JACK PINE SEED DISTRIBUTION USING THE BROHM SEEDER/PIPER PA-18A AIRCRAFT COMBINATION

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Frontispiece. Mr. K. Towers, pilot with General Airspray Limited, and Piper PA-18A aircraft with Brohm Seeder suspended beneath fuselage to rear of landing gear.

ABSTRACT

An aerial seeding trial was conducted in the spring of 1975 to investigate jack pine (*Pinus banksiana* Lamb.) seed distribution, and the effect of wind and flying height on that seed distribution, provided by the Brohm Seeder/Piper PA-18A aircraft combination commonly used in aerial seeding applications in Ontario. A number of flights at each of three nominal sowing prescriptions (25,000, 50,000 and 75,000 seed/ha) were made over an array of 621 seed traps (1/36,640 ha each) spread over 0.28 ha.

There were significant discrepancies between prescribed and deposited seeding rates: the sources of these discrepancies are discussed. Seed distribution, across the dispersal swath and along the flight line, holds a general form but is uneven. A marked asymmetry of swath occurs around the aircraft track. This asymmetry has a major influence on the overall coverage of the seeding chance when parallel but opposed flight lines are flown. Typical cross-sectional seed distribution diagrams are provided for multiple pass seeding operations at inter-pass spacings of 22.9, 20 and 18 m.

Wind speed and direction do not materially affect general seed distribution patterns, but strongly influence the location of seedfall relative to the aircraft track and overall seeding coverage when parallel but opposed lines are flown. Flying height alone, within a range of 15-34 m, does not significantly affect seed distribution patterns or swath width, but does affect the degree of swath shift occurring as a result of wind.

Variation in mean seed deposition at 25,000 seed/ha is considered too great to be satisfactory. Almost half of the area receives seed at a rate too low to provide reasonable assurance of adequate stocking. Variation in mean seed deposition at the 50,000 and 75,000 seed/ha rates is deemed acceptable. However, when the sowing rate is increased from 50,000 seed/ha to 75,000 seed/ha, the bulk of the extra seed is deposited on approximately one-quarter of the swath cross-section and little benefit in subsequent stocking of jack pine can be expected. A series of recommendations, including a sowing rate of 50,000 seed/ha at an inter-pass spacing of 18 m, is made for most effective seed deposition and distribution from the seeding combination.

A seed deposition and distribution standard for evaluating seeder/aircraft combinations is proposed. The Brohm Seeder, in combination with the single-engined, fixed-wing Piper PA-18A aircraft used in the trial, meets the standard at sowing rates of 50,000 and 75,000 seed/ha and an inter-pass spacing of 18 m. However, the unit has limitations and is very sensitive to the application of calibration and flying procedures. This is used to urge the development of a more effective seeding unit, one that will provide greater uniformity of catch and greater precision of dispersal, and will be more tolerant of operational variables.

RÉSUMÉ

Pour étudier la distribution des graines du Pin gris (*Pinus banksiana* Lamb.) et les effets du vent et de l'altitude de vol sur celle-ci, un essai d'ensemencement aérien a été conduit au printemps 1975 avec un aéronef Piper PA-18A équipé du nouveau semoir Brohm, combinaison fréquemment employée pour l'ensemencement aérien en Ontario. Un certain nombre de vols à chacune des trois prescriptions nominales d'ensemencement (25,000, 50,000 et 75,000 graines/ha) ont été effectués au-dessus d'une rangée de 621 pièges à semences (de 1/36,640 ha chacun) sur une étendue de 0.28 ha.

On a noté des différences significatives entre les taux d'ensemencement prescrits et ceux effectivement obtenus; il est ici question de ces différences. La distribution des graines, à travers l'espace de dispersion et le long de la ligne de vol, conserve une allure générale mais inégale. Un sillage très asymétrique se produit autour de la trajectoire de l'aéronef. Une telle asymétrie a une forte influence sur l'assiette des chances d'ensemencement lorsque les trajectoires de vol sont parallèles mais opposées. Des diagrammes typiques de distribution tranversale sont fournis pour de multiples opérations d'ensemencement dans des couloirs espacés de 22.9, 20 et 18 m.

La vitesse et la direction du vent n'affectent pas beaucoup les modèles de distribution des graines mais ont une forte influence sur la chute de celles-ci quant à la trajectoire de l'aéronef et au rayon global d'ensemencement lorsque l'appareil vole selon des lignes parallèles mais opposées. A l'intérieur d'une gamme de 15 à 34 m, l'altitude de vol seule n'affecte pas significativement les modèles de distribution ni l'étendue du sillage, mais elle affecte le degré de changement de sillage dû au vent.

La variation enregistrée dans le dépôt moyen des graines à raison de 25,000/ha est considéré trop grande pour être satisfaisante. Presque la moitié du secteur ensemencé reçoit les graines à un rythme trop lent pour assurer un ensemencement raisonnablement adéquat. Par contre, une variation dans le dépôt moyen qui atteint un taux entre 50,000 et 75,000 graines/ha est considérée comme acceptable. Toutefois, lorsque le taux d'ensemencement est accru de 50,000 à 75,000 graines/ha, la majeure partie des semences excédentaires se dépose sur près du quart de la coupe transversale du sillage, ce qui permet de prévoir peu de succès dans l'ensemencement du Pin gris. Une série de recommandations, y compris un taux d'ensemencement de 50,000 graines/ha avec un espacement de 18 m est offerte en vue d'un dépôt et d'une distribution de semences des plus efficaces à partir de la combinaison d'ensemencement précitée.

On propose une norme de dépôt et de distribution des semences, pour évaluer les combinaisons semences/aéronef. La combinaison semoir Brohm et avion Piper PA-18A à voilure fixe utilisée dans cet essai se conforme à la norme de taux d'ensemencement de 50,000 et de 75,000 graines/ha avec espacement de 18 m. Toutefois, l'unité comporte certaines limitations et s'avère très sensible au calibrage d'application et aux méthodes de vol. Elle sert à accélérer la mise au point d'une meilleure unité d'ensemencement, qui fournira une plus grande uniformité de réception et une plus grande précision de dispersion, tout en acceptant mieu les variables opérationnelles.

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INTRODUCTION

Aerial seeding of jack pine (*Pinus banksiana* Lamb.) has been used as an operational reforestation technique in Ontario since 1962. That year approximately 542 ha were seeded by helicopter with the newly developed Brohm Seeder.[1] By 1967 the area being treated annually had increased to 3,440 ha. To offset the rising cost of seeding, the seeder was adapted to small, light, monoplanes in 1968, and by 1972 the area being treated had increased to over 6,070 ha per year (Brown 1973). By 1976 this had more than doubled as treatment surpassed the 14,200 ha mark.[2] Since the changeover in 1968, most aerial seeding in the province has been carried out with fixed-wing aircraft (ibid.).

Although results obtained from seedings during the 1960s were generally successful there were some failures, wide variation in stockings and densities, and numerous reseedings. This indicated that field control of operational variables was uncertain or difficult and that more information was required if greater uniformity and certainty of catch was to be assured.

In 1970 the Great Lakes Forest Research Centre initiated an aerial seeding research program in cooperation with the Ontario Ministry of Natural Resources. The program was designed to determine the economic optimum combination of degree of scarification and rate of seeding required to obtain desired stockings and densities. By 1974, results were suggesting an optimum combination of 25% receptive seedbed and a seeding rate of 50,000 seed/ha (Riley 1975). It was apparent, however, that this "economic optimum" carried with it a practical upper stocking limit of approximately 80% on a 2 metre square quadrat (2 m^2) basis[3] after one year. This undoubtedly would be considered an excellent result if it were to remain at that level over the commonly accepted three-year establishment period. But normal mortality can be expected to reduce stocking somewhat by the end of the third year. Therefore, it would be desirable to achieve even better stocking after one year if it could be accomplished at reasonable cost.

When the aerial seeding trials were initiated it was assumed that seed distribution afforded by the Brohm Seeder was more or less uniform and that the volume of seed dispersed would be very close to the prescribed rate. The trial results indicated, however, that this might not be the case and that improvement in these areas might significantly improve seeding results with little or no increase in operating cost. It was decided, therefore, to initiate another set of trials to examine

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[1] Developed by H.H. Brohm (retired), Ontario Ministry of Natural Resources, Maple, Ontario.

[2] Personal communication from F.C. Robinson, Forest Management Branch, Ontario Ministry of Natural Resources.

[3] This designation indicates a quadrat whose sides are each 2 metres in length and whose area is 4 square metres.

deposition rates and distribution pattern(s)[4] of jack pine seedfall from a Brohm Seeder/fixed-wing aircraft combination and, if possible, investigate the effect of flying height and wind. A field trial to obtain this information was carried out in April, 1975 in cooperation with General Airspray Limited of St. Thomas, Ontario.

EQUIPMENT

The following three major items were used during the trial.

Brohm Seeder, Mark III

Worgan (1973) gave the following description of the Brohm Seeder and its operation: "The seeder consists of a seed tank or 'hopper' (Fig. 1), to the bottom of which is affixed the grain-type auger that moves seed to a revolving slinger (Fig. 2). This slinger is basically a central hub with four protruding, horizontal plastic tubes, from which the seed is cast from beneath the moving aircraft. The seed auger is powered by a mechanical drive from an electrical motor, which also provides a constant speed, through belt drive, to the slinger.

"The speed of the seed auger can be varied (Fig. 3), to control seed output, and hence number of seeds per hectare. The auger speed is monitored on a tachometer (Fig. 3). The slinger rotation is maintained at a constant 1,000 revolutions per minute."

Aircraft

Worgan (1973) also described the aircraft most commonly used for aerial seeding in Ontario: "The PA-18A, more commonly known as a Super Cub (Frontispiece), was developed by Piper for crop dusting and spraying; it is a fixed, high-wing aircraft with a 135 hp Lycoming engine. A very economical, flexible and dependable aircraft to operate, the Super Cub uses only 23 litres of fuel per hour when seeding and 30 litres per hour when cruising cross-country at 75% power. With its two wing fuel tanks, the Super Cub has an endurance of 5 hours plus a 45-minute reserve. More simply this means that the Super Cub can fly out approximately 160 km and seed for 2-3 hours, covering approximately 80-600 ha depending on the number, size and shape of the areas to be seeded."

Seed Traps

Seed traps were used to monitor seedfall deposition rates and distribution patterns. Each trap consisted of a wooden frame fabricated from nominal 2.54 cm x 7.62 cm stock with either screen mesh or clear 4-mil polyethylene sheeting closely fitted to the bottom. The catch area of each trap measured 52.1 cm x 52.1 cm, i.e., 1/36,840 ha.

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[4] For greater clarity, definitions of certain terms used in this paper are provided in Appendix A.

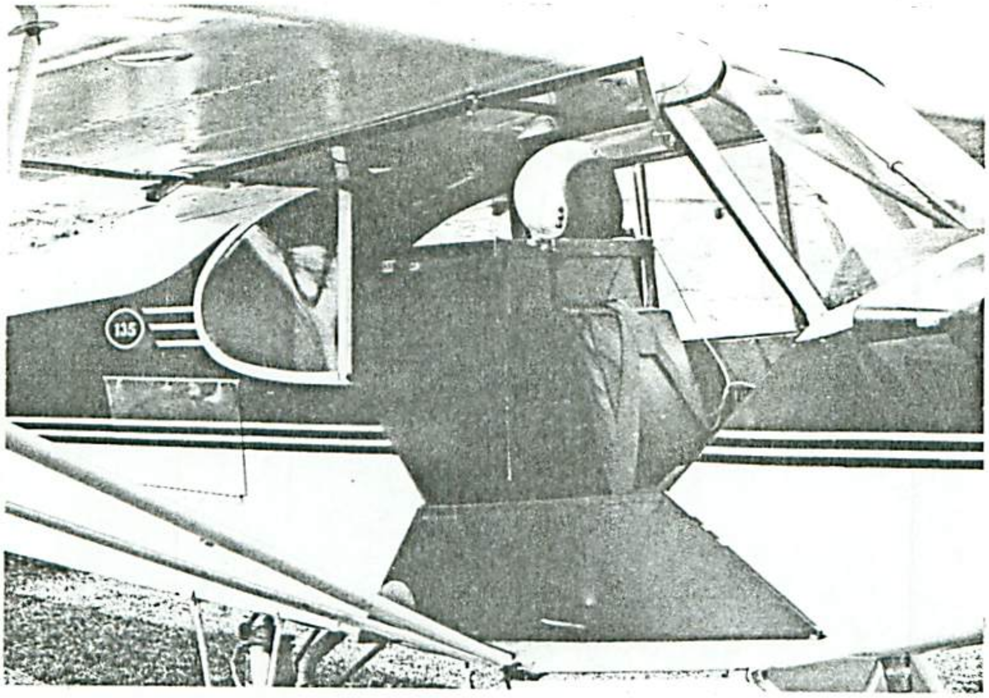

Fig. 1. Seed hopper mounted behind pilot's seat.

