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Enhancing the Container-Stock Seeding Efficiency in Forest Nurseries

by

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Abstract

By modelling seed-count distributions per seedling tray, it is possible to determine the optimal seeding rate that leads to lowest labour costs for maximal container-stock production. The optimal seeding rate decreases with increasing seeding precision, seed viability, and seed costs. These results are illustrated for Paper pots and Jiffy pots seeded with black spruce. Survey-type information is provided for other species (jack pine, red pine, Norway spruce, white spruce).

Key Words: Seeding, seed costs, transplanting, thinning, Binomial distribution.

Résumé

En simulant la distribution des semences dans les récipients, il est possible de déterminer le taux optimum de semences qui permet d'obtenir le plus bas coût de main-d'oeuvre et la production maximale de semis en récipient. Le taux optimum de semences diminue selon l'accroissement de la précision de l'ensemencement, le taux de germination et les coûts des semences. Ces résultats sont démontrés pour les récipients "Paper pots" et "Jiffy pots" dans lesquels on a ensemencé de l'épinette noire. Une information préliminaire est disponible pour d'autres espèces (pin gris, pin rouge, épinette de Norvège et épinette blanche).

Mots-clés: ensemencement, coûts des semences, transplantation, éclaircie, distribution binomiale.

Introduction

Increasing reforestation in Canada and elsewhere has substantially increased the demand for high-quality seedling stock, particularly for spruce and pine. To meet this demand, forest nurseries have increased their annual production of container stock. Currently, efforts are underway to optimize the production efficiency of existing facilities. "Overseeding" or "underseeding" are the main sources of inefficiency: multiple-seedling pots waste seed, are unacceptable for biological reasons, and require "thinning." Empty pots are wasteful of space, materials, and shipping, and require "transplanting." Obviously, one would like to maximize seedling production at minimal cost. The problem is how to deliver seeds to each seedling pot such that the combined seed, thinning and transplanting cost is minimized, and each pot contains exactly one viable seedling. To address this problem, two probabilities need to be considered: the probability of $k = 0, 1, 2, 3, \dots$ seeds per pot, and the probability that $j = 0, 1, 2, \dots, k$ seeds form seedlings. An assessment of these probabilities should allow one to estimate the expected number of seedlings per pot. These numbers, in turn, are useful for estimating the combined seed, thinning and transplanting cost for producing trays with exactly one seedling in each pot.

The objective of this paper is to show how such costs were estimated at the Kingsclear Provincial Tree Nursery near Fredericton, New Brunswick. This nursery has an annual container-stock production of approximately 18 million seedlings. At present, 50% of this production is black spruce (*Picea mariana* [Mill.] B.S.P.), and 30% is jack pine (*Pinus banksiana* Lamb.). The remainder is red pine (*Pinus resinosa* Ait.), Norway spruce (*Picea abies* [L.] Karst.), and white spruce (*Picea glauca* [Moench] Voss).

Experience at the Kingsclear Forest Nursery favours the production of single-seedling pots. Compared with the total cost of growing and delivering container stock (about \$130 per 1 000 seedlings), combined seed, thinning and transplanting costs tend to be small (about \$5 to \$10 per 1 000 seedlings). The use of genetically improved seed stock, however, increases these costs and demands a tight control of the seeding operation.

Pot Types and Seeding Devices

Two types of seedling containers are used at Kingsclear: Paper pots and Jiffy pots. Sixty to seventy percent of the total production is with Paper pots. These pots come in magazines of compressed sets (336 hexagonal pots per set, 12 rows and 28 columns). Each set is expanded, and placed into a seedling tray (one set per tray, with the actual pot-by-pot arrangement somewhat irregular). The tray is then conveyed into a peat-filling line prior to seeding.

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Jiffy pots start as compressed peat discs contained within biodegradable webbing. Each seedling tray (same size as the Paper-pot trays) holds 280 pots all arranged in a rectangular pattern (10 rows, 28 columns). The top of each disc is concave to promote seed drop towards centre. After seeding, the trays are covered with moist paper and grit to prevent seed displacement during watering and pot expansion.

