# Herbicide Incorporation Analysis Using Computer Vision

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## ABSTRACT

A procedure using computer vision and fluorescent dye was developed to determine the incorporation characteristics of tillage tools. It was assumed that the fluorescent dye represented herbicide and would be displaced in a similar manner as herbicide applied to the soil. Image processing was used to store and analyze the incorporation profiles.

The Kolmogorov-Smirnov statistical test was used to quantitatively compare incorporation profiles. The procedure was very quick and accurate.

## INTRODUCTION

Effective weed control is essential for profitable crop production. Herbicides can help provide this weed control when selected and applied properly. Proper use includes uniform application and, for some herbicides, uniform incorporation. Uniform incorporation maximizes the probability of weeds coming into contact with the herbicide and reduces crop damage due to high concentrations of the herbicide. Incorporation minimizes herbicide volatilization and photodecomposition. Environmental contamination due to herbicide in rainfall runoff is also reduced by incorporating the herbicide into the soil.

Uniform placement of herbicides in the soil results in the use of less chemical to control weeds and thus decreases weed control costs. Savings in money, energy, and time are direct benefits of uniform herbicide incorporation.

Two incorporation passes are commonly used to improve the uniformity of herbicide incorporation (Schafer et al., 1984). Single pass incorporation can result in non-uniform placement of the herbicide (Thompson et al., 1981), causing streaked weed control. Associated high concentrations of herbicide can cause crop injury. Subjective, qualitative procedures have been used previously to determine the uniformity of herbicide incorporation.

The objective of this research was to develop a quick and accurate procedure to quantitatively analyze the uniformity of herbicide incorporation in the soil. This procedure will be used in subsequent research to determine the operating parameters that result in uniform herbicide incorporation.

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## LITERATURE REVIEW

### Tracing Techniques

An accurate method must be used to trace and analyze the location of the herbicides after incorporation. Thompson et al. (1981) used a fluorescent dye and blacklights to trace soil displacement by tillage tools. Visual comparisons were made of the resulting dye distributions in the soil profiles.

Bode and Gebhardt (1969) extracted trifluralin and analyzed samples with a gas chromatograph. Wauchope et al. (1977) used copper sulfate as a tracer and analyzed soil cores with atomic absorption spectrophotometry.

Ladd and Futral (1966) used iron filings and iron balls as tracers and recovered them with a magnet after incorporation. Tollner et al. (1986) used X-rays to view soil displaced by a tool. Soil failure cracks and differences in soil reactions due to moisture content could be viewed. Williford et al. (1968) incorporated fluorescent tracers and extracted the tracers from soil samples. The resulting extracts were analyzed with a fluorometer.

Hulbert and Menzel (1953) incorporated a radioactive phosphate tracer into the soil. Implement incorporation characteristics were determined by phosphate levels. Sorghum grain was also used as a tracer in other experiments. A coefficient of variation was used to describe uniformity of the tracer incorporation. James and Wilkins (1965) incorporated radioactive glass spheres. A scanning mechanism gave quantitative results by detecting the radioactive spheres.

Matthews (1970) extracted chloride tracers following incorporation. Numbered wood blocks (Gill, 1969) and pins placed in the soil have also been used. Salyani and Bowen (1983) incorporated dye coated sand particles into the soil and manually digitized black and white photographs of soil cross-sections.

These procedures used by previous researchers took from one hour to four days to analyze one soil cross-section.

### Analysis Techniques

Smith (1955) used a mixing coefficient, expressed as the ratio of the standard deviation at zero mixing to the observed standard deviation of spot samples after mixing. Read et al. (1968) used an analysis of variance to evaluate the uniformity of tracer incorporation.

Sistler et al. (1982) developed a method to analyze cards containing droplets from aerial application patterns. An image analyzer gave the areas and diameters of droplet images, counted the number of droplets, and calculated the number of droplets per unit area.

Salyani and Bowen (1985) developed a procedure to express the uniformity of dispersion of soil amendments quantitatively. The method accounts for the effects of spacing, location, and symmetry of points.

## HERBICIDE TRACING INVESTIGATIONS

Available methods of tracing the herbicide displacements were examined for accuracy, cost, and efficiency. Use of X-rays of a tracer were studied initially. It was proposed that a portable X-ray unit could be taken to the field and a metallic tracer distribution measured without disturbing the soil. Variations in the soil profile due to air pockets, non-uniform bulk density, and distortion due to projection of the image on the X-ray plates made identification of the tracers difficult. Each X-ray plate cost about $25. Thus, the X-ray method was determined to be inaccurate and expensive.