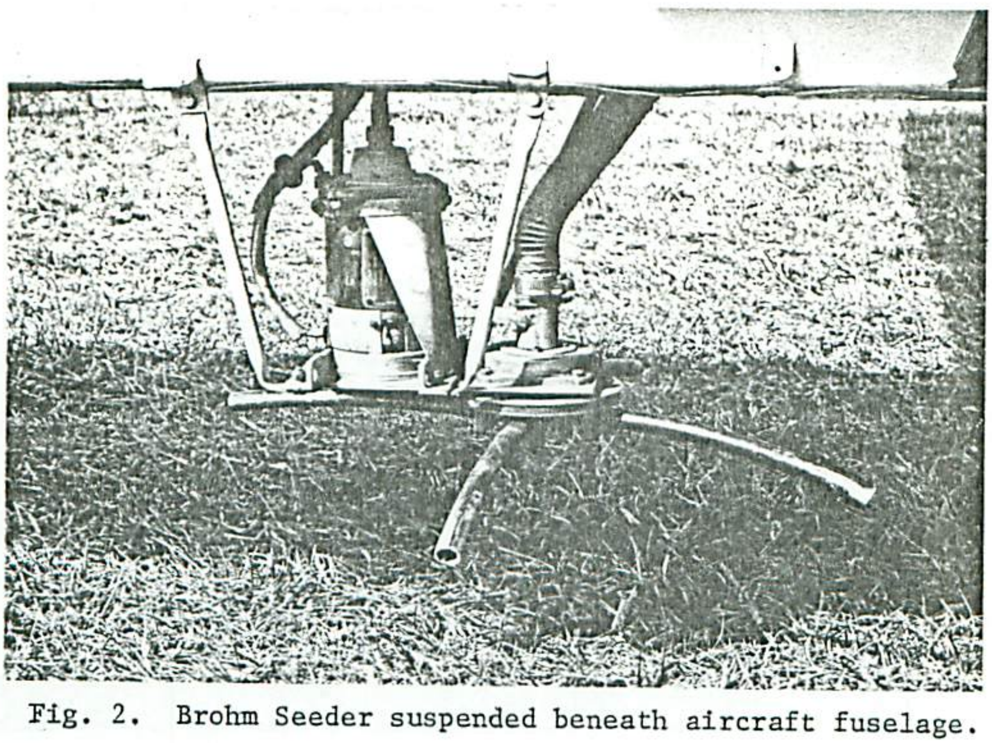

Fig. 2. Brohm Seeder suspended beneath aircraft fuselage.

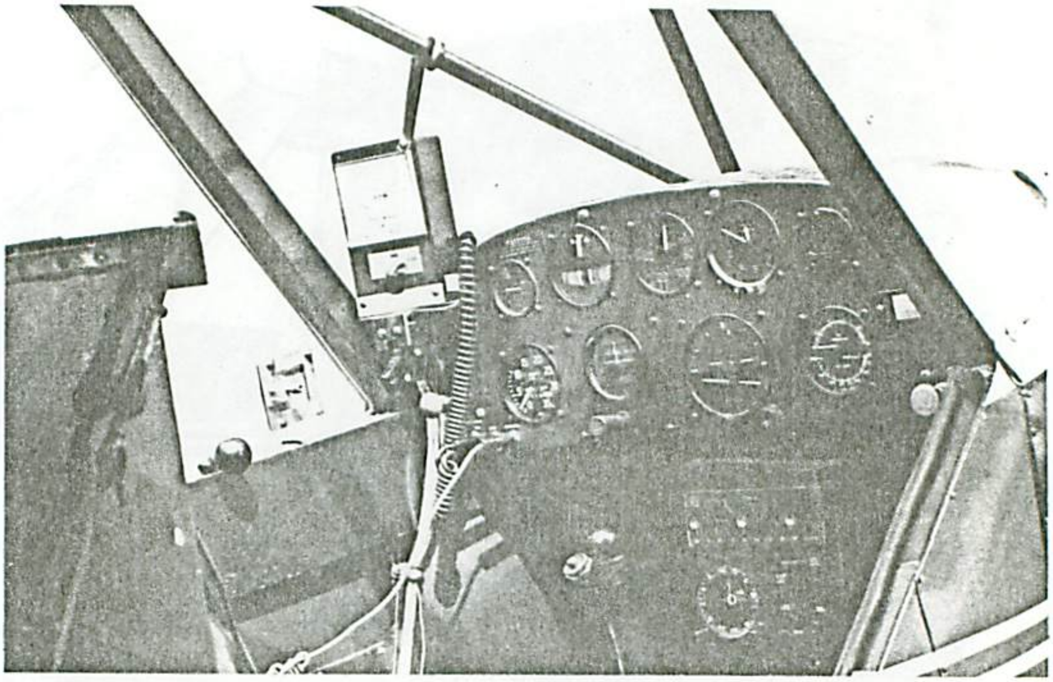

Fig. 3. Cockpit controls for seeder, including tachometer, for monitoring seed auger RPM.

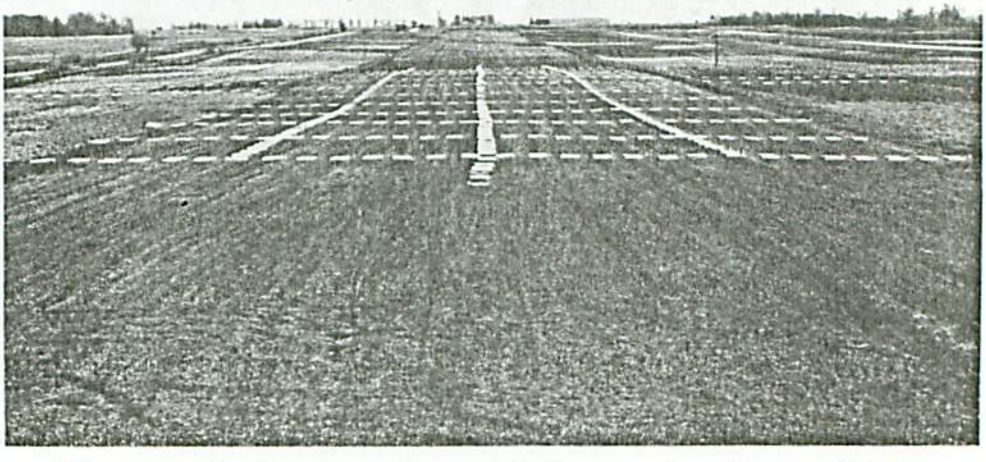

Fig. 4. Seed trap array used for monitoring seedfall.

PROCEDURES

The trial was conducted at the General Airspray Limited airfield near Lucan, Ontario. Our purpose was to determine the deposition rates and distribution patterns of the seedfall of jack pine at each of the nominal rates used in the field trials of aerial seeding, namely, 25,000, 50,000 and 75,000 seed per hectare.[5] As far as possible, conditions were similar to those which could be expected to occur during an actual seeding operation, i.e., seeder calibration, flying height and speed, wind factors, etc.

Layout

An array of 621 numbered seed traps (Fig. 4 and 5) was set out on a very gently undulating and slightly sloping (in the direction of flight) air strip. The array consisted of six ranks of 30 traps alternating with six ranks of 29 traps and three files of 89 traps each. Ranks were aligned perpendicular to the aircraft track to determine patterns across the width of the seedfall zone. Files were set out to determine variation in distribution along the flight line. Traps were set at 104 cm centres in both ranks and files, leaving a blank equivalent to one trap space between each trap. Ranks and files were set out approximately 7.8 m apart, as determined by trap position (Fig. 5). The traps in each rank were offset laterally from those in adjacent ranks by 52 cm (i.e., one trap space). Dimensions of the area covered by the array were 30.5 m x 91.4 m.

As shown in Figure 4, additional traps were set out at the sides of the array to monitor side drift of the seed and at the ends to ensure that seedfall was occurring beyond the ends of the array.

Calibration of Seeder

A lot of approximately one million jack pine seed containing 282 viable seed per gram[6] and treated with aluminum and latex was used for the test program. The seeder was calibrated for the three nominal seed rates using normal field procedure (after Worgan 1973). The calibration procedure is described in Appendix B, and was followed carefully in calibrating for each seeding rate.

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[5] The trials were conducted in the English system with seeding rate values of 10,000, 20,000 and 30,000 seeds/acre. For reporting purposes all values have been converted to S.I. units. Seeding rate data have been normalized to the more convenient values of 25,000, 50,000 and 75,000 seed/ha.

[6] Obtained from data sheet provided with shipment from OMNR's Angus Tree Seed Plant.

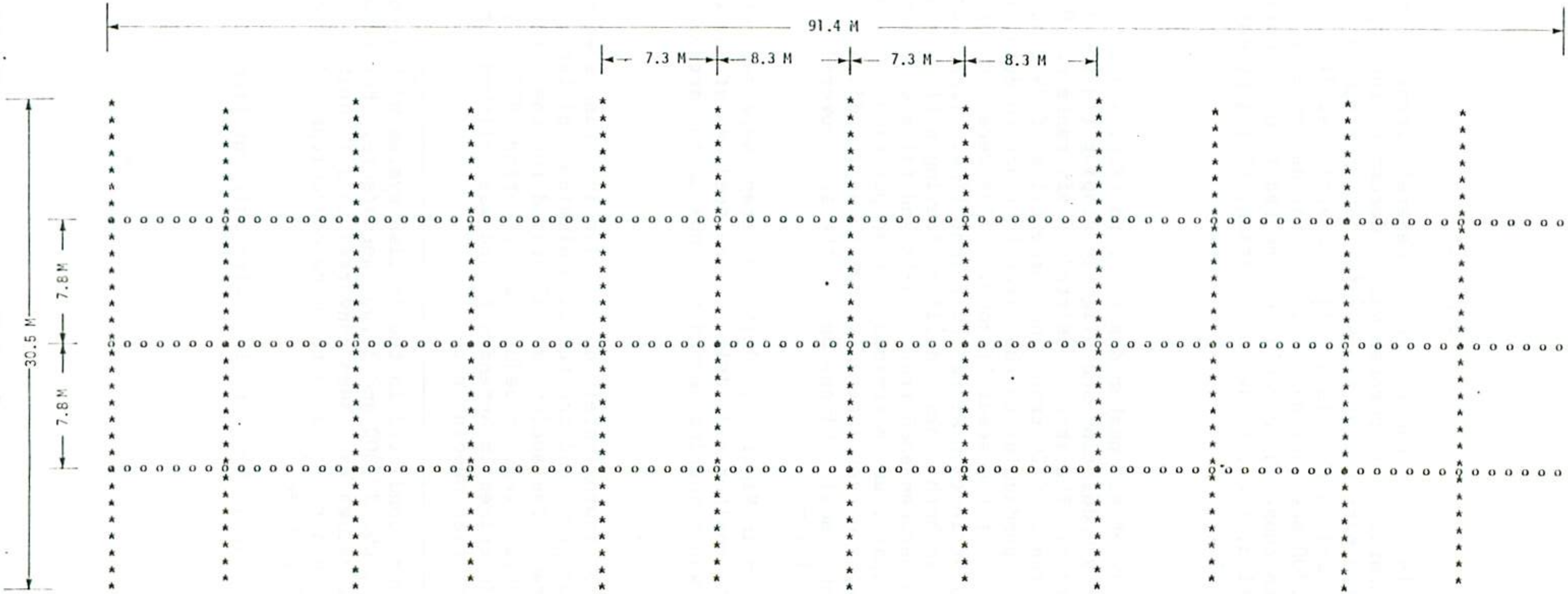

Fig. 5. Diagram of seed trap layout.

Sowing

The Piper PA-18A used in the trials was flown by a General Airspray Limited pilot with previous experience in operational seedings for the Ontario Ministry of Natural Resources. Six flights were made at the 25,000 rate, 16 at the 50,000 rate and six at the 75,000 rate; the greatest number was made at the intermediate rate because it is the most commonly applied operational rate.

The first flights were made down the centre of the trap array. It soon became apparent that even light winds markedly shifted the seedfall and that even with the 30.5 m array width some seed was falling outside the catch area. In order to ensure that most seed fell within the catch area, the track of the aircraft was shifted an appropriate distance (as wind conditions and judgment dictated) from the centre line of the array for each of the remaining flights, and this location was noted. Wind speed and direction and flying height were recorded for each flight.

The auger was turned on well in advance of the first rank of traps and was not turned off until the aircraft was well past the last rank. After each flight seed traps were examined, the number of seeds caught in each trap was recorded by trap number, and traps were emptied and set back in place.

Flying Height

In order to determine the actual flying height of the aircraft on each pass, a large range pole (Fig. 6a) and movie camera (Fig. 6b) were set up to one side of the trap array. The movie camera was located such that the line of sight from the camera through the range pole was at right angles to the centre line of the seed trap array and proposed flight line. Elevations and horizontal distances of the range pole and movie camera were established in relation to each other and to ground level at the centre line of the trap array, specifically the first trap in the centre file.

The passage of the aircraft past the range pole was recorded on film for each flight. A frame-by-frame analysis of the movie film located the image of the seed slinger on the image of the range pole. The height of the seed slinger above the trap array was then calculated ($\pm$75 cm) by triangulation.

Prior to the trial the pilot was requested to fly at the normal aerial seeding height of 23 m to 26 m above general ground level. During the trial, however, he was instructed to vary this somewhat to obtain an indication of the effect of various flying heights on distribution. Over the course of the trial flying heights ranged from 15 m to 34 m.

