THE EFFECT OF PELLETING AND ENCAPSULATION ON GERMINATION OF SOME CONIFER SEEDS NATIVE TO ONTARIO

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ABSTRACT

Experiments to determine the influence of pelleting and encapsulation on the germination of several species of conifers native to Ontario are discussed. Encapsulation has an unacceptably adverse effect on germination. Pelleting does not influence germination of black spruce (*Picea mariana* [Mill.] B.S.P.) seeds adversely within the optimum germination-temperature range for this species but does so, significantly, toward the upper and lower range of cardinal germination temperatures. Pelleting does have a significant, adverse effect on germination of white spruce (*P. glauca* [Moench] Voss), jack pine (*Pinus banksiana* Lamb.) and red pine (*P. resinosa* Ait.) seeds. Storage of pelleted black spruce seeds for up to three years had no adverse effect on germination at the optimum temperature, 21C.

RÉSUMÉ

Discussion d'expériences destinées à déterminer l'influence de l'enrobage et du capsulage sur la germination de plusieurs espèces de conifères indigènes de l'Ontario. Le capsulage a un effet adverse inacceptable sur la germination. L'enrobage n'affecte pas la germination des graines d'Épinette noire (*Picea mariana* [Mill.] B.S.P.) d'une façon adverse dans l'intervalle de températures optimales pour cette essence, mais il l'affecte significativement au voisinage des deux extrémités de cette gamme. L'enrobage a un effet adverse significatif sur la germination des graines d'Épinette blanche (*Picea glauca* [Moench] Voss), du Pin gris (*Pinus banksiana* Lamb.) et du Pin rouge (*P. resinosa* Ait.). L'entreposage des graines enrobées d'Épinette noire pendant des périodes allant jusqu'à 3 ans n'a présenté aucun effet adverse sur la germination à la température optimale de 21C.

ACKNOWLEDGMENTS

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We also thank former forest research technician, J.M. Shoup, for his assistance in the early stages of the pelleting experiments.

The GLFRC pelleting machine is based on the machine developed by Dr. William F. Millier, Professor, Department of Agricultural Engineering, New York State College of Agriculture and Life Sciences, A Statutory College of the State University, Cornell University, Ithaca, New York 14853.

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INTRODUCTION

This report deals primarily with the influence of two types of pelleting and two methods of encapsulation on germination of black spruce (*Picea mariana* [Mill.] B.S.P.) and jack pine (*Pinus banksiana* Lamb.) seeds. It also documents the influence of one of the two types of pelleting on germination of red pine (*Pinus resinosa* Ait.) and white spruce (*Picea glauca* [Moench] Voss) seeds, and the influence of length of storage on germination of pelleted black spruce seeds.

The rationale for pelleting conifer seeds was presented in a previous paper on seed treatments (Fraser 1974). There the author reviewed current literature on coating, pelleting or pelletizing, and encapsulation of conifer seeds[1], and presented some preliminary results of experiments initiated at the Great Lakes Forest Research Centre to assess the influence of these seed treatments on the germination of some conifer seeds. This report documents the end results of these experiments, and those of several ancillary experiments carried out subsequently at the Great Lakes Forest Research Centre.

METHODS AND MATERIALS

The seven experiments documented here have the following features in common:

1) All seeds were supplied by the Ontario Ministry of Natural Resources (OMNR).

2) Germination was tested on saturated, short-grain black germination paper over saturated, bleached Kimpak[2] in covered, sterile petri dishes, under low-level incandescent light and at specified constant optimum temperatures ± 0.5C (Fraser 1970 a and b, 1971) in controlled temperature cabinets or incubators.[3]

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[1]In this report "coating" means applying a layer of material to a seed without altering its shape to any extent; "pelleting" means applying material to a seed in such a way as to embed the seed in a uniformly (more or less) spherical pellet; "encapsulating" means enclosing a seed at the centre of two identical preformed tablets.

[2]Mention of companies and/or products in this report does not constitute endorsement of either by the Great Lakes Forest Research Centre.

[3]See Experiment 5 for greenhouse germination conditions and criterion.

3) The germination medium was maintained at or near saturation by adding measured amounts of distilled water whenever the medium showed signs of drying (rarely).

4) Germination was recorded daily for 28 days. Untreated (control) seeds were tallied as having germinated when radicles were 2 mm long or longer than the long dimensions of the seeds[3], or in the case of pelleted seeds when radicles pierced the pellets and were visible on the outside.

5) All data were analyzed by the Chi-square method. Means, standard deviations and coefficients of variation were calculated for fixed intervals, 7, 14, 21 and 28 days after seeding.

Experiment 1

Untreated, Moran-pelleted (trademark "Moran-Coat Seeds")[4] and FMC-encapsulated[5] black spruce and jack pine seeds (hereafter referred to as control, Moran-Coat and FMC seeds, respectively (Fig. 1), were tested at 21C. There were 200 seeds per treatment in Experiment 1; in experiments 2 to 7 inclusive there were four replicates of 100 seeds per treatment per temperature).