Two mechanical seeders are in use: (1) the Lannen Drum Seeder (a straight-line drum seeder), and (2) the Hamilton Seeder (a tube seeder). Both seeders can seed either pot type, but the Lannen Drum Seeder is used to seed the Paper pots. This device operates as follows: Seeds are picked up by vacuum action from a tray that is in contact with a cylindrical drum (length of the drum $\approx$ width of seedling tray). The drum contains small and equal-sized holes for seed pick-up, all arranged along a straight line (diameter of pick-up holes $<$ seed size; number of pick-up holes = number of pots along the width of the tray). Seeds are dropped on to the pots, one row at a time. The average number of seeds clustered at each seeding head is controlled by vacuum adjustment to within ± 0.25 seeds per pot.

The Hamilton seeder also operates by vacuum. With this device, seeds are picked up with adjustable seeding heads mounted on a metal bar. Seeds are lifted from a seed tray and are dropped into plastic tubes. These tubes direct the seeds to each pot (there are as many tubes and nipples on the seeder bar as there are pots in two rows).

Seed Distributions

The staff at the Kingsclear Nursery determined actual seed counts per pot for a number of seedling trays, by pot type and species (Table 1). Typical seed distributions are shown in Figure 1 for black spruce. Evidently, these distributions vary with average seeding rate ($\bar{x}$) and seeder. Plots of seed-count variance (s^2) versus seed weight (number of

seeds per gram) and seeding rate are given in Figure 2. The main sources of seed-count variance are (i) variations of the number of seeds clustered at the seeding head (variations in seed size, shape and orientation being partly responsible) and (ii) irregular spacings of the Paper pots. Minor variations arise from seeds falling into cracks between the pots, and from grit (seed purity is 99% or better).

An examination of overall seed number pattern suggested that the seed distributions can be modelled by an appropriate frequency distribution. Two models were considered: (1) the Poisson probability distribution, and (2) the Binomial probability distribution.

The Poisson distribution (Johnson and Kotz 1969) is a one-parameter model, and is given by

$$\Pr(x=k) = \frac{e^{-\bar{x}} \bar{x}^k}{k!},$$

where k is the number of seeds per cell. The Binomial distribution is a two-parameter model given by

$$\Pr(x=k) = \frac{N!}{k!(N-k)!} p^k (1-p)^{N-k},$$

where p and N can be estimated from

$$p = 1 - s^2 / \bar{x}, \text{ and } N = \bar{x} / p = \bar{x}^2 / (\bar{x} - s^2). \quad [1a,b]$$

Besides accepting p and N as "parameters", one can interpret p and N in a Binomial fashion: N would be equivalent to a set number of successive but independent trials to deliver k seeds to each pot, and p would be the probability of a seed delivered to each pot in any one of the N trials. During actual seeding, the N trials would merge into a single action. For a perfect seeder, $p = 1$ and $N = k$.

Table 1. Seed and seeding information for black spruce (bSp), white spruce (wSp), Norway spruce (nSp), jack pine (jP) and red pine (rP) at the Provincial Forest Nursery, Kingsclear, New Brunswick.

		bSp	wSp	nSp	jP	rP
Seeds g⁻¹						
Wild seeds	average	729	449	156	280	112
	range	670-787	374-523	130-182	156-454 ^a	66-156 ^a
Orchard seeds	average	602	—	—	294	—
Germination rates						
Germ. chamber (%)		93-98	—	—	92-97	—
Greenhouse (%)		78	—	—	88	—
Paper pots^b						
Trays sampled		118	18	11	—	24
Seeding rate ^d	average	2.21	2.21	1.98	—	1.98
	range	1.63-3.24	1.46-2.85	1.84-2.11	—	1.90-2.06
$\bar{x} \pm \text{SE(Poisson)}$		57 $\pm$ 3	57 $\pm$ 9	203 $\pm$ 0.37	—	222 $\pm$ 20
$\bar{x} \pm \text{SE(Binomial)}$		16 $\pm$ 1	33 $\pm$ 7	54 $\pm$ 13	—	47 $\pm$ 5
$\bar{p} \pm \text{SE}$		0.43 $\pm$ 0.01	0.38 $\pm$ 0.02	0.66 $\pm$ 0.04	—	0.69 $\pm$ 0.02
$\bar{N} \pm \text{SE}$		5.4 $\pm$ 0.1	6.2 $\pm$ 0.4	3.1 $\pm$ 0.2	—	2.9 $\pm$ 0.09
Jiffy pots^c						
Trays sampled		35	—	—	9	—
Seeding rate	average	2.67	—	—	1.40	—
	range	1.56 $\pm$ 3.68	—	—	0.96 $\pm$ 1.95	—
$\bar{x} \pm \text{SE(Poisson)}$		167 $\pm$ 8	—	—	476 $\pm$ 37	—
$\bar{x} \pm \text{SE(Binomial)}$		44 $\pm$ 5	—	—	67 $\pm$ 14	—
$\bar{p} \pm \text{SE}$		0.66 $\pm$ 0.02	—	—	0.91 $\pm$ 0.93	—
$\bar{N} \pm \text{SE}$		4.3 $\pm$ 0.3	—	—	1.6 $\pm$ 0.2	—

