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FACTORS AFFECTING AND IMPROVED EQUIPMENT FOR ACCURATE AERIAL APPLICATION OF GRANULAR FERTILISER TO NEW ZEALAND FORESTS

BY

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FRI/INDUSTRY RESEARCH COOPERATIVES

EXECUTIVE SUMMARY

This paper examines the problems associated with the aerial spreading of fertilisers to forests and the current technology available to provide for even and assured fertiliser distribution.

This paper is a pre-publication release to participants of the National Forest Fertilising Cooperative. This material is unpublished and confidential. Financial assistance for this project was provided for by the Silvicultural Equipment Development Committee (SEDC). It is intended that the article will be released as an FRI Bulletin.

FACTORS AFFECTING AND IMPROVED EQUIPMENT FOR ACCURATE AERIAL APPLICATION OF GRANULAR FERTILISERS TO NEW ZEALAND FORESTS

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ABSTRACT

This paper examines several major causes of irregular fertiliser dispersal from helicopters and fixed wing airplanes. Factors of particular importance include the pilots experience, his ability to maintain accurate flight patterns with or without navigation aids. The physical and balistic properties of the products being applied are investigated. Spreading equipment and navigation aids have been developed to deliver correct quantities of material in swaths of adequate width. Compartments should be suitably arranged and demarcated. Fertiliser should be stored undercover and remain dry and weatherproof. Adverse weather conditions, especially strong and gusting winds, can also produce an unsatisfactory distribution of fertilisers.

INTRODUCTION

Fertilisers were first applied to pine plantations in New Zealand in the 1950s, but it was not until the 1970s that large-scale programmes were introduced to correct nutrient deficiencies and promote optimum tree growth.

The use of fertilisers has now become a routine part of efficient forest management in a number of forests in New Zealand. Many forests are located on infertile soils and are unsuitable for agriculture. Although trees have lower nutrient demands than agricultural crops, some of these soils do not contain adequate nutrient supplies for good forest growth. In particular, nitrogen, phosphorus, and boron deficiencies severely affect tree growth in parts of both the North and South Islands, unless adequate fertilisation programmes are maintained, tree growth and timber quality through malformation decline (Will, G.M.; Hodgkiss, P.D.; NZJFS 7()77.

Phosphorus deficiency is the major nutrient deficiency limiting pasture growth on much of New Zealand's farmland, but because of steep topography it is often impracticable to spread fertiliser from the ground. In the 1940s the aerial application of superphosphate was pioneered using converted Tiger Moth aircraft. It soon became evident that aerial topdressing was the answer to increasing productivity and an extensive industry soon developed.

New fixed-wing aircraft with improved performance have been specially designed for aerial topdressing but, while carrying capacity, speed, manoeuvreability, etc., have been improved, the fertiliser is still "released out of a hole in the bottom of the aeroplane". This is a major factor contributing to the uneven spread of fertiliser. Uneven distribution has not been seen as a serious disadvantage in the pastoral situation where frequency of repeat applications and fertility transfer by grazing animals are considered effective counteracting factors. Very simply, a farmer might have to apply 14 tonnes to 100 ha using present methods to get the same response as from 10 tonnes if the fertiliser was applied more accurately (Mead and Gadgil 1978, FRI Bulletin No. 34). However, soon after aerial applications of fertilisers to forests began in the 1950s it became evident that, with fertiliser applications four to 10 years apart and no animal fertility transfer, uneven distribution was a major factor in causing variability in tree size and thereby reducing the profitability of harvested trees.

Part of Riverhead Forest aerially topdressed in 1959. The uneven growth response –the strip effect– evident in this photograph taken in 1969 has been largely caused by uneven fertiliser distribution. (FRI BW 51988)

It was not until the late 1970s that major steps were taken to improve fertiliser distribution over forests. A change was then made to using a helicopter guided by an electronic navigation and tracking system, called a Flying Flagman, and equipped with a fertiliser hopper and motor-driven spinner.

This combination aimed to improve fertiliser distribution across each swath and to ensure that flight lines were evenly spaced and parallel.

Although significant improvements in overall fertiliser spread were noticed (Will, Hedderwick 1984), in 1983 it was felt that further improvements in the navigation and tracking equipment and fertiliser hopper were both desirable and possible. The increasing use of high analysis fertilisers and ever increasing cost helped prompt this concern.

RESEARCH NEEDS IDENTIFIED AND THE DEVELOPMENT OF THE FRI HOPPER

In order to further improve the distribution of fertiliser, the following research and development needs were identified:

1. Fertiliser flow rate of a given material, together with the helicopter velocity, would enable a kg/ha rate for a plantation to be calculated. To keep this rate constant during sowing, it would be advantageous to having an accurate display of ground speed for the Pilot. Air speed indications at such low velocities are notoriously inaccurate due to head and tail winds and the characteristics of the helicopters velocity sensor.

2. The flow rate from the hopper should automatically adjust itself in relation to the helicopter ground speed to maintain the desired kg/ha rate.

3. The hopper spinner should be hydraulically driven from a power take-off on the helicopter, increasing both reliability and power to weight ratio.

4. The spinner should be redesigned to give a more even swath by:

   (a) decreasing shatter of fertiliser granules on its vanes.

   (b) avoiding granules from hitting the hopper leg structure.

5. The hopper capacity should be increased to accommodate 800 kg fertiliser bags and wide enough to allow "self loading" by the helicopter.

The Forest Research Institute responded with the development and manufacture of a new hopper and spinner to meet the above requirements, to improve performance, and to suit the high analysis fertilisers used today.

The prototype has been used operationally since the 1986-87 topdressing season and can provide the pilot all the advantages of the Flying Flagman system together with the following:

1. The hopper is based on a "simplex" design, has a constant flow rate through to the spinner, and can hold 800 kg of urea, a nitrogenous fertiliser larger in volume for a given weight than most other fertilisers used today.

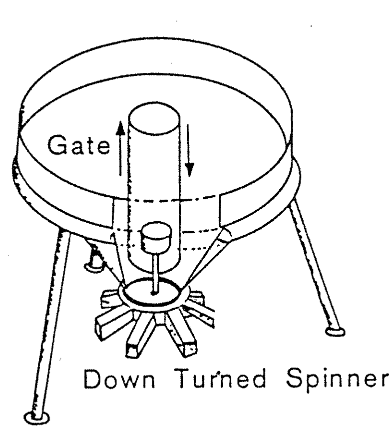
2. The spinner has down-turned and angled slingers to increase the swath width and virtually eliminate shatter of granulated fertilisers. The spinner is hydraulically driven, cheap to manufacture, and light.

3. The pilot has been provided with an indication of the helicopter ground speed during operation.

4. A hopper gate proportional controller operates the movement of a cylinder gate inside the hopper. The flow rate from the hopper is controlled by the vertical movement of this cylinder gate, which is infinitely variable between the fully opened and fully closed positions. The upper limit of travel can be set electronically to a fixed point, or automatically adjusted to maintain a preset kg/ha flow rate. This flow rate is maintained by 'taking' the ground speed information and using it, through the controller, to guide the adjustment of the cylinder gate.

In all modes, the cylinder gate can be fully opened by manual override to clear blockages in flight or dump the load.

Fig. 2 - FRI Hopper



..it experience has shown that with the guidance system, ground speed indication
ground speed guided hopper cylinder gate, and the FRI hopper, used in
n with well-granulated fertilisers, application rates can be reduced due to
venness of fertiliser distribution.

DESIGN OF EQUIPMENT - FIXED-WING Vs HELICOPTER

piex - Type systems for use on helicopters

quent method of fertiliser application uses a Simplex-type hopper suspended
tely 6 m beneath a helicopter.

implex hopper uses a revolving impeller to disperse the fertiliser; this equipment
of a metal disc approximately 60 cm in diameter through which several vanes
f om the centre to the circumference. When the aperture of the hopper is opened
s gravity-fed to the centre of the rotating impeller, and is thrown out through the

early designs of the impeller a significant amount of the fertiliser granules were
attered by the vanes, turning them to dust and affecting the overall swath pattern.
design adopted a "swept back and down" configuration which reduced the impact of
ules on the vanes and throws the material down and below the hopper leg structure,
g in insignificant breakage and improved swath pattern.

Hoppers that are aerodynamically unstable can swing or gyrate, which limits the pilots ability to spread in straight swaths and contributes to irregular distribution of material. Stability can be improved by attaching a fin to the hopper provided the correct position and optimum fin size are determined. When topdressing with an application rate of 200 kg/ha plus, a fin is essential to counteract the torque developed by the impeller underload. In some cases the design of the suspending strop configuration can overcome this phenomenon.

Particle breakage is less severe when using relatively low revolutions (i.e., 600 RPM). The FRI impeller revolves at 1150 RPM. In field trials the high angular velocity of the impeller improved the swath width and uniformity of fertiliser distribution within the swath. Spreading in wider swaths contributes to more precise application throughout the treatment unit, since fewer flight lines are involved and accuracy of overlapping is greater.

The impeller on early Simplex-type hoppers are driven by belts connected to a petrol or hydraulic motor, these belts of a conventional V-shape configuration tend to slip under load, causing variations in spinner speed and consequent changes in swath width. Some applicators have adopted a notched or nodule gear belt to drive the impeller which provides a positive drive and successfully eliminates slippage. One disadvantage of this method is the build up of dust and fertiliser between the notches of the belt, this eventually alters the belt tension causing severe strain on the bearings of both impeller and drive gears. Unlike V-belts, notched belts have a steel-braided core and do not stretch.

