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BORON SUPPLEMENTS

Response of Alfalfa to Applications of a Soluble Borate and a Slightly Soluble Borosilicate Glass

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Boron response of Ranger alfalfa grown from Evesboro sandy loam to additions of a coarsely ground experimental borosilicate glass has been compared to that of borax under greenhouse conditions. The concentration of boron in the plant tended to become approximately proportional to application and to reach a minimum value, in each treatment, during late summer growth. Significant increases in yield were produced by borax from 5 to 80 pounds and by glass from 12 to 360 pounds per acre, indicating that a material of intermediate solubility could be used to better advantage.

Soil-boron deficiencies are, ordinarily, corrected by the application of sodium tetraborate in the form of borax, the decahydrate, or fertilizer borate, the pentahydrate. These compounds are not entirely satisfactory for this use, and the difficulties experienced are associated with the circumstance that the solubilities of sodium borates exceed so very greatly the optimal boron concentration needed in soil solution for healthy vegetative growth. Although plants, generally, require boron as a nutrient in small amounts, they are very sensitive to the element. An excess in soluble form may seriously impair plant growth and there is an ever-present danger in application of localized high concentrations. Furthermore, the high solubility of the compounds now in use makes them very susceptible to rapid losses from the root zone by leaching. In boron-deficient areas, frequent small applications are often used in order to maintain the concentration in soil solution at a level suitable for crop production.

The possible advantages of slightly soluble substances, as carriers of boron (or other trace nutrients), has been the subject of a number of recent investigations (*4–8, 11*). Borosilicate glass is of special interest, as its solubility behavior can be adjusted over a broad range of varying chemical composition. Studies with this type of carrier showed that some glasses do supply boron and may be used in relatively large amounts without producing toxicity.

The application of supplemental boron to a light soil in the form of a coarsely ground borosilicate glass at two different degrees of fineness has been compared to equivalent treatments with borax for growth of alfalfa under greenhouse conditions. Response of the crop to these materials is reported in terms of yield and boron content.

Culture Preparation and Management

Soil. Evesboro sandy loam was weighed out in 7.5-pound portions which were placed in No. 10 plastic-coated metal cans serving as plant pots. In a lime treatment, equal molecular amounts of calcium hydroxide and magnesium oxide, equivalent in total to 2200 pounds of calcium carbonate per acre (weight basis), were mixed thoroughly with the soil. The cultures were kept in a moist condition for 4 weeks to permit equilibration with the lime; the average pH attained was 6.9. The general fertility status was raised at this time to a suitable level for good growth by mixing the cultures with the equivalent of:

Chemical	Pounds/Acre (Area Basis)
N	200
P_2O_5	300
K_2O	200
$CuSO_4 \cdot 5H_2O$	5
$ZnSO_4 \cdot 7H_2O$	5
$MnCl_2 \cdot 4H_2O$	15
MoO_3	1

Supplemental potassium, equivalent to 100 pounds of potassium oxide per acre, was added shortly after the second harvest. The chemicals used to effect each of the above basal treatments were substantially boron-free, as shown by analysis prior to use.

Boron Carriers. The chemical compositions of the boron-containing substances were as follows:

Constituent	Carrier, % of Total	
	Borax[a]	Glass 176-C[b]
B_2O_3	36.52	14.25
SiO_2	...	52.81
Fe_2O_3	...	0.07
Al_2O_3	...	8.11
CaO	...	5.00
K_2O	...	4.39
Na_2O	16.25	14.00
H_2O	47.24	...

[a] Theoretical composition.
[b] Values determined by analysis. Glass supplied by J. A. Naftel, Pacific Coast Borax Co.

