Influence of Seed Germination Percentage and Number of Seeds Sown per Cell on Expected Numbers of Seedlings in Plug Trays

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ADDITIONAL INDEX WORDS. bedding plant plugs, binomial distribution, statistical analysis

SUMMARY. Binomial probability distributions were used to determine the effects of percent seed germination and number of seeds sown per cell on expected numbers of seedlings in plug trays. Expected numbers of empty cells in five types of plug trays (128, 273, 338, 406, and 512 cells/tray) were calculated for cases where one to seven seeds were sown per cell and seed germination ranged from 50% to 95%. Generally, one additional seed was required per plug cell for each 10% decrease in the germination percentage in order to attain the same number of filled cells per plug tray. Expected frequencies were calculated for the number of seedlings in plug trays when one to five seeds were sown per cell and seed germination ranged from 50% to 95%. When the number of seeds sown per cell remained constant, uniformity in seedling number per cell increased as the germination percentage increased. When percent seed germination remained constant and the number of seeds sown per cell was increased, the percentage of cells with at least one seedling increased, whereas the uniformity in seedling number per cell decreased. Additional examples are presented in the article on the utility of binomial distributions in determining expected number of seedlings.

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Massachusetts Agricultural Experiment Station publication no. 3328. This research was funded in part by the Cooperative State Research, Extension, Education Service, U.S. Department of Agriculture, Massachusetts Agricultural Experiment Station, under Project 746.

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Plugs are used worldwide for producing seedlings of bedding plants, cut flowers, and vegetables. Plug production began in the late 1960s and currently accounts for about 90% of all bedding plants produced in the United States and Canada (Styer and Koranski, 1997).

Seed viability and vigor are critical issues for plug growers. Plug growers desire to obtain a minimum of 90% usable seedlings from sowing a single seed in each plug cell (McDonald, 1996). Seed companies have responded to plug growers' demands for high-quality seed and have developed specialty seed lots with higher germination percentages (≥85%), accelerated germination rates, greater seedling uniformity, and easier handling of seeds for mechanical seeders than standard seed lots (Halmer, 2000; McDonald, 2000).

Efforts to improve seed quality have focused mainly on economically important bedding plant crops such as impatiens (*Impatiens walleriana*), pansy (*Viola ×wittrockiana*), and petunia (*Petunia ×hybrida*). However, germination problems persist for many seed-propagated species. For example, many herbaceous perennials exhibit erratic and/or poor germination, resulting in suboptimal numbers of usable seedlings per plug tray when only one seed is sown per cell (Perry, 1998).

To obtain the desired number of seedlings per plug tray, growers may increase the number of plug trays per item and use the extra plants to fill in empty cells (patching), or they may sow multiple seeds per cell (Pyle, 2000). The actual method chosen by growers depends on seed cost, percent seed germination, and the desirability of having multiple seedlings per cell (Pyle, 2000).

Multiseeded pellets of some annuals such lobelia (*Lobelia erinus*), portulaca (*Portulaca grandiflora*), and sweet alyssum (*Lobularia maritima*) are manufactured to increase the precision and speed of sowing several seeds per cell using mechanical seeders (Halmer, 2000). However, most of the bedding plant, cut flower, and vegetable seeds sold commercially are packaged as bulk lots of individual seed.

Little published information exists on the relationships between percent seed germination, number of seeds sown per cell, and expected numbers of seedlings. Binomial probability distributions are applicable to experiments in which samples of any size are drawn from populations and one of only two possible outcomes can occur (Sokal and Rohlf, 1981). Examples of variables which fit binomial distributions are percent germination (germinated seeds vs. nongerminated seeds) and percent usable seedlings (phenotypically normal seedling vs. abnormal or dead seedling). The following research was performed to discern trends and relationships between germination percentage, number of seeds sown per cell, and expected numbers of seedlings in plug trays using binomial probability distributions.

Materials and methods

Binomial expansions were generated for sample sizes ranging from one to ten (Table 1). Relative expected frequencies for obtaining an empty plug cell were calculated for germination percentages ranging from 5% to 95% and with one to 10 seeds sown per cell (Table 2). For example, assume an infinitely large population of seeds of which 75% are capable of germinating. If the sample size is four, then

Table 1. Binomial expansions for sample sizes ranging from one to ten.