In New Zealand the majority of forest topdressing is carried out with SA 315B Lama helicopters fitted with hydraulic Power-Take-Off (PTO) from their jet turbo engines. The PTO allows the use of hydraulic drive of the impeller. It is normal for the hydraulic drive motor to be directly coupled to the impeller thus eliminating any drive belts and their associated problems.

Using an hydraulic system has further advantages over previous drive methods in that it is relatively cheap in the long term, can operate in a harsh environment, does not require daily servicing or refueling and is small and light. The power/weight/size ratios of these hydraulic motors allows them to be fitted internally in the hoppers, thus eliminating motor mounting sub-structures and/or external hoses, with the consequent saving in weight.

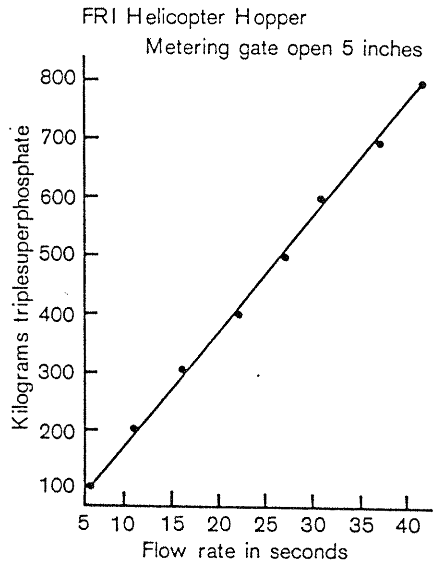
It has been suggested that as a hopper empties under gravity the decreasing head pressure causes a reduction in flow of material to the impeller resulting in a reduced application rate.

The FRI hopper has been tested under a static condition (non-flying) for flow rate under varying load condition.

The correlation is linear, showing the rate of flow remained constant whatever the level of fertiliser in the hopper.

The variation in head-pressure during the test did not alter the flow rate, it can therefore be suggested that this steady flow rate is maintained in flight.

Fig. 3 – Static Flow Rate



(ii) **Venturi-Type Systems for use on fixed-wing**

Fixed-wing aircraft generally use a venturi-type apparatus for spreading fertiliser. This equipment uses an air current produced by slipstream to direct the fertiliser past deflecting surfaces, resulting in a fan-shaped discharge. Initially, the venturi spreaders used for forest fertilising were of a ducted design intended for agricultural projects, in which application rates normally approximate 100 kg/ha.

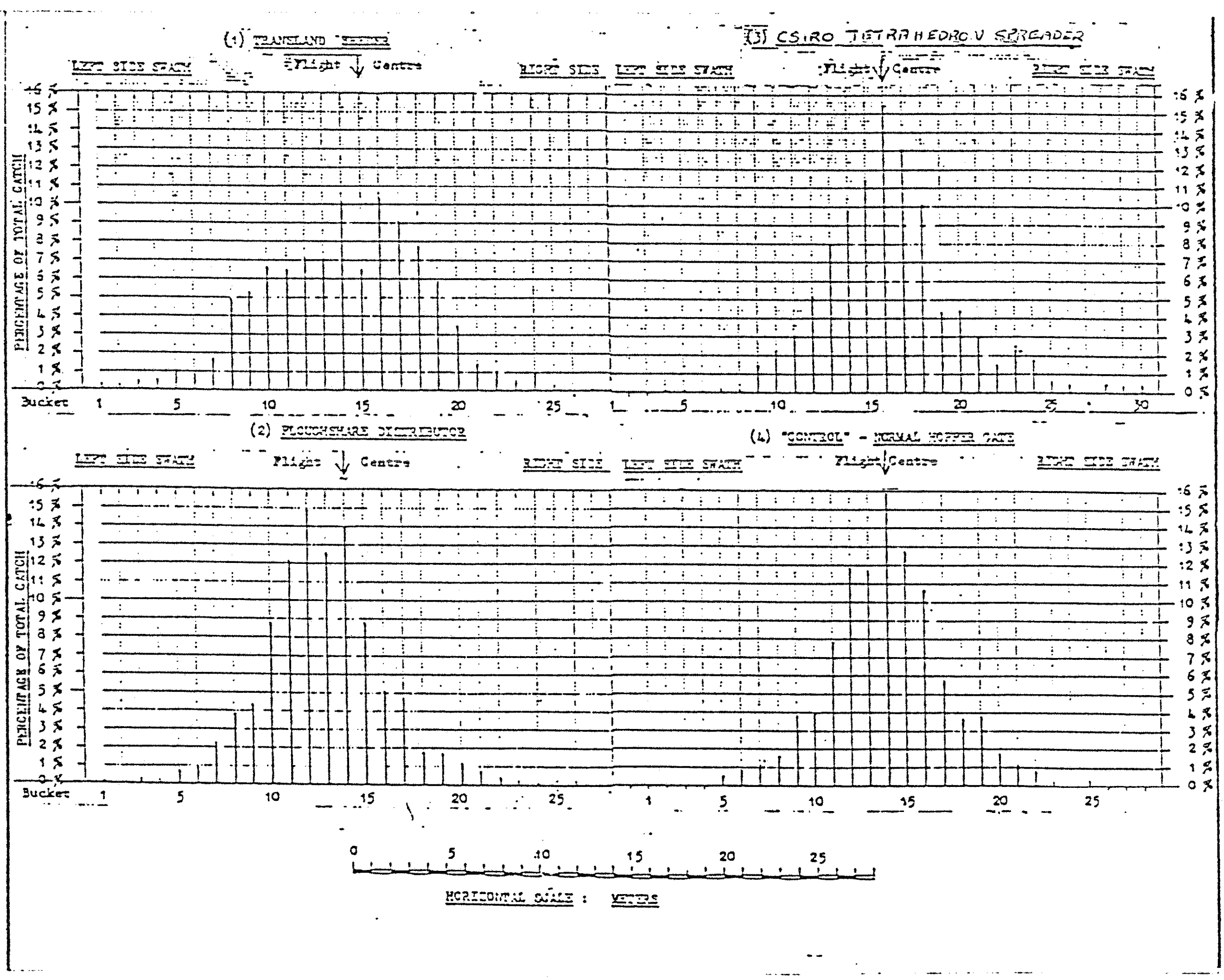
For forestry purposes, however, rates exceeding 400 kg/ha of fertiliser are common, and with these quantities the slipstream is less effective, intermittent clogging occurs in the ducts or aperture of the hopper, and a very unsatisfactory distribution of material is obtained. To try to overcome this problem several fixed wing spreading devices have been built and tested with various claims as to their performance.

In 1985 the opportunity was taken to carry out some comparative tests between three of the more widely used spreaders. The results are as follows:

(a) The fixed-wing swaths are narrow and peaked.

Are characteristically narrow with the heaviest zone of deposition with fertilisers, such as Di-ammonium Phosphate D.A.P. confined to a width of some seven metres reaching the highest peak in the swath centre. Of the three spreaders fitted - Transland Seeder, CSIRO Tetrahedron Spreader, and Ploughshare - only the Transland Seeder showed a slightly better pattern than using no spreader at all. To ensure a uniform distribution, flight bouts must be flown at close intervals and with great accuracy.

Fig. 4 - COMPARISON OF SWATH PATTERNS USING DIFFERENT SPREADERS BENEATH A FLETCHER AIRCRAFT



For the topdressing operation investigated, the Transland Seeder was not used because of the wear and tear caused by abrasion on the internal fin faces when using granulated fertiliser. The CSIRO spreader was discarded because of the high drag factor and no demonstrable benefit. The ploughshare was used as it was technically a "spreader" and had an advantage under the terms of the contract.

(b) Larger granules remain near the centre of a fixed-wing swath

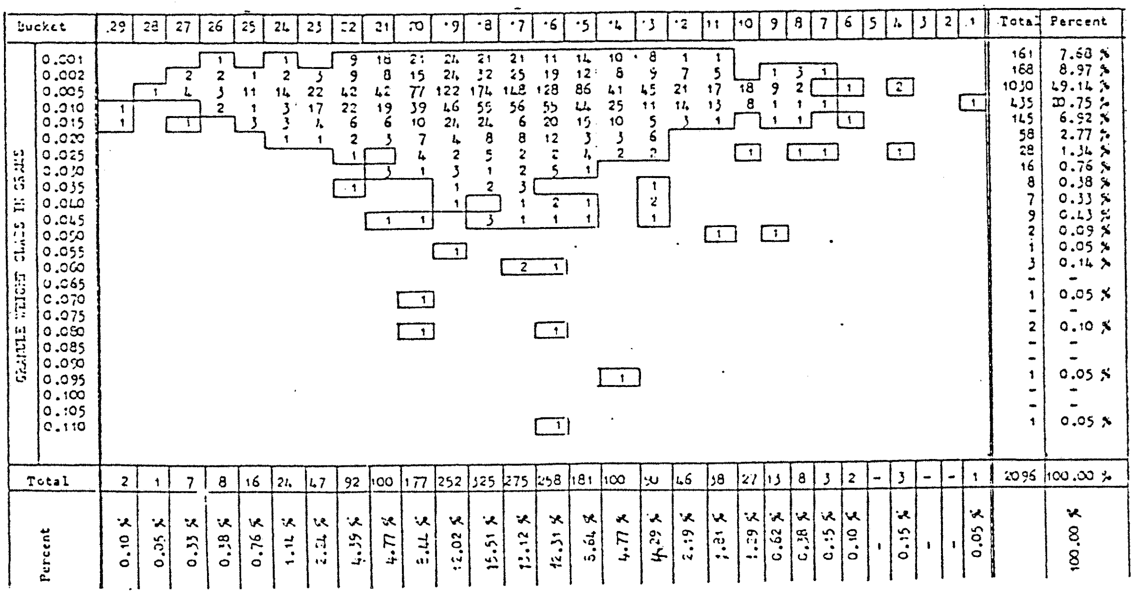
The larger, heavier granules have no ballistic advantage in increasing the swath width, unlike that conferred by the centrifugal force imparted by the powered spinner on the helicopter hopper - although there appears a definite upper optimum granule size limit which has yet to be defined for various materials.