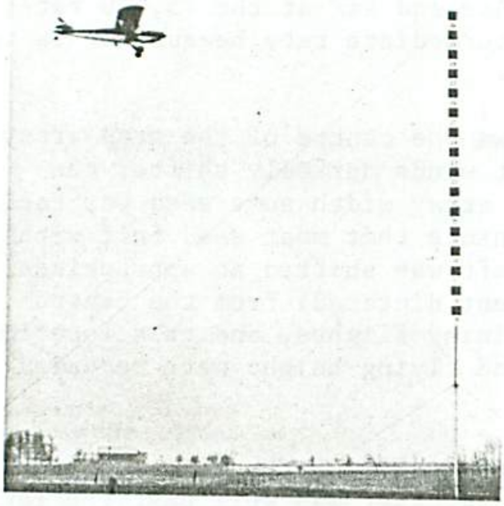

Fig. 6a. Range pole

Fig. 6b. Movie camera

Apparatus used to obtain data to determine flying height while seeding.

Wind

Windspeed was measured using a method devised by Silversides (1974). A 30-g pilot balloon was filled with helium to standard lift (30 g) and released. The balloon was tracked by the observer and, at a height of approximately 23 m (5 to 7 seconds after release), the vertical angle was read by clinometer (Fig. 7). The windspeed was then obtained from the table provided by Silversides. Wind direction was recorded by observing the airfield windsock.

Fig. 7. Apparatus used to determine windspeed. A 30-g pilot balloon is released and tracked with a hand-held clinometer.

RESULTS

At the time of this trial, operational seedings with the Brohm Seeder were being conducted on the assumption that the main seedfall occurs over a swath 22.9 m wide. Seeder calibration was carried out accordingly. Therefore, the calculations that follow are also based on a swath width of 22.9 m. The analysis is based on data obtained from 21 of the 28 flights made. The remaining seven flights have been excluded from further consideration, insufficient seed having fallen on the trap array (because of wind drift of seed, improper aircraft track location over the array or, as on one flight, seeder malfunction) to warrant their inclusion. Data for the 21 acceptable flights are presented in Table 1. Total seed deposition per hectare has been determined by compressing the number of seed caught on the array on each flight to a catch width of 22.9 m. For example, if seed was caught over a 25 m swath on a particular flight, that amount of seed was considered to have fallen over a 22.9 m swath and the seed per hectare for that flight was calculated accordingly. This was deemed valid since, if the spacing between aircraft passes on operational seedings is maintained at 22.9 m but seedfall covers a wider swath, adjacent swaths will overlap and, over a large area, will provide a deposition closely approximating that calculated for the compressed swath.

Seed deposition was less than the prescribed rate for all flights and varied markedly from flight to flight. Total deposition by individual flight varied between 59% and 92% of the prescribed rate. Mean depositions were 78.6%, 75.1% and 80.9% of the prescribed 25,000, 50,000 and 75,000 seed/ha seeding rates, respectively, representing shortfalls of 19.1% to 24.9%. It had been observed from the monitor traps to the side of the array that, even on some of the accepted flights, not all of the seed cast fell on the array. Table 2 reveals that there were minor differences only in the mean depositions at each seeding rate between those flights on which all seed was caught on the array and those on which some seed was observed to have missed the array. These calculations indicate that, for the accepted flights, seed falling off the array did not contribute meaningfully to the discrepancies between the prescribed rates and the mean depositions.

Seed deposition swath widths varied up to 30.5 m but no flight had a deposition width of less than 22.9 m. From Table 1 it is seen that deposition on the best 22.9 m for individual flights ranged from 88.8% to 100% of the total deposition for the given flight. For all flights combined 95% of the total deposition was caught on the best 22.9 m sections. Therefore, the assumed swath width used in operational seedings appears to be valid. Most seed dispersed does fall with a 22.9 m swath width.

An investigation of the cross-sectional seed deposition of each flight indicates a high degree of non-uniformity of seed dispersal across the swath. To illustrate this, three of the most representative

Table 1. Seed deposition data for each accepted flight.

Flight number	Seeder height (m)	Wind speed (kph)	Total deposition[a] (seed/ha)	Percent of prescribed rate	Percent of mean total deposition	Deposition on best 22.9 m of swath (seed/ha)	Percent of total deposition on best 22.9 m of swath	Percent of traps in best 22.9 m of swath with $\geq$1 seed
			Prescribed rate: 25,000 seed per hectare					
2	19.5	0-5	22000	88.0	111.9	21700	98.6	42
3*	26.5	0-5	21200	84.8	107.8	19700	92.9	39
4	28.0	0-5	16500	66.0	83.9	16500	100.0	33
5*	31.7	0-5	20700	82.8	105.3	19200	92.8	38
6*	28.6	0-5	17900	71.6	91.0	17600	98.3	38
Mean			19660	78.6	100.0	18940	96.5	38
Standard deviation			2346	9.4	11.9			
Standard error of the mean			1049	4.2	5.3			
			Prescribed rate: 50,000 seed per hectare					
8*	22.6	calm	33400	66.8	89.0	31800	95.2	56
9	21.0	calm	34700	69.4	92.4	32200	92.8	52
11	23.5	5	40100	80.2	106.8	39600	98.8	63
12*	28.0	calm	45900	91.8	122.3	42300	92.2	67
13	29.6	13	33400	66.8	89.0	30700	91.9	55
14*	32.6	5	35900	71.8	95.6	33800	94.2	56
15	28.6	5	29500	59.0	78.6	27000	91.5	48
18	16.5	21	36500	73.0	97.2	34400	94.2	59
19	15.2	16	42600	85.2	113.5	39900	93.7	64
21	22.0	8	43800	87.6	116.7	43800	100.0	64
22	22.0	calm	37200	74.4	99.1	37200	100.0	57
Mean			37545	75.1	100.0	35700	95.0	58
Standard deviation			5021	10.0	13.4			
Standard error of the mean			1514	3.0	4.0			
			Prescribed rate: 75,000 seed per hectare					
24	18.3	calm	62600	83.5	103.2	58000	92.7	75
25*	21.3	11	63400	84.5	104.5	58700	92.6	78
26*	15.2	14	56400	75.2	93.0	53600	95.0	67
27*	21.3	12	66500	88.7	109.6	65800	98.9	75
28	23.5	18	54400	72.5	89.7	48300	88.8	71
Mean			60660	80.9	100.0	56880	93.6	73
Standard deviation			5067	6.8	8.3			
Standard error of the mean			2266	3.0	3.7			

*Denotes flights selected for preparing Figures 8a, 8b, 8c.

[a]Total seed per hectare calculated by compressing total seed deposition on array to a 22.9 m width.

Table 2. Comparison of seed deposition between flights with 100% deposition on the array and flights with seed falling only partially on the array area (accepted flights only).

	Average seedfall - seed/hectare					
Nominal seeding rate	25,000 seed/ha		50,000 seed/ha		75,000 seed/ha	
Flights with 100% catch	19,932	(80%)[a]	37,948	(76%)	62,998	(84%)
Flights with <100% catch	19,248	(77%)	37,045	(74%)	59,090	(79%)
Difference		-3%		-2%		-5%

[a] Percent of prescribed rate

flights were combined at each of the nominal seeding rates and cross-sectional deposition diagrams were developed as shown in Figures 8a, 8b and 8c. The diagram for each rate illustrates the general pattern of seed distribution across the swath for that rate. This combining of depositions tends to smooth out the irregularity across the swath. The unevenness of distribution for individual flights tends to be greater than is shown in Figure 8. Individual flight profiles at each seeding rate exhibit the same general form as that shown, i.e., two peaks, one higher than the other, with a central valley. At the two lowest rates the higher peak occurs on the right side of the swath whereas at the 75,000 seeding rate the peak occurs on the left. This apparent anomaly is considered further in the "Discussion" section. Seed distribution is asymmetrical about the flight track with a general shift to the left in evidence, a normal occurrence in aerial applications using single-engine, fixed-wing aircraft with clockwise propeller rotation (as viewed from the cockpit). This observation is confirmed by Armstrong (1978a) and supported by Wickens.[7]

The data obtained are inadequate for a detailed analysis of the effects of wind and flying height on this phenomenon. It was observed, however, that headwinds and/or winds from the right increase the shift to the left, whereas tailwinds and/or winds from the left tend to reduce the leftward shift or, if of sufficient force, may even push the asymmetry to the right side of the aircraft track. Flying height has a bearing on the extent to which wind can affect the shift; the greater the flying height, the greater the effect. These results are supported by Armstrong (1978b). Flying height alone, within the range used over all flights (15 m to 34 m), has little effect on the width of swath.

[7] Personal communication from R.H. Wickens, National Research Council of Canada.

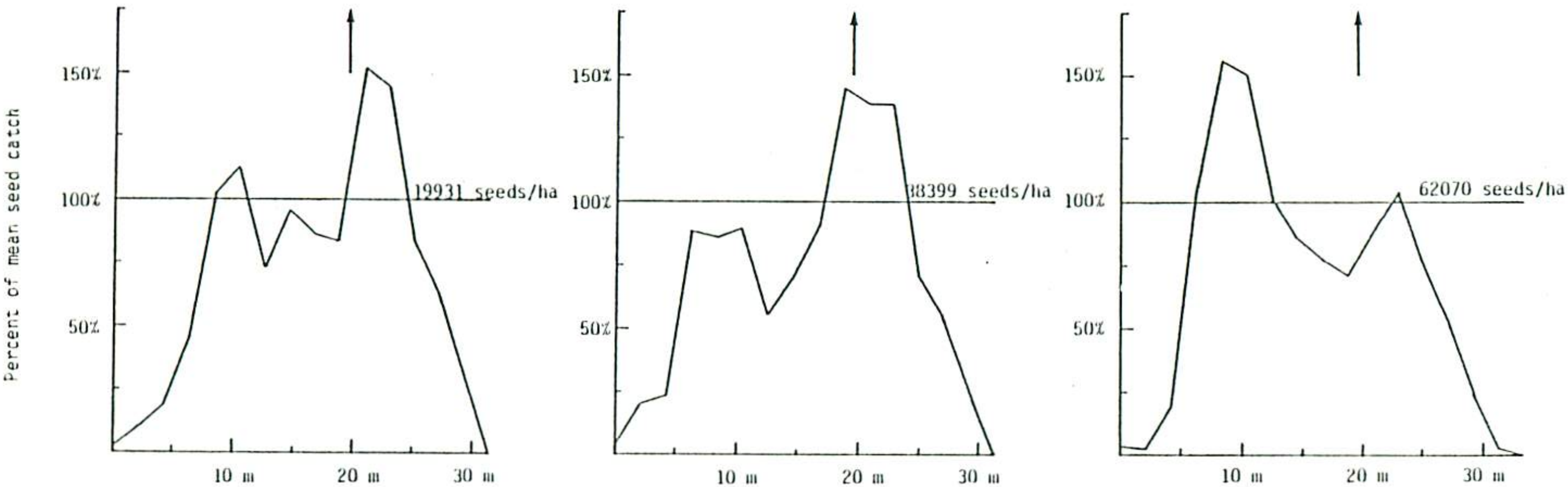

Figure 8a. 25,000 seeds/ha prescribed

Figure 8b. 50,000 seeds/ha prescribed

Figure 8c. 75,000 seeds/ha prescribed

⟶ Indicates location and direction of aircraft track in relation to seedswath.

Note: 100% is the mean total seed deposition for the three selected flights at each seed rate.

Fig. 8. Mean seed deposition and distribution for three selected flights at each of three seeding rates.

Flying height, wind speed and wind direction have little effect on the general form of the cross-sectional seed distribution.

Seed distribution along the flight line is variable but displays a periodicity that is more or less regular. A representative flight at each seeding rate was selected and seed distribution diagrams (Fig. 9a, 9b and 9c) for each file in the trap array were prepared to illustrate the phenomenon. In each case files X, Y and Z closely approximate the catch positions of the right peak, central valley and left peak, respectively, of the cross-section profile as illustrated in Figure 8.

As is to be expected the percentage of traps catching at least one seed increases with increasing seeding rates. This is illustrated in Table 1 where the percentage is given for each flight. The percentage of traps receiving seed increases by 53% as the seeding rate is raised from 25,000 seed/ha to 50,000 seed/ha. This increase is much reduced, to only 26%, as the seeding rate is raised from 50,000 seed/ha to 75,000 seed/ha.

Table 3 gives the percentage of traps receiving 0, 1, 2, 3 and 4 or more seed on the best 22.9 m of swath width. Also given is the percentage of the total seedcatch falling in each catch class. The traps receiving the larger amounts of seed tended to be located under the deposition peaks (illustrated in the diagrams in Figure 8). The average number of seeds, in traps catching seed, was 1.3, 1.6, and 2.1, respectively, for the 25,000, 50,000 and 75,000 seeding rates. The maximum catch per trap was four seeds at the 25,000 rate, and seven seeds at each of the 50,000 and 75,000 rates.

DISCUSSION

As indicated previously, seed deposition was, without exception, less than the prescribed rate over all flights. Confidence limits of 95% for mean seed deposition and for seed deposition for individual flights have been calculated for each seeding rate. The results are depicted in Figure 10.

The upper limit of mean seed deposition is well below the prescribed rate in each case. The upper limit of seed deposition for individual flights exceeds the prescribed rate in the case of the 25,000 seed/ha rate only, and then only marginally. This strongly suggests that the discrepancies between prescribed rates and deposited rates in the trial are related to calibration and/or sowing procedures and not to mere chance. An examination of these procedures, the same as those used on operational seedings, has identified four principal, contributing procedural errors.

