A STUDY OF BAND SPRAYING AND DIRECT DRILLING AS A TECHNIQUE FOR INCREASING THE WINTER PRODUCTION OF PASTURES.

A thesis presented in partial fulfilment of
the requirements for the Degree of Master
of Agricultural Science in Agronomy at
Massey University.

Richard Michael Collins
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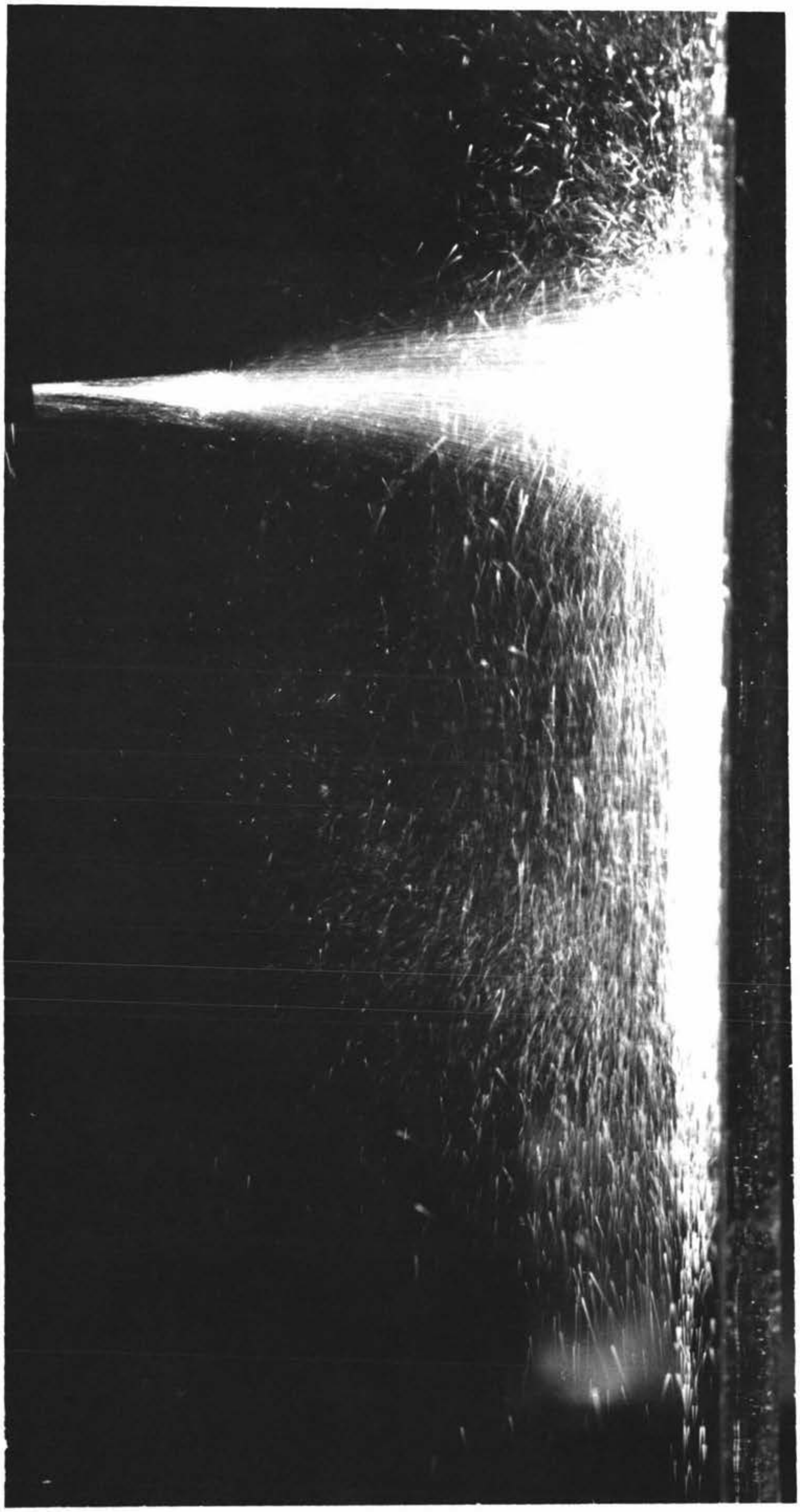

ABSTRACT

"Band spraying and direct drilling", a technique in which bands are sprayed in a pasture with paraquat, followed by the direct drilling of seed into the centre of the bands, was investigated, with the aim of increasing the winter yield of pastures.

The work was divided into two parts. In the first, a band sprayer was constructed and tested, and with it a pasture band sprayed and direct drilled in autumn. The resulting production was measured over the following winter period. The second part consisted of an investigation into the distribution of spray within the bands and spray bounce outside the bands, using the same nozzles and operating heights as in the earlier work.

The band sprayer was constructed on a disc - drill so that bands could be sprayed and drilled in the same operation, the coulter spacing being 6 in. Measurements were taken of several performance characteristics of a variety of nozzles in order to select three sizes spraying 1 in., 2 in., and 3½in. bands at 30 gal. liquid per sprayed acre.

Seed coating with bentonite with the aim of reducing paraquat damage (if this was a problem) was briefly examined, and abandoned after finding that the coat reduced seed germination considerably more than any paraquat damage that may have resulted.

In the autumn - winter trial, the factors included were : 4 band widths ("blanket" plus those mentioned above); 3 paraquat application rates (1, 2, and 4 oz. a.i./acre); 2 varieties ("Grasslands Tama" Western Wolths ryegrass and ryecorn); and a nitrogen sub-plot treatment (each half of every plot had either 0 or 1 cwt. nitrolime/acre placed with the seed).

Irrigation was carried out prior to spraying and drilling, and was followed by a dry spell of four weeks. This combination appeared to have a deletarious effect on the resulting establishment of the sown species, which together with the wet winter period were partially to blame for the poorer yields in all treated plots (compared to control plots).

Measurements taken were mainly of soil moisture, seedling emergence, botanical composition and dry matter yields. Results were analysed by means of t-tests and analysis of variance where these tests were suitable.

The results and literature suggested various hypotheses as to the fate of bands and the growth of plants within them and it would appear that defoliation frequency and intensity are important factors. The defoliation treatment in the trial (i.e. at 6-8 in. height) was considered inadequate.

The investigations from the second part of the thesis work led to the use of two techniques which could have further use in spray distribution analysis. In the first, the spray liquid incorporated a metal salt (e.g. copper sulphate) in solution and was collected on narrow blotting paper strips. The metal concentration was measured by an atomic absorption spectrophotometer. With this method, a graph could be drawn of the within band spray distribution, and with log. transformation of the results, spray bounce outside the edge of a band width pasture strip could be confidently measured to $3\frac{1}{2}$ in. from the band. The total amount of spray outside the band was small however. (rarely above 10%), and largely within an inch to either side of the band with the nozzles used.

In the other technique, the spray nozzle was photographed in action, the lighting and exposure methods used enabling the extent of spray splash to be observed.

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1. INTRODUCTION.

Winter feeding of livestock is becoming an increasingly major operation on New Zealand farms. With increased stocking rates and a greater drive for efficiency, farmers and research workers have tried many systems. One system however, which has not undergone extensive evaluation is that of "band spraying and direct drilling".

The term "band spraying" is now well established in crop production work, where the technique involves spraying either a non-selective herbicide between crop rows or a selective herbicide in the crop rows (with mechanical weed control between rows). To date, few attempts have been made to band spray a plant free track into pasture with the object of subsequently sowing and establishing a new species in that sward. The concept is similar to that of overdrilling, where a plant free track is left by mechanical means. Behind both of these techniques is the idea that a plant's closest neighbours are its greatest competitors, and that when removing competition from around a plant, diminishing returns presumably set in, the removal of the closest neighbours being of most help to the plant (in this case the sown one).

Direct drilling, in which seed is drilled directly into the mechanically undisturbed soil after the existing vegetation has been killed by a herbicide, usually paraquat, offers the advantages of a quick easy establishment technique for cash, forage crops and pastures. Usually, the technique offers cheapness and considerable management flexibility. It seems likely that the unknowns of the relationship between seed bed requirements of previously used species, drilling machinery performance and soil conditions, are keys to the success or failure of any crop drilled in this way.

Nevertheless, band spraying and direct drilling has been shown to be feasible with regard to the mechanics of the operation (Blackmore 1962, Kay 1966). To be of acceptance however, any new technique must have advantages over other techniques. Because of its use of similar drilling machinery and operation in similar soil conditions, direct drilling in conjunction with band spraying is likely to suffer similar limitations to the technique of direct drilling. In direct drilling for regrassing purposes there has usually been a lowering of production over the first winter. It is suggested that this could possibly be overcome with the use of fast growing winter species such as "Grasslands Tama" Western Wolths ryegrass or cereals such as oats or ryecorn. With band spraying the aim would be to kill only as much of the existing vegetation as is needed for the establishment of the new species and so minimise the amount of yield reduction. In this manner one would be changing only the botanical balance of the existing award.

In common with direct drilling after blanket herbicide application, band spraying would be expected to have the same advantages over conventional establishment methods with respect to speed and flexibility, and to have the disadvantage of the added risk of establishment failure. Some gain in total winter crop or pasture production is likely in comparison with either blanket spraying and direct drilling or conventional establishment methods in that the unsprayed areas could contribute to the total yield. Furthermore, re-establishment of the pasture may be unnecessary in the following season.

A factor of vital importance to band spraying would therefore appear to be band width and its effect on the yield of sown and existing species. A compensatory effect between the two is likely as the greater the yield from the existing species (related largely to band width) the less from sown species. As the total yield is the sum of the yield from the existing and sown species, the optimum band width would be where the yield came to a peak.

When considering the effectiveness of a certain width of band in reducing competition, the question of pasture reaction to a band of dead herbage must also be considered. The band would initially leave a "vacuum" which would subsequently be followed by a competitive struggle from many plants to fill the gap. The initial reduced competition adjacent to the existing plants may allow them to spread laterally and perhaps overshadow the band. With a narrow band this may lead to a dark environment which is difficult for the new plant to inhabit. Cutting frequency and height may be considered as associated and interacting factors.

Recolonisation could be expected from three sources.
(i) From seeds in the ground that had undergone band treatment. These would include seeds from the present and previous inhabitants of the area as well as those sown by the drill.
(ii) From plants suppressed by the spray, but in the process of recovery from paraquat spraying.
(iii) From the species outside the band. Stoloniferous species might be expected to make a faster invasion of the area while tufted species could also recolonize the band as they tillered.

As in blanket spraying, a factor that should be of importance is the rate of paraquat application within any one band. Both the economics and rate of in-band recovery would be thus affected. The question may well be asked, which is better, a narrow band and heavy rate, or wide band and lighter rate ?

From the viewpoint of the mechanics of creating bands of variable width, obviously a field requiring major attention, is the design of suitable equipment and the performance testing of spray nozzles in relation to eveness of application and within pasture bounce.

2. BAND SPRAYING AND DIRECT DRILLING FIELD TRIAL WORK.

2.1. INTRODUCTION.

In this section of the work a band sprayer was constructed, tested and used to execute a field trial. The lack of earlier work as a suitable guideline led to a trial of a rather extensive nature, with observations being limited as a result.

2.2. LITERATURE REVIEW.

2.2.1. INTRODUCTION: PARAQUAT AND DIRECT DRILLING.

Paraquat has been used as a herbicide in agriculture for nearly ten years (Calderbank 1968) and its advantages have resulted in its use as one of the major chemicals in direct drilling. Jones (1962) listed the advantages as follow:-

1. No soil residual toxicity, enabling oversowing and direct drilling to be carried out almost immediately after spraying.

2. Quick uptake by the plant, hence results are not greatly affected by rain falling soon after application of the chemical.

3. Rapid action, coupled with (1) allow establishment in a short time.

4. Toxic at low concentrations of active ingredient.

5. Selectivity among grass species, the order of which is of practical significance, as the desirable species are favoured. Also, it is selective for clovers.

At this stage direct drilling should be defined. Baker (1969) defined direct drilling as entailing "eradication (or suppression) of vegetation without mechanical disturbance (using spray applied herbicides, and more recently flaming) followed by drilling and positive placement of seed into the soil". This procedure has been developed since the mid 1950's (Blackmore 1957) and became more popular with the availability of paraquat in the early 1960's (Allen 1967, Charles 1962, Calderbank 1968).

Since that time much experience has been gained in Britain, the U.S.A. and New Zealand in the use of the technique. Generally, it has been found that as a "short cut" method (Baker 1969), success depends very much on the fulfilment of certain agronomic conditions. These have been summarised by Jeater (1966) for the establishment of kale and cereals in Britain:-

1. Suitable soil conditions. At present the lighter, well-drained soils are the most suitable for direct drilling.

2. The ability of the herbicide to eradicate the existing vegetation. Thus, areas dominated by plants with rhyzomes or large tap roots which enable the plant to recover from paraquat treatments are not at present suitable for this technique.

3. A suitable means of introducing the seed into the soil. The drill must be adjusted so that it produces the type of slit which is conducive to seed germination and seedling development, and this slit must be closed after drilling to guard against slug and bird attack.

4. Adequate levels of fertiliser, particularly nitrogen, must be applied to the crop.

For pasture establishment a further point enumerated by Charles (1962) in reference to surface seeding (i.e. oversowing, overdrilling and direct drilling) must be added:

5. Suitable management before, during, and after establishment.

Where these requirements have been met, crops and pastures as good as, or better than, those established under conventional methods have resulted (Calderbank 1968, Blackmore 1967). However, Baker (1969) noted the lack of suitable fundamental design data with reference to direct drilling machinery to enable the meeting of the third requirement. Blackmore (1955) made similar comments in reference to overdrilling and generally there appears to be a greater risk in this technique than in conventional practices (Anon. 1969).

It is not the purpose of this review to cover all aspects of direct drilling or the uses of paraquat, which have been reviewed by Allen (1967) and Calderbank (1968). Rather, certain aspects will be dealt with, in an attempt to show the present limits of knowledge in these fields. These aspects will be those related to the main field trial of the thesis.

2.2.2. COMPETITION AND PLANT ESTABLISHMENT IN RELATION TO DIRECT DRILLING.

"Competition occurs when each of two or more organisms seeks the measure it wants of any particular factor or thing and when the immediate supply of the factor or thing is below the combined demand of the organisms" (Donald 1963).

The action of a herbicide, according to Elliott (1960), has three main phases:

1. The period of direct action following application.
2. A static period due to residual activity in soil or plant.
3. The regrowth to a new sward equilibrium.

Phase one with paraquat is particularly rapid, the scorching being visible within 24 hours of application, with the full effect on foliage being reached in 7-10 days (Elliott and Allen 1964). According to Calderbank (1968) paraquat is virtually non selective, killing all green tissue and having little, if any effect, on roots. Phase two can hardly be said to exist for paraquat because it is rapidly absorbed and inactivated on contact with most soils. Thus, the beginning of phase three is reached by all species soon after spraying. The foliage of the sward is uniformly dead, and regrowth starts from unharmed tiller buds and surviving root systems (Elliott and Allen 1964), most perennial plants in fact regrowing after the first application (Calderbank 1968).

The resulting composition of the recovering sward is then affected by the ability of the plant to withstand the action of the herbicide (by having parts undamaged from which it can grow) and its ability to regrow from those parts undamaged by the herbicide. Elliott and Allen (1964) mentioned other factors as well. Apart from these agronomic requirements quoted earlier, there is the case of the proportion and pattern of the desired specie (or species) within the pasture (this was in particular reference to the practice of selective control of grasses in permanent pastures). They felt that the tufted habit of most so called desirable grasses was perhaps unfortunate as they were less able to recolonize vacant spaces vegetatively than were the stoloniferous ones, the majority of which were undesirable. These authors felt that white clover had an important part to play in the recolonization of the pasture by desirable species because of its stoloniferous habit. The success of desirable species in colonization is related to season of active growth, proportion of the species in the pasture, and the pattern of these species within the pasture. They proposed a threshold presence of colonisers (varied by the other factors mentioned) above which the spaces could be filled in in reasonable time and below which they could not. It was added that almost nothing is known about these threshold values.

Very little appears in the literature in reference to the pattern of competition suppression. The few references that make any attempt at measuring competition suppression make no mention of the pattern of this suppression. Sprague et al (1962) investigated the growth of sudan grass in competition with partially killed grass swards. Percentage control of indigenous species was calculated from numbers of square inches free of the species in a 1 x 100 in. strip. They concluded that germination and emergence was little affected by live or dead sod grasses, but both the growth and development of the seedling from ten days after emergence until harvest was altered by a factor up to 20 times. This severe competition was consistent where *Poa pratensis*, timothy, or cocksfoot was present. Competition was also evident to the same relative degree under conditions of high or low nitrogen fertility, in years of abundant rainfall, and in years where soil moisture was limiting. Some idea of pattern of competition suppression is implied in the work that has been done on band spraying.

2.2.3. BANDSPRAYING.

Robinson and Cross (1960) described "overdrilling" as drilling seed into the soil without prior cultivation of the established pasture. The normal procedure usually incorporates "a plant free track" with which overdrilling has been successful (Blackmore 1955). The width of this plant free track has been variously quoted as 2 in. (Blackmore loc.cit.) and 1½ in. (Cross 1963).

Successful practice has hinged very much on post treatment management to keep the competition from the pasture growing between the rows to a minimum. Blackmore (1955) summarised the situation: "For each and every species, then, there is a critical level in a given set of ecological circumstances above which the opposing forces are too great for the seedlings to survive. This establishment barrier is by no means fixed but is in a constant state of flux and is influenced most strongly by the prevailing weather conditions". With direct drilling "chemicals used for crop establishment must give sufficiently lasting control of the pasture species to ensure that recovery growth does not compete with the crop" (Bramley 1962).

Band spraying is a combination of both techniques: a direct drilling situation within rows and an overdrilling situation overall. Several workers have investigated band spraying, including Blackmore (1962). Hammerton and Johnson (1962), Kay (1964, 1966) and Lewis and Martin (1967).

Blackmore (1962) carried out his trial in autumn on a 20 year old ryegrass-browntop dominant pasture. He sprayed 2 in bands of paraquat at 12 lb. a.i. in 10 gal. of water per sprayed acre. Choumoellier, turnips, a pasture mixture, and ryecorn were sown at the same time as drilling. The strike and establishment in the band of all species was good, especially in the case of a sub-treatment of ryecorn, where 1 cwt./acre of ammonium-nitrate lime mixture was added to the plot (not stated whether drilled with seed or broadcast). No yield figures were taken.

Hammerton and Johnson (1962) used the "sod-seeder" of Ellison (1961) in a trial of several treatments including 2 lb. paraquat/acre in 6-7 in. bands and 10 in. row widths. Immediately after sowing, spraying was carried out. Rape was sown into a 4 year old ryegrass white clover ley. The band treatment yielded 6.1 cwt. versus 12.7 cwt./acre for the cultivated control, being significantly different at the 1% probability level. The banded yield was little different from the paraquat blanket application. Yield reduction in the banded rows was probably due to gappiness in establishment and possibly also to incomplete competition removal. The relevant data is reproduced below:

	Control *	Cultivated Control	Paraquat (2 lb./ acre blanket)	Paraquat (2lb./ acre banded)	L. S. D. P=0.01	L. S. D. P=0.05
Rape	0.2	12.7	8.8	6.1	6.40	4.62
Residual sward	16.3	0.6	0.5	6.1	3.33	2.41

* Control - drilled into untreated pasture.

Table I. Band Spraying Versus Other Establishment Methods. (Hammerton and Johnson 1962)

It will be noticed that the significant reduction in residual sward yield that took place with the spraying of 3-4 in. more pasture in the blanket sprayed treatment was accompanied by an insignificant increase in rape yield. This would support the argument that competition removal is more important close to the introduced plant. It will also be noticed that the one third band of residual sward remaining in the banded treatment produced more than one third of the control total.

Kay (1964, 1966) tried band spraying with the introduction of phalaris tuberosa and subterranean clover on to rangelands in California. Bands tried varied from $5\frac{1}{2}$ in. to 11 in., with a 22 in. row spacing. In the earlier work narrow bands were found to be as successful as blanket applications of paraquat. In the later work, wide bands (11 in. versus $5\frac{1}{2}$ in.) were found to be slightly better than narrow ones, but both treatments were not significantly lower in phalaris-clover establishment than the blanket treatment.

Species	Subclover		Phalaris tuberosa	
Sampling date*	April 22, 1964		January 12, 1965	
Grazing treatment	Grazed	Not grazed	Grazed	Not grazed
Paraquat treatment	Per cent stocked+			
Complete coverage	81	87	75	29
11 in. band (50% coverage)	80	86	60	19
$5\frac{1}{2}$ in. band (25% coverage)	74	84	58	12
Check-no spray	48	6	0	0
LSD .05	14	7	17	17
.01	21	11	25	24

* Planted October 25, 1963.

\+ Per cent of samples with at least one plant per foot of row in Phalaris tuberosa and per six-in. of row with subclover.

Table II. Phalaris tuberosa and Subclover Establishment on Band Sprayed Plots (typical results from Kay, 1966).

The figures illustrate the importance of correct post-sowing management in the success of surface sowing practices. Grass was more favourably affected than the clover. Kay (1966) mentioned the cost saving and erosion control afforded by the use of band spraying but he has since concluded (pers.comm) that it is perhaps a form of insurance to spray the entire area.

Shear (1968) mentioned several references concerning the band spraying of maize. In one of these (Lewis and Martin 1967), one third of the area was band sprayed and the unkilled sod was found to compete highly with the corn, especially for water. Triplett et al. (1964) wrote in connection with corn growing in the United States that almost no competition from non crop plants could be tolerated.

Summarised in Table III is the work concluded to date with band spraying. The herbicide used in all cases has been paraquat, which appears to be the only suitable non residual grass killing herbicide available at present.

It would appear that when band spraying and direct drilling has been successful, there has been adequate competition removal in relation to meeting the needs of the other factors, i.e. ensuring a good strike of sown seed, and managing this correctly so that it continues to compete successfully with the resident species. There appears to be no mention in the literature of a possible interaction between paraquat rate and band width.

2.2.4. COMPLICATIONS ARISING FROM THE USE OF "SPRAY-SOW" TECHNIQUES WITH PARAQUAT.

Calderbank (1968) in reviewing the bipyridylium herbicides made reference to work that shows that paraquat is quickly inactivated, in both the plant and soil. Some literature exists in which observations are made of the situation when sowing is close to the time of spraying.

I. Spraying Before or After Drilling.

Evans et al (1964) sprayed one trial either before or after seeding and found that spraying before drilling was better than the latter. It was found that soil disturbed by the drill covered herbage, preventing it from being touched by the paraquat.

II. Residual Herbicide.

Hammerton and Johnson (1962) noted chlorotic rims on cotyledons and chlorotic spots on the true leaves of rape, which appeared to be fairly definitely due to residual paraquat on the herbage. It was postulated that gappiness in the establishment of these plants could be attributed to a lethal dose of paraquat. They observed that this was probably the first time that this effect had been noted in the literature. Hood et al (1964) postulated that their poorer barley and wheat establishment with paraquat may have been due to damage from residual paraquat on the dead herbage.

Author	Band width	Coulter spacing	Paraquat rate*	Varieties sown	Original pasture
Blackmore (1962)	2 in.	7 in.	6 oz.	pasture spp. brassicas, cereals	20 yr. old 45% browntop, 45% ryegrass, 10% white clover
Hammerton & Johnson (1962)	6-7 in.	10 in.	2 lb.	rape	4 yr. old ryegrass/ white clover cut for hay
Kay (1964)	8 in.	22 in.	0.5 lb.	Phalaris tuberosa & sub-clover	Bromus tectorum dominant rangelands
Kay (1966)	5½ in. 11 in. 22 in.	22 in.	0.25 -0.5	"	"
Lewis & Martin (1967)	⅓ of total area		-	maize	average "sod"

* Per acre

Comments:

Blackmore (1962) "shows considerable promise in the successful introduction of desirable species into pastures at comparatively low cost, but there is no proof, however, that the method is superior to recently developed techniques of making wide, plant free tracks mechanically in the turf".

Hammerton and Johnson (1962): "yield of rape on the banded plots was low, probably due to the gappiness of the rape observed on this treatment, but possibly also due to incomplete removal of competition from the sward".

Kay (1964, 1966): Great promise for rangelands too steep for cultivation yet traversable by crawler.

Lewis and Martin (1967): Unkilled pasture competed greatly with crop, especially for water.

Table III. Summary of Published Bandspraying Work.

III. Seed Damage by Paraquat.

Pelleting of seed with bentonite or montmorrilonite to avoid damage by paraquat would be counteracted to some extent by a likely fall in germination because of the lack of oxygen available to the seed. Millier and Sooter (1967) noted this when working with the pelleting of lettuce and other vegetable seeds.

2.2.5. NUTRIENT LOCKUP.

In New Zealand, Blackmore (1957) first mentioned the possibility of nutrient lock up from the chemical killing of herbage. Theoretically, the micro-organisms in the soil break down the dead material, thus depleting the available nutrients and starving the seedlings sown. Nitrogen appears to be the most important. Blackmore (loc. cit.) noted that there was often a boost in growth approximately six weeks after sowing, possibly due to the release of these nutrients.

Indications similar to this have been in evidence in chemical establishment work all over the world particularly on low N status soils (Calderbank 1968). In New Zealand there has not been much quantitative investigation. Three investigations are however worth noting:

Blackmore (1961) studied the release of nutrients from the breakdown of turf on low, medium, and high fertility soils, and the effect of fallowing after spraying on the resulting crop. He concluded that the poorer the natural fertility the greater the fallow and/or fertiliser application needed for success. Later, Blackmore (1967) investigated the establishment of wheat with chemical fallow methods (to allow nutrient mineralisation), and compared this with conventional cultivation techniques. He concluded that seedbed preparation by chemicals led to a significant increase in the yield of wheat over spring cultivation alone, provided clover was suppressed and fertility increased either by preconditioning by chemical means (fallow), or supplying nitrogen to the crop. He also found that conventional cultivation was equal to direct drilling where the former was preceded by a mid-winter treatment of paraquat to precondition the soil.

During et al (1963) studied various intensities of cultivation and the effect on soil nitrate levels. Conventional cultivation was found to significantly affect levels of nitrate in the topsoil and these levels were significantly related to crop yields. In the case of chemically prepared seedbeds, yields were as good in the first year as conventional cultivation but produced inferior crops in the second year. Presumably, in the first year the crops benefitted from the presence of large amounts of decomposing plant residue derived from grass-clover pasture, there being much less of this in the soil during the second year.

With blanket spraying and oversowing, Cross and Robinson (1964) found slow establishment of permanent pasture species on infertile hill country, ascribing this to lack of nitrogen during the period before full decomposition of the killed resident vegetation. In comparison, overdrilling initially produced greater growth but grass growth after a while seemed retarded through lack of nitrogen. Two years after sowing, the oversown pasture was of better quality than the overdrilled although clover levels were similar. Whilst the oversown area was dominant in perennial ryegrass the overdrilled area was dominant in browntop.

In the United States more quantitative work has been recorded. Much of this work relates to stubble mulch practices, where yield reductions are similarly related to unavailability of nutrients from the dead herbage present on the soil surface.

Gamble et al (1952), using a double-cut plough to produce a mulch and a conventional "turn plough" as a comparison, investigated microbiological activity in soil samples. They concluded that under the conditions of their investigation, the following microbiological factors might be related to the plant food "tie up" problems:

(a) The environmental conditions of better oxygen supply and more organic matter in the 0–6 in. horizon seemed to favour the stimulation of the soil fungi in the mulch plots. This group of soil micro-organisms might cause a temporary loss of nitrate nitrogen as a result of protein synthesis by the mould cells.

(b) Biochemical nitrification as determined with the perfusion apparatus of Lees and Quastel showed slightly lower amounts of nitrate nitrogen formed from the mulch than from the turn plough samples. They also thought that soil pH should be considered as an environmental factor having considerable influence on the activity of the soil population. Fungi populations were found to be higher in the mulched plots than those ploughed whereas bacteria were found in similar numbers in both treatments. Moody et al (1952) also investigated the effect of the double cut plough method of mulch tillage on fertility, and measured soil nitrate-N, soluble nutrients in the leaf and other parts of the corn plant, grain yield, and physical properties of the soil. The standard three year rotation of corn, small grain, and clover grass with mulch tillage practice during the corn year was compared with a similar rotation using conventional clean tillage practice. The percentage of N in the corn plant was lower where mulch tillage was used. The differences were significant (5% level) for high yield seasons. P in the plant was not affected by tillage method. Differences in K content of corn plants between tillage methods, although usually large, were inconsistent. In general, soil nitrate N and soluble N-P-K in leaf tissue was lower during the early part of the growing season under mulch tillage. Yields were equal when the planter was modified to push the mulch from the row. They thought that the changes in N status were chiefly due to changes in soil microflora due to the different tillage practices.

2.2.6. DIRECT DRILLING MACHINERY DESIGN.

Band spraying machinery has been described by Blackmore (1962) and Kay (1966) largely in relation to the production of bands rather than drill requirements. There is no reason to suppose that the drill requirements for band spraying are any different from those for direct drilling. According to Baker (1969) it had become increasingly apparent that one of the major and most influential variables in the short-cut seed establishment of direct drilling is the method and machinery used in drilling the seed. He also noted the lack of fundamental data available for the designing of suitable direct drilling machinery. Seed placement, and root and shoot development of seedlings, in relation to the physical properties of the drill slit require particular emphasis in design research. It appears, however, that the use of direct drilling machinery in marginal areas (such as drier soil conditions) is helping in this research (Anon 1969, Baker 1969).

2.2.7. IMPORTANT DEFICIENCIES IN BAND SPRAYING LITERATURE.

Three main categories of knowledge deficiency relating to band spraying exist. These are :

I. Competition and Establishment.

A paucity of knowledge appears to exist with reference to the relation of the level of competition removal to the results achieved in direct drilling and overdrilling techniques. Virtually nothing has been recorded describing the pattern of competition removal and its effect on the subsequent establishment. Kay (1966) has been the only worker to publish investigations into varying band width effects. As his aim was to obtain the best establishment possible he eventually used a blanket spray application for the insurance it afforded (Kay pers. comm).

II. Band Spraying as an Establishment Technique.

To date no discussion has been published concerning the ways in which band spraying could be used. However, trial results suggest that:

(i) In the instances where sown species were of greatest importance (e.g. the growing of maize in pasture, Lewis and Martin 1967), competition from the remaining herbage was such that the risk or actual competition led to the abandonment of the technique.

(ii) Existing species could add to the resulting herbage yield (e.g. in the case of stock feed). The trials of Blackmore (1962) and Hammerton and Johnson (1962) were in this category but they did not mention the concept of a complementary effect between sown and existing species, whilst only the latter pair quoted quantitative results.

III. Drilling Machinery Requirements.

The lack of fundamental design data has been briefly noted.

2.3. MATERIALS AND METHODS.

2.3.1. DESIGN, CONSTRUCTION AND PERFORMANCE OF BAND SPRAYER.

2.3.1.1. BASIC DESIGN REQUIREMENTS OF BAND SPRAYER.

The following four points were considered important in the design of the band sprayer:

I. The band width produced should be constant at any one band width setting regardless of changes in the microtopography of the ground surface.

II. There be means of adjustment so that various widths of band could be sprayed.

III. All bands should be sprayed at the same rate of water per sprayed acre.

IV. The spray nozzle and seed sowing coulter should follow the same path, the coulter being centred to the band produced.

2.3.1.2. DESIGN OF BAND SPRAYER.

The above objectives were achieved in the following manner:

I. Even Band Width.

Band widths could conceivably be produced by several different methods:

(i) By maintaining the spray nozzle at a constant height above the pasture, the resulting band width would depend on the nozzle height and spray angle. This method was used by Blackmore (1962) and Kay (1966). Blackmore (1962) trailed skids just in front of the disc coulters of the drill. These were mounted on a long rod at the front of the drill and swung in a vertical arc to follow the ground countour, whilst springs ensured that contact was maintained on the roughest of surfaces. Kay (1966) used discs with depth bands, and had the nozzle mounted on the disc assembly. The depth bands ensured that the well loaded discs (157 lb. on the 20 in. double discs) worked at an even depth.

(ii) By the use of shields to allow only a certain width of spray to reach the ground. These could be either horizontal or vertical. There are, however, complications: vertical shields lead to spray concentrations at the edge of the band and horizontal shields need some means of drainage as the liquid must not be allowed on other then the sprayed area. This method was discarded as likely to be more complicated and troublesome than the use of a nozzle mounted on a disc or trailed skid.

The drill used was a Connor Shea disc drill that could be modified for direct drilling work by tipping the discs so that they were practically vertical (negative tilt angle approx. 5°) when in contact with the soil (Plate 1).

Plate 1. Bandsprayer and Drill in Operation.

These discs did not have depth bands and so a trailed skid was considered a more reliable mount for the nozzle to enable a constant band width to be kept. It was known that ground conditions in the trial area were smooth, and thus it was decided that weighting springs on the trailed skids would be unnecessary especially as the operating speed would be low.

II. Production of Different Band Widths.

As method (i) (above) was chosen for the production of even bands, band widths were altered by changing the nozzle mounting heights.

III. Maintenance of Spraying Rate.

So that rates (gallons of spray mixture per acre of area sprayed) could be maintained at the same level, nozzles were changed when nozzle heights were changed. Higher output nozzles were therefore used for the wider bands.

IV. Maintenance of Same Relative Positions of Nozzle and Coulter.

The placement of the trailed skids on a rod in front of the coulters enabled adjustment so that the coulters did in fact trail behind the skids. The coulters tended to move sideways upon placement in the soil but this amount remained constant under the conditions of use, so that initial adjustment sideways of the skid was adequate for correction. There were three reasons why the bands were sprayed before the seed drilled:

(i) Paraquat may affect the germination of seed (Blackmore, pers. comm. 1967) and any spray carried down the drill slit to the seed could lower germination. Therefore it was considered safer to spray before the slit was opened up.

(ii) Disturbed soil from the coulter is likely to cover and thus protect some pasture from the spray.

(iii) It was easier to mount a bar at the front rather than back of the drill, and possible to mount the nozzles closer to the discs when mounted in front of them.

2.3.1.3. DESCRIPTION OF THE BAND SPRAYER.

I. Skids and Mountings.

A 9/16 in. steel rod was mounted across the front of the drill on to a bracket at each end. The skids were made out of 5/16 in. steel rod, illustrated in Plates 2 and 3.

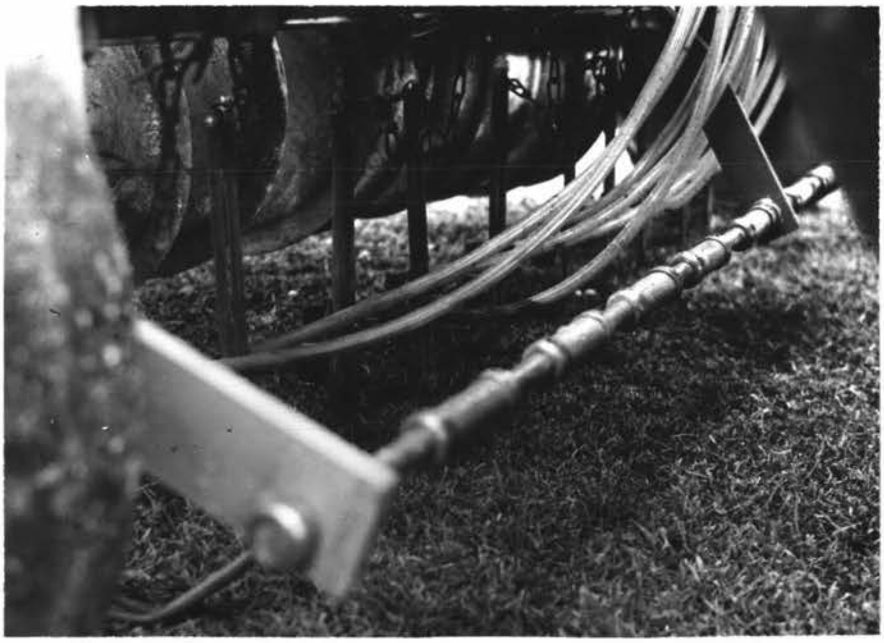


Plate 2. Details of Bandsprayer Construction.
(i) Showing skid mounting rod with skids and collars, spray supply tubes, nozzle mounts, movement limit chains and proximity of skids to disc coulters.

The shape of the skid was such that the short mid section trailed on the ground, with the vertical part allowing for vertical nozzle adjustment. Nozzles were mounted on galvanised steel sheet brackets, attached to the skid by a $\frac{1}{4}$ in. bolt, washer and wing nut. They were screwed on to a plastic "Delevan" nozzle mount which was clamped by the nozzle mount lock washer to a "U" shaped slot in the galvanized steel sheet bracket. The skids were located laterally on the 9/16 in. rod by screwed collars.

Adjustment of the nozzle was thus possible vertically and laterally, and the trailing of the skid on the ground ensured that nozzle height was maintained relatively constantly.