Figures 5 - The numbers of granules per monitoring bucket classified in 0.005 gram weight classes - buckets at one metre centres.

Fig. 5A - TRANSLAND SEEDER

Bucket / Granule weight class in grams	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	Total	Percent
0.001								3	2	2	4	3	8	17	1	11	13	4	1	4	2	2		1						78	5.68 %
0.002						4	5	2	2	2	11	7	14	25	3	22	19	10	6	4	5		2		2					145	10.62 %
0.005			2	2	3	5	7	15	17	26	46	43	55	72	34	79	86	61	49	29	16	10	9	5	5		1	2		679	49.42 %
0.010	1	1		3	2	1	8	12	9	24	20	23	20	18	15	33	21	18	19	2	4	3		4						261	19.00 %
0.015	1	1			2	1	4	3	4	5	5	8	5	9	8	14	12	4	7	2	2	1	1	1				1		101	7.35 %
0.020				1		2		5	2	3	1		4	7	4	3	3	3	2	1		1		1						43	3.13 %
0.025	1							1	3	1	1	1	1		1	1	1	1	2	2										17	1.24 %
0.030								2	1	1	1		1	1	1	2		3		1										14	1.03 %
0.035								1		3	1	1			1		2			1										10	0.73 %
0.040			1					2	2				1	1	1															8	0.58 %
0.045									1			2				1			1											5	0.36 %
0.050					1							1			1					1										4	0.29 %
0.055										1			1					1												3	0.22 %
0.060																														-	-
0.065																		1												1	0.07 %
0.070									1																					1	0.07 %
0.075											1																			1	0.07 %
0.080														1																1	0.07 %
0.085																														-	-
0.090																														-	-
0.095														1																1	0.07 %
0.100																														-	-
0.105																														-	-
0.110																														-	-
Totals	2	2	3	6	8	13	24	46	44	68	92	89	110	153	70	166	157	106	87	47	29	17	12	12	7	-	1	3	-	1374	100.00 %
Percent	0.14 %	0.14 %	0.22 %	0.44 %	0.59 %	0.95 %	1.75 %	3.35 %	3.20 %	4.95 %	6.70 %	6.48 %	8.01 %	11.14 %	5.09 %	12.08 %	11.43 %	7.71 %	6.33 %	3.42 %	2.11 %	1.24 %	0.87 %	0.87 %	0.51 %	-	0.07 %	0.22 %	-	100.00 %	

Fig. 5B - PLOUGHSHARE DISTRIBUTOR



Fertilisers with a large percentage of granules exceeding two milligrams will prove practically impossible to evenly distribute without stripping using fixed-wing aircraft and the spreaders hitherto investigated.

Because of basic inefficiency of design (Amsden 1977) the possibilities are limited for improving venturi-type spreaders to obtain wider swaths and more uniform distribution of fertiliser. Aerodynamic drag and flight handling are adversely affected if the spreader is lengthened to achieve greater particle acceleration, or if discharge width is increased to assist fertiliser dispersal (Akenson and Yates 1962, Amsden 1977) as is the case with the CSIRO Tetrahedron Spreader.

Several innovative suggestions for significantly different designs have been made all with limited success. A more viable solution involves the installation of powered spinners or rotary paddles positioned directly beneath the aircraft hopper. The rotors eject a portion of the fertiliser at 90° to the left and right of the flight line, while the remaining material is released directly into the airstream (Yates *et al.*, 1970) for application rates of 340 kg/ha, this system produces a slightly improved swath pattern and swath width (18 m) than the conventional methods used by fixed-wing aircraft.

Many problems have had to be overcome in using powered spreaders from fixed-wing aircraft, such as the power-take-off (PTO) point. Full power from the aircraft engine is required for take-off when fully loaded, this has lead to the PTO requiring an engaged/disengaged ability.

The combination of granulated fertilisers and powered spinners have in some cases caused "sand blasting" of the tail, underbody and landing gear structures.

If fixed-wing aircraft continue to be used for applying fertiliser to forests, the need is suggested for further design studies to improve capabilities of existing equipment, to develop entirely new spreading techniques, or both.

Comparison of Fixed-Wing and Helicopter Swaths flown operationally

The two swaths shown below were both flown with Di-ammonium Phosphate fertiliser (DAP) supplied from the same source, with the object of spreading the fertiliser over the forest at 500 kg/ha.

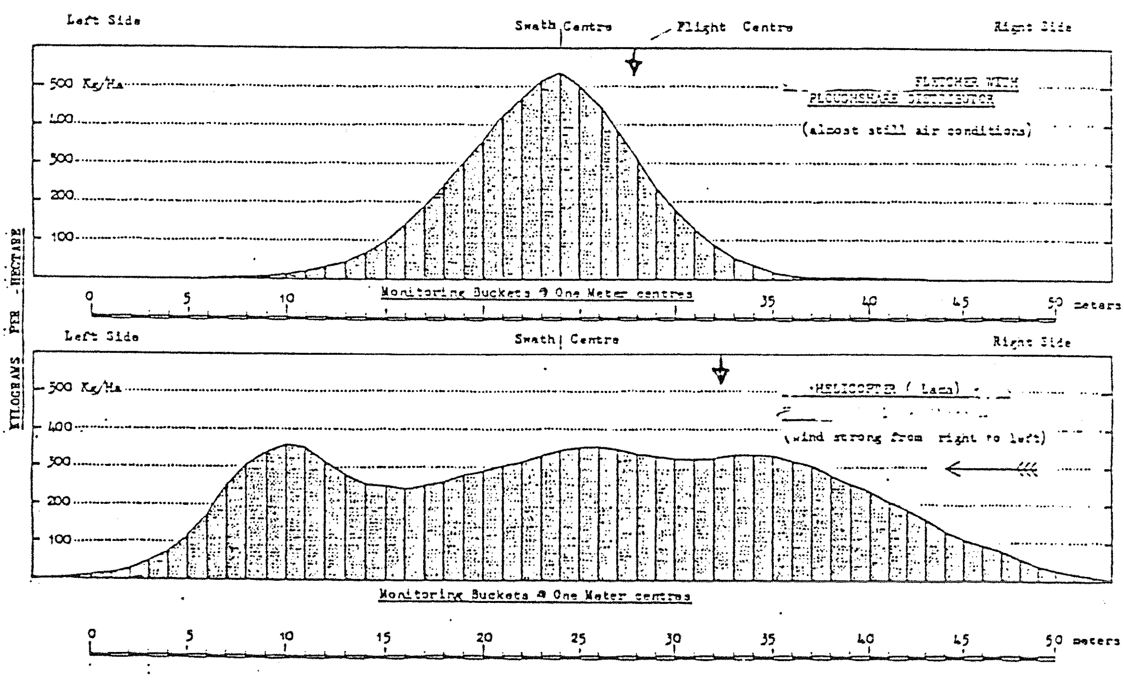
The top swath was obtained by a Fletcher aircraft fitted with the Ploughshare Distributor and flown under calm conditions at a height of about 25 metres.

The bottom swath was flown by a SA 315B Lama helicopter with a hydraulic powered spinning disc at the base of a suspended hopper from a height of about 25 metres. A strong cross-wind of 15-20 knts was blowing from right to left, displacing the swath centre.

The Fletcher would be flying at approx. 100 knots and the Lama at 50 knots.

