THE APPLICATION OF ELECTROSTATIC CHARGING TO THE DEPOSITION OF INSECTICIDES AND FUNGICIDES ON PLANT SURFACES

Thesis for the Degree of M. S.

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This is to certify that the

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PETER HEBBLETHWAITE ABSTRACT

Various workers have published papers on the frictional charging of dust particles, but the subject of charging agricultural dusts by the use of an ionized field has been relatively neglected. This thesis deals with this latter aspect. A charge is placed on the individual particles by passing them through a negative corona, ionized field charging nozzle. Charging results in an improvement in the deposition, both quantitatively and qualitatively.

Laboratory tests were performed with charged dusts to show the relation of dust deposit to the current applied to the nozzle, to the relative humidity, to the temperature, and to the distance of the surface being dusted from the nozzle.

Field tests were carried out in six different types of crops. Pest attacks were light in the fields under test and in consequence no spectacular results were obtained. All the indications, however, were in favour of electrostatic dusting, and considered collectively the results were encouraging.

Some preliminary trials were carried out on the charging of pesticidal fogs and smokes. These showed definite promise, and indicated that further study in this direction would be worthwhile.

Techniques for the evaluation of dust and fog deposits are discussed in some detail.

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INTRODUCTION

At the present time in farming practice, no great use is being made of the electrostatic forces which are available to improve the operation of crop dusting. That such forces exist is indisputable, but their extent and behaviour is not fully known. It was the purpose of this work, therefore, to increase the knowledge available about these forces, and to bring a step nearer the day when they can be fully utilized.

The work that is to be dealt with, follows directly upon that which is detailed in the thesis by Bowen (3) and to which frequent reference will be made. This reference will be made, because as far as is possible, it is the author's intention to avoid repetition of material contained in that thesis.

Contact with farmers and the many other people interested in the protection of plants from pest attack, has indicated very clearly that crop dusting would grow very rapidly in popularity if its efficiency could be increased, even if only by a comparatively small percentage. At the present time spraying is more popular than dusting, and the following can be listed as the main reasons for this:

1. Sprays give better coverage of the plant surfaces than do conventional dusting methods.

2. Spraying is more efficient than dusting; the amount of toxic agent required per acre being generally greater in the case of dusting. The reason for this is apparent when the amount of drift losses in dusting are observed.

3. Sprays are less susceptible to meteorological conditions, both at the time of application and afterwards. The wind is less troublesome to spraying, and when a spray deposit dries and adheres closely to the leaf surface it is less rapidly washed off by rain, than is a similar quantity of dust.

Coverage and distribution are two words which are used frequently in dusting work, so before proceeding further these should be clearly defined. Coverage means the amount of toxic material on a plant surface and also embraces the word distribution; good coverage means that the correct quantity of material has been placed on a surface, and that it is evenly distributed upon that surface. Further, in order to discuss distribution more closely two other definitions will be made:

Macro-distribution, distribution between one leaf surface and another. For perfect macro-distribution each leaf surface would have on it the same quantity of toxic material when expressed in terms of weight per unit area.

Micro-distribution, is the distribution upon one leaf surface, and the position of each particle relative to the others. Perfect micro-distribution however is less easily defined, certainly it should be even and regular, but when it comes to specifying how far from one another the particles may be spaced, the biologists who have worked on this subject are a little hesitant. One attempt at such a definition is to say that for disease prevention perfect micro-distribution is accomplished when there is no space between dust particles large enough to contain a spore, without that spore touching one of those particles. It is recognized that this does not give a complete picture of the requirements, which should include consideration of such things as the volatilty of the substance used. This question will, however, not be pursued any further at the moment because to do so is to become side-tracked from the main purpose.

Bowen has cited references on the relationship between dust particle size and deposition, and has described the barrier layer which makes itself apparent on all surfaces when an attempt is made to deposit fine particles. This layer which is believed to be of thermal origin, deflects those particles which have insufficient momentum to penetrate to the surface, and it is believed that it is for this reason that when small dust particles are used (say below 10 μ in diameter) few of them are deposited upon the plant surface.

Field dusters at present on the market utilize high outlet velocities with the object of giving the dust particles as much momentum as possible but, as has been suggested, this is usually insufficient to cause the penetration of the really small particles. The object of electrostatic dusting, therefore, is to place a controlled electrical charge upon all the dust particles, and in so doing to make use of the forces of electrostatic attraction to draw the particles through the barrier layer. Bowen has described these attraction forces in some detail, and divided them into two parts, the image force and the field force. Subsequent work has in no way altered the conception of these forces which he set out, but up to the present time it has not been possible to measure their relative magnitude, due to the lack of suitable instrumentation; their collective effect is, however, very apparent, and it is this effect which is the subject of the present investigation.

In all this work we depend upon two basic laws of electrostatics:

The image force depends upon the fact that unlike charges attract each other.

The field force depends upon the law which states that when a charged particle is placed in an electric field, that particle will tend to move along the lines of force of that field, and in a direction determined by its sign.

Now returning to the practical aspect of this study, it is hoped that the utilization of electrostatic forces will either erase, or considerably reduce the magnitude of the three aspects in which dusting at present lags behind spraying. With these objections removed and with the factors which are already in favour of dusting still present, dusting should come into its own and make the operations of pest control and

destruction, cheaper and more effective. Already present in favour of dusting are the ease of operation, the absence of the need for carting large quantities of water to the field, the cheaper equipment, and higher speeds of operation compared with spraying, and the fact that less skill is required of the operator. The author is also of the opinion that by purely mechanical improvements in duster design the macro-distribution of dust on plants can be considerably improved.

Electrostatic precipitation will increase the recovery of all sizes of particles, but in recovering the small particles it will make its greatest contribution. McGovran et al. (22) have shown very conclusively that at least under the conditions of their test, the smaller particles (in their case 1.1 μ diameter) provide much more efficient control than do the larger ones. Further it is the author's belief that this finding can be applied generally to all dusting work, providing that these small particles can be applied successfully to the leaves.

Finally it should be made clear that at least with the present equipment, the forces of attraction are only important for particles placed close to the leaf surface; the image force equalling the pull of gravity on a well charged 10 μ diameter particle only when that particle is placed at a distance of approximately 20 μ from a leaf surface. The field force is active over greater distances, but the view is at present held that even with the use of charged dust, the duster must by mechanical means be effective at placing dust in close proximity to all plant surfaces.

Review of Literature

There are two principal ways of charging particles; either by use of an ionized field, which method has been used in the present study, or by the use of frictional or contact charging.

A review of the literature has revealed a very considerable amount of work on the electrostatic charging of particles, however, the work on the charging of insecticides and fungicides is more limited, and only two workers, Hampe (10)(11) and Hansen (12), appear to have published work on the charging of insecticides and fungicides by the use of ionized field charging equipment.

In all dusting work, friction charging does take place, and many workers, for example MacLeod (20), have commented upon, and investigated this aspect. Yadoff (22), however, appears to be the only worker who has really set out to utilize friction charging, and as a result of his work a small hand machine which is designed to produce high friction charges, is at present on the market in France. The utility of the friction charging which occurs in conventional dusters and even in dusters specifically designed to produce such a charge is, however, believed to be strictly limited because of its unreliable nature. Friction charging is very susceptible to humidity, and the extent and even the sign of the charge on a particle depends upon its size, its chemical nature, and upon the material and length of the duster tubes (MacLeod).

In this connection the following observation of Hansen's gives a good idea of the true picture, even if it is rather emphatic.

> Most of the workers in the field of frictional electricity have published only a single paper, the implication being that having once tasted its difficulties they returned to more fruitful fields .... It appears to be a most perverse, inconsistent, unduplicatable, and unpredictable subject.

Hansen did some laboratory work using an ionized field charging nozzle but did no field work. In his work he expressed the opinion.

> The inductive attraction of a particle to a surface was found to be negligible. It was concluded that charge has no effect in attracting a particle to a surface, but is important in holding it on the surface, thus increasing deposition. This effect is independent of the sign but is a function of its magnitude. Small particles have too small a charge to stick, but the more highly charged among the larger particles or aggregates will adhere.

It is believed that here Hansen has been guilty of making too categorical a statement. It has already been mentioned that the forces of attraction with which we are working, operate only when the particle is in very close proximity to the leaf surface, and in addition the boundary layer is a phenomenon which only occurs close to leaf surfaces. In view of this, Hansen would only be in a position to make such a statement if he had observed the behaviour of charged particles when they approached within approximately 20 μ of a surface. From his description of the technique used it is apparent that he was not able to do this, and in addition, the magnitude of the charge on his dust particles appears to have been rather low when it is compared with the maximum attainable.

Further, as the charge over mass ratio is known to increase as particles become smaller, (and similarly the attraction over mass ratio increases with decreasing particle size) it is felt there is sufficient grounds for putting forward a theory which is contradictory to Hansen's. Finally it should be mentioned that during dusting experiments it has been repeatedly noticed that charging the dust causes a considerably greater increase in the deposition of small particles than it does of large particles.

Hampe, working in France, has done considerable work both in the laboratory and in the field using ionized field charging equipment. Generally his observations agree with those made at Michigan State College. Hampe has worked with charging nozzles similar to those used in this study, and also with a naked high tension wire placed to the rear of a conventional duster, in such a way that corona voltages occur near the wire, and a field is set up between the wire and the plants. So far it has not been possible to test this latter type of equipment in this study, but such a test is certainly recommended if the required high voltages can be obtained. Unfortunately it has not been possible to obtain any information from Hampe additional to that which is presented in the two references. In correspondence it was learned that he was not able to release further information because he has had difficulty in obtaining patent coverage in the United States.

The charging of smokes and aerosols has also been briefly studied, but since the previous work in this field has not been connected with electrostatic dusting, the literature pertaining to it will be dealt with in a later section.

Statement of the Problem

Dust particles can be charged by utilizing ionized field charging nozzles, and the improvement which can be obtained in the recovery of dust on plants and test surfaces by the use of such charged particles, has already been demonstrated.

Further information is, however, required on the method of obtaining such a charge, and upon the behaviour of the charged particles, so that full use can be made of the forces of electrostatic attraction. In addition to this theoretical side of the problem, the method must be applied in the field, and an effort must be made to attain all of the advantages projected for electrostatic dusting.

APPARATUS AND METHODS

General

One of the major problems in methodology in this study has been the evaluation of the dust deposits which have been obtained. Several different techniques have been utilized, but as this work is rather distinct from the actual dusting study their description has been included in Appendix I.

The equipment used for specific tests is described in those particular sections, but as the construction of the charging nozzles is of general application a short description is included here.

Nozzles for Charging Dust Particles

All of the work involved in the development of type III and type IV (see Figures 1 and 2) nozzles and the major share of that on type V (Figure 3) has been done by Bowen and will form part of the subject for a Ph. D. thesis at present in preparation. For the sake of completeness, however, their description will follow.

Basically all ionized field charging nozzles consist of a wire, a point, or a series of points which are placed in the dust-air stream, and are maintained at a sufficiently high potential to produce corona voltages in the region of the wire or point. In this way an ionized field is produced.

Throughout this study a negative potential has been used, because of the greater efficiency of the negative corona; for a detailed discussion of this and of the theory of charging the reader is referred to Bowen's work (3).

The source of the high negative potential is immaterial providing that the current is direct and fairly steady. In this study the original source of the power has been either a battery or the mains, stepped up to the required voltage; Hampe, however, utilized a frictional generator which generated the required voltage directly.

Type III Charging Nozzle

This nozzle is illustrated in Figure 1. The dust-air stream enters the nozzle from the flexible tube 4, and as it leaves the nozzle passes through the ionized field which is set up between the fine high tension wire 3 and the semi-circular section metal plates 1, which are grounded.

During the earlier work this nozzle was operated in a rather different way; the sheet metal plate 2 and the plates 1 were maintained at a negative potential, with, the wire also negative, but at a potential sufficiently above that of the plates to create a corona voltage near the wire. The purpose of plate 2 was to create a field between it and the plants being dusted, and in this way increase the field force acting upon the particles. The use of this plate did increase the deposit, but the deposit showed serious fringing, (concentration of the deposit at the edge of the leaves) and for this reason its use was discontinued. The possibility of using such a plate for certain special cases must not, however, be overlooked; in dusting onions for example fringing could hardly occur, and the plate may prove useful. Without the use of the plate, the only field force present is that produced by the dust cloud itself, there being a field between a cloud of particles all charged to one sign, and the grounded plant. The cloud is charged negative, and by induction the plants exhibit a positive charge.

In connection with the charge on the plant, the question is frequently asked, what influence does the natural charge which plants possess have upon the induction effect just described? In answer it can be said that the magnitude of the natural charge is very small compared with the induced charge, and that all observations indicate that it has no significant influence upon the end result.

Type IV Charging Nozzle

Figure 2 illustrates a later development of nozzle which it is believed is more efficient in charging. This was developed from the type of equipment used by Cottrell in industrial smoke cleaning. The dust-air stream passes through the grounded tube, and the ionized field is set up between the fine wire and the tube wall. Plexiglas insulators were used to bring the high tension lead through the cylinder wall.

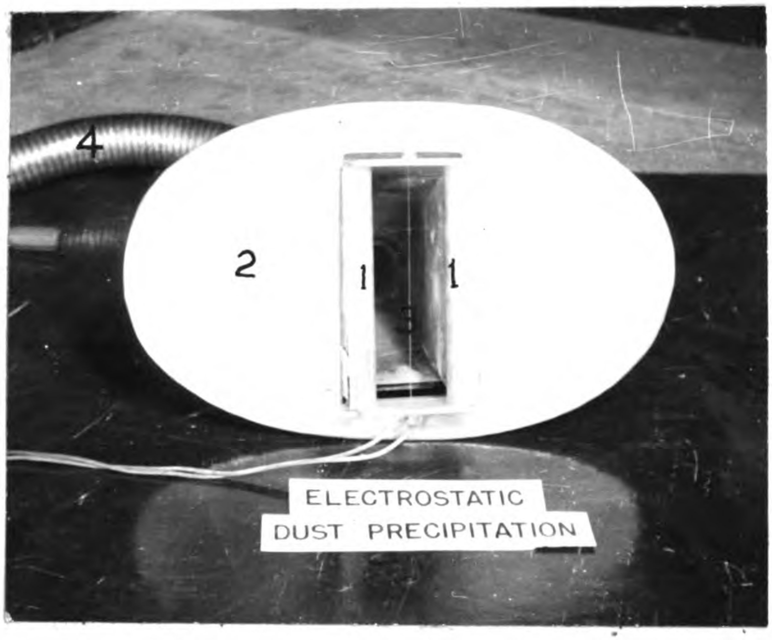


Figure 1. Type III charging nozzle.

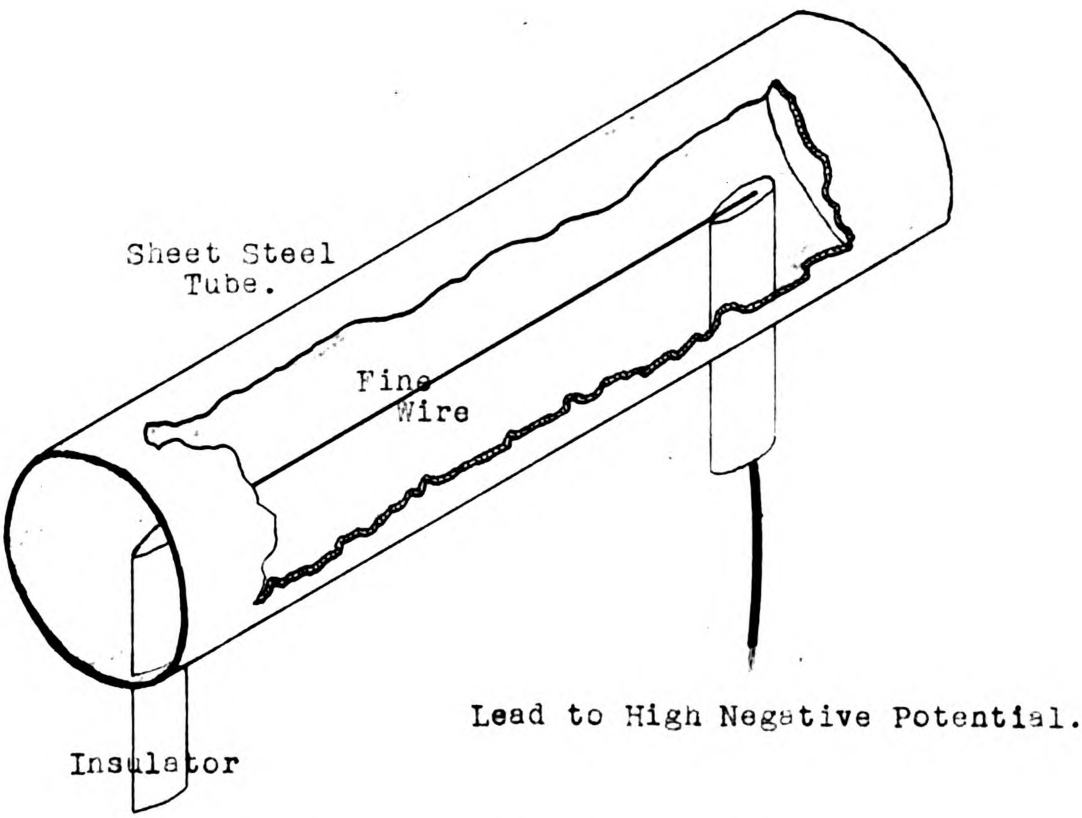


Figure 2. Type IV charging nozzle.

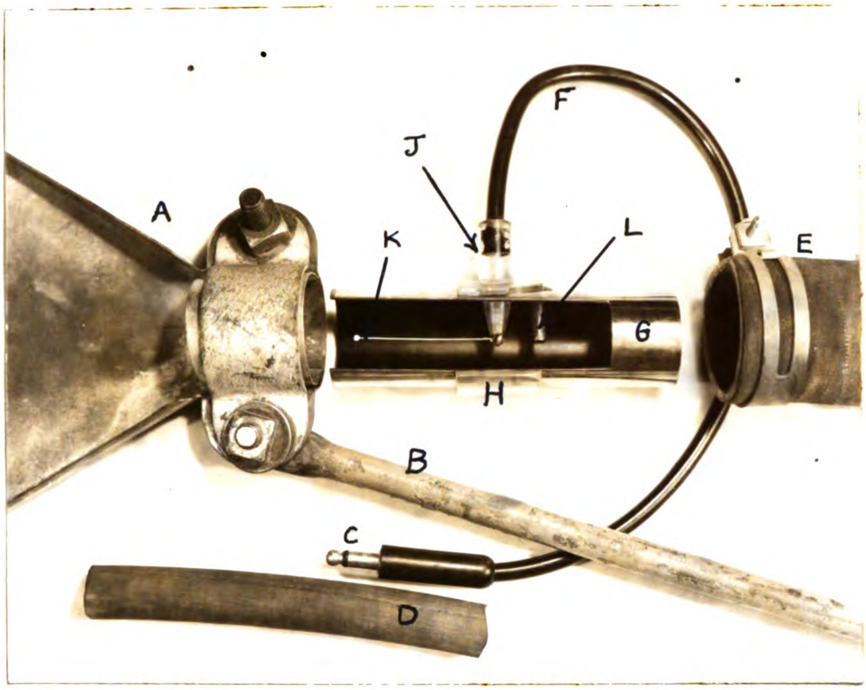


Figure 3. Photograph of type V charging nozzle with a section cut away to show interior.