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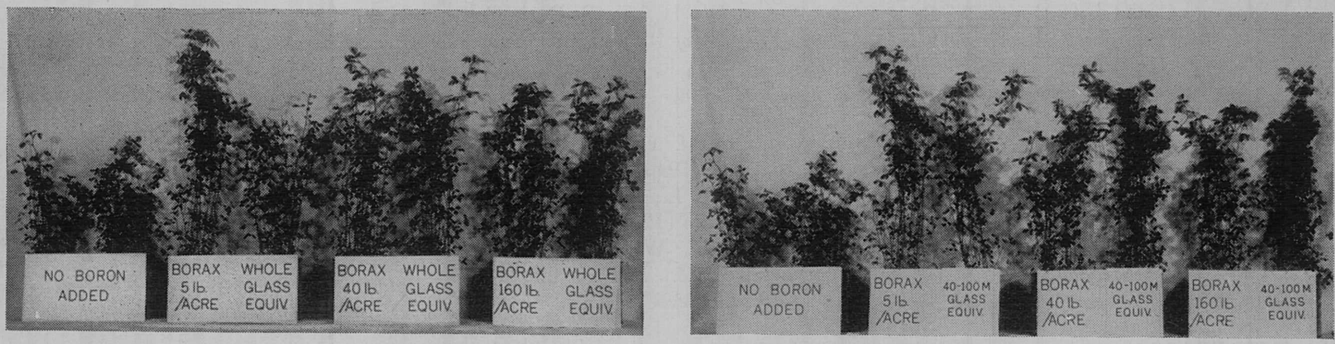


Figure 1. General appearance of alfalfa as affected by borax or equivalent boron additions of the glass (term "whole glass" in left-hand photo refers to —20-mesh glass)

Physically, the glass was a coarsely ground material which by sieve analysis was 46% 20- to 48-mesh, 23% 48- to 100-mesh, and 31% — 100-mesh. No free crystalline material was detected by microscopic examination.

No supplemental boron was added to six of the culture pots, which served as controls. All other treatments were made in triplicate. In a standard series various amounts of borax were applied to the soil. In two other series, the soil was treated with the composite — 20-mesh glass and the 48- to 100-mesh sieve fraction of the same glass, respectively, in amounts approximately equivalent in boron to each level of the borax series.

Crop. Ranger alfalfa was planted April 22 immediately after the boron treatments. The plants were grown until about two thirds in bloom and were harvested, through six consecutive growth periods. Yield and boron content of the crop were determined on an oven-dry basis (65° C.).

Analytical Methods

The boron content of the plant tissue was determined by the curcumin method, as described by Dible, Truog, and Berger (*3*). The procedures followed in determining the composition of the glass were *o*-phenanthroline (*10*) for iron, Versenate titration (*2*) for calcium, and ASTM standard methods (*1*) for the other constituents.

Vegetative Response

Visual Appearance. The alfalfa grew somewhat taller and was generally better in appearance where boron was added (Figure 1). It developed abnormalities at certain high and low levels of application. Deficiency symptoms appeared in the control plants which received no supplemental boron. Perceptible, but much less extensive, deficiency symptoms also appeared with treatments of 12 to 24 pounds of glass per acre. To eliminate all visible signs of deficiency, 5 pounds of borax were sufficient but 49 pounds of glass were needed. The readily soluble borax was toxic to the plant at 80 and 160 pounds, while the glass, added in amounts as high as 390 pounds per acre, did not cause plant injury.

Serious maladjustments in soil boron were not always visually evident, the development of characteristic symptoms being partially dependent on seasonal factors. The control plants had the appearance of normal alfalfa in the first and last cuttings, yet in the intervening growth periods they displayed characteristic deficiency deformities, which were most pronounced during the late-summer growth. The first visible evidence of toxicity, as occurred in the borax series, did not develop until the third cutting and, unlike deficiency effects, slowly increased in degree throughout the rest of the season.

Yield. The dry-weight yields of alfalfa grown with boron additions (Table I) were significantly larger than those obtained without such additions. The total yield for six cuttings at either 160 pounds of borax or 12 pounds of glass (equivalent to 4.75 pounds of borax) were less than in other treatments. Otherwise, the results show no significant difference between levels of application or material types.

The influence of boron supply and season on growth rate of the crop is illustrated by the data given in Table II. Plant growth took place more slowly in the first interval when the root system was being formed, and in the last interval, occurring during the months of November and December, the growth rate approximately doubled during the intervening period. The data, when compared according to physiological conditions of the plant, show that lower yields were obtained when