In the Moran-Coat process, single seeds are enclosed in uniformly spherical pellets of an inert substance, and the minimum size of the pellet depends on the long dimension of the seed being pelleted. In FMC encapsulation single seeds are enclosed in a semi-spherical cavity at the centre of a flat, round disk (tablet) formed by cementing together two identical halves of vermiculite (Fig. 1). One FMC treatment (FMC 1) and the control and Moran treatments were watered from *below* by adding water to the Kimpak so that it was absorbed upwards by the germination paper. In a second FMC treatment (FMC 2) water was added from *above* directly onto the germination paper -- frequently onto the tablets. Encapsulated seeds were tallied as germinants when radicles were visible outside the tablets.

Experiment 2

In this experiment, encapsulated black spruce and jack pine seeds were tested against controls, also at 21C, but in this instance

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[4]Moran Seeds, Inc., 1155 Harkins Road, Salinas, California, 93901.

[5]FMC Export Corporation, Niagara Chemical Division, Box 2091, Modesto, California, 95353.

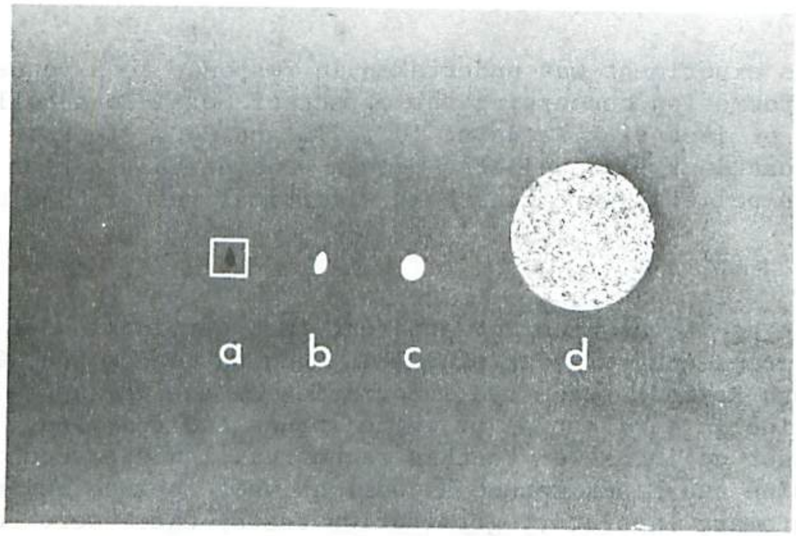

Figure 1. A comparison of (a) untreated, (b) coated, (c) pelleted, and (d) encapsulated black spruce seeds (actual size).

two encapsulation techniques were involved. The first (FMC I) was the one described above and illustrated in Figure 1 with the seed enclosed in a cavity at the centre of the tablet. In the second (FMC II), the seed was embedded at the centre of a one-piece tablet identical in size and shape to the FMC I tablet.

Experiment 3

Following the initial trials with Moran-Coat black spruce (Experiment 1) a second test of Moran-Coat black spruce also included two Asgrow pelleting treatments[6] (trademark "Asgrow Lite-Coat"). One, more aptly described as a *coating* since it did not greatly alter either the size or shape of the seed, is designated hereafter Asgrow Coat or AC, and the second, comparable in shape and size to the Moran-Coat pellet, is designated Asgrow Pellet or AP.

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[6]Asgrow Seed Company, Kalamazoo, Michigan, 49001.

Experiment 4

This experiment was undertaken in response to a request from OMNR for information concerning the effect of Moran-Coat pelleting on germination of jack pine seeds at 10C, 21C and 32C. In this instance, the Moran-Coat jack pine pellets, though considerably larger than the black spruce pellets, were generally elliptical rather than spherical.

Experiment 5

Just as it was becoming apparent that germination of pelleted jack pine versus control jack pine left much to be desired, OMNR (Northwestern Region) requested information on the influence of Moran-Coat pelleting on germination of white spruce and red pine. The experiment set up in answer to this request included a second series with jack pine and black spruce as well as white spruce and red pine. For the customary laboratory-germination tests[7] there were four replicates of 100 seeds of each species, control and pelleted, at 10C, 21C and 32C.

The entire experiment was paralleled in the greenhouse where the seeds were sown onto the surface of a saturated 1:1 mixture of peat moss and vermiculite, then lightly top dressed with coarse quartz sand. Greenhouse temperatures at bench level alternated between 22C (daytime) and 20C (night-time). All treatments were "misted" as required to maintain the medium near saturation. In these and subsequent greenhouse trials, seeds were tallied as having germinated[7] when radicles were sufficiently anchored to raise the seed in or above the top dressing, i.e., "emergence".

