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FEASIBILITY OF SURVEYING PESTICIDE COVERAGE WITH AIRBORNE FLUOROMETER *

By

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ABSTRACT

Response of a Fraunhofer line discriminator (FLD) to varying distributions of granulated corncobs stained with varying concentrations of Rhodamine WT dye was tested on the ground and from an H-19 helicopter. By design the instrument detected fluorescence specifically at the sodium D_2 Fraunhofer line (5890 angstroms). The granules are used as a vehicle for airborne emplacement of poison to control fire ants in the eastern and southeastern United States. The granules are dropped with considerable precision but some targets are inevitably missed. It was hoped that the FLD could aid in detecting missed target areas. Test results showed that the granules are detectable by FLD but that the concentration must be too great to be practical with the present FLD. Possible methods for enhancement of response may include: (1) increasing dye concentration; (2) incorporating with the poisoned granules a second material to carry the dye alone; (3) use of a more strongly fluorescent substance (at 5890 A); (4) modifying the time interval after dyeing, or modifying the method of dyeing; (5) modifying the FLD for greater efficiency, increased field of view (FOV), or larger optics; or (6) experimenting with laser-stimulated fluorescence.

INTRODUCTION

Granulated corncobs used as a vehicle for airborne spreading of poison have the general size and texture of coarse sand, advantages being their light weight, low cost, non-abrasiveness, compatibility with soil constituents, high absorption, and suitability for use in standard seed-spreading equipment. A uniform rate of flow through the hopper of a seed-spreader is an important requirement, particularly in airborne spreading, where rates of flow must be high and uniform coverage of the target area is essential. This is particularly true in control of fire ants, since a missed target area will allow the ants to breed and soon infest the surrounding terrain. It is not likely that alternative materials having all of these characteristics will be found in the near future. Therefore, in our brief experiments no effort was made to substitute alternative materials, since it should first be determined that they are compatible with the control procedures now in use by the Department of Agriculture.

The procedure for spreading the granules utilizes a sophisticated system of navigation by means of Decca radar. A map of the desired target area is visible to the pilot, while a moving needle traces his position across the map as he follows a pattern of traverses designed to provide complete coverage, the direction of flight undoubtedly being partly dependent on wind, topography, cultural features and other factors. Some missed target areas must inevitably result from such things as wind gusts, spreader malfunction, pilot error, and probably electronic malfunction. The quantity of granules required is on the order of one pound per acre, and the cost is kept as low as a few cents per acre by operating over large areas. Because of the very sparse scattering there is as yet no practical way to survey missed target areas, even from the ground, and because of the low cost of the whole operation it would be equally impractical to do any significant part of this spreading on the ground.

Nature of the problem

It was hoped that a practical method could be found to dye the granules with a fluorescent dye and to detect their areal coverage by means of an airborne fluorometer such as the experimental Fraunhofer line discriminator (FLD). Basic problems involved in using this technique of remote sensing include:

(1) To dye the granules without altering other desirable characteristics such as their dryness or uniform rate of flow through a hopper.

(2) To detect the granules by means of their fluorescence when their distribution is no denser than about one pound per acre.

(3) To conduct the survey on a bright, cloudless day, when intense fluorescence of the granules is stimulated by sunlight.

(4) To avoid cloud shadows during such a survey, or alternatively to distinguish their masking effect on fluorescence from that of missed target areas.

(5) To conduct the survey during high sun angles, when vegetation shadows on the granules are at a minimum, and to differentiate variations in fluorescence due to shadow effects from those due to granule concentration.

(6) To record the resulting data in mappable form so that missed target areas could be covered soon after the initial dropping of the granules.

Most of these problems have not been solved, and initial test results must be considered negative.

Previous work

Some previous work in the use of fluorescent tracers of agricultural chemicals has been briefly summarized (Hemphill, Stoertz, and Markle, 1969). Yates and Akesson (1963) noted that drift of sprayed agricultural pesticides and herbicides outside the area of intended treatment is one of the major problems during aerial or ground application. They successfully used the dye Brilliant Sulpho Flavine as a fluorescent tracer in two pesticides sprayed at concentrations of 7 to 10 gallons per acre, and verified coverage by means of laboratory fluorometer. Himel and others (1965) conducted similar experiments using particles of fluorescent zinc cadmium sulfide suspended in insecticide sprayed from a helicopter.

Objectives and limitations of recent tests

Ground and airborne tests were conducted during December 1969 at: Needles, California; Prescott, Arizona; and Menlo Park, California. Principal objectives were to test response of the sodium-D_2 FLD to varying distributions of the granulated corncobs stained with varying concentrations of Rhodamine WT dye. Limitations of these tests were:

(1) Dye concentrations tested were limited to solutions of 0.1 percent, 0.5 percent, and 1.0 percent by weight.

(2) Tests were limited to Rhodamine WT, which is the highly soluble dye intended primarily for hydrologic studies. The much less soluble rhodamine B, and other rhodamine dyes used in the dyeing of materials, were not tested.

(3) Other possible fluorescent tracers that were not tested include fluorescent powders comparable to the zinc cadmium sulfide mentioned above and a wide range of fluorescent pigments of the type

used in making yellow and orange fluorescent spray paints, inks, and papers.

(4) Time limitations prevented an assessment of the effect of modifying the time interval after dyeing, or modifying the method of dyeing; granules used in our tests had been dyed from two to four weeks prior to the tests.

(5) Mechanical problems prevented an airborne test at altitudes higher than about 50 feet, and therefore the effect of altitude was not assessed.

(6) The instrumental field of view (FOV) was approximately one degree (1°) of arc during the airborne tests; effect of increasing the FOV to approximately ten degrees (10°) has not been assessed.

(7) Sun angles during our tests were low, ranging from 23° to 33° during the airborne tests and from 18° to 24° during the ground tests; limitations of weather, season, and logistics prevented tests at higher sun angles.