Water soluble fluorescent dyes were then examined. Thompson et al. (1981) showed that the incorporation pattern of fluorescent dye when applied to soil was similar to the incorporation pattern of herbicides. Fluorescent dyes were applied to the soil surface, incorporated, and titrated with methanol or ethanol. The resulting solution was analyzed using a fluorometer to determine the amount of dye extracted from a soil section. The amount of dye extracted was inconsistent with amounts varying from 20% to 80% and the procedure was very time consuming. Analysis of a single incorporation profile required up to 10 h to sample, titrate, and analyze. Therefore, this method was not used to analyze incorporation profiles in this study.

Powdered dyes were then examined. Red, green, or blue Day-Glo fluorescent powdered dyes were spread on the soil surface and incorporated. A soil cross-section was cut and fluoresced with two filtered General Electric F20T12-BLB blacklights. If more than one dye color was present, matching Kodak Wratten gelatin filters isolated one color at a time. The spectral curves of the dyes were matched to the spectrophotometric absorption curves of the filters. A No. 61 green, No. 92 red, or No. 98 blue filter was used to isolate green, red, and blue dye, respectively, while filtering out all other colors. The filters were placed in a 58 mm Kenko technical filter holder.

The resulting profiles were recorded using both 35 mm Ektachrome film (ASA 200) and a Sony Trinicon HVC-2800 video camera with a SLO-340 videocassette $\beta$1 recorder. Photographs were taken with a 50 mm f/1.4 lens with exposure times of 5, 10, 20, and 30 s at a distance of 90 cm. Videos were taken with the aperture set completely open at all times. A visual assessment of the recording procedures was made. The 5 s exposure of the 35 mm film showed the most representative profile when compared to the other exposure times. The profiles on the photographs were then compared to those on video and to the actual cross-section. The video camera consistently gave results that visually most closely matched the actual cross-section. Use of the video camera proved to be a fast, accurate, and economical method for recording soil profiles. Thus, this method was used to record cross-sections in the incorporation tests.

## VIDEO DATA COLLECTION PROCEDURES

The procedures used to record the cross-sections were developed in a soil bin at Deere & Company Technical Center, Moline, IL and in the field at the Agricultural Engineering Research Farm, University of Illinois, Urbana, IL. Powered fluorescent dyes and a video camera were used to record the incorporation characteristics of tillage tools.

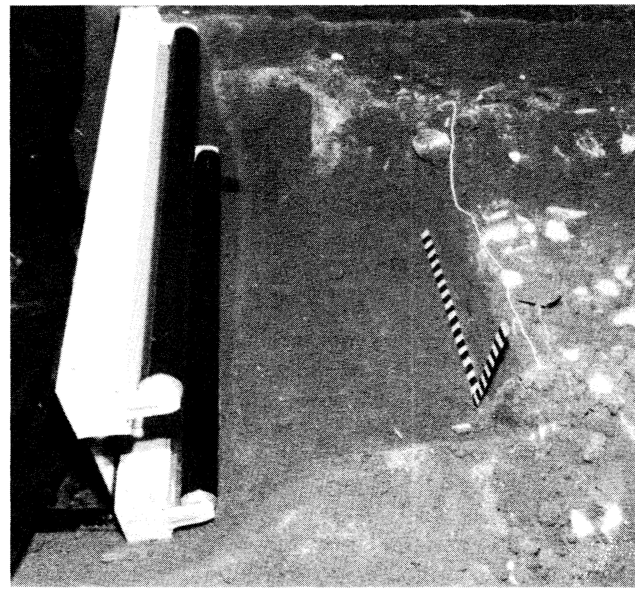

**Fig. 1—Blacklights used to fluoresce incorporated dye in an excavated cross-section.**

A fluorescent dye was spread on the soil surface and then incorporated. A plexiglass plate was inserted into the soil and the soil cleared from the front of the plate. The plate was removed along with the dye that had been smeared as the plate was inserted. A vertical and horizontal axis containing 1 cm increments were placed along the right and lower sides of the profile. Fluorescent markers were used to mark the original soil surface and where the tool shanks had passed through the soil. A fluorescent string marked the soil surface after incorporation. The filtered blacklights and video camera were then positioned, Fig. 1. A black plastic cover was placed over the cross-section and blacklights to eliminate visible light. The camera lens was placed through a hole in the plastic and focused. Five counts on the video recorder were recorded of the axes and a tag showing the test number. A filter, if needed, was then placed over the lens and 10 additional counts filmed. Two additional replications of cross-sections were then cut and filmed. The excavated soil was then replaced and the procedure repeated for additional tests.

Single and multiple shank incorporation tests were run with a 15 cm medium crown sweep at spacings of 10, 15, and 20 cm and speeds of 6.4, 9.6, and 12.9 km/h. Tool depth was set at 7.6 cm for all tests. Multiple shanks were set up with 9 shanks on 3 rows of the cultivator. About one minute of video tape for each cross-section was recorded in the field.