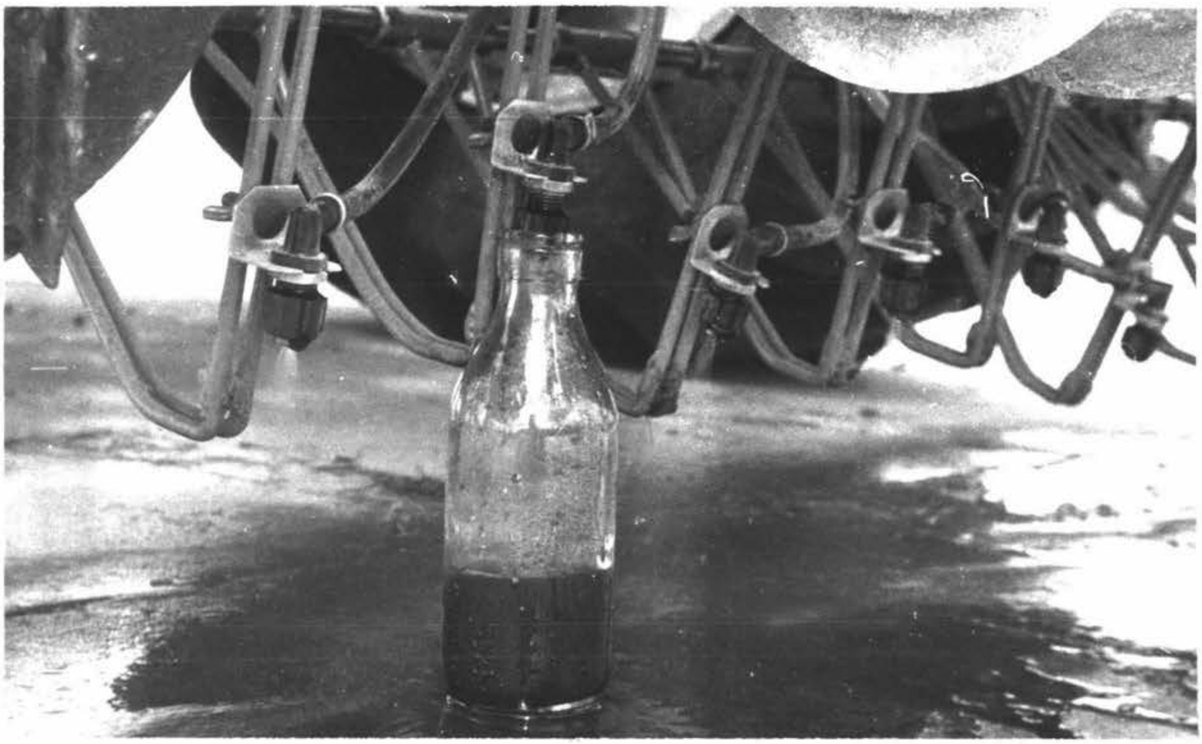


Plate 3. Details of Bandsprayer Construction.
(ii) Showing skids, nozzle mounts, and nozzle output timing operation.

II. "Nozzle Supply" Equipment.

The equipment that supplied spray under pressure to the nozzles was similar to that of a conventional boom sprayer. The power take off mounted pump ("Relnown") was supplied by a $\frac{3}{4}$ in. plastic hose and pumped through a $\frac{1}{2}$ in. hose to a "Sprayrite" pressure regulator and a 0-30 p.s.i. reading gauge. A $\frac{1}{2}$ in. hose led from the pressure regulator to the "distributor" and another acted as a return hose to the drums. As the drill was tractor mounted, the supply drums were attached by brackets to the front of the tractor. The three rates of chemical used necessitated the use of three 12 gallon drums (Plate 4).

Plate 4. Bandsprayer-Direct Drilling Rig.

The distributor was constructed of brass pipe, $1\frac{1}{4}$ in. in diameter and $8\frac{1}{2}$ in. long, on to which was silver soldered ten $\frac{1}{4}$ in. diameter nipples. From these nipples, $\frac{1}{4}$ in. polythene tube was connected to the Delevan nozzle mounts.

2.3.1.4. NOZZLE SELECTION PROCEDURE.

Three factors were considered in nozzle selection procedure:

I. Band Width.

Band widths were set at 1 in., 2 in., $3\frac{1}{2}$ in. and 6 in., the first three of which were to be sprayed by the band sprayer (refer to Section 2.3.2.3. for the reasons behind the selection of these bands).

II. Spraying Rate.

In the trial, the recommended rate of application of 20-30 gallons of water per acre with gramoxone was followed and the application rates of chemical were 1, 2 and 4 oz. a.i./acre.

III. Spray Distribution Within the Band.

The within band distribution requirement was that it should be even in rate laterally with sharply cut off edges.

The first two factors may be considered interrelated with rigidly set limits, with the third as a qualifying limit on any proposed way of producing a band.

For convenience of design, construction, and operation of the band sprayer, the variables leading to different band widths and spray rates were investigated, with the aim of holding as many as possible constant. The variables affecting band width and spraying rate are as follow:

(i) Forward speed of sprayer.

(ii) Nozzle characteristics.

(iii) Pressure.

(iv) Nozzle height.

(v) Concentration of the spray mixture.

These variables are also interrelated: for instance, nozzle characteristics determine the effect that pressure has on the resulting nozzle spray angle and output, the first affecting the band width, the second the spraying rate (all other variables remaining constant).

From the outset, the forward speed of the sprayer was fixed as speed could possibly have an effect on the performance of the drill. For convenience and economy it was hoped to keep the number of mixtures sprayed to a minimum. When the operating pressure of a nozzle is altered the change in rate is roughly proportional to the square root of the change in pressure. This meant that pressure alteration alone would not allow the adjustment of spraying rates sufficiently for the spray rate changes required. Thus three mixtures were the minimum possible, i.e. one for each paraquat rate.

Seven different nozzle sizes were selected by reference to the performance data given in manufacturers' catalogues, and modified by the availability of nozzles. As a result, all were of the hollow cone type. Fan nozzles specially designed for band spraying (in row crop work) were available, but this was not known at the time. Initial work was with Delevan FS 2.5 fan nozzles, from which the procedure was worked out, and were used in the initial band spraying pilot trial. The performance characteristics (such as spray angle versus pressure, and rate versus pressure) were fixed for any nozzle; thus final selection was done with the remaining two variables, nozzle height and pressure. Graphical results were required of the effect of various pressures on band width at different nozzle heights and the effect on spraying rate performance so that intermediate values could be easily calculated. These were achieved in the following manner.

Initially, output per nozzle at different pressures was measured by taking the time the nozzle took to fill a pint milk bottle (Plate 3). Two or three nozzles of each size were tested -

Appendix I incorporates a table of results for the three nozzles eventually used. The nozzles were then set at different heights on the nozzle mount skids and the band sprayer run over newsprint at different pressures, spraying methylene blue (Plate 5) or Rhodamine BN450 (a red dye) solution. Bands were reasonably well defined, with widths varying up to ½ in., but usually about 0.2 - 0.3 in. The average width was taken at the lower pressures (7, 10 and sometimes 15 p.s.i.), but coverage was not as good as with the higher pressures. Graphs drawn up from the results of these tests enabled the selection of the three nozzles used (Figs. 1, 2 and 3 illustrate the results of the Monarch 4.6 H C nozzle used for the 2 in. band). It was possible to spray the two narrow bands at 20 p.s.i. but with the 3½ in. band it was necessary to spray at 25 p.s.i..

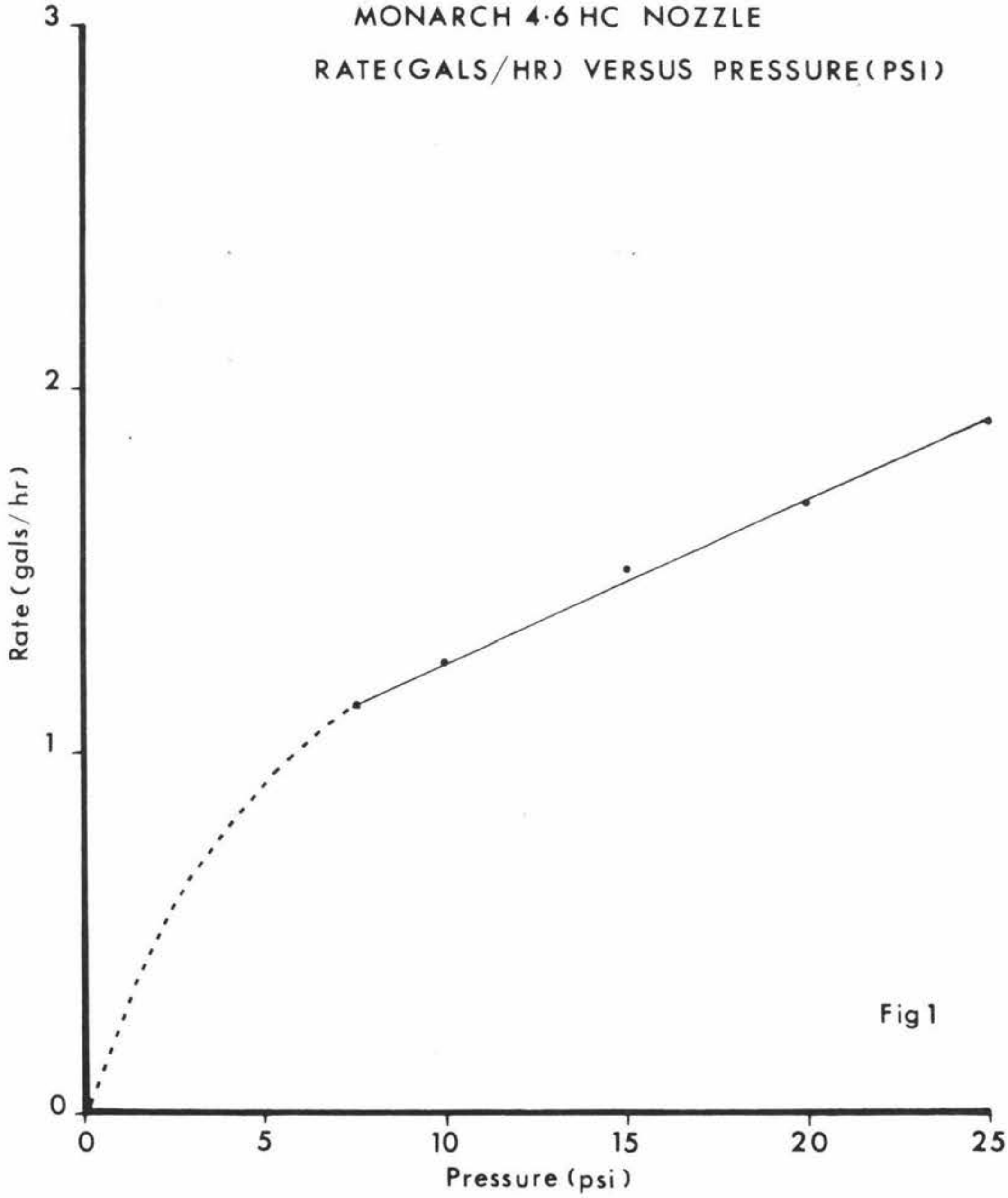
The nozzles selected and other relevant data for the production of the bands were as follow:

Band width (in.)	Nozzle	Nozzle height (in.)	Ford 4000 engine r.p.m.	Pressure (p.s.i.)	Gear	Speed m.p.h.
1	*S.S. ¼Y 1.5	1-7/16	1000	20	7th	2.6
2	Monarch 4.6 HC	1-7/32	1000	20	7th	2.6
3½	Monarch 6.4 HC	1-7/8	1500	25	5th	2.7

*Spraying Systems

Table IV. Details of Band Production.

Difficulty was experienced with the nozzle angle variation of the 1 in. band nozzles. Nozzles were thus set at two different heights (1-7/16 and 1-7/32 in.). The application rate used was 30 gal./acre (this figure appeared to fit better than a lower one for the nozzles and pressures used).


MONARCH 4·6 HC NOZZLE
RATE(GALS/HR) VERSUS PRESSURE(PSI)
Rate (gals/hr)
3
2
1
0
0
5
10
15
20
25
Pressure (psi)
Fig 1

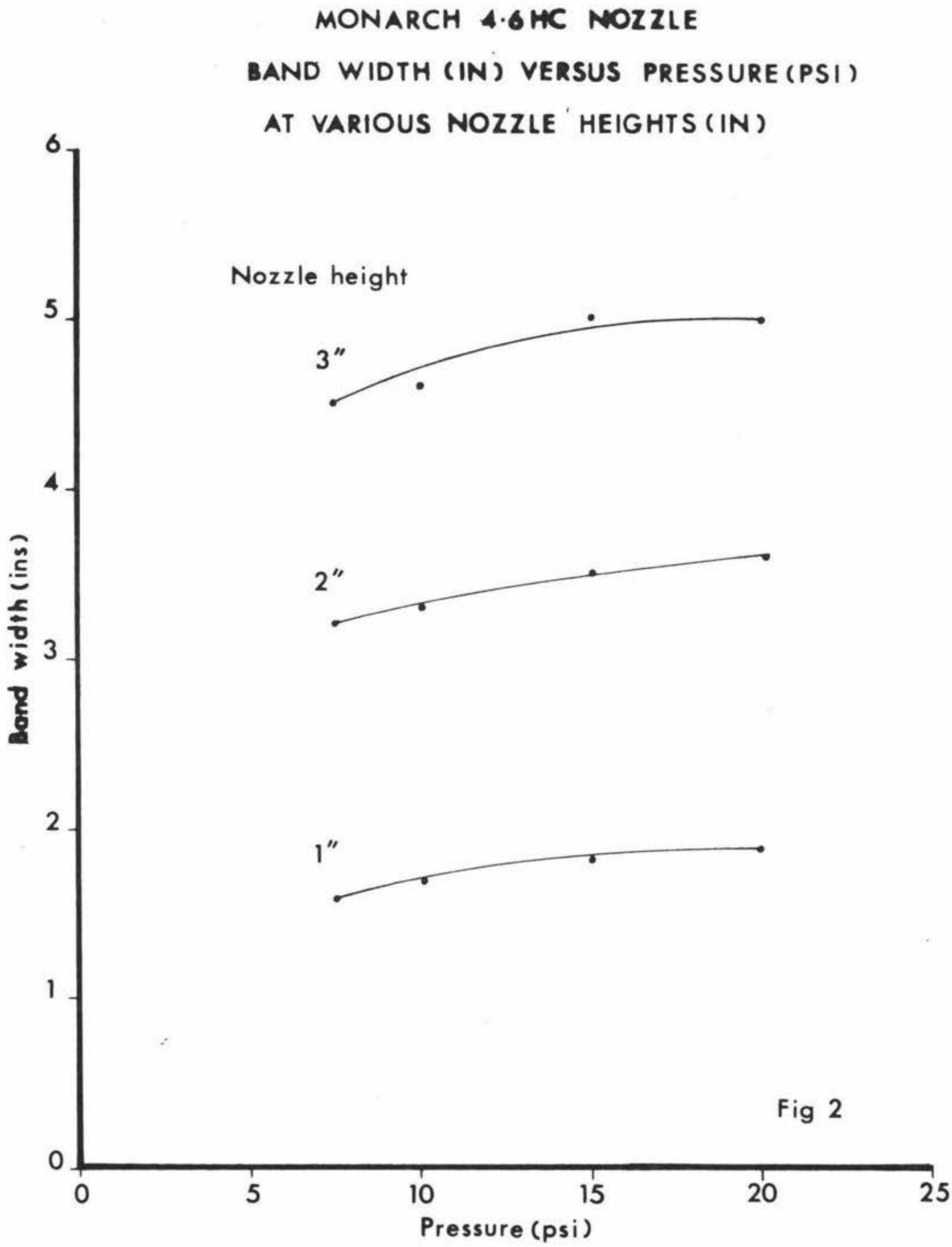
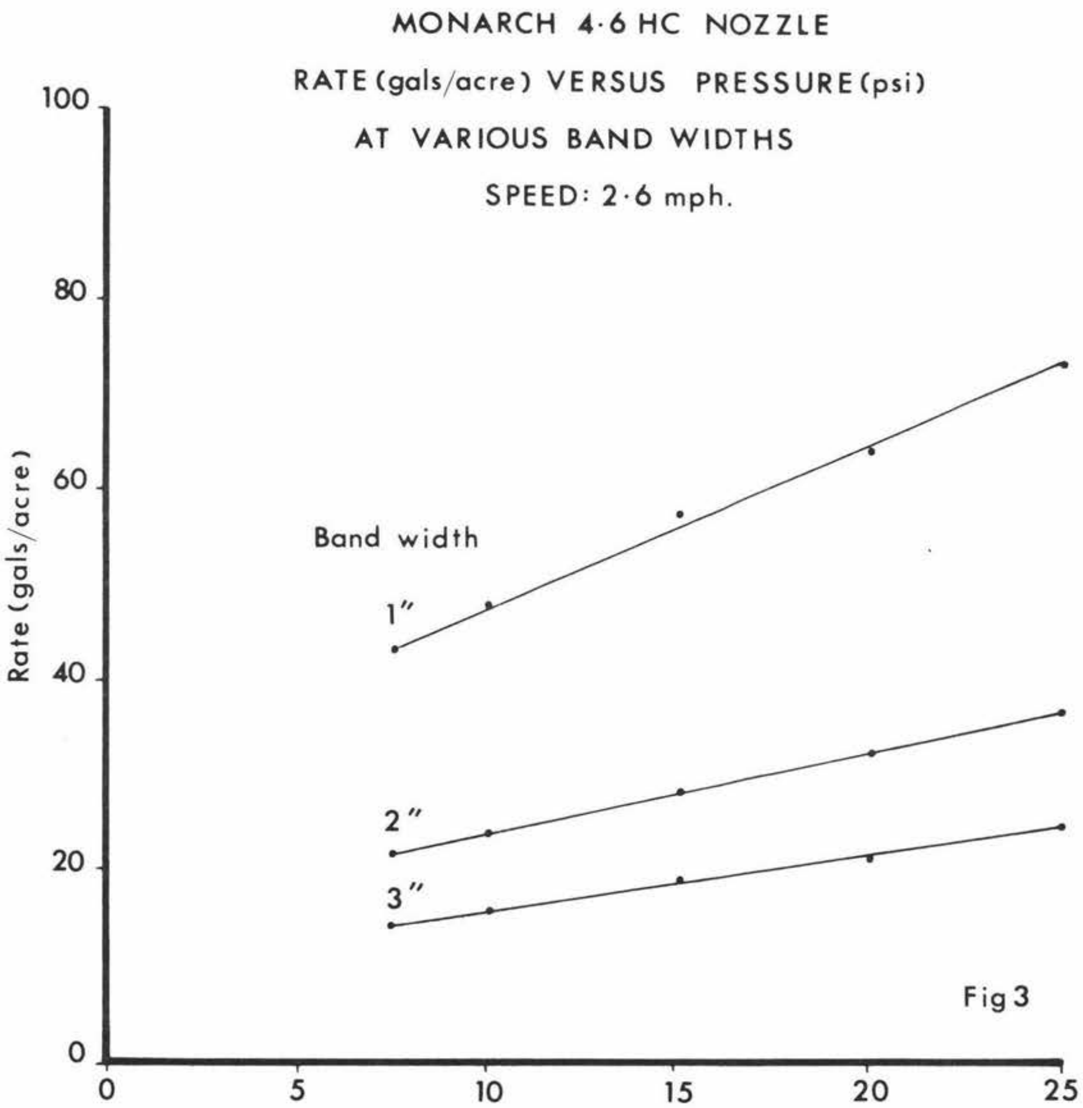

MONARCH 4·6HC NOZZLE
BAND WIDTH (IN) VERSUS PRESSURE (PSI)
AT VARIOUS NOZZLE HEIGHTS (IN)
Nozzle height
3"
2"
1"
Band width (ins)
Pressure (psi)
0
1
2
3
4
5
6
0
5
10
15
20
25

Fig 2


MONARCH 4·6 HC NOZZLE
RATE (gals/acre) VERSUS PRESSURE (psi)
AT VARIOUS BAND WIDTHS
SPEED: 2·6 mph.
Rate (gals/acre)
100
80
60
40
20
0
Band width
1"
2"
3"
Fig 3
0
5
10
15
20
25
Pressure (psi)

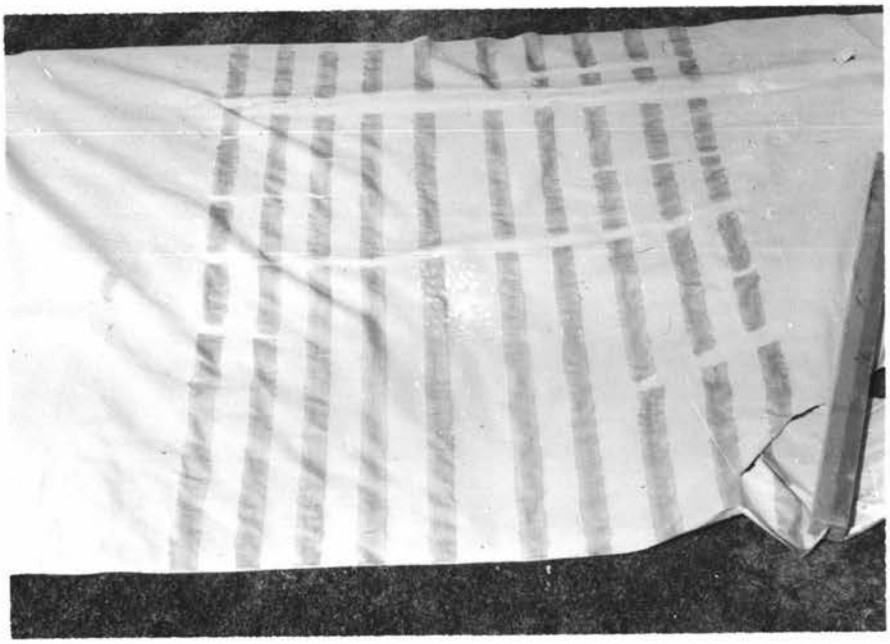


Plate 5. Resulting Bands from Bandspraying on Newsprint.

2.3.1.5. BAND SPRAYER ADJUSTMENTS.

The band sprayer was adjusted with the aid of two pilot trials.

I. Pilot Trial No. 1.

This trial was carried out to ascertain whether bentonite coating of the seed used in the main trial (to protect it against paraquat damage) would be worthwhile, to check that bands sprayed on pasture were as well defined as those on newsprint, and to assist the correct positioning of the skids in relation to the coulters (refer to Appendix II for further details of this trial).

Conclusions from the first pilot trial:

The germination results showed that if there had been any gain from the use of bentonite coating in protecting seed from paraquat, this was well offset by the lowering of germination due to the coat. The germination of uncoated seed was about double that of coated seed. The bands produced (sprayed on short pasture) were found to be of similar variability to those on newsprint (i.e. up to $\frac{1}{2}$ in. but usually $\frac{1}{4}$ in.). Measurements were taken of the position of the drill coulter slit in relation to the band and the nozzle mounting skids were adjusted accordingly.

II. Pilot Trial No. 2.

After the first pilot trial, a second trial was considered necessary for the following reasons:

(a) To drill in more ideal soil conditions, i.e. at a higher soil moisture than in the first trial to allow better penetration of the discs and therefore better seed placement.

(b) To test the possibility of keeping all nozzles at the one height for the different band widths. A height of 1-3/16 in. was chosen. Three of each of the three nozzle sizes were used.

(c) To see whether it was possible to produce a 1 in. band.

(d) To see whether the coulter would follow the nozzle accurately enough for it to keep in the middle of the band (especially with the narrower bands).

(e) To spray at 1 pt./acre and compare the kill with the 2 pt./acre sprayed in the first trial (refer to Appendix II for further details).

Conclusions from the second pilot trial:

(a) Given suitable soil conditions and disc drill performed adequately with regard to penetration. Steps were taken in the main trial to ensure that the soil was sufficiently moist for this.

(b) The resulting bands were not of the widths required and so it was decided, as previously noted in Table IV, to set the nozzles at different heights. A gauge was constructed to enable height adjustments (for the different band widths) to be made quickly in the field.

(c) It was found that satisfactory bands of 1 in. width could be produced.

(d) There was some movement of the coulter from side to side that was not followed by the nozzle, but as more even ground was to be used in later work this was not felt to be excessive.

(e) Kill was satisfactory with 1 pt. of paraquat per acre.

After this work was completed, the band sprayer was considered ready for use in later trial work.

2.3.2. MAIN FIELD TRIAL.

2.3.2.1. SITE.

The site chosen was on the Massey University Terrace sheep farm. It was located in paddock 15, on slightly sloping ground with a north-easterly aspect. A pine hedge on the south-western side was separated from the plot by a road. This hedge tended to shade the plot during the late afternoon, provide shelter from westerly winds, and partially litter Block A with needles.

Soil type was Tokomaru silt loam which is prone to pan formation and poor drainage. The area, known for its wetness in winter, was also poorly drained, having been last tiled about 20-25 years ago.

Pasture was the main criteria in site selection. An adequate clover-ryegrass balance was present in the site selected. The aim was to try and improve the winter production of a good pasture - the reasoning being that if the pasture was not a good one, then other more permanent improvements should be undertaken first. the botanical analysis at the start of the trial was, in summary : clover 14%, ryegrass 42%, other grasses 38%, weeds 6% (refer to Appendix III for further details).

2.3.2.2. SITE PREPARATION.

Between February 21-24 the site was fenced off, mown with a forage harvester to bring the pasture to a common base height, and plots were marked out. Rainfall was low in the early part of 1968 (Appendix IV) and thus the plots were irrigated at intervals until March 8. Three 50 ft. perforated hoses were used. Because of the sheep farm daytime water demands most of this irrigation was accomplished during the nights of March 1-8. Total water application amountedto approximately $1\frac{1}{2}$ in. This enabled the blocks to grow luxuriantly and the soil moisture content to increase and ensure good penetration of the drill.

Soil moisture on March 15, on a dry weight basis, was 30.7%, compared with 17.7% in the non-irrigated area (refer to Appendix V for further details). Mowing was carried out on February 29 with a "Gravelly" mower and on March 4 with a rotary lawn mower. The drilling date was postponed several days to allow further irrigation (it was hoped that rain would fall earlier) and to enable its effects to become apparent. It was perhaps unfortunate that the plots were not mown again before spraying, as the pasture started growing rapidly by March 8 and was possibly too long at the time of drilling (March 13 and 14).

2.3.2.3. TRIAL DESIGN.

I. Trial Design Factors.

The following factors were chosen for investigation:

(i) Band Width. It was estimated that four widths would be adequate to cover the range. Coulter spacing on the drill was 6 in.: thus a blanket application to enable comparisons with normal direct drilling practice would represent the widest (i.e. 6 in.) band. The width of band chosen by Blackmore (1962) of 2 in. was also used, with a narrower one (1 in.) and wider ($3\frac{1}{2}$ in.). This latter band width was chosen in preference to 3 in. as it was closer to the middle of the 2-6 in. range.

(ii) Spraying Rates. Prior to the initiation of the trial the I.C.I. Research team had achieved some success in pasture renovation using low rates of paraquat application (Williams 1967). Of interest also, was the question of a possible interaction between paraquat rate and band width and how the same amount of paraquat applied in different ways (e.g. light rate, wide band versus heavy rate, narrow band) would affect results. Rates chosen therefore were 1, 2 and 4 oz. a.i.*/acre ($\frac{1}{4}$, $\frac{1}{2}$ and 1 pt./acre of the liquid). The above two factors allowed 12 (i.e. 4 x 3) competition suppression treatments, both arealy and in intensity.

(iii) Varieties. "Grasslands Tama" Western Wolths Ryegrass (subsequently referred to as "Tama ryegrass" or "Tama") and ryecorn (a cereal) were chosen mainly because of the successful experience of Barclay and Vartha (1966). Sowing rates were 30 lb./acre for Tama ryegrass and 150 lb./acre for ryecorn.

(iv) Nitrogen. The bulk of literature suggesting that nitrogen deficiency was a factor of importance in pasture or crop establishment where herbicides were used close to the time of sowing led to its consideration in the trial. It was incorporated as a sub-plot effect, 1 cwt. nitrolime being sown with half of the seed.

(v) Fertiliser. Two cwt. of serpentine super was sown with the seed on all plots that were drilled, and broadcast on the undrilled plots.

II. Layout.

(i) Replication. Past experience suggested the minimum requirement of four replications, and the limitations imposed by the treatment number actually resulted in four being used.

(ii) Plot Number. With 4 replications (subsequently referred to as blocks), 4 band widths, 3 spraying rates, 2 varieties, and 2 nitrogen levels, 192 plots plus "controls" were necessary.

* active ingredient

In order to save some space the nitrogen level was incorporated as a split or sub-plot effect. Control plots were of three types:

A. No drilling or spraying.

B. No spraying, but drilled with ryecorn.

C. No spraying, but drilled with Tama ryegrass.

Each of these was split with the nitrogen sub-treatment. The resulting sub-plot number was 224.

(iii) Plot Size. Plot size was determined by drill width and sampling area, whilst economical area use was considered. The resulting design is shown in Fig. 4. The 25 ft. headland was to enable easy manouvering of the tractor (Ford 4000). Ten feet was considered adequate at the ends of the plot for the tractor to pass from one headland to the next. The drill width of 5 ft. and the wheel tracking of the tractor used made a 6 ft. wide plot ideal. W hen the plots were band sprayed and drilled, the tractor moved from the headland towards the centre of the plot. Wheel mark areas were common for adjacent plots. The subplot division in the middle of the plot gave an "a" and "b" area to each plot (see Fig. 4). A subplot length of 15 ft. was considered suitable.

(iv) Randomisation of Plots. Plots were randomised with blocks by drawing from a hat, whilst subplot ends were randomised by tossing a coin. The resulting treatment plan is shown in Table V.

2.3.2.4. TRIAL EXECUTION.

On March 12, "6 in." band plots were sprayed with a knapsack sprayer. All plots were drilled and other bands sprayed during the following two days. Plots were drilled in a predetermined order to reduce adjustments and nozzle changes to a minimum. The Ford 4000 tractor (Plate 5) had a "select-o-speed" transmission and this was used advantageously on a speed control basis. The plot was approached at right angles along the far side of the headland and turning accomplished at the specific moment to ensure the correct directional approach to the plot. The drill-band sprayer was placed on the ground, seed and fertilser chutes checked for correct positioning, power take-off engaged and the pressure brought up to the operating level. The assembly was then moved forward at correct speed until it reached the border of the opposite subplot and then stopped. The p.t.o. was disengaged, spray valve turned off, the drill lifted and nozzles allowed to stop dribbling. The tractor was then driven off across the opposite subplot (i.e. the tractor continued forwards). After the four subplots of one treatment were sprayed, the concentration was changed for the following four. After another of these changes, the nozzles would be changed and heights adjusted.

MAIN BANDSPRAYING TRIAL LAYOUT

MASSEY 'TERRACE' FARM
Paddock No 15.

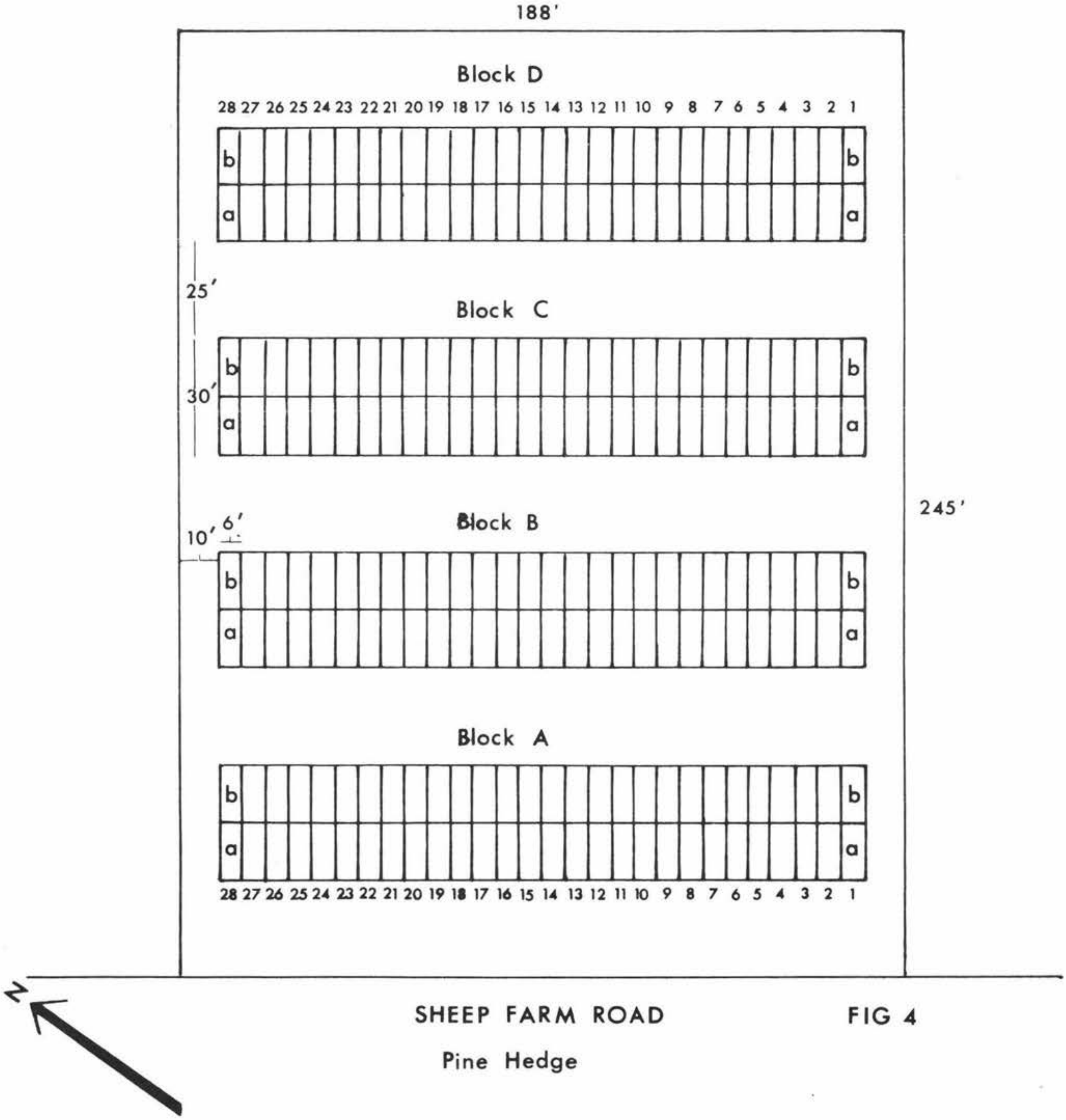


FIG 4

Plot No.	Block A a*	b	B a	b	C a	b	D a	b
1	43½T1	43½T0	16R1	16R0	11R1	11R0	22T0	22T1
2	43½R1	43½R0	41R1	41R0	13½T0	13½T1	46T0	46T1
3	23½T0	23½T1	43½T0	43½T1	46R0	46R1	46R0	46R1
4	12T1	12T0	23½R1	23½R0	16R1	16R0	0001	0000
5	26R0	26R1	46R1	46R0	11T1	11T0	00T1	00T0
6	00R0	00R1	42T0	42T1	12R1	12R0	22R1	22R0
7	0001	0000	22T0	22T1	41T1	41T0	23½R1	23½R0
8	26T0	26T1	11R0	11R1	43½R1	43½R0	11R0	11R1
9	13½R0	13½R1	00T0	00T1	26T1	26T0	43½R0	43½R1
10	42R0	42R1	26T0	26T1	13½R1	13½R0	42T1	42T0
11	22R1	22R0	16T0	16T1	23½T1	23½T0	21T0	21T1
12	46R0	46R1	0001	0000	43½T0	43½T1	00R0	00R1
13	11T0	11T1	26R0	26R1	23½R1	23½R0	16T0	16T1
14	16R1	16R0	42R1	42R0	0001	0000	26T1	26T0
15	16T1	16T0	12R1	12R0	42T0	42T1	43½T1	43½T0
16	46T1	46T0	0000	0001	26R1	26R0	13½T1	13½T0
17	42T0	42T1	23½T1	23½T0	0001	0000	41R1	41R0
18	41R1	41R0	00R0	00R1	21T0	21T1	26R0	26R1
19	11R1	11R0	12T1	12T0	42R0	12T1	23½T0	23½T1
20	0000	0001	46T0	46T1	12T0	42R1	16R1	16R0
21	22T1	22T0	21T0	21T1	46T1	46T0	0001	0000
22	41T1	41T0	41T0	41T1	41R1	41R0	12R1	12R0
23	21R0	21R1	22R1	22R0	00T0	00T1	13½R1	13½R0
24	23½R0	23½R1	13½R1	13½R0	21R0	21R1	42R0	42R1
25	00T0	00T1	43½R0	43½R1	22R0	22R1	11T0	11T1
26	13½T0	13½T1	13½T1	13½T0	00R1	00R0	41T0	41T1
27	21T1	21T0	21R0	21R1	22T0	22T1	21R1	21R0
28	12R0	12R1	11T1	11T0	16T1	16T0	12T1	12T0

* Plot end or subplot

Key: 1st figure - paraquat rate, oz. a.i./acre
2nd figure - band widths, in.
1st letter - variety T = "Grasslands Tama" Tetraploid Western Wolths ryegrass
R = ryecorn
3rd figure = 0 = no nitrogen applied with seed
1 = 1 cwt./acre nitrolime applied with seed

Table V. Layout of Treatments in Main Trial.

In summary, the order of operation was :

March 13 morning: Tama ryegrass seed, No (i.e. no nitrolime sown with seed)

(a) All sown-not-sprayed and blanket application plots

(b) $3\frac{1}{2}$ in. band, 1 oz. a.i./acre
2 oz. a.i./acre
4 oz. a.i./acre

(c) 2 in. band, 4 oz. a.i./acre
2 oz. a.i./acre
1 oz. a.i./acre

(d) 1 in. band, 1 oz. a.i./acre
2 oz. a.i./acre
4 oz. a.i./acre

March 13 afternoon: Ryecorn and No with a reversed order.