Experiment 6

The smaller size and mass of black spruce seeds relative to jack pine seeds preclude aerial seeding of both species simultaneously from the same hopper with any assurance of either equal or uniform seeding rates and dispersal. The potential advantages of being able to do so prompted this experiment with Moran-Coat black spruce and jack pine seeds in the same size of spherical pellet, i.e., in a pellet large enough to accommodate the larger jack pine seeds. The experiment paralleled Experiment 5 in all other respects, both in the laboratory and in the greenhouse.

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[7]Laboratory germination is germination occurring on germination paper in incubators; greenhouse germination is germination occurring in peat-vermiculite in the greenhouse.

Experiment 7

The final experiment documented here explored the effects on germination of storing pelleted black spruce seed (Moran-Coat) for three years at 2C-4C. The laboratory germination tests, at 21C, were based on four replications of 100 seeds for each treatment (control and pelleted).

RESULTS

Experiment 1

The results of Experiment 1 are presented in Table 1.

None of the FMC-encapsulated jack pine seeds germinated.

Moran-Coat black spruce seeds germinated as well as control seeds except during the first week following seeding when there were significantly fewer germinants from pelleted than from control seeds.

Germination from encapsulated black spruce seeds was consistently and significantly slower and poorer than from control and/or pelleted seeds (< 50% in 28 days vs 100% in 14 days). The initial trend of significantly better germination when tablets were watered from *below* (17% vs 8%) did not persist beyond the 14th day.

Experiment 2

The results of Experiment 2 are presented in Table 2.

For two weeks after seeding, germination from the second FMC treatment was better than from the first but the reverse was true thereafter. Although the results of this experiment are statistically valid, the only practical significance of these data is that germination from encapsulated black spruce seeds was consistently and significantly inferior to germination from control seeds.

For jack pine the only relevant result is that, for all practical purposes, none of the encapsulated jack pine seeds germinated.

Experiment 3

The results of Experiment 3 are presented in Table 3.

There was no germination at 10C from any treatment until the third week after seeding. At weekly intervals thereafter germination was consistently and significantly better from the control, Moran-Coat, Asgrow-Coat, and Asgrow-Pellet treatments in that order, although effectively there was no germination (1%) from the AP treatment.

Table 1. Mean cumulative percent germination[a] of untreated (control), pelleted (Moran) and encapsulated (FMC) black spruce and jack pine seeds at 21C.

Days since seeding	Control	Moran pellet	FMC 1	FMC 2
	Jack pine			
7	76		0	0
14	84		0	0
21	84		0	0
28	84		0	0
	Black spruce			
7	97	18	0	0
14	100 a	100 a	17	8
21	100 a	100 a	39 b	45 b
28	100 a	100 a	42 b	48 b

FMC 1 = watered from below

FMC 2 = watered from above

[a]There is no significant difference (p = 0.05) between values joined by the same vertical line or between those with the same lower case letter(s) in any given horizontal line.

At 21C, germination from the MC treatment was as good as that from the control except during the first week after seeding when there were significantly fewer germinants from the MC treatment than from the control. The initial trend of significantly better (albeit exceptionally poor) germination from the AC than from the AP treatment did not persist beyond the 14th day, by which time it is doubtful if the statistically significant difference between germination from the two Asgrow treatments (96%) and control and Moran treatments (98% and 99%) had any practical significance.

At 32C, as at 10C, germination from the control treatment was complete by the 14th day and was consistently and significantly better than from the MC, AC, and AP treatments. However, at 32C, germination, poor as it was (2% or less) from the pelleted treatments, began during

Table 2. Mean cumulative percent germination[a] of untreated (control) and encapsulated (FMC) black spruce and jack pine seeds at 21C.

Days since seeding	Black spruce				Jack pine			
	Control		FMC		Control		FMC	
	1	2	I	II	1	2	I	II
7	99	13	0	1	88	93	0	0
14	99	96	25	31	88	93	0	1
21	99	96	50	40	89	93	0	1
28	99	96	52	40	89	94	0	1

FMC I = capsule with centre cavity holding seed

FMC II = capsule without centre cavity: seed imbedded in capsule.

[a]There is no significant difference (p = 0.05) between values joined by the same vertical line, nor within species between those with the same lower case letter(s).

the first week and was complete by the end of the third week. Also, at this temperature, germination after the first seven days was consistently and significantly better from the AC treatment than from the MC and AP treatments.

The coefficients of variation (Table 3) indicate that germination was generally more uniform at the optimum temperature (21C) than at either extreme (10C and 32C), particularly for untreated (control) seeds, although pelleted seeds germinated just as uniformly as control seeds at the optimum temperature.

Experiment 4

The results of Experiment 4 are presented in Table 4.

At 10C, jack pine germination began during the third and fourth weeks in the control and pelleted treatments, respectively, and was always significantly better in the control treatment. This same pattern occurred at 21C and at 32C.