Binomial term[z]	Binomial expansion
$(p + q)^1$	$1p + 1q$
$(p + q)^2$	$1p^2 + 2pq + 1q^2$
$(p + q)^3$	$1p^3 + 3p^2q + 3pq^2 + 1q^3$
$(p + q)^4$	$1p^4 + 4p^3q + 6p^2q^2 + 4pq^3 + 1q^4$
$(p + q)^5$	$1p^5 + 5p^4q + 10p^3q^2 + 10p^2q^3 + 4pq^4 + 1q^5$
$(p + q)^6$	$1p^6 + 6p^5q + 15p^4q^2 + 20p^3q^3 + 15p^2q^4 + 6pq^5 + 1q^6$
$(p + q)^7$	$1p^7 + 7p^6q + 21p^5q^2 + 35p^4q^3 + 35p^3q^4 + 21p^2q^5 + 7pq^6 + 1q^7$
$(p + q)^8$	$1p^8 + 8p^7q + 28p^6q^2 + 56p^5q^3 + 70p^4q^4 + 56p^3q^5 + 28p^2q^6 + 8pq^7 + 1q^8$
$(p + q)^9$	$1p^9 + 9p^8q + 36p^7q^2 + 84p^6q^3 + 126p^5q^4 + 126p^4q^5 + 84p^3q^6 + 36p^2q^7 + 9pq^8 + 1q^9$
$(p + q)^{10}$	$1p^{10} + 10p^9q + 45p^8q^2 + 120p^7q^3 + 210p^6q^4 + 252p^5q^5 + 210p^4q^6 + 120p^3q^7 + 45p^2q^8 + 10pq^9 + 1q^{10}$

[z] p = Probability that germination will occur; q = probability that germination will not occur.

the expected frequencies of samples with four germinated seeds, three germinated and one nongerminated seeds, two germinated and two nongerminated seeds, one germinated and three nongerminated seeds, and four nongerminated seeds are calculated by expanding the binomial $(p + q)^n$, where p is the probability of occurrence of germinating, q is the probability of not germinating ($q = 1 - p$), and n is the sample size. For $p = 0.75$ and $n = 4$, then $(0.75 + 0.25)^4$ or $1(0.75)^4 + 4(0.75)^3(0.25) + 6(0.75)^2(0.25)^2 + 4(0.75)(0.25)^3 + 1(0.25)^4$. The expected distribution of outcomes in random samples of four seeds randomly selected from a population with 75% germination will therefore be (respectively) 0.3164 + 0.4219 + 0.2109 + 0.0469 + 0.0039 (Sokal and Rohlf, 1981). The probability of obtaining an empty cell (four nongerminated seeds) would thus be 0.0039 (Table 2).

The relative expected frequency data in Table 2 were used to calculate the expected number of empty cells in five types of plug trays (128, 273, 338, 406, and 512 cells/tray) when one to seven seeds were sown per cell and seed germination ranged from 50% to 95% (Table 3). Lastly, the binomial expansions in Table 1 were used to calculate expected frequencies of seedlings in plug trays when one to five seeds were sown per cell and seed germination ranged from 50% to 95% (Table 4).

Results and discussion

The values presented in Table 3 are absolute expected frequencies and assume 100% survival of germinated seeds with no losses due to disease or other causes. Generally, one additional seed must be sown per cell for each 10% decrease in the germination percentage in order to attain the same number of filled cells per tray. Therefore, the expected number of empty cells per tray would be approximately the same with 90% germination and two seeds per cell, 80% germination and three seeds per cell, 70% germination and four seeds per cell, and 60% germination and five seeds per cell (Table 3). Also, the law of diminishing returns was applicable to sowing of multiple seeds per cell. For example, when seed germination is 80%, each 512 tray would be expected to contain 82 more usable plugs (with seedlings) when two seeds are sown per cell than when one seed is sown per cell (102 – 20 = 82). However, when three seeds are sown per cell instead of two, there is a gain of only 16 additional usable plugs in a 512 tray. Similarly, when four seeds are sown per cell instead of three, only three additional usable plugs are obtained per tray.