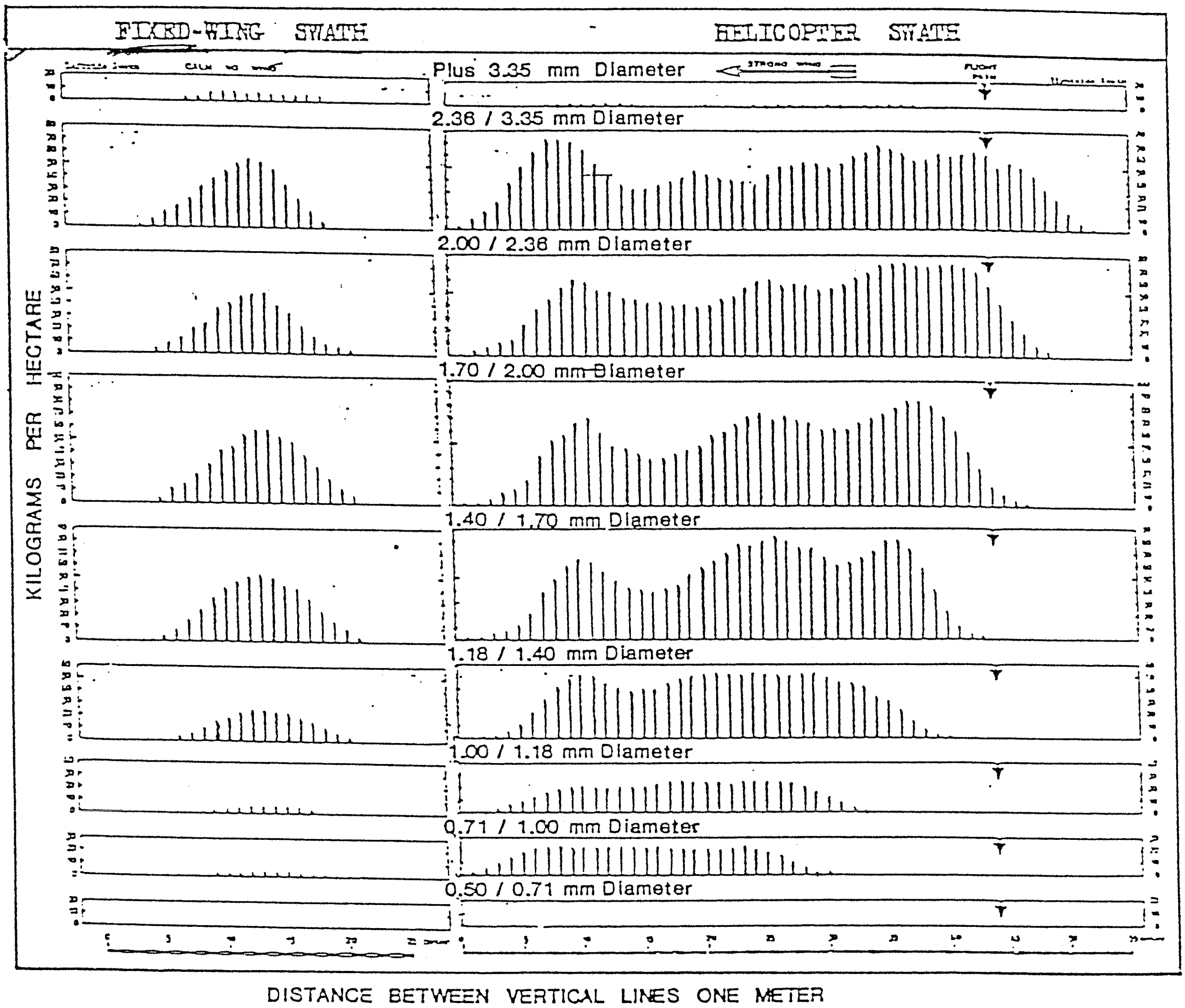
Comparison between DAP Swath Patterns from Fixed-Wing and helicopter Hopper

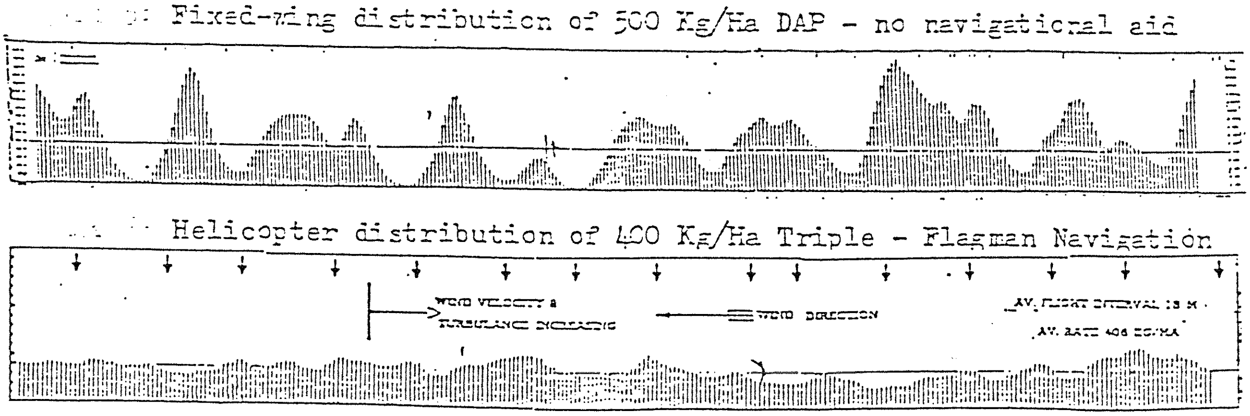
FIGURE 6 COMPARISON BETWEEN DAP SWATH PATTERNS FROM FIXED-WING AND HELICOPTER HOPPER



An analysis of granule distribution by diameter classes across these two swaths is presented in Figure 7 below.

Fig. 7 - DISTRIBUTION OF DAP GRANULES BY DIAMETER CLASSES





Horizontal scales the same - 1 m between vertical lines. The horizontal line shows desired distribution rate.

FIGURE 8 - Comparison of Fertiliser Distribution across a Forest

The topdressing by fixed-wing was carried out in almost calm conditions, the average rate was 653 kg/ha with a range of 60 to 1600 kg/ha. There were 34 flights over the monitoring line, the average flight interval being 8.94 metres (range 0 to 29 m). Each flight was one of a pair, one outward from airstrip, the other towards the strip. The average interval between pairs was 25.5 metres (range 0 to 58 metres). In terms of flight sequence across the forest there were underlaps, overlaps and doubles. Flight tracks across the compartment varied up to 10°.

The helicopter topdressing commenced across a bowl shaped block under relatively calm conditions (left edge of histogram) but had to increase altitude and became progressively more exposed to a wind of increasing force and turbulence at right angles to the flight track. The flights were parallel using the Flying Flagman navigation system. The flight intervals from left to right of the histogram being 20, 17, 21, 18, 20, 16, 19, 21, 8, 19, 18, 18, 19 and 20 metres, an average of 18.21 metres. The average rate of fertiliser was 406 kg/ha with a range of 230 to 646 kg/ha. Towards the right hand of the histogram, granules were being collected from the fifth and sixth flights beyond the end of the monitoring bucket line, upwind. The FRI hopper was used in this operation.

Having, on the evidence presented so far, eliminated the fixed-wing from a role in the accurate distribution of granular materials over forest lands, we turn to the consideration of the steps taken to-date and outline further the developments taken to achieve an even distribution of granular materials at the rate specified using the helicopter as the vehicle.

HELICOPTER HOPPER METERING SYSTEMS TO CONTROL FLOW RATE

Three basic methods, with some minor variations, have been met operationally:

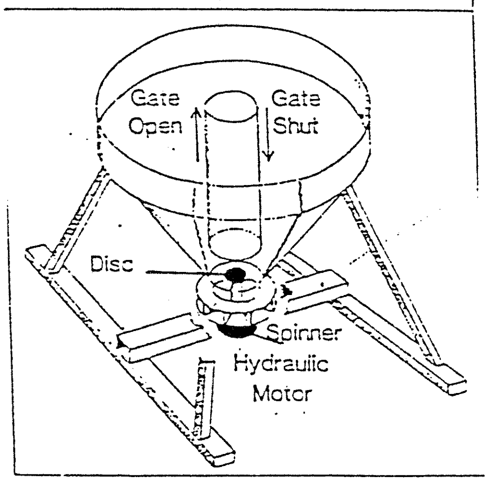
(i) **The centre mounted disc**

The vertical cylinder inside the hopper is seated on a seal around the rim of the hole in the hopper base. This cylinder can be lifted vertically by an internal ram, air or hydraulic. There are two positions - fully open and fully closed gate.

To alter the flow rate of material leaving the hopper when the gate is open, a metal disc is fitted in the centre of the throat by bolting to the top of the spinner housing. the spinner drive being from below.

By employing discs of different diameters, the annular area between the edge of the disc and the hopper throat can be altered to increase or decrease the rate or flow.

METHOD (1) Disc in Throat



This system has three <u>disadvantages</u> -

1. The spinner is driven from below of necessity, requiring a substantial cross-brace between the hopper legs to mount the drive mechanism and shield the hydraulic hoselines. There is granule shatter and swath pattern distortion in consequence, creating the "three hill" effect discernible in Figure 7 in granule diameter classes 1.40/1.70 mm, 1.70/2.00 mm and 2.00/2.36 mm. A spinner with down-turned delivery tubes can not be fitted.

2. For low flow rates a large diameter disc is installed and the material is deposited around a narrow ring towards the spinner rim. For the highest flow rates the minimum disc diameter can be no less than the diameter of the upper bearing housing of the spinner, which deflects some of the material towards the spinner edge. In neither case is it possible to utilise fully the centrifugal forces. Rather, the area of granular deposition results in a disc brake effect, limiting spinner speed, and at a high flow rate with a heavy material - for example North Carolina rock phosphate as a sand - can impose a severe strain on the hydraulic system, reducing swath width dramatically.

3. The discs, and therefore flow rate, cannot be altered in flight. In the event of a blockage using a large diameter disc, the aircraft may have to land and the disc removed.

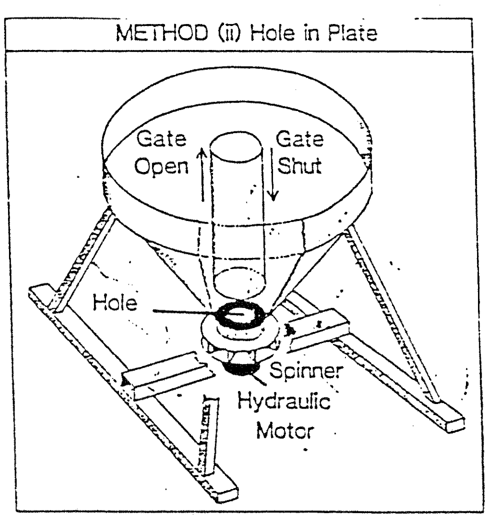
(ii) **The plate with holes method**

This is the opposite approach to Method I. A plate with a circular hole of appropriate diameter is secured beneath the hopper throat.

There may be one hole per plate, or a sliding rectangular plate with a series of holes of different diameters which can be moved manually or by remote control allowing in-flight flow rate alterations over a discreet range. In practice the grooves in which the plate can slide, quickly become clogged with fertiliser particles and rendered inoperative.