The seed metering mechanism is operated for 15-second intervals in the calibration procedure (Appendix B). Minor errors in timing

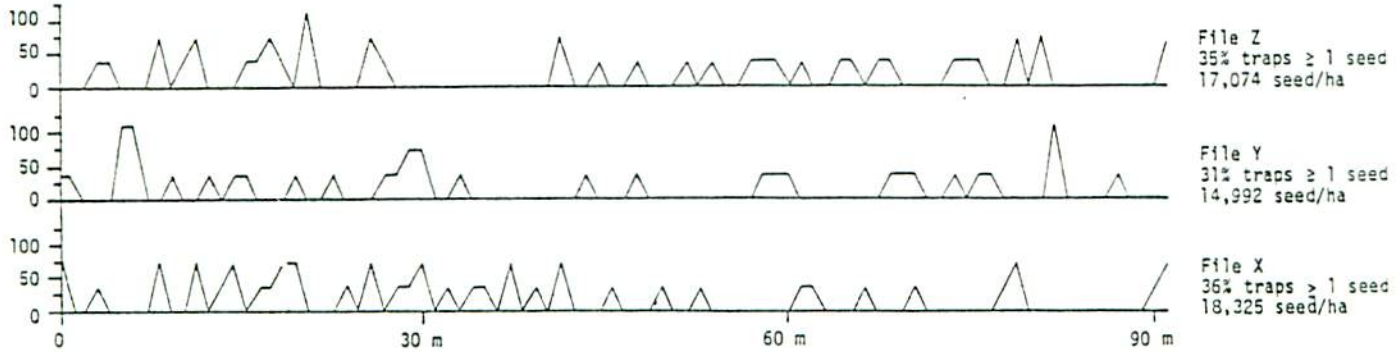

Figure 9a. Representative flight at 25,000 seeds/ha.

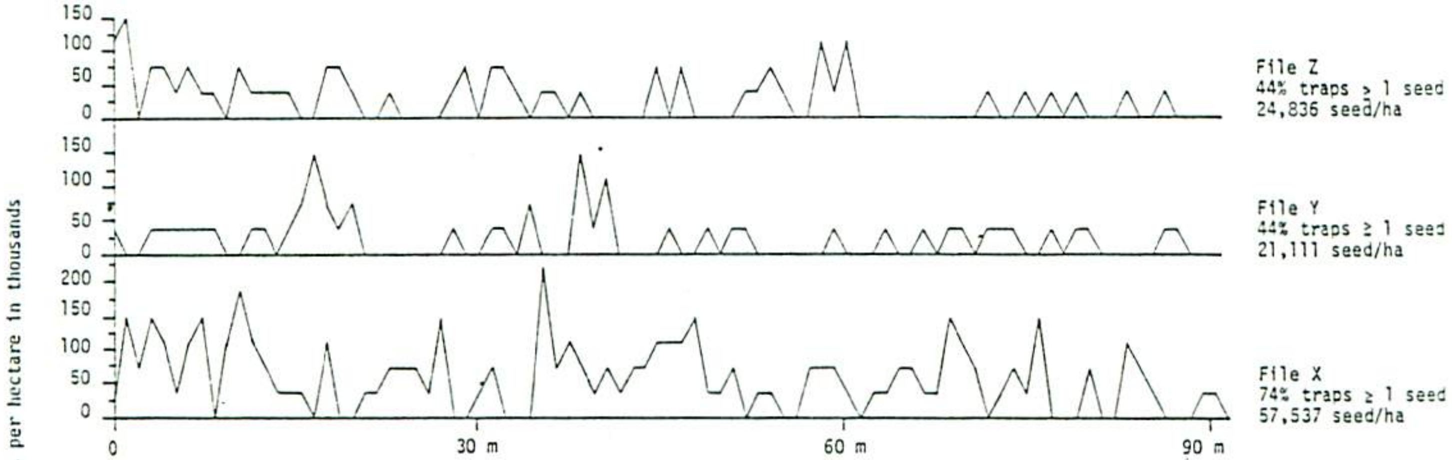

Figure 9b. Representative flight at 50,000 seeds/ha.

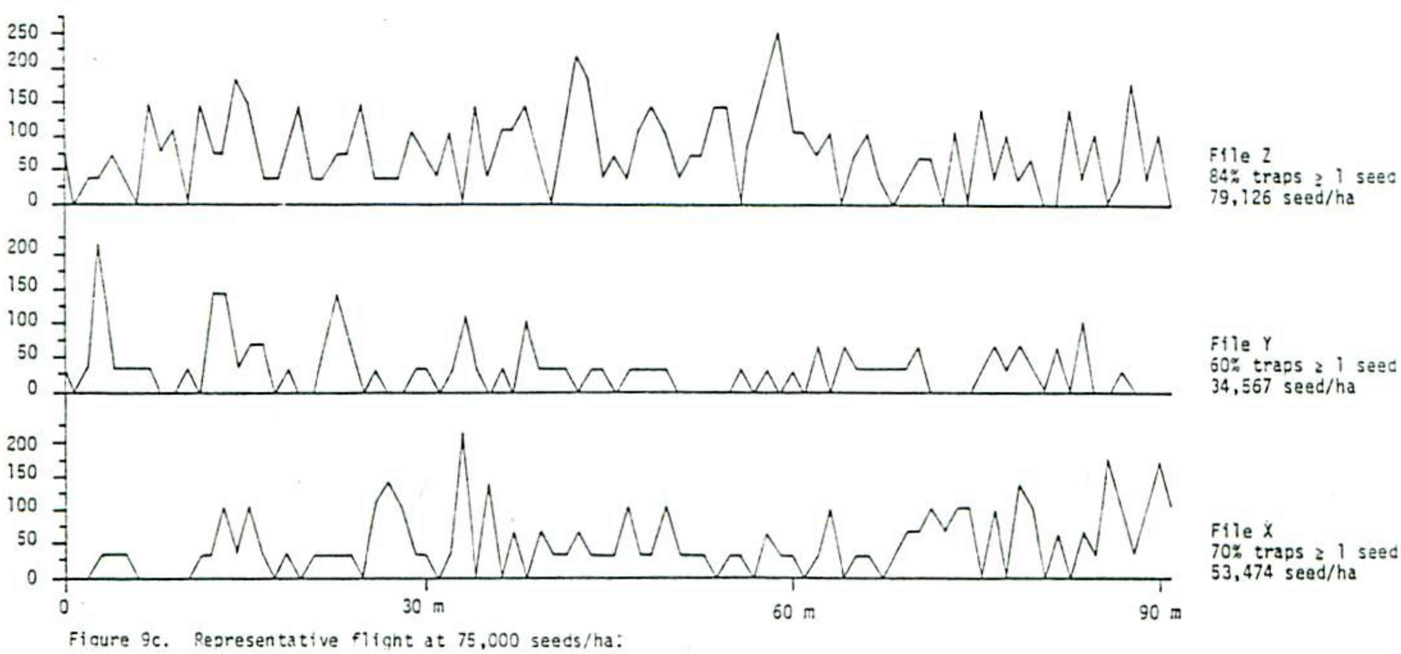

Figure 9c. Representative flight at 75,000 seeds/ha.

Fig. 9. Typical seed deposition along files.

Table 3. Percentage of traps on best 22.9 m of swath receiving specified amounts of seed.

Nominal seeding rate (seed/ha)		Number of seeds in trap: 0	1	2	3	4 or more	Total	Number of traps	Number of seeds caught
25,000	% of traps	62.0	28.3	7.0	2.2	0.4	99.9	1320	
	% of seeds		56.0	27.9	13.1	3.0	100.0	501	667
50,000	% of traps	41.8	33.4	15.9	6.6	2.3	100.0	2904	
	% of seeds		35.2	33.4	21.0	10.4	100.0	1689	2759
75,000	% of traps	26.6	29.4	22.9	12.3	8.7	100.0	1320	
	% of seeds		19.4	30.3	24.3	26.1	100.1	969	2001

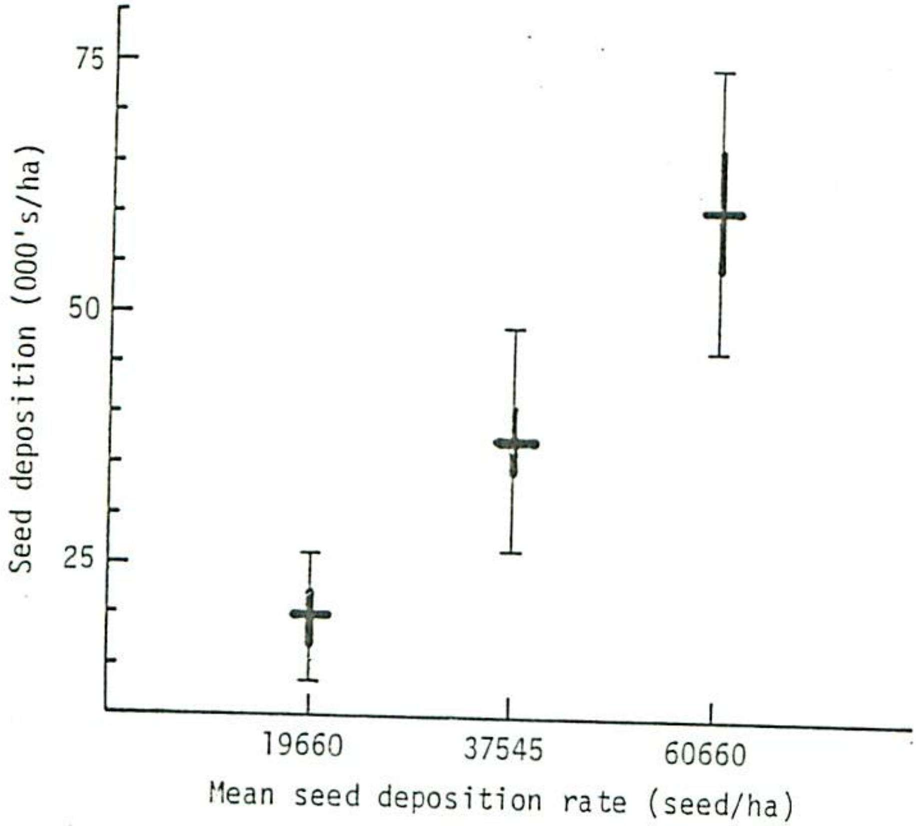

Fig. 10. Confidence limits (95%) for seed deposition in Lucan trials. The mean seed deposition for each seeding rate is shown by the heavy crossbar. Mean seed deposition limits are shown by the heavy vertical lines and individual flight deposition limits by the thin vertical lines.

during this process can introduce significant calibration errors. For example, an error of ± 0.5 seconds in turning the seed metering mechanism on or off will cause an error in calibration of $\mp 3.3\%$.

The seeds-per-gram value used in the calibration calculation may be incorrect. In normal practice, the seeds-per-gram value is taken from the packing slip enclosed with the seed shipment. As shown in Appendix C, it has been found that seed weight may increase by as much as 12% from what it was at the time of determination for packing slip purposes. If such is the case at time of calibration, the seeds-per-gram value is lowered by 12% and this error is introduced into the calibration calculation.

An error of ±5 g in weighing the seed during calibration will introduce an error of ±4.5% from the prescribed 25,000 rate, ±2.3% from the prescribed 50,000 rate and ±1.5% from the prescribed 75,000 rate.

Ground speed of the aircraft in flight may differ from the 129 km/h value normally applied in the calibration calculation. A variance of 10 km/h will change the seed deposition rate by ±7.4% from that calibrated. For example, a ground speed of 139 km/h will reduce calibrated seeding rates of 25,000, 50,000 and 75,000 seed/ha to 23,150, 46,300 and 69,450, respectively.

It is suggested that a complex of these factors accounts for the major portion of the shortfalls encountered in the trials. Further, it is safe to assume that these same factors come into play during operational seedings and that the resulting deposition rates are similarly influenced.

Although the foregoing helps to explain discrepancies between prescribed and deposited rates, it does not explain the variation in seed deposition between individual flights at a particular seeding rate, as recorded in Table 1 and illustrated in Figure 10. Such variation is not the result of calibration error since, once the seeder is calibrated, it should remain at that calibration throughout the seeding operation. Hence, factors other than seeder calibration are strongly affecting seed deposition. Prominent among these are irregularities in seed feed (inherent in the design of the feed mechanisms) and variation in ground speed of the aircraft during flight (due to flying conditions, principally winds) (Armstrong 1978a, 1978b).

The extent of the between-flight variation is shown more clearly in Figure 11 where the 95% confidence limit diagrams of Figure 10 have been normalized and where the 100% level represents a variable (over an indefinite but limited range) mean seed deposition value. The figure indicates that the reliability with which the seeder deposits calibrated amounts is improved somewhat as seeding rates are increased. It is seen, however, that even if the calibration procedure is errorless, seed deposition can still be expected to vary widely. For example, if the three crossbars in the diagrams of Figure 11 are assigned mean deposition values of 25,000, 50,000 and 75,000 seed/ha from left to right respectively, the confidence limits for mean seed deposition and for individual flights will be as shown in Table 4.