A Fan shaped nozzle of duster into which charging nozzle fits.

B Support, clamps nozzle to beam of duster.

C High tension lead coupling.

D Rubber insulator to cover lead coupling.

E Rubber hose, connects nozzle to duster tube.

F High tension lead.

G Main tube of charging nozzle, with section cut out.

H Plexiglas insulator clip.

J Insulator.

K Charging needle.

L Post to deflect air stream.

Type V Charging Nozzle

Figure 3 is a photograph of this type of nozzle. Basically it is the same as a type IV, except for the fact that a fine needle is used instead of the wire, and this is supported at only one end for simplicity of construction.

This type of nozzle was used on both of the dusters used in the field trials. Plexiglas insulators were used as before, but early in the field work it was found that the high air velocities in these field dusters caused a compacted layer of dust to build up on the upstream side of these insulators, and this layer was sufficient of a conductor to allow arcing over, between the needle and the tube wall. As soon as such arcing occurs the corona breaks down and the nozzle no longer charges the dust. Several methods were tried to avoid this arcing, including the streamlining of the insulator, but the use of a small deflection post placed just upstream from the insulator proved to be the most effective. After fitting this, no further trouble was experienced with these nozzles during the field work.

Method of Presentation

The first section of this thesis will deal with the laboratory tests which have been carried out to test the more fundamental aspects of the work.

The second section deals with the application of electrostatic dusting in the field and the methods used to test it.

Finally a brief description of the exploratory work on the charging of smokes and aerosols is included.

LABORATORY INVESTIGATIONS

The Sign of the Net Charge on a Cloud of Charged Dust

The theory of particle charging described by Bowen (3) concludes that a negative high potential on the charging wire of a nozzle will yield negatively charged dust.

To support this theory a simple experiment was done to prove that the dust actually carries a negative charge. Only a qualitative determination was made of the net sign. To investigate further, and to work with the charge on individual particles would have required much more complicated equipment.

Apparatus used

A circuit diagram of the equipment used is shown in Figure 4. One pole of the sensitive micro-ammeter was connected to ground, and the other to a sheet metal disc which was mounted on a Plexiglas support to provide good insulation. Thus, when charged particles approached or struck the plate a small current, which could be measured on the ammeter, flowed to ground. The ammeter needle was centered on the scale, and the net sign of the cloud of particles determined whether the needle deflected to the right, or to the left.

To determine the sign of the charge, it is first necessary to have a practical definition of either a positive or

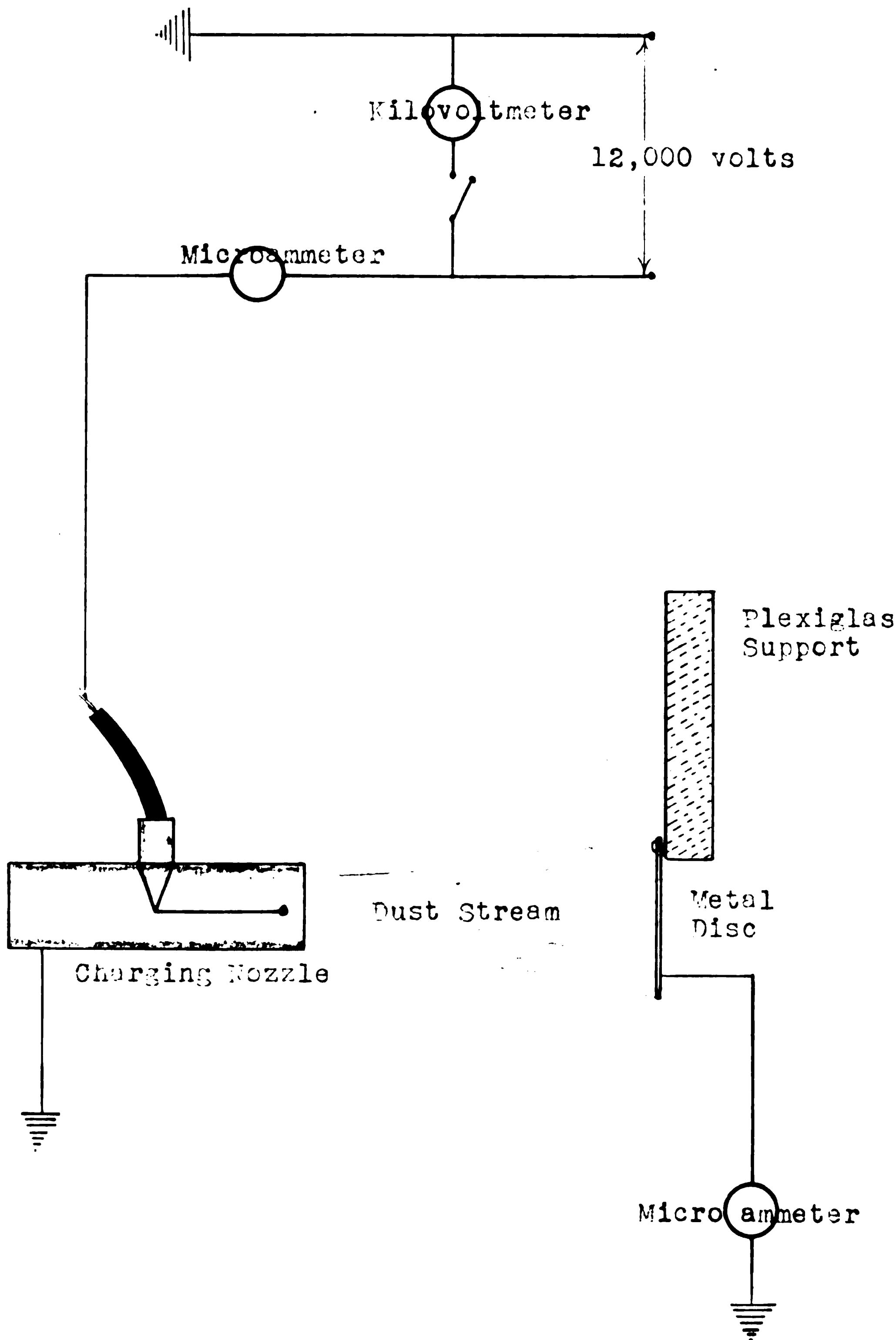


Figure 4. Circuit diagram of equipment used to determine sign of charge.

a negative charge. Atwood (1) has defined a positive charge as the charge which a glass rod takes when it is rubbed with a piece of dry silk.

Results

A glass rod charged by rubbing on dry silk was brought up to the plate and was found to cause a deflection of the ammeter needle to the left. Equal quantities of several different samples of dust were then blown at the plate from a single outlet duster which was fitted with a type V charging nozzle. When the charging nozzle was left switched off, the ammeter indicated currents of varying magnitudes according to the dust being used. Some of the dusts caused a deflection to the left, that is they possessed a positive charge, and some gave a negative deflection. The phenomenon exhibited here is friction charging.

When the charging nozzle was switched on, all the dusts gave a strong negative deflection regardless of what their friction charge had been. The magnitudes of the currents in this case were also much higher than any of those resulting from the friction charge.

Finally the duster air stream alone was directed at the plate. Without the charging nozzle on, the air stream produced only a trace of a deflection. When the nozzle was switched on a slight negative deflection was observed, but it did not approach the magnitude of the deflection produced by the dusts, either with the charging nozzle operating or with it switched off.

Conclusions

It has been indicated that amongst the dust samples tested, some exhibited a negative friction charge, whilst others charged positive by friction. In spite of this, however, all the dusts tested possessed a strong net negative charge after passing through a type V negative corona charging nozzle.

This test was not intended to be in any way complete with respect to dusts tested, but it does suggest a test for a charging nozzle, which would subject it to the most difficult charging task it would be likely to meet in the field. This would consist of selecting that dust (and particle size) which charges more strongly than any other dust in the positive direction (the work of MacLeod (20) could be used to determine this), and feeding this through the nozzle at rates up to the highest required in the field; this work being done under atmospheric conditions conducive to friction charging. If the charging nozzle could produce a high net negative charge on the dust under these conditions, it would be safe to conclude that its capacity would be sufficient for all field operations.

Visual Demonstrations of Electrostatic Charging

In order to gain a picture of what can be expected of electrostatic dusting, two simple demonstrations will be described.

Apple demonstration

In this demonstration a single outlet duster fitted with a type IV nozzle was used. The outlet velocity in this case was, however, considerably lower than that usually encountered in field dusters.

A clean apple was selected and suspended in the duster air stream by means of a slightly moistened string, which was grounded. A small quantity of commercial talc dust (or any white material) was then put through the duster with the charging nozzle operating. This process was repeated with another apple and the same quantity of dust, but in this case the nozzle was switched off.

On comparison it could be seen that the charged dust produced a much better coverage than the uncharged, and that whilst there was quite a good dynamical catch (particles which penetrate to, and are deposited on, the surface due to their momentum) of larger particles on both apples on the side facing the dust stream; the charged dust gave good coverage on all surfaces of the apple, and also caused the precipitation of a much larger number of small particles. Because of the presence of these small particles it was possible to blow a fairly strong jet of air at the apple which had been electrostatically dusted without completely destroying the coverage, whilst this was not possible in the case of the apple dusted with uncharged dust.

Leaf dusting

In this demonstration potted celery plants were substituted for the apples, but otherwise the same arrangement was used as in the apple test.

The results of this demonstration are best seen by examining Figures 5 and 6. Note the greatly increased quantity of dust on both surfaces of the charged leaf, and also the increase in the number of small particles present. In the case of the uncharged dust it will be seen that this low velocity of air, which incidentally might quite easily occur in the field in the center of plant foliage, produced only the poorest coverage on the under surface of the leaf.

Figure 5. Upper surface of dusted celery leaves magnified approximately five times. Leaf on the left charged dust; leaf on the right uncharged dust.

Figure 6. View of the under sides of the two leaves illustrated in Figure 5.

The Behaviour of Charged Dust at Varying Distances from the Outlet

The application of electrostatic dusting in the field depends to a large extent on the distance from the nozzle at which the forces of attraction will continue to act. Thus if the maximum distance over which the dust may be blown without losing its charge were six feet, this type of dusting could be used for ground crops, but would be of no value for orchard work. Charged dust particles lose their charge by contact with free ions in the atmosphere; for a fuller discussion of this the reader is referred to Bowen's thesis (3).

With a view to estimating this effect Bowen has described a test which was carried out in a special, low velocity wind tunnel. Soon after this wind tunnel test was carried out, however, it was realized that although its results in all probability give a good indication of the true effect, there might have been some interference due to the presence of the tunnel wall surrounding the dust cloud. According to the magnitude of the various disturbing effects which the walls could have upon the result, the dust deposit could be either increased or decreased by their presence. In view of this it was decided to repeat the test in the open, comparing charged dust with uncharged at various distances from the outlet.

Apparatus and Method

The duster used for this test was constructed from a household vacuum cleaner, and fitted with a type V charging nozzle. The outlet velocity was adjusted so that it corresponded exactly with that of the field duster X1 (which will be described in a later section). This velocity was estimated to be approximately 10,000 feet per minute. The amperage supplied to the nozzle when the dust was being charged was 40 microamps. The dust deposit produced at various distances from the duster outlet was assessed by using the blackened metal discs, and the light meter evaluation which is described in detail in Appendix I. Only one disc at a time was used, and for each reading reported in the results table, three replications were made. The test disc faced the outlet of the duster, and the distance between duster and disc was increased by stages up to 33 feet, at each position the disc being centered in the dust-air stream. During the test the relative humidity was low, being approximately 40%.

The test was performed in a large room, but unlike the wind tunnel test reported by Bowen, the dust cloud was unrestricted and moved from station to station only by virtue of its own momentum.

To get a truer picture of the loss of charge, the amount of dust deposited on a test surface should be compared with the amount available in the air for precipitation. Such a comparison was not possible because equipment for measuring the dust content of the air was not easily available. An attempt was made, however, to correct for this thinning out of the dust cloud, as it fanned out in travelling away from the duster. The area of cross section of the cloud was estimated by placing a blackened strip of metal in the cloud at each test station and in this way locating its boundary by examining the strip for dust. Having estimated the various areas, each dust recovery reading was corrected so that it was stated in terms of the reading at the first station; for example if the cloud area at station two was 2 units, and that at station one was 1, then the dust recovery at station one would be stated as it was read, but that at the second station would be corrected by multiplying by two. This method does not, however, take into account the dust which settles out of the cloud, and neither of these correction methods allow for the fact that as the cloud is thinned out, the field force which aids in the precipitation of charged particles, is itself reduced.

Two different samples of dust were used. One was a sample of Nytal talc, which had been "Micronized" (that is ground in a micronizing mill) and had a mean particle size of 3 microns, and the other was a commercial 325 Mesh talc (which means that the dust had passed a 325 Mesh screen). A microscope count of this latter sample showed the mean particle size to be 7 microns, but it contained a much wider range of sizes than the other dust.

During the test the duster was kept running, and for each test run a fixed quantity of dust (6.9 c.c. by volume) was put through the machine. This produced a jet of dust which was only of comparatively short length.

Visual results

The distance between the different stations can be seen by consulting Table I. Figure 7 is a photograph of a set of dusted discs obtained during the test with the commercial talc dust. From this photograph it will be apparent that at every station the charged dust was superior to the uncharged.

It was also noted that at the two most distant stations the dust recovered tended to consist of larger particles than that at the nearer stations. An explanation of this may be, that when the cloud becomes thinned out, the consequent lowering of the field force on the particles has a greater depressing effect upon the recovery of small particles, than it does on the large; the large particles being affected by the image force at a greater distance out from a surface than are the small ones.

Numerical results

The results of this test are presented in Table I and graphs drawn from these results are given in Figure 8. In the graphs the actual observed readings are represented by the solid lines, whilst the readings which have been corrected are joined by a broken line. In each case the charged dust is the upper of a pair of curves.

It should be noted that in view of the wide range covered by the light meter readings they have been plotted on a logarithmic scale.

This range would have been considerably reduced if the discs had all been placed either side-to or back-to, the dust-air stream. This, however, is rather biasing ones results in favour of the charging, whereas facing the stream is biased for the uncharged dust. To gain a complete picture both should be considered.

Conclusions

The ratio of the improvement caused by charging the dust varies from station to station, all the way from an infinite improvement to something less than a doubling. No single value will, therefore, be picked out as representative, for it can be seen how widely the results vary according to circumstances. This caution should be exercised when examining all the laboratory results. No ratio of improvement should be singled out unless all of the variables which affect the result are detailed.

The attempt at correcting the curves for cloud spread was not entirely successful, because of the two variables (reduced field force, and loss of particles by settling) for which allowance is not made.

To sum up, these results agree well with Bowen's and, further, show that under the conditions of this test, the dust retains a useful amount of its charge at 33 feet from the outlet even when the movement of the cloud is unrestricted.

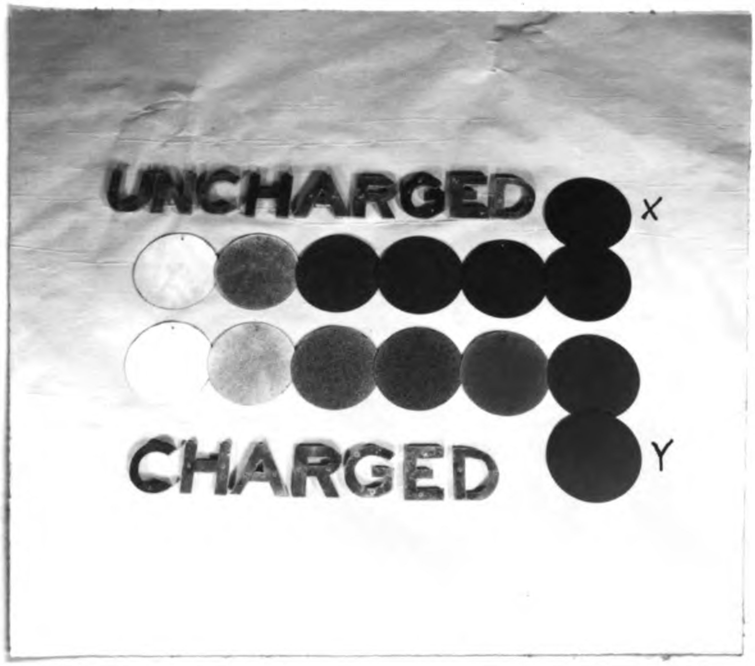
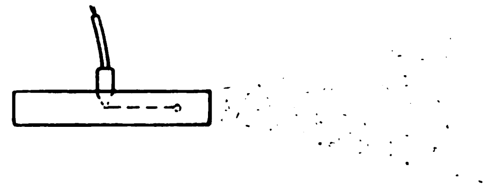


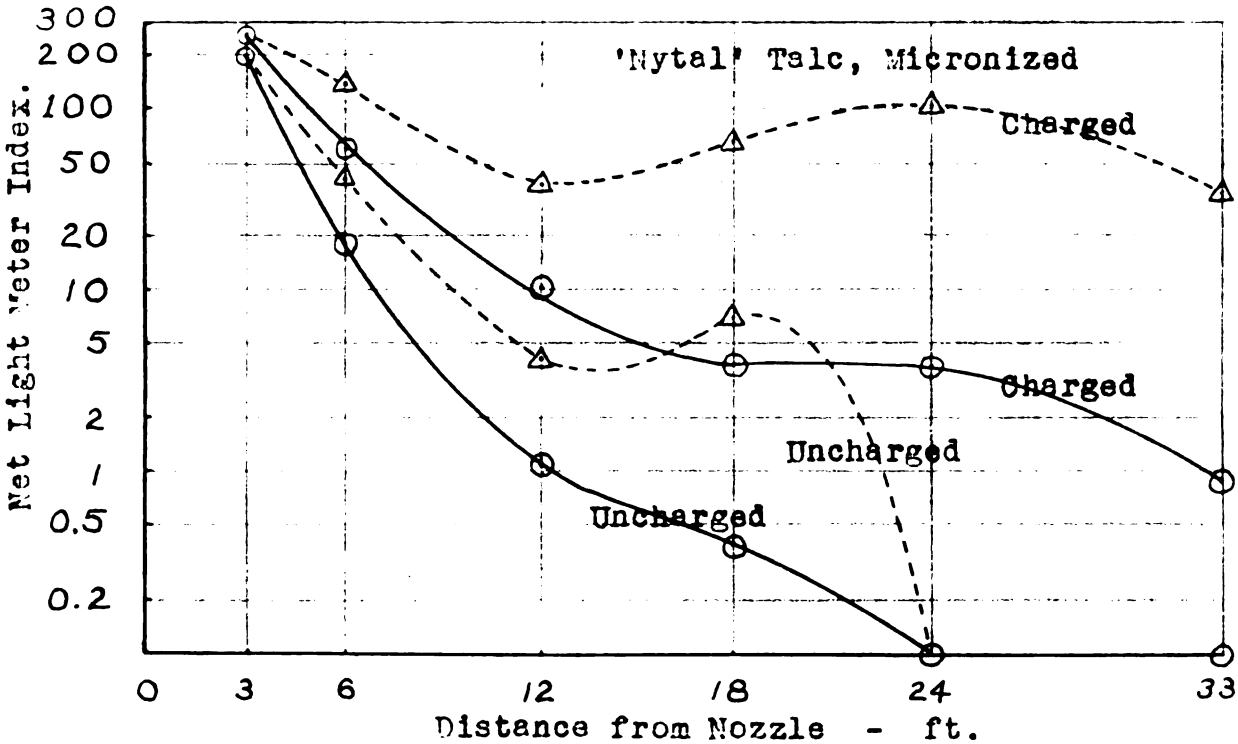
Figure 7. Discs used in the distance test (325 Mesh talc) upper row uncharged dust, lower charged. Disc X & Y were undusted. Passing from left to right the discs represent the stations at increasing distances from the duster outlet.