^aSchopmeyer 1974. ^bSeeded with a straight-line seeder. ^cSeeded with a tube seeder. ^dSeeding rate = average number of seeds per pot per seedling tray.

Figure 1. Typical seed distributions for black spruce on Paper pots seeded with a straight-line drum seeder, and on Jiffy pots seeded with a tube seeder. Superimposed on each histogram are the best-fitted Poisson and Binomial distributions.

The Poisson model is solely dependent on $\bar{x}$. Hence, this model cannot be used for assessing differences between species, seeding device and seed size. The Binomial model, in contrast, offers flexibility in this respect because its two parameters are related to both $\bar{x}$ and s^2 .

The chi-square test was employed to examine the Poisson and the Binomial models for their ability to simulate actual seed count distributions. Chi-square scores were generated from

$$\chi^2 = \sum_{k=1}^M (O_k - E_k)^2 / E_k,$$

where O_k = observed counts, E_k = simulated counts (Binomial or Poisson), and M is maximum number of seeds found in any pot. The resulting scores for black spruce are presented in Figure 3. Average scores ($\bar{\chi} \pm SE$) for all the

species and seeding arrangements tested are listed in Table 1. Evidently, the scores achieved with the Binomial model are significantly smaller than the scores achieved with the Poisson model. Note that the Paper-pot seed counts can form better with the Binomial model than the Jiffy-pot seed counts, i.e.

$$\chi^2 (\text{Paper pot}) < \chi^2 (\text{Jiffy pot}).$$

This is in spite of the fact that

$$s^2 (\text{Paper pot}) > s^2 (\text{Jiffy pot})$$

at comparable seeding rates.

Values for N and p (each generated from $\bar{x}$ and s^2 via Eq. [1a,b]) are plotted in Figure 4 for black spruce against seeding rate and each pot type. Superimposed onto these plots are the linear regressions

Figure 2. Scatter plot of seed count variance per pot (s^2) versus number of seeds per gram of seeds (top), and seeding rate $\bar{x}$ (bottom). Lines and equations give the best-fitted regressions for s^2 (common slopes) for Paper pots and Jiffy pots.

$$N = a_N + b_N \bar{x} \text{ and } p = a_p + b_p \bar{x}$$

with a_i as intercept, and b_i as regression coefficient ($i = N, p$). These regressions have a high r^2 for Jiffy-pot seeding, and a low r^2 for Paper-pot seeding.

Having estimated N and p as function of seeding rate, one can simulate the expected seed count distributions. The calculated values for N , however, are generally non-integer, but N must be integer for Binomial calculations. This problem can be resolved (approximately) by substituting $N!$, $k!$, and $(N-k)!$ in Equation [2] with $\Gamma(N+1)$, $\Gamma(k+1)$, and $\Gamma(N-k+1)$, respectively (Γ denotes the Gamma function). In this way, $\Pr(k)$ is calculable when N is not integer. The result of doing so is shown in Figure 5. Here, the number of pots (out of 1000 pots) containing 0, 1, 2, 3, and 4 seeds are plotted against $\bar{x}$, by pot type. Superimposed are actual pot counts (Poisson-expected pot counts are included for comparison). These results suggest that the Binomial model is reliable in predicting the number of vacant pots ($k=0$), and pots with one seed ($k=1$) for both pot types. The frequencies for finding 2 seeds per pot are generally under-estimated, and the frequencies for finding 4 seeds per pot are generally overestimated.

