

DISTRIBUTION OF AERIALLY APPLIED FERTILIZER
ON THE NASHWAAK EXPERIMENTAL WATERSHED

by

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ABSTRACT

Lake Brook Basin in the Nashwaak Experimental Watershed was treated in June 1975 with ammonium nitrate fertilizer using fixed-wing aircraft. The distribution of fertilizer on the ground was measured in a mid-section of the basin, comprising about 40% the total area. Fertilizer which reached the ground as solid prills and that which was washed down by rain water as stemflow and throughfall was measured.

Fertilizer was applied during a 4-day period. On each day, large variations were observed in the quantity of fertilizer caught in traps. Distribution rates ranged from 0 to 2000 kg ha^{-1} , with a mean value of 300 kg ha^{-1} ; the intended rate was 672 kg ha^{-1} . About 90% of the fertilizer reached the ground as prills; the remaining 10% was washed down from the tree canopy by rainwater. About 20% of the measured area of the basin did not receive any fertilizer. The upper end of the basin, where fertilizer release was started during each flight, received larger quantities than the lower portion of the basin.

Calculated values for the uniformity quotient and half value suggest that there is much room for improvement in the evenness of fertilizer distribution. Fertilizer release rates from the aircraft must be adjusted until the desired values for the mean application rate, uniformity quotient, and half value are obtained. Only then should fertilizer application be undertaken. Proper demarkation of the area to be fertilized is also essential for a successful operation.

RESUME

En juin 1975, on a traité au nitrate d'ammonium le bassin du lac Brook, dans le bassin versant expérimental Nashwaak, à l'aide d'un avion ordinaire. La distribution du fertilisant au sol fut mesurée dans une section médiane, comptant environ 40% du secteur entier. La quantité de fertilisant qui atteignit le sol sous forme de granules solides et la quantité délavée par la pluie, soit par l'écoulement le long des tiges, soit par l'eau traversant les cimes, fut mesurée.

Le fertilisant fut appliqué pendant 4 jours. A chaque jour, on observa d'importantes variations dans la quantité de fertilisant retenue par divers obstacles. Les taux de distribution varièrent de 0 à 2000 kg ha⁻¹, avec une valeur moyenne de 300 kg ha⁻¹; le taux désiré étant de 672 kg⁻¹. Environ 90% du fertilisant se rendit au sol sous forme de granules; le reste, 10%, fut délavé dans la voûte foliacée par la pluie. Environ 20% de la surface mesurée du bassin ne reçut aucun fertilisant. La partie supérieure du bassin, où commença l'épandage du fertilisant au cours de chaque envoiée, en reçut de plus grandes quantités que la partie inférieure.

Les calculs du quotient d'uniformité et de la demi-valeur permettent de croire qu'on pourrait améliorer l'uniformité de la distribution du fertilisant. Les pourcentages de fertilisant relâchés par avion doivent être réglés jusqu'à ce que les valeurs désirées pour qu'un taux moyen d'application, un quotient d'uniformité et une demi-valeur soient atteints. C'est à ce moment-là seulement que l'application de fertilisant devrait être entreprise. Une démarcation convenable de la zone à fertiliser est aussi essentielle au succès de l'opération.

INTRODUCTION

Lake Brook Basin is one of three watersheds being studied as part of the Nashwaak Experimental Watershed Project. The project is aimed at evaluating the overall biological and environmental impacts of forestry practices, such as clearcutting of large blocks of forest, application of pesticides against defoliating insects, and fertilizer treatments. It is a joint venture of the Canada Department of the Environment, the University of New Brunswick, the Province of New Brunswick, and St. Anne Nackawic Pulp and Paper Co. Ltd. (Anon 1976).

Lake Brook Basin was fertilized with ammonium nitrate in 1975, with the main objective of assessing the possibility and extent to which fertilizer materials would leach through the soil profile and into the streams. Growth response to fertilization and the effects of fertilization on spruce budworm defoliation are also slated for evaluation. Conclusions and recommendations resulting from these studies are expected to have a great impact on future fertilization programs in the region. The nature and magnitude of the effects of fertilization are dependent on the patterns of fertilizer deposition within the treated area. It was therefore considered important to monitor the distribution patterns of fertilizer applied from the air to Lake Brook Basin.

Since the early 1950's, when fertilizers were first applied to trees on an experimental basis, forest fertilization has been increasingly adopted as an ameliorative measure to correct nutritional problems in forest stands. On an operational scale, the application of fertilizers to forest stands has been carried out using both fixed-wing aircraft and helicopters (Beaton 1973; Leaf 1974). Although more uniform distribution of fertilizers can be expected when they are applied by helicopter as compared to fixed-wing aircraft, large variations in rates and patterns of distribution have been found using both methods (Ballard and Will 1971). The use of helicopters for forest fertilization is limited by its high cost (Beaton 1973) as compared to that for fixed wing aircraft.

Several workers have attempted to monitor and characterize the distribution on the ground of aerially-applied fertilizer materials. As a result, a few parameters have evolved that are considered useful in assessing the uniformity of fertilizer distribution.

In Sweden, a "uniformity quotient" has been used as a measure for rating the performance of the aircraft and the pilots (Hagner 1966). Uniformity quotient (U.Q.) is defined as:

$$U.Q. = P_{(\max)} / P_{(\min)}$$

where

$P_{(\max)}$ = The sum of the quantities of fertilizer present in that half of the traps which contained more fertilizer than the median value.

$P_{(\min)}$ = The sum of the quantities of fertilizer present in that half of the traps which contained less fertilizer than the median value.

In Sweden a U.Q. value of 3 or less, was considered to represent fairly uniform distribution of fertilizer. A value of 3, means that on average, half the stand received three times the quantity of fertilizer distributed in the other half. The accuracy of the results depends on the number and size of the traps with respect to the direction of flight of the aircraft (Armson 1972; Roberge and Gagnon 1974; Mallonee and Strand 1974).

While evaluating the distribution of fertilizer applied from aircraft in New Zealand, Ballard and Will (1971) found a low uniformity quotient which would indicate an even distribution, but the average quantity of fertilizer recovered on the ground was less than the amount expected, according to the intended rate of application. Ballard and Will (1971) therefore introduced the term 'half value' which is the proportion (percent) of the fertilized area that receives less than half the desired rate of application. The lower the half value the more uniform the distribution.

In addition to the above two parameters, Armson (1972) calculated the proportion of the treated area where the measured quantity of fertilizer varied within certain predetermined limits of the intended rate of treatment. In this case the larger the calculated value the more uniform the distribution of fertilizer.

MATERIALS AND METHODS

Description of the Basin

Lake Brook Basin, is located about 48 km (30 miles) northeast of Fredericton, New Brunswick. The entire fertilizer-treated area is forested and slopes toward the south. The forest cover in the northern portion of the area is dominated by maple (Acer sp.) and beech (Fagus sp.). The cover in the southern portion consists mainly of a mixture of spruce (Picea sp.) and balsam fir (Abies balsamea). The average age of the trees is about 50-60 years. The distribution of forest cover types in the mid-section of the area, where fertilizer distribution was measured, is shown in the form of a computer-drawn map in Fig. 1. This area represents about 40% (50 ha) of the fertilizer-treated portion of Lake Brook Basin. Over most of the area, the ground cover consisted of feather (Pleurozium sp.) and sphagnum (Sphagnum sp.) mosses. Other lesser vegetation, where present, consisted of raspberry (Rubus sp.) and striped maple (Acer pensylvanicum L.) under hardwoods, and a few patches of ferns (Dryopteris sp.) and sheep laurel (Kalmia sp.) in wet areas under softwoods.