Table I. Influence of Boron Treatments on Alfalfa Yields

Treatment: Carrier	Amount added[b], lb./acre	Yield of Consecutive Cuttings, Grams/Pot[a]: 1st	2nd	3rd	4th	5th	6th	Total
None		3.31	3.14[c]	3.85[c]	4.42[c]	4.03[c]	2.71	21.36
		2.91	3.00[c]	3.59[c]	4.33[c]	3.84[c]	2.84	20.51
Borax	5	3.74	4.12	4.49	6.36	5.35	4.16	28.22
	10	4.11	4.44	4.94	6.88	5.64	3.65	29.66
	20	4.00	3.96	4.28	6.37	5.85	3.36	27.82
	40	3.95	4.15	4.54	6.56	5.47	3.42	28.09
	80	3.92	4.12	4.86[d]	7.25[d]	5.57[d]	4.12[d]	29.84
	160	3.49	3.96	4.52[d]	5.88[d]	4.64[d]	3.18[d]	25.67
Glass, — 20-mesh	12	3.69	4.04	4.72[c]	5.92[c]	4.34[c]	3.00	25.17
	24	4.05	4.16	4.90	5.86	5.03	3.43	27.43
	49	4.10	4.15	4.43	6.23	5.51	3.81	28.23
	97	4.09	4.83	5.19	6.57	5.51	3.55	29.74
	195	4.75	4.37	4.21	6.65	5.36	3.50	28.84
	390	3.90	3.71	4.66	6.59	5.55	4.27	28.68
Glass, 48- to 100-mesh	12	3.83	3.87	4.43[c]	5.61[c]	4.46[c]	3.34	25.54
	24	3.88	4.03	4.99	5.74	5.15[c]	3.62	27.41
	49	3.30	3.79	4.05	6.06	5.55	3.74	26.49
	97	4.63	4.45	4.78	6.13	5.62	3.72	29.33
	195	3.93	3.79	4.65	6.61	5.70	4.19	28.83
	390	4.09	3.84	4.69	6.57	5.35	3.88	28.42
LSD at 1%		0.88	0.90	1.05	1.65	1.08	0.98	4.14
LSD at 5%		0.66	0.67	0.79	1.23	0.81	0.73	3.09

[a] Oven-dry weight (65° C.).
[b] Amounts of boron applied in form of glass were essentially same as levels in borax series. By analysis quantities of glass were equivalent to: 4.75, 9.50, 19.00, 38.00, 76.00, 152.00 pounds of borax per acre, respectively.
[c] Deficiency symptoms observed.
[d] Toxicity symptoms observed.

there was a decided imbalance in boron level, even when no visible abnormalities had been observed during growth.

Boron Content of Crop

Variation with Applied Boron. The boron content of the plants was approximately proportional to the amount of applied boron. This relationship was established by borax in the first growth (Figure 2), but was attained more slowly by the glass (Figures 3 and 4). The curves of the − 20-mesh glass became nearly linear after the first cutting, while those of the 48- to 100-mesh glass approached this condition after the second cutting, through gradual stepwise changes toward linearity. The specific surface area of the − 20-mesh and 48- to 100-mesh glass (calculated, assuming a density of 2 and uniform spheres) were 244 and 135 sq. cm. per gram, respectively. Hence, the lower boron contents and slower changes exhibited by the 48- to 100-mesh glass are probably related in part to the difference in total surface area.

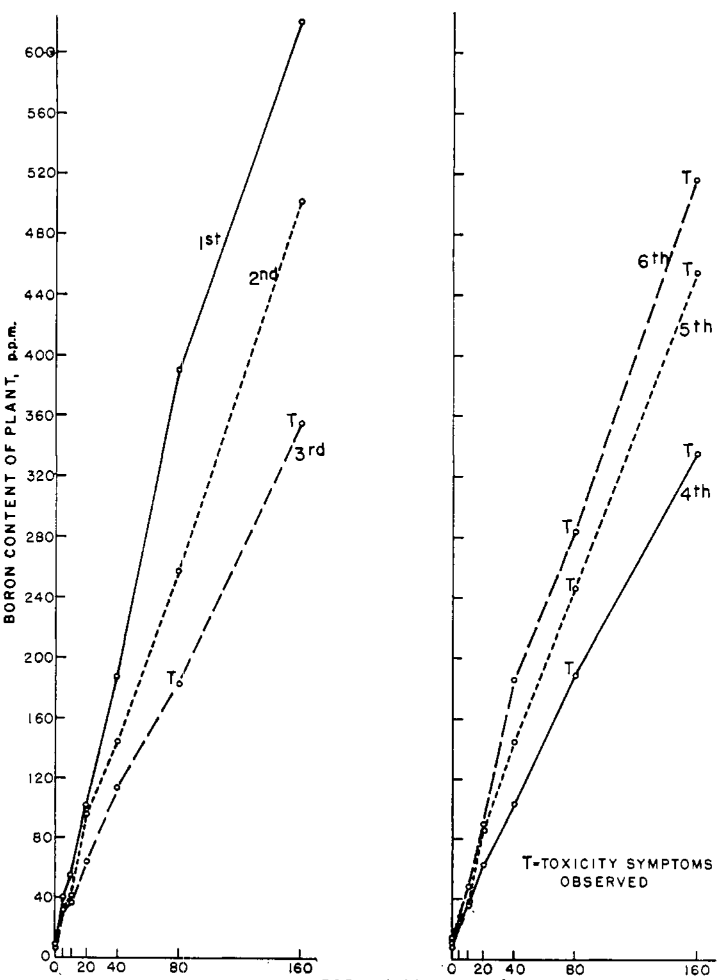
The plausible explanation for the dissimilar response patterns of the materials lies in the circumstance that the immediate supply of soluble boron from the slowly soluble glass is much smaller than the immediate supply from the readily soluble borax. The initially small accessible supply from the glass would be subjected to relatively large nonlinear and nonequilibrium sorption effects of the soil and the plant tissue. A balanced situation is approached in the growth system as it is acted upon by the further release of boron from the glass and by crop removal.