Operational details for March 14 were the same as for March 13, but in reverse order and with nitrolime added. In this way adjustments were minimised. All seed was drilled with serpentine super; the nitrolime was also mixed with the super and the sowing rate increased accordingly.

Concentration changes were achieved by a rapid change of the inlet hose from one drum to another. The return hose left in the initial concentration eventually ran white due to the air entering the inlet pipe in the change over. It was then allowed to run on to the ground until clear when it was placed in the next concentration. Seed was changed by sucking the seed box out with a vacuum cleaner driven off a petrol motor-generator set.

2.3.2.5. MEASUREMENTS.

The large number of plots considerably limited the measurements possible. Those taken were:

I. Soil Moisture Samples.

These were taken with a 1 in. core sampler to a depth of 4 in., the top $\frac{1}{2}$ in. being discarded. The remainder was weighed and dried in an oven (110°C.) for 24 hours before re-weighing. Soil moisture was expressed as a percentage of the dry weight. Random samples on the plots and headland were taken on five occasions throughout the trial period.

II. Botanical Composition of the Original Pasture Used.

A five wire vertical point frame was used to assess the composition of the pasture at the start of the trial. This was . carried out on March 18 on unsprayed plots. Ten positions were used per plot, 2 plots per block, giving a total of 400 points. Classification consisted of "clover", "ryegrass", "browntop", "Yorkshire fog", "cocksfoot", "poa species" and "weeds". Summarised results are to be found in Appendix III.

III. Seedling Counts.

Seedling counts were taken essentially to check on plant establishment. These were done on two occasions, March 21 (approx. 1 week post sowing) and April 1 ($2\frac{1}{2}$ weeks after sowing). The sampling "area" chosen was 24 in. of row, 4 per subplot, 10 subplots per block (at random), and repeated on each block for each variety. The Connor Shea drill has the concave surfaces of the discs facing out from the centre, five each side of the centre line. In the operation of the drill, the resulting flap tended to face in either a westerly or easterly direction (Fig. 5). Two of the four seedling count samples per subplot were taken from east and west facing plots to test whether this was a significant factor in the establishment of the plants. Presumably the "east" slot would have the sun shining more directly down it drying out the soil. At the second count when the plots were drying out from the edge, half the samples were taken from the edge and half from the middle of the plots.

IV. Dry matter Production.

Dry matter production cuts were taken on different occasions: April 18 - May 1 (5 to 7 weeks after sowing); May 28 - June 5 (11 weeks); August 6 (21 weeks); and September 16 (27 weeks). Pasture height at the time of cutting was 6-8 in. The sampling area was initially two 10 ft. by $1\frac{1}{2}$ ft. areas from each subplot. Before sampling, the blocks were trimmed to leave a 10 ft. strip over each

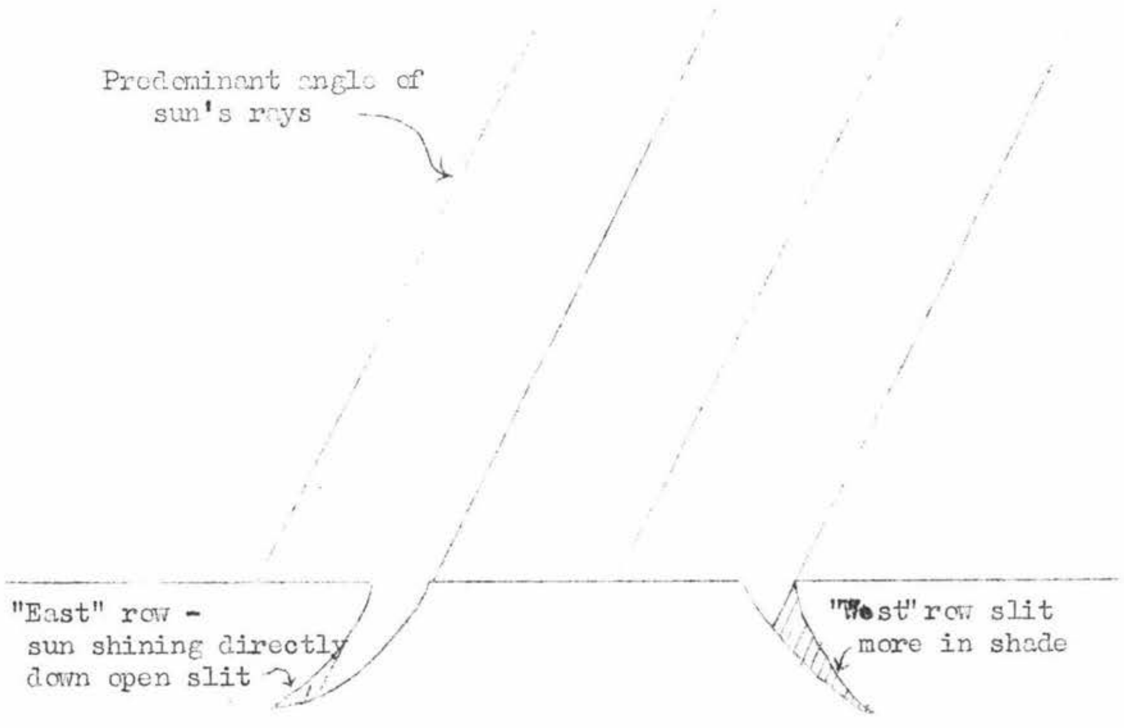


Fig. 5. Diagram of "Row Orientation" Effect.
(Effect exaggerated)

row of subplots. On each subplot a mower was run to cut and catch the herbage grown in an 18 in. strip (modified "Allen" sickle bar mower, later rotary lawn mower). This included 3 rows of the sown specie and 3 in. to either side of the outer row (Plate 14). Rows sampled were numbers 2-4 and 7-9. Rows 1 and 10 were sown into ground that had in total 4 passes of the tractor front and rear tyres. Rows 5 and 6 were planted closer together than the rest. There tended to be two banks of 5 rows, spaced at 6 in., with a 4-5 in. gap in the middle. This was due to the side thrust on the discs tending to bring them all toward the centre when operating.

Samples, when cut, were weighed on the spot and sub-sampled for dry matter determination. This was accomplished by weighing a 100-200 gm. sample wet, drying at 80°C. in an oven overnight, and re-weighing, using the resulting dry matter percentage to calculate the dry weight of the green field sample. From a knowledge of the area sampled, dry matter production/acre could be established. Plots were mown off after sampling to 1-2 in. in height.

The bulk of material handled and the need for fine weather when sampling (mowers choked otherwise) led to the abandonment of this technique after the second cut. In the last two cuts a 2 x 1 ft. quadrat and handshears were used. Two samples were taken per plot. The quadrat was placed parallel to the row, and thus a 2 ft. length of two rows were taken in each sample. The material was bagged and weighed green in the field laboratory. Sub-samples were taken for botanical analysis and dry matter analysis. The plots were grazed by sheep on June 9 and August 7 for a couple of days each time to remove excess herbage from the headlands.

V. Botanical Composition of the Cut Herbage.

Difficulty was encountered with this measurement and the method varied over the period. At the first cut a 1 sq. ft. quadrat was taken from each sub-plot, bulked over the plots and in many cases over blocks. This was largely due to the difficulty of sorting the young Tama ryegrass leaves from perennial ryegrass. Due to the load of work at this period, not all plots were sampled and a more practical method was sought.

At the second cut, the method used was one of cutting out 20 in. of row in an area not mown for the dry matter production cut. The dry weight of these samples was converted to dry matter/acre relatively easily because of the 6 in. row spacing. By the third and fourth cuts the ryecorn had virtually disappeared from the sward and the Tama ryegrass could be readily distinguished from the other ryegrasses, so they were sub-sampled from the dry matter production cuts.

In all cases the sown species were sorted from the rest of the material, which was discarded. The aim of the botanical analyses was to estimate the proportion of the production due to the introduced species.

VI. Photography.

Photographs were taken at intervals to enable a visual comparison of treatments and to record the "fading" of the bands. Many of these were coloured slides, some from which coloured prints have been made for inclusion in this thesis. Unfortunately, the colour reversal process used in the printing from these transparencies has led to some colour change in the prints (for instance, the "dead" bands were in fact much more yellow in the slide).

2.4. RESULTS.

2.4.1. PERFORMANCE OF BAND SPRAYER.

I. Faults and Improvements.

Generally, the band sprayer performed adequately. The worn pump was difficult to prime, but once running was satisfactory. Difficulty was also experienced as a result of the distance between the quick-action shutoff valve and nozzles. The pressure in the system was released by the nozzle dribbling after the valve had been turned off, causing the "dead" patches between the sub-plots. Care had to be taken when placing the 3-pt. linkage drill on the ground to ensure that the band sprayer skids were not damaged by weight placed upon them when unable to move clear. The movement limiting chains were slightly short. In future work a better pump would be used and the skid movement limit chains shortened. The centering of the nozzles to coulters was adequate in this trial, but penetration was no problem, speed was slow, and ground surface smooth. A more versatile machine might require skids individually mounted on each coulter to ensure the centering of bands and drill slot.

II. The Resulting Bands.

Immediately prior to spraying the pasture condition was fast growing, light green in colour and with no apparent moisture stress. Although the plots had been mown 5 and 6 days prior to spraying, growth was noticeable 3 days after mowing. Several reasons may be advanced for the sprayed bands being narrower than expected. At the time of spraying the pasture was 2-2½ in. high and the nozzles may have been mounted lower than their correct height. The latter was suspected as the nozzles of the last bands sprayed (3½ in.) were slightly low when the sprayer was dismantled. Setting of the nozzle heights in the field was not as satisfactory as it might have been. A gauge was used to measure the space between the outlet of the nozzle and the bottom of the skid and at times there was difficulty in assuring that the gauge was parallel to the bottom of the skid.

Plates 6 and 11 show typical resulting bands.

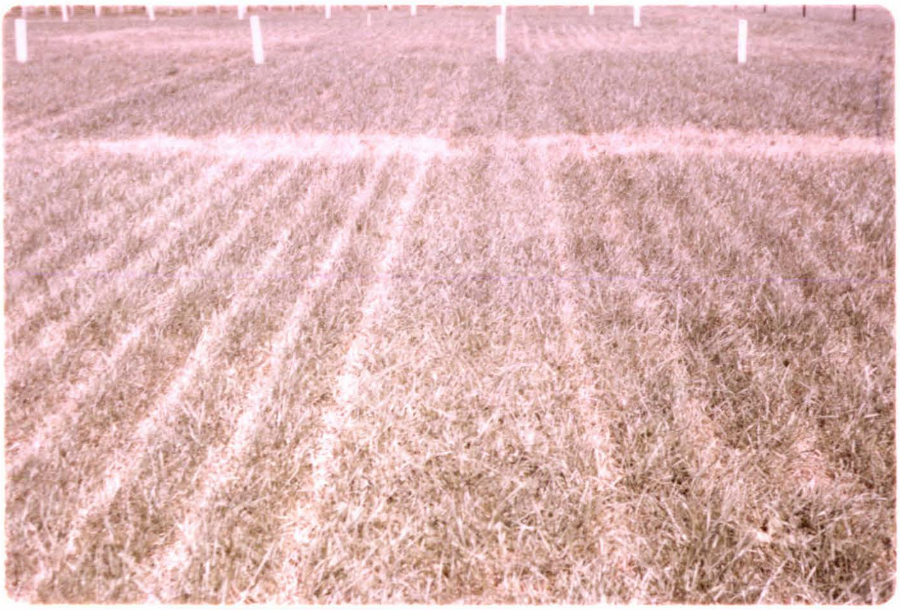


Plate 6. One in. Bands: 1 oz. a.i./acre on the left,
2 oz. a.i./acre on the right.
(Taken March 16, 1968)

The higher rates appeared to produce better bands than the light rates although this was not so evident in later production results. In the blanket treatments there was some unevenness and the kill poor at the lowest spray rate. The edges of the band were rather indistinct, and this was investigated further in the latter part of the thesis. In comparison with the bands initially produced in the pilot trials, the height of pasture was considered too great for really distinct bands. Moisture also appeared to have an effect on the bands; this is discussed later.

2.4.2. AGRONOMIC RESULTS.

Other results were analysed in four main classes:

soil moisture levels
seedling emergence counts
botanical analyses of dry matter yields
dry matter yields

The trial was designed with the latter two observations as top priorities. The other measurements were made to help explain some of the differences occurring in the dry matter yields and botanical analyses. Further conclusions drawn from results within these two categories are therefore restricted.

2.4.2.1. SOIL MOISTURE LEVELS.

The period over the time of band spraying and direct drilling was dry, with a January-March total of 5.28 in. (further details in Appendix IV). Irrigation was carried out for a week, 5 or 6 days before drilling. Approximately 1-1½ in. water was applied.

I. Block-Headland Differences.

A noticeable difference in soil moisture content in the top 4 in. due to irrigation was observed between blocks and headlands about the time of spraying (Plate 7). The difference is illustrated in Table VI, where on both dates, headlands and blocks had significantly different means.

Date	Block A	B	C	D	Headlands
Mar. 15 mean	33.3*	26.9	31.6	30.9	17.7
t-test results	B vs A, & B vs Headland: significant at 1% level				
April 5 mean	18.4	17.7	18.8	18.3	11.9
t-test results	B vs C not significant at 5% level, B vs Headland, significant at 1%.				

Table VI. Soil Moisture Measurements. (i) Differences Between Blocks and Headlands.

Plate 7. Panoramic Photograph of Main Trial. (i) Taken March 21.

II. Within and Between Block Unevenness.

The month long period between the last irrigation and first really wetting rain (Appendix IV) allowed the plots to dry considerably. This is reflected in the differences between the figures at the two dates of Table VI. Also noticeable is the difference between blocks. Block B was drier than Block A (significant at the 1% probability level) at the first sampling date, but not at the second.

As the blocks dried, their edges and ends appeared to dry out at a more rapid rate. Plate 8 illustrates this effect. Soil moisture samples taken on April 5 were recorded as being from the edge and the middle of the plots. The means of these classifications were found to be significantly different at the 5% level of probability (Table VII).

	Sampling position on plot. Side	Middle
No. in sample	19	22
Mean of sample	16.3*	19.2
t-test results	b[#]	a

* Soil moisture content, dry wt. basis.

\# Duncan's Multiple Range Test (Duncan 1955): Capital letters denote significant differences at the 1% level of probability; small letters, differences at 5% probability level.

Table VII. Soil Moisture Measurements. (ii) Differences Between "Side" and "Middle" of Plot Sampling Positions.

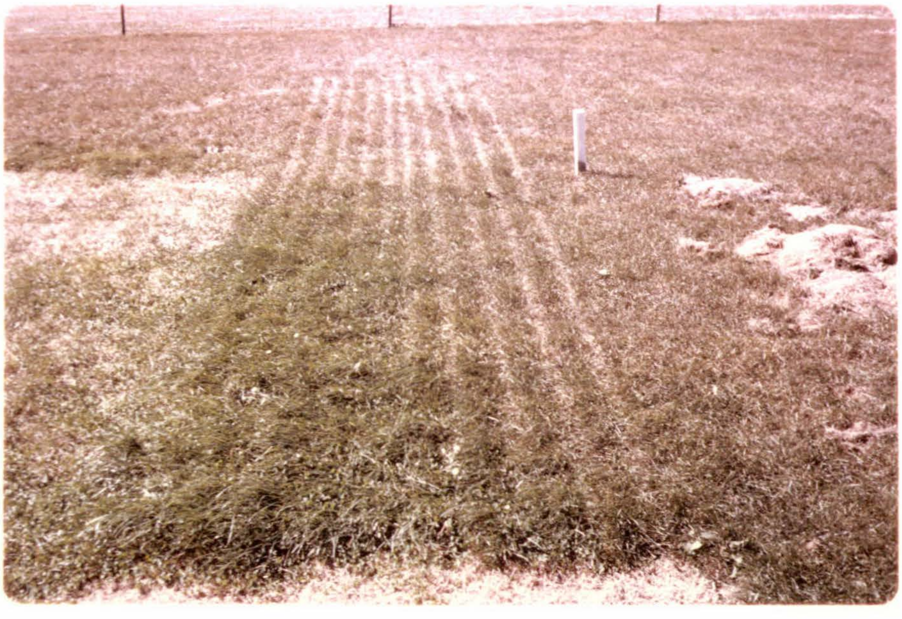


Plate 8. Edge Drying of Plots. (Taken April 5).

III. Soil Moisture and Distinctiveness of Bands.

Table VIII was compiled from data collected on March 29, and describes some of the differences between the irrigated and non-irrigated areas:

	Irrigated	Not irrigated
Pasture length at time of spraying	Long (up to $2\frac{1}{2}$-3 in.)	Open, shorter
Colour of band	Yellow	Brown
Width of band at 29/3/68 (i.e. 2 weeks post spraying)	Declining due to adjacent encroachment	Still quite distinct

Table VIII. Differences in Band due to Irrigation.

Further illustration of this effect can be seen in panoramic Plates 7 and 9. The bands on the headland are still very distinct more than two weeks after spraying (Plate 9). Plate 8 also shows this difference.

Plate 9. Panoramic Photograph of Main Trial.
(ii) Taken April 1 .

IV. Soil Moisture Differences between Band Treatments.

The soil moisture figures of both 15/3/68 (day or two after spraying) and 5/4/68 were analysed. Table IX illustrates the results:

Sampling point classification	"Band"[1]	"Blanket"[2]	"Un-sprayed"[3]
15/3/68.			
No. in sample	19	11	10
Mean of sample	30.0*	30.0	32.4
t-test results	"Band" vs "Blanket & "Blanket" vs "Un-sprayed", not significant at 5% probability level.		
5/4/68.			
No. in sample	27	10	3
Mean of sample	17.4*	21.1	17.6
t-test results	"Band" vs "Blanket" significant at 1% probability level. "Blanket" vs "Un-sprayed" insignificant at 5% probability level.		

* Soil moisture content, dry wt. basis
1 Plots of 1, 2 and $3\frac{1}{2}$ in. bands
2 Plots of 6 in. or blanket application
3 Untreated plots and plots drilled but not sprayed (i.e. "Controls")

Table IX. Soil Moisture Measurements. (iii) Differences Between Spraying Treatments.

Figures were classified according to whether they were taken from a plot that was band sprayed (i.e. 1 in., 2 in., and $3\frac{1}{2}$ in. treatments), blanket sprayed or unsparyed. At the first date there were no significant differences between any treatments. By the second date there was a significant difference (at the 1% probability level) between the blanket treatment mean and the band treatment mean. The difference between the blanket application mean and the non-sprayed mean was not significant, and this could have been largely due to the small sample size (and hence large standard error for a given standard deviation). At the time, no attempt was made to record whether or not soil samples were taken in the bands or between them.

V. Soil Moisture Levels over the Trial Period.

Soil moisture measurements taken over the trial period are summarised in Table X. The blocks were initially wetter than the headlands, and stayed that way throughout the trial period. The entire area became very wet from June to virtually the end of the trial.

Sampling Date		15/3	29/3	5/4	9/6	7/8
Sampling Position:						
Headland:	No. in sample	10	5	4	5	1
	Mean	17.7*	12.7	11.9	48.2	51.5
Plots:	No. in sample	40	5	40	4	2
	Mean	30.7*	17.7	18.3	51.7	56.5

* Soil moisture content, dry wt. basis
t-tests of means: 15/3 and 5/4 refer to Table V.., 9/6, Plots vs Headlands not significant at 5% probability level.

Table X. Soil Moisture Measurements. (iv) Differences Over the Main Trial Period.

2.4.2.2. SEEDLING EMERGENCE COUNTS.

I. Differences Between Blocks.

In an analysis of variance the block mean differences were found to be significant at the 5% probability level, bulked over varieties, sampling dates and row orientation (Table XI). No t-tests were carried out to find which pair of means differed. These tended to follow the soil moisture means of the blocks (Fig. 6). Soilmoisture and seedling emergence measurements were not taken on exactly the same dates.

	Block A	B	C	D	Mean
Tama ryegrass					
21, 22/3	6.2*	4.5	5.4	4.0	5.0
1/4	5.5	5.1	6.1	3.0	5.0
Ryecorn:					
22/3	13.9	9.1	9.2	11.5	12.2
2, 3/4	16.6	11.1	12.9	12.5	12.3

* Seedlings/ft. length of row.

Table XI. Seedling Counts. (i) Block Effects.

II. Differences Between Band and Blanket Sprayed Areas.

Whilst the trend of block soil moisture levels and seedling germination was in the direction expected (Fig. 6), the comparison between band and blanket sprayed areas was not. In Table XII the only significant differences are in a reverse order to those above. The means of the Tama ryegrass tended to follow the moisture level trend but mean differences were not significant.

Variety	Tama ryegrass					
Sampling date	21,22/3/68			1/4/68		
Treatment	Band	Blanket	Unsprayed	Band	Blanket	Unsprayed
Sample mean	4.8 *	5.3	4.9	4.7	5.9	4.3
Variety	Ryecorn					
Sampling date	22/3			2, 3/4		
Treatment	Band	Blanket	Unsprayed	Band	Blanket	Unsprayed
Sample Mean	11.3	9.4	11.6	14.1	12.8	10.6

* Seedlings/ft. length of row.
t-tests between band and blanket treatment means of same variety and sampling date: only significant difference at 5% probability level for ryecorn, 22/3/68.

Table XII. Seedling Counts. (ii) Spray Treatment Effect.

III. Differences Between Side and Middle of Blocks.

The third recording of soil moisture and emergence was taken in relation to the side (i.e. next to headlands) and middle (i.e. away from headlands) of the blocks. This data is summarised in Table XIII. The emergence of both varieties was significantly better away from the drying side of the block.

Variety	Tama ryegrass		Ryecorn	
Position in plot	Side	Middle	Side	Middle
Seedling/ft. row	3.9	6.1	12.6	14.2

t-tests between side and middle of plot observations within varieties, showed means to be significantly different at the 1% probability level for the Tama ryegrass and 5% for the ryecorn.

Table XIII. Seedling Counts. (iii) Effect of Sampling Position in Plot.

IV. Varietal Differences.

An analysis of variance showed variety difference to be significant at the 1% probability level (Table XI). This was partially a reflection of seeding rates. No germination tests were carried out on the seed samples used, but the "percentage emergence" was calculated using the 1,000 seed weights, theoretical sowing rate (i.e. assuming the drill sowed 30 lb./acre and 150 lb./acre for Tama ryegrass and ryecorn respectively), and seedling emergence at the second count, non nitrogen treatment. The resulting "percentage emergence" was 16% for the Tama ryegrass and 40% for the ryecorn. These low figures could have been due to a poor "potential" germination of the seed, poor seedbed conditions, or an actual sowing rate somewhat lower than the theoretical one.

V. Orientation-Variety Interactions.

Tama ryegrass responded in an opposite manner to ryecorn in relation to the orientation factor (see paragraph 2.3.2.5. III and Fig. 5). The results are summarised in Table XIV. The interaction was highly significant at the 1% probability level. The combined varietal results would probably thus have led to an insignificant "orientation" effect in the analysis of variance. "Orientation" means within varieties were not significantly different at the 5% probability level.

Variety	Orientation East	Orientation West
Tama	5.4*	4.5
Ryecorn	11.1	13.1

* Seedlings/ft. of row.
t-tests of variety means at each orientation were not significant at 5% probability level.

Table XIV. Seedling Counts. (iv) Effect of Row Orientation.

VI. Nitrogen Effect.

T-tests were carried out to test the sub-plot treatment, and summarised in Table XV. The trend in all cases was that no nitrogen sown with the seed was better than 1 cwt./acre sown with the seed. The effect was less distinct at the second count.

Variety	Tama ryegrass				Ryecorn			
Nitrogen treatment (cwt.nitrolime/acre	0		1		0		1	
Sample seedlings/	1st*	2nd	1st	2nd	1st	2nd	1st	2nd
Mean (seedlings/ ft. row)	5.6	5.2	3.9	4.6	13.3	15.0	9.0	12.0

* Table XII for these dates.

Table XV. Seedling Counts. (v) Nitrogen Effect.

(Cont'd. over page)

Table XV. (Cont'd.) t-tests: pairs of means tested - both dates within each N treatment and both N treatments at each date (all within varieties) -

At 5% probability level (i) within 1 cwt. N treatment of ryecorn counts significantly differed between dates; (ii) within second count ryecorn, count significantly differed between N treatments.

At 1% probability level, within first count ryecorn, counts significantly differed between N treatments.

VII. Drill Slits and Emergence.

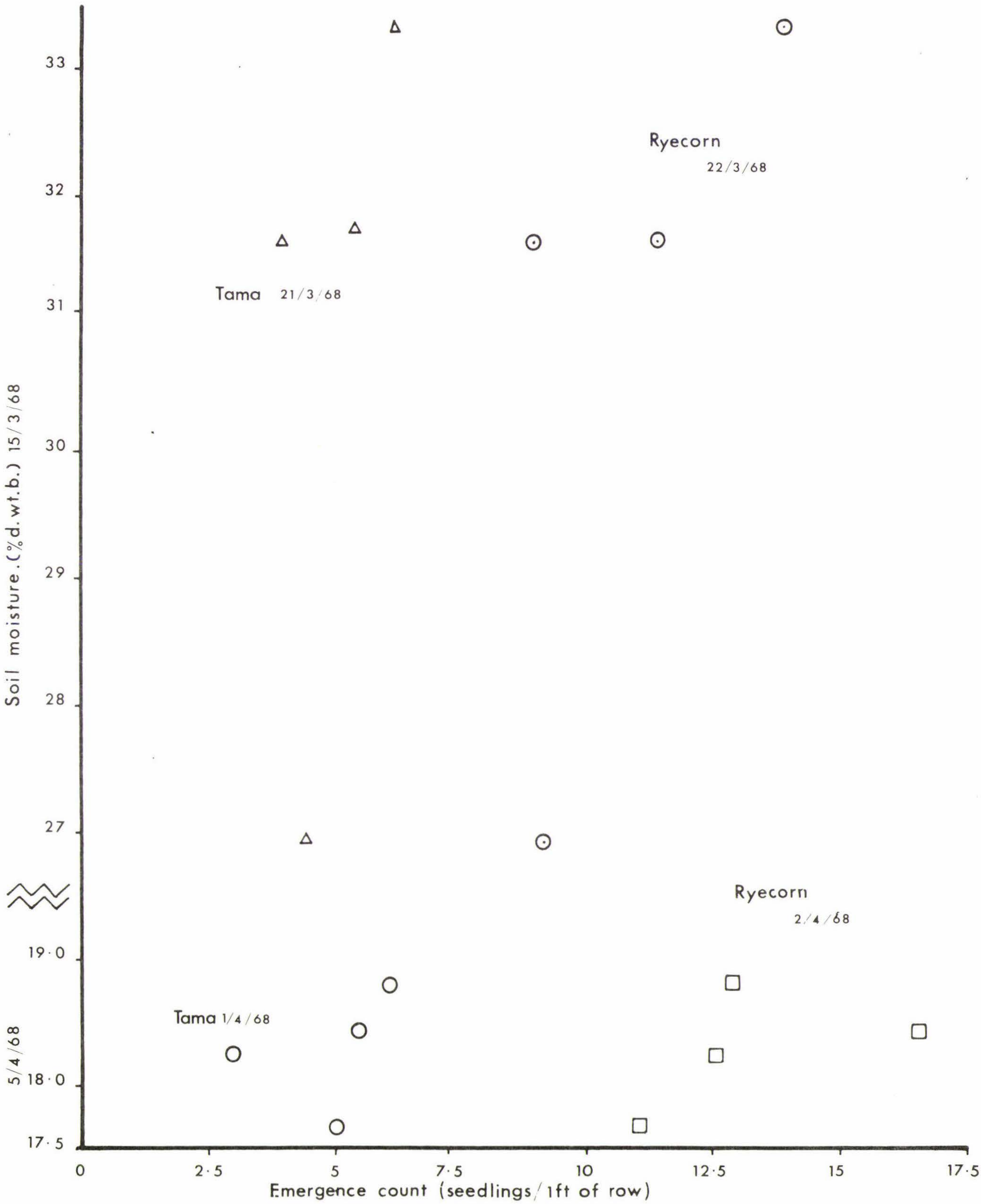
A proportion of the emergence data for the first count of the Tama ryegrass was scored in two subjective ways. Some of the drill slits were noted as "deep", "medium" or "shallow", "deep" being the deepest ones and up to $1\frac{1}{2}$ in. in depth. Some slits were also scored as being "open" and as such were more visually pronounced than the others. In each case, where 2 ft. of row was taken per measurement, the classification was according to what the majority of the row was judged to be. These somewhat subjective results are illustrated in Tables XVI and XVII. The mean of "open" slits differed from those of "less obvious" or "closed" slits at the 1% probability level. Means of "deep" and "shallow" slits were different at the 1% probability level. There was no interaction between slit openness and slit depth.

Slit definition	Open	Less obviously open & closed
No. in sample	18	22
Seedlings/ft. row	8.8	3.8
Signif. of t-tests	A	B

Table XVI. Seedling Counts. (vi) Slit Definition Effect.

Slit depth	Shallow	Medium	Deep
No. in sample	4	4	6
Seedlings/ft. row	2.0	5.3	7.7
Signif. of t-tests	B	AB	A

Table XVII. Seedling Counts. (vii) Slit Depth Effect.



SEEDLING EMERGENCE VERSUS SOIL MOISTURE (COMPARISON OF BLOCKMEANS) FIG 6

2.4.2.3. BOTANICAL ANALYSES.

Data from the second cut was analysed, whilst observations on data from other cuts has also been included where relevant.

I. Differences Between Blocks.

Table XVIII illustrates the differences between means and their significance in terms of the overall means. Blocks C and D would appear to be higher than Blocks A and B in both varieties. In relation to soil moisture in the early part of the trial, one might expect Blocks A and C to lead, as soil moisture in the first few weeks after sowing appears to be important in plant establishment. However, Block A was next to a *Pinus radiata* hedge and had more late afternoon shade and more needles fell on it than the other blocks. This might have affected growth. Competition must account for the majority of this difference however and these figures should be compared with yield figures (Table XXIII). Where the total yield was greatest, the yield of the sown variety was least and vice versa.

Block	A	B	C	D
Mean yield Tama	66.1*	48.3	94.0	147.6
" " ryecorn	47.8	56.4	101.0	90.6
Overall means	57.0	52.3	97.5	118.1
Signif. of overall mean differences	Bc	Bc	Ab	Aa

* lb. dry matter/acre

Table XVIII. Botanical Analyses. (i) Block Effect.

II. Band Width Effect.

Differences between band width treatments were significant at the extreme treatments (Table XIX). The differences between the blanket (6 in. band) treatment and the other treatments are clearly noticeable.

Treatment (Band width in.)	0 (Control)	1	22	$3\frac{1}{2}$	6
Ryecorn	18.8[1]	17.8	23.4	46.2	208.4
t-tests: Control vs. others				*	**
1R vs 2R & $3\frac{1}{2}$R				**	
Tama ryegrass	13.8[1]	11.7	47.7	30.4	266.2
t-tests: Control vs. others			*		**
1T vs 2T & $3\frac{1}{2}$T			**	*	
Overall mean (both varieties)		14.8	35.6	38.3	237.3
t-tests on differences between overall means		Bc	Bb	Bb	Aa

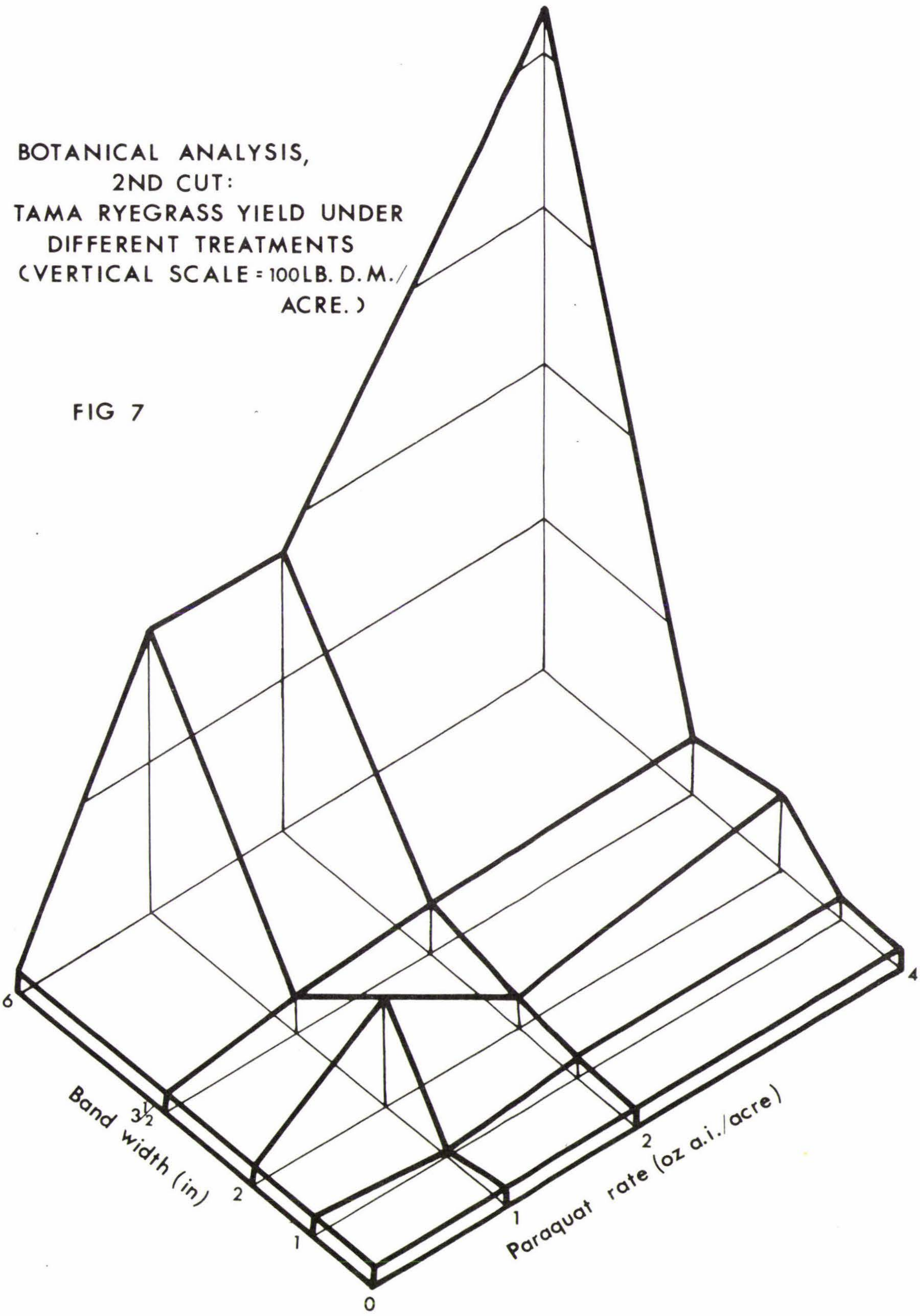
1 lb. dry matter/acre
* Means significantly different at 5% probability level
** Means significantly different at 1 % probability level

Table XIX. Botanical Analyses. (ii) Band Effect.

When the unsprayed treatment was compared with the banded treatment (Table XIX) only the blanket sprayed treatment was significantly better at the 1% probability level. The small sample size (4 versus 12) of the unsprayed treatments was contributary to the lack of significance in some of the comparison of means. However, the three dimensional graphs (Figs. 7 and 8) do illustrate the obvious difference between the blanket sprayed treatments and any others. The amount of Tama ryegrass in the unsprayed treatment at the 3rd and 4th cuts was either nil or insignificant. Ryecorn had disappeared almost completely and no attempt at measurement was made (Plates 10 and 13).

BOTANICAL ANALYSIS,
2ND CUT:
TAMA RYEGRASS YIELD UNDER
DIFFERENT TREATMENTS
(VERTICAL SCALE = 100LB. D.M./
ACRE.)