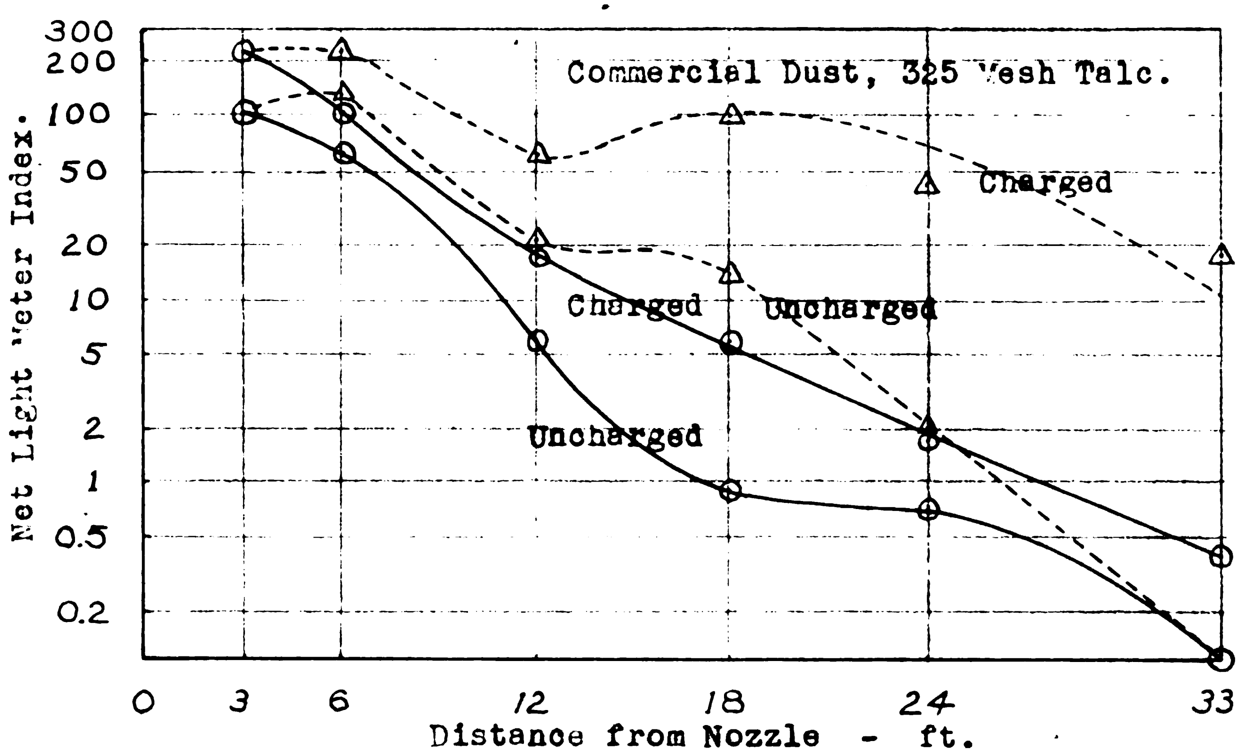


Duster Nozzle			Test	Discs.		
Distance from Nozzle - ft.	3	6	12	18	24	33
Estimated Air Speed - f.p.m.	1220	796	420	238	140	95
Estimated Cross Section of dust Jet (Cloud) - in.^{2}	380	855	1,450	6,700	10,500	15,000
Dust Collected on Test Discs. (Wet Light Meter Index).						
Micronized Nytal - Charged.	245	59	10.2	3.9	3.7	0.9
Micronized Nytal - Uncharged.	138	18.3	1.1	0.4	0	0
325 Mesh Talc - Charged.	225	103	17.2	6.0	1.7	0.4
325 Mesh Talc - Uncharged.	107	65	6.0	0.9	0.7	0

TABLE I

DUST DEPOSITED AT VARYING DISTANCE FROM THE CHARGING NOZZLE





(△ --- Dotted curves drawn by correcting for spread of cloud)

Figure 8. Graphical representation of the distance - deposit test. Upper block micronized talc dust, lower block 325 mesh talc.

The Effect of Varying the Current Supplied to a Charging Nozzle upon the Amount of Dust Deposited

According to the theory on the charging of particles in an ionized field, the charge that they acquire is proportional to the strength of that field. Preliminary trials, however, indicated that the dust deposited on test surfaces was reduced in quantity when a certain value for the current through the charging nozzle was exceeded. It was to determine if this reduction actually occurred, and at approximately what current level, that this test was set up.

Before proceeding it should be stated that increase in amperage is obtained by increasing the voltage applied to the nozzle, and as the amperage is increased so is the strength of the field. The voltage-amperage relationship, however, is not the same as for a current flowing in a wire, for, once the corona voltage is reached, small increments of voltage produce large increases in the amperage.

Apparatus and Method

The same apparatus and dusts were used in this test as in the previous, distance test, but less dust was put through for each run (in this case 2.3 c.c.). Assessment of the results was by means of the black discs, which were centered in the dust cloud, at three feet from the outlet. In this case the backs of the discs were evaluated for deposit; in this way the interference of the dynamical catch is avoided.

The amperage input to the nozzle was measured on a micro-ammeter, and was increased by stages from zero to 500 micro-amps.

Three replications were made at each setting, and between each set of three replications the inside of the nozzle wall was cleaned of dust.

The results of the tests are given in Table II and are presented graphically in Figure 9.

The differences between the tests were as follows:

Test 1	Micronized talc,	outlet	velocity	10,000 f.p.m. approx.		
Test 2	Commercial talc,	"	"	10,000 f.p.m. approx.		
*Test 2'	"	"	"	"	"	"
**Test 2"	"	"	"	"	"	"
Test 3	"	"	"	"	3,200 f.p.m. approx.	

*With one exception all the tests were performed on the same day, when the relative humidity was approximately 40%. The exception being Test 2'. Unfortunately the humidity for the latter test is not known.

**Before each of the four runs of this test a layer of dust was built up on the inside of the nozzle, by passing through a quantity of the same kind of dust. This was an attempt to simulate the condition the nozzle would be operating in, in the field.

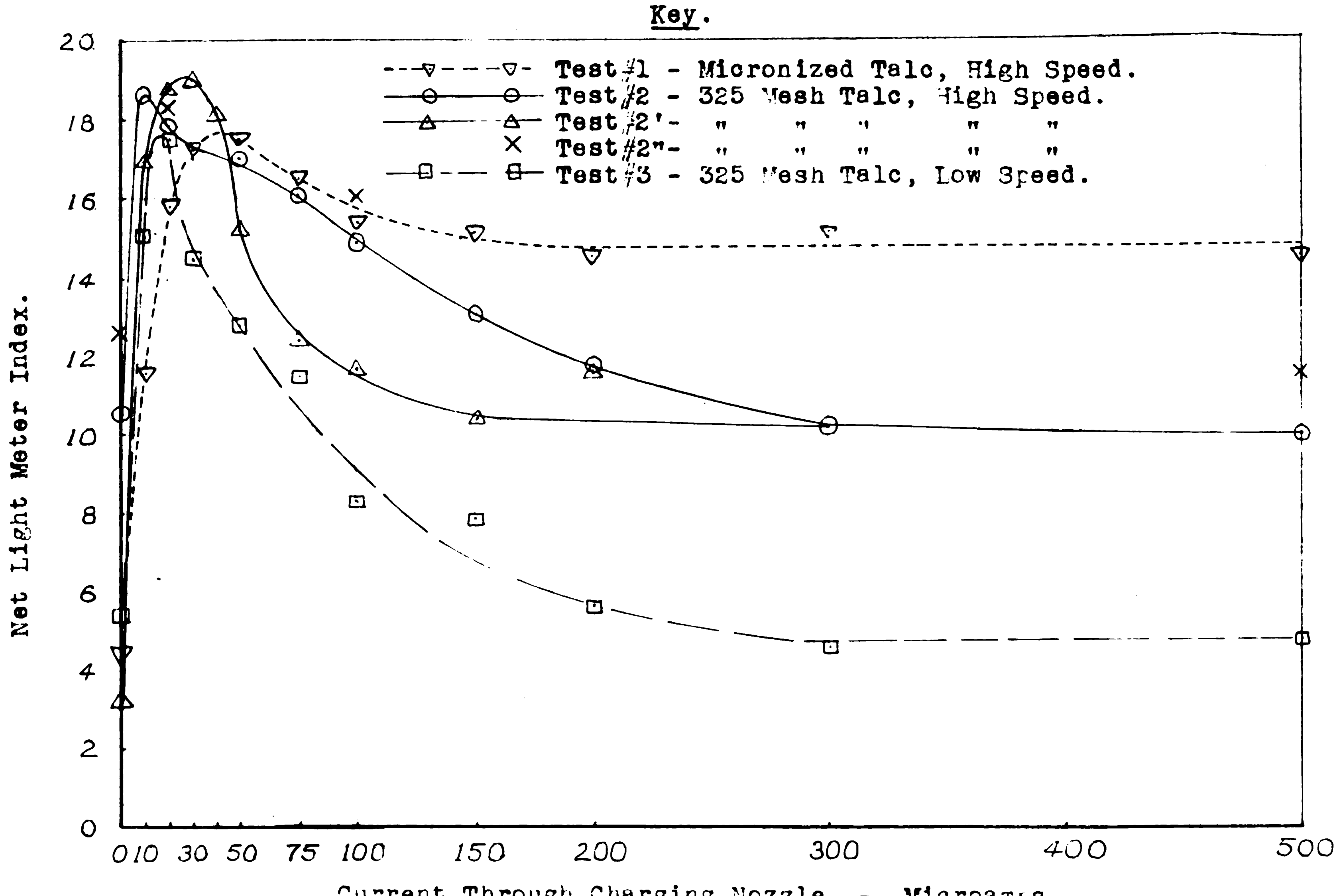


Figure 9. The effect of varying current upon dust deposit.

TABLE II

THE EFFECT OF VARYING CURRENT UPON DUST DEPOSIT

Current Applied to Nozzle Microamps	Net Light Meter Indices				
	Test 1	Test 2	Test 2'	Test 2"	Test 3
0	4.3	10.5	3.2	12.6	5.4
10	11.6	18.6	16.9		15.0
20	15.8	17.8	18.7	18.3	17.5
30	17.2	17.0	19.0		14.4
40			18.1		
50	17.5	17.0	15.2		12.8
75	16.5	16.1	12.3		11.5
100	15.3	14.9	11.7	16.1	8.3
150	15.7	13.0	10.3		7.8
200	14.5	11.7	11.6		5.6
300	15.2	10.2	10.3		4.6
500	15.0	10.0	10.0	11.6	4.9
Symbol used on curves on previous page	▽	⊙	△	×	⊡

Results

The results of these tests confirm that a relationship does exist between deposit and amperage, and that when a certain amperage is exceeded the recovery of dust is reduced.

This result is of practical importance in the field, for based upon these results, (where an optimum occurs at about 25 microamps) the field duster X1 was operated on too high an amperage (100 microamps) to get the best results possible.

Test 1 showed that the Micronized talc required more current to produce optimum results than was required in any other test. This is not surprising, because the charge per unit weight which a dust can take on, increases with decreasing particle size.

Comparison of tests 2 and 2' indicates that some changes, probably atmospheric, from day to day alter the optimum current.

Test 2" shows that a dust layer on the wall of the charging nozzle has little effect upon the optimum value.

In test 3 although the optimum current has changed little, the use of a lower velocity results in a poorer recovery of dust particularly at the higher current levels.

Conclusions

For one particular sample of dust under one set of conditions, there is an optimum level for the charging nozzle current. If this optimum is not reached, or if it is exceeded, electrostatic dusting will not yield its best results.

The fact that this optimum current varies according to conditions and from dust to dust has also been shown.

For the future it is obviously important that the mean level, and variabilty of the optimum current be known, so that this may be correlated with nozzle design and so that recommendations can be made for field operation. Further tests are envisaged, and in these the effect of different rates of throughput, (throughput was constant and undetermined in this study) should be examined.

The cause of the falling off in the amount of deposit at high current levels is not apparent, but the following suggestions are offered as avenues for investigation.

1. The higher currents may cause the particles to become highly charged early in their travel through the nozzle, and the stronger field would tend to precipitate them more rapidly on the nozzle walls. Weighing of the wall deposit could check this.

2. The higher currents and stronger field may have an influence upon the formation of dust agglomerates. If the first suggestion proves to be false, it should be possible to check the veracity of this one by analyzing the dust cloud at the different current levels.

3. The dust may carry a higher charge when the nozzle current is high, and if the dust is a non-conductor, may

build up a negative layer on the test surface which tends to repel further particles from that surface. From the results, however, this would seem to be the least likely suggestion.

The Influence of Humidity and Temperature upon the Deposition of Charged Dusts

Atmospheric humidities vary in the field over a wide range during the growing season, and due to the urgency of making dust applications when attack is imminent, it is important that any dusting method used should be able to operate throughout this range.

Many growers like to dust at night, when the foliage is moist and when inversion conditions prevail. Whether this will be necessary when electrostatic dusting is used is questionable, but if it is still desirable to dust at night, the machine must be capable of operating under conditions of 100% relative humidity.

Bowen has described a test which was designed to investigate the influence of humidity upon deposit, but the results were very variable and exhibited no clear-cut relationship. In view of this, an attempt was made to obtain more consistent results by exercising more control over the variables. It was hoped in this way to find some indication of the cause of the humidity relationship.

Apparatus and Method

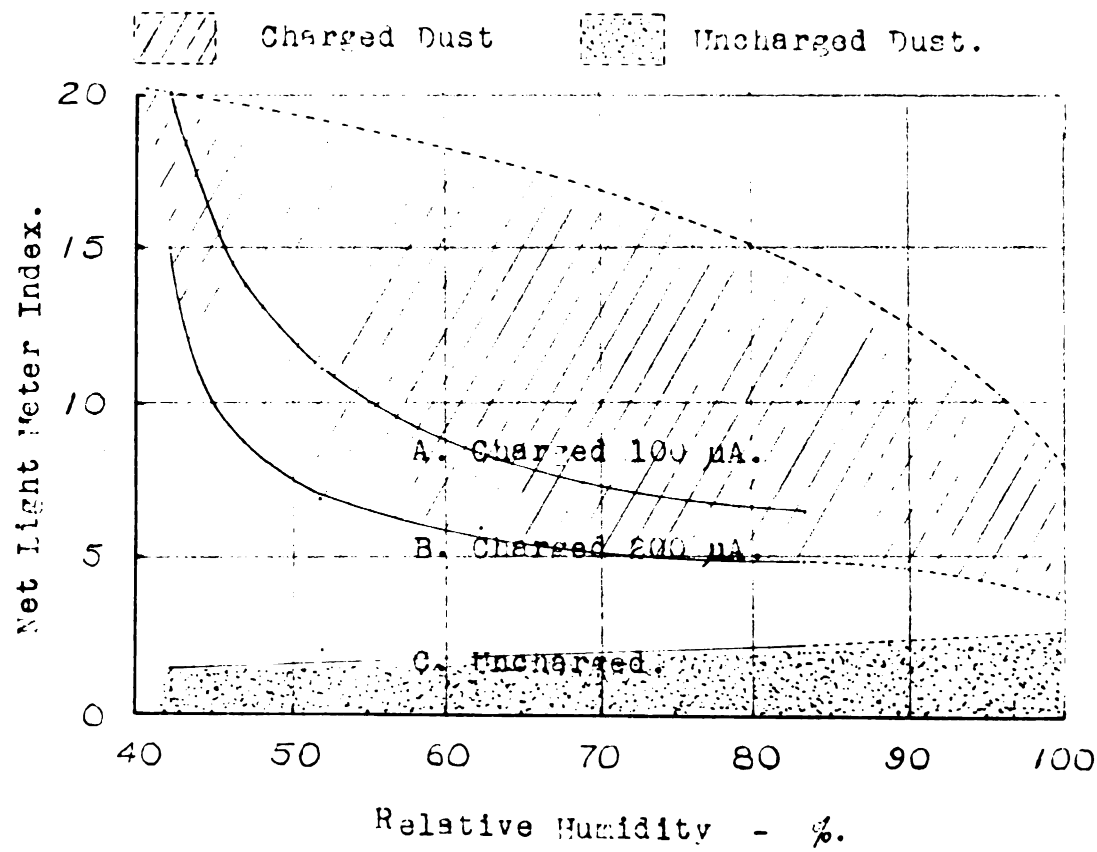
The test was carried out using substantially the same equipment as that used by Bowen, that is a low velocity single outlet duster, fitted with type III nozzle. The work was carried out in a walk-in refrigerator, humidified with a steam jet, and heated with electric heaters.

This work was done before the field duster was built and as a result the air velocities used on the laboratory duster were very low by comparison. Measured at a distance of two feet from the outlet, various values between 90 and 640 feet per minute were used (this represents an outlet velocity of not greater than 2,000 to 2,500 f.p.m. for the higher of these values).