On the basis of mean seed deposition alone, the variation likely on any given seeding operation would appear to be modest. However, this is misleading and could lead to a false sense of a job well done. Examination of the individual flight variation provides another picture. On some individual passes of the aircraft, *average* seed deposition for each 2 m^2 quadrat (equivalent to 1 milacre) may be as low as seven seeds at the 25,000 rate, 14 seeds at the 50,000 rate and 23 seeds at the 75,000 rate. At the other extreme, for some passes *average* seed

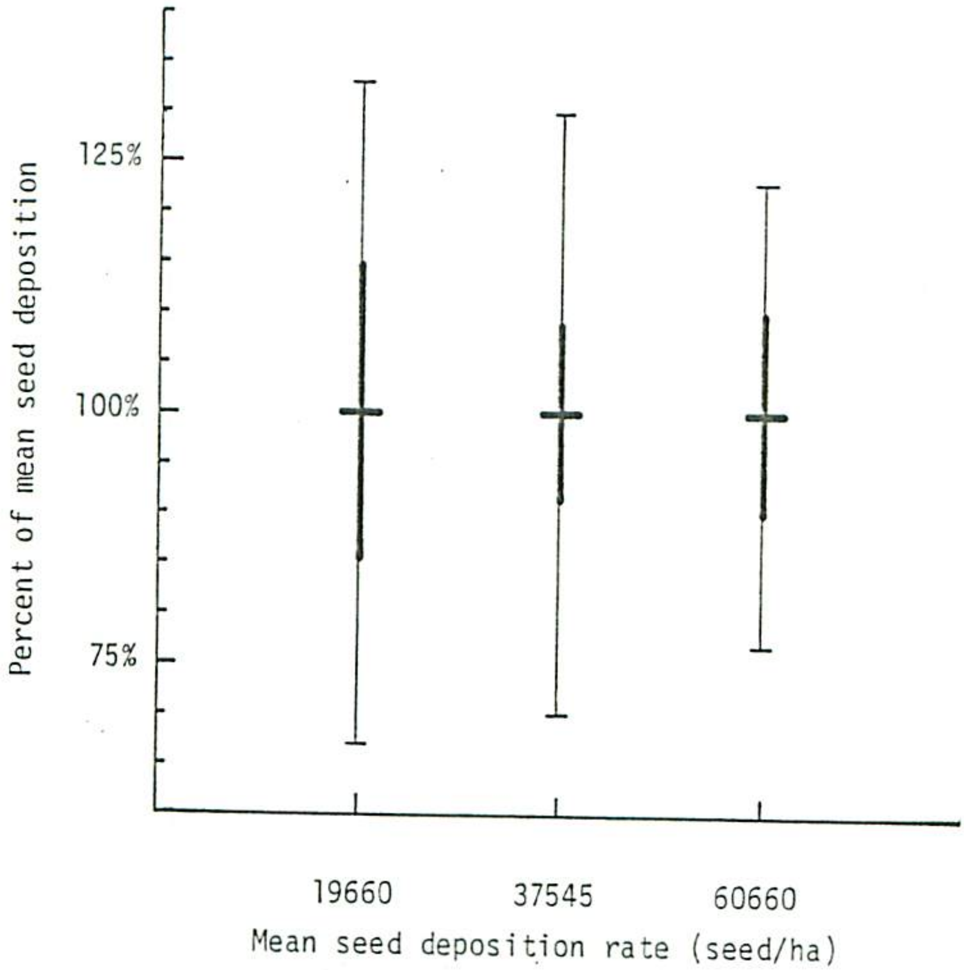

Fig. 11. Normalized confidence limits (95%) for seed deposition in Lucan trials. Mean seed deposition for each seeding rate is shown by the heavy crossbar. Mean seed deposition limits are shown by the heavy vertical lines and individual flight deposition limits by the thin vertical lines.

Table 4. Confidence limits (95%) for seed deposition at three selected seeding rates.

	Seeding rate per hectare		
	25,000	50,000	75,000
Limits for mean seed deposition for a job	21,300 -28,700	45,500 -54,500	67,300 -82,700
Limits for seed deposition for individual flights within a job	16,700 -33,300	35,000 -65,000	57,700 -92,300

deposition per 2 m^2 quadrat could be as high as 13 seeds at the 25,000 rate, 26 seeds at the 50,000 rate and 37 seeds at the 75,000 rate. Further, as shown in Figures 8 and 9, the pattern of seed deposition from the Brohm Seeder/PA-18A aircraft combination is uneven across the swath and along the flight line. Although the number of points along the flight line receiving no seed is reduced as seeding rates are increased, the unevenness of deposition remains. Similarly, the general seedfall pattern of widely disparate highs and lows across the swath persists at all seeding rates. Hence, not only is there a wide range in mean seed deposition for individual passes, there is also considerable variation in seed deposition around the mean which results in irregular seed catch at any given ground location. This helps to explain the generally satisfactory but spotty or irregular stocking results often obtained from operational aerial seedings.

As represented in Figure 8, deposition of seed across the swath follows a definite pattern, i.e., two peaks with a central valley. The transposition of the higher peak to the left side of the seed deposition pattern at the 75,000 rate (as opposed to the right side at the other two rates) is an anomaly that is difficult to explain. Four of the five accepted flights at the 75,000 rate strongly exhibit this characteristic. Each of these, including the three selected for Figure 8c, have winds of 10-15 km/h quartering from the rear of the aircraft. The fifth accepted flight and the one rejected flight at the 75,000 rate were made in calm conditions. Both of these exhibit the peaking habit shown for the 25,000 and 50,000 rates, i.e., the higher peak on the right side of the seed deposition pattern. All flights at the two lowest rates, including flights with winds similar to those of the 75,000 rate where the dominant peak is on the left, follow the dominant right hand peak form regardless of wind speed or direction. From the evidence it can be suggested only that the anomaly is a function of greater seed loadings of the seeder under certain wind conditions.

Except under the circumstances noted earlier, the location of the seed swath is asymmetrical to the left of the flight line. Figure 12 shows the effect of this phenomenon on the cross-sectional seed deposition diagrams of Figure 8 when parallel swaths 22.9 m wide are flown under *calm* conditions. The "tail" areas illustrated in Figure 8, i.e., the seedfall (or lack of it) beyond 11.4 m on either side of the aircraft track, will overlap. During the flying of adjacent passes seedfall in these "tail" areas is cumulative and, since the "tail" to the left of the aircraft is longer, the seed deposition in this area is considerably increased, and may even exceed the maximum depositions of single passes. Maximum seed deposition rates are slightly less than twice the mean seed deposition for nominal rates of 25,000 and 50,000 seed/ha and approximately three times the mean seed deposition for the nominal 75,000 seed/ha. On the other hand, because the "tail" to the right is much shorter, there may be no overlap and, as in the case of both the 25,000 and 50,000 rates, areas

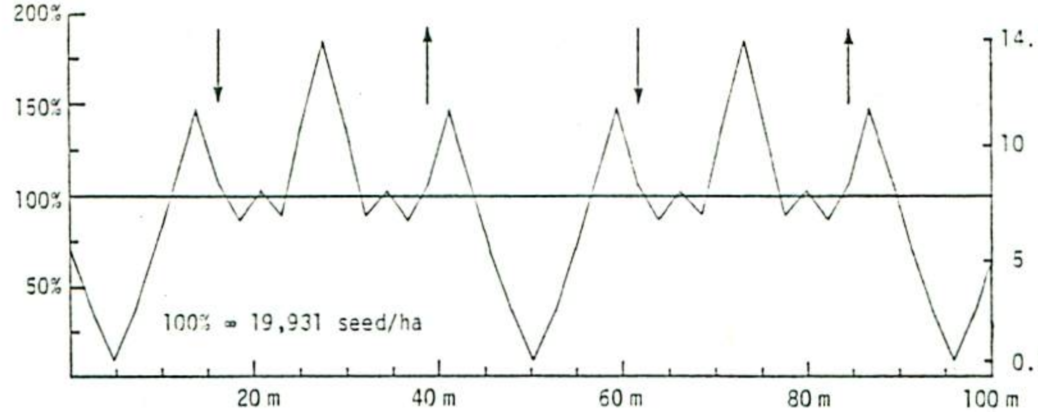

Figure 12a. Effect of asymmetry of seed deposition relative to flight path, with parallel passes at 22.9 m intervals, 25,000 seeds/ha prescribed.

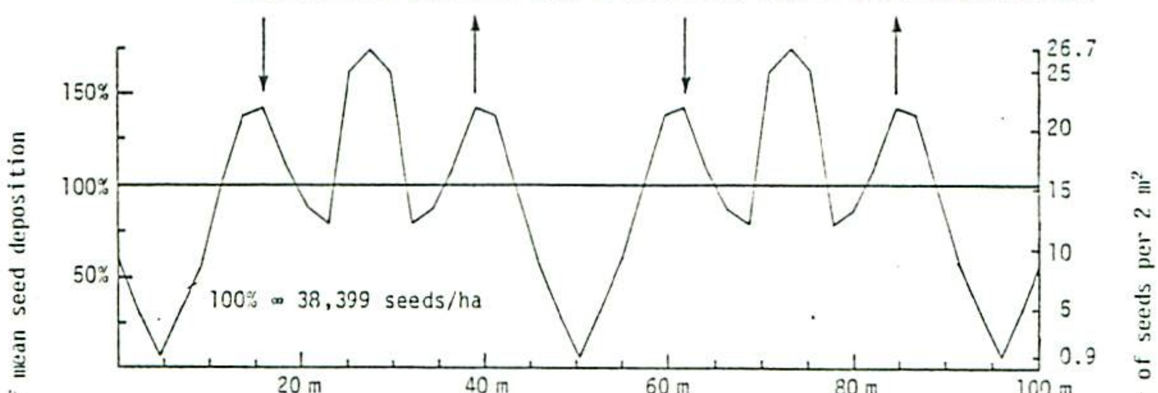

Figure 12b. Effect of asymmetry of seed deposition relative to flight path, with parallel passes at 22.9 m intervals, 50,000 seeds/ha prescribed.

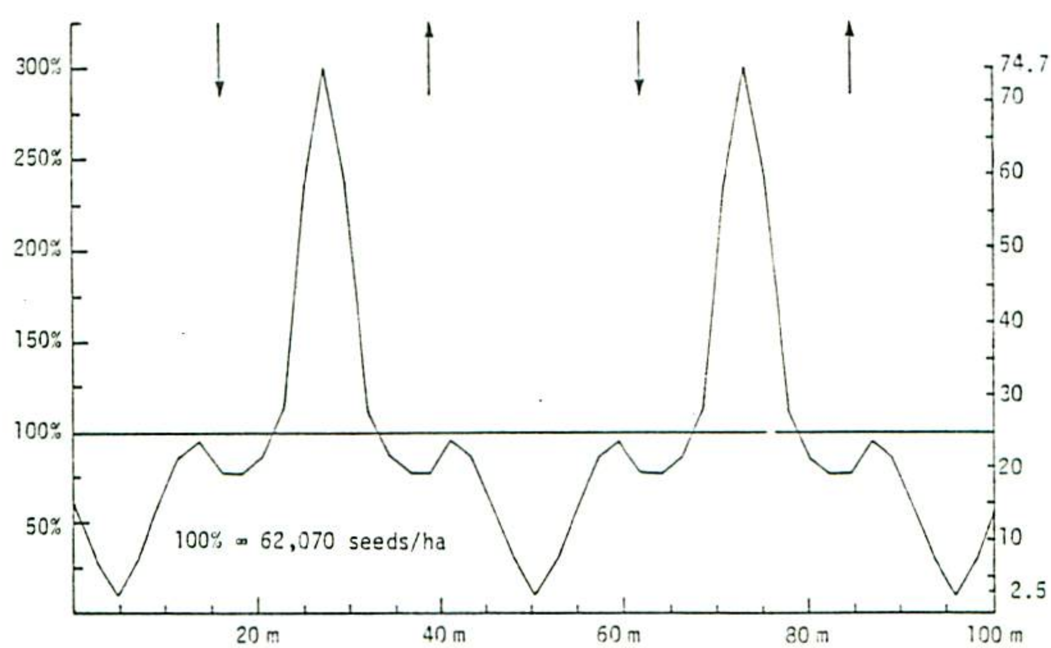

Figure 12c. Effect of asymmetry of seed deposition relative to flight path, with parallel passes at 22.9 m intervals, 75,000 seeds/ha prescribed.

——→ Indicates location and direction of aircraft track in relation to seedswath.

devoid or nearly devoid of seed may occur. (The situation is, of course, reversed at the 75,000 rate because of the transposed peak configuration.) While increasing the overall deposition per swath, this overlapping effect tends, also, to magnify distribution extremes. The reason for "banding" in jack pine stands arising from aerial seed application is made quite clear. When seed is applied at very high rates over certain portions of each double pass, high stockings and excessive densities result, whereas other portions receive inadequate seed or none at all, and poorly stocked or unstocked areas result.

This situation is illustrated in Figure 13 where it is shown that, on the best 22.9 m of swath for all accepted flights combined, most seed is caught by a relatively small number of traps. For example, 25% of the traps accounted for 69%, 65% and 56% of the seed catch for the 25,000, 50,000 and 75,000 rates, respectively. Further, 50% of the traps accounted for 91% and 95% of the seed catch at the 50,000 and 75,000 rates respectively while, at the 25,000 rate, 100% of the catch occurred over just 44% of the traps.