Fertilizer application

Fertilizer was applied by an agricultural aviation company under contract to the Province of New Brunswick. The application was carried out between June 19 and 22, 1975, using fixed-wing aircraft (Cessna Agwagon). On June 20, 1975, efforts were made to calibrate the rate of fertilizer application. The aircraft dropped the fertilizer along the road dividing the basin (insert in Fig. 1), where 31 traps were placed in six rows perpendicular to the direction of flight (Fig. 2). The traps consisted of cardboard boxes (30 x 37.5 cm) fitted with polyethylene bags. The aircraft made three passes over the road releasing the fertilizer. Within a few minutes after each flight, dry fertilizer prills were recovered from each trap for weighing and counting. During operational fertilization, the aircraft flew downstream, beginning at the upper end above transect 0 and finishing at the bottom of the basin (below transect A (Fig. 1)). A complete aircraft load was deposited in each pass over the basin.

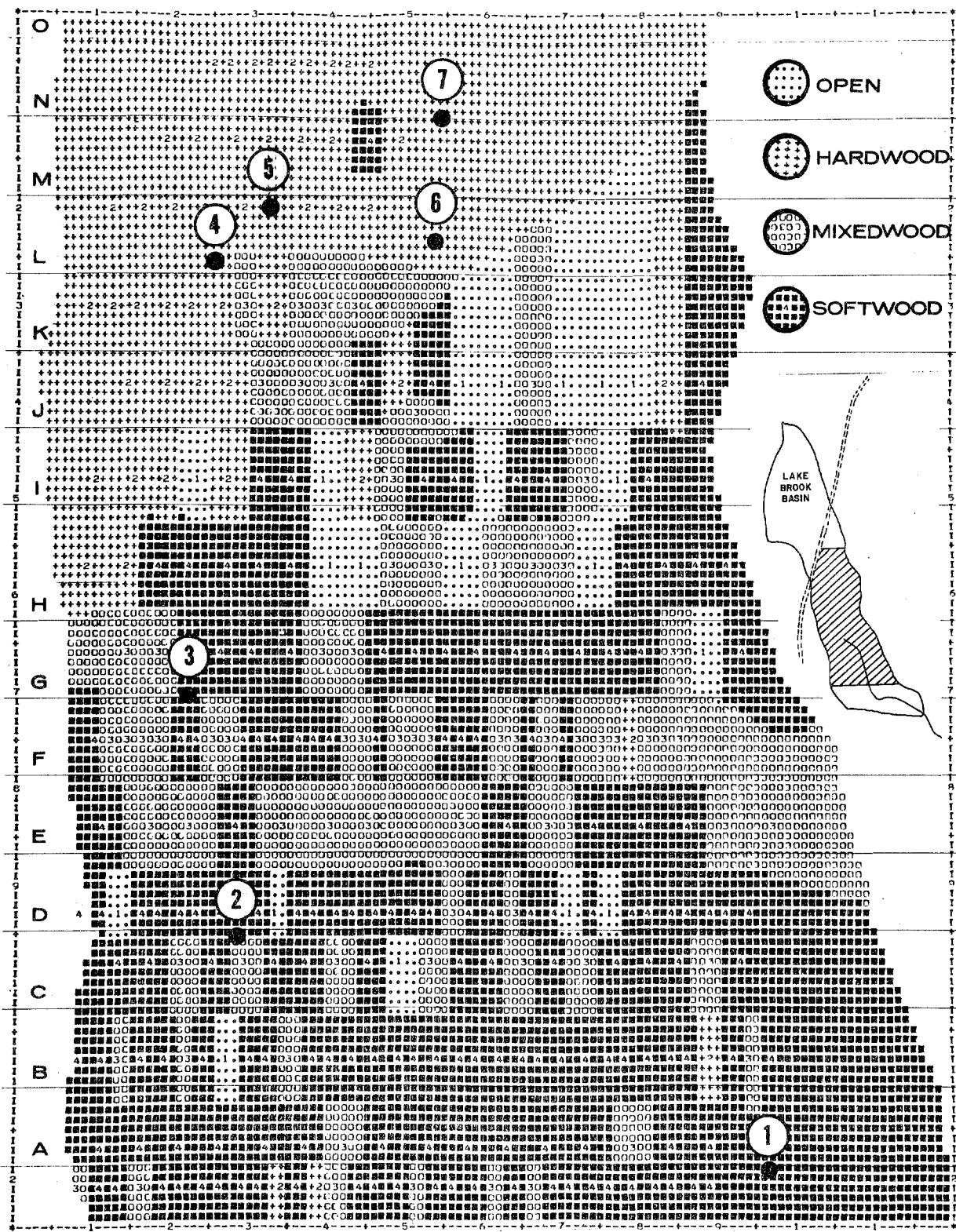


Fig. 1. Forest cover type of the area where fertilizer distribution was monitored.