Statistically, germination in the control treatment was complete by the end of the second and first weeks at 21C and 32C, respectively. Germination in the pelleted treatment began one week later at 21C, i.e., during the second week, and increased significantly each week thereafter to a low maximum of 54%. At 32C, although germination in the pelleted treatment began during the first week and increased significantly (statistically) between the second and fourth weeks, for all practical purposes no pelleted seed germinated at this temperature. The lower coefficients of variation throughout the control treatment vs the pelleted treatment and at 21C vs 10C and 32C for the control and pelleted treatments indicate that untreated seeds germinated more uniformly than pelleted seeds and that germination from untreated and from pelleted seeds was more uniform at the optimum temperature, 21C.

Table 3. Mean percent germination[a] of black spruce seeds by seed treatment (at 10C, 21C and 32C) 7, 14, 21 and 28 days after seeding.

Temp. (°C)	Days since seeding	Control		Moran pellet		Asgrow coat		Asgrow pellet	
		Mean	CV	Mean	CV	Mean	CV	Mean	CV
	7	0	0	0	0	0	0	0	0
10	14	0	0	0	0	0	0	0	0
	21	66	16	24	34	4	80	0	0
	28	98	0	67	11	11	50	1	141
	7	|98	1	23	52	37	19	3	15
21	14	|98 a	1	|98 a	1	|96	2	93	3
	21	|98 a	1	|98 a	1	|96 b	2	|95 b	2
	28	|98 a	1	|98 a	1	|96 b	2	|96 b	2
	7	75	7	1 a	116	2 a	76	1 a	128
32	14	|97	2	21	37	40	18	6	21
	21	|98	2	|28	40	|50	13	|16	26
	28	|98	2	|29	41	|52	14	|19	27

CV = coefficient of variation

[a]There is no significant difference (p = 0.05) between values joined by the same vertical line within seed treatments or between those with the same lower case letter(s) in any horizontal line.

Table 4. Mean cumulative percent germination[a] of jack pine seeds at (at 10C, 21C and 32C) 7, 14, 21 and 28 days after seeding.

Temp. (°C)	Days since seeding	Control		Moran pellet	
		Mean	CV	Mean	CV
10	7	0	0	0	0
	14	0	0	0	0
	21	19	29	0	0
	28	77	10	14	31
21	7	84	8	0	0
	14	92	3	10	17
	21	92	3	47	17
	28	92	3	54	19
32	7	89	5	1	16
	14	90	4	2	84
	21	90	4	4	42
	28	90	4	5	50

CV = coefficient of variation.

[a] There is no significant difference (p = 0.05) between percentages joined by the same vertical line or between those with the same lower case letter(s).

Experiment 5

The results of Experiment 5 are presented in Table 5.

The black spruce and jack pine laboratory germination results in Table 5 confirm the control vs pelleted seed germination patterns for these species in Tables 1, 3 and 4.

Germination in the control red pine treatment was significantly better and faster than in the pelleted treatment where there was no germination at all until the third week after seeding, and where germination, although it increased significantly in the fourth week, never exceeded 43%.

Germination in the control white spruce treatment, though somewhat poorer and slower than in treatments with other species, was nevertheless significantly better than in the pelleted treatment. There, although germination increased significantly each week, it never exceeded 38%.

Table 5. Mean cumulative percent germination[a] and coefficients of variation of untreated and pelleted black spruce, jack pine, red pine and white spruce at optimum germination temperatures for each species.

Days since seeding	Black spruce (21C)				Jack pine (27C)				Red pine (27C)				White pine (21C)			
	Control		Pelleted		Control		Pelleted		Control		Pelleted		Control		Pelleted	
	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
Incubators																
7	74	17	0	0	93	4	0	0	7	24	0	0	2	127	0	0
14	99	1	92	2	94	4	8	23	92	4	0	0	55	6	8	52
21	99	1	96	2	94	4	20	17	93	3	22	40	66	4	27	20
28	99	1	96	2	94	4	22	16	93	3	43	13	69	4	38	21
Greenhouse																
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	94	3	38	25	96	5	21	44	62	9	0	0	16	38	0	0
21	96 a	3	94 a	3	96	5	81	3	92	7	2	72	62	3	10	45
28	97 a	3	96 a	2	96	5	92	3	92	6	44	7	68	2	28	2

[a] There is no significant difference ($p = 0.05$) between values joined by the same vertical line, nor within species, by those with the same lower case letter(s) in any given horizontal line.

In the greenhouse trials, germination generally was slower, initially, than in the laboratory trials. This is attributed to the fact that there was a different criterion for germination in the greenhouse trials and that it was difficult to apply it as accurately as the criterion for laboratory germination.

Otherwise, greenhouse germination patterns for control vs pelleted seeds were similar to those for laboratory germination for black spruce and red pine. However, although greenhouse germination of pelleted jack pine was never as good (statistically) as germination of untreated jack pine, by the end of the fourth week there was no practical difference (4%) between them, i.e., 92% vs 96%. Interestingly, germination of pelleted jack pine was significantly better in the greenhouse than in the laboratory.