Variation with Season. The absorption of boron by the plants varied markedly during the season. The sizable changes that occurred are shown by the boron contents of the borax series, which are plotted with respect to time in Figure 5. The concentration of boron in the plant decreased steadily in the course of the first three cuttings and increased in the last three successively. The same effect was reflected in the results when the soil had been treated with the

Table II. Growth Rate of Alfalfa as Affected by Boron Level and Season

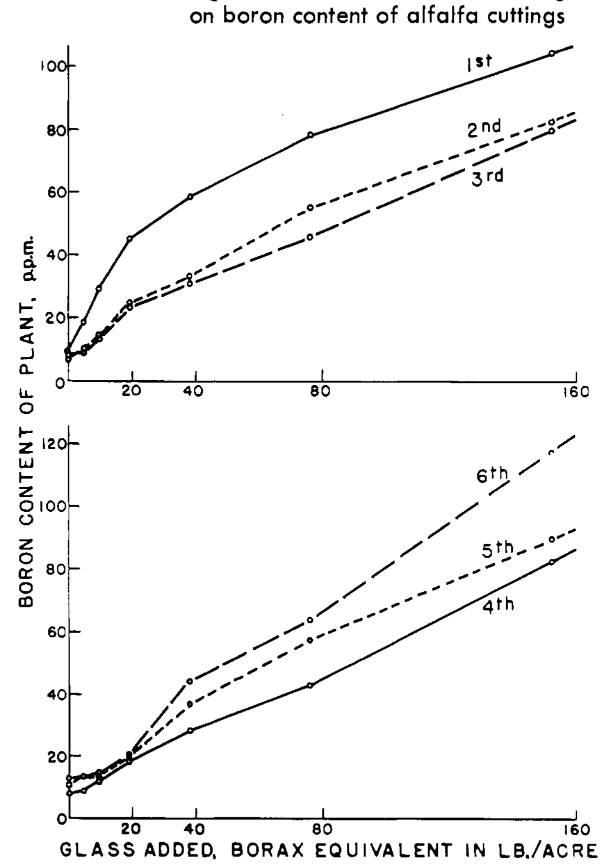
Harvest			Average Growth, Mg./Day[a]		
Cutting	*Date*	*Length of growth period, days*	*Boron-deficient plants*[b]	*Normal plants*[c]	*Plants showing boron toxicity*[d]
1	June 25	64	49[e]	63	55[e]
2	July 23	28	110	148	141[e]
3	Aug. 24	32	116	143	141
4	Oct. 4	41	107	158	143
5	Nov. 8	35	112	158	133
6	Dec. 27	49	57[e]	97	65
	Standard error		±2.7	±2.3	±6.1

[a] Oven-dry weight (65° C.).
[b] Control plants with no supplemental boron.
[c] Average values for soil treatments of 5 to 40 pounds of borax and 49 to 390 pounds of glass per acre.
[d] Soil treated with 160 pounds of borax per acre.
[e] No plant abnormality observed.