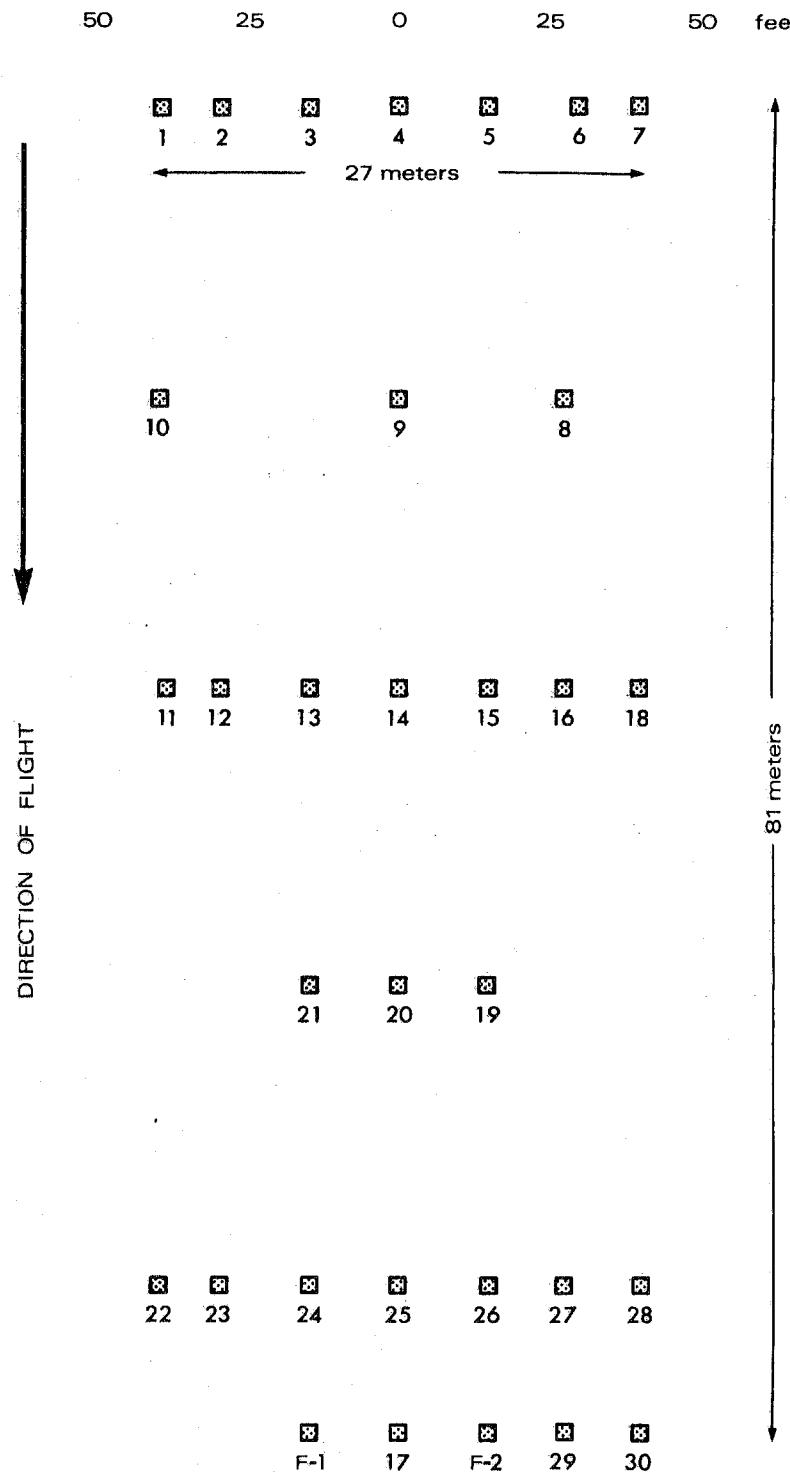


Fig. 2. Schematic arrangement of the traps on the road used for calibration of fertilizer application rate.

Collection of fertilizer

A total of 304 traps, as described earlier, was placed along 15 transects (lines A-O in Fig. 1; shaded area of insert) to collect the fertilizer prills that reached the ground. The transects were about 120 m apart and were perpendicular to the slope of the watershed and to the intended flight path. The distance between traps alternated from 15 m to 20-30 m starting with transect A, except under hardwood cover on transects L, M, N, and O where the boxes were spaced at 40 m. Fertilizer trapped in the boxes was collected twice daily; fertilizer applied prior to 7:00 p.m. was recovered from the traps the same day, and material applied late in the evening was collected during the morning of the following day. At the time of collection, all fertilizer materials, insect frass, pollen, flowers, etc. in the boxes were scooped with large spoons into small labelled polyethylene bags and the traps were then returned to their original positions. The collected materials were stored in a cold room (1-2°C) until they were processed for analysis.

Collection of throughfall and stemflow

Stemflow samples were collected from the trees in seven circular plots (Fig. 1). Three plots were located in softwood, and four in hardwood stands. In each plot, 10 trees were fitted with lead collars and connected to 5-gal containers to collect stemflow (Mahendrappa and Ogden 1973). Also four rain gauges were placed in each of the plots for determining the proportion of total rainfall reaching the ground as throughfall. Samples from these rain gauges were not used for nitrogen analysis.

A total of 136 throughfall collectors were placed along the same 15 transects used for fertilizer collection. Each throughfall collector consisted of a plastic bottle and a 6.5-cm-diameter funnel mounted on a 120-cm-high wooden stake.

Throughfall and stemflow samples were collected on three occasions. The first set of samples was collected 1 week before, and the second immediately after fertilizer application. Following the second collection, new throughfall collectors were installed, and a final collection was made 2 weeks after fertilization. Each of these collections followed rain events (Table 1).

Analysis

Although efforts were made to collect the fertilizer materials soon after application, only a few samples were in a state dry enough to either weigh or count the prills. The fertilizer prills in the traps absorbed moisture due to drizzling precipitation during the fertilizer application (Table 1), high atmospheric humidity, and insect frass (from spruce budworm and maple leaf roller) which was present in large quantities. Therefore, most of the samples were dissolved in 100 ml distilled water and filtered. Stemflow and throughfall samples were also filtered and stored in plastic bottles. All the samples were analyzed for nitrate and ammoniacal N using appropriate ion-selective electrodes (Mahendrappa 1969).

Table 1. Rainfall recorded at Lake Brook Basin during the sampling period

Date	Rainfall, mm	Remarks
June 13	27.5	
14	10.0	
15-16	Nil	
17	Nil	Samples collected prior to fertilization
18-19	2.5	
20-22	Nil	
23	Nil	Samples collected immediately following fertilization
June 24		
-July 1	Nil	
2	2.5	
3	2.5	
4	5.0	
5	10.0	
6	Nil	
7	Nil	Samples collected two weeks after fertilization

RESULTS AND DISCUSSION

Calibration of the rate of fertilizer application

Average quantities of fertilizers recovered during calibration flights from the traps placed on the road, together with some of the parameters calculated from the data obtained, are presented in Table 2. In all three calibration flights the average quantity of fertilizer recovered per box was less than half the expected value. The second and third calibration flights, in which the average quantity of fertilizer recovered per box was close to half of the expected value, can be considered suitable provided that the flight swaths have a 50% overlap (White 1956). High coefficients of variation, however, indicate that the application rate and distribution of fertilizer was less uniform than desired. On the basis of the Swedish standard of a required uniformity quotient of less than 3, only the first calibration flight was acceptable (Hagner 1966). However, the half value for the first calibration flight was 100% indicating that the rate of fertilizer application was low over the entire area covered by the traps. In calibration flights 2 and 3 the calculated values for uniformity quotients were higher and half values lower than those in calibration flight 1.

Table 2. Characteristics of fertilizer distribution during three calibration flights

Parameters Determined	Flight No.			Desired value
	1	2	3	
Fertilizer/box (g) (Average of 30)	0.46	1.86	1.51	3.8
Coefficient of variation (%)	57	117	110	
Uniformity quotient	1.94	40.68	24.00	3.00
Half value (%)	100	62	54	10
No. of boxes with no fertilizer	0 (0%)	3 (10%)	5 (17%)	0 (0%)

Low average values for the quantities of fertilizer recovered per box could have been due to either a higher flight speed than intended or to uneven release of the materials during the flight. On the basis of these results, it was decided to carry out the operational fertilization with the settings used for the second and third calibrations, and with a 50% overlap of the swaths. Fertilizer recovered, during calibration flights, from the boxes farthest from the centre of the road indicated an effective swath width of about 25 m.

Recovery of fertilizer

Ammonium nitrate prills were found in a dry condition, and without any extraneous material, in only a very few traps. Such samples were weighed and the number of prills counted before dissolving them in distilled water for nitrate and ammonium N analyses. There were, on average, 95 dry ammonium nitrate prills per gram of the material used for fertilization. Analysis of the materials recovered from the field showed a similar value for the number of prills per unit weight.

Fertilizer was applied to the area containing traps on June 20, 21, and 22. On June 20, fertilization was carried out during both morning and evening hours. Fertilizer was found in 109 of the 304 traps, or about 36%. The fertilizer distribution pattern, determined on the basis of the quantities of fertilizer recovered from these 109 traps, is presented in Fig. 3. The traps that received fertilizer were not located in any specific portion of the basin. The calculated uniformity quotient (U.Q.) for this set of data (excluding traps with no fertilizer) was 8.7. According to the Swedish standard, fertilizer distribution on this day cannot be considered satisfactory. Half value for these data was 79%, a figure much higher than the desired value of 10%. The average rate of application on June 20 was 129 kg per hectare.