FIG 7



BOTANICAL ANALYSIS,
2ND CUT:
RYECORN YIELD UNDER
DIFFERENT TREATMENTS
(VERTICAL SCALE = 100 LB. D.M./ACRE)

FIG 8

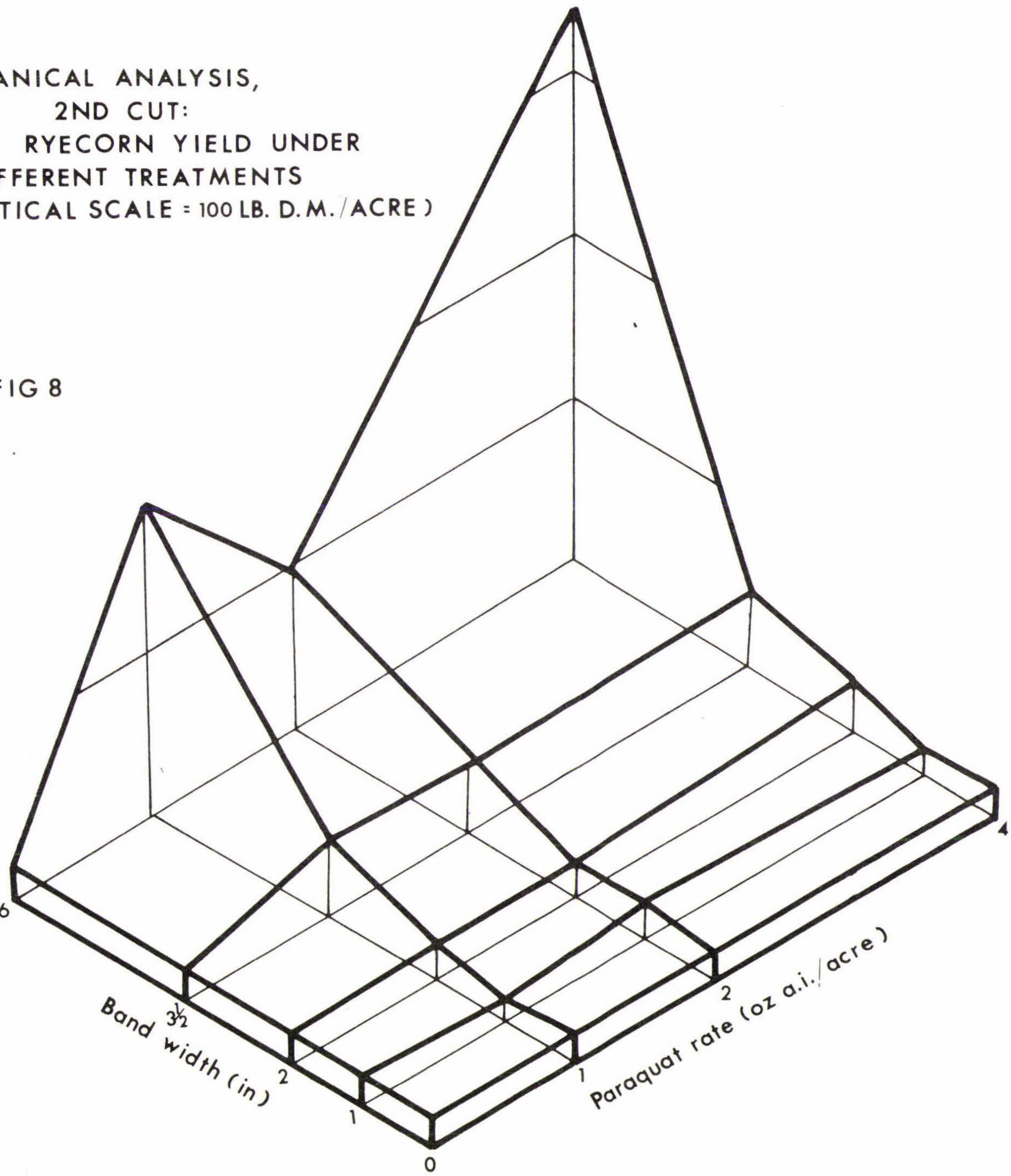


Plate 10. Comparison of Band Width and Varietal Differences, September 16.

On the left, the 41R treatment shows little sign of ryecorn, whilst the 46T treatment (Tama ryegrass) on the right is quite obvious.

III. Paraquat Rates.

The analysis of the second cut data in respect of paraquat rates is presented in Table XX. In this case a negative response (significant over means of both varieties at the 5% probability level) was found to 2 oz./ acre of paraquat compared with that of 1 oz./acre. Similarly, 1 oz./acre was better than none, but the difference between 2 oz. and none was not significant at the 5% level. There was a similar trend of 1 oz. being better than 2 oz. a.i./acre in the third and fourth cuts but this was not significant statistically.

Treatment (oz. a.i./acre)	Control	1	2	4
Ryecorn (lb. d.m./ acre)	18.8	68.2	45.7	108.0
t-tests: Control vs Others		*		*
1R vs 2R & 4R				
Tama (lb. d.m./ acre)	13.8	71.8	62.4	132.8
t-tests: Control vs Others				
1T vs 2T & 4T		*		*
Mean of both varieties		70.0	54.0	120.4
t-tests of mean differences		Bb	Bc	Aa

* Means significantly different at 5% probability level

Table XX. Botanical Analyses. (iii) Paraquat Rate Effect.

IV. Band Width - Chemical Rate Interaction.

The analysis of the second cut data showed a significant band width - chemical rate interaction (at the 1% level). A study of the table of figures failed to show anything meaningful so the three dimensional graphs (Figs. 7 and 8) were drawn up. The figures for these graphs are shown in Table XXI. Rate of paraquat does not appear to be greatly important in the banded applications. On the other hand, band width is more important and there is a gradual rise in yield of the introduced variety over the 1 to $3\frac{1}{2}$ in. band treatments. The high figure in the 2 in. band 1 oz./acre Tama ryegrass treatment was due to an exceptionally high measurement and over the mean of four in the sample the effect is still apparent. No significant differences were found with the t-tests between the 1 oz. and other rates within varieties (Table XXI). There were however, differences between band treatments. Six in. bands were not tested with the one in. band but assumed to be significantly different as a result of comparisons between Figs. 7 and 8.

Band width (in.)	1	2	$3\frac{1}{2}$	6
Paraquat rate (oz. a.i./acre)				
		Tama ryegrass		
1	4.2*	73.0	23.7	185.9
2	16.2	20.4	33.0	180.0
4	16.8	49.5	36.5	432.5
		Ryecorn		
1	14.4	22.0	48.0	188.5
2	22.2	19.4	44.4	96.8
4	14.3	28.8	46.6	340.0

* lb. d.m./acre

Table XXI. Botanical Analyses. (iv) Band Width, Paraquat Rate Interaction.

2.4.2.4. DRY MATTER PRODUCTION.

Initial plot dry matter yields were analysed minus the inclusion of the "control" and "sown but not sprayed" plots. These were not incorporated because they did not fit conveniently into the analysis design. The significant results of these were as follow:

First Cut: Blocks at 1% probability level, band widths at 1% probability level, nitrogen-variety-paraquat rate interaction at 5% probability level.

Second Cut: Paraquat rate at 5% probability level.

Third Cut: Blocks at 1% probability level.

Fourth Cut: Blocks at 5% probability level.

A series of t-tests were also carried out between groups of treatments (Table XXII). These results will be presented below.

Defoliation	Grouped Treatments						
	Not treated (1)	Sown but not sprayed (2)	Band Sprayed (3)	Blanket Sprayed (4)	Sprayed (5)	Sown (6)	Unsprayed (7)
1st	1288*	1187	1080	574	954	972	1238
2nd	1113	1063	1092	1023	1076	1075	1088
3rd	638	609			620	618	623
4th	476	505			591	574	490

* lb. d.m./acre

Significance of t-tests of mean differences.

I. 1st cut: (i) 1 vs 2 vs 3 vs 4; 1 vs 3 & 4 at 1% prob. level, 4 & others at 1% prob. level

(ii) 5 vs 7; at 1% prob. level

(iii) 1 vs 6; at 1% prob. level

II. 2nd cut: (i) 1 vs 2 vs 3 vs 4; 3 vs 4 at 5% prob. level

(ii) 5 vs 7; NS+

(iii) 1 vs 6; NS

III. 3rd cut: (i) 1 vs 2 vs 5; NS

(ii) 5 vs 7; NS

(iii) 1 vs 6; NS

IV. 4th cut: (i) 1 vs 2 vs 5; NS

(ii) 5 vs 7; NS

(iii) 1 vs 6; NS

+NS = Not Significant at 5% probability level.

Table XXII. Dry Matter Yields. (i) Various Groups of Treatments.

I. Differences Between Blocks.

The block means were significantly different at almost all cutting times (Table XXIII). This is due partly to the differences in growth period between defoliations (plots were not always cut on the same day, and growth periods varied up to 13 days). When the ranking of the block mean magnitudes are compared with the ranking in regard to growth periods, a similarity is evident. The fourth cut however, does not include this factor, yet some block means are significantly different at the 1% probability level.

Block	A	B	C	D
1st cut	862 (33)*	916 (44)	795 (39)	1245 (46)
2nd cut	1065 (40)	1165 (39)	1049 (36)	1025 (33)
3rd cut	774 (70)	471 (63)	681 (69)	544 (65)
4th cut	515 (41)	400 (41)	741 (41)	650 (41)

* Days between cuts

1 lb. d.m./acre

Significance of t-tests between all blocks at each cutting period.

1st; A different from D, at 1% probability level

2nd; No significant differences

3rd; A vs B, at 1% probability level

D vs A, B and C at 5% probability level

4th; A vs C at 1% probability level

B vs C at 5% probability level

Table XXIII. Dry Matter Yield. (ii) Block Effect.

II. Band Width Effect.

Within the first cut there was little contribution from sown species to the yield and the figures obtained illustrate a yield depression related to band width (Table XXIV). The greater the proportion of the area sprayed the greater was the reduction in yield. During the period between spraying and the first cut, any difference between the 2 in. and 3½ in. band disappeared. When the treatments are grouped as "control", "sown, not sprayed", "blanket sprayed", and "band sprayed" more significant differences are apparent (Table XXII).

Band width (in.)	1	2	3½	6
	1st cut			
Mean (lb. d.m./acre)	1110	982	980	574
Signif. of difference of means	A	B	B	C
	2nd cut			
Mean (lb. d.m./acre)	1106	1070	1099	1027
Signif. of difference of means	There were no significant differences			

Table XXIV. Dry Matter Yields. (iii) Band Width Effect.

Neither banded (with the exception of 42T), nor ryecorn treatments were sampled after the second cut and so comparisons were made only with Tama ryegrass: i.e. blanket treatments with control, and Tama ryegrass unsprayed. The comparisons have been made both on a total basis (Fig.10) and on a per day growth (taking the different block growth intervals into account) (Fig. 9). The data for Figs. 9 and 10 is shown in Tables XXVII and XXVIII.

III. Paraquat Application Rates.

Differences between paraquat rates were significant only at the second cut (Table XXV). There would appear to be less growth suppression with the 1 oz. rate than either of 2 or 4 oz. a.i./acre rates, which were not significantly different from each other. At the first cut the suppression was more equable for all rates.

Paraquat rate, oz. a.i./acre	1	2	4
1st cut mean	915*	992	957
Signif. of differences between means	There were no significant differences between means		
2nd cut mean	1142	1041	1044
Signif. of differences between means	A	B	B

* lb. d.m./acre.

Table XXV. Dry Matter Yields. (iv) Paraquat Rate Effect.

IV. Nitrogen - Variety - Paraquat Rate Interaction.

There was, at the 5% probability level, a significant nitrogen - variety - paraquat rate interaction (Table XXVI). When graphed, a rather meaningless pattern emerged. At the low paraquat rate, the nitrolime treatment was favourable to ryecorn but deleterious to Tama ryegrass. At the high rate the situation was altered, nitrolime being unfavourable to both varieties. The dry matter production to this date was largely from plants other than those sown. This would indicate that either another or other factors are involved, or alternatively that this was a random occurrence.

Nitrogen treatment (cwt. nitrolime/acre) Treatments *	0	1
1 oz. R	764	1058
2 oz. R	976	1015
4 oz. R	1053	923
1 oz. T	963	876
2 oz. T	975	1001
4 oz. T	959	892

* for key, see Table V, page 30.

Table XXVI. Dry Matter Yields. (v) Paraquat rate - Nitrogen Treatment Interaction.

Defoliation	1st	2nd	3rd	4th
Control	32.01*	30.77	9.52	11.62
Tama unsprayed	29.12	29.17	9.08	12.30
Banded	26.75	30.03	-	-
Blanket	14.04	28.25	-	-
Tama blanket	12.61	29.58	9.67	14.58

* Growth rate, lb. d.m./day

Table XXVII. Dry Matter Yields.(vi) Growth Rate of Different Treatments over Winter Period.

Defoliation	1st	2nd	3rd	4th
Control	1288*	2404	3041	3517
Tama unsprayed	1167	2317	2925	3430
Banded	1080	2172	-	-
Blanket	574	1603	-	-
Tama Blanket	522	1249	1901	2498

* lb. d.m./acre

Table XXVIII. Dry Matter Yields. (vii) Total Yields for Different Treatments over Winter Period.

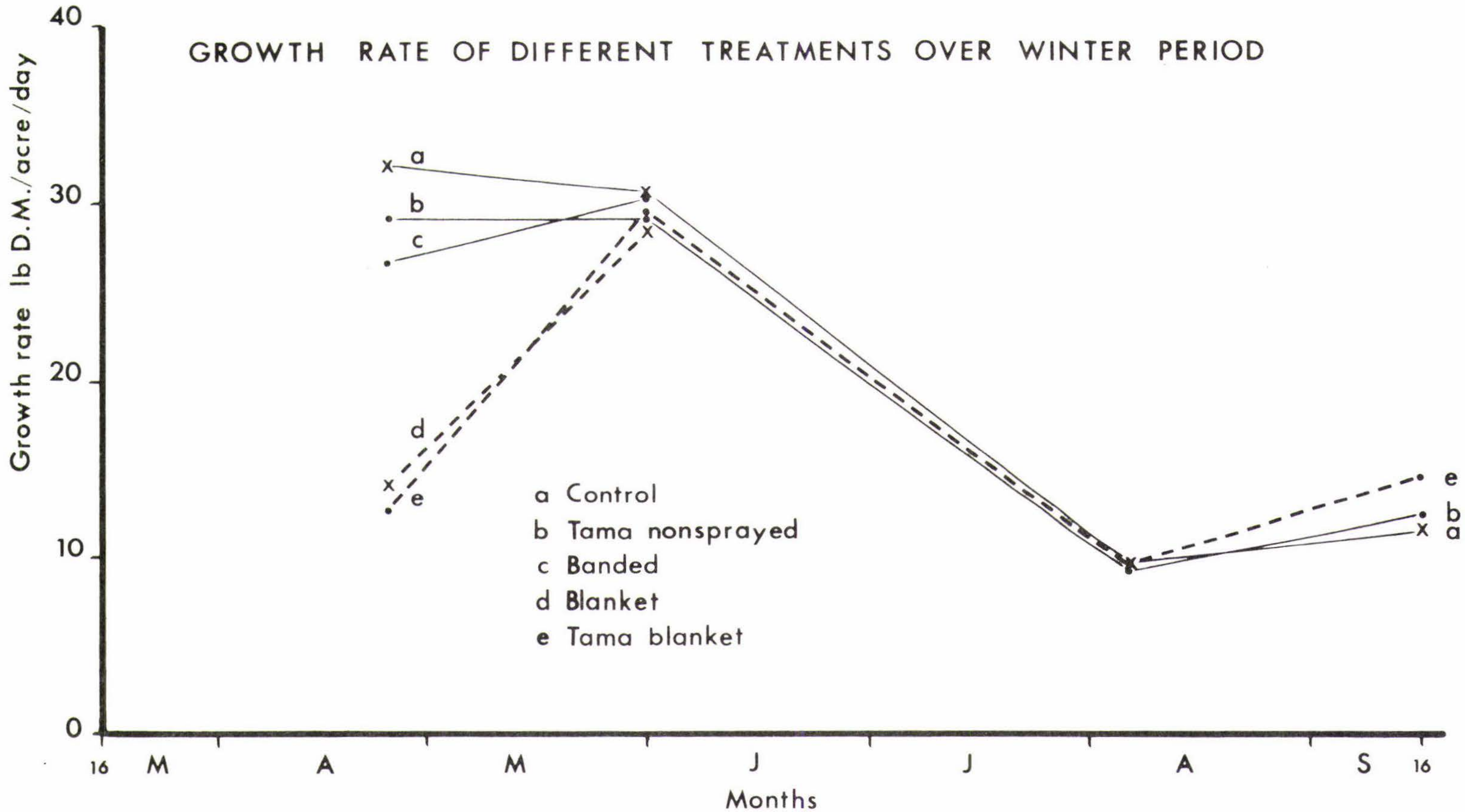

GROWTH RATE OF DIFFERENT TREATMENTS OVER WINTER PERIOD
Growth rate lb D.M./acre/day
40
30
20
10
0
a
b
c
d
e
a Control
b Tama nonsprayed
c Banded
d Blanket
e Tama blanket
16
M
A
M
J
J
A
S
16
Months

FIG 9

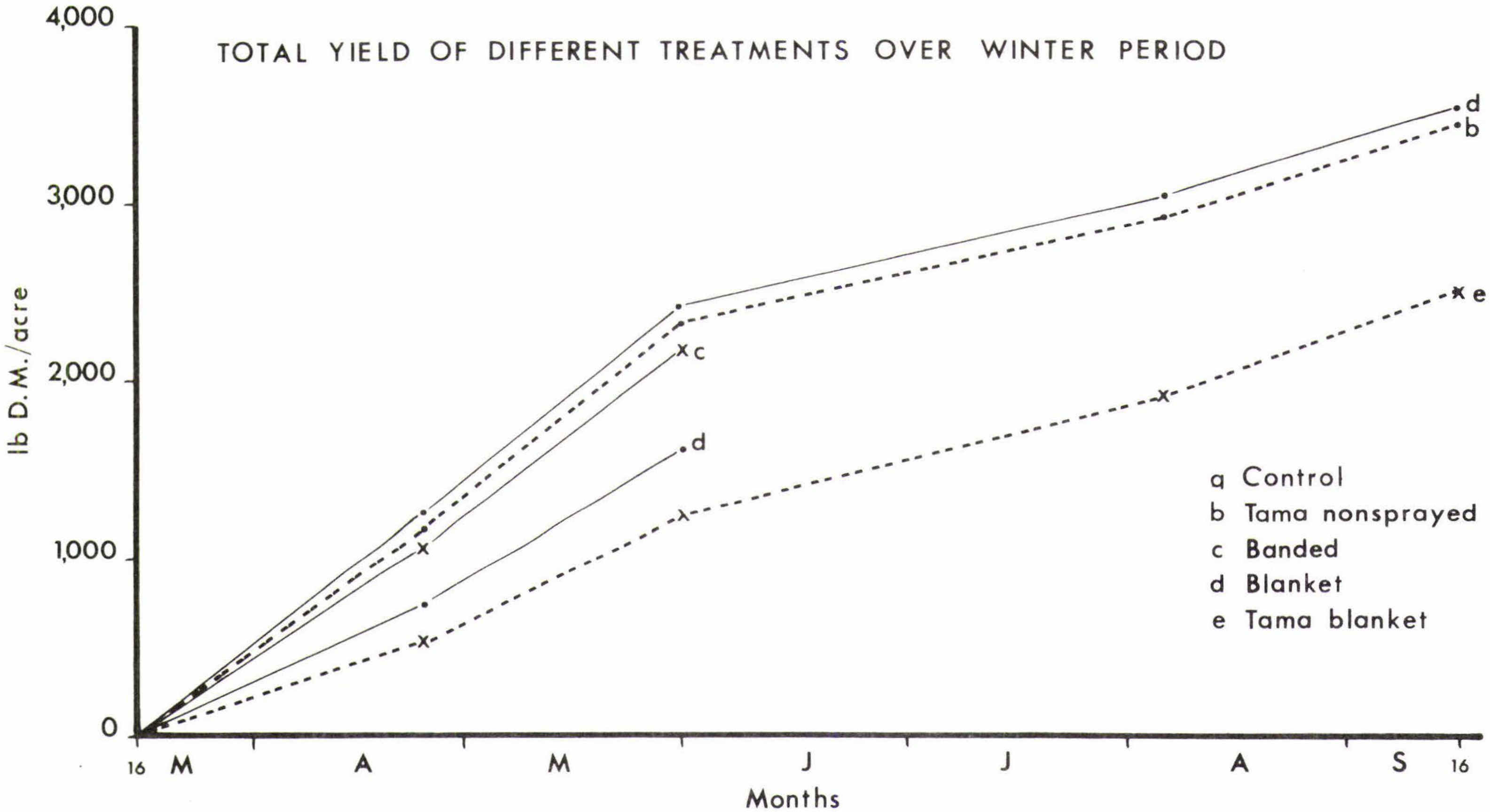

TOTAL YIELD OF DIFFERENT TREATMENTS OVER WINTER PERIOD
4,000
3,000
2,000
1,000
0
lb D.M./acre
16 M A M J J A S 16
Months
d
b
c
d
e
a Control
b Tama nonsprayed
c Banded
d Blanket
e Tama blanket

FIG 10

2.5. DISCUSSION.

2.5.1. SOIL MOISTURE.

I. Effects of Irrigation and a Drying Environment.

The irrigation accomplished (approximately $1\frac{1}{2}$ in. water on the blocks), caused large differences in the soil moisture of blocks and headlands, and in their pasture growth. Apparently, irrigation between blocks and within blocks wasn't even. This was indicated by the significant differences between block means, between "side" and "middle" of block measurements, as well as by the visual appearance of the blocks as they dried out. The use of three fifty foot "spray soak" hoses for irrigation would be partially to blame. Seven hose positions were required to cover each block. Differences in irrigation times (shifts were approximately $1\frac{1}{2}$ hours), hose performances (quite visible even along the length of one hose), hose positionings (irrigation was carried out at night when visibility was poor), all tended to produce soil moisture differences both between and within blocks.

II. Soil Moisture Effect on the Distinctiveness of Bands.

Plates 7, 8 and 9 illustrate the differences between the resulting bands due to soil moisture. Brian and Headford (1968) observed that plants under water stress were more affected by paraquat, whilst Bramley (1962) noted that a better kill with paraquat was achieved under drought conditions. Presumably, the plant's ability to recover was affected by water shortage in this instance, as the bands disappeared rapidly once the rain had fallen and growth resumed.

No examination outside the plot area was carried out to ascertain whether there was a similar effect (i.e. bands remaining distinct at ground level) as that illustrated in Plate 14.

III. Effect of Bands on Subsequent Moisture Levels under a Drying Regime.

The grouping of the soil moisture results in Table IX illustrate an interesting banding effect on the soil moisture. The cores were taken to a depth of 4 in. but most of the differences were likely to appear in the upper layers. Little effect is to be expected from the banded treatments at the first measurement taken close to spraying, but differences were apparent at the second measurement. More recent field trial observations have indicated that direct drilled paraquat sprayed areas at times of moisture stress have been higher in moisture in the surface layers at least, than either conventional seedbeds (where presumably the less compact soil would be a less efficient conductor of soil moisture from the subsoil), or untreated pasture (where the evapotranspiration rate from existing herbage appears to dry the soil more).

IV. Soil Moisture Levels Over the Trial Period.

The general wetness experienced over the winter period (illustrated by Table X figures) resulted from the winter rainfall (Appendix IV) and poor soil drainage characteristics. The early disappearance of the ryecorn (Plates 10 and 13) could well be related to this wetness. At times, the area was almost impossible to walk across, and soil surface samples taken in the later stages may have underestimated the soil moisture, as there was often much free water about at the time of sampling.

2.5.2. SEEDLING EMERGENCE.

I. Soil Moisture Levels and Seedling Emergence.

Tables VI and IX may be compared with Tables XI and XII. The trial had not been designed with such comparisons in mind and in the cases of Tables IX and XII, group samples (i.e. "band", "blanket" etc.) are of unequal size. Furthermore, it was not recorded whether soil samples were selected from within or between bands in the "band" group. However, seedlings were found growing within the bands. Therefore it is not surprising that the germination figures could be related more easily to the block differences in soil moisture than to the band treatment differences.

Although conclusions can not be drawn readily from results such as these, it is possible to say that soil moisture is important for seed germination. It was difficult to estimate from the data available, which variety responded more to moisture.

II. Effect of Row Orientation, Drill Slit Depth and Definition.

In this section, measurements were purely incidental. The results are indicated in Tables XIV, XVI, and XVII. Table XIV, indicating the slit orientation effect would provide the most valid of these, as measurements with both varieties were taken at both seedling count times, and over all samples. The slit definition and depth effects were taken for one variety (Tama ryegrass), at the second date only, and over one block (A). The orientation effect would be of significance probably only when the slits were open, and unfortunately the measurements were not scored for this effect.

Tables XVI and XVII indicate the relationships between slit openness and seedling emergence and slit depth and seedling emergence. Hence when conclusions are drawn from this data two observations must be kept in mind:

(i) the extremely subjective nature of the data,
(ii) the direct and indirect effects of slit openness and slit depth on seedling emergence.

Slit openness would, for instance, affect both soil moisture and temperature within the slit as well as the mechanical impedance to the seedling's emergence. Under the circumstances it is difficult to justify a cause-effect relationship. The reverse trend may have been obtained under a drier situation. The differences between the figures would suggest, however, that further work is warranted in this field.

III. Nitrogen Effect.

Nitrogen has been suggested as a limiting factor in the early growth of sown varieties in direct drilling. The combination in this instance of initial moist conditions followed by a drying regime was more deleterious than helpful. The close proximity of the seed to a high soil moisture concentration of fertiliser would presumably be the cause of this effect. Had rain fallen earlier, the response may have occurred in the opposite direction. Sprague (1962) noted that competition from existing unkilled herbage affected sudan grass seedlings by the time they were 10 days old, so presumably readily available nitrogen would be helpful to young seedlings in a band spraying situation.

2.5.3. BOTANICAL ANALYSES.

Great difficulty was experienced in separating Tama ryegrass from the remaining pasture at the first cutting. With a particularly heavy work load at this time botanical analyses were few and limited to ryecorn only. At the second cut a more detailed study was carried out with both varieties. By the third and fourth sampling dates the ryecorn had virtually disappeared from the sward and Tama ryegrass from practically all treatments except blanket treatments, so observations consisted mainly of Tama ryegrass blanket sprayed plots. Over time, observations were therefore rather limited.

The general effect of band width and paraquat rate (the two main variables here) and their interaction is illustrated for each variety at the second cut in Figs. 7 and 8.

The obviously better yield in the 6 in. band treatment is in sympathy with the work of others who have found that 100 per cent removal of the existing herbage is necessary for the successful establishment of various species. Sprague (1962) found this with sudan grass, and Triplett et al (1964) stated that in establishing "non-ploughed" maize "almost no competition from non crop plants can be tolerated".

It is also interesting to note that the mean of the 1 in. band with both varieties was lower than the unsprayed treatment, although this was not statistically significant. The gain from an inch width of competition removal could possibly be offset by the nitrogen "lock up" likely from the decomposition of the turf killed. The sketchy evidence presented from the first cut with ryecorn illustrated this same trend but because of the small samples, this could have been mere coincidence.

The interaction between rates and band widths appears to exist primarily with the 2 oz. rate "dips" at the 6 in. band in both varieties and at the 2 in. band with Tama ryegrass. Apart from this "dip" with Tama however, paraquat rates within the banded applications appear to be of low significance. On the other hand the effect of band widths is far more apparent, with the blanket application being very much superior to the best band treatment.

When compared with total yields, the proportions of sown species within the pasture were very low (below 5% in most banded treatments at the second cut). The maximum occurred in the highest rate blanket Tama treatment at the last cut (i.e.40%).

Summarised below are the results from this section:

(i) Within bands, paraquat rates are not important.

(ii) There is a significant band width effect, but blanket application is far superior to any bands.

(iii) There is a band width - paraquat rate interaction which appears to be mainly in the "dip" at 2 oz. in the blanket applications, supported in the 2 in. band by Tama ryegrass.

(iv) The amounts these species are contributing to the final yield are small, but towards the end of the trial period Tama ryegrass is contributing more in the 4 oz. blanket applications.

The reasons behind these results might be more clearly understood by a discussion of the hypothetical situation occurring over time within the band. Paraquat is a desiccant with low residual properties. The recolonization of the vacant space (Plate 11) (left as a result of spraying paraquat on growing herbage) is therefore a matter of the ability of the various plants in the pasture to mobilize and grow to fill the space. These plants could come from three sources:

(a) New plants from seeds in the soil of that space including those sown.

(b) Recovery of plants that were sprayed. Paraquat is not very well translocated in the plant and relies on photosynthesis and oxygen for its action (Calderbank 1968) and so woody and underground parts of plants are not as affected as green leaves. If a plant is capable of growing from these less affected parts it is possible that it will recolonize the sprayed area. White clover is one such plant, and Blackmore (1962) noted that his bands were clover dominant four weeks after spraying.

Plate 11. $3\frac{1}{2}$ in. Band, 4 oz. a.i./acre, Ryecorn Treatment.
(i) Immediately After Spraying 16/3/68.

(iii) Recolonization could result from areas unaffected by the spray (in this case between bands). Clover and other stoloniferous (or rhizomatous) plants have an advantage in this respect over the tufted species, which can only spread vegetatively by means of tiller production on the periphery of the area already inhabited (Elliott and Allen 1964).

When the band is examined in this light suggestions may be advanced to account for some of the effects noted. Initially, recolonization occurred from the sown seed and from encroachment of neighbouring plants (Plate 12). Clover covered the bands rapidly, especially after the conclusion of the dry spell. During this dry period the unsprayed areas grew slowly and were ready and able to grow immediately rain came. Sown plants on the other hand, would probably have found the situation rather more difficult. Growth from other seedlings were not greatly noticeable, nor initially was there much growth from the recovering sprayed plants.

Once the environment became more moist, the pasture quickly grew and the cutting height of 6-8 in. meant that the bands tended to be covered for quite a proportion of the time. At ground level, as Plate 14 illustrates, the bands were quite distinct by the first cut. An agronomy experiment conducted two years previously with an Ariki-white clover pasture showed the effect of sampling at the same site

Plate 12. 3½ in. Band, 4 oz. a.i./acre Ryecorn Treatment. (ii) Four Weeks After Spraying and Drilling, 11/4/68.

Plate 13. 3½ in. Band, 4 oz. a.i./acre Ryecorn Treatment. (iii) Three Months After Spraying, 14/5/38.

without removing the neighbouring shading herbage. One foot square quadrats were cut at intervals and growth of individual ringed tillers measured. Eventually the foot square quadrat became bare ground, with nothing growing. A somewhat similar effect could have been operative in the bands. The distinctiveness of bands at ground level would indicate that there had been little recovery from the sprayed plants and that few new plants had become established. The start gained by the sown plants in the initial moist period may have enabled them to grow enough so that when growth accelerated after the dry spell, they were able to keep up. Possibly the low proportion of of sown species in the banded treatments at the second cut is some indication of an inability to keep up with the unsprayed pasture.

Plate 14. Distinctiveness of Bands at Ground Level at the First Cut.

The presence of little other growth within the band except the sown species and clover that had grown in from the unsprayed areas (one examination early after rain had come showed little rooting of the clover within the band), would perhaps be the reason for the lack of difference between rates of paraquat for the banded treatments. In the blanket treatment however, the situation was different and there was competition from plants recovering within the sprayed area. There were no neighbouring plants shading the area and suppressing regrowth of the sprayed plants. The rate suppression relationship of paraquat to that pasture, which was ryegrass dominant, was thus more important in the blanket situations. In the light of more recent experience, I.C.I. (N.Z. Ltd.) now recommend a higher rate than even 4 oz. a.i. (1 pt. of the liquid) per acre for the introduction of new plants into a pasture (Anon. 1969). The highest rate of paraquat was better than the other rates for the blanket application as it gave a greater competition removal effect.

The dip at the 2 oz. rate appears more as a peak at the 1 oz. rate, and as mentioned earlier, this was due to a very high reading in this group of data.

A different defoliation frequency might have produced entirely different results. More frequent defoliation, following the above argument, could possibly have led to a greater difference in response to paraquat rate within the banded treatments. For the banding to be effective in reducing competition these bands should be such that no other herbage trespasses into the light that falls on that band. It would seem that more frequent cutting would help towards this end.

2. 5. 4. DRY MATTER PRODUCTION.

I. Differences Between Blocks.

Differences between blocks may be expected in a design such as this with the blocks on different sites down the slope from the pine hedge. The differences in cutting times, as shown in Table XXIV would be a major reason for these differences. The ranking of cutting times and yields in Table XXIV are in approximately the same order.

II. Band Width Effect.

The dry matter yield at the first cut (Table XXIV) illustrates a yield reduction where spraying was carried out. This reduction would initally have been directly proportional to the area sprayed, although by the first cut there would have been compensatory growth from the unsprayed areas. The reduced competition for the remaining plants would have allowed them to exploit the vacant areas, and as Plates 13 and 14 illustrate, this was noticeable in the aerial portions of the plant. The grouping of treatments in Table XXII also illustrates the difference between treatments and the way in which they disappear over time as compensatory growth occurs. Fig. 9 illustrates the compensatory growth. At the first cut growth rate calculations for different treatments differed greatly. By the second cut these differences had largely disappeared and over the winter period to the third cut, growth per plot was very much the same.

III. Effect of Paraquat Rate.

It is suspected that "rate differences" at the first cut did not occur as all plots would have been recovering from the kill of green herbage by paraquat. Table XXV illustrates that by the second cut the lowest rate plot had taken the lead. The greatest effect may have been expected in the blanket treatment where overshadowing of the unsprayed herbage did not occur to nullify the effect, but this did not prove to be the case, as the effect was noted over all band treatments.

2.6. CONCLUSIONS.

The nature of, and results from this experiment make conclusions of a definite nature difficult to draw. Various questions, ideas and hypotheses have however come forward which could direct further research in this field. As an exploratory trial this work has therefore been successful. Various aspects of the experiment in relation to the conclusions and further work are discussed below.

I. Band Width, Paraquat Rate and Defoliation Treatments.

Although evidence is sketchy, band width, paraquat rate and defoliation treatments appear to be interrelated factors. The results have indicated that "band spraying and direct drilling" is different from "blanket spraying and direct drilling". In blanket spraying, the sown species must contend with competition from recovering sprayed plants and other seedlings. In band spraying the added factor of competition from herbage growing between the bands must be recognised. In view of the competition removal, this herbage is likely to grow vigorously, and if not checked, swamp out all growth within the band. Defoliation frequency and intensity are therefore likely to be important factors. In the trial wider bands gave some relief to the sown plants from this competition but were only really effective when the band became a blanket application where there were long periods between cutting. Differential effects of paraquat rates were not obvious and possibly masked by unsprayed herbage shading the bands and so allowing no selection due to rate to take place.

It is a pity that a defoliation treatment was not included in the trial. Further work however, should investigate these three factors and their interrelationships within band spraying and direct drilling.

II. Varieties.

It was noticeable that Tama grew better than the untreated pasture towards the end of the experiment. This is indicative of the variety's growth pattern which may have been helped by earlier sowing. The lack of moisture after sowing was a factor mitigating against growth.

The ryecorn disappearance from the pasture was disappointing, but may be related to the wet soil conditions.

Both varieties have yielded much higher than they did in this trial (Barclay and Vartha 1966). The blanket treatments yielded far more than the banded treatments which must be accounted for largely by competition. The relative poor yields from the blanket treatments however, would illustrate the dry conditions of the establishment period and/ are typical poor direct drilling results.

With such results it is not possible to definitely recommend which variety is best suited to band spraying.

III. Nitrogen Treatment.

The negative response obtained in seedling counts to nitrogen led to the abandonment of this treatment after the first cut. One could assume that the dry conditions led to this response but there is no evidence to suggest what the longer term effect may have been.

IV. Band Sprayer Performance.

The band sprayer built for the trial work performed adequately. The less satisfactory bands probably resulted from pasture being too long and from incorrect nozzle height adjustments. With the use of superior band spraying nozzles, which produce a band with a more distinct edge and more even within band pattern than those used, the production of better bands can be envisaged for the future.

V. Drill Performance.

This work did not set out to assess drill performance but some observations when seedling counts were made pointed to the importance of correct drill slit specifications for any particular drilling situation. The fact that the drill slit affects seedling germination and emergence directly (e.g. closed slits may impede emergence), and indirectly (e.g. closed slits may be more moist than open ones, moisture affecting germination), would suggest that a complex situation is likely with many interacting factors. For the successful yield of any crop or pasture good establishment is vitally important, and as this appears to be one of the weak points of direct drilling (and therefore band spraying and direct drilling) further work is needed on the effect that different drill slit parameters under different conditions have on the resulting establishment of the plant.

VI. Irrigation.

During the trial, doubts were raised as to the wisdom of irrigation. These doubts resulted from the deleterious effects of the dry spell following irrigation (which could not be continued with the equipment used after drilling).

Without irrigation the operation of the drill and the placement of seed in the hard ground would have been impossible. Also, if drilling had been delayed until sufficient rain fell, the trial may have been too late for adequate winter growth.

Had rain fallen immediately after drilling, eliminating moisture stress, the question of irrigation would not have been a problem.

VII. Experiment Size.

The number of treatments made it difficult to take as full a set of data as was planned. In an initial investigation into a little known field the lack of precedence on which to weight the importance of different factors leads on the one hand to a very broad investigation and on the other, to the possibility of missing some important factor altogether. Both happened in this work and it was unfortunate that defoliation frequency and intensity, which now appear so important, were discarded as trial factors.

3. SPRAY DISTRIBUTION ANALYSIS.

3.1. INTRODUCTION.

In early experiments, band spraying with dye on to newsprint had resulted in bands of relatively even widths, with a "cut off" distance at the periphery of $\frac{1}{4}$ - $\frac{1}{2}$ in. and little spray visible outside these limits. Visual observations of the kill from the main trial spraying however, showed that band edges were indistinct. At the time of spraying the field trial, conditions were hot and drying, and indistinct band edges could possible have arisen from either the small amount of spray at the periphery causing temporary leaf edge burning, or from added splash out of the band due to the surface characteristics of the pasture (the pasture was longer in this trial than in earlier work).

This section of the thesis describes the techniques and results of the investigation into the pasture's role in causing spray to splash outside the band, and the amount of the total spray deposited here. At the same time, the spray pattern within bands was observed to check that the nozzles performed adequately at the low heights employed.

3.2. LITERATURE REVIEW.

3.2.1. SPRAY NOZZLE ACTION THEORY.

The action of spray nozzles in accelerating and disintegrating a liquid and dispersing the resulting drops has been well documented. Fraser and Eisenklam (1956), Pelij (1956), Courshee (1953), Byass (1963), and Westerman (1956) have each described the theory of spray nozzle action and the effect that the various parameters (liquid pressure, liquid surface tension, liquid viscosity, shape of nozzle internal passages etc.) have on the resulting population of moving droplets.