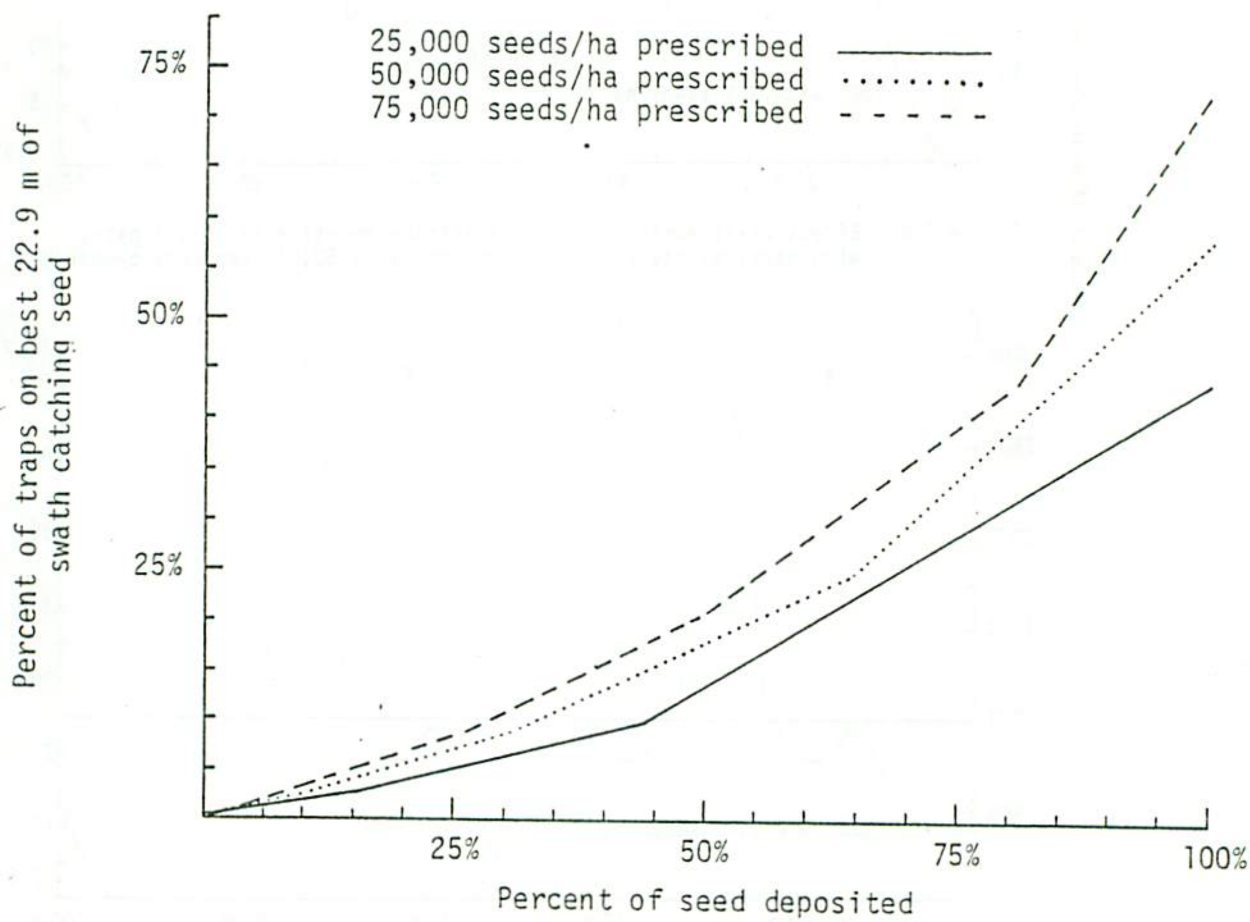

Fig. 13. Percent of seed traps on best 22.9 m of swath receiving seed for all acceptable flights at each seeding rate.

The seed distribution patterns from the Brohm Seeder/PA-18A aircraft combination are quite similar to the distribution patterns obtained with aerial application of fertilizers as reported by Ballard and Will (1971) and Armson (1972). A paraphrasing of Armson's reasoning on fertilizer application provides the logical suggestion that, since the stocking and/or density response to a seeding treatment will normally vary with the rate of application, an estimate of the proportion of the area receiving different rates of application is necessary for a realistic appraisal of the value of the distribution method.

Table 5 indicates the effect of overlapping, shown in Figure 12, on cross-sectional catch. The percentage of cross-section receiving various percentages of mean deposition are given.

Table 5. Percent of cross-section (Fig. 12) receiving amounts of seed in relation to mean seed deposition rates at an inter-pass spacing of 22.9 m.

	Percent of cross-section		
Nominal seeding rate	25,000	50,000	75,000
Mean deposition rate			
150% +	8	11	17
100% - 150%	40	42	8
50% - 100%	38	31	58
25% - 50%	8	9	9
<25%[a]	6	7	8
	100	100	100

[a] The apparent discrepancy between these values and the much higher percentage of traps indicated in Figure 13 as receiving no seed is the result of the combining of traps to provide the plotting points for the cross-sectional diagrams and the overlap effect from adjacent passes as illustrated in Figure 12.

If, indeed, stocking and/or density response to a seeding treatment vary directly with the rate of seed application (other factors held constant) then stands of jack pine obtained using the Brohm Seeder/PA-18A aircraft combination at 22.9 m inter-pass spacings will exhibit variable results. A high level of uniformity in seed distribution is required to obtain a uniformly stocked stand of jack pine (other factors constant). This raises the question: What objective standard for aerial distribution of jack pine seed should be established to assure satisfactory stocking at acceptable densities in the new forest, one that may be achieved by an aerial seeding contractor? This is a debatable question, but, until better technology becomes available, the authors suggest the following standard:

Mean seed deposition over an area shall equal the prescribed rate ±10% and minimum deposition, on a 2 m^2 quadrat basis over all of the area sown (i.e., seed distribution), shall be equal to or better than 50% of the mean deposition rate.

For example, if a rate of 50,000 seed/ha is prescribed, mean seed deposition over an area must lie between 45,000 and 55,000 seed/ha and each 2 m^2 quadrat on the area shall receive a minimum of 9-11 seeds, depending on the mean deposition rate achieved.

If this seems unnecessarily high, and the standard unnecessarily stringent, it should be remembered that, in field applications, quadrats of this size contain relatively little receptive seedbed. If, as is common, 20% of the quadrat is in receptive seedbed (Riley 1975), at a minimum only two seeds will be in a position to germinate and survive, given a uniform distribution of the seed over the quadrat. Even at a 75,000 seed/ha rate the minimum catch under the standard would be only three seeds on receptive seedbed, barely adequate to provide reasonable assurance that a tree will become established.

In this context accurate calibration of the seeder assumes new importance. But as noted, even flawless calibration will not ensure deposition rates equal to prescribed rates. Hence, increased attention must also be paid to flying procedures if the minimum standards are to be achieved.

It is readily apparent from Figure 12 and Table 6 that seedings with the Brohm Seeder/PA-18A combination at inter-pass spacings of 22.9 m do not meet the suggested distribution standard. One means of bringing seed distribution from this unit more in line with the standard is to narrow the interpass spacing of the aircraft while maintaining the other sowing variables. Because the width of seed spread remains unchanged, the amount of overlap will be increased. Thus, sowing will take place at the same *calibrated* rate but the *deposited* rate will be increased.

The results of narrowing the inter-pass spacing to 20 m are depicted in Figure 14. Mean deposition is increased by 14.5% over that of the 22.9 m spacing. However, a 20 m spacing does not satisfy the distribution standard at any of the three seeding rates. Voids are eliminated, but minimum catches across the swath are only 42%, 38% and 38% of mean deposition for nominal prescriptions of 25,000, 50,000 and 75,000 seed/ha, respectively. Peak catches, in terms of percent of mean deposition, are only marginally changed. In other words, the cross-sectional catches become somewhat less irregular than for the 22.9 m spacing.

Table 6. Percent of cross-section (see Fig. 14) receiving amounts of seed in relation to mean seed deposition rates at an inter-pass spacing of 20 m.

	Percent of cross-section		
Nominal seeding rate	25,000	50,000	75,000
Mean deposition rate			
150% +	9	2	19
100% - 150%	37	54	8
50% - 100%	43	30	59
25% - 50%	11	14	14
<25%	--	--	--
	100	100	100

Table 6 indicates the effect of overlapping on cross-sectional catch at the 20 m inter-pass spacing. These values can be compared directly with those of the 22.9 m spacing in Table 5. Considerable improvement is evident in most areas, particularly at the 50,000 seed/ha rate, but overall distribution characteristics are still poor.

The results of narrowing inter-pass spacing to 18 m are depicted in Figure 15. This spacing appears to satisfy fully both criteria of the standard at all three seeding rates. Mean deposition is increased by 27.2% over that for the 22.9 m spacing and 11.1% over that for the 20 m spacing. In fact, deposited rates at the 18 m spacing are 101%, 98% and 105% of the nominal rates of 25,000, 50,000 and 75,000 seed/ha, respectively.

At the 18 m spacing minimum catches are 62%, 55% and 50% of the mean deposition rates for nominal rates of 25,000, 50,000 and 75,000 seed/ha, respectively (Fig. 15). With the exception of the 25,000 seeding rate where there is only marginal reduction, peak catches in terms of percent of mean deposition are significantly reduced over those of the 22.9 m spacing. It should be noted, however, that absolute values of peak catch are only marginally changed across the three spacings at each seeding rate (see Fig. 12, 14, 15).

Table 7 indicates the effect of overlapping on cross-sectional catch at the 18 m inter-pass spacing. Again, these values can be compared directly with those of the other two spacings as noted in Tables 5 and 6.

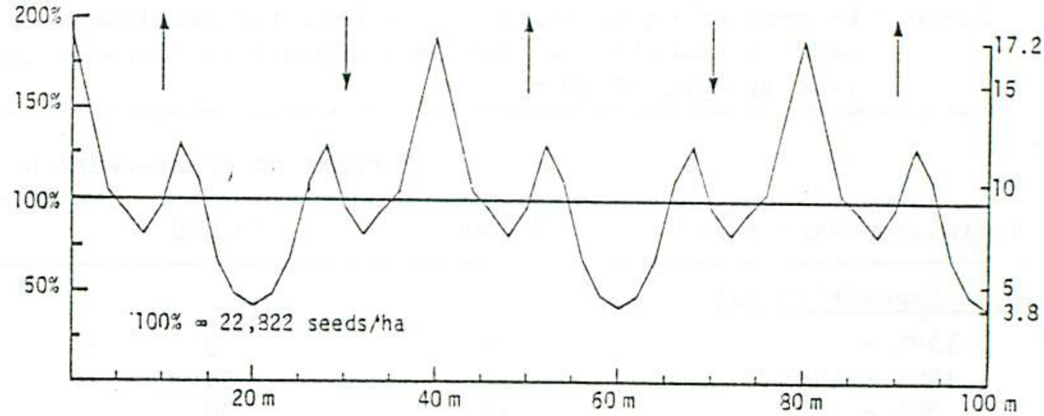

Figure 14a. Effect of asymmetry of seed deposition relative to flight path, with parallel passes at 20 m intervals, 25,000 seeds/ha prescribed.

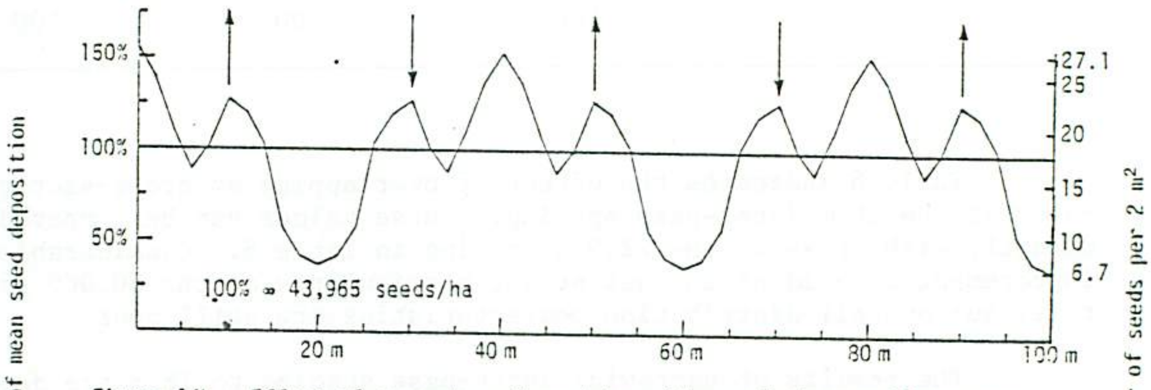

Figure 14b. Effect of asymmetry of seed deposition relative to flight path, with parallel passes at 20 m intervals, 50,000 seeds/ha prescribed.