On June 21, fertilizer was found in 142 traps (47% of the total), distributed throughout the area. The average rate of fertilizer application was 140 kg per hectare. The half value (77%) was the same as for the previous day, but the uniformity quotient was higher. This indicates that some areas received a much larger dose of fertilizer than others. From the fertilizer distribution pattern presented in Fig. 4, it is clear that larger quantities of fertilizer were applied to the upper portion (transects G-0) of the area than to the lower portion.

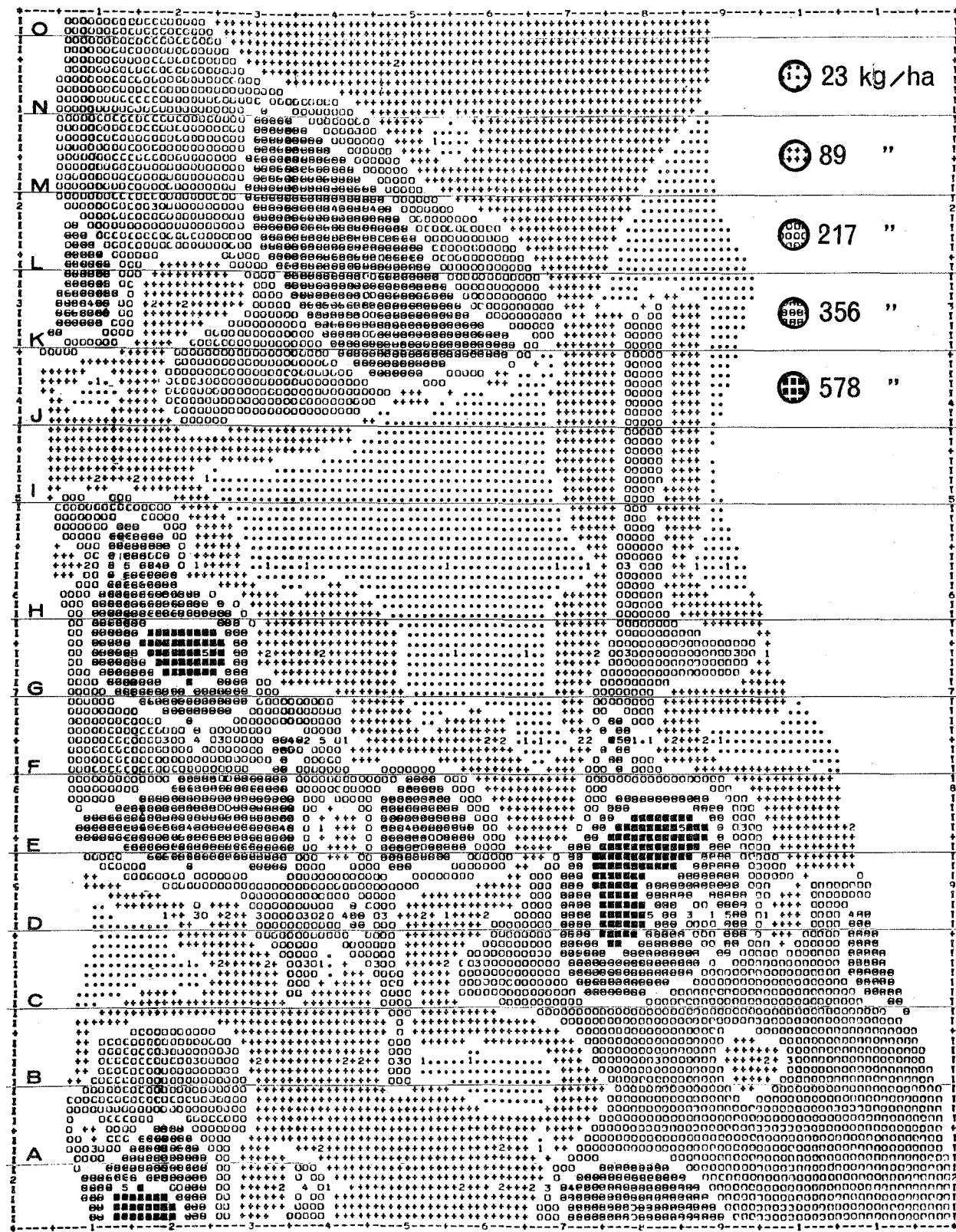


Fig. 3. Observed patterns of the distribution of fertilizer applied on 20th June 1975.