Blackened discs were used in the evaluation, and these were placed at two feet from the duster outlet with the face parallel to the air stream.

Results

The results of this test were again disappointing, merely confirming the irregularity of the results reported by Bowen. They do, however, give further confirmation to the important finding that even at 100% relative humidity, electrostatic dusting shows an improvement over conventional dusting, although that improvement is less than that which can be expected at lower humidities. Because of the irregularity of these results it was felt that nothing would be gained by reporting the conditions in detail, and, therefore, all the results have been drawn together, and presented graphically in Figure 10. The shaded area embrases all the curves obtained when using charged dust, and the dotted area covers all the corresponding comparison tests done with uncharged dust.



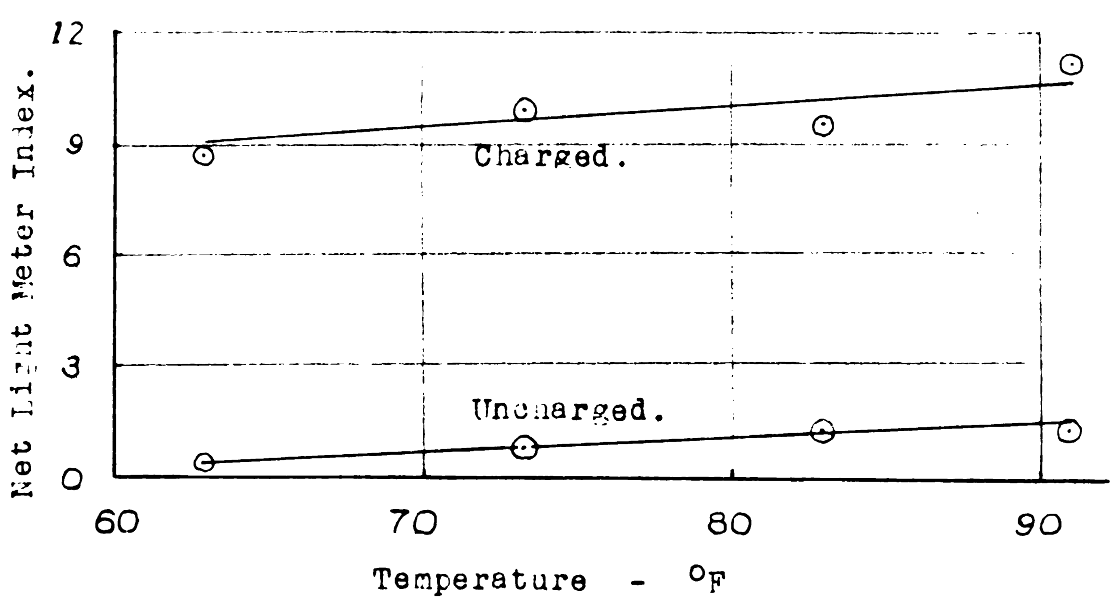


Figure 10. Upper graph. The effect of humidity upon dust deposit.
Lower graph. The effect of temperature upon dust deposit

One very brief trial which was carried out in conjunction with this test, was to remove the duster unit from the humidity chamber, and leave only the test disc on the inside. The duster blew dust into the chamber through a small inlet, but drew its air supply from the outside, where the relative humidity was down in the 40% region. In spite of this precaution the amount of deposit was still apparently susceptible to changes of humidity inside the chamber.

Two of the several curves obtained during this test are shown in Figure 10 because they further confirm the results of the last test. These curves show that consistently more dust was deposited when a current of 100 microamps was supplied to the charging nozzle in place of the 200 microamp current.

Conclusions

We may conclude that electrostatic dusting can be expected to work, but with a reduced efficiency, when the humidity is 100%. This finding has been confirmed in the field where dusting was done on several occasions with the humidity up at this level. In this respect this type of electrostatic dusting is superior to friction charge dusting, because that effect can be expected to cease at humidities above about 50%.

If duplicatable results are to be obtained in the future, it is certain that any investigator will have to take great care to control conditions, and wait until an equilibrium is reached before proceeding with a test run. Further, it is felt that if velocities approaching those used in the field, are employed in the test, then the influence of humidity upon deposit will be less serious.

Theoretically change in humidity should not affect charging, and the reason for the reduced deposit has yet to be explained. It has been suggested, however, that the effect is due to the influence of humidity upon the aggregation of the small particles; this would help to explain the inconsistent results, but the test where the duster was removed from the chamber, contradicts the explanation (the latter test, however, had very few replications, and can be questioned on these grounds).

Temperature influence upon deposit

This was run with the same equipment that was used in the previous test, and an attempt was made to vary the temperature whilst keeping the humidity constant. Just as with the humidity test this control was difficult, but a range of temperatures was obtained which fairly well covers field conditions.

A pair of curves comparing the effect of temperature upon the deposition of charged and uncharged dust is shown in Figure 10. From these it can be concluded that the effect of temperature, if any, is slight, and for practical purposes we may disregard it.

FIELD TESTS OF ELECTROSTATIC DUSTING

With any new method which shows potentialities for development into a farmer's tool, the necessity for field testing needs no emphasis. Accordingly during the summer of 1951 a number of field trials were carried out.

Two different dusters were adapted for this work, the first one being constructed expressly for this trial, whilst the other was a conventional Niagara Cropmaster, four outlet duster, with the electrostatic equipment added to it.

Description of Equipment

Experimental field duster X1

A general view of this duster is given in Figures 11 and 12. In order to facilitate description, the division into, frame, engine, duster unit, and the electrical equipment, will be made.

The main chassis, which was built in the shape of an arch, was of tubular steel construction, and designed for high clearance. The chassis was mounted on two rubber tired wheels, and was so constructed that the wheel supports could be telescoped out to give any desired wheel track between 54 inches and 118 inches. This wide range was necessary when the machine was constructed because it was not known exactly what crops would be dusted during the test. On the rear of this chassis was mounted a 12 ft. wide, channel section beam, to which the nozzle supports were clamped (the beam was a Niagara unit).

Power to drive the duster unit was supplied by a 7 H.P. Novo single cylinder gasoline engine. The drive between the engine and duster was a single "B" section V-belt. This belt was arranged so that the drive to the duster could be released by moving a tensioning pulley away from the belt. The engine also drove an automobile generator fitted for the purpose of keeping the 6 volt batteries charged. The power of this engine was above the actual requirement, but it was thought advisable to have power to spare so that a steady duster speed could be maintained, and also to allow for adjustments in that speed.

The duster unit used was a Niagara Evenfeed, this was chosen because the air velocities used in the Evenfeed are fairly representative of present day dusters, and because this machine is outstanding for its constant feed mechanism. It was felt that for experimental work an accurate feed was very necessary, (reference to Figure 14 will indicate how this is achieved). Many conventional dusters feed to the blower directly out of the main hopper, and, as the level of dust in the hopper falls, and thus the "head" on the outlet slit is reduced, a varying rate of output results. To avoid this, the Evenfeed feeds to the blower out of a small secondary hopper, which is continually kept full by a belt conveyor elevating dust from the main hopper. Originally the

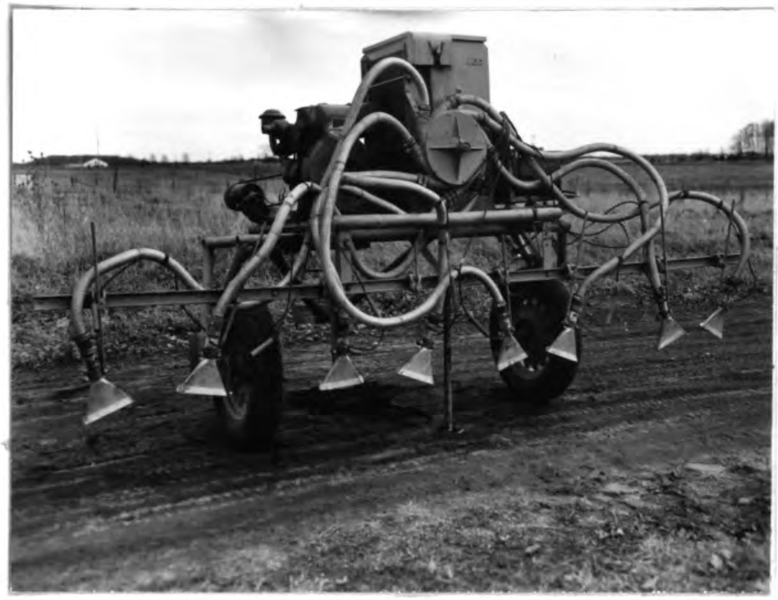


Figure 11. Rear view of field duster X1.

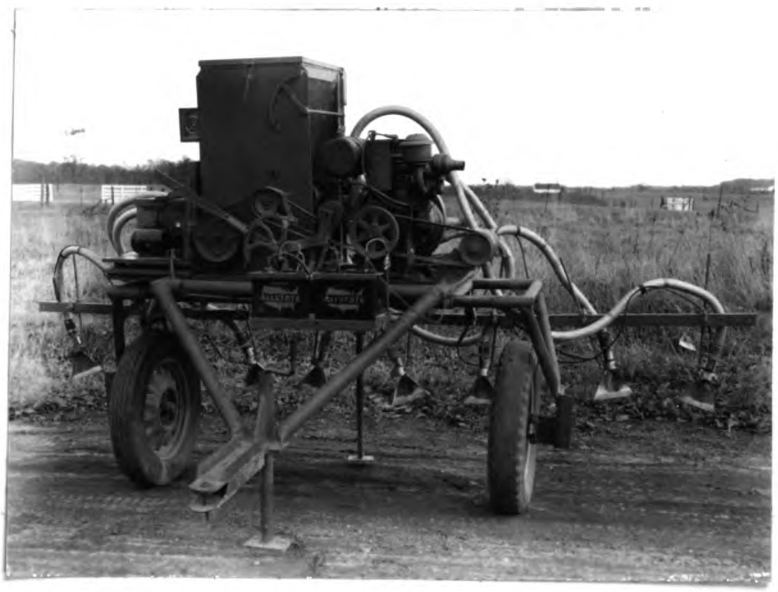


Figure 12. Front view of field duster X1.

Figure 13. The field duster X1 prior to modification from a six outlet to an eight outlet machine.

Figure 14. View inside the dust hopper of duster X1 showing the small V-belt conveyor which maintains a constant level in the small upper hopper.

duster was built as a six outlet machine, (see Figure 13) but when it was found that the electrical equipment had sufficient output for eight outlets, a conversion was made. At the same time a small inlet fan, obtained from Niagara, was fitted to improve the characteristics of the dust intake. On the advice of the manufacturer the main fan shaft was operated at approximately 4,000 r.p.m. The duster tubes supplied with the machine were used in the ordinary way, except that a type V charging nozzle was inserted between the end of the tube and the fan shaped outlet nozzle (Figure 17).

The componant parts of the electrical supply unit can be seen in Figure 15, and a circuit diagram is given in Figure 16. Two six volt batteries were fitted to this machine so that one could be charged whilst the other was in use. The purpose of this was to make the experimental duster a self-contained unit, although in practice the tractor's electrical system would be drawn upon. The 6 volt current from the battery first passed through a switch and ammeter, and then to the dynamotor (0.15 amp output rating) which converted 6 volts to 300 volts. The 300 volt current was in turn fed into the "High voltage supply" which produced the current for the nozzles. Measured at the nozzle, the voltage was approximately 12,000 for each outlet, but the current varied from 65 to 160 microamps, with a mean of 100. The reason for this variation is not known, and it is rather surprising in view of the fact that all the nozzles were built as nearly alike as possible.

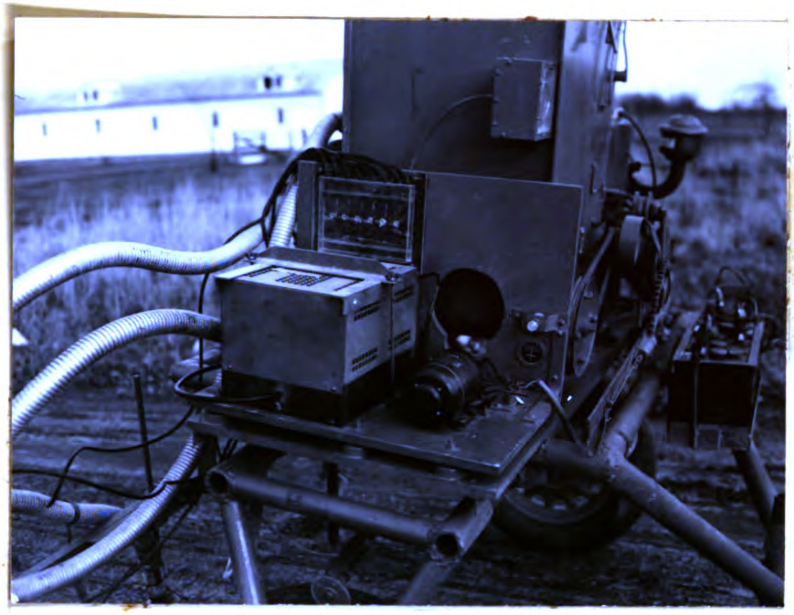


Figure 15. Side view of duster X1 showing power supply unit. The small dark, barrel shaped object is the dynamotor, to the left of this the rectangular box is the high voltage supply, and immediately above that, are the eight neon indicator lights.

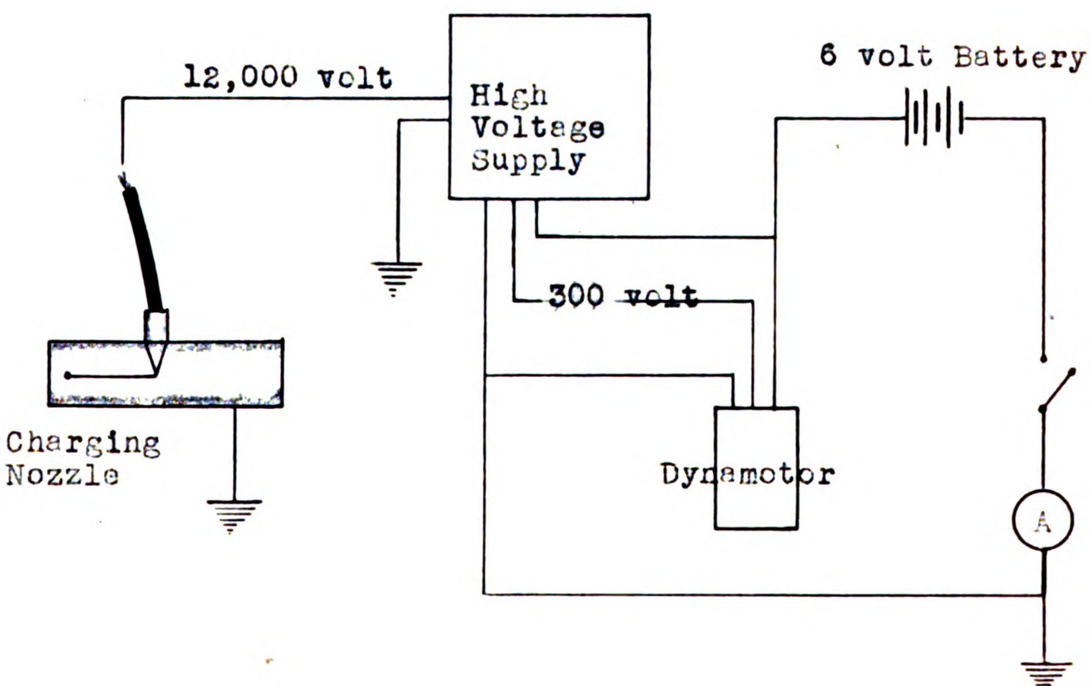


Figure 16. Circuit diagram of the electrical equipment used in the power supply.

The high tension leads were made from spark plug cable; this was found to be fairly good at insulating the high voltage, but not completely without leakage. In each high tension lead a connection was inserted to facilitate changing nozzles, in case this became necessary in the field. The connections were poor insulators and had to be covered with a rubber shield to prevent leakage to the frame. Purely for use during the experimental stage, each lead was fitted with a resistance, and a small neon indicator bulb shunting this resistance, so that if a short circuit occurred in one of the nozzles, the neon bulb lit up, and warned the operator. The majority of the credit for this wiring design is due to Bowen.

A speedometer, operated off the duster tire, was also fitted, so that rates of application could be more accurately measured in the field.

The metering of dust on this machine was by means of an adjustable slot in the small upper hopper previously mentioned. Before each field operation the duster was calibrated with the particular dust that was to be used.

Experimental field duster X2

In order to extend the field tests, a second duster, a Niagara Cropmaster four outlet machine, was adapted for electrostatic work. The outlets were fitted with type V charging nozzles in the same way as on the X1, and the same electrical equipment was used, except that in this case a 0.05 amp dynamotor was used, and only a single 6 volt battery was carried. As no generator was fitted, the battery had to be placed on a charger at intervals, but it is instructive to note that several hours dusting could be done on one charging.

Methods of Field Testing

Broadly speaking, there are two methods of testing the performance of a duster in the field; the nonbiological tests, and the biological. Clearly the latter are the more desirable, but as the incidence of pest attack is uncertain, and there are so many other variables occurring in field tests, it is extremely difficult to get a categorical result in one seasons work, or if conditions are adverse to get such a result even in two or three years.

Basically the field tests in this case are to answer one question and that is, "All factors being considered is electrostatic dusting going to be a worthwhile tool for the farmer's use?" To arrive at at least a good indication of the answer to this question without too much delay, the engineer can resort to the non-biological evaluations, and if these are encouraging, then the final biological work should largely be in the hands of the pathologist and the entomologist.

The author has arrived at this conclusion after carrying out both types of test. The engineer can run the preliminary biological evaluations, but the final acceptance tests should be in the hands of the experts in that field.

Figure 17. Duster X1, outlet nozzle of one of the tubes showing how the type V charging nozzle is attached.

Figure 18. Rear view of the Niagara Cropmaster duster adapted for electrostatic dusting. The box on the left of the machine, just in front of the main beam, contains all the electrical equipment.

The prime objective the engineer should set himself is to answer the question "Will the new method give as good or better coverage than existing dusting equipment, and in achieving such coverage what savings in dust materials or other economies can be made?" To qualify this a little more, the answer should be obtained on a representative range of crops, and as a suggestion for the future, the efficiency of the new dusting method could usefully be compared with conventional spray methods, both for recovery, and coverage.

Non-biological Tests

This work was carried out on field beans which had been drilled in 28 in. rows.

A number of rows in the field were picked out for their regularity, and these were dusted with a dust made up of 25% lead arsenate and 75% of 325 mesh talc as filler. The X1 field duster was used, and the dust was applied at 30.3 lb/acre. Half of the rows were dusted with the charging equipment on, and half with it switched off. The dusting was done at the end of July, in good weather.