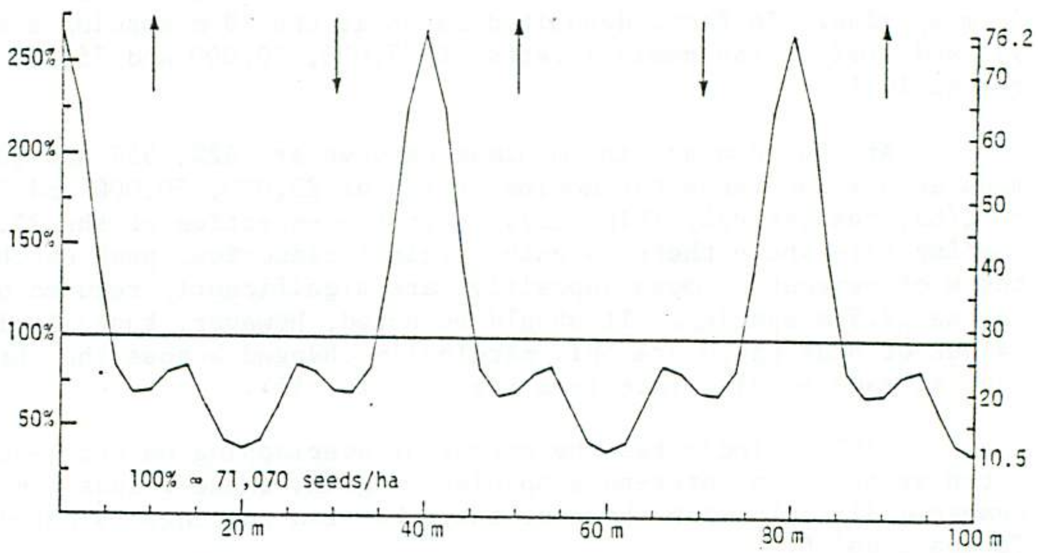

Figure 14c. Effect of asymmetry of seed deposition relative to flight path, with parallel passes at 20 m intervals, 75,000 seeds/ha prescribed.

——→ Indicates location and direction of aircraft track in relation to seedswath.

Table 7. Percent of cross-section (Fig. 15) receiving amounts of seed in relation to mean seed deposition rates at an inter-pass spacing of 18 m.

	Percent of cross-section		
Nominal seeding rate	25,000	50,000	75,000
Mean deposition rate			
150% +	7	--	22
100% - 150%	46	71	9
50% - 100%	47	29	69
25% - 50%	--	--	--
<25%	--	--	--
	100	100	100
Maximum	177%	140%	237%
Minimum	62%	55%	50%

As is indicated, the entire cross-section, on a multiple basis, catches seed at a rate of at least 50% of the mean deposition rate at each of the nominal seeding rates. However, at the 25,000 rate, almost half of the area (47%) catches seed below the 100% (of mean deposition) level. In terms of actual seed, this means that almost half of the 2 m^2 quadrats are catching 6-10 seeds (Fig. 15). If we return to the 20% receptive seedbed example discussed earlier, it is seen that these quadrats are likely to have only 1-2 seeds in a position to germinate and survive. By normal standards (Brown 1973), this is insufficient to establish a seedling. Therefore, while some of these quadrats would undoubtedly become stocked, there is a high potential for failure. Further, examination of Figure 11 shows that, for the 25,000 rate, mean seed deposition can be expected to vary by $\pm$15% at 95% confidence limits. Hence, this seeding rate does not satisfy the mean deposition criterion of the standard. Also, there is a high potential for non-stocking because of insufficient seed available on generally attained levels of receptive seedbed, and it is therefore concluded that the 25,000 seed/ha rate is unsuitable and is to be avoided in practice, regardless of inter-pass spacing.

Figure 11 shows that the 50,000 and 75,000 seeding rates meet the mean deposition criterion of the standard, i.e., at 95% confidence limits mean seed deposition varies by $\pm$10% or less.

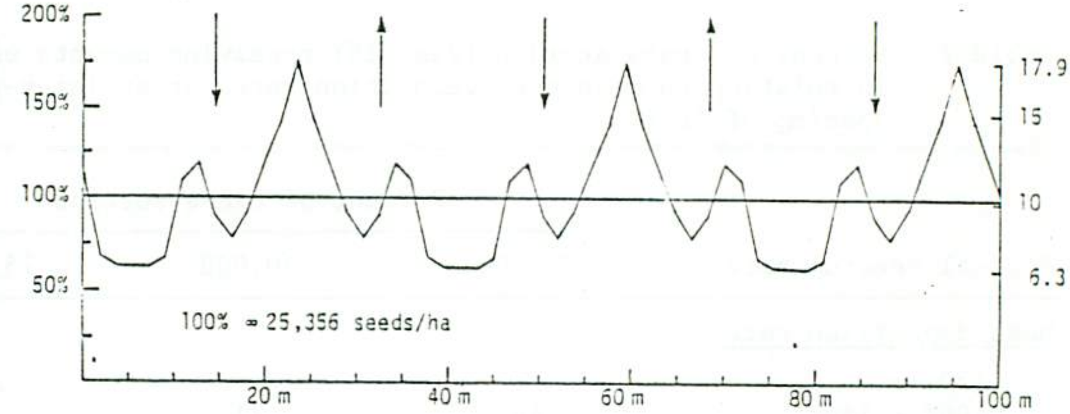

Figure 15a. Effect of asymmetry of seed deposition relative to flight path, with parallel passes at 18 m intervals, 25,000 seeds/ha prescribed.

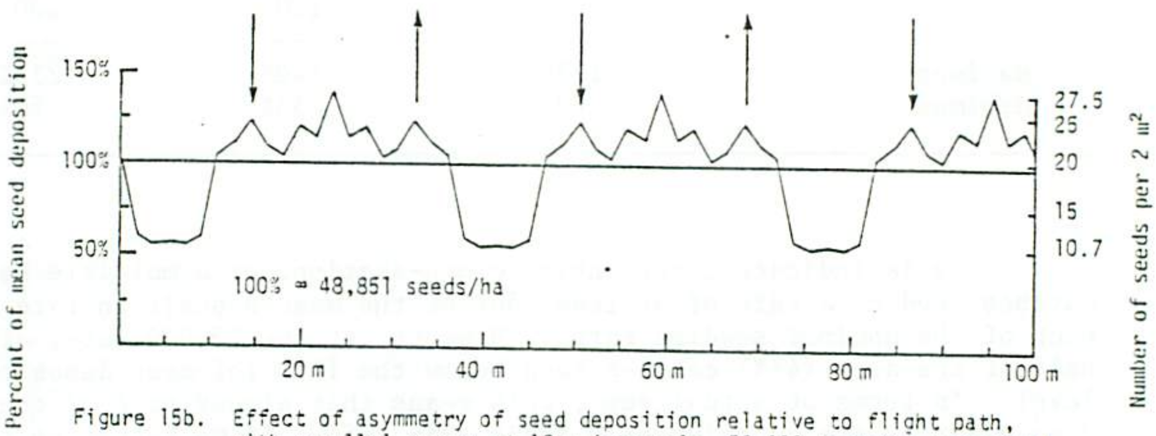

Figure 15b. Effect of asymmetry of seed deposition relative to flight path, with parallel passes at 18 m intervals, 50,000 seeds/ha prescribed.

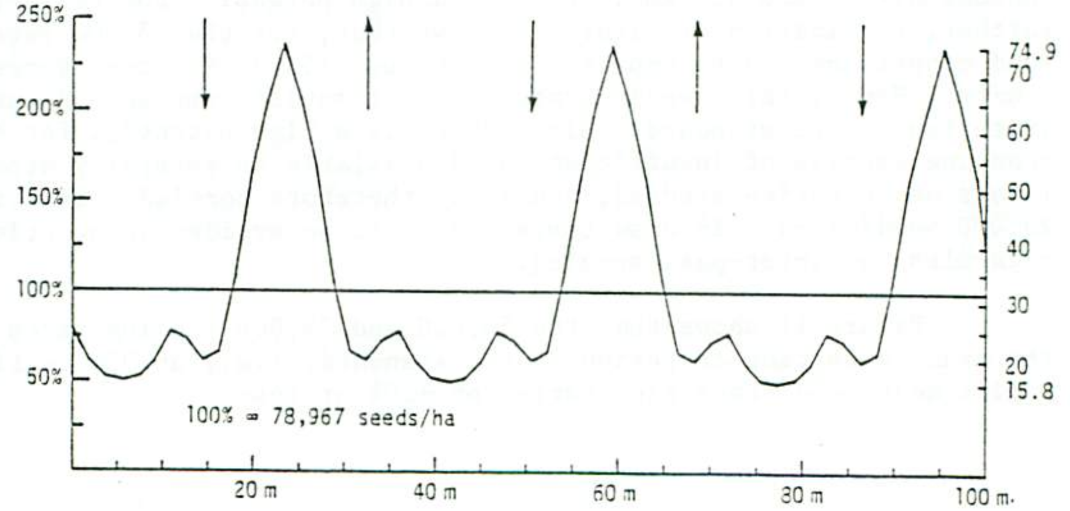

Figure 15c. Effect of asymmetry of seed deposition relative to flight path, with parallel passes at 18 m intervals, 75,000 seeds/ha prescribed.

——→ Indicates location and direction of aircraft track in relation to seedswath.

At the 50,000 rate the majority of the area (71%) receives seed at 100%-150% of the mean deposition rate. In other words, most of the area would receive 20-27 seeds per 2 m^2 quadrat (Fig. 15), or 4-5 seeds on receptive seedbed on the basis of the previous example. For the remainder of the area, quadrats would receive 2-4 seeds on receptive seedbed, a rate only marginally acceptable but nevertheless offering moderate opportunity for stocking success. Maximum deposition is 140% of the mean deposition rate.

With most of the area receiving seed at the level considered necessary for success, and the remainder approaching this level, it is suggested that the 50,000 seed/ha rate offers a high potential for stocking success with a minimum wastage of seed.

When a 75,000 seed/ha rate is prescribed at this spacing, it is seen from Table 7 that approximately two thirds (69%) of the area receives seed at 50% to 100% of the mean deposition rate. At this level the number of seeds received per quadrat would seem to be quite acceptable, i.e., 16-32 seeds or, on the basis of the 20% receptive seedbed example, 3-6 seeds in a position to germinate and survive. It should be remembered, however, that about two-thirds of the area is receiving seed at a rate below that which the forest manager has said is wanted. Only 9% of the area receives between 100% and 150% of mean deposition and almost one-quarter (22%) of the area receives seed at very high rates, i.e., greater than 150% of mean deposition. Deposition peaks at 237% of mean. In this upper range (150% +), the number of seeds per 2 m^2 quadrat ranges from 48 to 75 (10-15 seeds on receptive seedbed), and is more seed than is necessary to stock the quadrats. Hence, while the 75,000 seed/ha rate satisfies the criteria of the standard, it has little advantage over the 50,000 seed/ha rate and is, to a large extent, wasteful of seed.

The Brohm Seeder/PA-18A aircraft combination at 75,000 seed/ha, and at an 18 m spacing, does not adequately deposit the seed over 69% of the area and puts on much more than is required over 22% of the area.

As a result of the foregoing, it is suggested that, when the Brohm Seeder/PA-18A aircraft combination is used, neither the 25,000 seed/ha rate nor the 75,000 seed/ha rate is suitable, the former because it deposits insufficient seed over much of the area and does not meet one of the seeder performance criteria, and the latter because it is wasteful of seed and is far too irregular in its distribution pattern. For optimum performance from this seeding combination, a seeding rate[8] of 50,000 seed/ha and an inter-pass spacing of 18 m are recommended.

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[8] This corresponds to the seeding rate recommended by Riley (1975) as the optimum seeding rate for stocking and density results in jack pine.

It must be reiterated that the foregoing analysis applies to calm, or very nearly calm, conditions only. Although wind does not change the general form of the seed distribution pattern, the location and width of the seed swath are wind sensitive. As noted in the Results section, this sensitivity to wind is not uniform from side to side, and the extent of the shift is directly related to the side of the pattern from which the wind comes. This has a marked impact on seed distribution from parallel passes of the aircraft since the shift occurring from a pass in one direction is not equally compensated for by the shift occurring from the adjacent pass in the opposite direction. Hence, wind will tend to increase overlapping and voids between flight lines, although the extent to which this will occur has not been adequately quantified.

A flight-by-flight check of the flight lines in front of and past the trap array proper, supported by theoretical calculation, has indicated that, to ensure seedfall on the desired area over the entire flight line, the seeder should be turned on approximately 100 m before the area being sown on each pass is entered and should not be turned off more than approximately 50 m before the area being sown is left.

Finally, it is apparent from the literature that distribution patterns achieved are directly related to the specific equipment being used and the material being distributed. Armstrong (1978a) makes the following points: "Since the airflow patterns around and in the wake of an aircraft are sufficiently different, each type and series of aircraft needs testing. Virtually any change in the aircraft will change the distribution pattern." Armstrong (ibid.) comments further: "....minor changes in the surface characteristics of the granules (shape, surface finish, fineness or grind) alter the discharge rate. Because of the wide variation in granule sizes and types used, swath checks must be run with each type to determine the deposit pattern and swath spacing to be used." Thus, while distribution patterns similar to those reported here may be obtained when the Brohm Seeder is used with aircraft other than the Piper PA-18A used in these trials, or when seed other than that of jack pine is used, the forest manager should be aware that ground catches may be significantly altered. As a consequence, a decision to change aircraft types or to sow other species in the expectation of obtaining comparable results should not be made lightly.

RECOMMENDATIONS

Although the Brohm Seeder/PA-18A aircraft combination does have some limitations it will, in the absence of better seeding equipment, distribute seed in a manner that can provide acceptable levels of jack pine stockings and densities. However, calibration and flying procedures must be carried out carefully and precisely. Without adequate attention to these areas, it is highly unlikely that major discrepancies between mean deposition and the prescribed seeding rate can be avoided.