The expected frequency distributions of seedlings for various germination percentages and number of seeds sown per cell are shown in Table 4. The expected frequency distribution was symmetrical when germination percentage is 50%, but skewness increased as percent germination deviated from 50%. For example, with four seeds sown per cell and 50% germination, the expected percentages of cells with zero, one, two, three, or four seedlings would be 6.3%, 25.0%, 37.5%, 25.0%, and 6.3%, respectively. In contrast, when four seeds are sown per cell and 90% of the seeds germinated, the expected percentages of cells with zero, one, two, three, or four seedlings would be (respectively) 0.0%, 0.4%, 4.9%, 29.2%, and 65.6% (Table 4). Two important relationships can be discerned from Table 4.

1) When the number of seeds sown per cell is held constant, uniformity in seedling number per cell increases as the germination percentage increases from 50% to 95%.

2) When the germination percentage is held constant and the number of seeds sown per cell is increased, the percent-

Table 2. Expected frequencies of empty cells (no seedlings) when sampling from infinitely large populations with different seed germination percentages and sowing one to ten seeds per cell.

Seeds per cell	Germination (%)																		
(no.)	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
1	0.9500	0.9000	0.8500	0.8000	0.7500	0.7000	0.6500	0.6000	0.5500	0.5000	0.4500	0.4000	0.3500	0.3000	0.2500	0.2000	0.1500	0.1000	0.0500
2	0.9025	0.8100	0.7225	0.6400	0.5625	0.4900	0.4225	0.3600	0.3025	0.2500	0.2025	0.1600	0.1225	0.0900	0.0625	0.0400	0.0225	0.0100	0.0025
3	0.8574	0.7290	0.6141	0.5120	0.4219	0.3430	0.2746	0.2160	0.1664	0.1250	0.0911	0.0640	0.0429	0.0270	0.0156	0.0080	0.0034	0.0010	0.0001
4	0.8145	0.6561	0.5220	0.4096	0.3164	0.2401	0.1785	0.1296	0.0915	0.0625	0.0410	0.0256	0.0150	0.0081	0.0039	0.0016	0.0005	0.0001	<0.0001
5	0.7738	0.5905	0.4437	0.3277	0.2373	0.1681	0.1160	0.0778	0.0503	0.0313	0.0185	0.0102	0.0053	0.0024	0.0010	0.0003	0.0001	<0.0001	<0.0001
6	0.7351	0.5314	0.3771	0.2621	0.1780	0.1176	0.0754	0.0467	0.0277	0.0156	0.0083	0.0041	0.0018	0.0007	0.0002	0.0001	<0.0001	<0.0001	<0.0001
7	0.6983	0.4783	0.3206	0.2097	0.1335	0.0824	0.0490	0.0280	0.0152	0.0078	0.0037	0.0016	0.0006	0.0002	0.0001	<0.0001	<0.0001	<0.0001	<0.0001
8	0.6634	0.4305	0.2725	0.1678	0.1001	0.0576	0.0319	0.0168	0.0084	0.0039	0.0017	0.0007	0.0002	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
9	0.6302	0.3874	0.2316	0.1342	0.0751	0.0404	0.0207	0.0101	0.0046	0.0020	0.0008	0.0003	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
10	0.5987	0.3487	0.1969	0.1074	0.0563	0.0282	0.0135	0.0060	0.0025	0.0010	0.0003	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Table 3. Expected number of empty cells as a function of plug tray configuration, number of seeds sown per cell, and percent seed germination. Values calculated from the relative expected frequencies presented in Table 2.