Purpose of this report

The purposes of this report are: (1) to suggest possibilities of using an airborne FLD for surveying pesticide coverage; (2) to summarize our test results, which are generally negative; and (3) to suggest possible further experimentation to improve results.

Principle of the Fraunhofer line discriminator

The FLD is a unique experimental optical remote sensor that operates as an airborne fluorometer. It is capable of selectively sensing fluorescence by viewing a single Fraunhofer line (sodium D_2, 5890 A) in light from a substance suspected to fluoresce and comparing the relative darkness or depth of the line profile with the same line in the sun's spectrum. Any difference in the two is measured and converted into a coefficient of fluorescence of the substance.

The FLD, designed and constructed by the Perkin-Elmer Corporation under contract to the National Aeronautics and Space

Administration (NASA) and the Geological Survey, was completed in 1968. Its detailed design is best described by Ludwig, Markle, and Schlesinger (1968). Its operation and applications are described by Hemphill (1968) and by Stoertz, Hemphill, and Markle (1969). A concise description of the instrument has been published by NASA (1969). Mapping of the airborne FLD data is accomplished by means of a radar tracker, using methods described by Howell (1969). More specialized data, mainly concerning operation of the instrument over water, are available (Stoertz, 1969a, b, c, and d).

TEST APPARATUS AND PROCEDURES

The FLD consists of an optical unit and an electronic console, which are described in the publications cited above. Data are recorded along linear traverses by means of a Mosley dual-pen strip-chart recorder. The two pens record: (1) fluorescence coefficient of the target within the field of view of a downward-looking telescope; and (2) intensity of sunlight incident on a horizontal light collector, as observed through an upward-looking telescope (at 5892 angstroms). The latter record serves as an indicator of tilt of the aircraft, and serves as a double-check of those parts of the record that are erroneous, but otherwise this is not an essential part of the FLD record. Normally the plane is flown nearly level during traverses, and discrepancies are noted by hand on the strip-chart by the FLD operator. During operational use the flight path of the survey aircraft can be plotted on a map of the area in real time by means of the radar tracker, within a range up to about 20 miles, but this apparatus was not used during the granule tests.

Granule spreading

A small seed-spreader, operated by hand, was used to scatter granules in swaths approximately 8 feet wide and 30 feet long. Parallel swaths of varying distribution were laid down by adjusting the hopper slit-width. These widths were marked for later calibration of distribution in terms of pounds per acre, but this was not necessary in light of the initial negative results that indicated required distribution would exceed by several orders of magnitude the quantity required as a vehicle for the poison. In addition the dyed granules were found to have an undesirable hygroscopic property that caused them to moisten and adhere, even in the dry desert air of Needles, California. The moisture content was not measured but would very likely need to be considered in converting to pounds per acre.

Helicopter mounting of the FLD

For airborne tests the FLD was mounted on the starboard side of an H-19 helicopter (Figure 1) as described previously (Stoertz, Hemphill, and Markle, 1969, p. 16-17). Some ground tests were conducted at Needles and at Prescott with the instrument mounted on the aircraft. In flight the instrument operates from a generator which converts the 24-volt aircraft power into the 110-volt current required for the instrument. Ground tests were conducted by disconnecting the generator and plugging the FLD into an outside circuit by means of a 200-foot extension cord. A 24-volt mobile airport generator is suitable for the same purpose.

An aluminum slide 18 inches beneath the optical unit facilitated viewing of varying concentrations of granules while the FLD was mounted on the aircraft. The granules were placed on the standard target device, permitting them to be readily moved into and out of the field of view.

Mounting of FLD on casters

Ground tests of granule response in Menlo Park were facilitated by mounting the FLD on a work bench that was placed on casters (Figure 2). The FLD was supported by an aluminum framework, as shown, and the bench was rolled across swaths of granules that had been scattered on an asphalt parking lot. In this test, also, a 200-foot extension cord was used. With this apparatus, granules were also viewed in varying distributions on a horizontal surface 14 inches beneath the lower portal of the FLD. At this distance the FOV is apparently a circle approximately 1.3 inches in diameter, slightly larger than the diameter of the lens of the downward-looking telescope.

The precise location of the FOV in this type of test can be readily determined by means of a small acrylic resin cylinder of fluorescent dye placed in the sunlight on the horizontal surface beneath the FLD. The cylinder should be of a dimension close to that of the field of view or slightly smaller. While the FLD records fluorescence coefficient the cylinder is moved until a maximum reading is attained,

Figure 1. FLD mounted on H-19 helicopter during tests of response to fluorescent granules, Needles, Calif.