Although easier to fit and clear blockages than the disc, and placing the material more towards the spinner centre, it still has the inherent disadvantages of Method i resulting from below-spinner drive and lack of flexibility in smoothly altering flow rate.

FIGURE 10



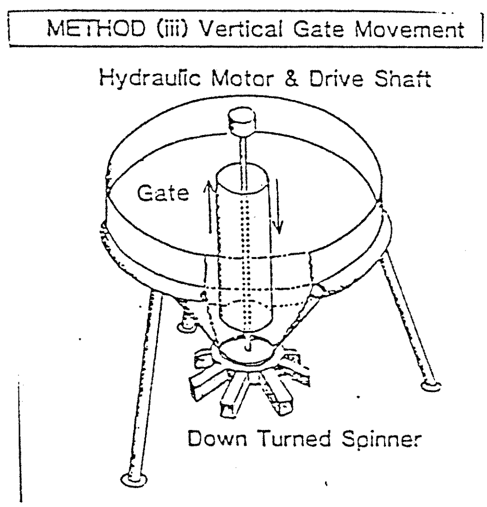
(iii) **Varying the vertical movement of the internal cylindrical gate**

This method of altering the flow rate is that adopted for the FRI helicopter hopper and associated systems.

The vertical movement of the cylinder can be varied infinitely between the fully closed and fully open position to control the flow rate.

The upper limit of travel can be set manually, by the pilot in flight, or the flow rate can be automatically adjusted in flight to match the ground speed by utilising the data generated by the Flagman navigation system concerning distance covered and time. This later refinement has been used in the FRI hopper.

FIGURE 11



In all variations the gate can be fully opened by manual over-ride to clear blockages in flight or dump the load.

This design permits fitting an internal spinner drive, wide spaced hopper supporting legs and the installation of a spinner with down-angled delivery chutes to project the material beneath all structural members, reducing granule shatter to a minimum whilst also clearing the vortex zone behind the hopper in flight, resulting in an improved swath pattern.

AUTOMATIC FLOW RATE CONTROL RELATIVE TO GROUND SPEED - FRI SYSTEM

To test the automatic control of flow rate using the ground-speed data generated by the Flagman navigation system, a trial was conducted in February 1986 with the hopper gate set at a two-inch opening for a ground-speed of fifty knots. Two flights were made, the first at 40 knots and the second at 60 knots by the pilot's ground-speed display.

The material was Texan partially acidulated rock phosphate granules. The results expressed as histograms below represent the granule recovery from two lines of monitoring buckets one-hundred metres apart along the flight path.

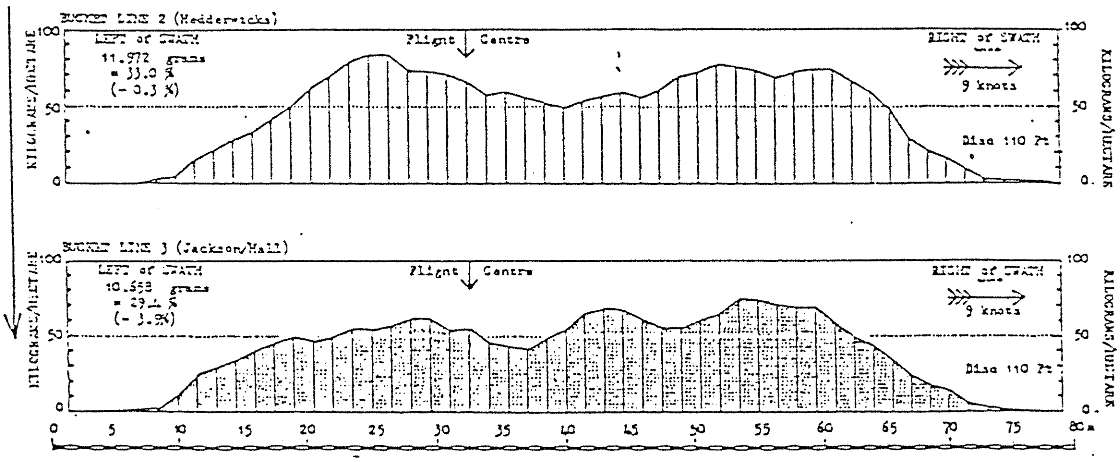


FIGURE 12 - Two swaths at 100 metre interval. Ground-speed 40 knots

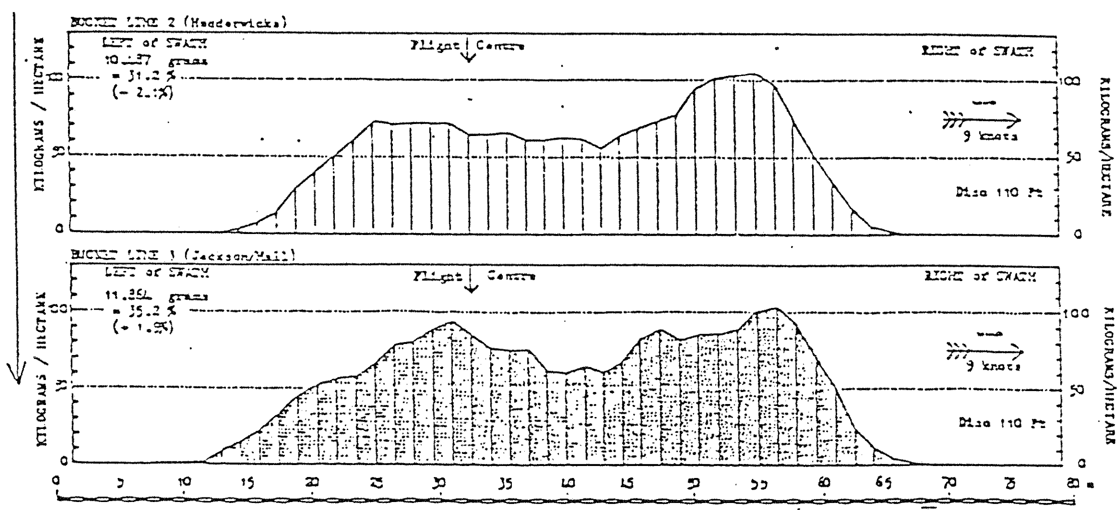


FIGURE 13 - Two swaths at 100 metre interval. Ground-speed 60 knots

The total weight of granules recovered from the two swaths flown at a ground-speed of <u>40 knots</u> was <u>22.630 grams</u>. the total weight recovered from the two swaths flown at a ground-speed of <u>60 knots</u> was <u>22.351</u> grams. If all weights are combined i.e., (22.630 +

22.351) = 44.981 grams and taken as 100% then the recovery from the 40 knot ground speed is 50.3% of the grand total and from the 60 knot ground-speed 49.7%. In this comparison it would seem that the hopper gate was compensating flow rate with ground-speed very satisfactorily.

THE EFFECT OF AIR SPEED ON SWATH WIDTH AND PATTERN

The most obvious difference in swath patterns between the slow flown pair (40 knots ground speed Figure 12) and the fast flying (60 knots ground speed Figure 13) is the contraction of swath width with greater speed. the steep slope on the leeward (right) side of the fast flying pattern reflects a bigger movement of the smaller granules down wind (see Figure 15) after leaving the spinner, in part.

