant species possesses a seed-water regime in the medium. Optimum germination for caragana seeds occurs within pF 1.0 to 4.0 and pF 1.5 to 3.5 for Austrian broom. As evidenced in turface, the amount of water required for after-ripening may be insufficient to germinate the seed. The medium used appears to have little effect on after-ripening and germination of caragana and Austrian broom, provided that sufficient water is made available.

BIBLIOGRAPHY

1. ANONYMOUS. 1963. Terralite Brand Vermiculite. W. R. Grace Co., Merchandise Mart Plaza, Chicago, pp. 1-4.

2. ANONYMOUS. 1968. Technical Service Bulletin - Turface. Wyandotte Chemical Corporation. J. B. Ford Division, Michigan, pp. 1-24.

3. ANONYMOUS. 1969. Wyandotte Turface Mulch. Wyandotte Chemical Corporation. J. B. Ford Division, Michigan. pp. 1-4.

4. AYER, A. D. 1952. Seed germination as affected by soil moisture and salinity. Agronomy Journ. *44*: 82-84.

5. BARSHAD, I. 1948. Vermiculite and its relation to biotite as revealed by base exchanged relations, x-ray analysis, differential thermal curves and water content. Amer. Minerol. *33*: 655-678.

6. BARTON, Lela V. 1934. Dormancy in *Tilia* seeds. Boyce Thompson Institute. *6*: 69-89.

7. BUCKMAN, H. O. and N. C. BRADY. 1969. The Nature and Properties of Soil. MacMillan Co., New York. p. 567.

8. CARLETON, R. M. 1946. Vermiculite. Flower Grower *33*: 87-88.

9. CHAHAL, R. S. 1964. Effect of temperature and trapped air on energy status of water in porous media. Soil Science *98*: 107-112.

10. CHILDS, E. C. 1969. An introduction to the physical basis of soil water phenomena. John Wiley & Sons Ltd. p. 493.

11. COLLIS-GEORGE, N. and J. B. HECTOR. 1966. Germination of seeds as influenced by matrix potential and by area of contact between seed and soil water. Australian Journ. Soil Res. *4*: 145-164.

12. COLLIS-GEORGE, N. and J. E. SANDS. 1962. Comparison of the effects of physical and chemical components of soil water energy on seed germination. Australian Journ. Soil Res. *13*: 575-584.

13. CORNS, Wm. G. and R. J. SCHRAA. 1962. Dormancy and germination of seeds of silverberry (*Elaeagnus commutata*). Can. Journ. of Botany. *40*: 1051-1055.

14. CROCKER, L. and L. V. BARTON. 1953. Physiology of seeds. Chronica Botanica Co., New York. p. 421.

15. DAVIS, H. O. 1927. Germination and early growth of *Cornus florida, Sambucus canadensis* and *Berberis thunbergii*. Bot. Gaz. *84*: 225-263.

16. DAVIS, W. E. and R. C. ROSE. 1921. The effect of external conditions upon the after-ripening of seeds of *Crataegus mollis*. Bot. Gaz. *54*: 49-62.

17. DUMBROFF, E. B. and D. P. WEBB. 1970. Factors influencing the stratification process in seeds of *Acer ginnala*. Can. Journ. of Bot. *48*: 2009-2015.

18. ECKERSON, Sophia. 1923. A physiological and chemical study of after-ripening. Bot. Gaz. *55*: 286-299.

19. FAWCETT, R. G. and N. COLLIS-GEORGE. 1967. A filter paper method of determining the moisture characteristics of soil. Australian Journ. of Exp. Ag. *7*: 162-167.

20. FERGUSON, G. A. 1966. Statistical analysis in psychology and education. McGraw-Hill Inc., New York. p. 576.

21. FOWLER, D. P. and T. W. DWIGHT. 1964. Provenance differences in the stratification requirements of white pine. Can. Journ. of Bot. *42*: 669-675.