◀ Figure 2. Effect of borax on boron content of alfalfa cuttings

Figure 3. Effect of —20-mesh glass on boron content of alfalfa cuttings



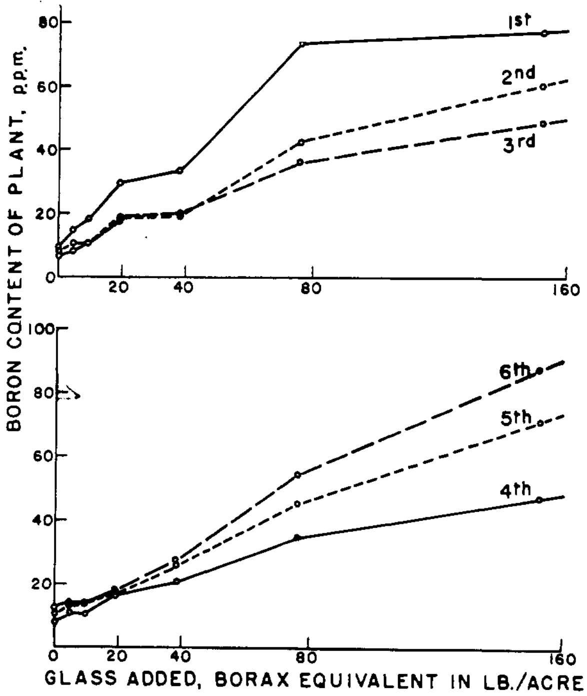


Figure 4. Effect of 48- to 100-mesh glass on boron content of alfalfa cuttings

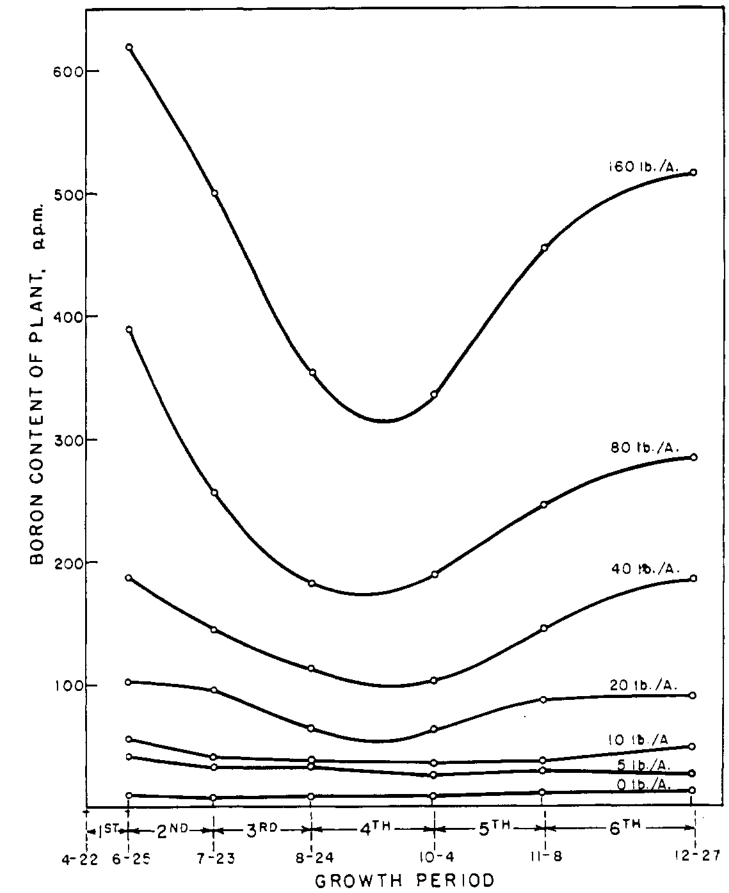


Figure 5. Influence of season on boron content of alfalfa at various levels of borax treatment

glass (Figures 3 and 4). In each case, minimum absorption occurred between the third and fourth cuttings.

The variation with season is attributed primarily to fluctuations in growth conditions. Plant maturity would influence the results to some extent, but after the first cutting, the repeated growths from stubble to bloom would seem to eliminate further change as directly attributable to this factor. The lower content in the middle cuttings may relate in part to the more rapid dilution caused by the higher growth rate (Table II). The total uptake, as well as concentration, was depressed during the late-summer growth (minimum in the third cutting, taken August 24). The data suggest that the absorption of boron by the plant may be varied to some extent by differences in the average soil moisture conditions, introduced by temperature and other seasonal factors.