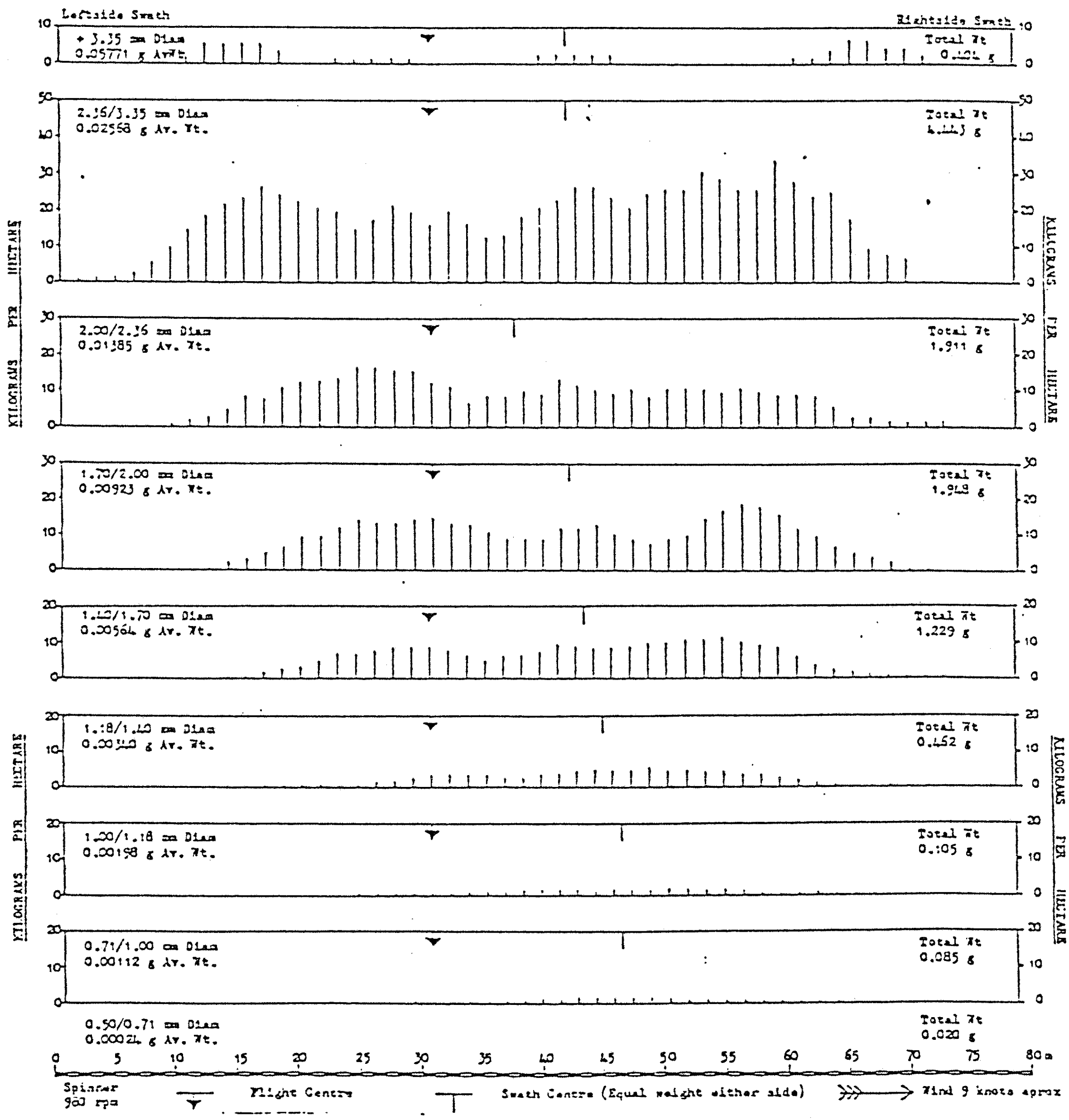


FIGURE 14: Slow Flying - analysis of granule distribution by granule diameter classes across swath (stippled histogram Fig. 15)

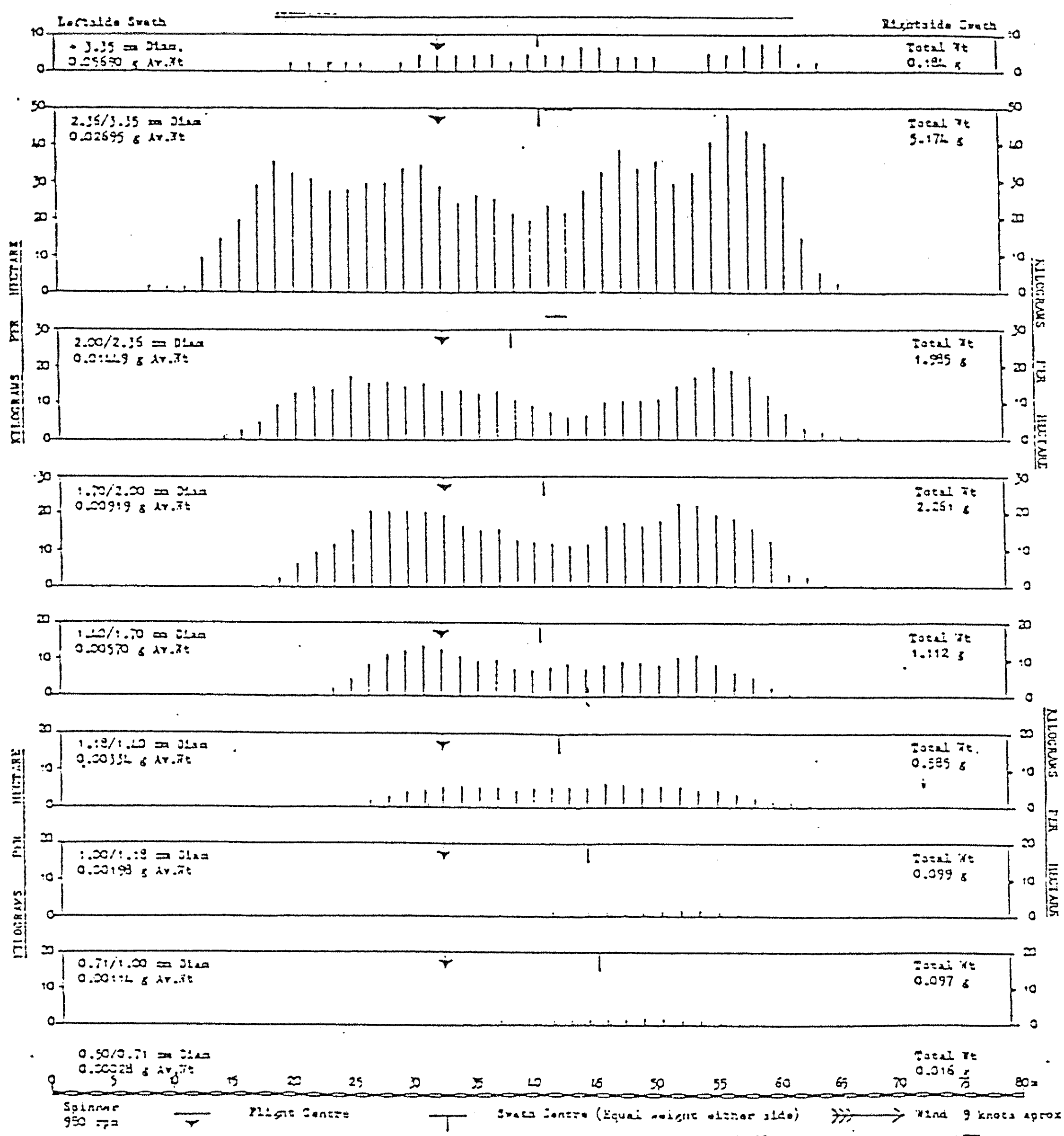


FIGURE 15: Fast Flying - analysis of granule distribution by granule diameter classes across swath (stippled histogram Fig. 16)

Both the fast and slow flights were flown with the same hopper-full of fertiliser from one 750 kg "big bag". The total weight of fertiliser recovered and the weights by granule diameter classes are very similar (see Figure 16) between the flights so direct comparison is valid.

Three significant facts are shown when comparing the swath patterns of the different granule diameter classes in Figures 14 and 15:

(a) The distribution pattern is essentially the same for each diameter class above 1.18 mm when flown at the same airspeed.

(b) The swath widths decrease with the reduction of granule diameter and weight (of Figure 7) when a spinning distributor is used.

(c) The lighter the granule, the further it drifts downwind.

The effects of different specific gravity and the different proportions of granule sizes on swath patterns - two fertilisers DAP and Texan PAR Phosphate compared.

The following data was obtained for the compilation of figures 7, 14 and 15

Sieved Granule Diam. mm	Di-ammonium phosphate			Texan PAR Phosphate		
	Fixed Wing	Heli-copter	Total	Total	Slow A/S	Fast A/s
+ 3.35 mm	0.400 g	0.227 g	0.627 g	0.588 g	0.404 g	0.184 g
2.36/3.35 mm	2.427 g	12.640 g	15.067 g	9.617 g	4.443 g	5.174 g
2.00/2.36 mm	2.271 g	11.959 g	14.230 g	3.896 g	1.911 g	1.985 g
1.70/2.00 mm	2.929 g	12.119 g	15.048 g	4.209 g	1.948 g	2.261 g
1.40/1.70 mm	2.707 g	11.106 g	13.813 g	2.341 g	1.229 g	1.112 g
1.18/1.40 mm	1.252 g	7.489 g	8.741 g	1.047 g	0.462 g	0.585 g
1.00/1.18 mm	0.294 g	3.016 g	3.310 g	0.204 g	0.105 g	0.099 g
0.71/1.00 mm	0.227 g	2.798 g	3.025 g	0.182 g	0.085 g	0.097 g
0.50/0.71 mm	0.048 g	0.183 g	0.231 g	0.036 g	0.020 g	0.016 g
Total Wt	12.555 g	61.537 g	74.092 g	22.120 g	10.607 g	11.513 g

FIGURE 16a - Weight of fertiliser recovered by granule diameter classes.
Texan PAR Phosphate flown by Helicopter

Sieved Granule Diam. mm	Di-ammonium phosphate			Texan PAR Phosphate		
	Fixed Wing	Heli-copter	Total	Total	Slow A/S	Fast A/s
+ 3.35 mm	3.2 %	0.4 %	0.8 %	2.7 %	3.8 %	1.6 %
2.36/3.35 mm	19.3 %	10.5 %	20.4 %	43.5 %	41.9 %	44.9 %
2.00/2.36 mm	18.1 %	19.4 %	19.2 %	17.6 %	18.0 %	17.3 %
1.70/2.00 mm	23.3 %	19.7 %	20.3 %	19.0 %	18.4 %	19.6 %
1.40/1.70 mm	21.6 %	18.1 %	18.6 %	10.6 %	11.6 %	9.7 %
1.18/1.40 mm	10.0 %	12.2 %	12.8 %	4.7 %	4.3 %	5.1 %
1.00/1.18 mm	2.3 %	4.9 %	4.5 %	0.9 %	1.0 %	0.9 %
0.71/1.00 mm	1.8 %	4.5 %	5.1 %	0.8 %	0.8 %	0.8 %
0.50/0.71 mm	0.4 %	0.3 %	0.3 %	0.2 %	0.2 %	0.1 %
Total Wt	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %

FIGURE 16b - Data in Figure 16a expressed as % of Total Weight

These data show that in the granule diameter classes contributing most significantly to the total weight, that there are no great differences between the two samples of DAP, and even less difference between the two samples of Texan PAR Phosphate from the same load.