Figure 3. Scatter plot of the Chi-square scores achieved by fitting the Poisson and Binomial models to actual seed counts per pot as function of seeding rate, Paper pots and Jiffy pots (black spruce).

Seedling Counts

An adjustment must be made to convert seed counts into seedling counts, because seed germination is $< 100\%$, especially under greenhouse conditions (Table 1). This adjustment is made by multiplying the expected seed counts with the expected probability of seed germination. Formally, this can be done by setting

$$\Pr(j \text{ viable seedlings pot}^{-1}) = \sum_{k=j}^N \Pr(k \text{ seeds pot}^{-1}) \Pr(j \text{ seeds germinate pot}^{-1}).$$

Here, seed germination and placement of k seeds per pot are considered to be independent events. Denoting the germination rate by g [$g = \Pr(\text{seed germinates})$], and assuming Binomial behaviour for seed germination, it follows that

$$\Pr(j \text{ viable seedlings pot}^{-1}) = \sum_{k=j}^N \Pr(k \text{ seeds pot}^{-1}) g^j (1-g)^{k-j} \frac{k!}{j!(k-j)!}.$$

To illustrate, the probability of an empty cell (a cell without a viable seedling) is given by

$$\begin{aligned} \Pr(0 \text{ seedlings pot}^{-1}) = & \Pr(0 \text{ seed pot}^{-1}) \\ & + \Pr(1 \text{ seed pot}^{-1}) * (1-g) \\ & + \Pr(2 \text{ seeds pot}^{-1}) * (1-g)^2 \\ & \dots + \Pr(k \text{ seeds pot}^{-1}) * (1-g)^k. \quad [4] \end{aligned}$$

Figure 5. Scatter plots for the actual number of pots containing k seeds (out of 1 000 pots) versus seeding rate (black spruce, Paper pots and Jiffy pots). Superimposed are the Binomial predictions, with p and N determined as in Figure 4.

Figure 6. Number of empty pots (per 1 000 pots) versus seeding rate at various germination rates (black spruce, Paper pots and Jiffy pots).

As shown in Figure 6, there are always empty pots to be filled by transplanting seedlings from overstocked pots nearby. Experience with black spruce has shown that transplanting should be done before lateral root development 3 to 5 weeks after germination (transplanting takes 20 to 30 seconds per pot). Doing so assures that the growth of the transplanted and undisturbed seedlings remains the same (unpublished Kingsclear survey trial, 1989).

Optimal Jiffy-pot seeding appears to be more economical than optimal Paper-pot seeding at high germination rates. This difference may be caused by tube seeding versus straight-line seeding. Switching the seeders, however, may not fully reverse the pattern because of the irregular Paper-pot spacings. Eliminating this irregularity should reduce the seed-count variance and, hence, lower the Paper-pot production cost at favourably high germination rates.

Further savings could be achieved with increased seeding precision. This can possibly be done by using seeds artificially enlarged with water-dispersible clay for example. Such a seed-coating process is not yet available in Canada, but is used elsewhere (e.g. Hilleshög, AB; Sweden).

Most of this work has dealt with black spruce, but the same principles apply to other species. For example, optimal seeding rates for jack pine, red pine, Norway spruce, and white spruce and any germination rate can be predicted from

Figure 7. Combined seed, thinning, and transplanting cost per 1 000 pots (each with exactly one viable black spruce seedling) as function of seeding rate for various germination rates for: Paper pots (left), Jiffy pots (right); wild seeds ———, orchard seeds ———.

Figure 8. Optimal seeding rate (bottom left) and optimal combined seed, thinning and transplanting cost (top) for black spruce (Paper pots, Jiffy pots, and perfect seeding) as function of germination rate for various seed costs.

Table 1 by way of Equation 4. It is prudent, however, to reestablish p and N as function of $\bar{x}$ by trial seedlings ranging from $\bar{x} = 1$ to 4 for each species, pot type, and seeder. Doing so is critical for precisely determining the optimal seeding conditions as affected by labour costs, seed cost, and germination.

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