22. GIERSBACH, Johanna. 1939. Germination and seedling production of species of *Viburnum*. Boyce Thompson Inst. *10*: 79-90.

23. ________________. 1939. Germination of *Arctostaphylos uva-ursi*. Boyce Thompson Inst. *10*: 71-89.

24. ________________. 1939. Germination and growth of gentian. Boyce Thompson Inst. *10*: 91-103.

25. ________________. 1934. After-ripening and germination of cotoneaster seeds. Boyce Thompson Inst. *6*: 323-328.

26. HARTMANN, H. J. and D. E. KESTER. 1959. Plant Propagation. Prentice-Hall Inc., Englewood Cliff, New Jersey.

27. HEYDECKER, W. 1961. The emergence of vegetable seedlings as a standard test of soil quality. Adv. Hort. Sci. *1*: 381-392.

28. HEYDECKER, W. 1962. From seed to seedling: Factors affecting the establishment of vegetable crops. Amer. Appl. Biol. *50*: 622-627.

29. HILLEL, D. 1971. Soil and Water. Academic Press, New York and London. p. 288.

30. KNOWLES, R. H. and S. ZALIK. 1958. Effects of temperature treatment and of native inhibitor on seed dormancy and cotyledon removal on epicotyl growth in *Viburnum trilobum* Marsh. Can. Journ. of Bot. *36*: 561-566.

31. KOZLOWSKI, T. T. 1972. Seed Biology. Academic Press, New York and London. p. 487.

32. KUENAN, Ph. H. 1960. Sand. Sci. Amer. *202*(4): 94-110.

33. LAWRENCE, W. J. C. and J. NEWELL. 1952. Seeding and potting composts. George Allen and Univ. Ltd., London. p. 383.

34. LINDQUIST, C. H. 1960. Note on moisture requirements of the stratifying media for seed of *Caragana arborescens* Lam. Can. Journ. Pl. Sci. *40*: 576.

35. LYON, T. L., BUCKMAN, H. O. and N. C. BRADY. 1954. The nature and properties of soils. MacMillan Co., New York. p. 591.

36. MAJOR, Wendy and E. H. ROBERTS. 1968. Dormancy in cereal seeds. Journ. of Exp. Bot. *19*: 90-101.

37. PACK, D. A. 1921. After-ripening and germination of Juniper seeds. Bot. Gaz. *71*: 32-60.

38. PILLAY, D. T. N., K. D. BRASE, and L. J. EDGERTON. 1965. Effects of pretreatments, temperature and duration of after-ripening on germination of Mazzard and Mahaleb seeds. Proc. Amer. Soc. Hort. Sci. *86*: 102-107.

39. PILLAY, D. T. N. and L. J. EDGERTON. 1965. Relationship of growth substance to rest period and germination in Mazzard cherry seeds. Proc. Amer. Soc. Hort. Sci. *86*: 108-114.

40. POLLOCK, B. M. and J. R. MANALO. 1969. Controlling substrate moisture-oxygen levels during imbibition stage of germination. Journ. Amer. Soc. Hort. Sci. *94*: 574-576.

41. POLLOCK, B. M. and V. K. TOOLE. 1961. After-ripening, rest period of dormancy seeds. The Yearbook of Agriculture. The United States Dept. of Agri. p. 327.

42. ROBERTS, E. H. 1972. Viability of seeds. Syracuse University Press, New York. p. 583.

43. ROSE, C. W. 1966. Agricultural Physics. Pergamon Press, Toronto, p. 266.

44. ROSE, R. C. 1919. After-ripening and germination of seeds of *Tilia*, *Sambucus* and *Rubus*. Bot. Gaz. *67*: 281-308.

45. SCHILLETTER, J. C. and H. W. RICHEY. 1940. Textbook of General Horticulture. McGraw-Hill Co., Inc., New York and London. p. 374.