Cells/ tray (no.)	Seeds/cell (no.)						
	1	2	3	4	5	6	7
50% germination							
128	64	32	16	8	4	2	1
273	137	68	34	17	9	4	2
338	169	85	42	21	11	5	3
406	203	102	51	25	13	6	3
512	256	128	64	32	16	8	5
55% germination							
128	58	26	12	5	2	1	<1
273	123	55	25	11	5	2	1
338	152	68	31	14	6	3	1
406	183	82	37	17	8	4	2
512	230	104	47	21	10	4	2
60% germination							
128	51	20	8	3	1	1	<1
273	109	44	17	7	3	1	<1
338	135	54	22	9	3	1	1
406	162	65	26	10	4	2	1
512	205	82	33	13	5	2	1
65% germination							
128	45	16	5	2	1	<1	<1
273	96	33	12	4	1	1	<1
338	118	41	14	5	2	1	<1
406	142	50	17	6	2	1	<1
512	179	63	22	8	3	1	<1
70% germination							
128	38	12	3	1	<1	<1	<1
273	82	25	7	2	1	<1	<1
338	101	30	9	3	1	<1	<1
406	122	37	11	3	1	<1	<1
512	154	46	14	4	1	<1	<1
75% germination							
128	32	8	2	1	<1	<1	<1
273	68	17	4	1	<1	<1	<1
338	85	21	5	1	<1	<1	<1
406	102	25	6	2	<1	<1	<1
512	128	32	8	2	1	<1	<1
80% germination							
128	26	5	1	<1	<1	<1	<1
273	55	11	2	<1	<1	<1	<1
338	68	14	3	1	<1	<1	<1
406	81	16	3	1	<1	<1	<1
512	102	20	4	1	<1	<1	<1
85% germination							
128	19	3	<1	<1	<1	<1	<1
273	41	6	1	<1	<1	<1	<1
338	51	8	1	<1	<1	<1	<1
406	61	9	1	<1	<1	<1	<1
512	77	12	2	<1	<1	<1	<1
90% germination							
128	13	1	<1	<1	<1	<1	<1
273	27	3	<1	<1	<1	<1	<1
338	34	3	<1	<1	<1	<1	<1
406	41	4	<1	<1	<1	<1	<1
512	51	5	1	<1	<1	<1	<1
95% germination							
128	6	<1	<1	<1	<1	<1	<1
273	14	1	<1	<1	<1	<1	<1
338	17	1	<1	<1	<1	<1	<1
406	20	1	<1	<1	<1	<1	<1
512	26	1	<1	<1	<1	<1	<1

Table 4. Influence of number of seeds sown per cell and percent seed germination on the expected frequencies of seedlings in germination trays. Expected frequencies expressed as percentages.

Seeds/ cell (no.)	Seedlings/ cell (no.)	Germination (%)									
		50	55	60	65	70	75	80	85	90	95
1	0	50.0	45.0	40.0	35.0	30.0	25.0	20.0	15.0	10.0	5.0
	1	50.0	55.0	60.0	65.0	70.0	75.0	80.0	85.0	90.0	95.0
2	0	25.0	20.2	16.0	12.2	9.0	6.2	4.0	2.2	1.0	0.2
	1	50.0	49.5	48.0	45.5	42.0	37.5	32.0	25.5	18.0	9.5
	2	25.0	30.3	36.0	42.3	49.0	56.3	64.0	72.3	81.0	90.3
3	0	12.5	9.1	6.4	4.3	2.7	1.6	0.8	0.3	0.1	0.0
	1	37.5	33.4	28.8	23.9	18.9	14.1	9.6	5.7	2.7	0.7
	2	37.5	40.8	43.2	44.4	44.1	42.2	38.4	32.5	24.3	13.5
	3	12.5	16.6	21.6	27.5	34.3	42.2	51.2	61.4	72.9	85.7
4	0	6.3	4.1	2.6	1.5	0.8	0.4	0.2	0.0	0.0	0.0
	1	25.0	20.0	15.4	11.1	7.6	4.7	2.6	1.1	0.4	0.0
	2	37.5	36.8	34.6	31.1	26.5	21.1	15.4	9.8	4.9	1.4
	3	25.0	29.9	34.6	38.4	41.2	42.2	41.0	36.8	29.2	17.1
	4	6.3	9.2	13.0	17.9	24.0	31.6	41.0	52.2	65.6	81.5
5	0	3.1	1.8	1.0	0.5	0.2	0.1	0.0	0.0	0.0	0.0
	1	15.6	11.3	7.7	4.9	2.8	1.5	0.6	0.2	0.0	0.0
	2	31.3	27.6	23.0	18.1	13.2	8.8	5.1	2.4	0.8	0.1
	3	31.3	33.7	34.6	33.6	30.9	26.4	20.5	13.8	7.3	2.1
	4	15.6	20.6	25.9	31.2	36.0	39.6	41.0	39.2	32.8	20.4
	5	3.1	5.0	7.8	11.6	16.8	23.7	32.8	44.4	59.0	77.4

age of cells with at least one seedling increases whereas uniformity in seedling number per cell decreases.