Optimal Boron Application. The effect of applied boron can be best related to concentration in the plant and yield. Deficiency symptoms developed when the dry plant tissue contained less than about 10 p.p.m. of boron. When the boron content was increased from about 10 to 20 p.p.m., larger yields were obtained, but no further increase was realized at higher levels. The plant requirement was satisfied at about 20 p.p.m. of boron. The upper limit of the optimal range was not definitely defined by either boron content or yield. No toxicity symptoms were observed at 620 p.p.m. of boron in the first cutting, while they were identified at as low as 182 p.p.m. in the third cutting. The tolerance of the plant to high levels of boron seems to be dependent on climatic factors and can be determined only for specific physical conditions that occur in field growth.

Powers and Jordan (*9*) state that thrifty alfalfa plants contain 20 to 50 p.p.m. of boron. As the results obtained for the lower limit were in agreement and the upper limit could not be estimated from the data, the above range was used in approximating the optimal application. The boron contents of the plants fell within this range when the soil had been treated with 5 pounds of borax per acre. Higher levels of applied boron did not produce any further increase in yield; therefore, the 5-pound addition may be considered optimal in the borax series, while the optimal addition of the glass in each test series was 97 pounds per acre.

Conclusions

Glass definitely raised the boron content of the plant, although it took larger amounts of glass than of borax to give a certain rise. The approximate relative effectiveness of the two materials was 1 pound of borax to 20 pounds of glass. There were significant increases in yield when as little as 12 pounds of glass per acre were applied. The low solubility of the glass could be utilized by the application of large amounts to the soil to supply boron over an extended period of time, but would preclude efficient use during a single season. Hence, the results suggest the use of a more soluble glass. It is not directly evident from the data whether or not boron was released from the glass steadily during plant growth.

Acknowledgment

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TOXICANT DISTRIBUTION

Determining the Distribution of Organic Insecticides in Powder Formulations

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The location and the quantitative distribution of the toxicant in a powder formulation of an organic insecticide, with an insoluble carrier or diluent, may influence greatly the effectiveness of the formulation. Results indicate that the deliquescence method is capable of determining this distribution. Exposure of the formulation to the vapor of an organic solvent causes deliquescence of the toxicant particles, and the resulting droplets could be observed under the microscope and used as an index to the location and quantity of toxicant originally present.

Dust and wettable powder formulations of organic insecticides may vary considerably in effectiveness, with the nature of the carrier or diluent, and with the technique used to combine the components (*5*). Much of this variation arises from differences in the distribution of the toxicant within the mixture and in the nature and extent of its association with the carrier. Most of the evidence on this point is indirect. For example, formulations prepared by mechanical grinding have been shown, in field experiments (*7*), to be markedly inferior to impregnated formulations in which the toxicant would be expected to be more uniformly distributed throughout the bulk, as well as on the surface of the individual particles. Harrison (*3*), using the air permeation method, compared the average particle sizes of different formulations with the average sizes of the particles left after extraction of the toxicant. A closer association of the components in some formulations than in others was indicated and laboratory tests on insects correlated well with these results. Work along these lines has been greatly handicapped by the lack of a satisfactory method for the direct observation of the distribution of the toxicant in a finished formulation.

Some information can be obtained by a careful microscopic examination of the formulation. Glass (*2*) observed free droplets of parathion when a wettable powder was mixed with water, and found that powdered materials which would eliminate these free droplets greatly reduced injury to susceptible apple foliage. Methods based on differences in optical properties between carrier and toxicant, such as refractive index or behavior in polarized light, give some information, but are seriously limited by the heterogeneous nature of most carriers and diluents. They are almost useless where the components are closely associated and, particularly, where a nonvolatile solvent for the toxicant is also present.

The most clear-cut difference between toxicant and carrier is that of solubility. Most of the diluents and carriers are inorganic minerals, and the few organic carriers, such as tobacco stems and walnut shell flour, have a relatively low content of material soluble in organic solvents, while most toxicants are extremely soluble in certain organic solvents. Exposure of a formulation to the vapor of a suitable solvent should, therefore, cause deliquescence of the toxicant but little or no deliquescence of the other constituents. Preliminary experiments showed that the phenomenon could be controlled so as to show, under the microscope, the location and relative quantity of toxicant either as separate particles or associated with particles of carrier, by producing liquid droplets at the location of each portion of toxicant. A procedure for this purpose was worked out and some tests made to determine the extent of the information which the method could furnish.

Procedure

Two microscope slides are cleaned and, if desired, coated with Dri-Film or other solvent-resisting coating. A

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