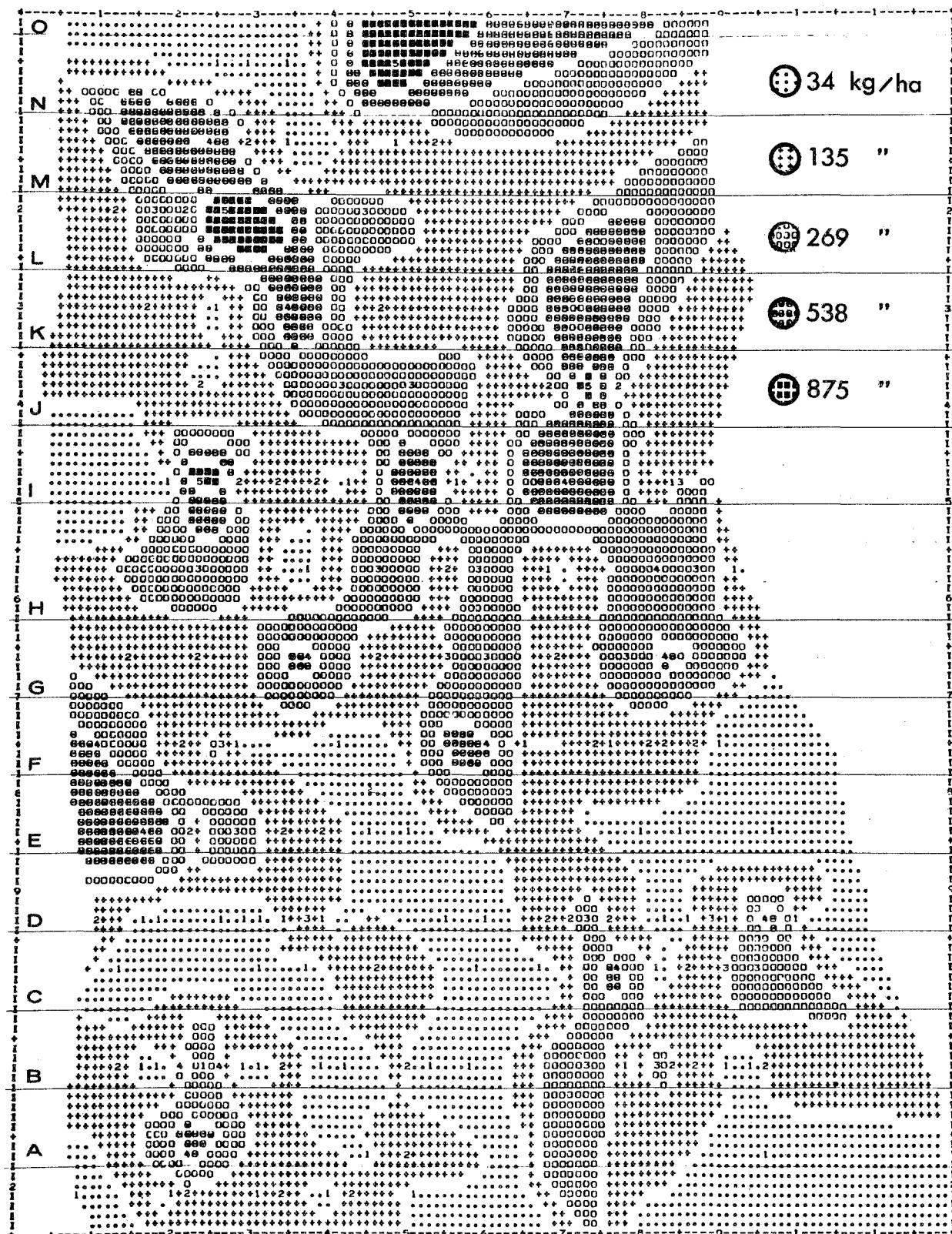


Fig. 4. Observed distribution patterns of fertilizer applied on 21st June 1975.

The fertilizer distribution pattern on June 22 (Fig. 5) was more uniform than that observed on the previous 2 days. Fertilizer was found in 157 traps and both the uniformity quotient (7.2) and half value (52%) were lower than for the previous 2 days. The average rate of fertilizer application was 242 kg per hectare.

During the period of June 20-22 fertilizer was collected more than once from some of the traps. This was expected because, it had been decided to systematically apply fertilizer over the basin as many times as was necessary until the full prescribed amount of fertilizer was distributed.

During the 3 days of fertilization, 243 of the 304 traps received fertilizer. This represents 80% of the area where fertilizer distribution was measured; 20% of the area therefore did not receive any fertilizer. The uniformity quotient and half value calculated for these combined data were 6.4 and 47% respectively. Values similar to these have been reported earlier (Ballard and Will 1971). The overall average rate of fertilizer application was 296 kg per hectare, which is slightly less than half the intended rate of 672 kg per hectare. More fertilizer was applied to the upper (north) end of the measured portion of the basin (Fig. 6), than to the lower (south) end, with a gradual decrease in the quantity of fertilizer recovered from north to south (Fig. 7). It is important to note here that fertilizer application commenced well above transect 0, outside the measured portion of the basin, and it is evident that this area must have received much higher dosages than did the measured area.

There are indications that more fertilizer was intercepted by conifers than by hardwoods. This, however, could not explain a gradient of fertilizer distribution of the magnitude observed. The observed gradient was also reflected in the occurrence and extent of moss kill. Sporadic patches of discolored mosses, resulting from direct contact with fertilizer material, were found at the lower end of the basin, as compared to extensive moss kill (indicating much greater contact) at the north end.

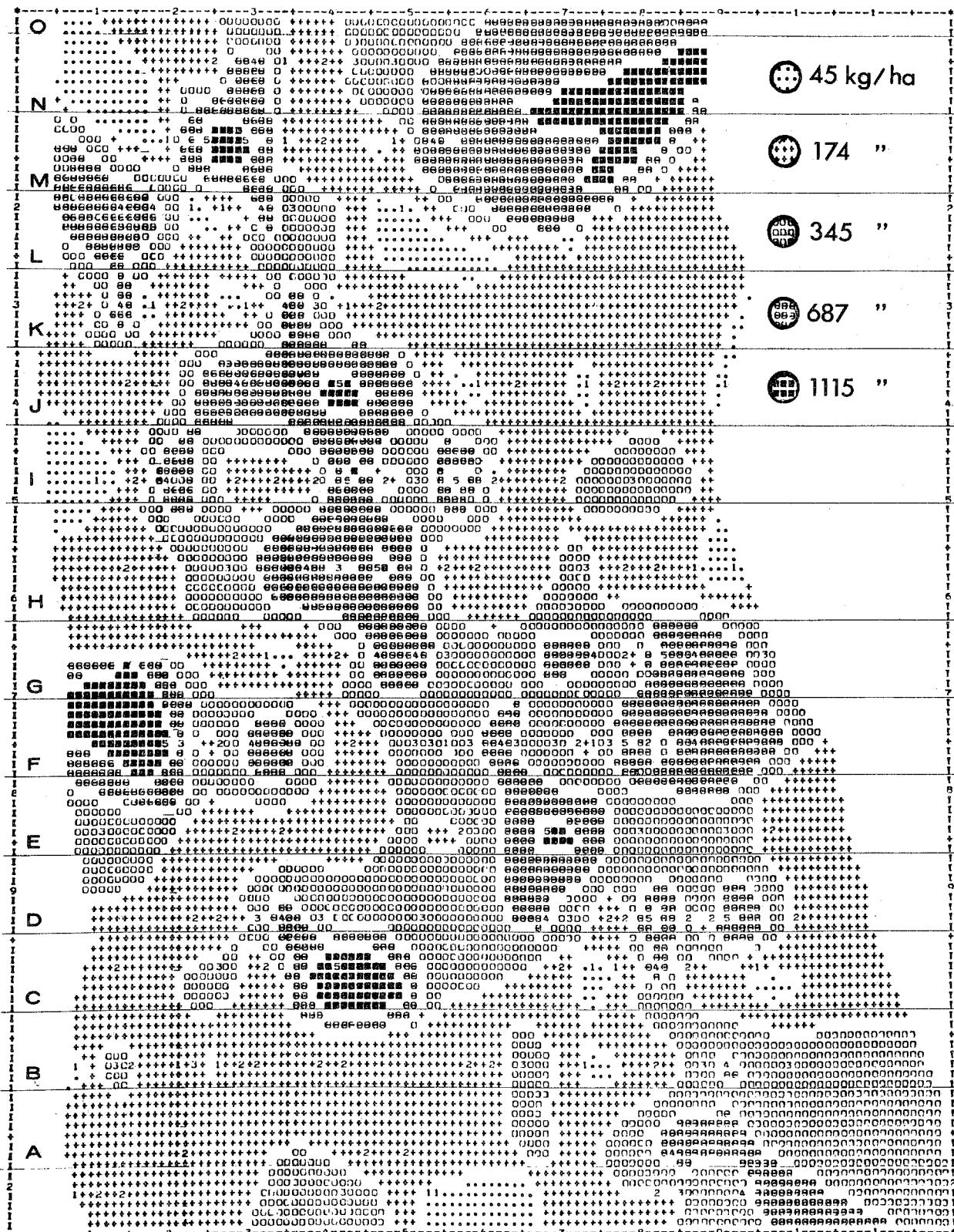


Fig. 5. Observed distribution patterns of fertilizer applied on 22nd June 1975.