3.2.2. EVALUATION OF SPRAY DISTRIBUTION.

Many tests have been devised to measure different spray nozzle characteristics (e.g. output at different pressures), but it would appear that the majority of work on spray nozzle performance has been with reference to spray distribution. Methods used to analyse this may be classified into two groups:

I. Those measuring quantitatively the spray deposited in different spray regions (including drift measurements) and taking no account of droplet size.

II. Those measuring droplet sizes and numbers at the sampling points. From these results, spray volume and surface area may be calculated.

The distinction between spray volume and droplet size and number must be noted. Spray droplet volume is related to diameter cubed (d^3), and surface area to diameter squared (d^2) (Byass 1963). Thus a population of small droplets has a greater surface area than the same volume of spray in fewer droplets. In terms of quantity (volume), a cloud of small droplets can be of little consequence. For example, tests on a commercial nozzle (Anon 1958) showed that whilst 96% of the spray droplets from the fan nozzle were under 100 microns in diameter, only 4.1% of the spray by volume was represented.

Reported techniques relating to spray droplet population collection and evaluation are not considered in detail in this review. Hebblethwaite and Richardson (1961) described the techniques used by the National Institute of Agricultural Engineering in the testing of some of the more commonly used production model sprayers. Courshee (1954, 1959 and 1961), Courshee and Ireson (1961a); Courshee and Valentine (1959), similarly discussed various droplet collecting, sampling, and evaluation techniques, and debated the advantages and disadvantages of using different droplet sizes, and methods of producing these. Furmidge (1954) discussed the testing of several methods of calculating average diameter, including the mass median diameter, the Sauter mean diameter, and arithmetic mean diameter. Contour diagrams of spray distribution volume patterns illustrated the differences between methods, which were due to the use of different spray droplet parameters in the calculations. Fraser and Eisenklam (1956) discussed the problems in finding a truly representative parameter to describe a spray drop population and noted that disparities between theories and actual results were often evident.

I. Quantitative Spray Analysis.

Liljedahl and Strait (1959) described two categories of spray analysis methods:

(i) Those used in the laboratory and collecting the spray close to the nozzle.

(ii) Those testing field performance, the results of which are influenced by ground roughness, spray surface characteristics and wind.

(i) Laboratory Techniques.

These may be subdivided into two main types: those employing patternators and those using sprayographs.

A. The Patternator. Liljedahl and Strait (1959) described the patternator as a corrugated devide to divide the spray into narrow bands for volumetric measurement. It's function is to give an indication of the potential distribution likely from a nozzle. There appear to be two basic types of patternator, each of which has been described by Hebblethwaite and Richardson (1961) and Kashayap and Pandya (1965). The "one dimensional" (Hebblethwaite and Richardson) or "dynamic" patternator (Kashayap and Pandya) consisted of a series of parallel collecting troughs. It measured the spray distribution in one direction only and showed the pattern produced by a nozzle moving parallel to the troughs. Trough widths have varied from 1 in. (Anon 1958) to 2.7 in. (Barger et al 1948). Hebblethwaite and Richardson (1961) felt that patternators tended to distort the pattern, making it appear wider than in fact it was, with a decrease in the central readings due to the entrained air being deflected horizontally by the surface and thus taking droplets with it. Their design, incorporating unconnected partitions and troughs allowing air to move downwards through the patternator, was an approach to solving this problem.

The other basic type was the "static" (Kashayap and Pandya 1965) or "two-dimensional" patternator (Hebblethwaite and Richardson 1961), and has apparently been used for initial nozzle design and development work. Kashayap and Pandya (1965) illustrated two types. One consisted of a circular plate with collectors along several radii; the other was a series of rows of collecting vessels. This latter type could yield both "one" and "two" dimensional pattern data. The plotting of iso-quant lines on a graph enabled the construction of a spray concentration surface.

More use appears to have been made however, of the "one dimensional" patternator, probably because it yields data directly relating to the "moving nozzle" situation. It has been applied to performance studies of single nozzles (Crosbie 1952, Nordby and Haman 1956, and Dransfield 1965) as well as boom sprayers (Rice 1967 and Gabriilides 1964, 1965). Hebblethwaite and Richardson (1961) stated that "unless a nozzle gives a good performance on the patternator, it cannot apply chemicals in the most economical way possible".

B. The Sprayograph. Shanks and Paterson (1952), claimed that the sprayograph was originally designed by Riley in 1909. It was described by Hebblethwaite and Richardson (1961) as "an enlarged version of a focal place shutter camera with an absorbent paper in place of a film". The sprayograph's chief function is similar to that of the "two-dimensional" patternator, with results more of a qualitative (visual) than quantitative nature. Shanks and Paterson's design (1952) had a 3 in. slit in a continuous belt which moved at 200 ft./minute. Ink or a similar substance was sprayed on to blotting paper placed under the belt. Examples of the patterns produced have been reproduced in spray nozzle manufacturers' catalogues, as well as by Watt (1958), Courshee (1959), and Bainer et al (1955).

One particular complication was noted by Hebblethwaite and Richardson (1961). This was the disturbance of the airstream by the motion of the slit, which could bias the sample by deflecting small drops more than large ones from their flight path.

(ii) Field Performance Techniques.

With the exception of the direct weighing method (considered by Taylor (1961) to be inaccurate because of spray evaporation and the small amount of spray collected), quantitative field methods utilize the incorporation of a substance in the spray that can be collected and measured, and according to the spray's original concentration, the spray deposit calculated. At times, suitable commercial spray materials are used for this purpose. Such materials are useful in relating distribution results to the "control" or "kill" achieved.

Yates and Akesson (1963) considered the following factors to be important when selecting a tracer:

(a) High sensitivity of evaluation (suggested 0.01µg).

(b) Availability of a rapid quantitative analysis.

(c) Must be soluble in spray mixture with a minimum physical effect on atomization and droplet evaporation.

(d) Distinctive property to differentiate from background or naturally occurring substances.

(e) Stable or predictable concentration relationships under environments encountered during experiments.

(f) Moderate cost.

(g) Non toxic.

In addition, Taylor (1961) stated that tracers should be free from surface active properties. For instance, materials which lowered surface tension were concentrated in the surface layers and were liable to be disproportionately represented in the fine droplets.

Collecting materials have been of two general types: those which have standardised surfaces, such as the 9 x 4 in. plexiglass plates used by Yates (1962); and crop surfaces, sampled adequately to be representative. Plant leaves as spray collectors have been used particularly with those methods which evaluate spray distribution directly from "real" sprays (Martin 1956). Standardised surfaces tend to overcome the problem of test repeatability but the results from leaf surfaces may be more easily related to the actual field situation. In this respect, Hebblethwaite and Richardson (1961) discussed the advantages that might have arisen from the use of an artificial tree, which would have incorporated the best features of both methods. Many of these techniques have also been used for droplet distribution analysis. The fluorescent techniques of Staniland (1959) and Nordby and Steenberg (1959), and the dyed cards of Davis and Elliott (1953) are such examples.

Several types of tracer methods have been reported:

A. Direct Titration. Taylor (1961) described two direct titration methods. In the first, he sprayed sodium carbonate (at 20 lb. hydrated weight per acre) and titrated against standard acid and methyl-red indicator. He found that a 3% error (which he considered the maximum allowable) was difficult to attain. The technique he used eventually in his aircraft spraying work utilized magnesium sulphate (10-20 lb. hydrated weight per acre in solution). The washed sample was titrated against sodium ethylene diamine tetra-acetate (EDTA) with Eriochrome Black T dye as the indicator, which was buffered to pH 10. Error was easily kept as low as 3% of the mean.

Techniques measure either the spray chemical directly, or alternatively, a factor of this. Sharp (1959), for example, outlined a procedure for estimating small concentrations of lime sulphur in the range 4.8-0.05µl, titrating sequestric acid against the calcium of the lime sulphur. He did not comment on the accuracy of the method.

Direct titration methods appear to be used frequently for the setting up of other methods: For example, the visual preparation method of Davis and Elliott (1953), or for checking the correlation between commercial sprays and other tracers (Yates and Akesson 1963).

B. Colorimetry. Sander's Colorimetric Method has been adopted as a standard method in the United States according to Taylor (1961). A strong solution of dye is sprayed over flat ground and collected on 6 x 3 in. rectangular plates of stainless steel. These are washed with distilled water and the amount of dye present is measured by an electrophotometer. Sander's (1953) original technique utilised 20 in. diameter aluminium pans containing 500 c.c. water as collecting vessels. On landing, the spray made a dilute coloured solution, some of which was transferred by test tubes to the absorption cell of the photometer. A calibration curve allowed rapid evaluation but care had to be taken to ensure that the photometer dial was correctly read as any error would be magnified by the calibration curve. Taylor (1961) pointed out that the dyes used, although selected for light stability, necessitated quick collection and storage in the dark. Yates and Akesson (1963) considered this technique was insufficiently accurate for drift measurements.

Several methods appear to be a combination of direct titration and colorimetry in that a chemical analysis is used, although the results have been measured as a colour development rather than as titration end-point. These techniques often directly evaluate commercial sprays, or a known factor present at a standard concentration (copper of bordeaux and other sprays, Martin, 1952, 1955, 1956; sulphur, Krentos et al 1956; DDT, gamma-BHC, chlorbenside, Martin 1952). In Martin's technique, the three above-mentioned substances could be separately evaluated from the same sample. Application of these techniques to spray retention and weathering studies has been made (Somers and Pring 1966) on the tenacity of captan on leaf surfaces. Most workers appeared to be satisfied with the accuracy of their methods. For example, Martin (1956) in discussing the colour development of the blue copper complex, stated that in the 0-50 µg range, the result was unaffected by as much as 100 µg each of quite a long list of different ions.

C. Visual Appraisal. In this technique, the deposit (either a dye on paper, or solvent on dyed paper) showed as a contrast to the card background and could be compared with standard cards to estimate the amount of spray present. Davis and Elliott (1953) described a technique using an oil spray and a red oil-soluble dye in the collecting card, considering it to be more accurate than using dye in the spray. The technique has subsequently been used by others including Calpouzos and Theis (1960). It was considered by these latter workers to be valuable where large numbers of samples were to be taken (assessment could be more rapid than with other techniques); where durability of the sample was an asset (e.g. in forestry spraying where the retrieving of thousands of cards might take several weeks); and thirdly where high accuracy was not essential.

The standards used by Davis and Elliott (1953) were created by spraying closely spaced cards and aluminium plates. The deposits on the plates were analysed chemically and assumed to have the same amount of spray as the neighbouring card. Courshee and Ireson (1961b) considered that standards should be made up for each spray trial. Their samples were classified into groups and a few from each group chemically analysed. As a result, 80% of the subjective assessments were found to be wrong by less than 15% (they assumed the chemical analysis result to be correct).

Taylor (1961) considered the visual method inaccurate. Although it gave an indication of the size of the droplets at different parts of the swath, he thought it tended to make the distribution appear more even and the effective swath width appear greater than was actually so.

D. Radioactive Tracers. Nordby and Steenberg (1959) used these to study the distribution of spray chemicals on orchard trees. A fungicide was rendered radioactive by irradiation in a reactor. Activity measurements quantitatively determined the amounts of spray deposited on the leaves whilst radioautograms illustrated the distribution on single leaves. The accuracy of this technique was not discussed.

E. Fluorescent Tracers. Fluorescent dyes have been used for both quantitative assessment of spray deposits (Yates and Akesson 1963, and Liljedahl and Strait 1959), and for evaluation of the pattern of deposit (Staniland 1959 and 1960). Quantitative analysis techniques use some form of ultra-violet (U.V.) illumination, filters to cut out all light except that which corresponds to the presence of the tracer, a sensor (photo-electric cell) and an indicator or recorder. Liljedahl and Strait (1959) allowed for continuous across swath analysis whereas Yates and Akesson (1963) used this method as a sample evaluation technique. The latter used various filters in the light beam to enable two dyes to be sprayed together but analysed separately. Both pairs found good correlations between fluorescent values and the amounts of chemical present. Yates and Akesson (loc.cit.) compared fluorescent dyes with pesticide chemicals (Tedion, Thiodan, Ethion, D.D.T.), collecting drift deposits on both mylar sheets and lucerne and found correlations to be very close to unity. They considered it a "rapid highly sensitive, accurate, nontoxic, and moderate cost procedure". Liljedahl and Strait (1959) estimated the maximum inaccuracies of their procedure under adverse conditions to be in the order of 10 per cent.

F. Spectrophotometry. The principles are similar to those of fluorimetry, except that a metal ion is used as the tracer and is "burnt" in a flame to give a characteristic emission, which is analysed by some form of photometer and associated equipment. West (1967) described atomic absorption spectroscopy. Yates (1962) used a Bechman DU flame spectrometer.

As tracers he used commercial grades of manganese sulphate and strontium chloride because of their high intensity emission spectra, solubility, rarity in spraying situations (therefore little likelihood of contamination), and economy. Concentrations ranging from 0.1 p.p.m. to several thousand p.p.m. were analysed and compared with standard solutions to provide a rapid quantitative analysis. This technique was adaptable to the concurrent use of several compounds, Yates using the two mentioned.

3.2.3. USE OF PHOTOGRAPHY IN SPRAY INVESTIGATION.

There appear to have been two main applications of photography to spraying:

I. Studies of spray deposition.

II. Studies of spray atomisation.

I. Spray Deposition. Staniland (1959, 1960) and Patterson (1963) have illustrated with photographs the deposits of saturn yellow and other fluorescent dyes on leaf surfaces. The process is a simple one. The dye, either in suspension or solution, is deposited with the droplets on to the sprayed surface. Under U.V. light in the dark, the dye stains show as brightly coloured spots (red, yellow, orange, green or blue depending on the dye, Staniland 1959). Photographs can be taken providing the camera is fitted with a U.V. filter. Patterson (1963) noted that care had to be taken in interpretation as there were sometimes differences between impressions from photographic and visual inspections. The photographs have been used in test work as a method of providing a permanent record of levels of spray coverage (i.e. standard) for scoring purposes. Staniland (1959) made a thorough investigation of the technique and later (1960) applied it to the testing of spraying machines.

II. Spray Atomisation. Much of the recent work on atomisation with the use of photographic methods has been conducted at the High Speed Fluids Kinetics Laboratory of the Department of Chemical Engineering, Imperial College of Science and Technology, London (Fraser, Dombrowski, Eisenklam and Hasson). These studies have been on such subjects as the disintegration of liquid sheets (Dombrowski and Fraser (1954-55), flow characteristics of single orifice fan nozzles (Dombrowski 1961), and drop formation from rapidly moving liquid sheets (Fraser and Eisenklam, Dombrowski and Hasson 1962). Other studies of fluids in motion and sprays using photographic techniques include those of Brown and York (1962) who were interested in sprays formed by flashing liquid jets, and Thomas and Potter (1958) who used a vibrating jet to determine dynamic surface tensions.

Key factors in using photography to study sprays and high speed liquids are lighting and exposure methods. Fraser and Dombrowski (1956) described eleven techniques that illustrated and elucidated phenomena associated with the disintegration of liquid sheets.

(i) Exposure Methods. Fast moving objects may be photographed either with the use of high speed shutter mechanisms or by means of a light flash of very short duration. The fastest mechanical shutters have a duration of the order of 500µs, during which time spray drops of an average size may travel as much as one hundred times their own diameter. Rapid light flashes with an effective duration of only a few micro-seconds can be produced by electrical discharges, and were considered to provide the only practical method of obtaining "still" photographs of spray particles (Dombrowski and Fraser 1954). Longer exposures have been used with special lighting effects to show different characteristics of sprays. Fraser and Dombrowski (1956) illustrated two spray characteristics with longer exposures: viz. thickness of sheet and how it varied as the sheet expanded, and direction of flow within the sheet as it passed through the rim of the sheet into the atmosphere. In the first, the exposure time was 0.02 secs., and in the second 0.01 secs.. This time was necessary in the first for the light to be reflected into the camera during some period of the wave motion, and in the second, to allow particles reflecting light to move far enough to enable the tracing of their path in the spray.

(ii) Lighting Methods. Fraser and Dombrowski (1956) concluded from their work that satisfactory results from spray photography could not be achieved through use of only one lighting technique as each method showed different features of the spray. They described four lighting methods:

(a) Diffused front light. This method was considered to be of little value with liquids unless they were milky or opaque as in emulsions or suspensions, or where a particle streak photograph was desired.

(b) Diffused rear illumination used for transparent illumination, the absorption being enhanced by the additions of suitable dyes.

(c) Specular reflection. In this method the amount of light reflected depends upon the reflectance increasing as the angle increases up to a maximum at grazing incidence. The width of the sheet will therefore be reduced because of the large angle which the camera must be to the sheet.

(d) Rear lighting with parallel light. This is the shadow or "shadowgraph" technique where parallel light (either with lenses or distant source) passes through the spray on to a plate, leaving a shadow pattern.

Fraser and Dombrowski (1954) described techniques used in the photography of spray sheets and the effect of different lighting methods and exposure times, and in 1954 discussed many of the factors affecting the disintegration of liquid sheets.

3.3. METHODS AND MATERIALS.

3.3.1. THE SPRAYER.

To enable simulated field trials to be undertaken an experimental sprayer was constructed.

I. Important Design Requirements were:

(i) Liquid pressure had to be adjustable and in the 15-25 p.s.i. range (in order that droplet velocity could be minimised, thus reducing splash from low heights of discharge as had been done in the field trials).

(ii) The power source should be convenient for indoor use.

(iii) Provision had to be made for spraying a variety of liquids without the possibility of contamination from residue left in the pump or regulator.

(iv) A means had to be found of simulating the field condition of a moving nozzle at a constant height above a sprayed pasture surface.

II. Design Details.

The last named requirement was largely fulfilled by the availability of a tillage and tool testing apparatus for turf samples (Baker 1969). This had a moving tool carrier suitable for the mouting of a small sprayer and infinitely variable speeds up to 2 m.p.h. in both directions. The m.p.h. was actually slower than the 2.6 m.p.h. used in the field but was the maximum available with this apparatus.

The sprayer consisted of a 1 H.P. electric motor coupled to a "Hypro 6000"[1] pump operating at 285 r.p.m., and hose fed from a 4 gallon kerosene tin modified for quick filling. Delivery was via a conventional pressure regulator and $\frac{1}{2}$ in. hose to a quick shut-off valve at the bottom of the fluid-isolating pressure vessel. Location of this valve on the exit side of the pressure vessel would have been desirable, for when the valve was closed there was several minutes' flow from the bag before the nozzle stopped spraying. It was possible to minimise this discharge by switching the sprayer off, and allowing the pressure in the pressure vessel to be released back through the pump, before turning off the valve. The pressure vessel was specially designed to fulfil the third requirement named above. The main cylinder was of 6 in. steel tube ($\frac{1}{2}$ in. walls), 10 in. long, with a $\frac{1}{4}$ in. plate bottom and a 1 in. thick steel flange at the top with a 1 in. wide upper surface (Fig.11). The removable circular lid of $8\frac{1}{2}$ in. diameter was $\frac{5}{8}$ in. thick with a $\frac{1}{8}$ in. brass liner.

1. Manufactured by Hypro Engineering Inc., Minneapolis, Minn., U.S.A.

All fittings at the top of the cylinder were brass, as they were in contact with the sometimes corrosive sprayed fluid. Located at the bottom of the vessel was a $\frac{1}{2}$ in. nipple for water entry and a $\frac{1}{4}$ in. nipple and draincock; in the lid a $\frac{1}{2}$ in. outlet nipple and a $1\frac{1}{4}$ in. filling plug. The lid fittings were brazed directly to the brass lining plate and passed loosely through the $\frac{5}{8}$ in. steel top plate. Gauze over the outlet hose in the brass plate was to prevent the bag from being squeezed thro' the hole together with its contents. A removable bent metal strip served the same function in relation to the filling plug when in operation.

The test nozzle was clamped to a steel rod, mounted on to the tool carrier, thus providing adjustment of the nozzle vertically, laterally and for orientation. A large collection tray of galvanised iron was placed on the bed of the tool testing apparatus. Drainage from the tray was through a hole at its centre, into a bucket.

III. Operation.

In operation, a 12 x 15 in. plastic bag (approximately 1 gallon capacity) has its upper edges placed between the top surface of the pressurised flange and the brass liner plate and is sealed by means of rubber rings. All components are clamped with five external "G" clamps. The top filling plug is removed, the bag filled with spray material, and the plug replaced. The pump is turned on and the quick shut-off valve opened. Water, entering the liquid isolating pressure vessel displaces the bag and in so doing ejects it's contents at the same liquid pressure through the delivery line to the nozzle.

IV. Testing the Pressure Vessel.

The pressure vessel output was tested to ensure that:

(i) Output did not vary as the bag emptied.

(ii) The sprayer output using the isolating bag did not vary from that when the bag was absent and the system was used with an uninterrupted liquid passage. The pressure bag was filled and the time taken for the first seven pints sprayed at 25-26 p.s.i., using a "Monarch 6.4 HC" nozzle. This was repeated three times. The bag was then removed and four successive pints timed. An analysis of variance showed that successive pints with the bag were significantly different at the 5% probability level. (Appendix IX for further details).

The greatest variation between successive pints was between the sixth and seventh. It appeared that this was due to the bag partially blocking the outlet when the bag was nearly empty. As the first 6 pints gave about 14 minutes' spraying time with the largest nozzle used, it was considered that use of the bag was satisfactory provided it was not allowed to discharge more than 6 pints before recharging. A subsequent test using the smallest nozzle ("Spraying Systems $\frac{1}{4}$Y 1.5") did not show this trend at the end, possibly because the flow rate was nearly quarter that of the largest nozzle used; thus one would expect there to be less tendency for the bag to be pushed over the gauze. Differences between timings with, and timings without the bag were found to be insignificant at the 5% probability level (means differed by 0.2 sec.). Rates within the safe range were therefore assumed to be unaffected by the pressure of the bag.

3.3.2. SPRAY DISTRIBUTION ANALYSIS METHODS INVESTIGATED.

In order to determine the extent to which spray discharge in bands from single nozzles close to the ground bounces on pasture, spray distribution analysis methods suitable for work with pasture were investigated.

I. The Quantitative Method Used for Measurement of Deposit on a Blotting Paper Surface.

The patternator principle for laboratory work was considered valuable in establishing bounce patterns using plane surfaces, but for several reasons the conventional design was discarded:

(i) As band widths were as narrow as 1 in. in one case, trough distances would have to have been no wider than about $\frac{1}{4}$ in. to yield meaningful results.

(ii) With a moving spray nozzle, it was considered doubtful that there would be sufficient volume of spray collected to measure accurately.

Collection Technique. Because the questions being examined were of an investigatory nature, rather than a detailed study, it was felt that as simple a collection and analysis technique as possible would be attempted. The experience gained in devising and refining a simple technique would be invaluable in the development of a more complex one if needed at a later date. (In this thesis work development would only take place if the simple technique did not enable the question of degree of bounce to be answered). A technique was evolved using a combination of the patternator principle and a Techtron AA - 3 atomic absorption spectrophotometer.

The use of the flame photometer first and the atomic absorption spectrophotometer later enabled the measurement of small amounts of sodium or copper from the spray. (Copper solutions could be measured to 0.1 p.p.m.). The simplest collector for this spray was blotting paper. To enable a transverse distribution graph to be drawn, blotting paper strips were laid parallel to the direction of travel of the nozzle. The strips were $\frac{1}{4}$ in. wide and were guillotined from 17 in. long sheets and taped at their ends to a sheet of glass; the glass was marked by parallel scratches at $\frac{1}{2}$ in. spacings to enable rapid placement of the strips).

PRESSURE VESSEL:
CROSS SECTION DIAGRAM

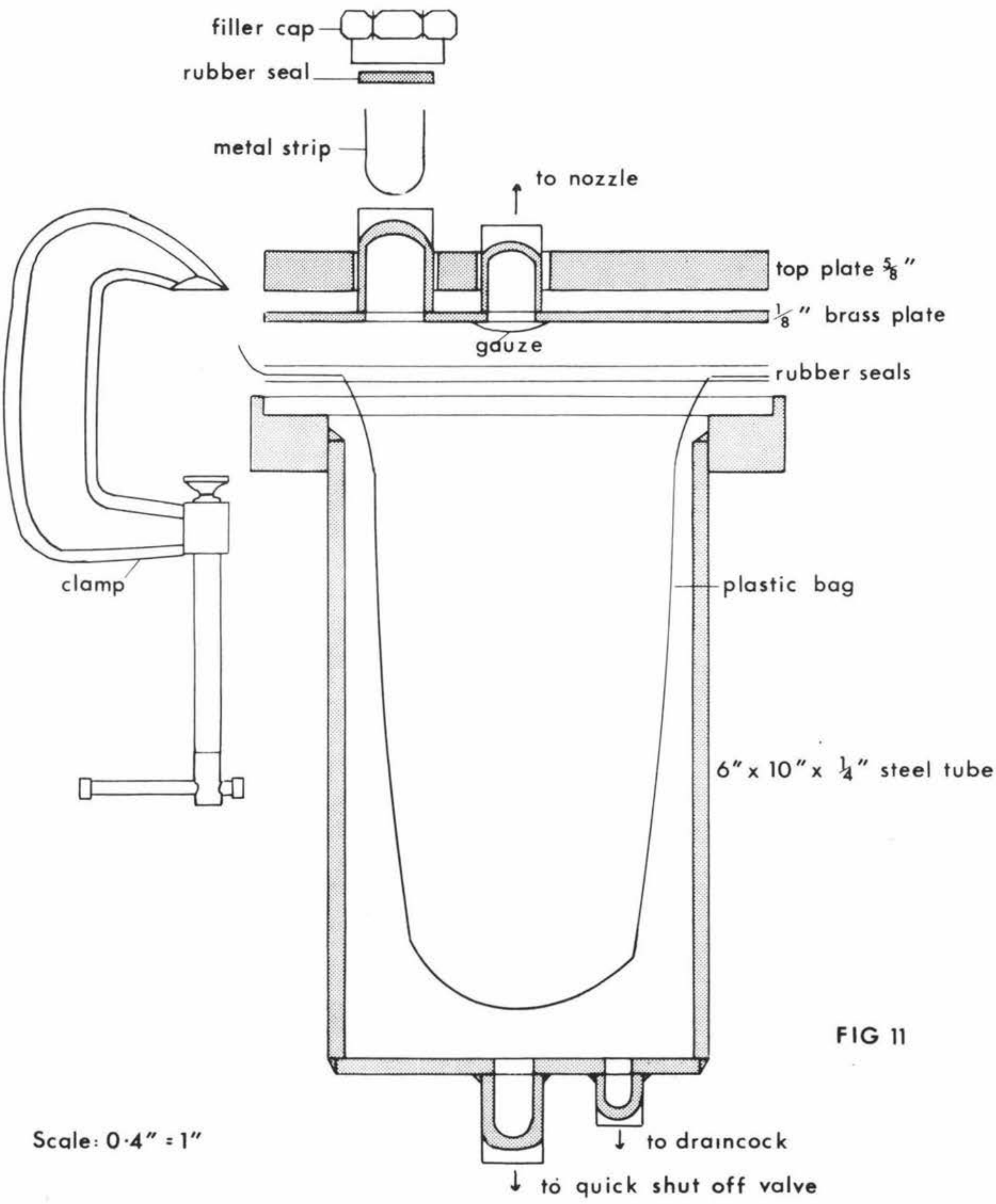


FIG 11

Scale: 0·4" = 1"

Collection on Blotting Paper. Initially, the 12 middle inches of the strip were cut out for spray evaluation, but during several trials, it was found that the strip length could be reduced to 6 in. and then 5 in.. With 6 in. strips, two measurements of the same strip could be taken; with 5 in. strips, three. It was felt that the extra information might add precision to the data. This data would show the pattern within the band; whether it looked "conventional"; and also give some indication of the degree of bounce outside the band.

Flame Photometer. In the initial trail work a Gallenkamp flame photometer was used and sodium chloride solution sprayed. This instrument is less precise than the atomic absorption spectrophotometer but was more quickly set up for operation. In operation, the sodium (or potassium) solution is burnt in a flame and the intensity measured by a photocell, giving a current displayed by a galvanometer. Standards were used to enable the plotting of a calibration curve (galvanometer reaching versus p.p.m.) and to ensure that the galvanometer needle did not "drift". The degree of drift was found to be tolerable for measurements within the band deposits but excessive for measurements of the deposit outside the band. Thus, the flame photometer and sodium chloride was abandoned and replaced by the adoption of the atomic absorption spectrophotometer and copper sulphate.

Spraying Rate. By rough calculations of the amount of the element required for analysis, dilution rates due to the acid, collecting areas, and spraying rate/area, 10 gm. sodium per litre of distilled water was thought to be a suitable concentration (25 gm. sodium chloride per litre). This solution was found to be suitable and trails A, B and C were carried out with this concentration. Later, when copper was used, the rate of the element per litre was doubled and 50 gm./litre of copper sulphate used (20 gm. copper). This was helpful because bounce measurements were the major consideration and deposits were naturally low in these outer strips. Also, less area was used at this stage to collect the spray (5" x $\frac{1}{4}$" versus 6" x $\frac{1}{4}$" versus the earlier 12" x $\frac{1}{4}$").

Laboratory Techniques. After spraying, the strips were cut into short pieces and placed in test tubes or small conical flasks, depending on the volume of acid used. The strips had been ruled into 12, 6 or 5 in. lengths before spraying. The container was given the strip number and sequence (i.e. "a", "b" or "c"). The acid used to elute the salt from the paper was 2N nitric for the sodium and 2N hydrochloric for the copper. Volumes of acid used varied, depending on the position of the strip in the spray swath. Fifty, forty, twenty-five, twenty, ten, five and two ml. were used in different trials at different times. (See Table XXIX). Two ml. was about the lowest volume that could be evaluated. The measurement was taken by sucking the solution through a fine tube into the flame. The rate of flow was about 1 ml. every 7-10 sec. Needle stabilisation time with 2 ml. was limited but found to be sufficient after practice. In between reading each test tube, acid was sucked through, to both clean the apparatus and prevent any "memory" effect, and to check that there had been no "drift".

Standard solutions were made up by weighing out the correct amount of salt for the strongest standard and diluting with the right quantity of water, and from this diluting for the other standards.

II. <u>The Measurement of Spray Deposition on Pasture.</u>

(i) <u>Visual or Qualitative Methods tried Unsuccessfully.</u>

A. <u>Fluorescent Tracers.</u> It was hoped initially, that by spraying pasture with a suitable dye, the spray distribution pattern might be visible under U.V. light and therefore possible to record photographically. Two dyes, Fluorescein and Rhodamine BN 450 were chosen for trials because of their availability. Very clear patterns were produced on blotting paper, but on pasture, the pattern was only visible when the spray was present as droplets. On drying there was no fluorescence on either soil or pasture. Spectrophotometric methods appeared more promising at this stage so further trials with other soluble dyes or dyes in suspension (such as Saturn Yellow, used successfully on foliage by Staniland (1959 and 1960)) were discarded.

B. <u>Paint Pigments and other "Visual" Techniques.</u> With the initial failure of fluorescent dyes in spray distribution investigation, other substances were investigated. Water plus the pigment of an orange acrylic paint were mixed to form a suspension and sprayed on to pasture. Orange was chosen as the greatest colour contrast to green. When photographed, the contrast possible would be heightened by the use of an orange filter on the camera. However, the material did not show up under concentrations of about 1:20 and it was felt that the operating characteristics of the nozzle might change if either a greater concentration of pigment, or paint itself, were used.

The above methods were discarded because of initial failure and the promising early results from the use of a metal ion tracer with quantitative evaluation by the flame photometer.

The use of the visual tracer substances presented the question of a true photographic indication of the spray distribution; the problem being that a portion of spray was deposited under the leaves and was therefore not visible from the camera situated above.

(ii) <u>Quantitative Techniques.</u>

A. <u>Measurement Directly on to Pasture.</u> Application of quantitative methods directly to pasture would have been difficult. Sampling areas would have to be small to enable a meaningful evaluation of the spray band, yet, with a spraying surface like pasture it would be extremely difficult to accurately divide the sample up into these areas. Perhaps if one sprayed a substance which was unknown in the soil and a "grid core sampler" constructed, this might be possible. The term "grid core sampler" refers to a hypothetical device designed to cut the pasture and soil below into the required areas. Careful removal and elution for a period of time with an acid to remove the tracer might enable precise measurements to be made. This idea was not followed up.

B. The Indirect Method Adopted. Initial trials with spectroscopic work on blotter were so promising that the application of this technique to the collection of spray on pasture was conjectured. Pasture and blotting paper are two entirely different surfaces. Pasture is multiplaned, with the planes at all angles and a hard shiny surface. The latter phenomena tends to cause droplet bounce whilst the angularity of the planes has the opposite effect of absorbing bounce. The blotting paper collectors, on the other hand, have a horizontal plane surface that is absorbant.

Much thought was given to the ways in which the blotting paper strips could be placed in the pasure. All were complicated and of questionable validity. The simplest method was that eventually used. This experiment was confined to the use of the conejet nozzle of the $3\frac{1}{2}$ in. band (i.e. "Monarch 6.4 HC"). A pasture strip of this width was cut and placed as accurately as possible, at the correct distance below the nozzle (the nozzle centred to the strip and its path parallel with the strip). Strips of blotter were taped to sheet glass as before, to cover $4\frac{1}{2}$ in. either side of the band at the level of the soil. This took no account of secondary bounce i.e. drops which would bounce again in the pasture. The strips did however, collect all spray except the amount that might bounce beyond $4\frac{1}{2}$ in. from the band edge, thus answering the question of the amount of spray that bounced outside the band and providing an estimation of where it was distributed.

Trial	Element and Concentration	Length & No. of $\frac{1}{4}$ in. strips per observation	Spraying Surface	Analysing Machine	Elution Volumes	Nozzles Used	Total No. of Runs
Initial	Na, 10 gm./1	12 in, 1	Blotting paper	Flame photometer	10ml. 20ml. 50ml.	Monarch 6.4 HC $3\frac{1}{2}$ in. band	2
A	Na, 10 gm./1	12 in, 1	Blotting paper	Flame photometer	10ml. 20ml. 40ml.	4.6HC $\frac{1}{4}$Y 1.5 FS 2.5	3
B	Na, 10 gm./1	6 in, 2	Blotting paper	Flame photometer	5ml. 10ml. 25ml.	6.4HC 4.6HC $\frac{1}{4}$Y 1.5 FS 2.5	8
C	Na, 10 gm./1	5 in, 3	Pasture collecting splash on blotter	Flame photometer	2ml. 4ml. 6ml.	6.4HC	3 left & right sides
D	Cu, 20 gm./1	5 in, 3	Blotter, pasture	*	2ml.	6.4HC	6

* Atomic Absorption Spectrophotometer

Trial Comments

Initial: Both sets of results lost due to unfamiliarity with procedure.

Trial A: Dilutions found to be excessive, wasting of acid.

Trial B: Procedure now fairly familiar. Technique suitable for band width - not for splash. Didn't plot standards.

Trial C: Plotted standards but couldn't obtain linear graphs so discarded results.

Trial D: Didn't plot standards but steadiness of dial needle enabled direct comparison of results.

Table XXIX. Summary of Quantitative Analysis Trials Showing Development of Technique.

3.3.3. PHOTOGRAPHIC TECHNIQUES.

Requirements considered important for a photographic technique were:

(i) A fast shutter speed to "freeze" the spray as much as possible. This would tend to clarify the spray and allow drop size comparison within the spray and to make the spray more distinct from any background.

(ii) Illumination of the spray to make it appear distinct from the background.

(iii) As small a field of view as possible to allow the maximum enlargement.

These requirements were met in the following ways:

(i) A brief survey of readily available photographic equipment lead to the use of a 1/900th sec. exposure. This was achieved with a professional electronic flash unit set on half power. The shutter speed on the camera was about 1/50th of a second necessitating the taking of the photographs in the dark so that exposure of the film took place only after the flash duration.

(ii) Illumination of the spray was difficult. Several unsuccessful attempts were experienced with the flash unit set up on the same side of the spray as the camera. The optimal setting was found to be with two flash heads set 45 degrees to the axis of the camera, 3 ft. from the spray and on the opposite side of the spray to the camera. (Fig. 11 (a).

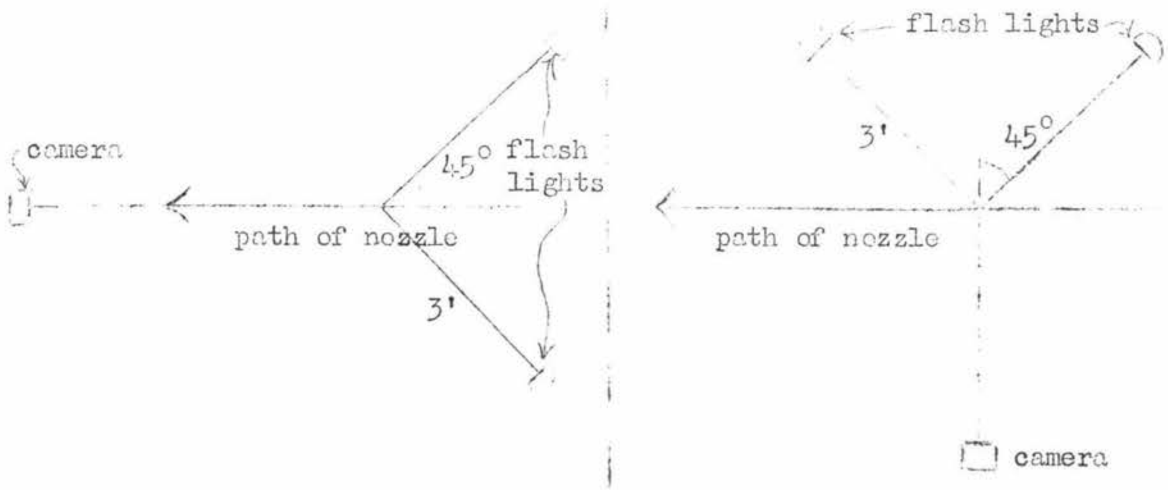


Fig. 11 (a). Diagram of Flashlight and Camera Positions related to the Photographing of the Moving Nozzle.