Initially, untreated (control) white spruce seeds germinated more slowly in the greenhouse than in the laboratory but by the end of the third week there was no significant difference between them. However, germination from pelleted seeds was significantly poorer in the greenhouse than in the laboratory throughout the trials.

Experiment 6

The results of Experiment 6 are presented in Table 6.

As in the earlier trials with the smaller pellet, black spruce germination was significantly better from untreated than from pelleted seeds at all three temperatures (10C, 21C and 32C), but it is doubtful that the statistically significant difference, i.e., $\leqslant$ 5% at 21C, 3-4 weeks after seeding, has any practical significance.

Not unexpectedly, laboratory germination from the larger pellet in this experiment was significantly slower and poorer than from the smaller pellet (cf. Tables 3 and 6).

In the greenhouse, germination from the larger pellet was initially slower than it was from the smaller pellet, but equally as good from the third week onward (cf. Tables 5 and 6).

None of the pelleted jack pine seeds germinated in the laboratory trials. In the greenhouse, germination of the pelleted seeds was consistently and significantly slower and poorer than from the control seeds and from the smaller pellet (cf. Tables 5 and 6).

Experiment 7

The results of Experiment 7 are presented in Table 7.

Table 6. Mean cumulative percent germination[a] of untreated and pelleted black spruce and jack pine seeds at 10C, 21C and 32C in incubators and at 20C to 22C in the greenhouse.

Temp. (°C)	Days since seeding	Incubator: Black spruce Control Mean	CV	Black spruce Pellet Mean	CV	Jack pine Control Mean	CV	Jack pine Pellet Mean	CV
10	7	0	0	0	0	0	0	No germination	
	14	0	0	0	0	0	0		
	21	52	7	1	67	24	36		
	28	97	1	10	47	73	5		
21 *b* (27)	7	92	3	0	0	94	3	No germination	
	14	99	0	62	10	95	4		
	21	99	1	94	3	95	4		
	28	99	1	96	3	95	4		
32	7	62	12	0	0	86	2	No germination	
	14	97	1	0	0	86	2		
	21	98	2	0	0	86	2		
	28	98	2	2	86	87	2		
Greenhouse									
20C/28C	7	0	0	0	0	0	0	0	0
	14	98	3	17	22	96	2	0	0
	21	98	2	91	2	96	2	2	128
	28	98	2	94	3	96	2	21	15

[a] There is no significant difference (p = 0.05) between values joined by the same vertical line, nor within species, between those with the same lower case letter(s) in any given horizontal line.

[b] 21C for black spruce and 27C for jack pine.

Table 7. Mean cumulative percent germination[a] at 21C of untreated and pelleted black spruce seeds freshly coated and after 1 and 3 years of storage.

Days since seeding	1973		1975	
	1 year's storage		3 years' storage	
	Control	Pellet	Control	Pellet
7	97 a	18	96 a	10
14	100 a	100 a	98 a	98 a
21	100 a	100 a	98 a	98 a
28	100 a	100 a	98 a	98 a

[a]There is no significant difference between values joined by the same vertical line, nor between those with the same lower case letter(s) in any given horizontal line.

It is self-evident from the data in this table that storing Moran-Coat black spruce for up to three years after the seeds were pelleted had no adverse effect on germination at the optimum germination temperature (21C).

DISCUSSION AND CONCLUSIONS

The first and foremost argument to be resolved in any consideration of pelleting or encapsulating conifer seeds for direct seeding cutovers or in nursery operations is whether they have any adverse effect on germination. In other words, to what extent, if any, do they delay and/or depress germination relative to that from untreated seeds.

The answer is very clear for the two types of encapsulation reported here, both for black spruce and for jack pine seeds (see Tables 1 and 2). Encapsulated jack pine seeds simply did not germinate (maximum 1%). Encapsulated black spruce seeds germinated sooner and better (numerically) than encapsulated jack pine seeds, but the obvious adverse effect of encapsulation on black spruce germination, i.e., much slower and significantly poorer germination relative to that from untreated seeds, precludes further consideration of encapsulating[8] either this species or jack pine.

Initially, at 21C, the optimum cardinal temperature for germination of black spruce seeds, aside from delaying germination during the first week after seeding, pelleting (Moran-Coat) had no adverse effect on germination (Table 1). When the experiment was repeated the results were almost identical (cf. Tables 1 and 3). Also, except for the same initial delay in germination, Asgrow Coat and Asgrow Pellet seeds (for all practical purposes) germinated equally well, and as well as Moran-Coat and untreated seeds.

At 10C, where nothing germinated until the third week, pelleting obviously affected germination adversely. Statistically (Table 3) the adverse effect of the Asgrow Pellet was greater than that of the Asgrow Coat, but for all practical purposes, relative to germination from untreated seeds, both treatments precluded realistic germination. Although the adverse effects of Moran-Coat on black spruce germination at this temperature are certainly less pronounced than those of the Asgrow treatments, they are still significant.