In Tables 1–3, expected frequency distributions were expressed using percent germination as the binomially distributed variable, but these frequency distributions would apply equally to other percentage variables used to describe seedling yields such as percent usable seedlings. PanAmerican Seed Company (2003) established a quality control program to quantify the minimum percentage of usable plugs (yield potential) that can be expected from several bedding plant cultivars. Using Table 3 and PanAmerican Seed Company's (2003) yield potential information, a grower could determine the minimum expected number of usable plugs (or maximum expected number of empty cells) for different tray configurations and numbers of seeds per cell. Hence, the ≥90% yield potential rating for the 'Stardust' series of impatiens cultivars would mean a yield of at least 246 usable plugs (or fewer than 27 empty cells) per 273 plug tray when seeds of these cultivars are stored and germinated under optimum environmental conditions and one seed is sown per cell (Table 3).

The equations in Table 1 can also be used to determine the effects of percent seed germination and number of seeds per cell on the expected number of seedlings from multiseeded pellets. Assume a lobelia seed lot with 90% germination is used to manufacture multi-seeded pellets containing eight seeds apiece. Solving for the binomial: $(p + q)^8 = (0.90 + 0.10)^8$ or $1(0.90)^8 + 8(0.90)^7(0.10) + 28(0.90)^6(0.10)^2 + 56(0.90)^5(0.10)^3 + 70(0.90)^4(0.10)^4 + 56(0.90)^3(0.10)^5 + 28(0.90)^2(0.10)^6 + 8(0.90)(0.10)^7 + 1(0.10)^8$. The expected distribution of outcomes in random samples of eight seeds selected from an infinitely large population with 90% germination would thus be (respectively) 0.4305 + 0.3826 + 0.1488 + 0.0331 + 0.0046 + 0.0004 + 0.0000 + 0.0000 + 0.0000. These relative expected frequencies indicate that nearly 96% of the cells sown with a single multiseeded pellet with eight seeds would contain six to eight seedlings each, and there would be a low probability ($P < 0.0004$) of cells containing fewer than four seedlings each.

In conclusion, sowing multiple seeds per cell can compensate for suboptimal germination and decrease the number of empty cells per germination tray. The data presented here demonstrate the utility of binomial distributions in elucidating relationships between percent seed germination, number of seeds sown per cell, and expected numbers of seedlings in containerized (plug) trays. This information may be useful to researchers and commercial growers as well as seed technologists.

Literature cited

Halmer, P. 2000. Commercial seed treatment technology, p. 257–286. In: M. Black and J.D. Bewley (eds.). Seed technology and its biological basis. Sheffield Academic Press, Sheffield, England and CRC Press, Boca Raton, Fla.

McDonald, M.B. 1996. The three v's of flower seed quality. Ohio Florists' Assn. Bul. 795:3–5.

McDonald, M.B. 2000. Seed priming, p. 287–325. In: M. Black and J.D. Bewley (eds.). Seed technology and its biological basis. Sheffield Academic Press, Sheffield, England and CRC Press, Boca Raton, Fla.

Perry, L.P. 1998. Herbaceous perennials production: A guide from propagation to marketing. Northeast Reg. Agr. Eng. Serv., Ithaca, N.Y.

PanAmerican Seed Company. 2003. Start to finish, PanAmerican Seed makes yield potential count! 4 June 2003. <http://www.panamseed.com/PAS/yield_potential_page.htm>.

Pyle, A. 2000. Germination of perennial seed. Can. Greenhouse Conf. 4 June 2003. <http://www.canadiangreenhouseconference.com/Talks-2000/Talks%20-%20Pyle1.htm>.

Sokal, R.R. and F.J. Rohlf. 1981. Biometry, 2nd ed. W.H. Freeman and Co., New York.

Styer, R.C. and D.S. Koranski. 1997. Plug and transplant production: A grower's guide. Ball Publishing, Batavia, Ill.