(iii) The camera used was an Asahi Pentax S1a with bellows and 100 mm. lens. This resulted in a narrow angle lens, which enabled the camera to be mounted a safe distance from the sprayer and yet have a small field.

In the procedure eventually used, the camera was mounted at the same level as the sprayed surface and with a horizontal axis. When the sprayer was photographed with the tool carrier moving towards the camera, the latter was mounted on a tripod just beyond the end of the track on which the tool carrier travelled. The flash heads were placed either side of the track and both they and the camera pointed at, and focused on the nozzle and sprayed surface when the tool carrier was stationary. A chalk mark on the rail at the position of the leading tool carrier wheel enabled the firing of the camera and flash units by cable at the right moment.

When taking the photographs side on to the direction of travel, the camera was positioned on one side of the tool carrier rails. Again, a chalk mark was used as a "firing point". When taking a photograph the focussing and setting up was carried out with the tool carrier and spray nozzle positioned correctly. Then the tool carrier was backed down the track, sprayer turned on, and the tool carrier set in motion at the correct speed. The white chalk mark could be only vaguely seen in the gloom and so a torch was set to shine on it, yet not interfere with the photographic results. As the leading wheel of the tool carrier crossed the chalk mark on the rail the cable release was triggered and the hand-operated clutch of the tool carrier drive disengaged. Below (Table XXX) is a precis of the trials carried out, and illustrates the gradual development of the technique.

Trial No.	Daylight or Dark	Flash position and no. of heads	Nozzles used	Surfaces sprayed	Head on or side on
1	Daylight	Near camera, 1	Monarch 6.4 HC	Glass, Pasture	H.O.
2	Dark	Near camera, 1	FS 2.5 6.4 HC	Glass	H.O. S.O.
3	Daylight	Near camera, 1	6.4 HC	Pasture	S.O. H.O.
4	Dark	Backlit, 45% to camera axis, 1	6.4 HC	Glass, Pasture, Blotter	S.O. & stationary nozzle for glass
5	Dark	Backlit, 45°, 2	$\frac{1}{4}$Y 1.5 6.4 HC FS 2.5	Pasture, Glass, Paper, Velvet	H.O.
6	Dark	Backlit, 45°, 2	$\frac{1}{4}$Y 1.5 6.4 HC FS 2.5	Pasture, Glass, Paper, Velvet	S.O.

Comments on Results

Trial No. 1: Camera too great an angle to horizontal. Splash seen indistinctly on glass but not on pasture.

Trial No. 2: Background visible even when black crepe paper used as background. Splash visible in side on shots, but indistinct.

Trial No. 3: $CaCO_3$ powder in spray, but splash still not very distinct.

Trial No. 4: Spray showed up well. Stationary shots indicated that two flash heads could balance the illumination.

Trial No. 5: Better positioning of flash heads required for equal illumination on right and left sides of the spray.

Trial No. 6: Results satisfactory.

Film Speed ASA 32 (trial 1, 2 and 3) or 50 (trial 4, 5 and 6). Camera - Asahi Pentax S1A, Flash units 3 ft. from subject, 1/900 sec. flash.

Table XXX. Summary of Details of Photographic Technique Development.

3.4. RESULTS AND DISCUSSION.

3.4.1. SPECTROPHOTOMETRIC ANALYSIS.

I. Trial Results.

Results of Trials A and B were reasonably valid for the "within band" or "peak" areas of spray distribution. Deposit outside the band limits was much lower than within band levels and as the flame photometer exhibited a tendency to be unsteady and "drift", little reliance was placed on the accuracy of these figures (Figs. 12-20 and Appendix IX).

In trial D, the spectrophotometer was much steadier, and it was thought that the use of standards could be avoided. However, it was impossible to plot all values on the one setting of the flame slit as centre values were off the dial scale. Overlapping readings of samples in the common area were recorded to enable the plotting of correlation coefficients. These, however, varied so much (although graphing showed the shapes of the curves to be similar) that there was no conversion of results from one "scale" to the other. Statistical analysis was concentrated on the runs that recorded the splash from pasture on to blotting paper, viz. runs 4, 5 and 6.

The standard curves plotted from trial C data were not linear due to either an error in the making up of standards or to a curvilinear relationship between the photometer reading and the element concentration. The cause of this trouble was not investigated. Suggested improvements to the analysis technique include:

(i) The use of copper sprays.

(ii) Analysis with an atomic absorption spectrophotometer.

(iii) The plotting of standards anticipated.

(iv) Extra dilution of the higher value samples to enable them all to be evaluated at the most sensitive (i.e. parallel) slit edge setting.

(v) Conversion of all results to p.p.m. of copper to enable direct comparisons to be made.

II. Discussion.

(i) Distribution Within the Band.

The graphs constructed from trials A, B and D reveal several important features (Figs. 12-21).

A. Distribution Graph Shapes. The distribution graph shapes tended to correspond to those obtained by other workers. The hollow cone nozzles (with the possible exception of the 1 in. band nozzle which had a single spike shaped distribution (Figs. 12 and 14)) have a double peaked distribution. These results correspond to those of Crosbie (1952) and Anon. (1958) whilst Kashayap and Pandya (1965) illustrated similar graphs drawn from hollow cone nozzles. The fan nozzle used was of the eliptical orifice type, described by Dombrowski and Fraser (1954) as "type D" with a single peak. Graphs from the Delevan FS 2.5 nozzle tended to have several peaks (usually 3 or 4) over a wide plateau falling sharply away at the edges (Figs. 19 and 20).

B. Band Definition. Distribution was difficult to define, as the boundary between "high intensity" and "low intensity" areas was indistinct and covered several $\frac{1}{4}$ in. strip widths. The $3\frac{1}{2}$ in. band, sprayed with a cone jet nozzle (Figs. 17, 18 and 21) may be considered 2-4 in. in width depending on the level of spray considered lethal. The 2 in. bands (Figs. 13, 15 and 16) had edges with a boundary over 2-3 strips each side and so varied from $1\frac{1}{4}$-$2\frac{1}{2}$ in. in width. The 1 in. bands (Figs 12 and 14) varied in shape according to the trial. In trial A (Fig. 12) there was a centre "spike" with two small spikes at the edges, bands varying in width from $1\frac{1}{2}$-$2\frac{1}{4}$ in.. In trial B (Fig. 14) there was a centre spike and width varied from 1-$1\frac{1}{2}$ in. depending again on the point taken as the "edge".

Fan nozzle widths (Figs. 19 and 20) were slightly greater in these trials than initially calculated, being run at 20 instead of 15 p.s.i. Theoretical width from the calibration graph was therefore nearer 4 in. and it was this width which was taken for later calculations. The range was 3-$5\frac{1}{4}$ in.. A "boundary" effect was observed in the initial work connected with finding the correct nozzle heights. This was a mixture of dyed and blank patches which varied in ratio and colour intensity. The latter effect was less marked than the former. Band width measurements were taken to the middle of the strip.

C. Between and Within Run Differences. Differences were noticed between and within runs of the same nozzle pressure and height. These may be either real or apparent. An apparent difference could result from unsteadiness in the galvanometer reading of the flame photometer whilst a real difference might arise from a change in the actual spray distribution over time. As standards were not satisfactorily taken at any stage, runs evaluated at different times were not strictly comparable. Often, 2 or 3 "sequences" of the same run appeared comparable (Figs. 15 and 16). The differences between sequences were more likely to be due to real differences in the spray than were differences between runs. When the tool carrier was moving at 2.0 m.p.m. and the distance between centres of sequences 6 in. the time lapse was approximately 1/6 sec.. There appears to have been no work done with patternators with short spray collection times. With some exceptions (e.g. Figs. 17 and 21) the general shapes of sequences within runs were similar. In this instance the exceptions may have been due to a partial nozzle blockage.

A further difference explicable only by a partial nozzle blockage is that between run 1 and 2 of trial B with the 1 in. band (Fig. 14). The standards taken at the time would indicate that run "a" peaked at more than twice the value of run "b".

(ii) Quantification of Differences.

The question of how best to express these differences within bands involved several possible solutions. Holly (1956) used a coefficient of variation calculation taking the middle 11 in. of the nozzle swath. This figure, he explained was not statistically correct but gave some idea of the variability. Gabriilides (1964) used the coefficient of variation over a boom sprayer pattern, thus eliminating the decision concerning band width. However, the choice of band width is likely to greatly alter the result and therefore a coefficient of variation has little real meaning in this band spraying situation.

A simpler calculation expresses the range as a percentage of the mean, but as this offered no suitable alternative in the choosing of the band width this method was also discarded.

(iii) Distribution Outside the Band.

A. Spray Directed Towards a Blotting Paper Surface. The unsteadiness exhibited by the photometer's galvanometer made the reliability of "outside band" deposits from trial A and B less than desirable. However, the data available allowed estimates of the amount of deposit fallen outside the bands to be made. The percentage of spray falling outside the bands was obtained by taking a "blank paper" reading for the same area from all samples. The "blank" reading was not always available, but on the basis of later results which indicated that most of the deposit was about 1 in. either side of the band, the use of an estimate slightly lower than the lower figure obtained was considered sufficient for the precision of the method.

Band Width	Trial (Series), Run and Sequence													
	A	B				D								
		1a	1b	2a	2b	1a	1b	1c	2a	2b	2c	3a	3b	3c
1"	34.7	7.6	4.7	6.0	12.0									
2"	6.4	2.8	2.0	2.9	3.2									
3½"		8.9	3.3	5.4	5.3	2.1	2.0	2.4	2.1	2.7	2.4	4.8	4.8	4.2
4"	6.3	8.8	6.7	1.1	5.3									

Table XXXI. Percentage of Spray Landing Outside the Band. (Spraying on Blotting Paper).

All percentages of spray outside the bands are below 10% with the exception of the 1 in. A series which is nearer 35% and has a band width of almost 2 in. This nozzle was troublesome and did not operate well at 20 p.s.i. with the conical sheet often being drawn in rather than opening to its fullest extent (Plate 25). Presumably the wider the swath measured, the greater the spray catch. The results generally corrobcrate this. The majority of spray outside the band was in the first quarter to half in. either side of the band.

B. Spray Specifically Directed on to Pasture. In trials C and D pasture strips were used as described above (Section 3.3.2.II.B). Trial C results were discarded because of the curvilinear standards curves resulting. Trial D compared bounce on both pasture and blotting paper. The measurements outside the "band width" for runs 1, 2 and 3 of trial D were abandoned because of the lack of confidence that could be placed on data converted from that obtained from one slit setting to that of the other. The results of runs 4, 5 and 6 were more useful as they were all read with the slit in the same position. Observations were as follow:

(a) Alignment of the Nozzle with the Strip. A consistent alignment error was evident. The strips on the left hand side of the grass strip were consistently higher than those on the right, and showed in an analysis of variance to be highly significant. Whether this was due to the nozzle not being "normal" to the strip, or the spray angle of the nozzle being greater one side of the centre than the other, is not known.

The question arose as to whether the right hand side collected spray bounce from the edge of the pasture strip and the left hand side collected some spray directly from the nozzle and therefore also spray bounce from the blotting paper. Alternatively, did the left hand side collect bounce from pasture only and the right hand side collect less than all the bounce ? Further investigation by photography would be needed to adequately answer this question.

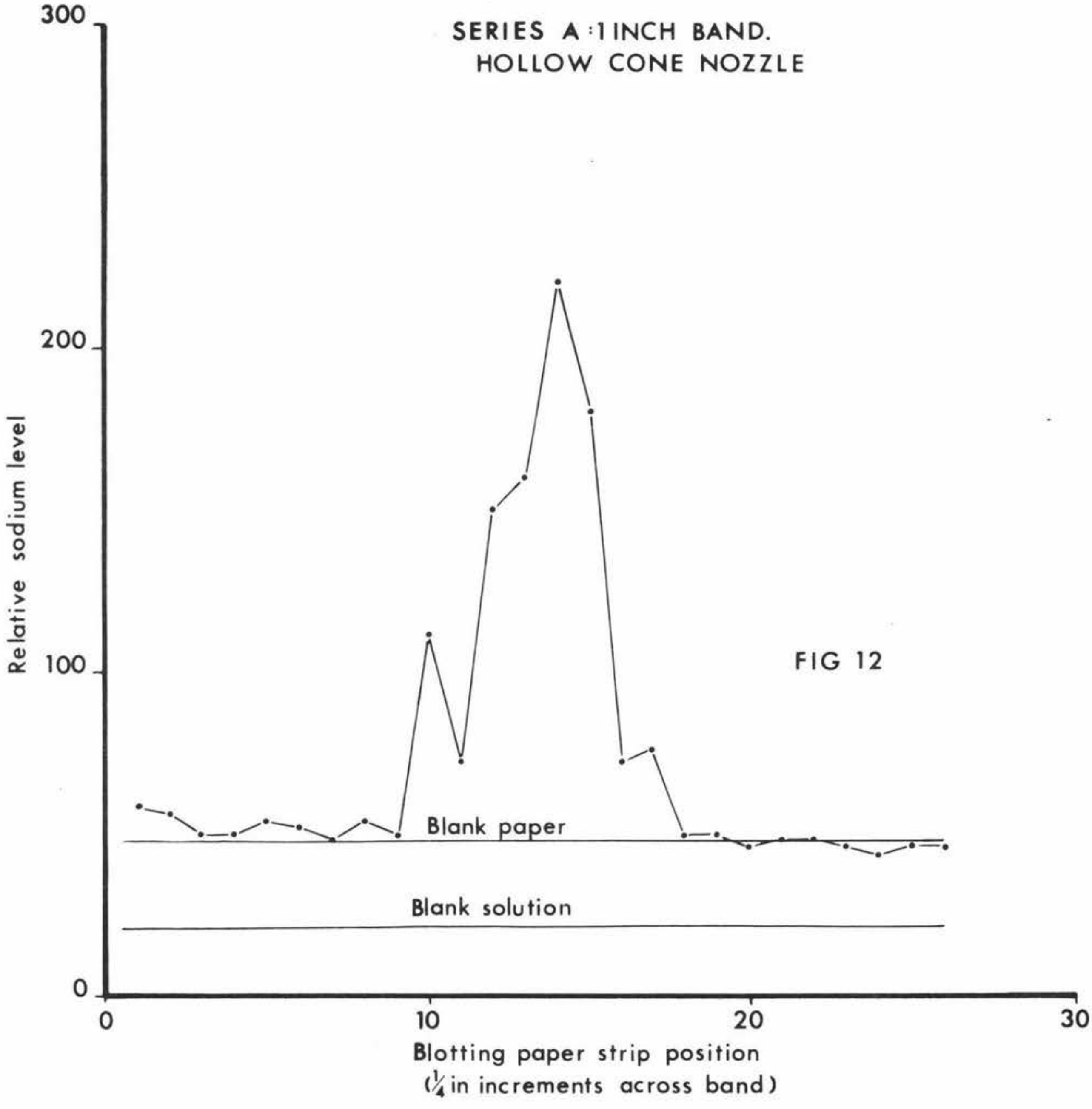
(b) Shape of the Graph. Initially, the curve running away from the band edge fell rapidly but later became much more gradual. This would indicate that the majority of bounce was in the first 1 in. from the band and if both sides are considered, within a total band width of 6 in. - an average of $1\frac{1}{4}$ in. either side of the band (band width $3\frac{1}{2}$ in.). Comparison of similar points and values for the graphed results taken at the different slit positions showed the high values to be of little significance compared with the total curve. For example, strip 14 of run 1, sequence "b", had a similar value to that of run 5, left side, sequence "a", which was about 12-14% of the peak value of run 1, sequence "b", and about 20% of the mean value of the band itself (Appendix X).

(c) Statistical Evaluation of Results.

(i) Analysis of Variance. A log. transformation was carried out on the data from runs 4-6 of trial D because of the range in values. These varied both from the closest to furthest strip from the band edge and from similar strip positions on the right and left sides. The resulting graph is illustrated by Fig. 22. The analysis used was a 3 x 2 x 18 x 3 factorial, the factors being blocks, side, lateral position (i.e. strip number), and sequence. Blocks, side and lateral position mean squares were tested against side and lateral interactions. Sequence and sequence interactions with side and lateral position were tested against error (residual). Sides and lateral position were found to be highly significant and blocks and sequence very significant at the 1% probability level (Appendix XI for log. transformed figures).

The use of different terms for deriving the F ratio appear to have an effect on the resultant ratio, but in this case the side lateral position interaction is larger than any of the other possible error terms even though the resulting ratios are rather high. The differences between the various sides and lateral positions are significant statistically. The differences between the means of blocks and sequences were not high but the small error term has made the differences significant.

(ii) Confidence Levels. Confidence levels for both 99% and 95% levels were plotted for both transformed and untransformed mean data (Fig. 22). The value for blank paper was assumed to have no variance. Whereas with the log. transformed data, confidence could be placed at the 99% level out to the 14th strip from the band edge (i.e. 3½ in. out either side), confidence could not be placed in the untransformed data after the third strip.


SERIES A: 1 INCH BAND.
HOLLOW CONE NOZZLE
300
200
100
0
Relative sodium level
FIG 12
Blank paper
Blank solution
0
10
20
30
Blotting paper strip position
(¼ in increments across band)

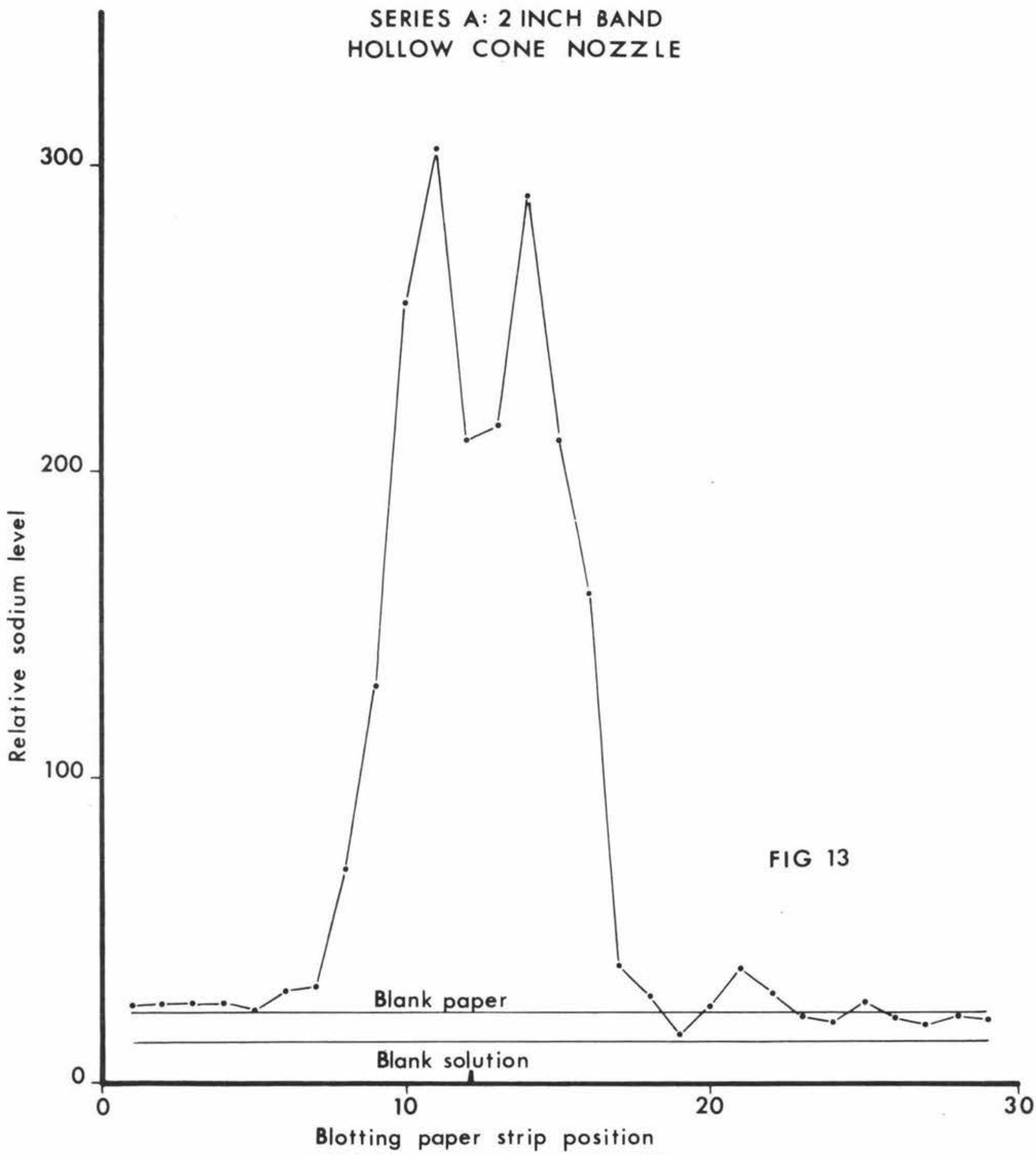

SERIES A: 2 INCH BAND
HOLLOW CONE NOZZLE
300
200
100
0
Relative sodium level
Blank paper
Blank solution
0
10
20
30
Blotting paper strip position
(1/4 in increments across band)

FIG 13

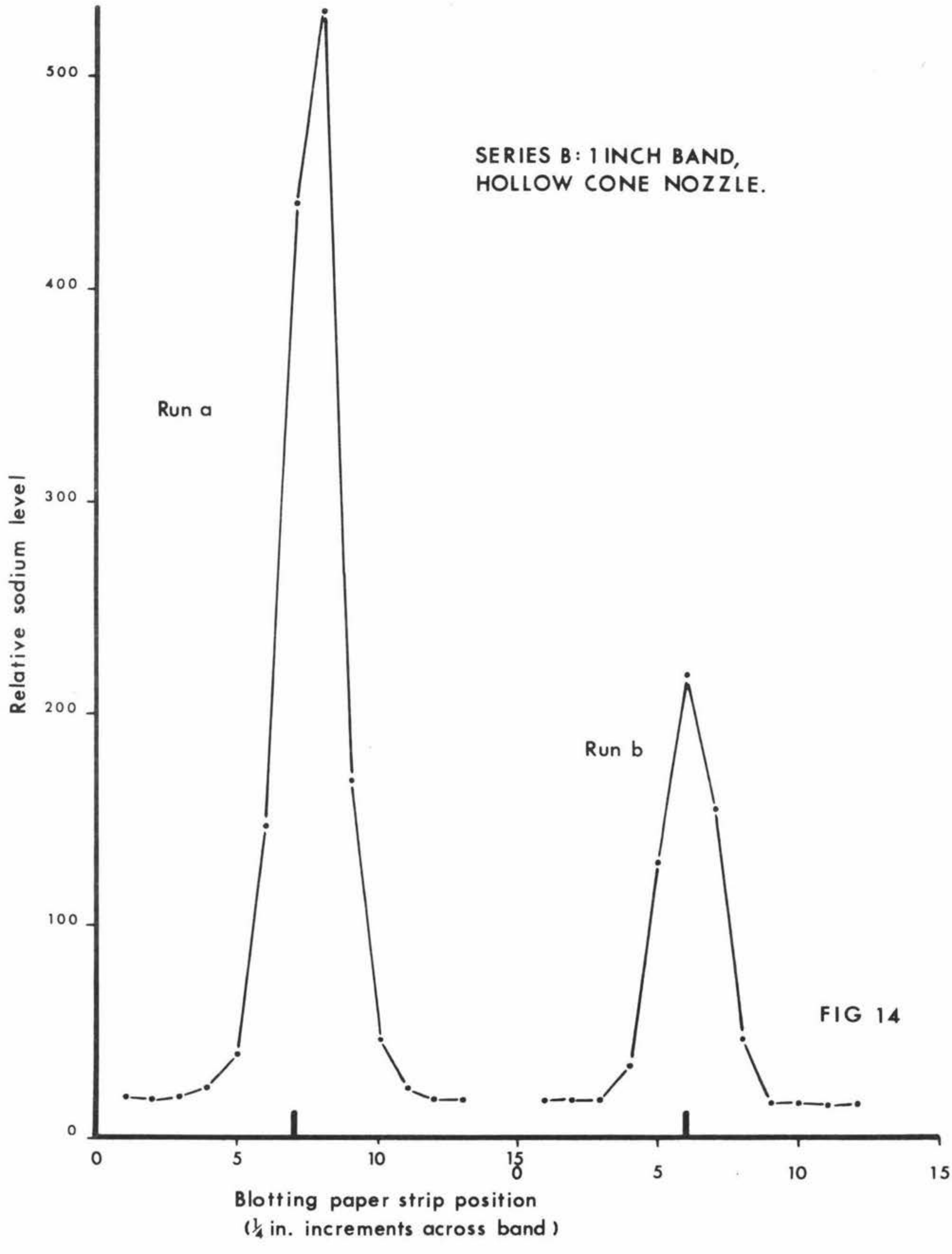

SERIES B: 1 INCH BAND,
HOLLOW CONE NOZZLE.
Run a
Run b
Relative sodium level
500
400
300
200
100
0
0
5
10
15
0
5
10
15
Blotting paper strip position
(¼ in. increments across band)

FIG 14

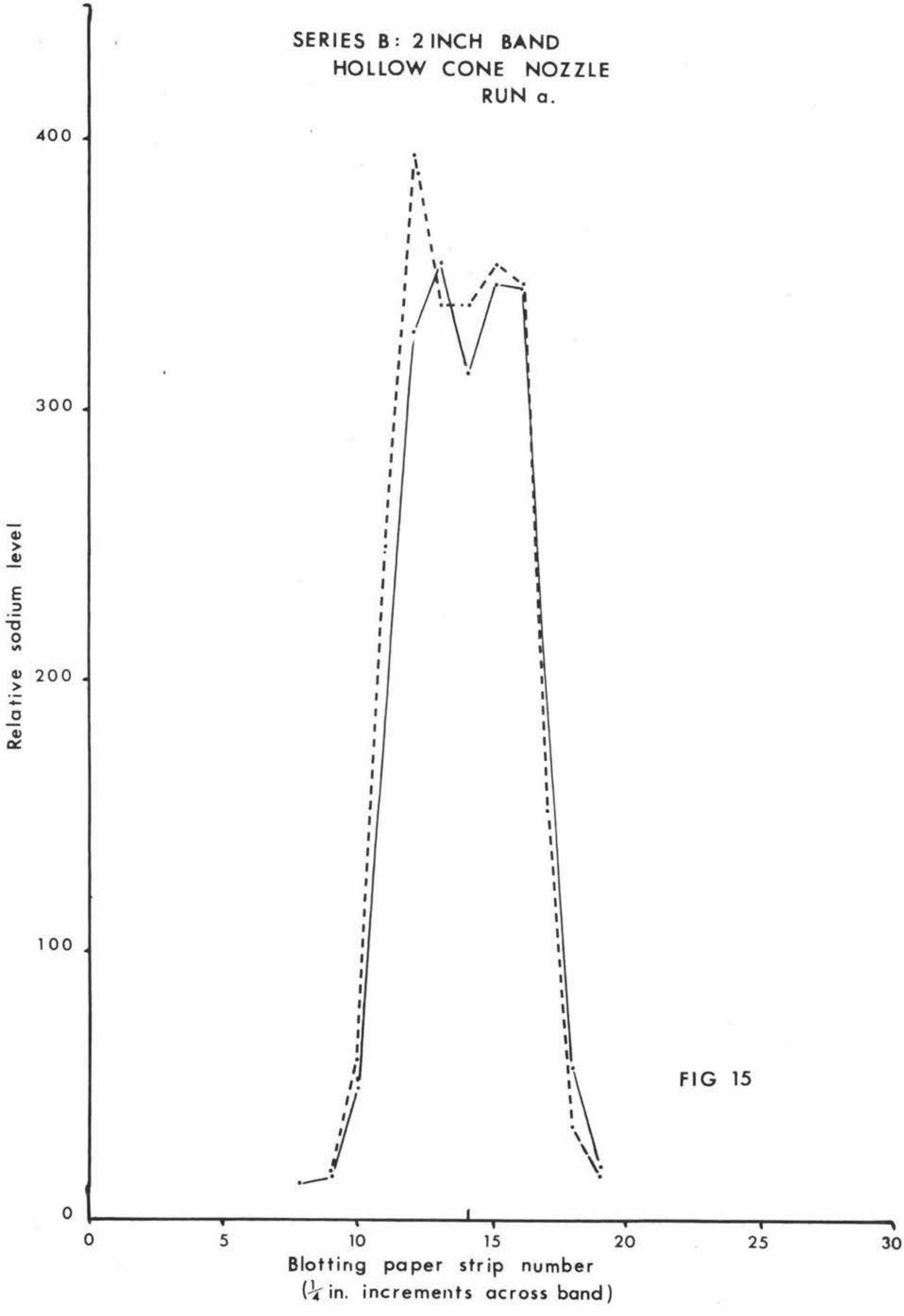

SERIES B: 2 INCH BAND
HOLLOW CONE NOZZLE
RUN a.
Relative sodium level
400
300
200
100
0
0
5
10
15
20
25
30
Blotting paper strip number
($\frac{1}{4}$ in. increments across band)

FIG 15

SERIES B: HOLLOW CONE NOZZLE. 2 INCH BAND.

RUN b

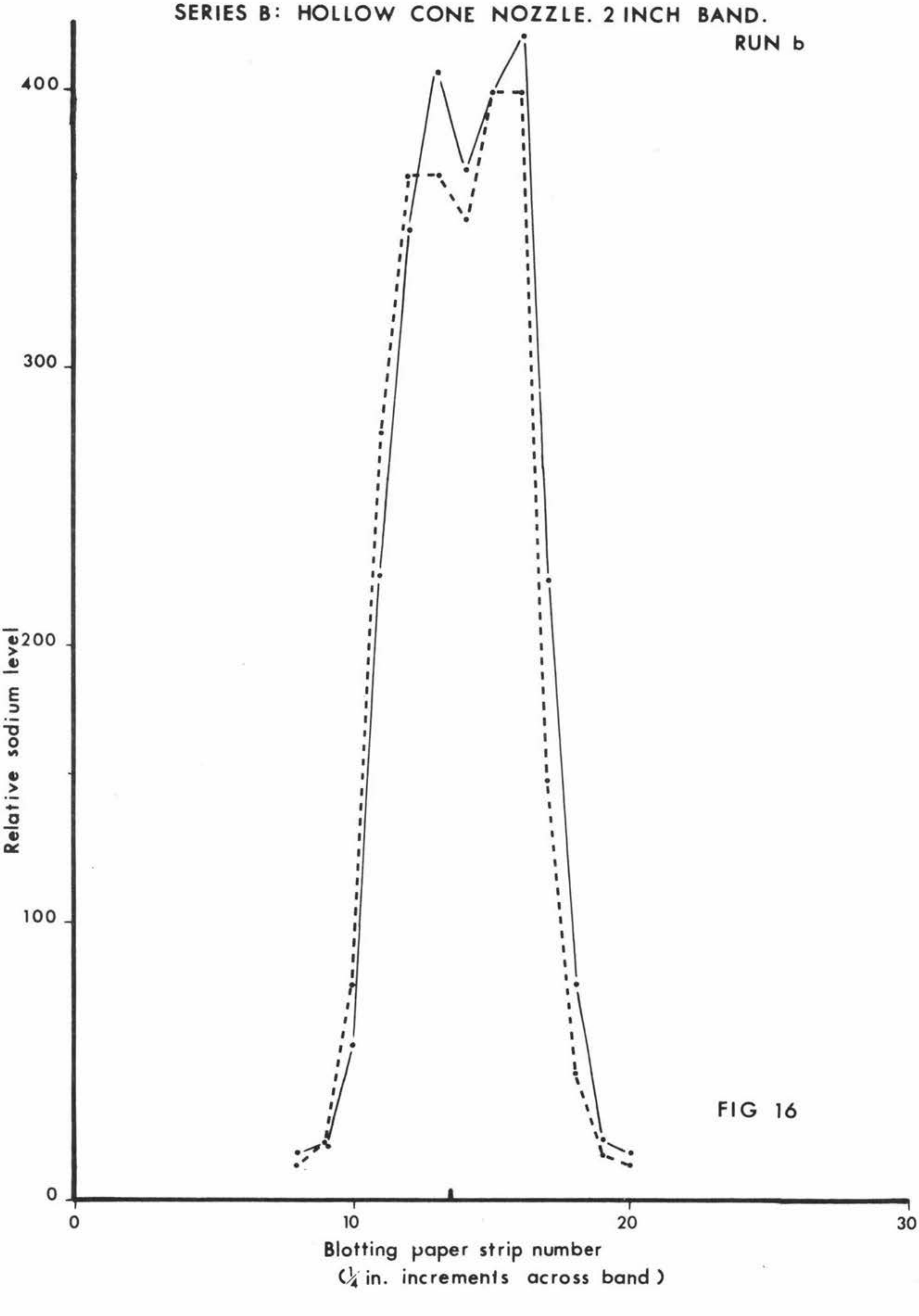
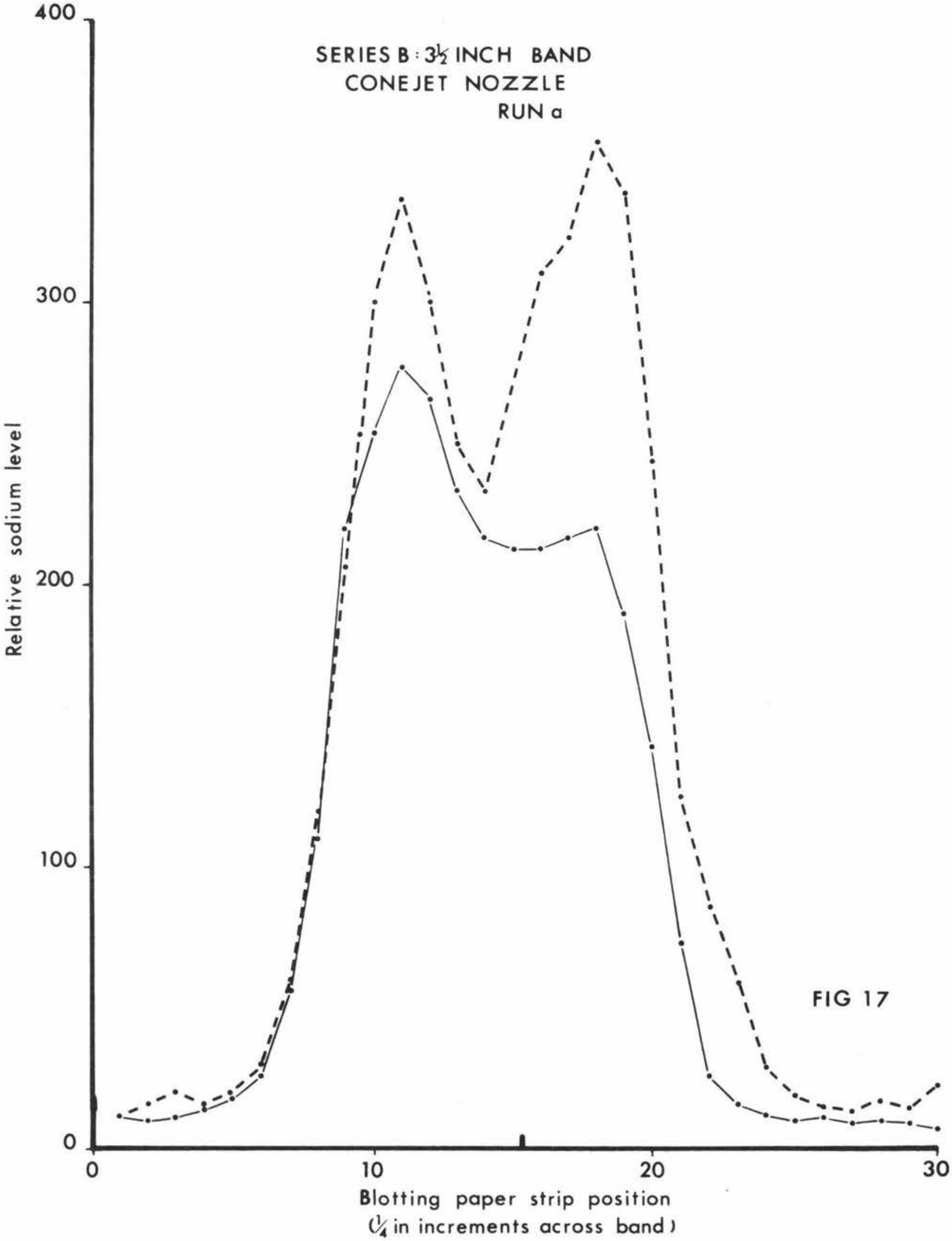


FIG 16



400
300
200
100
0
SERIES B : 3½ INCH BAND
CONEJET NOZZLE
RUN a
Relative sodium level
0
10
20
30
Blotting paper strip position
(¼ in increments across band)