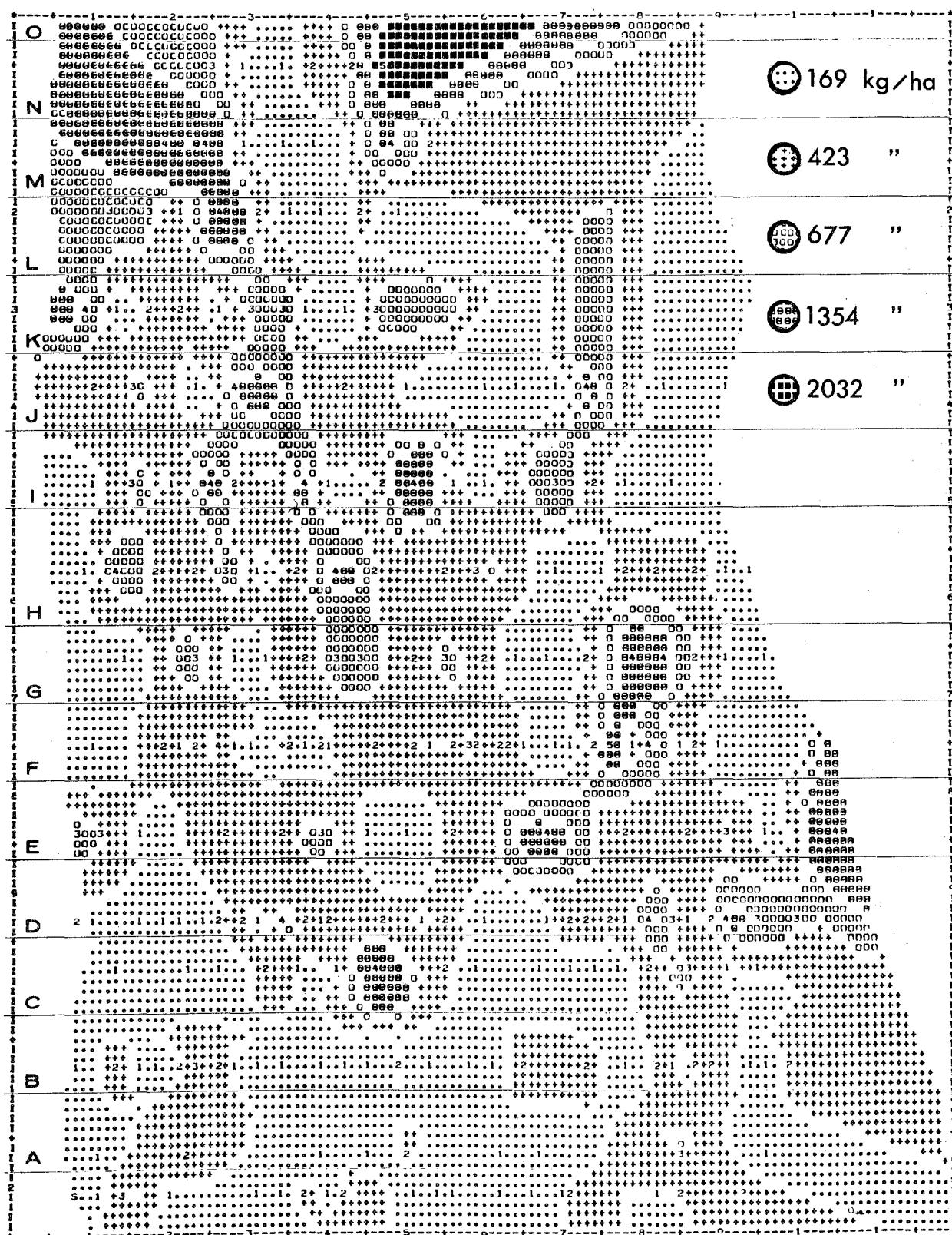


Fig. 6. Observed distribution pattern of fertilizer at the end of fertilization operation (Intended rate of application was 672 kg/ha).

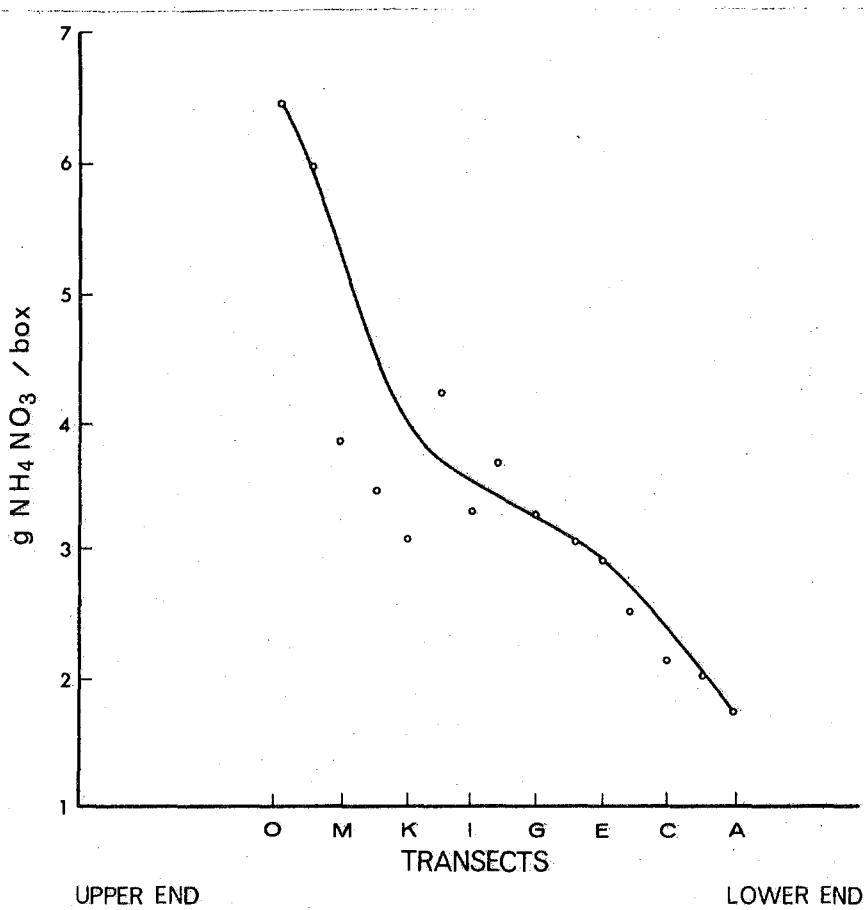


Fig. 7. Gradient of fertilizer distribution across transects.

Fertilizer recovered in stemflow and throughfall

On each of the three collection dates the 5-gal containers connected to the stemflow collars on hardwood trees were filled to capacity, while those on softwoods contained only small volumes of water. Rain gauge data indicated that fir-spruce stands intercepted 50% of the total rain and hardwood stands less than 30%.

Low concentrations of nitrogen, amounting only to a few grams of fertilizer per hectare, were found in the stemflow samples. The quantity of aerially-applied fertilizer reaching the ground in the form of stemflow can, therefore, be considered to be negligible (less than 0.5%).