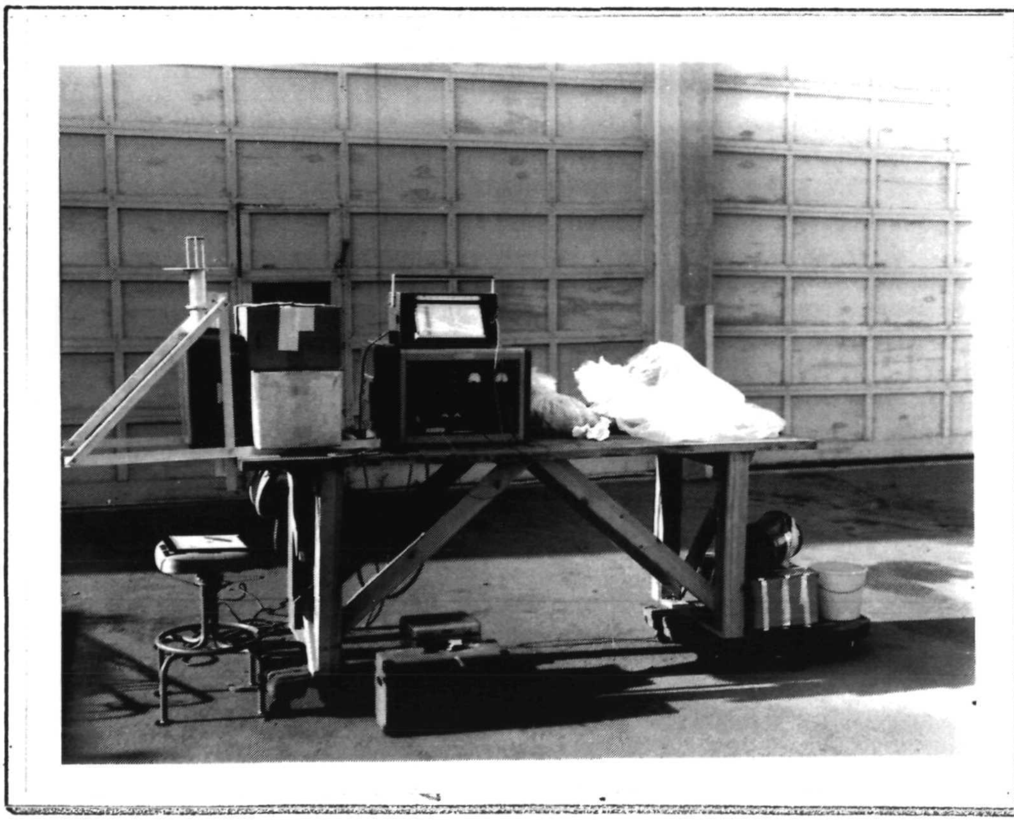


Figure 2. FLD mounted on casters for ground test over fluorescent granules, Menlo Park, Calif.

this location marking the center of the field of view. The size of the field of view can also be readily determined by means of a sheet of fluorescent art paper placed in the sunlight beneath the instrument. The borders are masked with black paper to produce progressively smaller apertures and to define the line at which the FLD readings of fluorescence coefficient are first affected, thus defining the field of view precisely.

INITIAL TEST RESULTS

Test results are subject to the limitations enumerated above ("Objectives and limitations of recent tests") and are therefore tentative and subject to revision.

Ground test using helicopter-mounted FLD

Granulated corncobs stained with a 1.0 percent solution of Rhodamine WT were viewed in varying distributions under the FLD at Needles Airport, California, on December 4 from 2:40 pm (Mountain Standard Time) to 4:27 pm. A portion of the strip-chart record from 4:05 to 4:16 pm is shown in Figure 3. The sky was cloudless, as evidenced by the very uniform level of solar intensity (upper pen, 5892 A, "component A") measured through the upward-looking telescope. However, the relatively low levels of both solar intensity and fluorescence coefficient (lower pen, or "rho") result from the low sun angle at that time and date (near the winter solstice).

The maximum level of fluorescence coefficient at the right edge of the chart represents complete coverage of the field of view with the granules. Complete absence of granules is shown at the left edge. A very slight response is noticeable when some granules are present, but when coverage is still less than 1 percent of the field of view. However this response appears too weak, by comparison with the noise level, to serve as a suitable means for airborne survey of granules having such a distribution. The distribution was only qualitatively recorded in this short series of tests, but it was apparent that the required distribution would greatly exceed one-pound per acre. Nevertheless, the test demonstrated that the FLD responds to the solar-stimulated granules, and roughly in proportion to their distribution frequency.