Coverage

To evaluate coverage the leaf printing technique or the microscope may be used. A description and a discussion of these two methods are included in Appendix I.

In this case leaf printing was used. Reproductions of the prints are not included in this thesis, because at the rate of application of lead arsenate used, they were rather faint. A visual analysis, however, yielded the following information. The macro-distribution of the toxic agent, lead arsenate, was improved by the use of electrostatic dusting. Impartial observers could in each case pick out the leaf prints which were derived from electrostatic dusting, because of the greater amount of lead present. The differences were not very great, but were the more apparent when the under surfaces of the leaves were compared. The micro-distribution, as judged from the prints of the electrostatically dusted leaves, was at least as good, if not better than leaves dusted by conventional methods. Another important observation emphasized by these prints, was the extreme unreliability of a purely visual comparison between dusted leaves. For both methods of dusting, leaves from the center of the plants were to the eye, practically devoid of dust, but upon printing, it was apparent that there was approximately as much toxic agent on these leaves as on the outer leaves. This difference is probably the consequence of two factors, firstly the presence of only the smaller particles on the inner leaves, and secondly what is called "Fractionation" of the dust mixture. Fractionation in this case means that the composition of the dust recovered on the leaf surfaces is different from one leaf to another, and also differs from that in the hopper of the duster, there being a considerably higher percentage of toxic agent on the inner leaves of the plants.

The phenomenon of fractionation has been reported before, and can result from a number of causes, however, in the case of this particular project it still remains to be studied. In this connection the following work of MacLeod's is of particular interest.

Avocado leaves were dusted with two different mixtures of a bentonite-redwood flour dust and the dust recovered on the leaf surfaces was analyzed. The duster used was of conventional pattern and without electrostatic equipment.

The results were:

Mixture	Analysis of Dust in Hopper. % of Bentonite	Analysis of Dust on Leaves. % of Bentonite
1	62	65
2	14	55

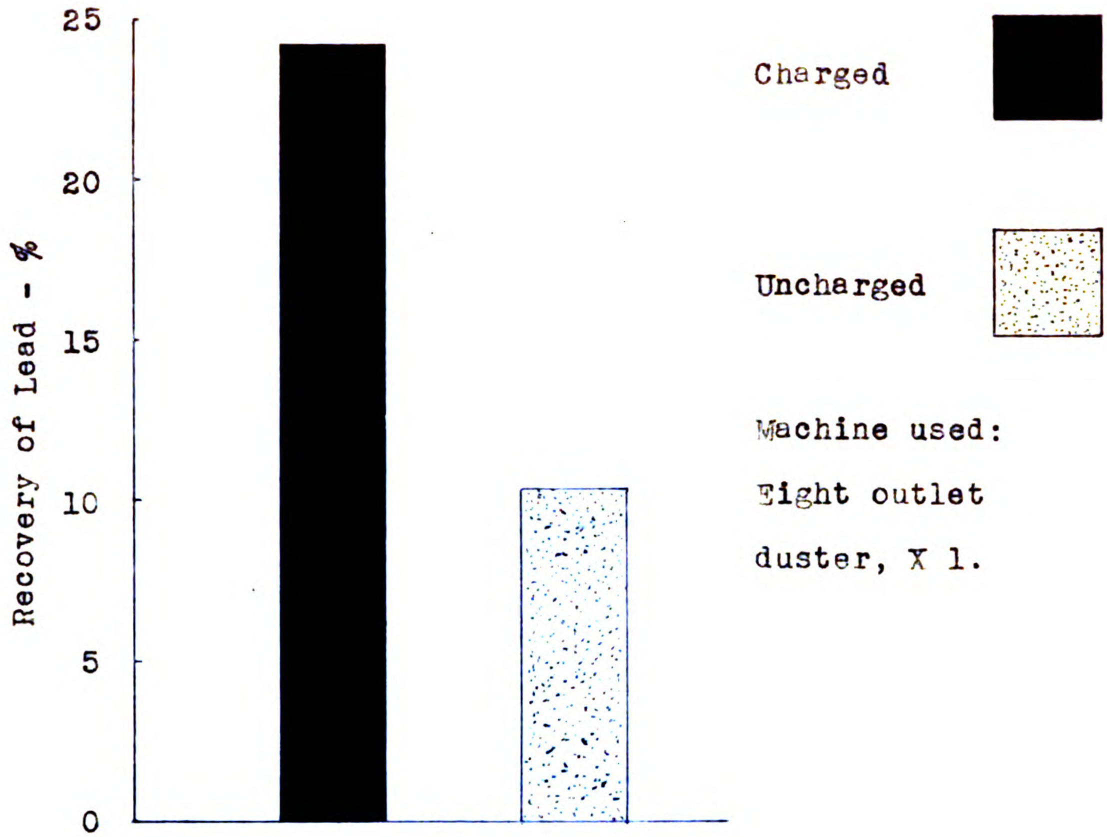
Such high fractionation would have important consequences in the field.

Quantity of dust deposited

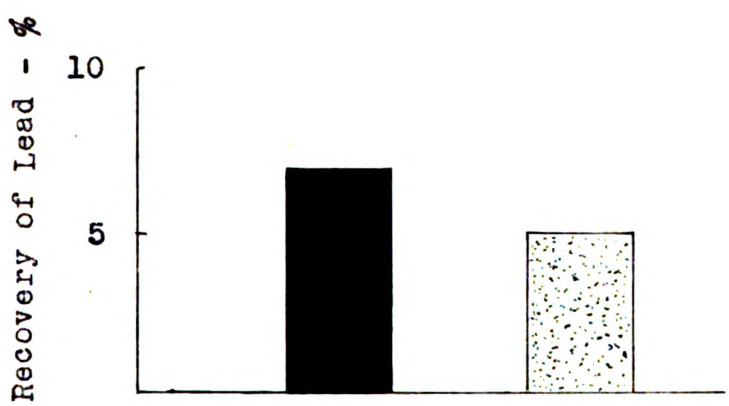
This was estimated by the technique described in Appendix I under the heading, chemical determination of the recovery of dust.

The results are presented graphically in Figure 19 and actual numerical results are given in Tables III and IV.

The determination made immediately after dusting shows that, under these particular conditions, compared with the



Immediately after Application - July 31st. 1951.



After 1-in. of rain - August 16th. 1951.

Figure 19. Histograms showing a comparison between the recovery of lead on field beans, when using charged and uncharged dust.

TABLE III

RECOVERY OF LEAD DUST ON BEAN PLANTS

Immediately after application, July 31st.

Sample No.	Micrograms Lead/ in^2		Result Expressed as % Recovery of Lead.	
	Dust Charged	Dust Uncharged	Dust Charged	Dust Uncharged
1.	23.2	9.0		
2.	21.7	8.2		
3.	16.5	7.9		
4.	18.0	8.7		
Mean	19.9	8.5	24.1	10.3

Statistical Analysis - t test for a significant difference between means.

Method	No. of Samples n	Deg. of Freedom	Mean Wt. Lead.	Sum of Squares.
Charged	4	3	19.9	29.3
Uncharged	4	3	8.5	0.7

Diff. = $\bar{x}_1 - \bar{x}_2 = 11.4$ Sum = 30.0

Pooled Variance $s^2 = 30/6 = 5$

$$s_{(\bar{x}_1 - \bar{x}_2)} = \sqrt{2s^2/n} = \sqrt{10/4} = 1.58$$

$$t_6 = \frac{11.4}{1.58} = 7.21^{**}$$

**Significant at the 1% level

TABLE IV

RECOVERY OF LEAD ON BEAN PLANTS, CONT'D.

After 1-in of rain had fallen, August 16th.
(No further dust applied after July 31st).

Sample No.	Micrograms Lead/ in^2		Result Expressed as % Recovery of Lead	
	Dust Charged	Dust Uncharged	Dust Charged	Dust Uncharged
1.	7.6	3.5		
2.	3.7	5.7		
3.	5.8	3.2		
Mean	5.7	4.1	6.9	5.0

Statistical Analysis - t test for a significant difference between means.

Method	No. of Samples n	Deg. of Freedom	Mean Wt. Lead.	Sum of Squares.
Charged	3	2	5.7	7.6
Uncharged	3	2	4.1	3.7

$$\text{Diff.} = \bar{x}_1 - \bar{x}_2 = 1.6 \qquad \text{Sum} = 11.3$$

$$\text{Pooled Variance } s^2 = 11.3/4 = 2.8$$

$$s(\bar{x}_1 - \bar{x}_2) = \sqrt{2s^2/n} = \sqrt{2 \times 2.8/3} = 1.37$$

$$t_4 = \frac{1.6}{1.37} = 1.2$$

This value of t is not significant at the 5% level.

conventional method electrostatic dusting more than doubled the qualtity of toxic agent deposited on the leaves; a highly significant result. Statistical analysis of the determinations of toxic agent remaining after rain had fallen, showed these particular results to be insignificant, there being insufficient replications to determine this rather small difference between the two sets of readings.

Biological Tests

Two distinct types of evaluation can be used for comparing the biological effects of the two dusting methods. Their respective effects upon the pest can be estimated, or alternatively, crop yields may be measured, and in this way obtain a measure of the extent of control which has been achieved.

The former comparison which consists of disease and insect counts, is the more laborious of the two, and it has to be repeated at intervals throughout the growing season.

In two of the crops where field testing was carried out, the peas and the potatoes, insect counts were made, but in both cases insignificant differences were obtained between the two methods. In the future, however, there is no reason why this method should not be used, but care should be exercised not to use pesticides which are too efficient. For example, in many cases D.D.T. (Dichloro-diphenyl-trichlorocthane) is effective in very low concentrations, and the normal rate of application includes a high safety factor. Thus it is

impossible to distinguish the reaction of the insects to variations in the quantity of dust until very low rates of application are reached.

The actual results from each field have been included in Appendix II, and these should be consulted for the individual results. In this section some conclusions will be drawn from these results.

Speaking generally the season of 1951 was unfortunate from the point of view of this work in that pest attacks were few and light, and because of this it was obviously impossible to obtain any spectacular results in favour of electrostatic dusting. Of the five fields tested the first yielded no favorable result, the second two gave only indications in favour of the electrostatic method, whilst the fourth and fifth gave more positive results in favour of the new method. Taken separately these results are but slim evidence to support the new method, but taken together, and particularly when the non-biological evaluation is included, they are very encouraging.

Recommendations for future tests

From this work it is possible to make certain recommendations regarding the planning of future tests.

1. The method of progressively reducing the levels of dust application to induce an attack is satisfactory, (see description of Field IV method Appendix II) but some thought

should be given to the adoption of a rather more drastic reduction of rates, such as 3 : 1-1/2 : 3/4 instead of the 3 : 2 : 1 which was actually used. Such a reduction will determine if, half the normal application of dust applied "electrostatically" will give as good or better protection than a normal application, applied without "electrostatics". Which statement is very strongly suggested by the results of the lead recovery test.

2. If possible, control rows should be randomized within the test rows to give a measure of the damage done by any attack.

3. The possibility of using a controlled infection (inoculation) with disease should be investigated.

4. The layout of Field V constitutes the minimum size of experiment, in terms of replications, which should be planned. Without that number of replications extremely broad differences in yield are required to produce significant results.

5. If practicable the use of unsampled rows between different plots, in the way described for Field IV, is recommended.

THE ELECTROSTATIC CHARGING OF PESTICIDAL FOGS AND SMOKES

The Charging of Fogs

Fogs, or as they are also termed, heat generated aerosols, are not used generally for the control of pests on cultivated crops. They are, however, in use for such work as mosquito control in swamps, and some work has been done on utilizing them for insect control in forests.

These fogs are usually produced by injecting a light petroleum oil into a stream of heated air, or by directing a jet of this oil at a heated plate. An invisible vapor is thus formed within the machine, and when this is allowed to escape into the open, a dense cloud of extremely fine oil droplets is formed. The pesticide which is being used is contained in the oil, and the oil thus acts as a carrier. The temperatures developed in fog generators are generally quite high, (an air temperature of over 300°C. at the outlet of one of the machines used in this test) but in spite of this, serious decomposition of the pesticide does not usually result, even if these substances are normally decomposed at such temperatures (Smith and Goodhue 23A).

If it were intended to treat cultivated crops with fog, it would be entirely possible to use a non-toxic oil as a carrier and thus prevent damage to the plants. This application is, however, not practicable at present, because even the slightest breeze makes fog operations impossible, and because the droplets are so small that they only deposit on horizontal surfaces, and then only when they are allowed long periods for settling (Yeomans et al. 29).

It was the aim, therefore, to use electrostatics in fog application to achieve the deposition of the fine droplets, as has been done with dust particles. Assuming that this method of application is practicable, it should be emphasized that it is not intended that fogs become a general substitute for sprays and dusts. Rather it is anticipated that fogs could provide an effective means of control for specific pests where present methods are handicapped for one reason or another.

Previous work

Apparently very little previous work has been done on the use of oil fogs for crop protection because of the practical difficulties previously mentioned. Latta (16) has reported, however, some results which are rather surprising. Using an insecticidal fog he was able to control pea aphids on alfalfa at distances up to 50 feet from the generator. Similarly, working on Gypsy Moth control in forests and working at night Latta (17) reports, "Complete mortality was obtained at a depth of 800 feet with as little as 0.138 oz. DDT/ foot of frontage". (This quantity of DDT is approximately equivalent to an application of 10 pounds of 5 per cent dust per acre.)

These results are surprising, and it can only be assumed that Latta worked under atmospheric conditions which were ideal for the deposition of small droplets (inversion conditions). They indicate that, given good deposition of droplets, effective control can be obtained by the use of oil fogs.

Description of equipment

Two fog generators were loaned by the manufacturers for this work; one was a "Todd Insecticidal Fog Applicator" and the other a "Dyna-Fog Jet Insecticidal Fog Generator". The former machine was of conventional pattern, with the oil-pesticide mixture joining a stream of hot combustion gases immediately after striking a heated metal plate. The Dyna-Fog consisted of a gasoline operated pulse jet engine, the tail pipe of which was coiled to form a heat exchanger for heating a stream of air. The oil-pesticide mixture was injected into the tail pipe just before the exhaust gases in the tail pipe joined the stream of heated air, and in this way the oil was vaporized. The resulting vapor issued from the fog outlet and became visible fog after travelling a few inches from the outlet.

In order to put a charge on the droplets it was thought necessary to allow the fog to become fully formed before passing it through the charging nozzle. Accordingly an air gap was left between the fog outlet and the charging nozzle, as can be seen in Figure 20. Several smaller sizes were tried before the final dimensions were decided upon. In order to fully contain the fog, a nozzle of 9-in. diameter with a 6-in. air gap was found to be necessary. This design was satisfactory as can be seen in Figure 23.

The charging nozzle was virtually an enlargement of a type IV nozzle and had a charging wire that was 10-in. long. Because of the high temperatures involved, it was not possible to use Plexiglas insulators, and, therefore, glass tubing insulators were used. The same electrical supply that was used on the X1 field duster was fitted at first, but this was later replaced by a unit operated off the mains, when it was realized that a higher current input would be desirable.

Method of test

In the fall of 1951 one test was carried out in an orchard using the equipment shown in Figure 20, but at the time the only methods of evaluation used were the carboned discs, (Appendix III) and a microscopic examination of the leaves. The inadequacy of these methods has now been realized, (Appendix III) and in view of this it is not surprising that completely negative results were reported for both the charged and the uncharged fog. Subsequently a series of tests were performed using sheets of aluminum as the test surfaces, and evaluating the quantity of oil deposited, by the fluorescence method described in Appendix III.

Figure 20. Dyna-Fog fog generator. Box on the right contains the electrical power supply. The charging nozzle is attached to the fog outlet.

Figure 21. View inside the fog charging nozzle.

As a result of the first trials the charging ability of the new 9-in. charging nozzle was in doubt, and because of this an additional test was made. A small part of the main fog output was diverted into a side tube, and passed through a type V charging nozzle. The deposit resulting from this lower output of fog was also measured.

By adjusting the input of fog oil to the generator it was possible to adjust the size of fog droplets produced, but as oleophobic slides were not in use for measuring the droplet size, they have only been designated in the results as large or small.

Early in the study it was noted that the cloud of fog as a whole exhibited a strong electrical charge after it had passed through the charging nozzle; the attraction of the hair on the back of the hand could be felt, and later the apparatus shown in Figure 4 was used for detecting the charge.

Results

The results of the fog deposit tests are given in Figure 22 and Table V.

It will be seen that when using the type V nozzle, the charged fog produced an appreciable deposit, but the uncharged fog gave virtually no deposit. Only two replications of each setting were used, and it is, therefore, not possible to distinguish any difference between the reaction of the small and large droplets to charging. Throttling the fog inlet to reduce the throughput also failed to alter the amount of oil deposited significantly.

It was noted during this work that when fog was passing through the nozzle, arcing between the charging needle and the nozzle wall occurred more readily than usual, indicating that the fog was, by comparison with air, a good conductor.

In the case of the results for the large, 9-in. charging nozzle, when the full volume of fog was in use, a fairly high dynamical catch of droplets is apparent in the case of the uncharged fog, and these droplets were large enough to be seen with the naked eye. In view of this high dynamical catch, which would be present in the case of both the charged and the uncharged fog, the improvement produced by charging the droplets was much less spectacular than when the small nozzle was in use. Comparing the two sets of results, the reason for the low dynamical catch with the type V nozzle, was that in passing through the pipe to this nozzle, many of the larger droplets were lost on the tube walls. In addition, the diversion of the stream of fog considerably reduced the velocity of the stream that was drawn off. It may be concluded, therefore, that the large nozzle was charging only a reduced number of the fog droplets.