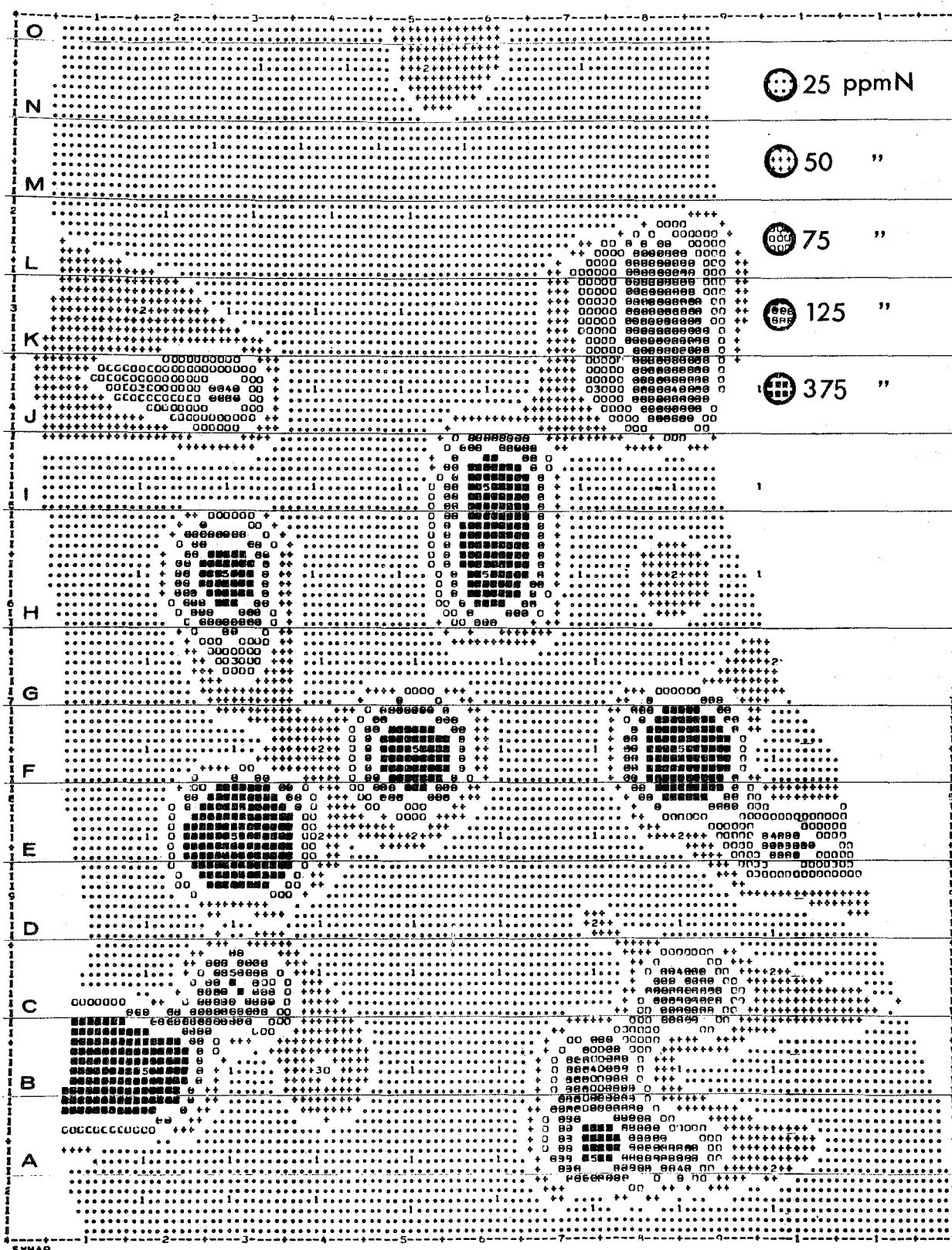


Fig. 8. Observed concentrations of ammoniacal nitrogen in the throughfall samples collected two weeks after fertilization.

Throughfall samples collected on June 17 (before fertilization) contained negligible quantities of both ammoniacal and nitrate nitrogen. During fertilization the throughfall collectors also trapped fertilizer prills. The collectors under hardwoods contained considerably more N than those under softwoods. This is in agreement with the gradient of fertilizer distribution, as shown in Fig. 7, and with the differences in interception of rainfall.

Rain occurred about 10 days after fertilization was completed. The final set of throughfall samples was collected on July 7; at that time all the receptacles contained water. The concentration of ammoniacal N in the throughfall samples is shown in Fig. 8. A comparison of Figs. 1 and 8 shows that higher concentrations of N were recovered in the area with softwood cover. Negligible levels of N were detected in the throughfall under hardwoods. Apparently, the hardwood canopy did not intercept as much fertilizer material as the conifer canopy. Nitrate N was present in all the samples with a distribution pattern similar to that of ammoniacal N.

Average values for the quantities of fertilizer N recovered in the solid form and in solution (as stemflow and throughfall) along different transects are presented in Table 3. The quantity of fertilizer recovered from the traps ranged from 128 to 496 kg per hectare, with an average of 294 kg ha^{-1} . The range for the quantity of N recovered as stemflow and throughfall was 4.7 to 51.3 kg per hectare with a mean of 29.4 kg per hectare. Overall, therefore, 90% of the fertilizer applied to Lake Brook Basin directly reached the ground as solid particles and 10% was washed down by rain. The quantity reaching the ground via stemflow and throughfall was much higher than the 1% reported by Roberge and Gagnon (1974) for balsam fir stands in Quebec.

Table 3. Quantities of fertilizer materials recovered as prills and as stemflow and throughfall

Transect	Fertilizer measured			
	Solid Prills		Stemflow + Throughfall	
	kg/ha	Percent of total	kg/ha	Percent of total
A	128	96.5	4.70	3.5
B	151	85.8	25.07	14.2
C	161	80.3	39.43	19.7
D	193	87.7	27.74	12.3
E	243	96.8	7.92	3.2
F	299	85.4	51.27	14.6
G	250	83.3	44.61	16.7
H	283	94.6	16.26	3.4
I	251	85.4	42.97	14.6
J	243	90.9	24.40	9.1
K	234	82.4	50.96	17.6
L	270	90.7	27.58	9.3
M	295	94.7	16.61	3.3
N	459	93.8	30.34	6.2
O	496	93.9	32.11	6.1
Average	294	90.03	29.42	9.97

CONCLUSIONS AND RECOMMENDATIONS

Results of this study show that aerial application of ammonium nitrate produced a very uneven distribution of the fertilizer in Lake Brook Basin. The average rate of application of the fertilizer was slightly less than half the intended level; an estimated 20% of the area did not receive any fertilizer. From this, and from experience gained by direct observation of the operation, some conclusions can be drawn:

1. Calibration of the fertilizer release rate from the aircraft, based on fertilizer distribution on the ground, is one of the most important prerequisites to ensure even distribution. Factors to be considered during calibration are a) effective swath width and the total area covered by each plane load of fertilizer, and b) the distribution pattern.

a) Effective swath width and ground speed of the aircraft must be adjusted so that a load of fertilizer is spread evenly between

two landmarks on the ground that are clearly visible from the aircraft. If the aircraft is emptied at some midpoint it is very difficult to achieve continuity of fertilizer spread. It is useful to arrange for a 50% overlap of swaths to avoid missing stands along the edges of the flight path.

b) Fertilizer distribution pattern must meet certain requirements in terms of calculated parameters, namely mean rate of application, uniformity quotient, and half value. These can be calculated on the spot in the field, and they provide a good measure of the evenness and rate of fertilizer application. First, the average quantity of fertilizer recovered from the traps must fall within predetermined limits of the desired level. Then the relationship between uniformity quotient and half value (Fig. 9) can be used as a measuring tool in the field to decide whether or not the evenness of distribution is adequate. If the calculated values of these two parameters do not conform to the upper limits of U.Q. and half value in Fig. 9, calibration flights must be continued until values for the U.Q. and half value fall within the desired range. A set of about 30 traps would be required at each point of collection to obtain reliable values with about 10% variation. For calibration, traps must be placed at three locations - at midpoint, and at each the beginning and end of the flight line. Calibration under these conditions should permit the avoidance of problems (as may have occurred at Lake Brook Basin) of varying application rates resulting from different hopper pressures.