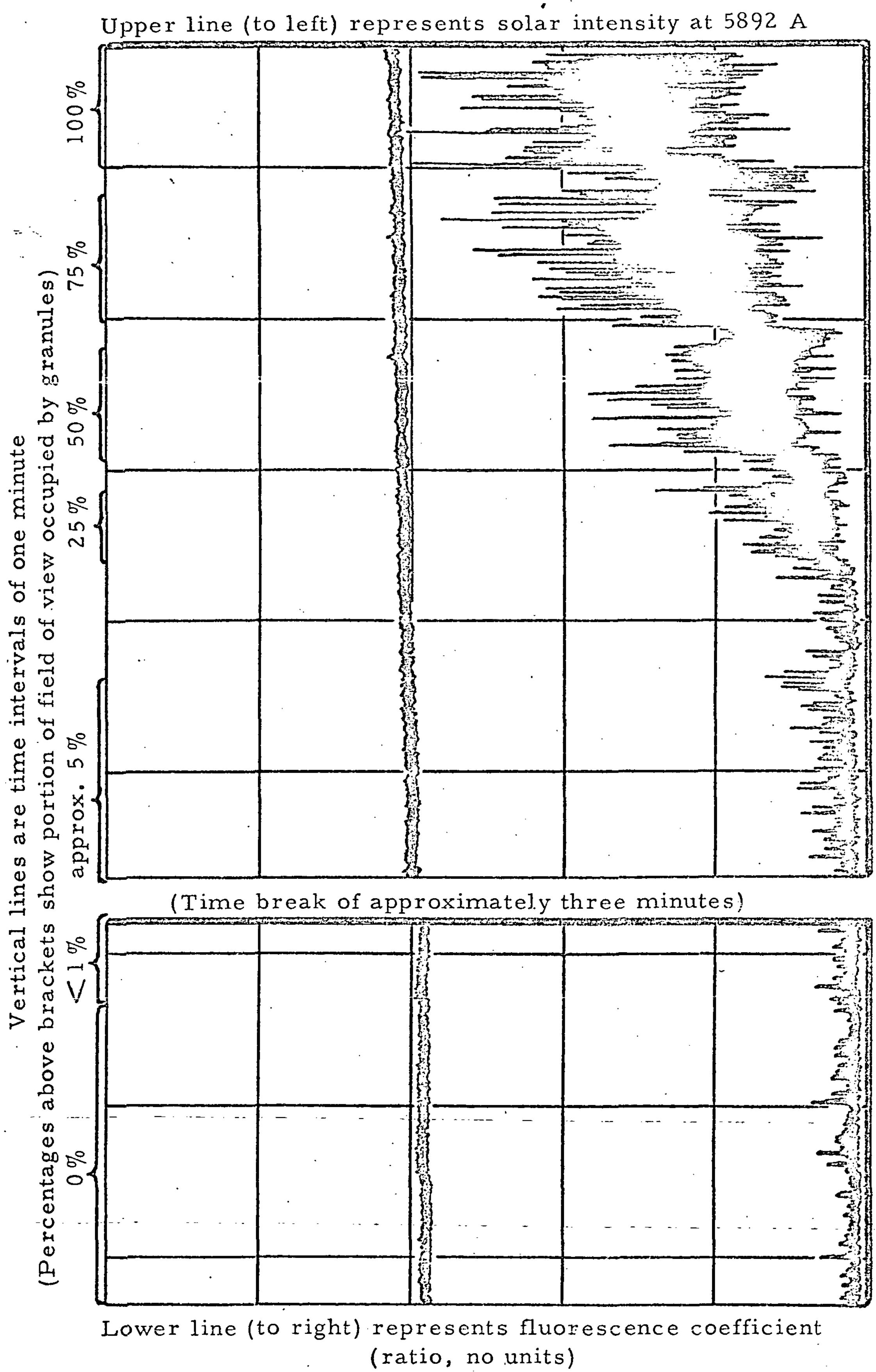


Figure 3. FLD response to varying distributions of fluorescent granules stained with 1.0 % Rhodamine WT (Dec. 4, 4:05 to 4:16 pm Mountain Standard Time, Needles, Calif.)

Airborne test over barren ground, Needles, California

Granules were spread in two parallel swaths each 8 feet wide and 50 feet long on barren terrain similar to that around the helicopter in Figure 1. The swaths were separated by 20 feet of ground free of granules. Both swaths were of granules stained with 1 percent Rhodamine WT, but were of two different distributions, corresponding to two slit-widths of the spreader hopper. The swaths were traversed by the helicopter at an altitude of 20 to 30 feet on December 6 at 10:13 am (Mountain Standard Time). Response of the FLD, shown on Figure 4 (right graph), appeared unsatisfactory, but we continued with unrelated airborne tests without landing to inspect the area of granules.

Another fly-over of the same area was conducted later on the same day at 12:29 pm. Response was similar to the first test, as shown on Figure 4 (left graph), although aircraft speed was slower. In both tests it was noted that readings of fluorescence coefficient over the adjoining asphalt parking area were slightly higher than over the densest swath of granules. Neither of the swaths was clearly recognizable on the strip-charts. It should be noted that both swaths represented distributions greatly in excess of one pound per acre.

The swaths of granules were examined after landing at 2:24 pm and it was then evident that more than two-thirds had been blown away by the helicopter prop-wash. Inspection of the surrounding terrain revealed that they had tended to accumulate around obstructions of all kinds such as grass tufts or other low vegetation and low mounds, including ant hills. No appreciable number were observed on the asphalt parking apron, but since this area happened to be a refueling station for aircraft any granules in that area would have tended to be blown away by any aircraft that refueled between 10:13 am and 2:24 pm.

There was no further opportunity to conduct this test at Needles, and therefore the test might be considered inconclusive. However the results offer little encouragement, because a sufficient number of granules are estimated to have been present during the initial traverse to be representative of a distribution much greater than one pound per acre, and because the on-ground tests were also viewed as negative.

The effect of altitude is insignificant within limits of at least several hundred feet, because fluorescence is non-collimated, emanating in all directions from the surface irradiated by sunlight. In this respect fluorescence is distinct from reflectance, which has a strong directional component related to the angle of incidence of the sunlight. Consequently, as long as a fluorescent target fills the field of view the