There is however a significant difference between the granule composition of DAP and Texan PAR Phosphate. In the latter fertiliser the 2.26/3.35 mm class comprises twice the weight of the DAP equivalent, the next two classes below are very similar in both fertilisers.

The 1.40/1.70 and the 1.18/1.40 mm classes in the DAP comprise almost double the weight of their Texan PAR Phosphate counter parts. The smallest granule diameter classes below 1.18 mm comprise almost 10% of the total weight of DAP but only 2% of Texan PAR Phosphate.

If the differences in specific gravity between the two fertilisers is also taken into account - expressed as average granule weight in the table below - it will be seen that DAP is also the lighter.

Sieved Granule Diam mm	Di-ammonium Phosphate DAP	Texan PAR Phosphate
+3.35 mm	0.03782 grams	0.05752 grams
2.36/3.35 mm	0.01695 grams	0.02739 grams
2.00/2.36 mm	0.01023 grams	0.01445 grams
1.70/200 mm	0.00631 grams	0.00926 grams
1.40/1.70 mm	0.00379 grams	0.00560 grams
1.18/1.40 mm	0.00217 grams	0.00333 grams
1.00/1.18 mm	0.00139 grams	0.00201 grams
0.71/1.00 mm	0.00075 grams	0.00114 grams
0.50/1.71 mm	0.00015 grams	0.00028 grams

FIGURE 17 - Average Granule weight by sieved diameter classes for DAP and Texan PAR Phosphate

If the swath is flown in a cross wind, there will be greater degree of distortion with the di-ammonium phosphate granules than with the Texan PAR Phosphate, because the DAP granules are not only lighter size for size, but also there are a larger number of smaller granules.

The DAP and the Texan PAR Phosphate granules have only been cited as examples as to what is likely to happen and why. Each of the variety of granular materials dropped by air will have its own swath characteristics, and there will also be differences with the same basic material manufactured in different places. It is therefore essential to have as much information about the material to be dropped in an operation at the planning stage as possible.

In some countries and particularly the pacific Northwest, Urea fertiliser, which is the type most commonly applied to forests in this area, is available as "forestry grade", having particle diameters 3.4 - 6.7 mm, or "agricultural grade" with smaller granules of 1.2 - 2.4 mm diameter. When urea was applied using a helicopter equipped with a Simplex-type system, the swath width obtained from the larger granules was 45% (Switzer 1972) to 72% (Olson 1979) greater compared with the spread produced by the smaller particles.

For a particular ejection velocity, large granules of fertiliser can achieve a greater lateral spread compared with smaller grains of similar specific gravity, indicating particle size significantly affects swath widths obtained in aerial application.

If "forestry grade" fertiliser granules were or could be manufactured at a competitive price the need is suggested for NZ forestry companies to utilise the advantages of larger granules.

Besides providing a greater lateral spread, use of larger fertiliser particles also improves uniformity of distribution within an individual swath (Switzer 1972). Strand (1979) found variability in application rate was significantly less using forestry grade urea compared with the smaller grained agricultural granules. Effects of wind partially explain the more regular dispersal of larger particles, since fine powders drift considerably.

Another reason for the unsatisfactory distribution of fine particles is their tendency for cohesion, which impedes mass flow (Amsden 1977), causing intermittent clogging of the discharge aperture.

OTHER FACTORS AFFECTING FERTILISER DISTRIBUTION

(a) Features of Forest compartments - Shape, Size and Demarcation

Because fertiliser is most conveniently applied in straight swaths, square or rectangular compartments are easier to fly compared with areas of irregular shape; fertiliser distribution can be unsatisfactory if the pilot has to follow sinuous boundaries or undertake complex manoeuvres to cover asymmetric blocks. Boundaries of each compartment must be clearly visible from the air to ensure all of the required area is treated without applying fertiliser outside the block. Boundary errors, involving parts of the compartment remaining unfertilised together with portions of surrounding stands inadvertently being treated, can correspond to 7%-14% of the size of blocks smaller than 25 ha. while for larger units the error may only be 1%-2% (Strand, 1972).

Wherever possible, distinctive natural outlines such as streams, ridgetops, gullys, and contrasting forest-cover types should be used as boundaries, in addition to man made features including roads and power lines. If the forest manager feels these boundaries are of particular importance, then the boundaries must be specially marked using flags, helium-filled balloons, or other devices. The number of such devices should be minimised to ensure adequate delineation of the compartment without causing confusion for the applicator (Evans 1972), and there positions accurately shown on aerial photographs for the pilot's reference.

It is important to note that electronic navigational systems used today will guide the pilot in a straight line but will not demarcate a boundary.

It is most convenient if one full load of fertiliser can be spread in an exact number of complete passes across the compartment, and dimensions of the block should, if possible, be determined accordingly. In practice the pilot will determine his most suitable "flight path" in accordance with the weight and type of fertiliser being spread, wind direction, loading pad location, and shape of the compartment.

If the material is expanded before a pass is finished and no navigational aid is being used, the pilot might experience difficulty in relocating his position to commence spreading the next load (Clark, 1968); this can result in parts of the area being untreated, some portions receiving dual applications, or both.

When measuring the size of a compartment to calculate the required quantity of fertiliser, it is necessary to use maps rather than aerial photographs, since the latter are subject to scale errors caused by distortion. Accurate knowledge of the fertiliser requirements for each individual block is essential to ensure the correct rate is applied.

TOPOGRAPHY

Flying over steep or irregularly contoured land is less conducive to uniform fertiliser distribution, compared with operations involving flat terrain. In mountainous topography, the entire compartment might not always be discernible to the pilot, boundaries become inconspicuous and difficult to "pick-up" for the unguided applicator. On hillsides and at higher elevations, air turbulence, anabatic and katabatic winds, and poor visibility can occur more frequently than on level terrain at lower altitudes.

In addition, it is often difficult for the pilot to maintain a constant ground speed, and an accurate height above the tree canopy when operating over irregular topography. Stable ground speed as opposed to air speed is a very important factor when trying to maintain an accurate application rate. Air speed indicators (Pilot tube driven) are notoriously inaccurate, particularly at helicopter topdressing speed (50 knots) and are affected to a large extent by head and tail wind strengths. Helicopters, because of their lower flying speed and inherent manoeuvrability can contour fly mountainous topography more efficiently than a fixed-wind airplane, which needs to fly at approximately 100 knots to remain airborne when fully loaded.

This combination of factors suggests the pattern of fertiliser distribution is probably less consistent in mountainous regions than on lowland sites, and standards specified for the applicator's performance might require appropriate adjustment if adverse topographic features predominant.

TREE CANOPY

Although, some reports suggest the tree canopy does not significantly obstruct aerial applications of fertilisers (White 1956, Ballard and Will 1971, Armson 1972), visual observations indicate considerable interception often occurs, especially with wet crowns and particles of small diameters. Quantitative studies of interception involve several practical difficulties, but during collection trials on an actual topdressing operations it has been found 13%-47% of applied fertiliser was not recovered in traps or bucket lines placed under the canopy, Olson (1979).

The eventual fate of the intercepted fertiliser is unclear, but some is washed down by rain and part is presumably displaced by wind. For urea, volatilisation might occur from particles held in the tree crowns, but the extent of such losses is unknown for either large or small granules.

FERTILISER PHYSICAL PROPERTIES

The bulk density of a fertiliser depends upon the specific gravity of individual granules and the number of particles per unit volume. Compared with lighter materials products with greater bulk densities can be spread in wider, more uniform swaths, and are less affected by wind (Amsden 1977). Because the flow of fertiliser through discharge apertures is measured volumetrically, dense materials might require very narrow outlets to achieve the correct application rates, such small openings are difficult to adjust accurately. if possible, for some materials such as Boron, a smaller concentration of active ingredient should be included, to ensure a suitably large discharge volume is used to obtain the necessary quantities of plant nutrients. In practice, bulk densities of many commonly used fertilisers are quite similar, and density is often less important than particle size in determining the uniformity of dispersal (Switzer, 1972).

Because they have little tendency to fracture, products composed of hard and resilient granules can be transported and spread without adversely affecting particle size. By contrast, material that is soft or brittle can abrade and break during handling, producing small granules and dust.

Smooth surfaces are essential for unimpeded mass flow, and abrasive particles that scratch the spreading equipment (e.g. Ulexite -from Hungary) could eventually cause unsatisfactory fertiliser dispersal. Wet material tends to form lumps, which can clog the spreader and result in very irregular distribution; wet fertiliser should be returned to the supplier, and dry products should receive adequate storage after unloading to ensure no moisture is absorbed as many materials are hydroscopic.

APPLICATION PROCEDURES

Application Rate

Swath width and uniformity of fertiliser dispersal are sometimes significantly related to quantity of material applied. A Simplex-type hopper with an underpowered spinner drive motor (petrol or hydraulic) will give a significantly reduced swath width when applying material in the upper kg/ha rates (i.e., 400 kg/ha).

Similar examples of apparent equipment overloading are also encountered with venturi-type spreaders, especially if application rate exceeds 280 kg/ha or mass flow from the aircraft hopper is faster than 16 kg/sec (Yates *et al.*, 1970). A ducted-style spreader delivered a swath width of 11 m when applying 110 kg/ha of fertiliser, but at rates of 340 kg/ha and 560 kg/ha the extent of coverage was reduced to 8 and 5 m respectively, and dispersal pattern was less satisfactory in the narrower swaths (Akesson and Yates, 1962).

For each type of spreader and fertiliser, tests must be conducted before operations commence to determine if the required application rate can be delivered uniformly in a swath of suitable width. These tests, which have been used extensively with NZ topdressing operations involve arranging containers of known surface area one metre apart; the extent of the line of containers exceeds the predicted swath width. Paper towels are placed in the bottom of the containers to prevent any bounce of the fertiliser granules.