At the higher temperature, 32C, untreated black spruce seeds germinated somewhat more slowly at first but just as well as at 21C two weeks after seeding. However, although pelleted seeds (all treatments) began to germinate two weeks sooner at 32C than they did at 10C, they never germinated as well as untreated seeds. At this temperature, Asgrow Coat had the least adverse effect on germination and Asgrow Pellet had the greatest, with Moran-Coat somewhere in between.

Asgrow Pelleting was eliminated from further consideration partly because it delayed germination at 21C slightly longer than the other treatments, but mainly because of its severe adverse effect on germination at 10C and 32C.

Although the Asgrow Coat had no practical adverse effect on germination at 21C, and had even less of an adverse effect at 32C than did Moran-Coat, it affected germination much more adversely than did Moran-Coat at 10C. For this reason, and because of the variation in size and shape of the "coated" seed, which is undesirable in mechanical precision seeding, Asgrow Coat was also eliminated from furthing testing.

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[8]FMC "have discontinued the precision planting system utilizing individual seed encapsulated in a vermiculite wafer" because "economics were unfavourable" (personal communication from W.L. Marlow).

Moran-Coat obviously had a significantly adverse effect on laboratory germination of jack pine seed at all three temperatures. It was particularly severe at 10C and 32C (Table 4) but even at the optimum temperature for jack pine, 21C, germination was unacceptably low.

Results of the experiment combining the two spruces and two pines confirm the effects of pelleting on laboratory germination of black spruce and jack pine at 21C. There is no disputing the fact that pelleting delayed and/or depressed laboratory germination of red pine and white spruce seeds (Table 5).

If one attributes the apparent delay in greenhouse vs laboratory germination of untreated seeds to the greater difficulty of applying the criterion for germination in the greenhouse, it is not unreasonable to assume that the appreciably longer delay in germination of pelleted seeds is due to the same difficulty. Otherwise pelleting had no adverse effect on greenhouse germination of black spruce, nor, given time (4 weeks), any adverse effect on greenhouse germination of jack pine.

It can be hypothesized that the vastly better germination of pelleted jack pine seeds in the greenhouse vs the laboratory is related to a drying effect, however slight, between "mistings" which may have contributed to "opening" the pellets for better aeration, easier emergence of radicles, etc. However, there is no evidence to support this in the greenhouse germination response of either red pine or white spruce, both of which were influenced adversely by pelleting.

As was anticipated, but to a lesser extent than was anticipated, pelleting black spruce seeds in the larger pellets required to accommodate jack pine seeds had a slight delaying effect on laboratory germination at 21C and on greenhouse germination, but, surprisingly, had no really adverse effect on final germination (Table 6). However, the larger pellet certainly inhibited germination drastically at 10C (maximum 10%) and effectively eliminated it at 32C (maximum 2%).

Again, pelleting affected jack pine germination adversely (Table 6) but even more so than previously (Tables 4 and 5). One can only assume that this was due to the larger pellet--larger in the sense that it was more spherical and hence the seed was embedded in a greater mass of the pelleting medium.

In conclusion:

1) FMC encapsulation has an unacceptably adverse effect on germination of black spruce and jack pine seeds.

2) Other than delaying germination somewhat, pelleting (Moran-Coat and Asgrow Coat) has no adverse effect on germination of black spruce seeds at 21C but delays and/or depresses it significantly at 10C and 32C.

3) Moran-Coat is more acceptable than Asgrow Coat for pelleting black spruce seeds because it has less adverse effect than the Asgrow "pellet" on germination at 10C and 32C and is better suited than the Asgrow "coating" for precision seeding.

4) Moran-Coat black spruce seeds can be stored for at least three years without any adverse effect on germination at 21C.

5) Moran-Coat pelleting affects germination of jack pine seeds adversely--unacceptably so in laboratory tests and significantly so in greenhouse trials.

6) Moran-Coat pelleting has an unacceptably adverse effect on germination of red pine and white spruce seeds.

Note that the equally good laboratory and greenhouse germination from Moran-Coat and untreated black spruce occurred at or near the optimum germination temperature (21C) and adequate moisture levels. This condition seldom occurs for any length of time in the field where temperatures and moisture conditions vary considerably throughout the growing season. Therefore, one should weigh carefully the documented germination response of pelleted black spruce seeds at 10C and 32C as well as those at 21C against the potential advantages of pelleting before opting for Moran-Coat seeds for operational seeding[9].

In the opinion of the authors, Moran-Coat pelleting of black spruce seed is an acceptable practice without any adverse effect on germination where conditions can be maintained in the optimum temperature range. It also warrants serious consideration in operational seeding *if* the potential advantages outweigh the likelihood of delayed and/or depressed germination and *if* provision is made to counteract these adverse effects, i.e., by sowing more seeds, earlier. However,

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[9]Parties interested in having seed pelleted by the Moran-Coat process should contact Moran Seeds Inc., (see footnote 3), Attention: J.L. Stuart, for current costs and schedules.

because of its adverse effects on germination, Moran-Coat pelleting is not an acceptable practice for jack pine, red pine or white spruce.