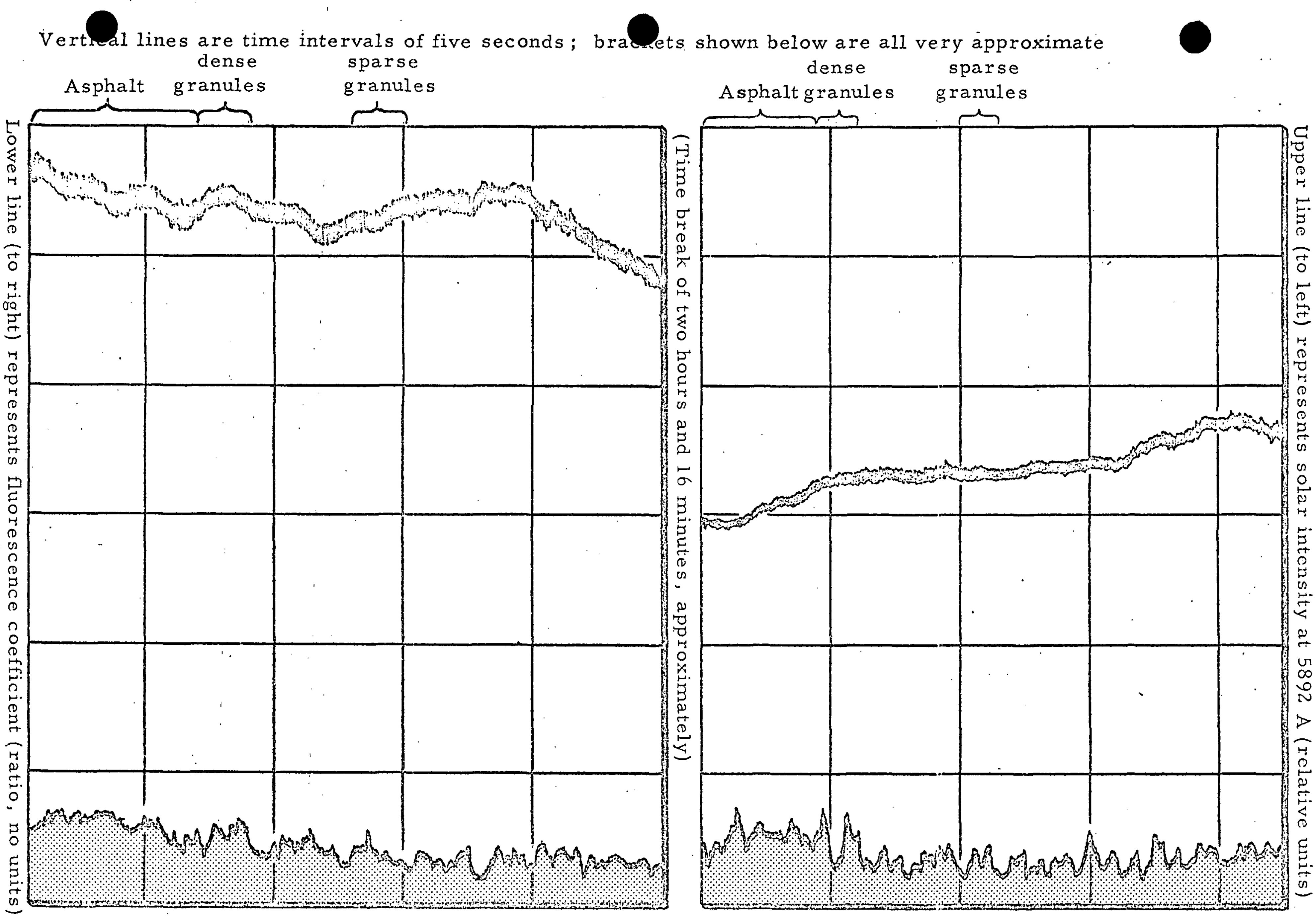


Figure 4. FLD response during airborne traverses over two swaths of fluorescent granules scattered on barren ground (December 6, 10:13 am and 12:29 pm Mountain Standard Time, Needles, Calif.)

detectable fluorescence should not diminish with increasing altitude, the fluorescence theoretically being directly proportional to the number of granules per unit area.

For this reason, a static on-ground test of response to granules immediately beneath the FLD should yield results similar to an airborne test from an altitude up to at least 100 feet. In either case the variable most closely related to FLD response appears to be the absolute spacing of the granules. At a given distance, this will be proportional to the number of granules within the field of view. Tests of FLD response to varying concentrations of Rhodamine WT dye in solution show similar results. The height of the FLD above a tank of the dye is apparently not a factor in determining the response, providing all of the dye within the field of view is uniformly illuminated by sunlight. Therefore the most economical method of testing is to predict response by on-ground tests, and preferably use the airborne tests mainly to substantiate these results.

Airborne test over dry grassland, Prescott, Arizona

Granules were spread in eight parallel swaths, each eight feet wide and approximately 30 feet long on a grass-covered plain situated 150 yards east of the Water Resources Research Laboratory compound at the municipal airport, Prescott, Arizona. The swaths were separated by 20 feet of ground free of granules, so that the entire set of swaths covered an area about 225 feet long and 30 feet wide. The ends were marked by orange panels to facilitate airborne traverses. The swaths were of granules stained with 1 percent Rhodamine WT, and were of increasing density of distribution from north to south. This was accomplished by making from 1 to 4 passes across each swath with the spreader, and by using two hopper slit-widths. The density of all swaths was considerably greater than one pound per acre.

The swaths were traversed several times at an altitude of 20 to 30 feet, from 3:10 pm to 3:20 pm (Mountain Standard Time). It had been intended to make these traverses at varying altitudes up to 1,000 feet, in order to test the effect of altitude, but this was abandoned because of negative results during low traverses, and because of lack of sufficient power for slow traverses at the high altitude of Prescott (approximately 5,200 feet).

Response of the FLD during even the slowest traverse, shown on Figure 5, was inappreciable. None of the swaths is recognizable