FIG 17

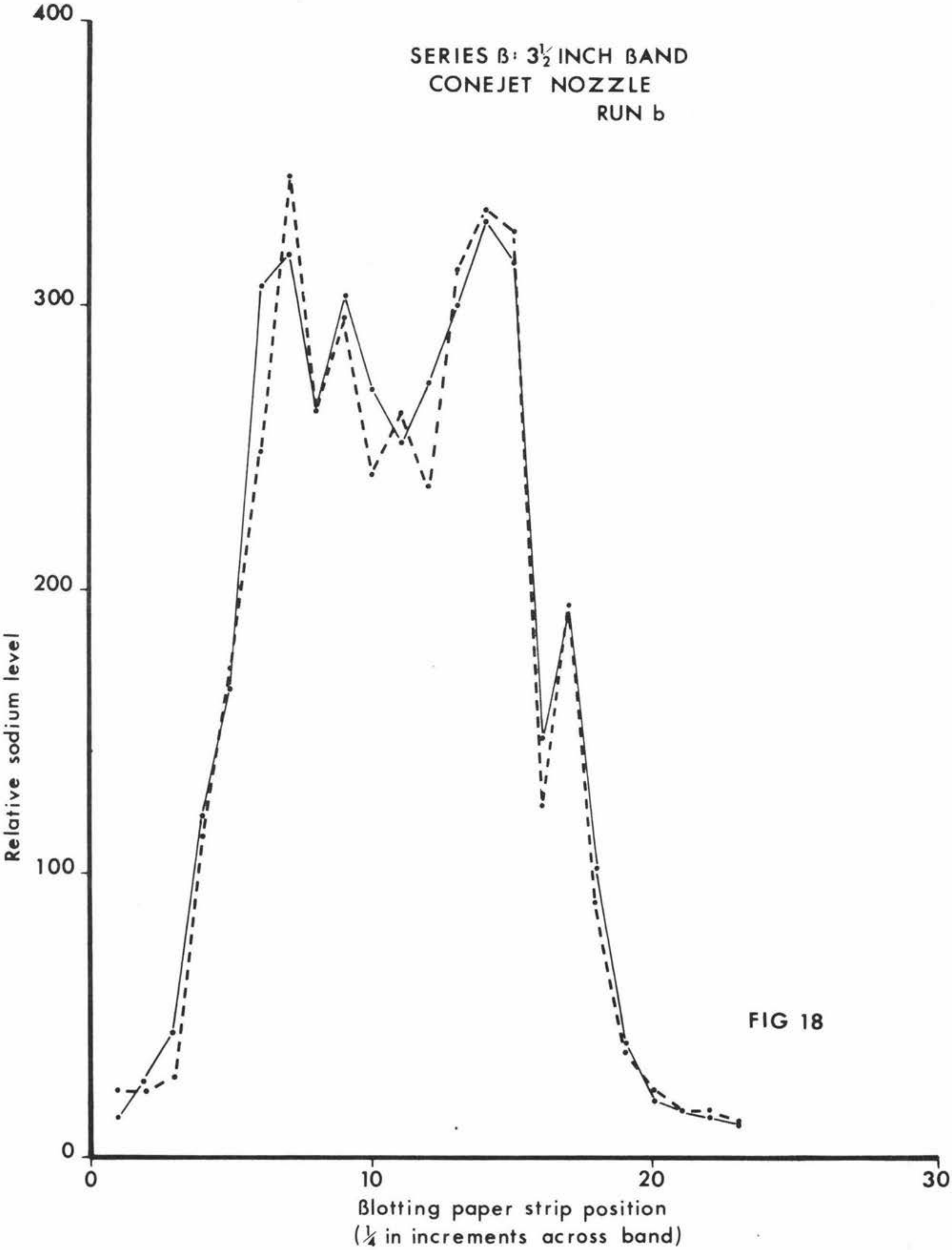

SERIES B: 3½ INCH BAND
CONEJET NOZZLE
RUN b
400
300
200
100
0
Relative sodium level
0
10
20
30
Blotting paper strip position
(¼ in increments across band)

FIG 18

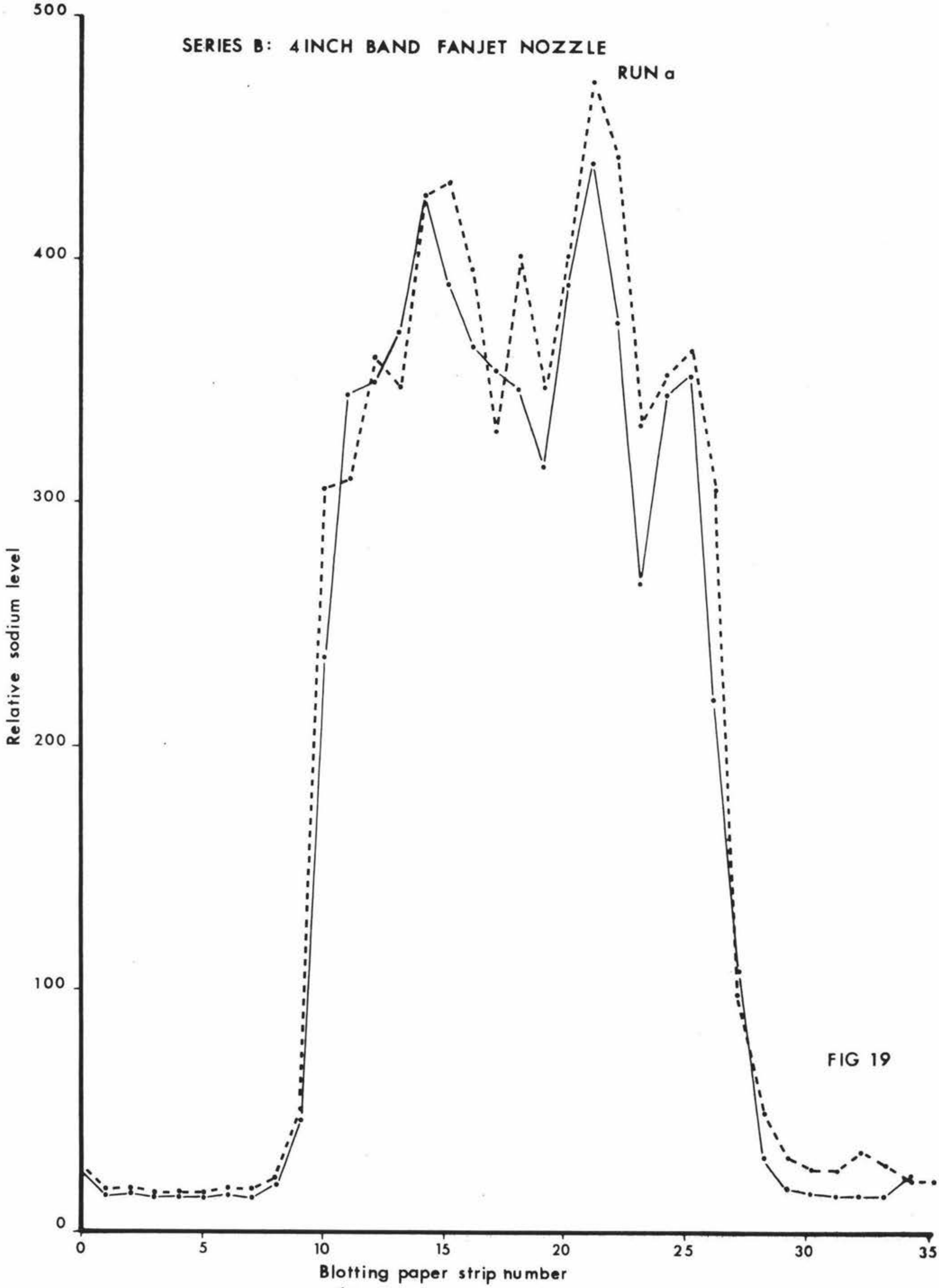

SERIES B: 4 INCH BAND FANJET NOZZLE
RUN a
Relative sodium level
500
400
300
200
100
0
0
5
10
15
20
25
30
35
Blotting paper strip number
(¼ in. increments across band)

FIG 19

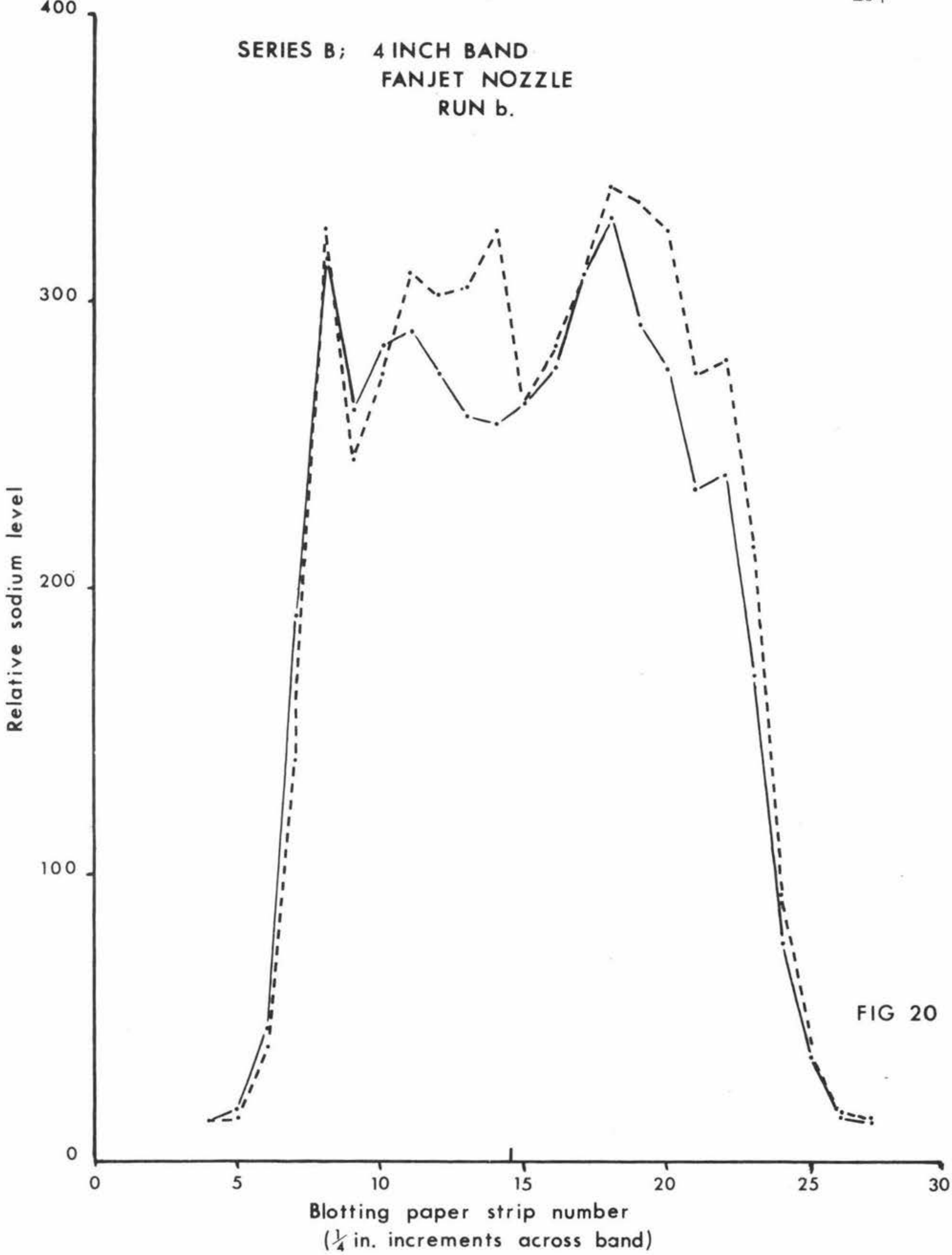

SERIES B; 4 INCH BAND
FANJET NOZZLE
RUN b.
Relative sodium level
400
300
200
100
0
0
5
10
15
20
25
30
Blotting paper strip number
(¼ in. increments across band)

FIG 20

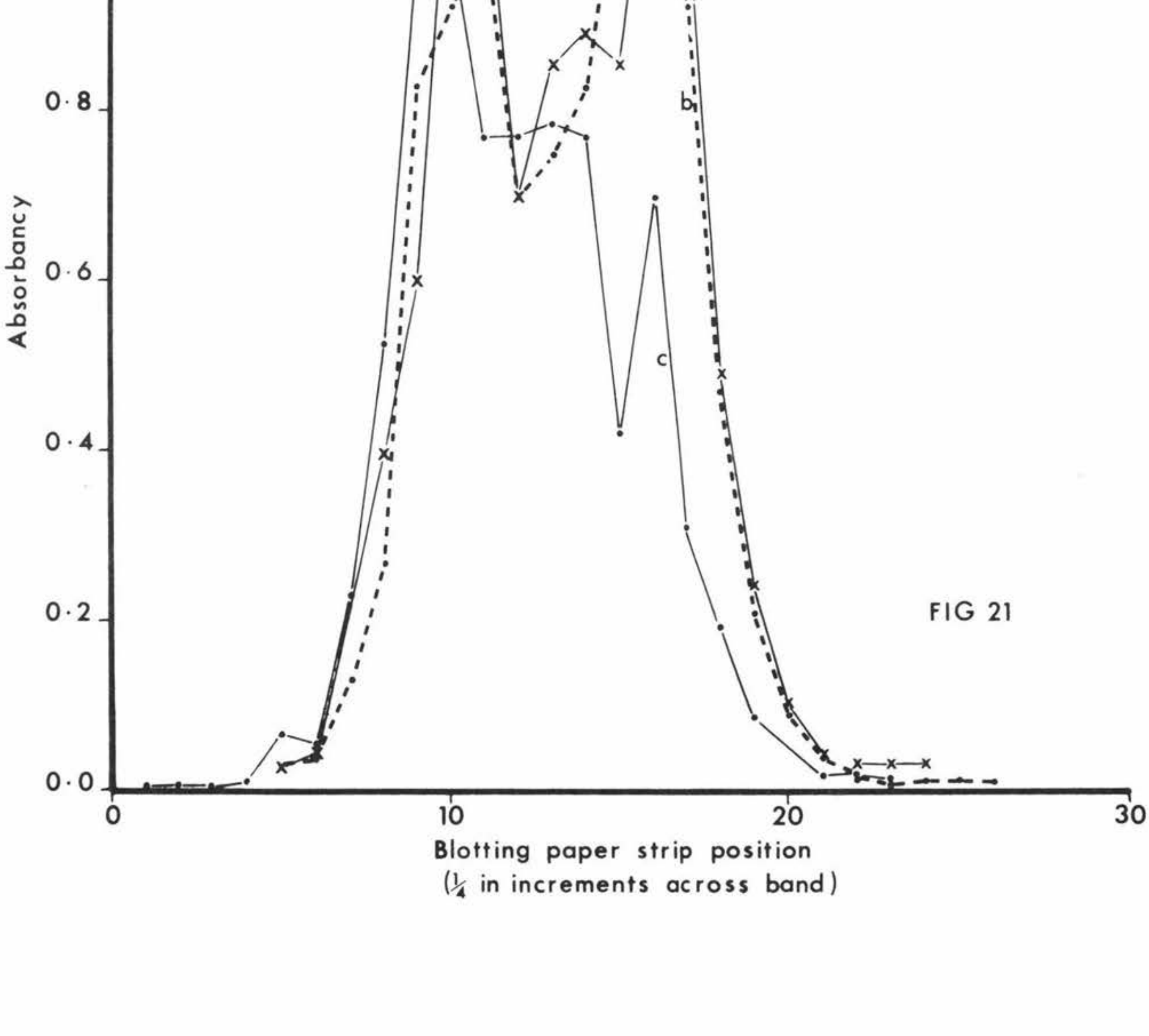

SERIES D: 3½ INCH BAND
HOLLOW CONE NOZZLE
1·2
1·0
0·8
0·6
0·4
0·2
0·0
Absorbancy
a
b
c
0
10
20
30
Blotting paper strip position
(¼ in increments across band)

FIG 21

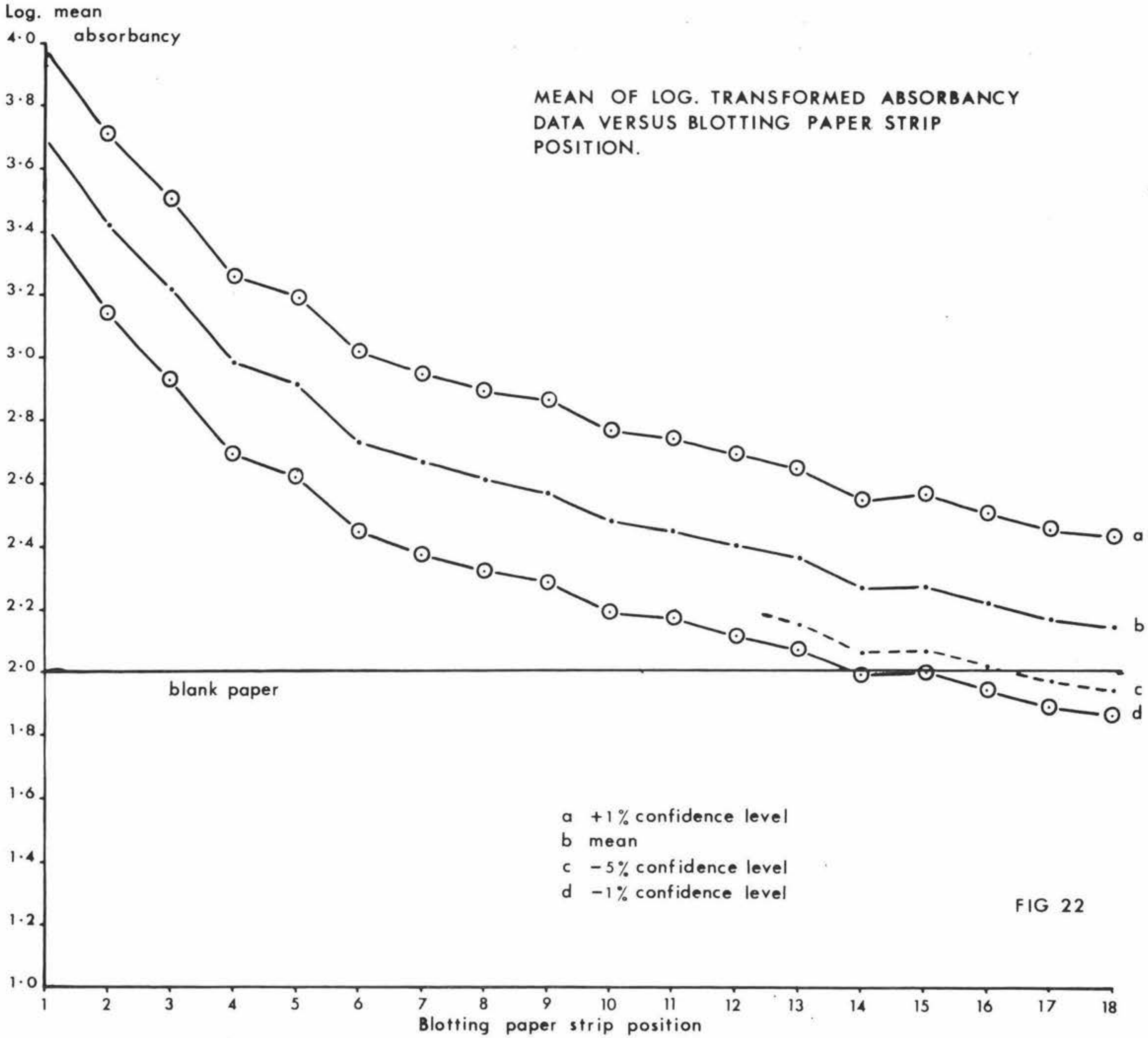

Log. mean absorbancy
4·0
3·8
3·6
3·4
3·2
3·0
2·8
2·6
2·4
2·2
2·0
1·8
1·6
1·4
1·2
1·0
MEAN OF LOG. TRANSFORMED ABSORBANCY DATA VERSUS BLOTTING PAPER STRIP POSITION.
blank paper
a
b
c
d
a +1% confidence level
b mean
c −5% confidence level
d −1% confidence level
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Blotting paper strip position

FIG 22

3.4.2. PHOTOGRAPHIC RESULTS.

I. Effect of Recording Technique.

Before drawing conclusions from the photographic material it is first necessary to understand the effect that variables of the technique have on the resulting photograph.

(i) Lighting: The combination of a focussed beam and an object travelling at 3 ft./sec. allowed little room for error. This alignment problem would account for some of the differences between the left and right hand side of the photograph (Plate 15).

Plate 15. Delevan FS 2.5 Fanjet, 3 in. Height, Spraying on to Felt Surface (Head on View).

(ii) Droplet Size: Droplets which were outside the field of focus appeared fuzzy or abnormally large, depending on the position of the droplet in relation to the focal point.

(iii) Dark Room Technique: Negative films were developed in a standard developer. However, different enlargement size of the prints and exposures produced variable results which could lead to error in interpretation. (Plates 16 and 17). Plate 16 is enlarged to a slightly greater extent and is less exposed than Plate 17. The spray appears to bounce to a greater height in 16, but many of the droplets are out of focus coming toward the camera and thus appear higher because of a "parallex" effect.

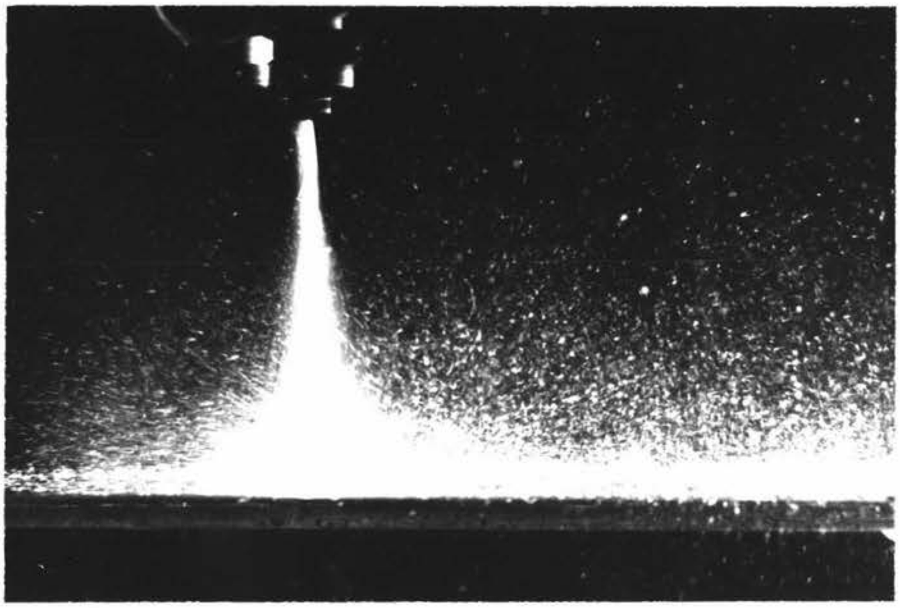


Plate 16. Delevan FS 2.5 Fanjet, 3 in. height, Spraying on to Glass Surface (side on view).

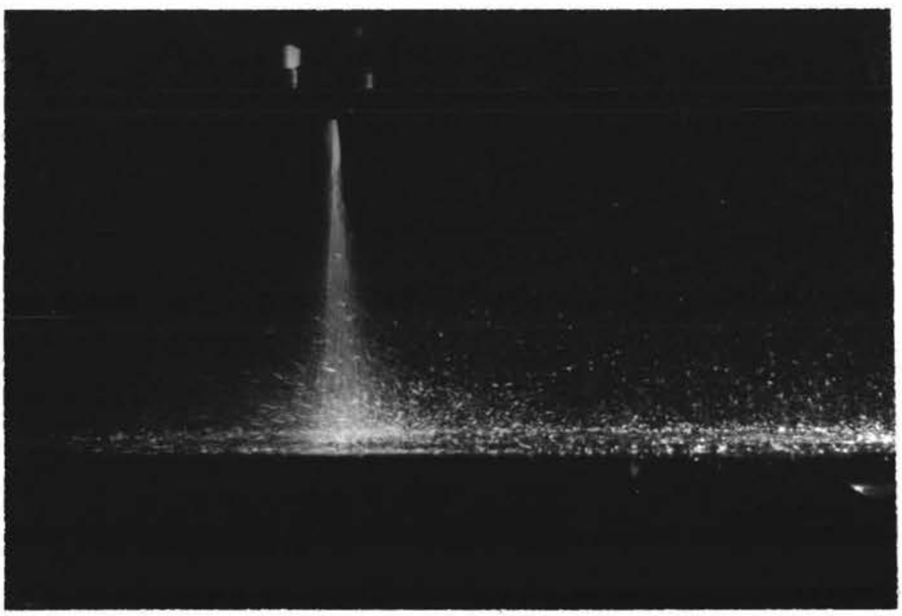


Plate 17. Delevan FS Fanjet, 3 in. height, Spraying on to Glass Surface (side on view).

II. Spray Bounch Results.

Spray bounce varied according to the sprayed surface, nozzle type, and nozzle height.

(i) Sprayed surface. The different surfaces could be broadly grouped into flat surfaces and pasture. Pasture tended to absorb the bounce. With the 1 in. band, and spraying on to a horizontal glass surface (Plate 18), splash was observed to a total width of at least 6 in. (i.e. $2\frac{1}{2}$ in. either side of the band). When pasture was sprayed (Plate 19), the total width of splash was nearer 3 in.. With the $3\frac{1}{2}$ in. cone nozzle, the total width of band and splash observed on a plate surface (Plate 20) was about 12 in., or more than 1 band width either side of the sprayed band.

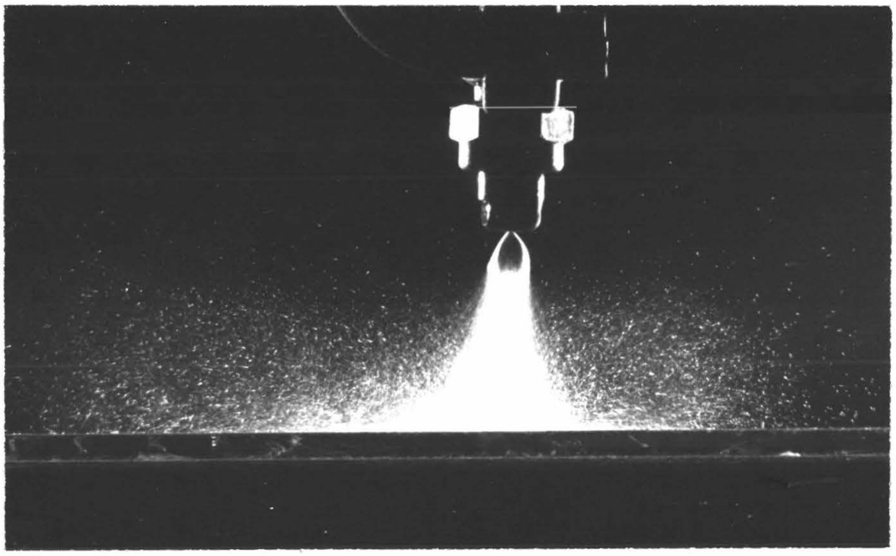


Plate 18. Spraying Systems $\frac{1}{4}$Y 1.5 Conejet, 1-7/16 in. height, Spraying on to Glass Surface (head on view).

On pasture the width was difficult to estimate as the pasture strip sprayed was $3\frac{1}{2}$ in. wide. Spray did bounce out of the strip however. Plate 21 (apart from spray collecting devices) illustrates this situation during trial of the quantitative work. Plate 16 illustrates the fan nozzle set 3 in. high and spraying a 4 in. wide band on felt, with bounce and drift at least this width either side of the band edge. On pasture (Plate 22), splash is less obvious with very little beyond one band width from the edge of the band. The plate also shows the left hand side of the nozzle to be working incorrectly.

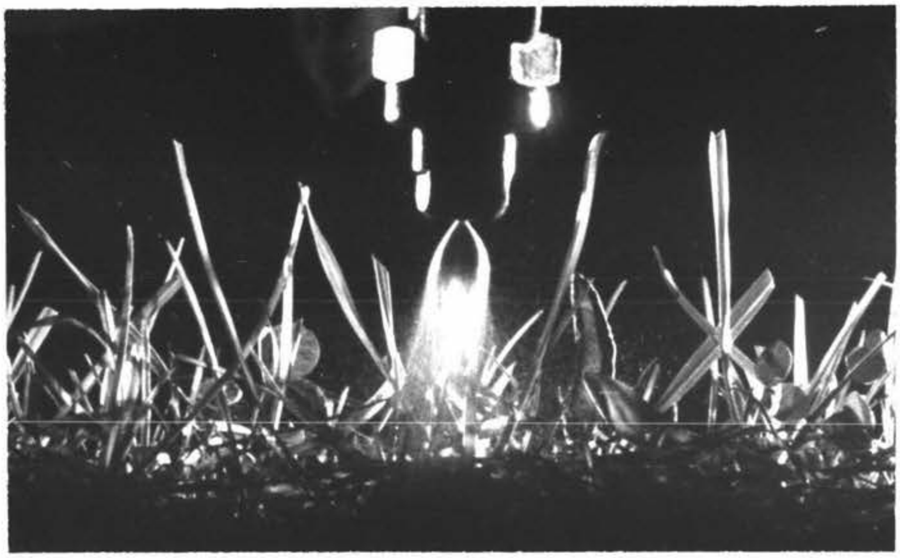


Plate 19. Spraying Systems $\frac{1}{4}$Y 1.5 Conejet, 1-7/16 in. height, Spraying on to Pasture Surface (head on view).

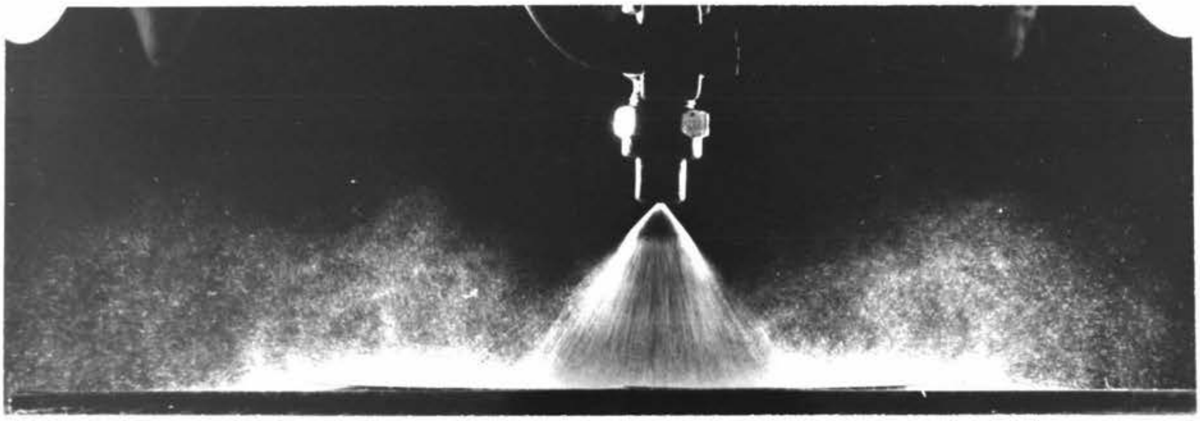


Plate 20. Monarch 6.4 HC Conejet, $1\frac{7}{8}$ in. height, Spraying on to Blotting Paper Surface (head on view).

Plate 23 shows the fan nozzle spraying on pasture from the side. In this instance droplets appear to have bounced to at least the height of the nozzle, i.e. 3 in.

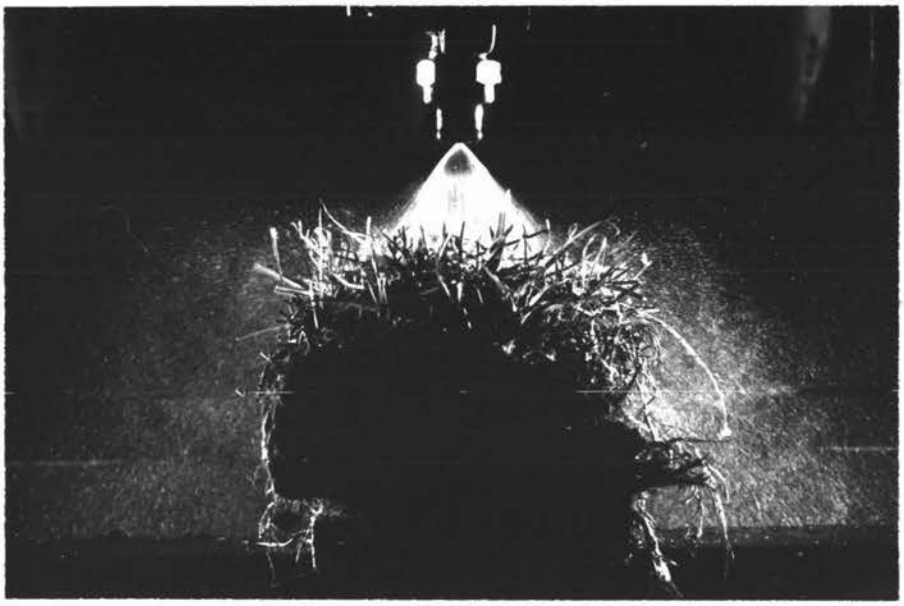


Plate 21. Monarch 6.4 HC Conejet, $1\frac{7}{8}$ in. height, Spraying on to Pasture Surface (head on view).

Plate 22. Delevan FS 2.5 Fanjet, 3 in. height, Spraying on to Pasture Surface (head on view).

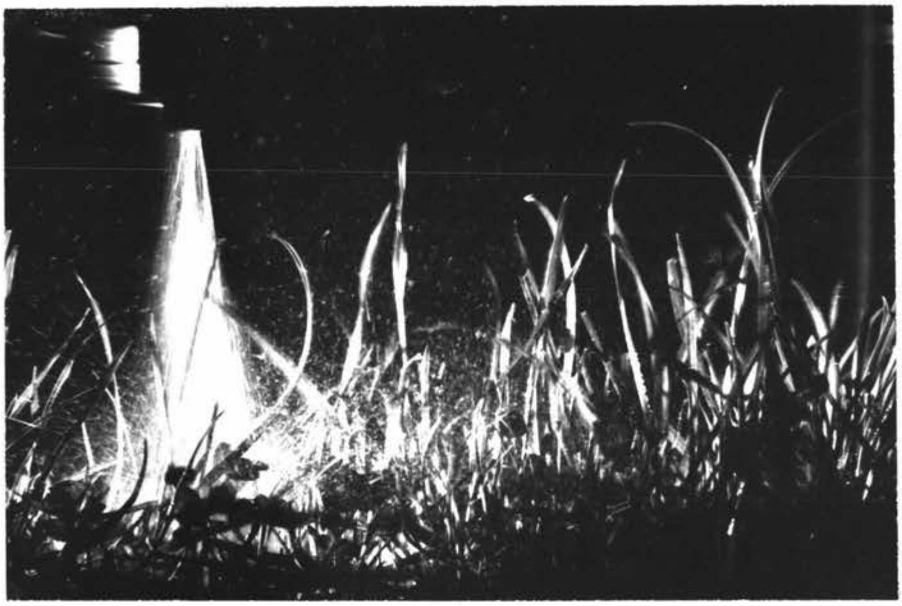


Plate 23. Delevan FS 2.5 Fanjet, 3 in. height, Spraying on to Pasture Surface (side on view).

(ii) Other observations. The frontispiece shows the flight of droplets over 3 in. in front of the moving nozzle. Some photographs showed turbulence in the stream of bounce droplets (Plate 20) which appeared to be affected by surface irregularities (Plate 15). Side photographs of cone nozzles often showed the swirling nature of the broken up sheet (Plates 24 and 25).

Plate 24. Monarch 6.4 HC Conejet, $1\frac{7}{8}$ in. height, Spraying on to Felt Surface (side on view).

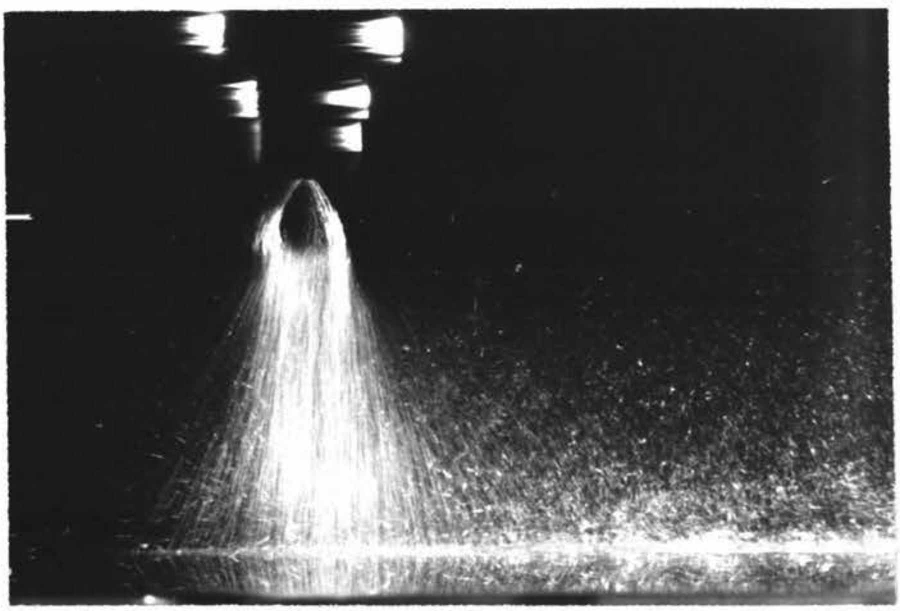


Plate 25. Spraying Systems $\frac{1}{4}$Y 1.5 Conejet, 1-7/16 in. height, Spraying on to Glass Surface (side on view).