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APPENDIX

APPENDIX

A Technique for Pelleting Small Quantities of Conifer Seed

The GLFRC pelleting machine (Fig. A1) is a prototype of the Cornell pelleting machine developed by Professor W.F. Millier, Cornell University. Professor Millier supplied us with a complete set of engineering drawings to enable us to have our own machine built locally. Because certain parts were not available, some modifications were made, but it is virtually the same design.

The machine consists of a reciprocating device holding a 25-cm diameter teflon-coated round frying pan. The pan holder is made to permit two distinct types of movement of the pan, back and forth (hereafter referred to as agitation) and circular (hereafter referred to as rotation). The machine is powered by a horizontally mounted variable-speed 3/4-horsepower motor which provides the drive to turn the device holding the pan. Both rotation and agitation speeds can be adjusted while the machine is moving. Proper action is necessary to ensure constant motion of the seeds for uniform distribution over the pan.

The binder is a polyvinyl alcohol (PVA) called Gelvatol 40-20, manufactured by Monsanto. It comes in a crystaline form and is water soluble. The concentration of the solution depends on the required strength of the pellet. If the solution is too weak the pellet may not stand handling; if it is too strong the pellet may not break down. For black spruce, a 5% solution is quite adequate. The binder is applied with a Wagner 71507 piston-type spray gun with a 0.4-mm aperture nozzle. The gun is adjusted to deliver the finest spray possible, which remains constant throughout the pelleting process.

The pelleting medium used is a very fine silica called Berkeley Fine Dry Sand obtained from the Pennsylvania Glass Corporation, Pittsburgh. The sand is sieved through a series of Tyler screens, mesh numbers 140, 170 and 200. Material which passes through the smallest screen, number 200, is suitable for pelleting black spruce. Coarser grains that pass through the 170 screen and are retained on the 200 screen are suitable for pelleting larger seeds, e.g., jack pine and red pine. Generally speaking, the larger the seed the coarser the grain size that can be used to produce the pellet.

The actual pelleting process is explained in the following series of steps and observations:

1) Place the desired number of seeds evenly over the pan, no more than one layer thick.

2) Turn on the machine and adjust both the rotation and agitation speeds so that the seeds cover the bottom of the pan uniformly.

(continued)