Apparently in contradiction to this there is the previous observation that the cloud of fog exhibited a strong charge. Use of the equipment shown in Figure 4, and described earlier, confirmed this observation and showed that for both nozzles

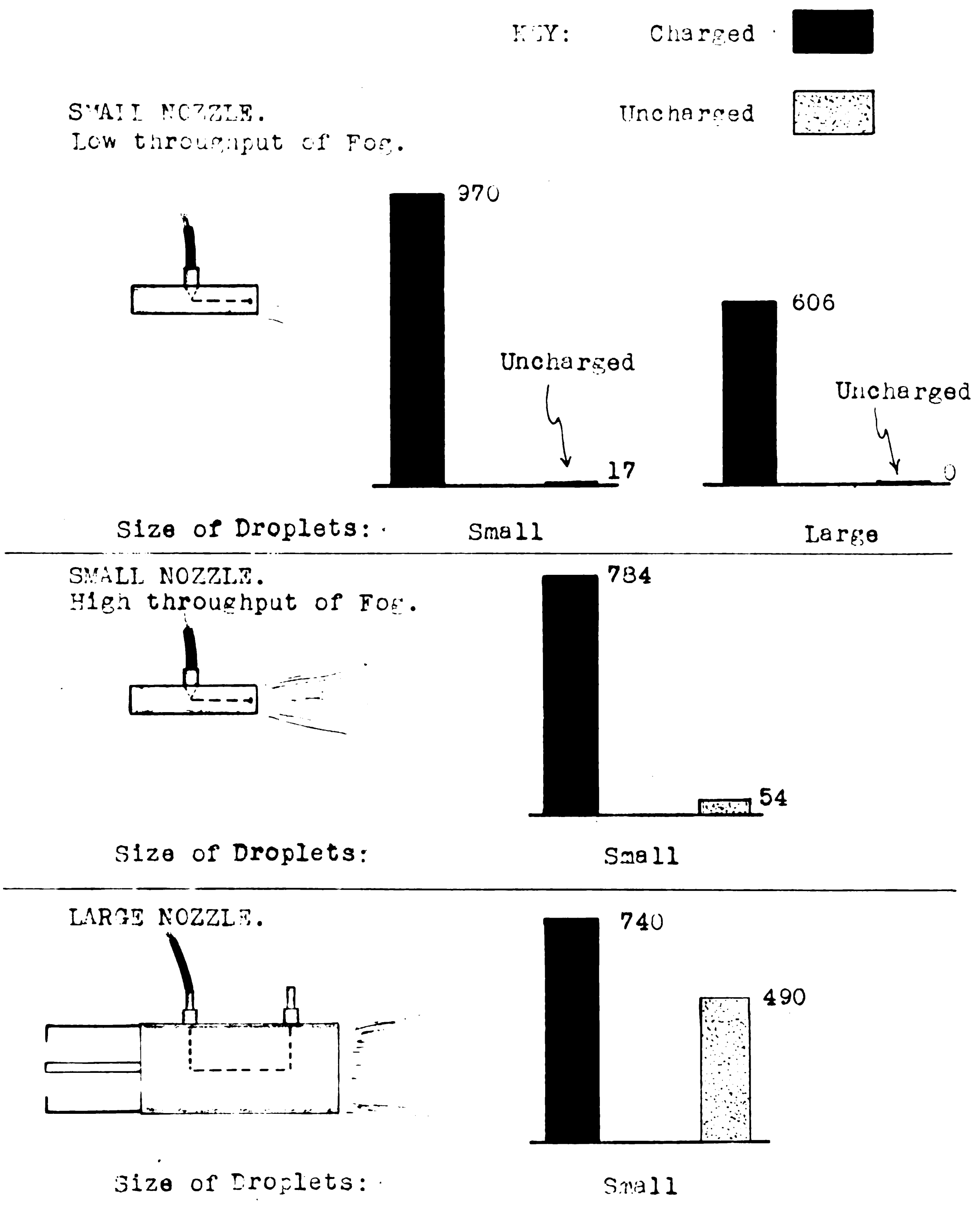


Figure 22. Graphical representation of the improvement resulting from charging fog droplets.

TABLE V

LABORATORY TESTS WITH THE PRECIPITATION OF OIL FOGS

Droplets Collected on 8 x 4 in. Sheets of Aluminum Foil

	Gross Weight of Oil γ/in^2	Net Weight of Oil γ/in^2	Mean Net Weight
Small (type V) Nozzle, Low Throughput of Fog.			
1. Small Droplets, Charged	826	789	970
2. " " "	1188	1151	
3. Small Droplets, Uncharged	59	22	17
4. " " "	49	12	
5. Large Droplets, Charged	257	220	606
6. " " "	1029	992	
7. Large Droplets, Uncharged	37	0	0
8. " " "	37	0	
Small (type V) Nozzle, High Throughput of Fog			
9. Small Droplets, Charged	821	784	784
10. " " Uncharged	91	54	54
Large (type VI) Nozzle,			
11. Small Droplets, Charged	710	673	740
12 " " "	845	808	
13. Small Droplets, Uncharged	429	392	490
14. " " "	625	588	
Blanks, foil without fog present.			
15. Blank I	37	-	-
16. Blank II	37	-	-

Weight of oil is expressed in terms of micrograms of oil per square inch (γ/in^2) of foil surface, including in this both front and back surfaces of the foil.

the cloud was negatively charged. In the case of the small nozzle and a low throughput of fog, a current of 1/2 microamp flowed to ground, whilst fog from the large nozzle caused the comparatively high current of 15 microamps to flow to ground. For both nozzles the fog exhibited practically no polarity when the electrical power supply was turned off.

Discussion and conclusions

All combustion and exhaust gases contain a much higher concentration of ions than does ordinary air (Lewis 18). It is upon this observation that the most likely explanation of these results appears to rest. A high concentration of ions would explain the higher conductivity of the fog, and it seems likely that the negative ions formed in the large charging nozzle were largely used up in neutralizing positive ions in the combustion gases, (which are mixed in with the fog) instead of being available to charge the droplets. This explanation would also account for the high net charge on the fog cloud, for if a large number of the positive ions in the combustion gases were neutralized, the cloud would be left with a high net negative charge, because the combustion gases normally contain equal numbers of positive and negative ions. In the case of the small, type V nozzle, it would seem that there were sufficient negative ions available in relation to the amount of fog, to neutralize the majority of the positive ions and also place a charge upon a reasonable percentage of the oil droplets. Before charging the fog droplets, therefore, it is necessary to clean the gases of positive ions. To accomplish this with the large nozzle would require a comparatively high current on the charging wire, and to avoid this serious drain on the available current Bowen (3), has suggested that the gases be cleaned before they enter the charging head. To do this he suggested tapping off a small percentage of the current in the 300 volt line of the power supply, and using this to charge a pair of grids placed in the fog stream before it reaches the nozzle. This would remove the ions without being such a tax on the output of the power supply. Such a unit could conveniently be located in an enclosed pipe, for it would not be necessary to allow the fog droplets to form before cleaning the ions from the gases.

Summing up, on both the machines used in the test it will be necessary to overcome the difficulty of the presence of ions in the fog, but it is thought that this can be done, and successful charging achieved. Once charged it has been shown that the deposition of the small fog droplets is greatly improved, and it appears that by charging the fog droplets it should be possible to extend the use of fogs considerably. Certainly even a casual glance at the nature and density of an oil fog indicates that it has very great potentialities for producing good coverage.

It is strongly recommended that this line of study be pursued.

The Charging of Pesticidal Smokes

The smoke used in this work came from "Gammexane Smoke Generators" which were obtained from Imperial Chemical Industries Limited, England. These generators simply consist of a canister of a chemical mixture which upon ignition generates an insecticidal smoke. They contain the insecticide technical gamma benzene hexachloride. The generators are used for the fumigation of indoor areas where the smoke can be sealed in, and given several hours to settle.

This particular test was only of the nature of a brief survey to indicate if there were any possibilities in the use of charged smoke.

Smoke from one of these generators was passed through a type V charging nozzle and the smoke deposited upon aluminum foil in exactly the same way as with the fog. In this particular case it was also possible to use glass slides to obtain a deposit.

Microscopic examination of these test surfaces showed that the uncharged smoke failed completely to form a deposit, whereas the charged smoke formed a thin but fairly regular deposit. A micro-photograph of the charged smoke deposit is shown in Figure 24. The slide exposed to the uncharged smoke was completely clear and is, therefore, not illustrated.

Summing up this test, it has been shown that this smoke can be charged, and deposition of the very fine particles achieved. Thus there are possibilities opened up for the

Figure 23. Dyna-Fog fog generator in operation. Drum on left contains fog oil.

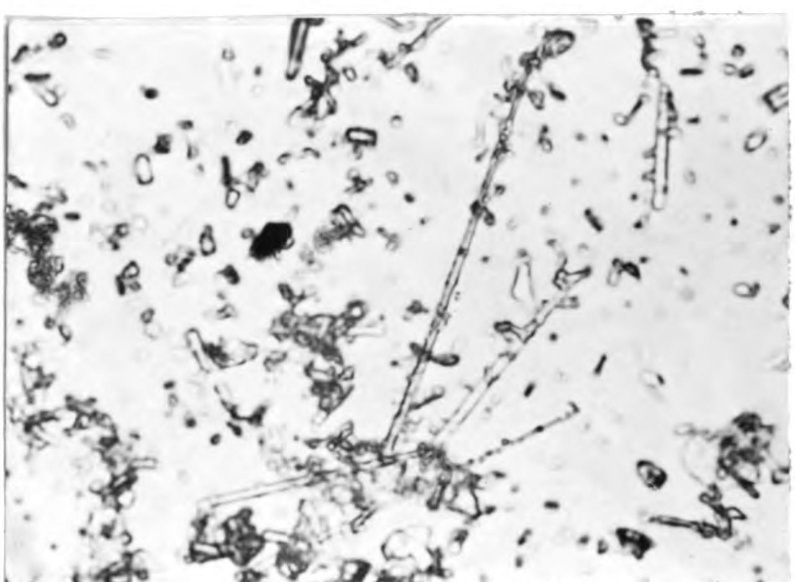


Figure 24. Microphotograph of deposit of charged insecticidal smoke on a glass slide (Magnified x 800)

more extensive use of pesticidal smoke, just as in the case of fogs. The very fine state of division of the particles suggests that good coverage of plant surfaces should be possible.

As with the oil fog, it is anticipated that this smoke, being a product of combustion, will contain more free ions than ordinary air. In view of this, if a large volume of smoke were to be charged, it would seem likely that it would be advantageous to remove these ions (as was suggested for the fog) before passing the smoke through a charging nozzle.

SUMMARY AND CONCLUSIONS

Prior to the inception of this study, the placing of a controlled electrostatic charge upon dust particles had shown considerable promise of improving the recovery of dust, and of improving its distribution on plant surfaces. The method had, however, not been field tested and further laboratory tests were needed before its possible value to the farmer could be assessed. The charge was applied to the particles by passing them through a negative corona, ionized field charging nozzle as they left the duster.

Firstly, additional laboratory tests were carried out to confirm some of the earlier results and also to establish some new relationships.

The fact that charged particles will retain their charge when they have travelled distances of up to 33 feet in the open from the charging nozzle, has been demonstrated; thus confirming and extending earlier results. The retention of a charge at such distances indicates that the application of electrostatic dusting to orchard work is a practical possibility.

It has been shown that under a specific set of conditions there exists a definite optimum current input for a charging nozzle. If the actual current either exceeds or falls short of this value, optimum dust deposition will not

be obtained. Although all the variables affecting this optimum have not been investigated, enough work has been done to show that the magnitude of the current is of sufficient importance in its effect upon deposition to warrant further study. In this way the very limited recommendations on the optimum current level which have been made in this thesis, can be extended to any set of circumstances which may occur in the field.

Work on the effect of relative humidity upon dust deposition, yielded no clear-cut relationship, and the question, "Why does increase in relative humidity reduce the improvement which can be gained by electrostatic dusting?" still remains unanswered. Several further observations on the subject have been contributed in this study, but no substantiated explanation of the phenomenon can be advanced. Humidity does depress the desirable effects of electrostatic charging, and this depression is important enough to warrent further work in an effort to remove or reduce this depression. The effect of a normal range of temperature variation (humidity remaining constant), upon electrostatic dusting has been shown to be only slight.

Two field model dusters were constructed, and fairly extensive field trials of electrostatic dusting were carried out during the summer of 1951. Dusting was done in six different types of field crops, and the practicability of this method was demonstrated. Biological evaluation of the value of electrostatic dusting was handicapped by a lack of pest attacks, but nevertheless all the indications were in favour of the new method, and considered collectively they were decidedly encouraging. A chemical estimation of the amounts of dust recovered on bean leaves illustrated very clearly the inefficiency of dusting as normally practiced, and lead the author to state that, electrostatic dusting is apparently capable of providing as good or better plant protection than conventional methods when the rate of application of charged dust is half the normal rate. During the field tests the occurence of dust fractionation was noted, and it is felt that this factor and also the actual saving of dust materials which can be obtained, should be further investigated. The field tests also provided several useful pointers to the layout of future trials. In view of the difficulty of obtaining categorical results from biological evaluations, the writer suggests that the engineer concentrate on the use of non-biological evaluations during the development stages of the new method.

It was realized early in the study of electrostatic dusting that "Electrostatics" could be applied to particles of matter other than dusts, for example aerosols, smokes, and sprays, (aqueous sprays would present problems of insulation which would have to be overcome). In pursuance of this observation, preliminary trials have demonstrated that the deposition of pesticidal fog droplets and smoke particles can be greatly accelerated and improved by the use of electrostatic charging. Continuance of this work should extend the usefulness of fogs and smokes in pest control operations.

APPENDIX I

THE EVALUATION OF DUST DEPOSITS

In any work with crop dusters it is very quickly apparent that one of the major problems which confront the investigator is the evaluation of the work done by the duster. Obviously the ideal evaluation is the biological one, and for the final answer we still have to resort to this, in the form of field trials of a machine and observation of its efficiency in pest control. Biological evaluation, however, is expensive of time, and for duster design work the engineer requires a much more rapid, even if less complete, method of evaluation.

A discussion of the use of field trials has been presented earlier, and this appendix therefore will deal with the rapid methods of evaluation which have been used.

It is unfortunately a fact that at the present time biologists are unable to give a clear definition of what constitutes "100% coverage" and therefore the engineer is in the difficult position of not knowing exactly what his goal is. Because of this none of the rapid tests which are to be described are directly related to any biological evaluation, but, by using two or three of these tests in conjunction with one another it is felt that a valid comparison can be made between dusting methods, and that the conclusions which result will be reproducible in the field.

The Light Reflection Comparison Test

This test is the most rapid of those which are to be described, and is essentially an estimation of the amount of dust on the test surface. The test surface consists of a $3\frac{1}{2}$ inch diameter sheet steel disc which is blackened immediately prior to use in the flame of an acetylene torch using only acetylene. These discs are used in a dusting test with light colored dust, and the amount of dust recovered on the disc is estimated by placing it in a fixture (see Figures A1 and A2) and directing a beam of light at the disc in such a way that it is reflected by the dust on the disc into the cell of a sensitive photo-electric light meter.

Several different surfaces have been tried on the discs, including numerous black paints, but none of the other surfaces tried compared favorably with the carbon black surface, either for low reflectivity, or in being consistent from one disc to another. Even the carbon surface reflected some light and before each test a reading of this was taken on the light meter; these "blank" readings being subtracted from the observed readings in every case to give the "Net Light Meter Index". With practice it was found possible to produce sets of black discs which differed to only an insignificant extent from one to another in their light reflectivity, and thus the same "blank" value was used for a particular set of observed readings. Another reason for the choice of the carboned discs as test surfaces was that this surface is not perfectly smooth, as a

Figure A1. Light reflection comparison of dust deposits.

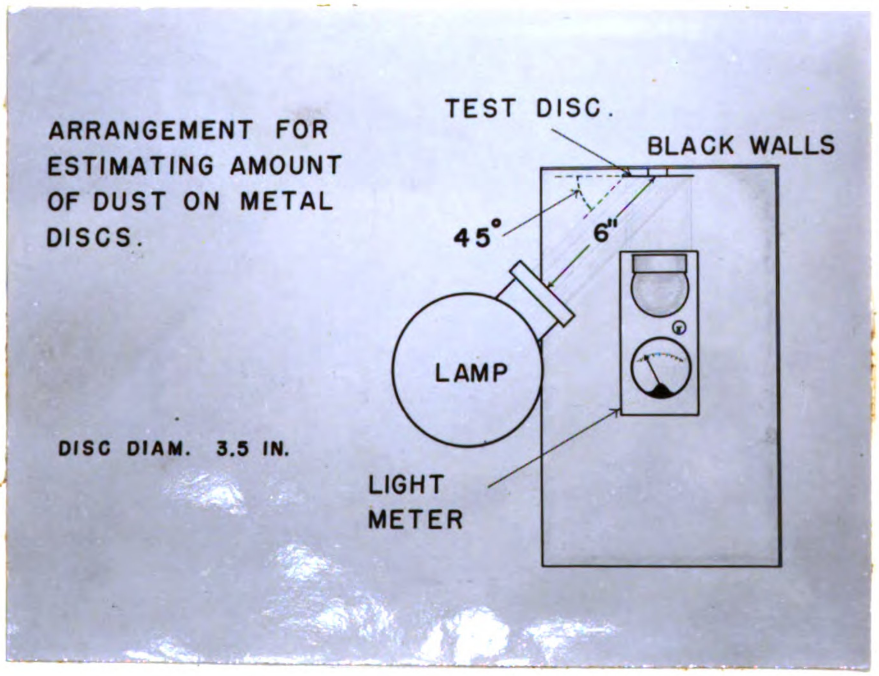


Figure A2. Arrangement diagram of reflection comparison of dust deposits.

metal or glass surface would be, and Yeomans et al. have shown that very low recovery of dust may result when such smooth surfaces are used.

The light source used was a microscope illuminator containing a 100 watt bulb. Comparison of this source with several other more powerful sources proved the illuminator to be the most sensitive.

Before it is possible to place confidence in a new method such as this we must compare it with some more basic method of measurement, and thus light meter readings were compared with the actual weight of dust on discs. Zinc oxide dust was used to dust a set of discs in such a way that they had a wide range of light meter values. These values were recorded and then the carbon film and the dust were washed off with dilute sulfuric acid. The resulting suspension was carefully evaporated to dryness, and then ashed. The ash consisted of anhyrdrous zinc sulfate which was weighed and the equivalent weight of zinc oxide determined by calculation. The curve which was obtained from this experiment is illustrated in figure A3, and this indicates that a satisfactory relationship between the two variables does exist. There is some divergence from the curve, however, and for this reason three replications were always made to obtain a single "Net Light Meter Index" as quoted in the earlier tests.