3.5. CONCLUSIONS.

3.5.1. SUITABILITY OF TECHNIQUES USED.

I. Spectrophotometric.

Improvement of the qualitative method (Section 3.4.1.I) would have led to more meaningful results, although the method used did answer the question originally asked - "how much spray bounces or splashes outside the band ?" There were problems in in determining the edge of the band and therefore which part of the spray to evaluate in trail D, but these were inherent because of the characteristics of the spray nozzles used.

A better comparison of the splash from the edges of the sprayed strip on pasture and blotting paper may have given some idea of the differences between the surfaces and their propensity to cause or to absorb splash. In general the technique was suitable and with further refinement could have a wider application and help answer some of the questions that arose in this section of the work.

II. Photographic.

The lighting technique is not similar to any reported in the literature but appears to be adequate with careful alignment. Exposure times of 1/900th sec. were not brief enough to "freeze" each droplet but to decrease exposure times still further would have necessitated greater exposure intensity. The droplet motion showed up well enough for estimating the distance which the splash travelled.

3.5.2. EXISTENCE AND EXTENT OF SPLASH WHEN SPRAYING A PASTURE SURFACE.

The photographs showed splash to exist for some distance from the band edge compared with the band width. Also, splash on pasture appeared less than that on plane surfaces. The quantitative data revealed that this amount was low in comparison to the total spray and was usually less than 10% depending on the width of the band taken. This suggests that nozzles with a sharp "fall off" at their edges might be useful, and as such nozzles are available, tests with these would be a logical step in improving band definition.

Logarithmic transformation enabled analysis of rather variable data to be undertaken and permitted the plotting of confidence limits that made the data at a 99% confidence level of positive value out to the 14th strip (i.e. $3\frac{1}{2}$ in. either side of the band). Use of more closely related data may make it possible to have confidence in results even further out from the band edge. This assumes that pasture and blotting paper will allow splash to travel with equal facility, which according to the photographic indication, is likely to be incorrect. The development of an analysis method using spray off pasture would help towards finding more applicable results relating to the distance the splash travels. Spraying of a metal ion rarely found in the soil or pasture and the use of a sampler that would slice the pasture into strips after spraying would be one approach to this problem. Splash may not be so important with the spraying of paraquat but with systematic sprays the 10% recorded may be of considerable importance.

APPENDIX I.

BAND SPRAYER NOZZLE CALIBRATION DATA
(for Figs. 1, 2 & 3)

(i) Rate (gal/hr) versus Pressure (p.s.i.)
Nozzle A = Spraying Systems $\frac{1}{4}$Y 1.5
Nozzle B = Monarch 4.6 HC
Nozzle C = Monarch 6.4 HC

Pressure	$7\frac{1}{2}$	10	15	20	25
Nozzle A		11:20*	9:30	8:00	8:00
			9:30	8:30	8:00
					8:50
Gal/hr.		0.66	0.77	0.87	0.90
Nozzle B	6:45	5:48	4:55	4:28	3:50
	6:50	5:48	5:05	4:35	4:05
	6:48	6:07	5:05	4:20	4:00
Gal/hr.	1.125	1.25	1.50	1.68	1.91
Nozzle C	4:27	4:05	3:20	3:02	2:40
	4:28	4:00	3:22	2:58	2:40
	4:27	3:58	3:20	2:55	2:40
Gal/hr.	1.44	1.875	2.25	2.52	2.84

* time for 1 pint, in minutes and seconds.

APPENDIX I (Cont'd.)

(ii) Band Width (in.) versus Nozzle height (in.) and Pressure (p.s.i.)

Pressure (p.s.i.)	7½			10			15			20		
Nozzle height (in.)	1	2	3	1	2	3	1	2	3	1	2	3
Nozzle A	-	-	-	-	-	-	1.5	-	-	-	-	-
	0.6*	0.9	2.8	0.7	1.4	2.8	1.0	1.9	3.3	1.1	2.4	3.4
	0.6	1.1	2.0	0.7	1.5	2.5	0.9	1.8	3.2	1.0	2.0	3.4
Mean	0.6	1.0	2.4	0.7	1.4	2.6	1.2	1.8	3.2	1.1	2.2	3.4
Nozzle B	1.6	3.2	4.5	1.7	3.2	4.5	-	3.5	5.0	-	3.5	5.0
	1.5	3.0	4.1	1.5	3.2	4.3	1.8	3.5	5.0	1.9	3.5	4.5
	1.7	3.3	4.8	1.8	3.3	5.5	1.9	3.7	3.0	2.0	3.8	5.5
Mean	1.6	3.2	4.5	1.7	3.2	4.6	1.8	3.5	5.0	1.9	3.6	5.0
Nozzle C	2.2	4.0	4.8	2.3	4.0	5.5	2.3	4.1	5.8	2.3	4.3	5.7
	2.4	4.0	5.5	2.3	4.0	5.0	2.4	4.2	5.8	2.3	4.3	5.7
	2.2	4.0	5.5	2.3	4.0	5.5	2.3	4.3	5.8	2.2	4.0	5.7
Mean	2.3	4.0	5.3	2.3	4.0	5.3	2.3	4.2	5.8	2.3	4.2	5.7

* Band width, in. Each measurement for a different nozzle.

(iii) Rate (gal/acre) versus Pressure (p.s.i.) at(2.6 m.p.h.)

Pressure (p.s.i.)	7½	10	15	20	25
Nozzle A: 1*		25.4	29.6	33.2	34.6
Nozzle A: 2		12.7	14.8	16.7	17.3
Nozzle A: 3		8.5	9.9	10.5	11.6
Nozzle B: 1	43.4+	48.0	57.7	64.5	73.2
Nozzle B: 2	21.8	24.0	28.9	32.3	36.7
Nozzle B: 3	14.5	16.0	19.2	21.6	24.5
Nozzle C: 1	55.3	72.2	86.4	96.8	109.2
Nozzle C: 2	27.7	36.2	43.3	48.5	54.6
Nozzle C: 3	18.5	24.1	28.9	32.3	37.4

* Band width (in.)
+ Gal/acre (i.e. sprayed area)

Calculated using equations:

$$\text{acres/hr.} = \frac{\text{in. width} \times \text{m.p.h.}}{99}$$

$$\text{gal/acre} = \text{gal/hr.} \div \text{acres/hr.}$$

APPENDIX II.

DETAILS OF PILOT TRIALS.

(i) 1st Trial, January 19-20, 1968.

Conditions:

Weather

19th. Dull, rain during the day but not at the time of spraying (4.30 - 5.4 p.m.). There had been rain during the several days previously.

20th. Windy, cool, fair to fine. Spraying 4.30 - 5.30 p.m. Temperatures would be in the 50's or 60's.

Soil Moisture

Five samples were taken on 20th, when soil moisture was found to be 20.7%.

Pasture Length

Pasture length was short, about one inch to three inches in places, with ryegrass stalks of greater length. Had been grazed a week previously.

Rates

Paraquat - 2 pts. (or 8 oz. ai.) per sprayed acre (12.5 fl. oz. in 10 gal.)

Water - 32 gal./sprayed acre (from graph using Delevan FS 2.5 nozzle).

Seed - Tama ryegrass, 10 lb./acre.

As the coated seed had some weight, it had to be put on at 27 lb./acre to give 10 lb. seed per acre.
Ryecorn - 134 lb./acre (200 lb. coated seed/acre).

Other Details

Pressure 15 p.s.i.
Nozzle height 3 in.
Theoretical band width $3\frac{1}{2}$ in. (from graph).

Results not included in text:

Bentonite Coating of Seed.

Ground conditions at sowing were dry and hard and as a result, drill penetration and seed coverage was poor. Irrigation was carried out until good rain (1.76 in.) on February 1 and 3. Little ryecorn was observed, but the strike of ryegrass was considered good enough for seedling counts to be made.

Five 20 in. lengths of row were counted on February 8 (19 days after sowing), there being two rows each of coated and uncoated seed. The number of seedlings in each of the 20 in. was recorded, to compare with periodicity figures from the drill at a later date.

These results were as follow:

Coulter No.		Coated		Uncoated	
		1	2	9	10
Total number of seedlings per 20 in.	A	1	4	6	12
	B	8	9	24	9
	C	6	22	14	8
	D	5	6	16	2
	E	9	1	10	29
Total for 100 in.		29	42	70	60
Total for 200 in.		71		130	

(ii) <u>2nd trial, February 4, 1968.</u>

Conditions:

Weather

2nd. Windy, some rain.
3rd. Windy and wet.
4th. Windy, fine, cool.

Soil Moisture

Soil moisture was not expected to be low. Five samples were taken on each 5th and 8th with the resulting soil moisture figures of 28.2 and 30.2% respectively.

Pasture Length

Short, about one to two inches.

Rates

Paraquat - 1 pt. (or 4 oz. a.i.) per sprayed acre

Water - 30 gal./sprayed acre (from graphs)

Seed - Ryecorn, at 134 lb./acre (200 lb. coated seed)

Other Details

Pressure 20 p.s.i.
Nozzle height 1-3/16 in.
Theoretical band widths: 1+in., $2\frac{1}{2}$ in., 3 in. from band width vs pressure graphs of SS$\frac{1}{4}$Y 1.5, Monarch 4.6 HC (Figs. 1, 2 and 3) and 6.4 HC nozzles.

Calibration

Calibration details as for Pilot Trial No. 1.

Sowing

Coulters Nos. 7 and 8 were used for coated seed (air dried) and Nos. 5 and 6 for uncoated seed.

APPENDIX III.

Botanical composition of original pasture (totals for each plot, using a five wire frame and taking 10 frames/plot, with the exception of plot A7, where 9 were taken).

Class Plot No.	Clover	Rye Grasses	Brown-top	York-shire fog	Cocks-foot	Poa spp.	Weeds
A 7	11	26	42	27	1	0	2
A20	13	38	43	12	0	0	21
B16	14	55	31	20	0	0	14
B12	13	57	58	44	0	0	10
C17	9	62	28	17	3	0	4
C14	16	49	31	15	2	1	0
D 4	20	63	45	1	0	1	6
D21	47	83	15	0	1	7	3
Total	143	433	293	96	7	9	60
%	13.7	41.7	28.1	9.2	0.7	0.9	5.8

APPENDIX IV.

RAINFALL, 1968.

	Jan.	Feb.	March	April
1	.03	.77		
2	.05	.04		.09
3		.95		
4				
5				
6		Trace		
7			.14	
8			.20	
9				1.05
10		.10	.08	1.00
11			.18	Trace
12	Trace		.08	
13				
14				.35
15				.85
16	.06		.08	
17	.11			.09
18	1.32			
19	.01			.08
20				
21				
22				.02
23				.58
24				.03
25				.24
26				.01
27				
28	.51		Trace	
29	.22	.11	.24	.07
30				.37
31				
Total for month (in.)	2.31	1.97	1.00	4.83

Totals for other months of trial period:

May	5.35 in.
June	6.46 in.
July	3.03 in.
August	2.69 in.
September	2.73 in.

APPENDIX V.

SOIL MOISTURE MEASUREMENTS.

Block A		Block B		Block C		Block D		Headlands
Plot	M.C.*	Plot	M.C.	Plot	M.C.	Plot	M.C.	M.C.
(i) 15/3/68.								
2	35.4	7	24.2	1	33.1	1	29.0	14.6
5	34.6	10	25.6	4	33.4	7	35.2	18.2
7	35.1	12	24.4	6	23.9	12	33.7	18.4
9	45.2	13	21.7	9	27.2	14	36.4	16.6
12	34.1	16	33.9	11	25.8	16	28.3	19.1
16	31.9	18	38.4	14	33.0	19	32.8	18.6
18	34.0	20	27.6	16	37.4	2[illegible]	19.8	17.5
20	30.2	22	32.2	17	29.3	21	33.4	17.4
23	26.3	24	19.3	20	37.6	26	25.0	17.5
26	26.6	27	21.9	23	35.7	28	35.0	19.1
Mean	33.3		26.9		31.6		30.9	17.7

(ii) 29/3/68.

Headland 12.5, 12.2, 12.5, 11.2, 14.9, mean 12.7

B2a (dry spot) 11.2, B2a (wet spot) 17.4

A5 (three sites) 20.0, 16.2, 23.7

* M.C. = Moisture Content % (dry wt. basis).

APPENDIX V. (Cont'd.)

Block A Plot	Block A M.C.*	Block B Plot	Block B M.C.	Block C Plot	Block C M.C.	Block D Plot	Block D M.C.	Headlands M.C.
(iii)	5/4/68							
1	21.0	6	18.7	1	17.8	3	21.6	12.1
3	17.2	9	13.5	1	14.3	7	17.3	12.7
5	21.9	13	15.5	1	20.0	11	11.8	11.3
7	20.0	15	13.8	3	23.8	15	18.4	11.5
9	16.7	18	21.2	6	15.4	17	17.4	
11	12.8	20	27.6	9	20.1	22	13.9	
15	20.3	22	18.0	11	16.7	25	24.6	
18	19.2	26	16.1	14	18.1	28	21.0	
23	16.7	27	16.1	16	24.0			
		28	16.4	18	18.8			
				20	20.0			
				25	18.9			
				28	16.4			
Mean	18.4		17.7		18.8		18.3	11.9

(iv) 9/6/68.

Headland 43.9, 49.8, 49.7, 45.8, 51.7, mean 48.2

A 51.0, B 56.1, C 50.1, D 49.7, mean 51.7

(v) 7/8/68.

Headland 51.5, A14 64.7, A5 48.3

* M.C. = Moisture Content % (dry wt. basis)

APPENDIX VI.

SEEDLING COUNTS.

(i) "Grasslands Tama" Western Wolths Ryegrass.

Plot	21,22/3/68 E*	21,22/3/68 W*	1/4/68 E (s m)+	1/4/68 W (m s)+	Plot	21,22/3/68 E	21,22/3/68 W	1/4/68 E (s m)	1/4/68 W (m s)
A1a	7, 0	3, 4	3,31	5, 7	B 3a	0, 0	1, 0	0, 0	0, 0
A3a	28,18	9,24	17,24	10, 5	B 6a	6, 9	10, 8	16, 11	5,12
A8a	3,20	4, 2	6,24	31,11	B 7a	9,16	10, 7	9, 29	16, 5
A13a	24,13	24,16	5,20	10,12	B 9a	3, 6	7, 1	10, 6	17,15
A15a	7,14	6, 8	2,23	35,15	B10a	9,19	3, 4	1, 10	8,11
A16a	45, 3	21, 5	1,49	22, 8	B17a	4,10	14, 4	5, 30	25,16
A21a	33, 3	15,24	8,12	7, 8	B19a	1,15	30, 3	5, 6	7,11
A22a	0,18	3,10	0,17	15, 7	B20a	6,32	6,10	27,11	17, 2
A25a	14,35	13, 3	0,14	5, 5	B21a	4,51	22, 7	29, 16	7, 3
A26a	0, 1	0, 2	0, 0	0, 1	B26a	0, 8	1, 0	2, 0	0, 3
Total	296	196	256	184		208	148	223	180
C2b	4, 0	1, 1	21, 7	20,25	D1b	0, 3	8,16	1, 4	10, 7
C5b	0, 8	13,14	16,10	25,15	D2b	0, 2	0, 0	0,17	0, 2
C7b	7,12	19,11	15, 7	4, 4	D5b	4,12	12,12	8, 4	4, 8
C9b	23,10	6,16	14,27	10, 9	D10b	22, 8	13,5	17, 6	3,20
C11b	14, 8	6,17	6,15	9, 7	D11b	5, 4	9,18	4, 5	9, 0
C12b	11,. 3	4, 4	9,18	9, 8	D13b	0, 0	0, 0	0, 0	0, 4
C15b	15,12	5,21	15, 8	30, 1	D14b	17,15	3,15	6,12	8, 7
C18b	15, 5	1,15	3,13	10, 4	D15b	12,10	12,17	12,13	14, 0
C21b	25,21	24,14	22,13	14,19	D16b	15, 7	0,17	2, 3	4, 3
C27b	12,11	4,17	9,17	5, 0	D19b	2, 9	6, 8	5,16	1, 0
Total	216	213	259	228		147	171	135	104

* Row orientation: "East" or "West"

\+ "side" or "middle" of plot. "Side" was drying more than "middle" at this time.

APPENDIX VI. (Cont'd.)

(ii) Ryecorn

Plot	22/3/68 E*	22/3/68 W*	2,3/4/68 E (s+ n+)	2,3/4/68 W (m s)	Plot	22/3/68 E	22/3/68 W	2,3/4/68 E (s m)	2,3/4/68 W (m s)
A2b	46,19	40,23	21,44	38,22	B2b	12,12	25,18	12,28	12,19
A5b	6,11	28,23	31,35	31,33	B5b	13,17	24,25	13,25	23, 8
A6b	17,31	17,20	18,43	9,32	B13b	6,13	12,12	14,17	24, 7
A9b	27,32	21,25	35,28	36,47	B14b	27,22	30,32	26,32	50,35
A10b	27,14	48,25	20,38	28,49	B15b	38, 8	14,10	22,48	18,16
A11b	22,50	44,46	40,38	25,42	B18b	27,20	30,29	9,13	34,20
A12b	17,16	29,19	16,50	38,43	B23b	22,19	31,22	39,35	28,34
A14b	20,20	36,22	24,44	20,24	B24b	11,24	18,19	42,19	20,38
A18b	22,35	34,34	27,40	27,56	B25b	16, 9	33,21	24, 7	28,16
A19b	29,31	39,46	38,27	33,35	B27b	1, 3	0, 3	3,10	12,10
Total	492	619	657	668		320	408	438	452
C1a	3,16	16, 9	4,12	49,19	D5a	20,17	17,23	0, 2	0, 0
C3a	27,25	28,44	15,26	14,15	D7a	26,42	25,29	9,29	34,35
C4a	7, 3	7, 3	10,29	26,15	D8a	33,19	34,36	23,17	7,24
C6a	6,10	30,13	16,22	23,24	D9a	23,22	36,42	34,34	31,23
C8a	12, 9	19,22	27,21	28,24	D12a	23,11	29,42	22,38	46,54
C10a	30, 8	19,22	17,25	25,38	D17a	29,10	11, 9	20, 7	23,36
C13a	8,15	23,22	17,12	34,25	C18a	22,34	16,11	28,34	27,29
C16a	28,14	20,25	20,43	32,23	D20a	13,11	25,10	37,22	19,23
C19a	23,18	42,32	40,44	55,50	D22a	32,16	22,16	33,35	40,20
C22a	12,11	26,25	24,27	32,29	D23a	15,18	20,27	22,37	21,31
Total	285	447	451	580		436	480	473	523

* Row orientation "East" or "West"

+ "Side" or "middle" of plot. "Side" was drying more than "middle" at this time.

APPENDIX VII.

BOTANICAL ANALYSES.

(lb. dry matter/acre.)

Treat-ment	i. 1st cut*		ii. 2nd cut*				Mean as % total yield
	A[1]	B,C,D	A	B	C	D	
00R[+]	12.5	28.8	5.5	1.5	52.8	14.4	1.9
00T	0.0		9.6	0.0	43.1	2.5	1.2
11R		14.4	12.0	19.2	14.4	12.0	1.2
11T			0.0	0.0	0.0	16.8	0.3
21R	6.7		14.4	28.6	38.4	7.2	2.2
21T	17.3		24.0	0.0	12.0	28.8	1.5
41R	33.6		28.8	9.6	14.4	14.4	6.0
41T	7.7		12.0	0.0	4.8	42.3	1.5
12R	9.6		28.8	1.5	33.6	24.0	1.8
12T			120.0	36.0	74.5	62.5	7.2
22R			16.8	31.2	24.0	5.5	1.8
22T	0.0		19.2	9.6	28.8	24.0	1.9
42R	19.2		24.0	31.2	19.2	40.8	2.9
42T			33.6	0.0	86.5	78.0	4.7
13½R	9.6		81.5	48.0	55.2	7.2	4.2
13½T	11.5		0.0	5.8	62.5	26.4	1.9
23½R	9.6		53.0	24.0	33.6	67.0	4.2
23½T	9.6		9.6	14.5	52.8	55.0	3.2
43½R	28.8	57.6	26.9	45.5	86.5	26.4	4.5
43½T	0.0		27.4	9.6	38.4	62.5	3.2
16R	88.8		163.0	96.0	293.0	202.0	18.8
16T			240.0	28.6	115.0	360.0	17.0
26R			28.8	19.2	163.0	176.0	10.6
26T	0.0		77.0	67.2	216.0	360.0	16.5
46R	78.8		96.0	322.2	437.0	505.0	33.0
46T	92.3	183.0	408.0	408.0	437.0	655.0	41.6

[+] See Table V, page 30 for code.

* 1st cut, April 22,23; 2nd cut, May 28 - June 6.

1 Block

APPENDIX VII (Cont'd.)

BOTANICAL ANALYSES.

(lb. dry matter/acre).

Treatment	BLOCK				Mean as % of Yield
	A	B	C	D	
(iii) 3rd cut, * August, 6.					
00T[1]	2.4	0.0	4.8	0.0	0
42T	4.8	3.6	0.0	14.3	1
16T	9.8	2.4	143.0	114.0	10
26T	6.0	35.7	71.4	105.0	9
46T	167.0	112.0	216.0	183.0	28
(iv) 4th cut, * September 16.					
00T	0.0	0.0	0.0	0.0	0
42T	100.0	7.1	4.5	43.0	7
16T	90.0	0.0	155.0	221.0	18
26T	-	38.0	172.0	95.0	11
46T	190.0	114.0	114.0	193.0	28

[1]For key to treatments, Table V, page 30.

APPENDIX VIII.

DRY MATTER YIELDS.

(lb. dry matter/acre).

(i) 1st cut (18/4 - 1/5/68).

Treatment	Non nitrogen*				Nitrogen				Mean+
	A	B	C	D	A	B	C	D	
000[1]	1185	1497	733	1360	1343	1457	916	1930	1296
000	1185	1430	1228	997	1202	1170	1398	1575	1273
00R	1134	1497	857	1433	1105	1340	920	1373	1207
00T	642	1130	1012	1270	1052	1043	880	2310	1168
11R	885	568	980	1336	1475	1270	698	1523	1092
11T	716	815	644	1450	1075	875	707	1440	965
21R	920	744	1207	808	1025	806	1152	1290	994
21T	1106	1333	1234	1570	930	1285	1060	2335	1357
41R	1460	957	1011	1240	1185	908	825	1413	1125
41T	1136	1217	1052	1620	1077	1305	617	1006	1126
12R	633	862	908	460	1224	1460	685	1505	967
12T	1175	1595	1138	1413	934	1497	1007	898	1207
22R	1285	1185	1024	1210	680	1185	1024	1548	1151
22T	1016	1080	989	1507	1123	1115	1034	1360	1153
42R	862	1007	990	1308	1213	1190	1152	1763	1186
42T	1067	1115	617	2147	1235	1115	1061	1590	1243
13½R	815	806	1172	598	1700	806	930	1083	1002
13½T	832	838	567	1062	739	554	708	1430	841
23½R	796	990	908	1800	975	998	642	1450	1070
23½T	762	884	862	1270	985	1297	535	970	946
43½R	975	753	1020	2695	472	797	695	1475	1110
43½T	795	763	767	1130	662	708	1224	1360	926
16R	617	695	339	547	386	753	175	1158	584
16T	498	994	209	1460	435	925	88	700	664
26R	435	744	640	925	805	453	1297	836	767
26T	386	453	466	680	443	367	386	787	496
46R	440	358	567	1200	490	500	355	338	531
46T	290	508	504	635	226	372	265	442	405

* sub (split) plot treatment.

\+ mean over subtreatment & blocks

1 for key to treatments, Table V, page 30.

APPENDIX VIII (Cont'd.)

DRY MATTER YIELDS

(lb. dry matter/acre).

(ii) 2nd cut (28/5 - 6/6/68).

Treat-ment	A	B	C	D	Mean
000*	1070	1025	970	1435	1125
000	1133	1085	1020	1165	1101
00R	1050	880	1090	885	976
00T	1217	1265	990	1125	1149
11R	975	1250	1215	1200	1160
11T	1143	1600	1385	920	1262
21R	745	1405	935	1010	1024
21T	948	1080	1095	1155	1070
41R	930	1380	940	1200	1113
41T	895	1085	1175	870	1006
12R	1090	1340	1250	1175	1214
12T	1090	898	1055	1005	1012
22R	1005	1075	1000	1145	1056
22T	1350	1005	1270	745	1093
42R	1090	1150	855	895	998
42T	1190	975	995	1040	1050
13½R	1228	1140	1030	1130	1132
13½T	1180	1335	1230	1290	1259
23½R	1150	1240	915	920	1056
23½T	1167	1050	900	980	1024
43½R	815	1320	875	1150	1040
43½T	1060	1150	1045	1070	1081
16R	1007	1220	895	895	1004
16T	1136	1095	1190	955	1094
26R	1080	1000	735	845	915
26T	1186	1005	1095	1070	1089
46R	1000	1060	1115	940	1029
46T	1074	1110	985	985	1039

* for key to treatments, refer to Table 5, page 30.

APPENDIX VIII (Cont'd.)

(iii) 3rd cut (6/8/68).

Treatment	A	B	C	D	Mean
000[1]	960	680	490	420	638
00T	800	465	545	625	609
42T	475	440	615	570	525
16T	960	450	765	515	673
26T	815	510	650	500	619
46T	820	490	830	510	613

(iv) 4th cut (16/9/68).

Treatment	A	B	C	D	Mean
000	270	670	440	525	476
00T	605	345	708	360	505
42T	570	420	740	560	558
16T	330	310	887	790	579
26T	600	585	720	780	671
46T	470	340	650	710	543

[1] for key to treatments, Table V, page 30.

APPENDIX IX.

PRESSURE VESSEL TESTS.

Times of successive pints from nozzles - 25-26 p.s.i.

(i) Without plastic bag. Monarch 6.4 HC nozzle.

*2:21.8+
2:22.4
2:21.9
2:22.3

* Minutes
\+ Seconds

(ii) With plastic bags. Same nozzle.

Pint	Run A	Run B	Run C	Mean
1	2:22.4	2:21.0	2:22.3	2:21.9
2	2:19.0	2:22.0	2:21.0	2:20.7
3	2:22.0	2:22.4	2:23.0	2:22.5
4	2:21.6	2:22.4	2:21.4	2:21.7
5	2:23.4	2:21.1	2:24.0	2:22.8
6	2:22.5	2:23.0	2:22.8	2:22.8
7	2:24.4	2:22.6	2:25.0	2:24.0

L.S.D. of mean: 5% level 0:01.8; 1% level 0:02.5

(iii) With plastic bag and Spraying Systems $\frac{1}{4}$Y 1.5 nozzle.

1	8:7.6
2	8:13.5
3	8:6.1
4	8:12.0
5	8:8.5
6	8:13.9
7	8:9.0

APPENDIX X.

SPRAY DISTRIBUTION ANALYSIS DATA.

(i) Spraying on to Blotter Surface.

Band width	Trial Series	Run and Sequence	Strip No. 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1 in.	A	1a	29*	28	25	25	27	26	24	27	25	56	36	75	80	110	90	36	38	25	25
	B	1a				15	15	15.5	18	43	190	480	520	124	38	17	17	15			
	B	1b				16.2	16	16.5	19	37	142	440	530	168	44	20	16	15			
	B	2a	15	16	16	34	130	215	150	43	18	14	14	14							
	B	2b	15	14	15	34	120	217	155	47	18	18	13	14							
2 in.	A		27	23	23	27	23	24	25	26	26	26	24	30	32	70	130	255	305	210	215
	B	1a								13	16	49	187	330	355	315	347	345	192	56	20
	B	1b								14	18	60	250	395	340	340	355	347	152	16	35
	B	2a								18	20	56	225	350	407	372	400	420	224	78	23
	B	2b								14	21	78	277	370	370	355	400	400	152	46	16
3½ in.	B	1a	21	19	12	20	19.5	17	24	30	25	31	45	90	180	310	450	505	450	375	335
	B	1b						15	15.6	16	29	20	40	80	330	380	415	400	350	325	320
	B	2a										18	36	58	160	220	410	425	350	405	360
	B	2b										32	30	38	150	230	365	460	350	395	360
	D	1a												269	458	2220	3980	6020	11550	10969	6990
	D	1b												315	506	1360	2680	8240	9210	10000	6990
	D	1c								88	88	88	110	655	386	2290	5230	10000	10000	7700	7700
	D	2a								66	66	177	88	757	2600	6780	8240	9210	8240	6990	7450
	D	2b									88	88	269	458	3010	4440	9210	8240	9210	6580	7450
	D	2c									66	88	137	177	655	2150	5850	8860	11550	9210	7450
	D	3a									88	88	177	200	655	3190	5380	8240	10457	8540	7700
	D	3b											88	132	458	2080	4560	8860	8540	6200	5690
	D	3c									132	177	155	269	605	2370	4950	9590	11550	9590	7700
4 in. (Fan Nozzle)	A		18	14	13.5	18	11	14	16.5	15	13	13	20	60	170	252	282	340	380	335	300
	B	1a	29	28.5	17.5	18	16.5	15.5	16	18	18	22	52	306	348	310	360	426	437	396	330
	B	1b	33	25.5	15	15.5	15	15	15	16	15	20	46	237	345	350	370	425	390	365	355
	B	2a									14	18	46	190	315	263	285	290	275	260	258
		2b									14	15	40	140	328	245	275	310	303	305	325

Band width	Trial Series	Run and Sequence	Strip No. 20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
1 in.	A	1a	23	24	24	23	22	23	23												
	B	1a																			
	B	1b																			
	B	2a																			
	B	2b																			
2 in.	A		290	210	160	38	28	16	25	37*	29	22	20	26	21	19	22	21	22		
	B	1a																			
	B	1b																			
	B	2a	18																		
	B	2b	14																		
3½ in.	B	1a	425	465	485	535	505	365	187	130	88	42	27	23	21	26	23	35	40	23	21
	B	1b	320	325	330	285	215	110	85	39	24	17	15	16	14	15	14	11	10	9	
	B	2a	335	365	400	440	420	195	260	136	50	27	24	18	17						
	B	2b	350	315	415	445	435	165	260	120	54	33	32	23	17						
	D	1a	8540	8860	8540	11550	10457	4950	2440	1020	434	315	312	312							
	D	1b	7450	8240	10969	10457	9210	4690	2080	862	386	155	132	132	132	110					
	D	1c	7830	7700	4200	6990	3100	1940	862	434	177	177	88								
	D	2a	7960	7700	10000	10000	5850	3570	1490	386	292	88	132								
	D	2b	7700	7700	10457	10000	7450	4560	916	315	223	132	110	88							
	D	2c	7700	7210	7700	9210	8540	8240	5690	2220	706	315	177	132	88						
	D	3a	6580	7210	6780	7450	8860	8540	9210	6380	2920	916	434	246	177	110	88				
	D	3b	5690	6020	6580	7450	9590	9590	9590	5690	2840	969	386	200	155	88	88	132	88		
	D	3c	6380	6990	5690	5690	7210	7960	7450	5090	1080	809	292	132	88	315	269				
4 in. (Fan Nozzle)	A		300	285	290	300	290	310	258	218	248	136	80	25	22	20	18	16	14	14	15
	B	1a	402	348	402	474	444	333	354	363	306	99	50	31	27	26	34	28	23	22	
	B	1b	347	315	390	440	375	267	345	352	220	108	31	19	17	16	16	16	24		
	B	2a	265	278	310	330	293	278	235	240	170	77	37	16	15						
		2b	265	285	310	340	335	325	275	280	215	94	36	19	15						

APPENDIX X.

SPRAY DISTRIBUTION ANALYSIS DATA

(ii) Spraying on to Pasture Surface, Collecting Bounce outside the Band Width Strip on Blotting Paper (Trial D)

Run	Side	Sequence	Strip No. (¼ in. increments from band edge) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
4	Right	a	1490	655	434	458	410	434	386	292	292	269	246	223	200	200	223	177	177	155	155
		b	1550	706	506	315	482	458	458	434	434	386	386	269	269	269	246	246	223	200	223
		c	1550	969	757	434	555	555	434	410	269	223	223	177	155	132	132	132	132	132	555
	Left	a	20000	10457	5808	3190	2220	1020	757	434	630	315	492	809	434	269	315	223	200	223	
		b	15224	8540	3670	2970	2920	555	783	605	506	434	434	264	386	177	132	223	223	177	177
		c	10457	9210	3980	3280	1550	1190	1020	706	757	458	386	269	269	269	458	246	269	292	315
5	Right	a	347	337	143	862	809	506	410	434	339	386	410	446	315	269	292	177	110	132	132
		b	319	155	862	458	531	434	446	339	315	315	223	269	269	200	223	177	132	110	155
		c	620	276	969	482	386	531	434	434	315	315	410	269	292	200	155	155	132	110	110
	Left	a	5690	4200	3620	1370	1550	835	835	731	757	506	458	315	269	200	223	200	155	110	132
		b	8860	5090	2920	655	915	458	434	434	506	246	315	292	292	223	177	132	132	132	200
		c	10705	5380	3720	1210	1190	506	458	482	580	269	269	223	269	223	246	177	177	155	155
6	Right	a	3670	1140	706	458	410	269	269	177	177	223	177	200	155	223	177	177	132	155	
		b	2150	969	809	757	434	292	246	223	223	177	132	132	88	88	88	155	88	110	
		c	2760	1370	1080	706	506	386	223	246	200	177	110	132	110	132	88	88	88	110	
	Left	a	10457	6990	3280	2290	1250	757	458	434	352	269	200	223	223	177	177	177	132	88	88
		b	8540	2370	1770	1490	555	506	458	434	315	434	386	315	315	155	223	155	155	132	110
		c	5530	2010	2150	1310	1280	482	446	458	315	292	315	177	155	110	132	177	132	132	132

APPENDIX XI.

LOG. TRANSFORMATION OF SPRAY DISTRIBUTION ANALYSIS DATA.

(i) Individual Results (Trial D).

Strip No. ($\frac{1}{4}$ in. increments from band edge)

Run	Side	Sequence	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
4	Right	a	3173	2816	2638	2661	2613	2638	2587	2465	2435	2430	2391	2348	2301	2301	2348	2248	2248	2190
		b	3190	2849	2904	2498	2683	2661	2661	2638	2638	2587	2587	2430	2430	2430	2391	2391	2348	2301
		c	3190	2986	2879	2638	2744	2744	2638	2613	2430	2348	2348	2248	2190	2121	2121	2121	2121	2121
	Left	a	4301	4019	3767	3504	3346	3009	2879	2638	2799	2498	2692	2908	2638	2430	2498	2348	2301	2348
		b	4182	3932	3565	3473	3465	2744	2894	2782	2704	2638	2638	2422	2587	2248	2121	2348	2348	2248
		c	4019	3964	3600	3516	3190	3076	3009	2849	2879	2661	2587	2430	2430	2430	2661	2661	2430	2465
5	Right	a	3540	3528	3155	2936	2906	2704	2613	2638	2530	2587	2613	2649	2498	2430	2465	2248	2041	2121
		b	3504	3190	2936	2661	2725	2638	2649	2530	2498	2498	2348	2430	2430	2301	2348	2248	2121	2041
		c	3792	3441	2986	2683	2587	2725	2638	2638	2498	2498	2613	2430	2465	2301	2190	2190	2121	2041
	Left	a	3755	3623	3559	3138	3190	2922	2922	2864	2879	2704	2661	2498	2430	2301	2348	2301	2190	2041
		b	3947	3707	3465	2816	2961	2661	2638	2638	2704	2391	2498	2465	2465	2348	2248	2121	2121	2121
		c	4029	3731	3571	3083	3076	2704	2661	2883	2763	2430	2430	2348	2430	2348	2391	2248	2248	2190
6	Right	a	3564	3057	2849	2661	2613	2430	2430	2248	2248	2348	2248	2301	2190	2348	2248	2121	2121	2190
		b	3332	2986	2908	2879	2638	2465	2391	2348	2348	2248	2121	2121	1945	1945	1945	1820	1945	2041
		c	3441	3138	3033	2849	2704	2587	2348	2391	2301	2248	2041	2121	2041	2121	1945	1945	1945	2041
	Left	a	4019	3844	3516	3360	3097	2879	2661	2638	2547	2430	2301	2348	2348	2248	2248	2248	2121	1945
		b	3932	3528	3248	3155	2744	2904	2661	2638	2498	2638	2587	2498	2498	2190	2348	2190	2190	2121
		c	3743	3303	3332	3117	3107	2683	2649	2661	2498	2465	2498	2248	2190	2041	2121	2248	2121	2121

(ii) Means and Confidence Levels

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
+ 1% Confidence Level	3988	3710	3502	3264	3196	3017	2948	2891	2853	2765	2741	2687	2646	2556	2562	2510	2456	2434
+ 5% " "	3910	3632	3424	3186	3118	2939	2870	2813	2775	2687	2663	2609	2568	2478	2484	2432	2378	2356
Mean	3703	3425	3217	2979	2911	2732	2663	2606	2568	2480	2456	2402	2361	2271	2277	2225	2171	2149
- 1% Confidence Level	3496	3218	3010	2772	2704	2525	2456	2399	2361	2273	2249	2195	2154	2064	2070	2018	1964	1942
- 5% " "	3418	3040	2932	2694	2626	2447	2370	2321	2283	2195	2171	2117	2076	1986	1992	1940	1886	1864

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