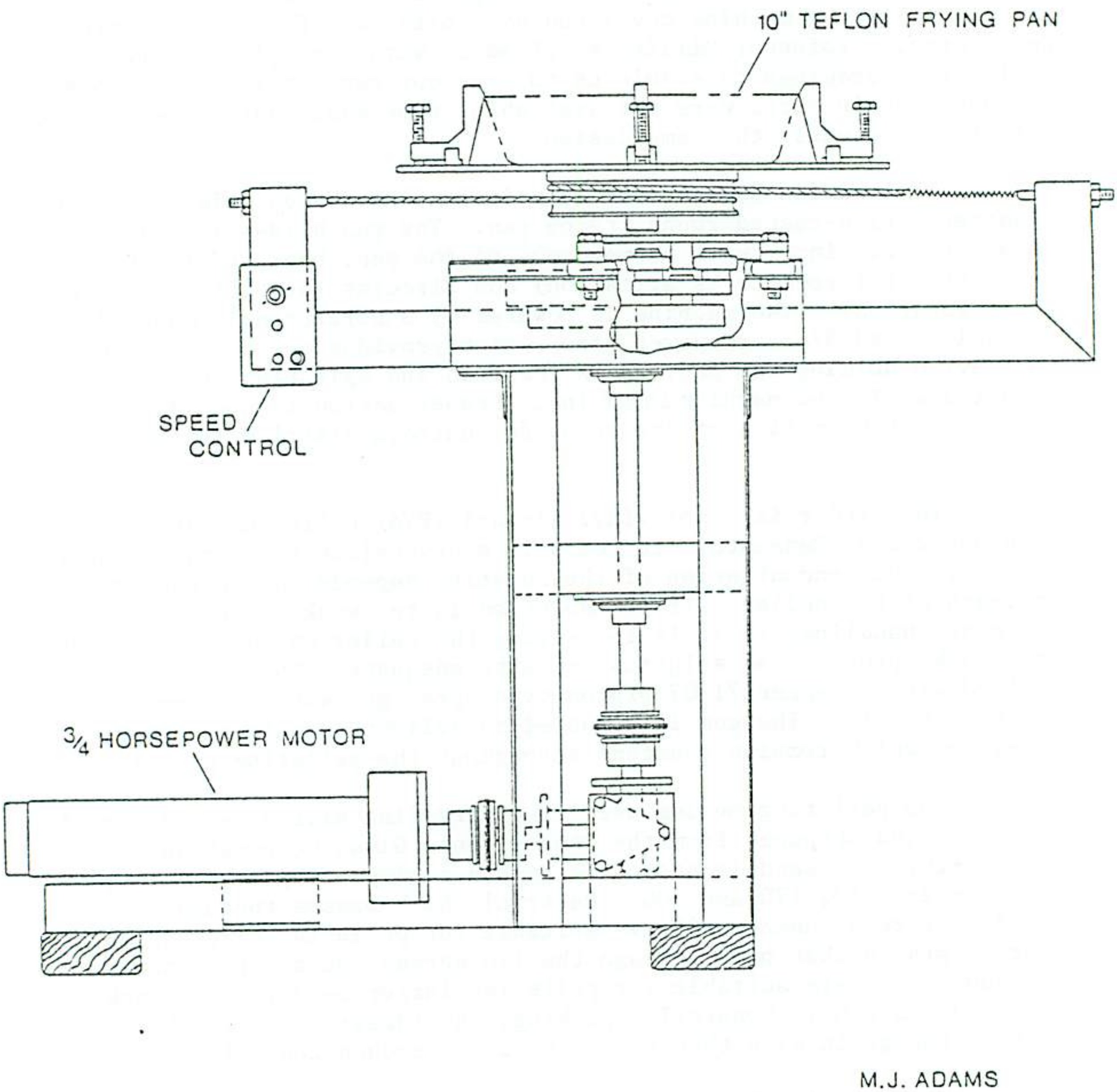

Figure A1. The GLFRC pelleting machine (after the Cornell University pelleting machine developed by W. F. Millier).

3) Position the spray gun approximately 45 cm from, and aimed directly at, the centre of the pan. The first burst of spray should be just enough to dampen the seeds; too much binder will cause the seeds either to adhere to one another or to stick to the bottom of the pan. Repeat this initial light spraying several times until the binder coats the seeds uniformly.

4) After the seeds are uniformly coated with binder, lightly dust them with the silica sand medium as evenly as possible. The sand is applied with a shaker at about the same rate you would apply salt to food. More binder should be applied immediately after adding the sand--then more sand, and so on. This is the most critical stage of pellet development. Applying too much sand will cause disorder in seed movement which eventually causes a "snowball effect" where grains of sand adhere to each other, forming seedless pellets. Too much binder causes the seeds to stick together and produces pellets containing more than one seed. The first five minutes are usually the most frustrating--it seems as if nothing is happening--so the tendency is to overcompensate by adding too much sand. The technique cannot be rushed, and patience is essential.

5) After five minutes increase the amount of binder slightly but not the rate or amount of sand. When increasing the amount of binder, spray in several short bursts (approximately 5 seconds in duration) as opposed to a single long burst. This will ensure even coverage.
   NOTE: The process can be stopped at any time so that one can observe pellet development.

6) As the pellets are "building up", a film forms on the bottom of the pan. This film is excess sand which is not picked up by the pellets. The deposit, which increases as the process continues, is not detrimental but requires constant adjustment of rotation speed to compensate for increased friction. To avoid improper seed movement as a result of excessive sand deposition, periodic pan changes are suggested (approximately every 20 minutes).

7) After about 30 minutes pellet development is quite evident. At this stage, the amount of binder applied becomes less critical but the application of sand should be minimal.

8) As pellets approach desired size they are "screened off" in a series of screens, and the smaller pellets which pass through the screens are put back into the pan and

(continued)

"built up" to the required size. Over-sized pellets are dissolved in water, and the seeds are air dried and returned for repelleting. After screening, the seeds are rolled back and forth on a metal cookie sheet for several minutes to harden the coat and round off any irregularities from the screening. The pellets are then placed in an oven at 38C for about 12 hours to achieve maximum hardness.

The time involved in the pelleting process depends on the type and number of seeds involved. As an example, the pelleting of two thousand black spruce seeds would take from 1.5 to 2 hours.

By this technique color-coded pellets containing various species of seed have been produced with no detrimental effects simply by adding food coloring to the binding solution. However, the best results are obtained by dusting the pellets while they are still damp with a powdered dye, produced by A.R. Monteith Limited (2615 Wharton Glen Ave., Mississauga, Ont.).

Currently we are producing an exceptionally spherical pellet similar to the Moran pellet developed by Moran Seeds, Inc., California. Further development is required to reduce pelleting time and to ensure that pellets can be reproduced which are consistent in size, shape and firmness. Meanwhile, the data tabulated below indicate that, although GLFRC-pelleted black spruce seeds do not germinate as quickly as untreated (control) seeds or Moran-Coat seeds, the GLFRC pellet, like the Moran pellet, has no significant adverse effect on final germination.

Percent germination[a] of black spruce seed (Ontario Seed Zone 3E) at 21C.

Days since seeding	Control (untreated)	Pelleted	
		Moran[b]	GLFRC
7	85	0	0
14	|98	92	62
21	|98 a	|96 a b	|94 b
28	|98 a	|96 a	|96 a

[a] There is no significant difference ($p = 0.05$) between values joined by the same vertical line, or between those with the same lower case letter(s) in any given horizontal line.

[b] From Table 5.