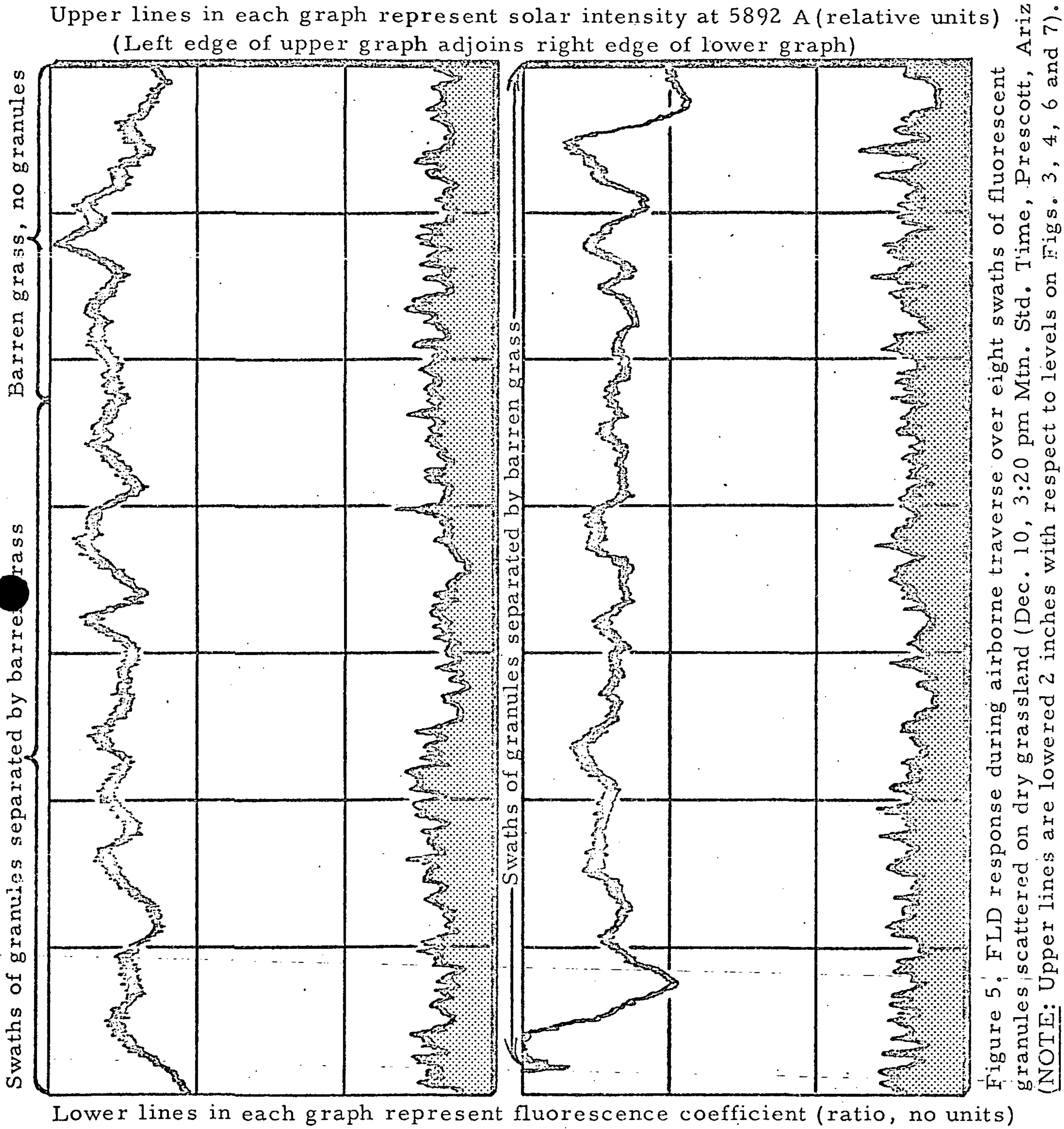


Figure 5. FLD response during airborne traverse over eight swaths of fluorescent granules scattered on dry grassland (Dec. 10, 3:20 pm Mtn. Std. Time, Prescott, Ariz.) (NOTE: Upper lines are lowered 2 inches with respect to levels on Figs. 3, 4, 6 and 7).

against the background noise level. This negative result is attributed largely to the fact that the ground surface and the granules were almost entirely shadowed by the grass. Although the grass was only about three inches high, it was sufficiently dry that virtually all the granules fell through to the ground, rather than lodging among the grass stems. A slight wind that rustled the grass contributed to this effect, although the helicopter prop-wash would undoubtedly have dislodged any granules that were not already down at the ground surface. The low sun angle at this late hour and late season must also have contributed to the shadowing effect. However it is felt that this effect would be a major problem even in midsummer near midday, because at that time the grass would be more lush and would cast a denser shadow, not only from the sunlight, but from the vertical viewing angle of the FLD telescope. It was not possible to repeat this test on another day at a higher sun angle, but it is felt that results would not have been appreciably different.

Laboratory test of sensitivity

Granules stained with a 1.0 percent solution of Rhodamine WT were viewed in varying distributions under the FLD at Menlo Park, California, on December 16, from 1:15 to 2:00 pm (Pacific Standard Time).

The instrument was mounted as shown in Figure 2, and the granules were placed in the sunlight at a point 14 inches below the lower portal. The field of view at this distance was a circle approximately 1.3 inches in diameter, which is also an area of about 1.3 square inches. The number of granules within this area was increased from 0 to 300, in 24 steps. The FLD response from 0 to 40 granules and from 50 to 200 granules is shown in Figures 6 and 7. When 200 granules were within the field of view, they were sufficiently close to shadow each other to some extent, due to the low sun angle (1:45 pm). Beyond that point there was an inappreciable response to increasing numbers of granules. The field of view was practically full at 300 granules.

The sky was slightly hazy during this test, as evidenced by slight fluctuations in solar intensity (upper pen on Figures 6 and 7). Some clouds were also present in the direction of the sun at 1:30 pm and at 1:50 pm, but these portions of the strip chart are not included. A comparison with the solar intensity levels recorded on Figure 3 (December 4, 4:05 to 4:16 pm) shows considerably higher levels on December 16, due to the earlier hour and higher sun angle.