46. SEXSMITH, J. J. 1970. Dormancy of Wild Oats. Weed Science *17*: 405-407.

47. SNEDECOR, G. W. and W. G. COCHRAN. 1967. Statistical Methods. Iowa State Univ. Press, Ames, Iowa. p. 593.

48. STEWART, R. N. and P. SEMENIUK. 1965. The effect of the interaction of temperature and compensating temperature on germination of seed of five species of *Rosa*. Amer. Journ. of Bot. *52*: 755-760.

49. TAYLORSON, S. and L. McWHORTER. 1970. Seed dormancy and germination of Johnson-grass. Weed Sci. *17*: 359-361.

50. VANDEN BORN, W. H. 1971. Green Foxtail. Seed Dormancy. Can. Journ. of Pl. Sci. *51*: 53-59.

51. VILLIERS, T. A. and P. F. WAREING. 1965. The possible role of low temperature in breaking the dormancy of seeds of *Fraxinus excelsoir* L. Journ. of Exp. Bot. *16*:519-531.

52. WEBB, D. P. and E. B. DUMBROFF. 1969. Factors influencing the stratification process in seeds of *Acer saccharum*. Can. Journ. of Bot. *47*: 1555-1563.

A P P E N D I X

APPENDIX TABLE 1

The percentage moisture content as related to a pF value in 15 gm of vermiculite.

g water/g media (D.W.) x 10	Moisture content (%) of oven dry filter paper	pF value
.7	23.09	4.40
1.3	25.79	4.34
2.0	28.60	4.05
2.7	30.26	3.90
3.3	31.85	3.73
7.0	38.29	3.41
10.0	43.30	3.18
13.0	49.12	2.92
16.7	51.61	2.86
20.0	63.30	2.61
23.3	86.90	2.25
26.7	111.81	1.93
30.0	122.52	1.75
33.3	129.60	1.63
36.7	166.20	1.13
40.0	171.70	1.04

APPENDIX TABLE 2

The percentage moisture content as related to the pF value in 15 gm of perlite.

g water/g media (D.W.) x 10	Moisture content (%) of oven dry filter paper	pF value
0.7	34.19	3.73
1.3	35.61	3.62
2.0	38.54	3.42
2.7	40.82	3.30
3.3	47.49	3.03
7.0	65.25	2.55
10.0	135.61	1.53
20.0	140.72	1.50
23.3	157.80	1.12
26.7	166.11	1.11

APPENDIX TABLE 3

The percentage moisture content relationship of pF values in 50 gm sand-peat mixture.

g water/g media (D.W.) x 10	Moisture content (%) of oven dry filter paper	pF value
0.2	9.0	5.91
1.0	27	4.13
2.0	42	3.05
3.0	57	2.7
4.0	95	2.25
5.0	117	1.85
6.0	135	1.58
7.0	144	1.40
8.0	150	1.38
9.0	158	1.28
10.0	166	1.11

APPENDIX TABLE 4

The percentage moisture content as related to the pF values in 25 gm of peat.

g water/g media (D.W.) x 10	Moisture content (%) of oven dry filter paper	pF value
4.0	30.26	3.9
8.0	38.06	3.4
10.0	44.59	3.1
12.0	53.57	2.75
15.0	59.59	2.65
20.0	79.86	2.4
25.0	108.09	2.03
30.0	126.45	1.75
35.0	139.23	1.55
40.0	150.29	1.36
F.C.	184.67	1.0

APPENDIX TABLE 5

The percentage moisture content as related to the pF values in 75 gm of turface.

g water/g media (D.W.) x 10	Moisture content (%) of oven dry filter paper	pF value
2.7	20.26	4.7
3.3	24.32	4.4
4.0	28.63	4.1
4.7	36.4	3.55
5.3	140.76	1.5
6.0	171.6	1.06
6.7	186.46	1.0
7.3	188.76	0.99
8.0	190.30	0.97