Trials are conducted on open land to exclude interception and deflection of fertiliser by trees. Wind velocity and direction should be noted. The pilot selects an air or ground speed - whichever is available, and altitude that coincides with those normally used during an operation (50 knots, 25 metres), he then aligns on the central axis of the container line, begins to release fertiliser well before reaching the first row of containers, this is vital so as to ensure that a constant RPM of the spinner has been achieved. Swath width is measured, and fertiliser in each container is weighed to determine application rate and uniformity of dispersal. Known quantities of fertiliser can be loaded into the hopper and a load timed at a fixed gate opening and flying speed. Using the following formulae the kg/ha rate can be determined.

Calibration formulae for kg/ha:

$$\frac{19438.5 \times WT}{KNTS \times SEC \times WIDTH}$$: for any speed measured in knots.

or

$$\frac{388.8 \times WT}{SEC \times WIDTH\ (m)}$$: for 50 knots only.

WT = weight of fertiliser
KNTS = speed in knots
SEC = time in seconds to dispense fertiliser
WIDTH = width of swath of fertiliser

* Multiply answers by 2 to allow for 1/2 overlap. For total kg/ha rate.

Flight Pattern

Accuracy of fertiliser distribution might be enhanced if one half the required amount is applied in each pass, and each line is flown twice; however, Ballard and Will (1971) obtained unsatisfactory coverage with this method, and suggested pilot error was similar for the two passes because the same landmarks were used for alignment. A better procedure involves spreading at half the desired rate, accompanied by a 50% successive swath overlap, this is the method adopted by all NZ forestry companies.

Other methods that have been tried is cross-flying as opposed to lap-flying. Cross-flying is often unfeasible in mountainous topography, or under adverse wind conditions and is sometimes unsuitable because of block size and shape, or the need to avoid ecologically sensitive areas. Two-third overlap has been tried delivering one third the desired rate, but sufficient uniformity is not always obtained by this system and has proved to be cost prohibitive because of the extra flying time required.

Flight Control and Navigation aids

The pilots ability to maintain parallel, equidistant flight lines is a major factor determining the uniformity of fertiliser application. when flying is inaccurate, parts of the unit are left untreated, or receive inadequate amounts of material while other portions of the block are fertilised too heavily. In many operations, the pilot visually estimates the distance between successive swaths, relying on natural features of the stand and topography to guide his progress across the block; this procedure can result in irregular distribution of fertiliser.

To assist the applicator obtain a satisfactory flight pattern, the customer must provide large-scale (e.g., 1:10,000) aerial photographs showing the outline of the treatment unit and ecologically sensitive areas. In addition the forest manager or supervisor should fly the area with the pilot to discuss and point out significant features such as gullies, swamps and power lines etc.

In recent years the use of electronic navigation equipment has assisted the pilot in improving the accuracy of his flight lines, resulting in a more satisfactory aerial distribution of fertiliser.

In essence, two remote transponders are interrigated by a master transmitter receiver in the aircraft and the round time of coded pulses measured by the aircrafts computer. With update rates selectable from 0.5 to 4.0 seconds, the range to each transponder is measured 100 times a second, averaged, and resolved into XY co-ordinates.

Two types of aerial are available for use with the transponders, 30 km and 80 km range types.

Range	Vertical Lobe	Horizontal Scan
80 km	7°	180°
30 km	19°	360°

It can be seen from the above specifications that distance is forsaken for vertical lobe, that is the ability the aerial has in scanning the aircraft at a given altitude or position relative to the aerial.

The transponder sites are selected on the basis of line-of-site, and fix geometry over the area to be flown. Their positions need not be known, although the transponders should be no more than 150° and no less than 30° to the compartment to be flown. The pilot designates two positions, P1 and P2 relative to the direction he wishes to fly the selected swath widths. the system then provides guidance to the pilot in the form of a light-bar to indicate distance off track. Both swath width and light-bar distance indication are operator selectable, usually one light equals one metre. To delineate material run-out positions, the pilot presses an MOP (Material Out Position) button. The system then provides distance to go to the particular MOP, allowing fertiliser or spraying to resume or stop at precise points within the compartment.

Data can be output onto a data logger and aircraft positions logged at the update interval together with P1, P2 and MOP.

Time is similarly output with each position and a keypad complete with liquid crystal display (LCD) allows forest identification number, run number, wind speed and direction, start time, speed window and update rate to be input.

All data recorded can be post plotted and printouts provide the forest manager of flight and fertiliser accuracy and coverage. The printout can be used as both a management tool quality control check, and are useful for environmental issues.

Airspeed vs Groundspeed

Airspeed on helicopters is generally measured using a pitot tube sensor. This type of velocity sensor can prove to be inaccurate at slow speeds and when used to determine 'speed over the ground', head and tail wind influences on the pitot tube sensor have to be considered. As impeller-type distributors are used with helicopters and designed to maintain a constant flow of fertiliser, application rate varies inversely with airspeed (Switzer 1972).

True ground speed is by far the better medium to use in guiding the pilot to maintain a steady velocity over the ground.

Helicopters normally fly at 45-55 knots when spreading fertiliser, the target speed should be maintained at all times to enable a constant rate and constant swath width of fertiliser to be applied

WEATHER

Wind

Wind is the most significant weather factor that influences aerial distribution of fertiliser. Calm conditions seldom exist in mountainous, forested terrain in NZ.

Flying should cease when winds are strong gusting or both if the forest is to receive a uniform application. While the applicator can best judge the 'safety' of wind conditions, his customer must insist on postponing operations if distribution of material is shown to be unsatisfactory, and an appropriate contract clause will guarantee the clients prerogative.

Wind affects the pilots ability to keep a straight course, even when using guidance equipment, resulting in uneven or nonparallel swaths.

In addition, strong crosswinds can cause material to drift (see figure 6) especially if released from 20 m or more above the trees. Given the choice and the prevalent wind on the day, the recommendation is to fly into and down the wind as far less effect on uniformity of fertiliser dispersal takes place. The pilot can experience a considerable drop in 'lift' when turning, from 'into wind flying' to 'down wind flying' the forest manager must appreciate the safety factors involved in carrying up to 1 tonne below the helicopter in strong winds.

Visibility

Poor visibility, caused by mist, rain or low cloud, makes accurate flying difficult, especially without navigation equipment. This can result in nonparallel swaths, incorrect distances between successive flight paths, and imprecise swath widths.

Applicators using helicopters consider fertiliser can be spread in light rain, provided visibility is adequate; in such circumstances the material must be dispersed from the hopper immediately after loading, to ensure it does not become wet and clog the impeller. Although safety conditions involving rain and poor visibility must be determined by the pilot, concerns regarding uniform fertiliser coverage can be minimised if a suitable contract clause permits the client to postpone flying at his discretion.

PILOT ABILITY AND EXPERIENCE

Uniform application of fertiliser requires skilled and conscientious pilots consistently capable of accurate flying in adverse topographic and climatic conditions.

Inexperienced and inattentive applicators are unlikely to achieve parallel, equidistant flight lines and precise swath lengths; inadequately trained personnel might also be unable to maintain constant altitude and airspeed in undulating terrain, especially without navigation equipment equipped with ground speed readout. Pilot proficiency can be determined according to total hours flying experience, including amount of time spent fertilising or spraying in mountainous forested areas (Belluschi 1972).

In addition, applicators should have sufficient expertise in operating the particular weight class, make, and model of machine that will be used in each project. Inexperienced personnel must be taught by pilots having at least 2 yrs participation in forest fertilising, and trainees should be instructed and observed regularly throughout their first season of application (Olson, 1972). Before operations commence, the customer should be aware of the pilots experience to ensure the contractor provides properly qualified personnel.

CONCLUSIONS

When helicopters and fixed-wing aircraft are used to disperse fertiliser, uniformity of coverage depends predominantly on pilot experience, motivation flying accuracy, and particle size of the material being applied. In addition, spreading equipment must be designed to deliver consistently the correct quantity of fertiliser in a swath of suitable width, and treatment units should preferably be large rectangular or square blocks to simplify flight procedures. Adverse weather can also cause unsatisfactory distribution of material, especially in mountainous terrain where strong winds and poor visibility can occur.

Several factors that affect fertiliser distribution are interrelated. For example the extent of drifting caused by crosswinds varies with particle diameter and height from which material is dispersed, while the influence of granule size on swath width depends upon airspeed or groundspeed, flying height, and velocity of fertiliser ejection from the hopper spinner. Furthermore, choice of flight pattern might be determined by size, shape, and topography of treatment areas, and the pilots ability to maintain constant altitude and speed is often related to contour features. Because there are many possible reasons for unsatisfactory dispersal of material, cooperative trials have, and still are, required to assess the performance of the pilot and his equipment in several topographic and climatic conditions, with various flight procedures, using fertilisers having different physical properties. Engineers are best qualified to ensure correct design of spreading apparatus, and to study aerodynamic properties of solid particles, while fertiliser manufacturers must recognise their customers requirements and develop suitable new products if necessary.

Foresters and applicators should collaborate to establish adequate procedures for arrangement of treatment units, and to provide accurate methods of flight control using ground personnel or more favourably, navigation systems together with printout facilities and ground speed readout control. Finally, researchers must relate tree growth to amount of fertiliser applied, explain the silvicultural implications of inconsistent coverage, and define standards for aerial distribution that are feasible for the operator and acceptable to the forest manager.

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