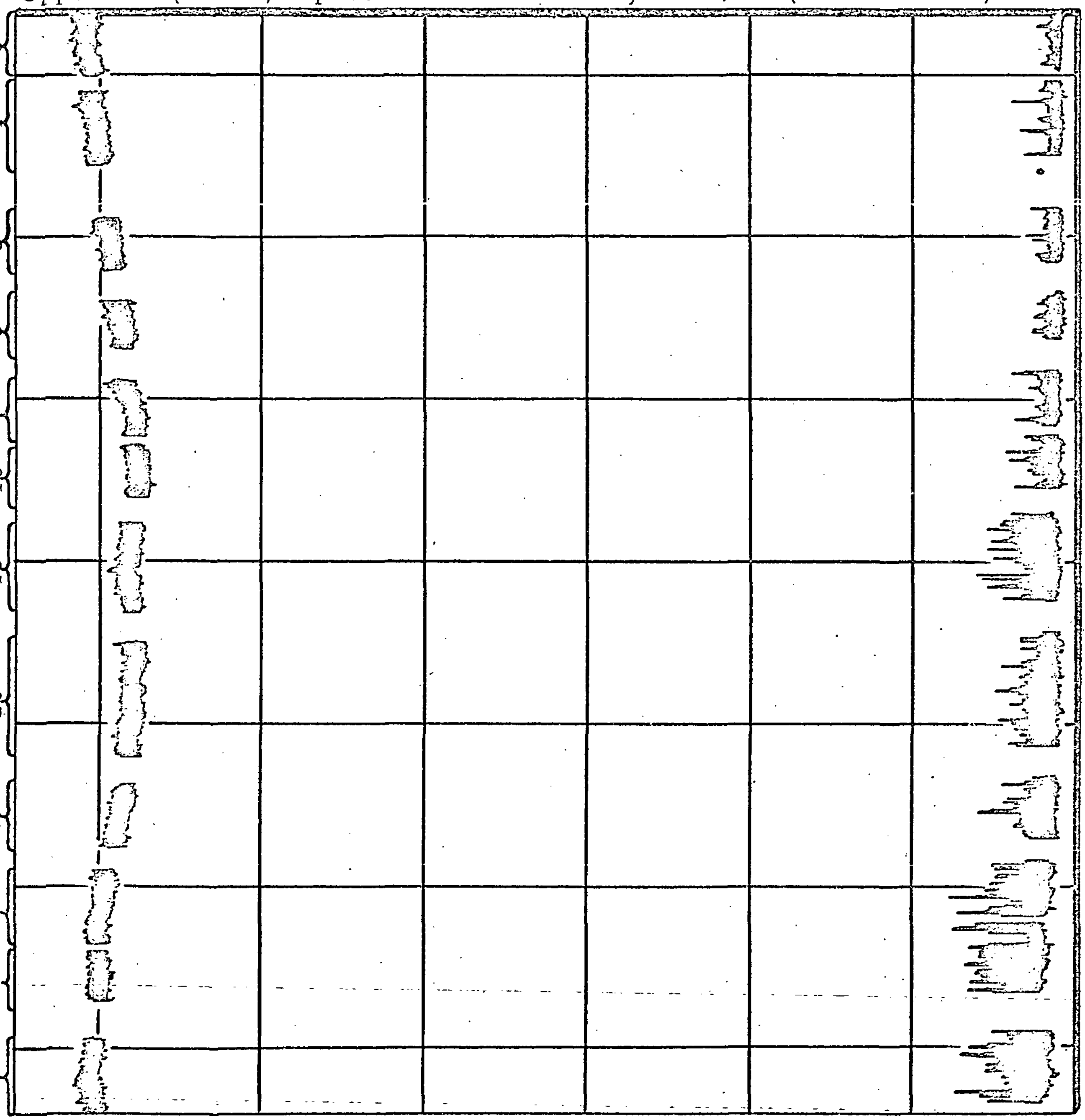
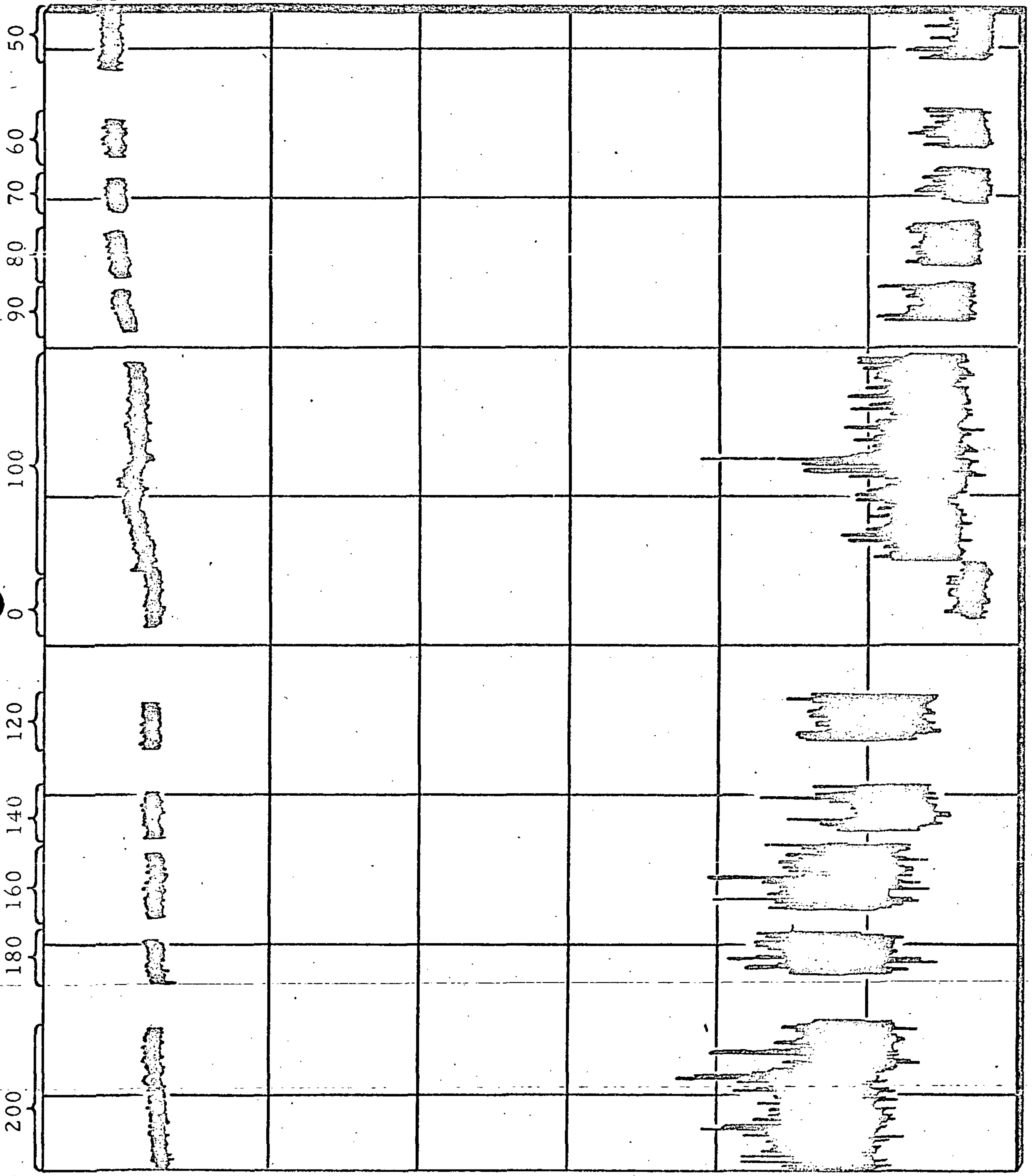


Figure 6. FLD response to fluorescent granules stained with 1.0% Rhodamine WT, from 0 to 40 granules per 1.3 sq. in. (Dec. 16, 1:13 to 1:27 pm, Menlo Park, Calif.)