In using this test the extremely high and extremely low readings were avoided whenever possible because the sensitivity

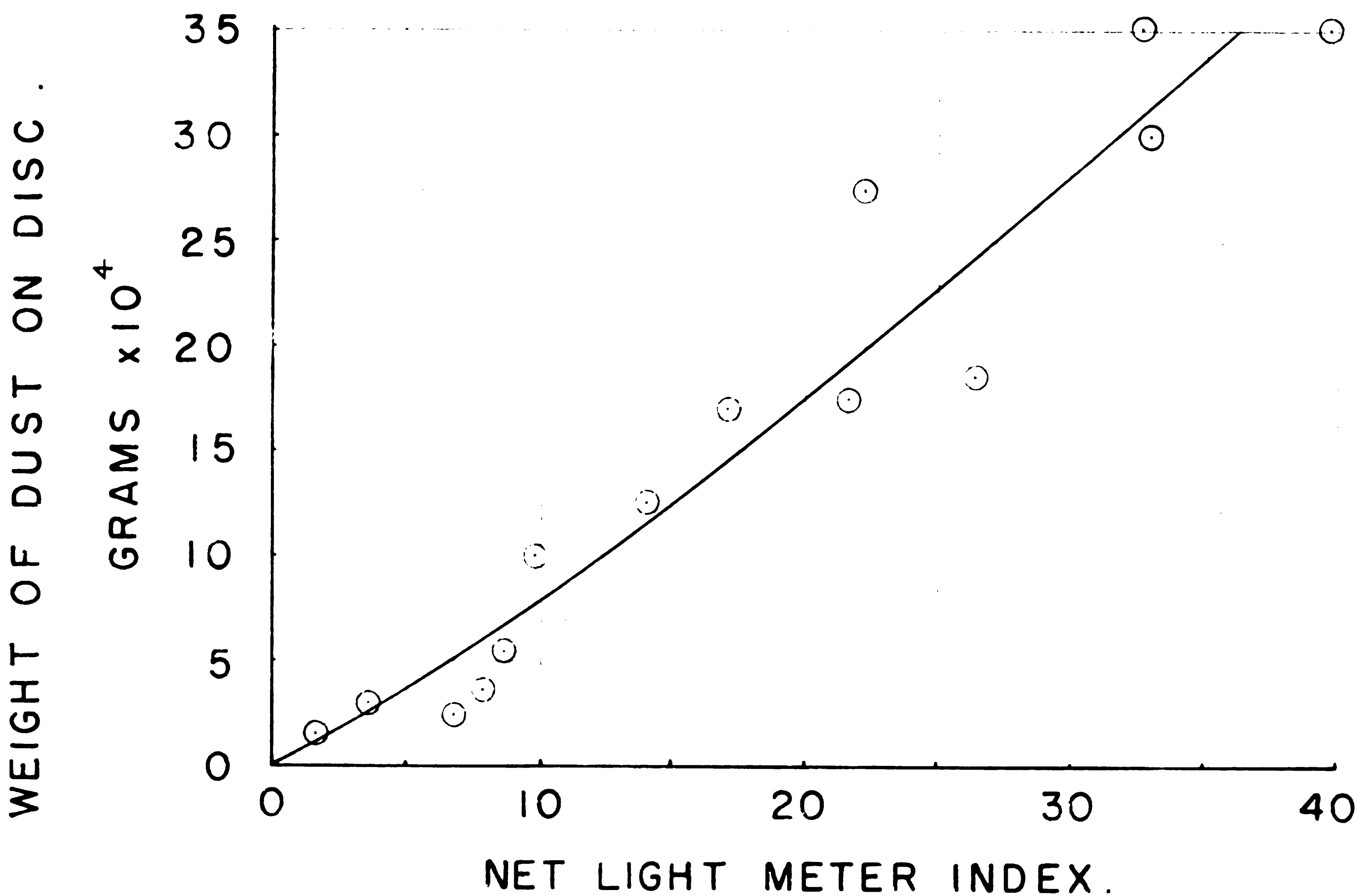


Figure A3. Calibration curve for light reflection method of comparing dust deposits.

will obviously fall off in the low range, and in the high, the readings will be inaccurate as soon as a significant number of particles become stacked one upon another.

It is interesting to note that this result is in good agreement with the work of Czerny who obtained a similar curve when he plotted amount of dust on glass plates, against the light obscuring effect of the dust. Czerny's method of evaluation incidentally was of no value for the work with electrostatic dusting because of the impossibility of grounding glass plates properly. (Czerny 7)

Chemical Determination of the Recovery of Dust on Plant Surfaces

The weighing of a dust deposit such as that described as a check for the light reflection method, or alternatively, the chemical determination of such a deposit, is an accurate method if the work is done under carefully controlled laboratory conditions. This method is slow, however, and was therefore not used in the laboratory dusting tests, but it was used in the experiment on the recovery of lead arsenate dust on beans in field dusting.

For each one of the readings obtained in the latter experiment a sample was drawn in the following way. A 1-foot length of the dusted row was marked off and from this a sample of nine leaves was taken in such a way that they represented as closely as possible all the leaves in this row length. That is, some were outside leaves, some were inside, and others intermediate. The sample thus gathered was placed in a bottle and analyzed for lead content in the laboratory, using a modification of the method described by Winter. Samples of undusted leaves, or blanks, were also drawn for use in the analysis.

The amount of dust put out by the duster was determined by a calibration, and then to obtain the results in terms of percentage recovery of dust the following procedure was adopted. As the leaves for the lead analysis were picked, another group of nine leaves (as nearly identical in size with the first set as possible: this was facilitated by picking from similar pairs of leaflets) was collected and placed on treated paper for the printing technique which will be described subsequently. In this printing method the leaves are squeezed between two sheets of moist paper, after which the leaf outlines are clearly visible. The leaf areas were determined by using a planimeter on these outlines and thus the analysis results could be expressed as micrograms of lead per square inch of surface. Finally to express the result as percentage recovery, it was necessary to determine the area of leaf surface per foot of row and from this the leaf area per acre. Sample lengths of 1-foot were used for this, and leaf areas determined as just described.

$$\text{Percentage Recovery} = \frac{(\text{Wt. of Lead/in}^2\text{ of leaf})\ (\text{Area of leaves, in}^2\text{/acre}) \times 100 \times 100}{(\text{Wt. of dust applied per acre})\ (\text{Percentage Lead in Dust})}\ \%$$

Leaf Printing Technique

Both of the evaluations just described are purely quantitative, and give no indication of how a dust deposit is distributed on a surface such as that of a leaf. This factor of distribution is most important if effective protection is to be afforded to the plants, and, it is for this reason that the leaf printing technique is a useful adjunct to the quantitative tests. Referring back to a previous definition, leaf printing allows us to compare the macro-distributions produced by different dusting methods and also to get a good idea of the micro-distributions.

The technique used was obtained from Klingbeil, who in turn credits it to Hamilton (9).

The details of the technique can be obtained from either of these references, but it should be mentioned that the method was considerably shortened when it was used in the field.

Basically the steps used were as follows:

1. The plants were dusted with lead arsenate dust or a mixture containing this compound.

2. The sample leaves were placed between two sheets of sensitized paper. This paper was prepared by soaking good bond paper in 5% sodium hydroxide solution for one minute and draining.

3. This "sandwich" of paper and leaves was squeezed between two foam rubber pads in a hydraulic press for one minute. In the field the required pressure was merely estimated, and a press consisting essentially of a hydraulic type automobile jack and two sheets of steel was used.

4. The leaves were removed from the paper and the paper placed in a 5% solution of lime-sulphur. The sheets were allowed to stand until the dark spots of lead sufide (which denoted the location of dust particles) ceased to become darker.

5. All the yellow color was washed from the paper in clear water.

6. The sheets were dried.

This method is somewhat rough compared with the Klingbeil (15) technique, but it nevertheless gave satisfactory results in the field.

With the prints obtained in this way it is possible to compare distributions quite easily for the dust shows up dark brown on a white background. Another advantage is that it is possible to compare the front and back of the same leaf.

It should be noted that it is also possible to make prints when using copper dusts as described by McDonald (21).

Microscopic Examination

The microscope can provide both qualitative and quantitative evaluation of dust deposits, but its use in particle size determination and in particle counts is very laborious when a large number of readings are to be taken. There have been some attempts to simplify this work, and it may be that these will render the microscope much more useful for dust counts.

Examination of Figure A4 will illustrate the difficulty of measuring and counting particles. To distinguish between aggregates and individual particles being one of the most difficult tasks. It is worthy of mention that since obtaining this last illustration, which was taken by transmitted light, the superiority of dark field illumination or the use of a dark background, both for photomicrographs and for counting, has been learned.

During the dusting work only a few particle counts were made, but in doing these the method of MacLeod was followed: "Taking the longest dimension of a particle as the one by which it is characterized".

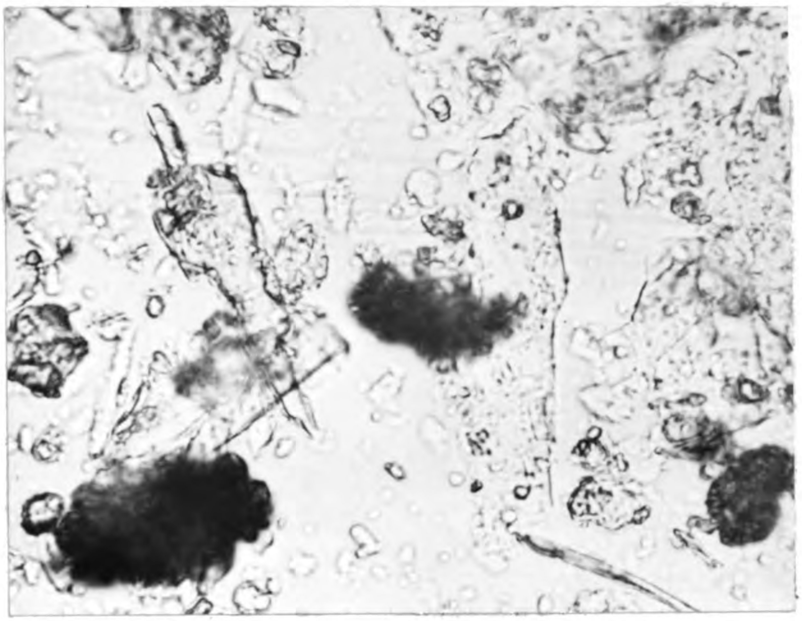


Figure A5. Microphotograph of commercial onion dust. Main constituent 325 mesh talc. (Magnified x 800)

Colorometric Estimation

In the search for a rapid, field method of evaluating dust deposits, and also with the possibility in mind of differentiating between the different constituents of a dust mixture, the Michigan State College "Dusting Team" suggested that the dust be colored, and the quantity on a particular leaf estimated by washing it in water to obtain a colored solution, and then comparing this solution with a set of comparator tubes containing a series of known dilutions of the color.

This proposal was discussed with J. F. LesVaux of the Niagara Division of the Food Machinery Corporation, and as a result representatives of that organization have developed such a dyed dust. The following extract from a report by Tidwell of Niagara illustrates what has been done:

> A talc impregnated with a water soluble dye was produced for dusting experiments and a method of analysis was developed for determining the talc deposits on the leaves. The best dye for the impregnation was National Brilliant Scarlet 3R produced by the National Aniline Division of Allied Chemical and Dye Corporation. The analytical method is capable of detecting 0.5 mg. of talc under field conditions and may be adapted for laboratory use to detect talc concentrations as low as 5 micrograms. (24)

The method has not yet been field tested but it appears to be promising and should repay further development. The sensitivity seems to be adequate, for in the bean dusting experiment, 0.7 mg. of dust were recovered on each leaf.

APPENDIX II

Dusting of Celery (Field I)

Location: Cramer Farm, Comstock, Michigan.

Crop: "Michigan State Green Gold" Celery, on muck soil.

Duster used: Field duster X2.

Applications of dust: Ten between June 27th and August 30th 1951.

Type of dust: This experiment was done in connection with another one which set out specifically to test different types of dust (Nelson, M.S.C.). Each different number on the rows in the table below denotes a different type of dust.

Pests: Celery Blight.

Evaluation of results: Yield of celery after trimming of the diseased, unsalable parts. Yield, pounds per 1/62 acre.

Results:

Plot A - Early Harvest - 8-18-51

Row	Charged dust-lb.	Uncharged dust-lb.
1.	236.5	245.0
2.	243.0	264.0
3.	256.5	243.0
4.	249.0	264.0
5.	247.0	256.5
6.	250.5	248.0
7.	275.5	253.0
8.	256.5	239.0
*9.	247.5	246.0
**Mean	251.7	251.5

*Control rows undusted.
**Mean calculated without including control rows.

Plot B - Late Harvest - 9-12-51

Row	Charged dust-lb.	Uncharged dust-lb.
1.	163.0	134.0
2.	180.5	136.0
3.	173.0	124.0
4.	136.5	113.5
5.	139.0	106.0
6.	139.5	111.0
7.	164.0	126.0
8.	138.0	121.0
*9.	129.5	94.5
**Mean	158.2	121.8

*Control rows undusted.
**Mean calculated without including control rows.

Conclusions. It was originally intended that both plots would be harvested at the same time, and, as the charged section of plot A was located at the opposite end of the field to the charged section of plot B, to gain in this way an indication of the variability of the field. Economic reasons made the early harvest of one plot necessary, and thus this control was lost.

It is very apparent from plot A results that no serious infection had taken place by harvest time; the control rows show practically no difference from the means and as would be expected under these circumstances the charged part does not differ significantly from the uncharged.

In plot B, however, comparison of the control rows with the plot means shows that infection has taken place and that the dust has given considerable protection where it was used. The means of the charged and uncharged sections of plot B show an improvement in favour of charging of 26.6% but this difference cannot be proved statistically significant, due to the fact that the charged and uncharged rows were not randomized within the plot, and because the control rows indicate that there was an actual difference in soil or other environmental conditions, between the charged section and the uncharged. It is felt, however, that this difference is probably due to the recovery of some of the charged dust which drifted onto the control rows from the neighbouring rows, and afforded the control rows some protection. Drift of uncharged dust into an undusted row would on the other hand afford little protection, because the majority of the dust which drifts consists of the smaller sized particles which do not tend to deposit on the leaf surfaces when they are not charged.

We may only conclude therefore that the improvement in yield <u>may</u> have been due to the charging of the dust and visual observation rather confirmed this, both at harvest and when the dusting was in progress (more dust could be seen on the leaves with the charged dust, and the coverage of the undersides was somewhat better.)

For the future, we may learn the lesson that test rows should, if possible, be separated from other test rows, (preferably by two rows which would not be evaluated) in order to prevent the trouble from drift which was suspected in this case.

Dusting of Peas (Field II)

Location: Fremont, Michigan, crop grown under contract to Gerbers Products.

Crop: Canning Peas.

Duster used: Field duster X1.

Application of dust: Once on June 26th 1951.

Type of dust: 5% D.D.T. In 325 Mesh Talc as filler. 35 lbs. per acre.

Pests: Pea Aphis.

Evaluation of results: Insect counts.

Results: This was the first occasion on which the duster X1 was tried out in the field, and due to some trouble with arcing over in the charging nozzles, it was not certain that the dust was being charged all the time. The insect counts yielded no significant results but a difference in the amount of dust on the leaves was visible to the eye.

In connection with the use of D.D.T. for such tests it has been suggested that this insecticide may not behave in a quantitative way, that is, because it is effective in very low concentrations, increasing the amount of dust recovered on the leaf surfaces may not yield corresponding improvements in plant protection.

Dusting of Onions (Field III)

Location: The Jack Kelly Farm, Parma, Michigan.

Crop: Onions grown on muck soil.

Duster used: Field duster X2.

Applications of dust: Eight between July 5th and August 16th 1951.

Type of dust: As with the celery dusting, this experiment was done in conjunction with some work on dust types (Nelson, M.S.C.) and, as before, each different number in the table represents a different dust.

Pests: Onion mildew.

Evaluation of results: Yield of onions in pounds per 1/122 acre.

Results:

Row	Charged dust - lb.	Uncharged dust - lb.
1.	323	330
2.	350	315
3.	309	304
4.	316	306
5.	317	332
*6.	297	310
7.	310	301
**Mean	321	315

*Control rows undusted.
**Mean calculated without including control rows.

The plots in this experiment were located in the field in substantially the same way as they are presented in the table. It is unfortunate that the plots were not set out with the work on dust charging fully in mind for without randomization there is little statistical control possible, and, as would be expected, the small differences in favour of dust charging which can be seen in the results, are not statistically significant.

The visible improvement in dust recovery when using charged dust was particularly apparent.

Dusting of Onions (Field IV)

Location: The Michigan State College Muck Experimental Farm, Laingsburg, Michigan.

Crop: Onions.

Duster used: X1. As is general with onions, one nozzle per row was used, that is eight rows were dusted at a time. The rows were arranged in groups of four with a wide space between each group. To dust these plants the duster was driven so that it straddled one group of four rows, and dusted two rows in each of the adjacent groups with the two nozzles at each end of the duster boom. This arrangement proved to be very satisfactory, for, as results were only determined from the rows which had been straddled, border effects, which probably gave difficulty in Field I, were practically eliminated.

Applications of dust: Five dustings between July 21st and August 8th.

Type of dust: Sulphur-dithane-D.D.T. mixture. The normal application of dust was 50 lb./acre, but in case no infection resulted at this level, further plots were dusted with reduced quantities in an effort to induce an attack. The reduction in rates was in the ratio 3 : 2 : 1, with three representing the normal level. In the table of results which follows, the column headings, C1, U2, C3, etc., represent C for charged dust, U for uncharged, and the numeral for the three rates of application. The three different rates were obtained by keeping the output of the duster constant, and altering the forward speed of the tractor.

Pests: Onion Mildew and Onion Thrips.

Evaluation of results: Yield of onions expressed in pounds per 1/111 acre. Mildew attack was apparent in the later stages of growth.

Results: The experimental design used was:

U3 U1 C3 U2 C1 C2 U3 C2 U1 C1 U2 C3

The treatments were allocated at random within each of the two blocks.

The yield results were:

Block	C3	C2	C1	U3	U2	U1
1.	396.0	407.7	407.9	295.8	378.0	359.5
2.	461.0	395.5	399.4	381.2	403.7	397.1
Mean	428.5	401.6	403.6	338.5	390.8	378.3

Mean of all charged plots 411.2 Mean of all uncharged plots 369.2

An analysis of variance of these results was made as follows:

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Total	11	16,092	1,463
Blocks	1	3,104	3,104
Charging (C)	1	5,300	5,300
Levels (L)	2	327	164
Interaction C x L	2	3,558	1,779
Error	5	3,803	761

The following F ratios would normally be derived:

$$F_{2,5}\ \frac{\text{Interaction}}{\text{Error}} = 2.34 \text{ (Not significant at 5\% point)}$$

$$F_{1,2}\ \frac{\text{Charging}}{\text{Interaction}} = 2.97 \text{ (Not significant at 5\% point)}$$

We may derive some further information by taking the ratio,

$$F_{1,5}\ \frac{\text{Charging}}{\text{Error}} = 6.97 \text{ (Significant at the 5\% point)}$$

This comparison is strictly one between error variances and the charging variance plus the interaction. Such results may mean one of two things, either, that neither the charging nor the interaction have any significant effect upon yield, or it may mean that at one particular level the charge is having a significant effect upon the yield whilst at the others it is not.

To test if there was such a difference at particular levels the following "t" test gave a fair indication of the situation.

Comparing the means of treatments C3 and U3.

$$t_5 = \frac{428.5 - 388.5}{\sqrt{761\ (1/2 + 1/2)}} = 3.26^*$$

*This result is significant at the 5% point. To make this "t" test, t takes the degrees of freedom of the overall experimental variance and this variance (761 in this case) is used as the estimate of variance in the comparison between means.