2. Demarcation of the boundaries of the stand to be fertilized is very important. One of the techniques used for this purpose is the hoisting helium-filled balloons. These can be used either for marking the outer limits of the stand or for directing the aircraft during each flight. One of the problems associated with the use of balloons is drifting caused by the wind. Depending on windspeed, the length of the string, and the height at which the balloons are fixed, the drift can be as much as the swath width. The use of spotter planes, as adopted during insecticide spray programs, may be helpful. Other techniques of marking the stands include installation of bright colored boards or similar objects, or killing the trees in a line with chemicals. Dropping

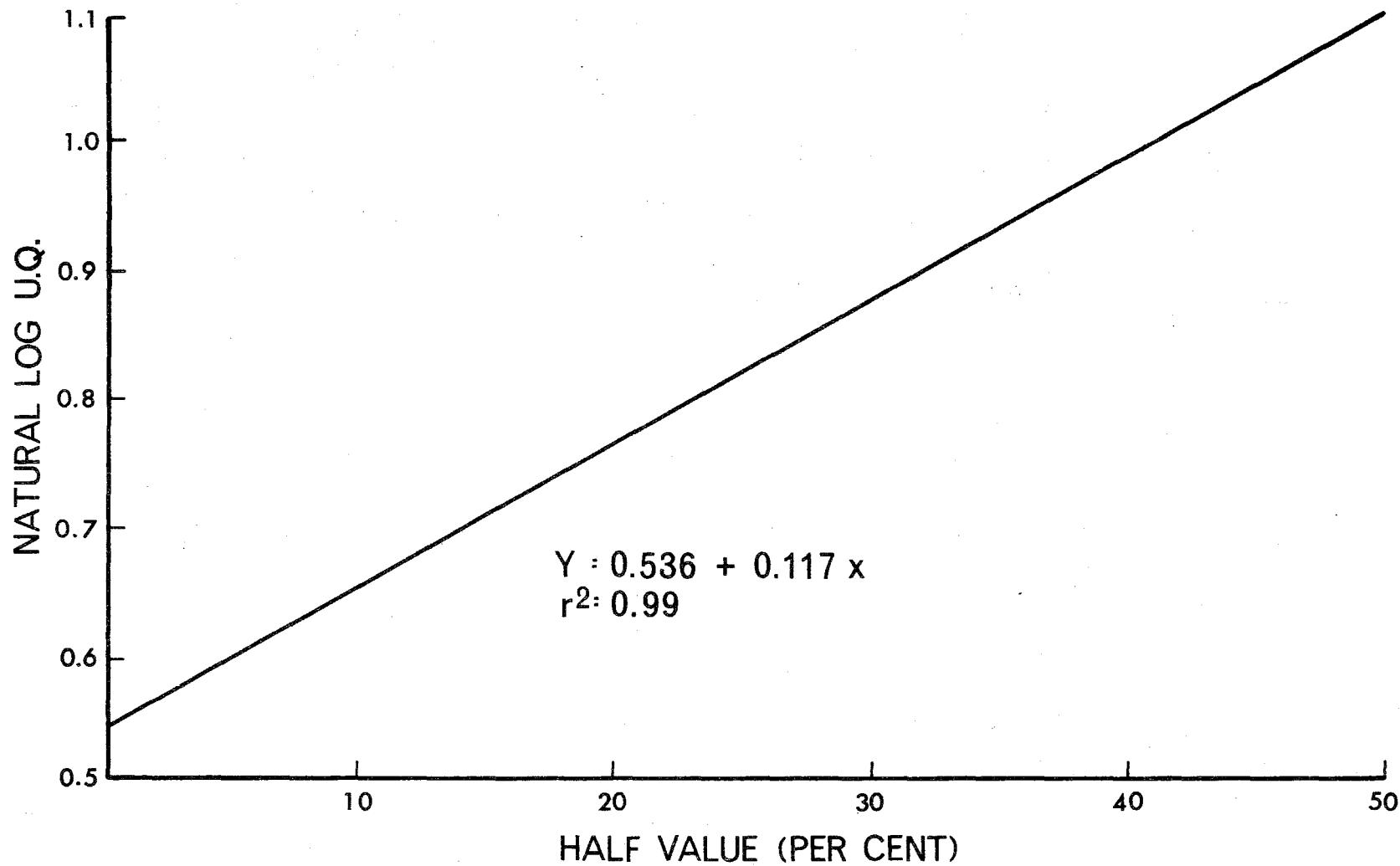


Fig. 9. Relationship between half value (percent) and the uniformity quotient (U.Q.)

rolls of white tissue paper can be effective in marking the starting and end points of each strip.

3. Comparisons of different shaped traps have not shown any significant difference. Various workers have compared traps of different sizes, and those with 930 cm^2 (1 ft^2) openings have been found to be most suitable.

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REFERENCES

- Anonymous. 1976. Nashwaak Experimental Watershed Project: A cooperative study of the environmental impacts of forestry practices, 12 pp. Nashwaak Experimental Watershed Project, P.O. Box 4000, Fredericton, N.B.
- Armson, K.A. 1972. Fertilizer distribution and sampling techniques in aerial fertilization of forests. Tech. Rep. No. 11. Fac. For. Univ. Toronto.
- Ballard, R., and G.M. Will. 1971. Distribution of aerially applied fertilizer in New Zealand Forests. N.Z. For. Sci. 1: 50-59.
- Beaton, J.D. 1973. Fertilizer methods and applications to forestry practice. In: Forest Fertilization Symposium Proceedings. USDA For. Serv. Gen. Tech. Rep. NE-3.
- Hagner, S. 1966. Timber production by forest fertilization. Can. For. Serv. Trans. ODF TR 279 (1968).
- Leaf, A.L. 1974. Where are we in forest fertilization? p. 1-5. In: Proceedings of a Workshop on Forest Fertilization in Canada. Great Lakes For. Res. Centre, Sault Ste. Marie, Ont. For. Tech. Rep. 5.
- Mallonee, E.H., and R.F. Strand. 1974. Work plan and establishment report for 1974 aerial fertilization at Tsolum Flat. Crown Zellerbach Corp., Central Res. Division, Centralia, Wash.
- Mahendrappa, M.K. 1969. Determination of nitrate nitrogen in soil extracts using a specific ion activity electrode. Soil Sci. 108: 132-136.
- Mahendrappa, M.K., and E.D. Ogden. 1973. Effects of fertilization of a black spruce stand on nitrogen contents of stemflow, throughfall and litterfall. Can. J. For. Res. 3: 54-60.
- Mahendrappa, M.K. 1974. Volatilization of oxides of nitrogen from nitrate-treated black spruce raw humus. Soil Sci. Soc. Amer. Proc. 38: 522-523.
- Roberge, M.R., and J.D. Gagnon. 1974. Etude d'un épandage aérien d'urée en forêt. Can. J. For. Res. 4: 482-490.
- White, D.P. 1956. Aerial application of potash fertilizer to coniferous plantations. J. For. 54: 762-768.