Upper line (to left) represents solar intensity at 5892 A (relative units)



Vertical lines are time intervals of two minutes
(Numbers above brackets show no. of granules in field of view, at distance of 14 inches)

Lower line (to right) represents fluorescence coefficient (ratio, no units)

Figure 7. FLD response to fluorescent granules stained with 1.0% Rhodamine WT, from 50 to 200 granules per 1.3 square inches (Dec. 16, 1:34 to 1:50 pm Pac. Std. Time, Menlo Park, Cal.)

In terms of percent coverage, three granules can be considered roughly equivalent to 1 percent coverage, 30 granules to 10 percent coverage, and so forth. In terms of size, the average granule apparently has an area between 2.5 and 3.0 square millimeters, or slightly smaller than 1/16-inch square. In terms of distribution, 10 granules within the FOV implies a frequency of about eight granules per square inch, and 30 granules a frequency of about 23 granules per square inch. In terms of spacing, 25 granules within the FOV implies an average spacing of roughly 1/4-inch between granules. We have not calculated these distributions in terms of pounds per acre, but a very rough estimate is that only one granule within the FOV (of 1.3 square inches) is equivalent to approximately 8 to 12 pounds per acre. A rough estimate is that one pound of granules per acre would result in a distribution of about one granule for every 10 to 15 square inches, or one granule per 3- to 4-inch square, which is equivalent to an average spacing of about 3 to 4 inches between granules.

If the foregoing estimates are correct, it is evident that sensitivity of the FLD to the granules used in December is only about one-tenth the bare-minimum sensitivity required for detection of the granules, and about one-hundredth the degree of sensitivity that would be desirable to afford a basis for an efficient survey system. In other words, sensitivity would need to be increased by one or two orders of magnitude.

Mobile ground test in parking lot, Menlo Park, Calif.

Granulated corncobs stained with a 0.5 percent solution of Rhodamine WT were spread in several swaths on an asphalt parking area behind Hangar #20 at the Geological Survey's Office of Marine Geology (old Hiller Aircraft plant), near Dumbarton Bridge, in Menlo Park. The swaths were of two different distributions, corresponding to the two slit-widths of the spreader hopper. The object was to duplicate the conditions of the airborne tests described above, while eliminating indeterminate factors such as the effect of the aircraft prop-wash and the shadowing effect by the grass. This was accomplished by rolling the FLD across the swaths while mounted on casters, as shown in Figure 2.

The granules were traversed at approximately 3:30 pm. No appreciable response to the granules was noted on the FLD strip-chart. It should be noted that granules used in this test were less fluorescent than those used in previous tests, due to near exhaustion of the supply of the darker granules.

CONCLUSIONS AND RECOMMENDATIONS

(1) Granulated corncobs stained with a 1.0 percent solution of Rhodamine WT are detectable by FLD, and the response is roughly proportional to the spacing of the granules.

(2) At a given distance beneath the FLD, the response is roughly proportional to the number of granules within the field of view, provided they are all fully illuminated by sunlight.

(3) However, the response to granules used during the tests was too slight to be of foreseeable use in an efficient system for surveying pesticide coverage.

(4) The sensitivity was such that an increase of one order of magnitude (i.e., about 10-fold) would be required for bare-minimum detection of the granules as they are typically distributed for fire-ant control (approximately one pound per acre). An increase of about two orders of magnitude (i.e., about 100-fold) would be required to provide a workable system.

(5) The granules stained with dye appear to have a hygroscopic character that causes them to absorb moisture, even in dry desert air. This may interfere with uniform flow through a hopper. It is not certain whether this results from addition of the dye, or from the character of the corncobs.

(6) Use of this method for surveying pesticide coverage would require bright sunny weather, a factor that might severely limit its value in the eastern and southeastern United States, where fire-ant control is a problem. Alternatively, it would either be necessary to avoid cloud shadows during such a survey, or to distinguish them from areas lacking pesticide.

(7) The greatest foreseeable problem in successfully using this method would be to differentiate variations in detectable fluorescence due to shadow effects from those due to pesticide coverage. At low sun angles, in vegetated areas, and in areas of rough microrelief (e.g., ploughed fields) the shadow effects are likely to be so great as to preclude use of this method for solid granules, no matter how great the sensitivity.

(8) Therefore it is recommended that the problem of shadow effects be more fully evaluated before further efforts are made to improve sensitivity.

(9) Possible methods for improving sensitivity, that might be considered, include:

(a) increasing dye concentration beyond the 1.0 percent limitation in tests to date;

(b) using other fluorescent dyes, including other rhodamine dyes;

(c) using other fluorescent powders and pigments, including those used in making yellow and orange fluorescent spray paints, inks, and papers;

(d) determining whether the time interval after dyeing, or the method of dyeing, are factors related to sensitivity; and

(e) modifying the FLD for greater efficiency, increased field of view, or larger optics.

(10) A possible method for solving some of the problems of weather, sun angle, shadow effects, and possibly sensitivity is the use of a laser beam for stimulation of fluorescence. Further consideration or experimentation with this method is recommended.

(11) Further consideration might be given to use of the FLD in surveying coverage of sprayed pesticides, as this would eliminate some of the problems of shadow effects and should result in a much greater exposure to solar illumination per unit weight of the deposited material.

ACKNOWLEDGMENTS

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