Similar comparisons at the other levels yielded respectively: at level 2, t = 0.39 and at level 3, t = 0.92, neither value being significant.

Conclusions. All of the treatment means show in favour of the charged dust, but upon statistical analysis it appears that only at the high level of application is charging producing a significant improvement. This is rather contrary to the expected result, which would be to have charging yielding its best results at the lowest level of dust application. No actual explanation of this incongruity can be offered, but it should be mentioned that there is some reasonable doubt as to the validity of the result from the U3 plot which yielded 295.5 lb. If this latter plot were disregarded, then the significant result at the high level would disappear.

One other incongruity is also apparent in these results, and that is the very low, levels variance; the charged treatment means assend with increased dust, whilst the uncharged treatment means descend and give this low, levels variance.

To sum up, there is some indication that charging is beneficial, but this is only statistically significant at the high rate of dust application. There is every indication that this experiment had too few replications.

As in the other fields the improvement due to charging could be seen by eye.

Dusting Potatoes (Field V)

Location: Farm of Mr. Willard Wiltse, Pinckney, Michigan.

Crop: Maincrop potatoes.

Duster used: X1. Two nozzles per row.

Applications of dust: Eight between July 24th and September 22nd.

Type of dust: The first application was with,
5% D.D.T.
7% Metallic copper
Filler 325 Mesh Talc.

The D.D.T. gave a complete kill. of thrips even at the lowest rate of application, and for this reason was replaced by 1/10% Pyrethrum in subsequent applications, in an attempt to obtain differential results on the insect counts. The basic application of dust was at 35 lb./acre, but as with Field IV the rates of application were successively reduced from this, in the ratio 3 : 2 : 1 with three representing the base level. In the table of results which follows, the column headings C1, U2, C3, etc., represent C for charged dust, U for uncharged and the figure for the three levels of application.

Pests: Late Blight, and Leaf Hoppers.

Evaluation of results: Insect counts and yield of potatoes. Yield expressed in pounds per two foot length of row. In this field no precautions were taken to eliminate border effects on the plots; however, it is thought that these would not be as serious with this work as with the onions.

Results: The insect counts were obtained by the sweeping technique. All these counts were low, and entirely without significant difference between the charged and the uncharged dust.

The experimental design used was:

U2	U1	C3	U1	U3	U2	C1	C2	U3
C2	C1	U3	C1	C3	C2	U1	U2	C3

The rows were 430 ft. long and were divided in the middle so that one end received charged dust, while the other received uncharged. Otherwise the treatments were allocated in a completely random way within the blocks. This arrangement of splitting the rows in the middle considerably facilitated the dusting operation.

The yield results were:

Block	C3	C2	C1	U3	U2	U1
1.	3.31	3.09	3.30	3.10	3.10	2.99
2.	2.62	2.87	3.06	2.79	2.39	2.70
3.	2.82	3.30	3.46	3.25	3.13	2.83
Mean	2.92	3.09	3.27	3.05	2.87	2.84

Mean of all charged plots 3.09

Mean of all uncharged plots 2.92

An analysis of variance of these results was made as follows:

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Total	17	1.327	
Blocks	2	0.646	0.323
Charge (C)	1	0.133	0.133
Level (L)	2	0.023	0.011
Interaction C x L	2	0.242	0.121*
Error	10	0.283	0.028

Proceeding as for the analysis in Field IV

$$F_{2,10} = \frac{\text{Interaction}}{\text{Error}} = 4.27*$$

*Significant at the 5% point.

$$F_{1,2} = \frac{\text{Charge}}{\text{Interaction}} = 1.1 \text{ Not significant}$$

$$F_{1,10} = \frac{\text{Charge}}{\text{Error}} = 4.71$$ Which approaches the value of F at the 5% point which is 4.96

As in the analysis of the Field IV results, such F values would result if the charge produced an effect at only one particular level of dust application. To test this, the same t test was used.

For the level 1.

$$t_{10} = \frac{3.27 - 2.84}{\sqrt{.028 \times (\frac{1}{3} + \frac{1}{3})}} = 3.15*$$

*Significant at the 5% point and almost at the 1%.

Similarly at the other levels: at level 2, t = 1.6 and at level 3, t = 0.95 neither value being significant.

Conclusions: The treatment means at the two lower levels of dust application show in favour of the charged dust but only at the lowest level is this difference significant as tested by the t test.

From observation in the field no severe attack of blight was apparent and for this reason wide differences in yield cannot be expected.

The occurrence of a result significantly in favour of charging at the lowest level is as expected, for one would naturally expect to find any attack where the least dust had been applied.

Once again we find that there is a very low levels variance due to an ascent of the treatment means with levels in the case of the uncharged dust, whilst the converse occurs with the charged dust. This difference between the reaction of charged and uncharged dust at different levels also occurred in Field IV but in that instance it was the charged dust treatment means which ascended with levels. No full explanation of this phenomenon can be offered, but it may be that treatment C3 applied excess dust and copper injury resulted.

Summing up, there is a definite indication that the charging of the dust has been beneficial at the lowest rate of application, and further it would seem that this experiment is of the minimum size which will lend itself to a satisfactory analysis of variance.

The improvement in coverage due to charging was apparent to the eye.

APPENDIX III

THE EVALUATION OF FOG OIL DEPOSITS ON TEST SURFACES

Before work on the electrostatic charging of oil fogs could proceed, it was first necessary to develop some method of evaluating the oil deposited on leaves and test surfaces. In this work there are two basic problems; firstly the deposit on the leaves is quite invisible, and secondly the droplets and quantities involved are so small that quantitative estimation is into the range of micro-analysis.

The Use of Dyes in the Oil

The aim in this work was to dye the oil in such a way that the color would be retained in the deposited droplets, enabling the quantity of oil on the leaves to be determined by washing it off in a clear solvent, and then determining the quantity by conventional colorometric methods. It was also hoped that a visual estimate of the distribution of the oil on the leaf surfaces could be obtained by pressing the leaves on white paper.

Tests were carried out with four different dyes, (Sudan III, Crystal Violet, and two commercial blue dyes designated "Oil soluble vat dye") but all proved to be rather disappointing, due mainly to the low solubilities of the dyes, and the weak color in the solvent washings which resulted.

Since this work, further enquiries have indicated that Fluorescein or Eosin (if sufficiently oil soluble) may be more satisfactory as oil dyes because they are visible at low concentrations. Dupont Oil Red is another dye which similarly may be useful.

At this stage the work with dyes was shelved in favour of the more promising fluorescence determination. This, however, does not mean that further work will not produce a satisfactory method using dye; the simplicity of the projected method certainly recommends it.

The Use of Fluorescence in Evaluation

The use of fluorescence is envisaged for both quantitative and qualitative evaluation of oil deposits, and since the start of this work which is to be described, it has been noted that several of the merits of the method recommend it for other applications, such as the differentiation of the different constituents of dust mixtures applied to plant surfaces.

Quantitative estimation of fog oil deposits. The instrument used for this work was a "Lumetron Photo-Electric Fluorescence Meter" Model 402 E.F. (Photovolt Corp. N.Y.) Basically this consists of a source of ultra-violet light which directs a beam through the sample solution contained in a small glass cuvette, or cell. The ultra-violet light causes the fluorescent material in the sample to emit visible light, and the amount of this fluorescence is then measured

by means of a photoelectric unit located close to the side of the cuvette.

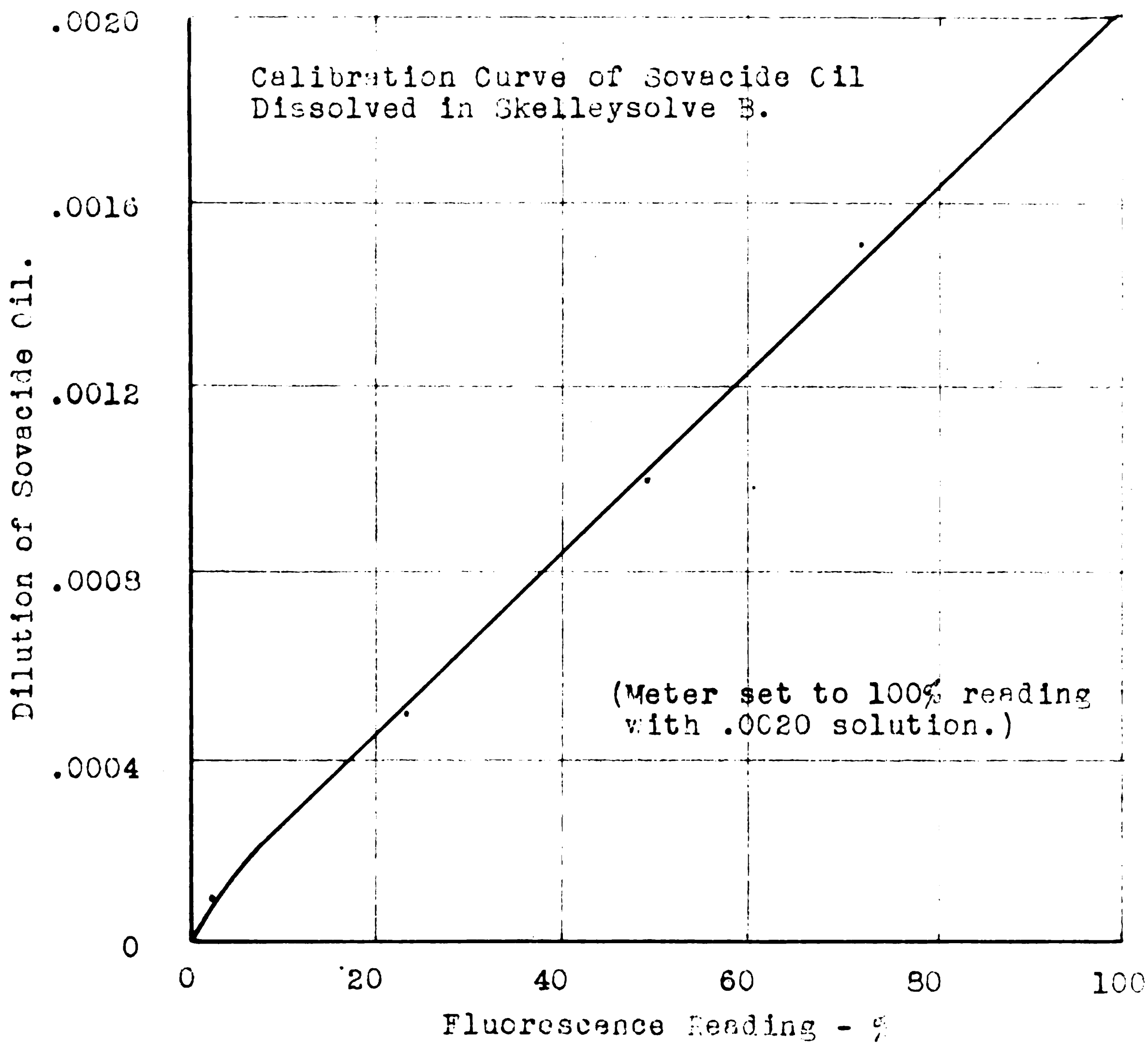
The instrument is calibrated against a solution of the substance under test made up to a known concentration. The concentration used should be slightly above the strongest sample to be determined. (Frequently this is a matter of trial and error when a new set of readings is to be made.) This known solution is placed in the instrument and the setting adjusted until the main control, (which is numbered 0-100) reads 100. The main control is next set to zero and the instrument again balanced with a cuvette containing the solvent only, replacing the known solution. If the test solution is known to possess a straight line relation between concentration and fluorescence in the chosen range, then, after this procedure, solutions can be determined merely by placing them in the instrument, balancing with the main control and reading off the concentration on the main control as a percentage of the first, known solutions concentration. When more accurate results are required or when the characteristics of the test solution are not known, a calibration curve similar to those shown in Figure A4 should be made by determining a series of different, known dilutions in the required range.

The first fog oil used (a Shell product) was almost non-fluorescent, but the second oil, Sovacide, exhibited strong fluorescence. If work has to be done with a non-fluorescent oil, it should be practicable to add some fluorescent material such as vaseline, to make these determinations possible.

Samples of the fog were taken by exposing 8 x 4 inch sheets of aluminum foil to the fog, for a period of thirty seconds. The foil was then rolled loosely and sealed in a sample bottle for transport to the laboratory. In the laboratory a fixed quantity of solvent was added to each bottle and shaken to wash the oil off the foil. (In this particular case 15 ml. of a petroleum ether type solvent, Skelleysolve B, was used, however, this quantity and the dilution will vary from one case to another according to the amount of oil present.)

In choosing the dilution for any set of determinations reference should be made to calibration curves such as those in Figure A4. The slope of the lower of these two curves can be seen to increase as the concentration is increased, but obviously determinations will be satisfactory up to a 0.010 dilution (a dilution by volume, equal to one part of Skelleysolve to .010 parts of fog oil) particularly if the results are taken from a calibration curve.

It should be noted, however, that with many substances when the high concentration range is approached, the slope of the curve continues to increase, and finally becomes negative, that is the fluorescence falls off with an increase in concentration. The previous preparation of such a curve will, however, ensure that this range of concentrations is avoided.



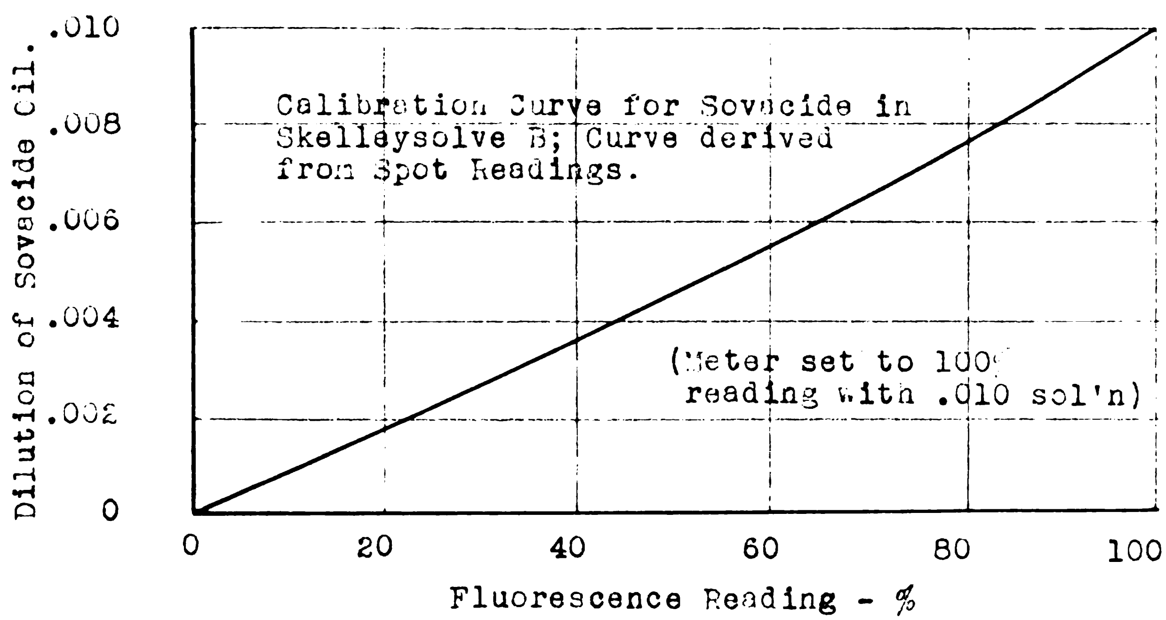


Figure A4. Calibration curves for Sovacide fog oil estimations using a photo-electric fluorescence meter.

The upper curve in Figure A4 was prepared to demonstrate the accuracy of the method, but the readings quoted in the section on the charging of fogs were obtained in the range of the lower curve. Dilution or concentration of solutions can, however, be used to adjust the range as desired. Too high a dilution should of course be avoided because the sensitivity of the instrument tends to fall off and the curve becomes irregular in this region.

Up to the present time only exploratory tests have been done using plant material. Groups of four green tobacco leaves were sprayed with a small quantity of Sovacide, and then treated with solvent in the same way as the aluminum foil.

The following sample results indicate the value of the method:

Solution	Dilution as % of known solution	Actual calculated volume dilution
1. "Known" solution used for calibration.	100	0.0005
2. Washings off 4 leaves sprayed with Sovacide.	51.5	0.000257
3. Washings off 4 leaves not sprayed	8.5	0.0000425
*4. Washings off fingers	4.5	-

*This reading was included to indicate the precautions necessary at high dilutions.

The quantity of oil on the leaves was thus very small, and it now appears that in the field the amounts may be larger than this when the fog is charged. Reading 3 indicates the presence of fluorescent material on the plant leaves, and illustrates the necessity for doing such blank readings whenever plant material is used.

Qualitative evaluation of fog oil deposits. A fog oil deposit is difficult to detect with the naked eye or with a microscope unless special precautions are taken to prevent the oil from spreading on the test surface. Several test surfaces, such as the carboned discs described in Appendix I, are not able to indicate the presence of fine oil droplets. Discs thus treated, and which were known to have oil on the surface, could not be differentiated from discs without oil, even under the microscope. It is, however, possible that a carbon film would be sensitive if special care were taken to prepare a very thin film.

For laboratory work oil droplets can be examined on glass slides prepared in the way described in the following precis, extracted from an article by Collins (1947):

> Dust the glass slides with Merck Zinc Stearate toilet powder using a medium sized camel's hair brush. Leave the slide thinly coated with a white film of stearate. Place the slide on a hot plate until the film of zinc stearate melts.
>
> This film then appears to clear, but almost immediately becomes slightly milky. Heating should be continued until the film again clears, for if heating is stopped before the second clearing, very small clear particles remain which can be confused with the oil later to be deposited on the slide. The prepared slides can be replaced in the normal slide box for field use. (5)

Yeomans (1949) has also described the use of similar oleophobic slides for the examination of oil deposits, and his method also involves the estimation of actual droplet size and an estimation of the quantity of the deposit present by means of a droplet count. Droplet counts are, however, very laborious, particularly if they are to be accurate, and for use with slides it is felt that the fluorescence measurements are more useful for the work in hand.

No reference has been found, in the literature searched, to the examination of oil deposits on leaf surfaces. This will obviously be necessary in working with oil fogs on crop plants; the following observations on this are therefore included. Tests have shown that spray sized droplets of oil can be seen on leaf surfaces as points of light when the leaves are exposed to ultra-violet light in a darkened room, whereas in daylight the smaller sizes of the droplets are invisible. So far no similar test has been made with leaves that have been exposed to oil fog, but it is strongly recommended that this trial be made. If these droplets are visible, it should also be possible to photograph them to record the distribution. The use of this method may also prove of value in examining very light dust deposits which are otherwise practically invisible on plant surfaces.

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