Similarly, uniformity of distribution, though much more dependent on flying procedure and the specific distribution pattern of the seeder/aircraft unit being used than on seeder calibration, will suffer dramatically if caution is not exercised. The resultant distribution extremes will cause high depositions on some parts of the seeded area and little or no deposition on other parts. The resulting stand will suffer accordingly.

The following recommendations are made for the use of the Brohm Seeder/PA-18A aircraft combination (or the Brohm Seeder in combination with any other light, single-engined, fixed-wing aircraft) to increase the effectiveness with which seed is distributed and, consequently, the uniformity and degree of stocking in the resulting stand.

1. Calibrate the seeder carefully with foreknowledge of the factors that will affect deposition rates and the extent to which these factors will affect deposition. The principal factors to be considered are (i) number of seeds/g, (ii) precision in calibration procedure, (iii) inter-pass spacing, and (iv) ground speed of aircraft.

2. Just prior to sowing, determine the number of seeds/g for the seedlot to be used. Do not open the seed container before it is necessary and do not allow the seed to remain exposed to the air, either in the container or in the aircraft hopper, for longer than necessary since moisture content of the seed, and thus the deposition rate, will fluctuate with changes in relative humidity.

3. Increase the length of calibration test intervals from 15 sec. to 30 sec. Use a precise gram balance to weigh seed when calibrating.

4. Sow at 18 m inter-pass spacings. Ensure that the swath width factor in the calibration formula is altered accordingly.

5. As has been shown in Figures 12, 14 and 15, seed distribution patterns over an area are very sensitive to inter-pass spacing. Whenever possible ground guidance should be provided to the pilot to assist in maintaining the selected inter-pass spacing.

6. Position of seed deposition relative to the track of the aircraft is sensitive to wind speed and direction. Seeding operations should be conducted under calm conditions whenever possible but, when winds are unavoidable, they should be steady and have a velocity of less than 5 km/h.

It is further recommended that the following basic seeding standard be used to determine whether or not any new seeding unit (or seeding unit/aircraft combination) developed or considered for operational use is acceptable.

Mean seed deposition over an area shall equal the prescribed rate ±10%, and minimum deposition, on a 2 m^2 quadrat basis over all of the area sown (i.e., seed distribution), shall be equal to or better than 50% of the mean deposition rate.

The acceptability of this standard to the forest manager remains to be seen, but it is recognized that aerial seeding must be continued as an operational technique in Ontario. It is recommended, however, that in no case should equipment with capabilities inferior to those of the Brohm Seeder/PA-18A aircraft combination be used.

Finally, these trials have provided a clear indication that the Brohm Seeder/PA-18A aircraft combination has limitations in its seed deposition and distribution capabilities. *It is recommended that this work be used as a basis for the development of a more effective seeding unit, one that will deposit and distribute seed with greater uniformity and a higher degree of precision, and one that will be less sensitive to operational variables and procedures so easily overlooked during field operations.*

REFERENCES

Armson, K.A. 1972. Fertilizer distribution and sampling techniques in the aerial fertilization of forests. Fac. For., Univ. Toronto, Toronto, Ont. Tech. Rep. No. 11. 27 p.

Armstrong, K. 1978a. Calibration and swath pattern. p. 8-19 *in* Report of the Fourteenth Northeast Aerial Applicators Conference, Ithaca, New York, Feb. 21-23, 1978. Compiled and edited by The Chemicals-Pesticides Program, Cornell Univ., Ithaca, New York.

Armstrong, K. 1978b. Droplet size and drift. p. 32-38 *in* Report of the Fourteenth Northeast Aerial Applicators Conference, Ithaca, New York, Feb. 21-23, 1978. Compiled and edited by The Chemicals-Pesticides Program, Cornell Univ., Ithaca, New York.

Ballard, R. and Will, G.M. 1971. Distribution of aerially applied fertilizer in New Zealand forests. N.Z. J. For. Sci. 1 (1): 50-59.

Brown, G. 1973. Direct seeding in Ontario. p. 119-124 *in* J.H. Cayford, *Ed.* Direct Seeding Symposium, Timmins, Ont., Sep. 11-13, 1973. Dep. Environ., Can. For. Serv., Ottawa, Ont. Publ. No. 1339.

Riley, L.F. 1975. Assessment of site preparation and its effect on aerial seeding success. P. 23-36 *in* Mechanization of silviculture in northern Ontario. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. Symp. Proc., O-P-3.

Silversides, R.H. 1974. An inexpensive and simple technique for measuring wind velocity in the lower 600 m of the atmosphere. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. Inf. Rep. O-X-200. 9 p. + Appendix.

Worgan, D. 1973. Aerial seeding by fixed-wing aircraft. p. 125-129 *in* J.H. Cayford, *Ed.* Direct Seeding Symposium, Timmins, Ont., Sep. 11-13, 1973. Dep. Environ., Can. For. Serv., Ottawa, Ont. Publ. No. 1339.

APPENDICES

APPENDIX A

DEFINITIONS

Forestry

Density

Number of plants of a species per unit area, (e.g., 4,412 jack pine trees per hectare).

Receptive seedbed

The part(s) of the forest floor where desirable conditions occur, either naturally or artificially, to afford a seed a reasonable opportunity to germinate, survive and grow as a viable plant.

Scarification

Purposeful disturbance of the forest floor to create a desirable condition, e.g., receptive seedbed for aerial seeding.

Stocking

An expression of the frequency (percent) with which small, equal-sized land units (e.g., 2 m^2 quadrats) over an area are occupied by a particular species. Should be expressed in terms of percent, species and land unit size (e.g., 67% stocked to jack pine on a 2 m^2 quadrat basis).

Comparison of stocking and density

A forest stand is described as having a stocking of 67% jack pine on a 2 m^2 quadrat basis and a density of 4,412 jack pine stems per hectare. This indicates that 1,675 quadrats of a possible 2,500 quadrats in a hectare are stocked to one or more jack pine and that the same hectare contains 4,412 jack pine. The average number of jack pine stems for each stocked quadrat is 2.6.

Seeding

Air speed

The speed of an aircraft relative to the air mass through which it is passing.

Ground speed

The speed of an aircraft relative to the ground over which it is passing.

Calibrated rate

The number of seeds per minute constantly dispensed by the seeder. (May be expressed in terms of seed per hectare for a given set of variables such as number of seed per gram, specified swath width and specified ground speed of aircraft. A change in any of these variables will not change the calibrated rate but will change the deposited rate.)

Deposited rate

The amount of seed that actually falls on an area of land; in this case expressed as seed/ha.

Distribution pattern

The pattern of seed deposition on small, equal-sized land units within a large land area (e.g., the number of seed deposited on a series of contiguous 2 m^2 quadrats oriented perpendicular and/or parallel to the aircraft track).

Inter-pass spacing

The distance between repeated, parallel flights of an aircraft over an area.

Nominal rate

A prescribed rate existing in name only, not real or actual.

Prescribed rate

A seeding rate selected in advance and set out authoritatively that, if achieved, will satisfy a predetermined objective.

Seeder calibration

The act and art of adjusting the seed dispensing mechanism to assure that seed deposition over the area being sown will equal the prescribed rate. Some of the variables to be considered in seeder calibration are: (1) prescribed rate, (2) number of seeds/ gram, (3) ground speed of aircraft, (4) inter-pass spacing and (5) effective swath width.

Swath width

The width of the strip of land upon which seed is deposited from an aircraft during a single pass.

Effective swath width

The width of that portion of the swath within which the deposited density of seed lies at or above the minimum required for effective treatment. This will define the distance between successive parallel runs or passes of the aircraft (i.e., "inter-pass spacing").

APPENDIX B

The procedure used by General Airspray Limited for calibrating the Brohm Seeder for use in fixed-wing aircraft applications is outlined below. The general approach is to calibrate the seeder to meter sufficient seed through the auger, and hence out the slinger outlets, for the proposed flying speed, height and swath width to provide a seedfall at the prescribed rate.

Prescribed aircraft ground speed - 128.75 kmh

Prescribed inter-pass spacing - 22.9 m

Prescribed flying height - 22.9 m

Area covered per minute of flight

$$= \text{Aircraft ground speed (m/min)} \times \frac{\text{inter-pass spacing (m)}}{\text{m}^2/\text{ha}}$$

$$= \frac{128.75 \times 1000}{60} \times \frac{22.9}{10{,}000} = 4.9 \text{ ha}$$

$$\text{Weight of seed required per hectare} = \frac{\text{Prescribed seeding rate/ha}}{\text{No. seed/g}}$$

The seeder is calibrated on the ground over 15-sec. intervals. The speed of the auger is adjusted until the calculated weight of seed is obtained consistently over a series of 15-sec. intervals.[a]

CALIBRATION EXAMPLE

Prescribed seeding rate: 50,000 seed/ha

$$\text{Weight of seed required per hectare} = \frac{50{,}000}{282^{b}} = 177.3 \text{ g}$$

Weight of seed which must be dispersed during 15-sec. period

$$= \frac{4.9 \times 177.3}{4} = 217.2 \text{ g}$$

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[a] It is recommended in the report that this time interval be increased to 30 sec.

[b] As taken from Ontario Tree Seed Plant data sheet received with seed used during the Lucan trials.

APPENDIX C

As a result of lower-than-prescribed depositions on both the Lucan trial and the operational trials of aerial seeding noted in the Introduction section, it was suspected that there were some problems associated with the calibration of the Brohm Seeder prior to seeding that were affecting expected deposition rates. If this is true, a basic flaw, irrespective of distribution patterns, arises immediately in any operational attempt to disseminate a predetermined quantity of seed per unit area. To investigate this, a small calibration trial was undertaken by staff of the Centre during the winter of 1975-1976. The trial was preceded by, and then spurred on by, results obtained from weighings of samples of a jack pine seed lot which had been cool-stored for a year at the Centre and which was to have been used in the seeder calibration trial. The seed had been received from the OMNR seed plant at Angus and was treated with the usual latex-aluminum flake coating. Weighings and subsequent seed counts of 10 samples in a container of fixed volume indicated that the number of viable seeds per gram was noticeably below the values given on the data sheet for the seed lot. Similarly, the range of seed per gram in the sample was greater than expected.

To test this further, a sealed container, recently shipped from the Angus seed plant and containing approximately 2,000,000 jack pine seed treated with latex and aluminum, was obtained from OMNR's Wawa District. The seal was broken and the seed and packing slip (Table A1) were removed. The seed was immediately weighed on a balance and then set out in two shallow plastic pans in a well ventilated room maintained at 21°C. Relative humidity varied from 20% to 40%. The seed was reweighed from time to time.

Table A1. Packing slip data.

Order number	:	2771
Species	:	jack pine
Date	:	November 4, 1975
Container number	:	75-40
Amount	:	6.921 kg
Site region	:	3E
Year	:	1975
Viable seed per gram	:	289
Germination	:	estimated 97%
Total viable seeds	:	2,000,169

(6,921 g x 289 - 2,000,169)

Treated with latex, aluminum flakes

Immediately after the first weighing of the seed lot, 12 samples were taken in plastic creamer cups. These were weighed and counted and then reweighed 5 days later. They were then returned to the main seed lot. The results of the weighings of the full seed lot are presented in Table A2 and those of the individual samples in Table A3.

Table A2. Weighings of full seed lot.

Weighing date 1976	Net weight (g)	Number of viable seeds[a]	Number of viable seeds per g
March 18	7,777	2,000,169	257.2
March 23[b]	7,550		264.9
March 26	7,471		267.7
April 5	7,250		275.9

[a] As determined from seed plant data sheet.

[b] After return of samples.

Table A3. Weighings of individual samples.

Weighing date 1976	Number of samples	Average number of viable seeds per g[a]	Range of number of viable seeds per g
March 18	12	266	256-277
March 23	12	275	270-283

[a] Determined by actual count and adjusted for viability (97%) as given by packing slip.

From both tables it is readily evident that the laboratory count of viable seeds per g was lower than that indicated on the packing slip and that the total weight of the lot when received was much greater than when weighed at the seed plant (by 12.4%). From discussion with C. Lane, Tree Seed Improvement, Forest Resources Branch, OMNR, it is evident that this is not the result of improper weighing at the seed plant or in the laboratory. Weighings at the seed plant were made before coating, which is carried out by means of a slurry treatment. This added weight over and above that noted on the packing slip, which indicated storage weight. Secondly, since seed is stored at the seed plant at about 6% moisture content, it immediately takes on moisture and, consequently, additional weight, as soon as it leaves storage, whether treated or not. Depending on relative humidity conditions, this increase may be enhanced once the seed is removed from its polyethylene container by the recipient. Hence, the weight at time of seeding can be much higher (and the number of viable seeds per g correspondingly lower) at the time of seeding than during storage. Since calibration for a seeding job is usually carried out using the seeds per g data on the packing slip, calculated at a time and under conditions other than those existing at calibration, the number of seeds per g at calibration will be lower than that required for the prescription rate (by as much as 12%). When this value is translated into a seeding operation it means that a prescribed rate of 50,000 seed/ha can be an actual rate of only 44,000 seed/ha. Hence it is important for accurate calibration of the seeder feed rate that seeds per g be determined just prior to sowing and that the seeder not be calibrated on the basis of data provided by the seed plant packing slip.