## IMAGE PROCESSING AND STORAGE

Cross-sections filmed in the field were later analyzed using a PC/AT based computer vision system. The essential parts of the system consist of the computer, a PCVision Frame Grabber hardware board, and accompanying software produced by Imaging Technologies. A library of software routines was also obtained from Imaging Technologies which allows the user to program routines to control the image processing steps. User written routines read and analyzed the incorporation profiles from the video tape. Continuous footage of one cross-section was read from the video cassette tape and viewed in the video monitor of the image system until the image stabilized. The digitized image was then captured and stored on disk by the computer vision system. Another cross-section was then viewed and the process repeated until all recorded field data were transferred from video tape to disk files.

The stored cross-sections were later retrieved and analyzed. Routines were written to threshold the digitized image at an appropriate grey level to remove noise from the image. Another routine enabled the section to be further cleaned up by allowing the user to erase selected areas in the image. This resulted in an image containing only the dye particles and, if desired, the string marking the surface of the soil. Thresholding of the digitized cross-section occurred while comparing it to the actual cross-section viewed on a separate video monitor. This minimized removal of dye particles mistaken as noise in the digitized cross-section. Plots of the coordinates of the dye particles, using a computer spreadsheet, provided a hard copy of the resulting soil cross-section.

Statistical procedures were then performed on the digitized cross-section or on the coordinates of the dye particles stored on disk. A cross-section of soil can be transferred to disk and analyzed in less than 5 min.

## STATISTICAL ANALYSIS

A statistical procedure resulting in accurate quantitative values to compare the cross-section is desired. Calculation of a dispersion index described by Salyani and Bowen (1985) was used initially to compare the cross-sections. However, large isolated clusters of dye, typical for this research, were not accounted for. This method gave inconsistent values for the profiles analyzed in this research and was not used for further analysis.

Other statistical procedures were then evaluated on trial soil sections in an attempt to develop a statistical method for analysis of incorporation profiles. Computer programs written in "C" programming language were used to analyze data obtained from the vision system. The mean of the cross-sections, calculated by dividing the total number of dye particles by the area of the cross-section, gave an indication of the amount of dye particles but not the distribution.

In another analysis, the soil cross-section was divided into 2 cm to 0.02 cm square increments and the variance of the number of dye particles in each increment was calculated. This method did not account for clusters in the incorporation profile. A profile with evenly placed concentrations of dye could have the same variance as one with isolated concentrations. It could not be determined if a large variance was due to non-uniform vertical or horizontal distributions.

It was then decided to analyze the profiles for vertical and horizontal distributions separately. For horizontal

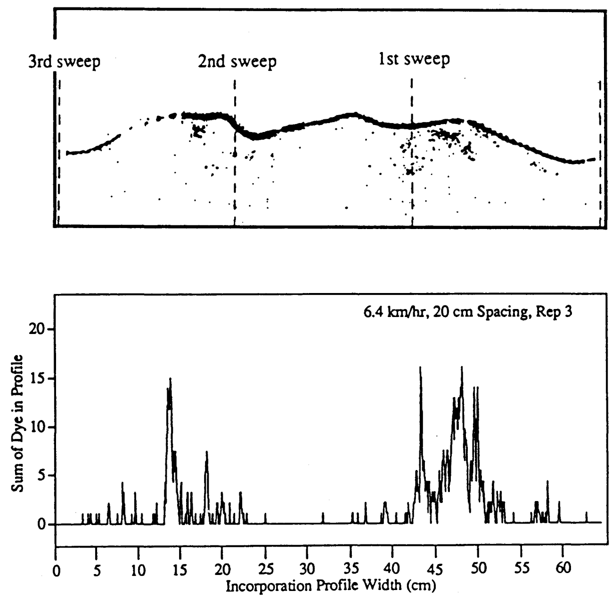


**Fig. 2—Horizontal wave form derived from a profile incorporated at 6.4 km/h with 15 cm sweeps on 20 cm spacings.**

distribution, the number of dye particles were summed in each vertical section of 0.05 cm in width. The total number of dye particles in each vertical section was plotted versus horizontal distance resulting in a wave form, Fig. 2. Vertical distributions were analyzed similarly. The centroid of the vertical wave form gave an indication of the depth of incorporation.

The Kolmogorov-Smirnov (K.S.) two-sample test (Steel and Torrie, 1980) provides a method of comparing the wave forms of different incorporation profiles. The K.S. test is a non-parametric statistic that compares the distributions rather than the parameters. It can test for differences in the location of dye particles and for differences in the variances of two incorporation profiles. The test compares the wave forms from two incorporation profiles and determines, within a specified level of confidence, if the two incorporation profiles came from the same parent incorporation profile.

Two comparisons can be made with the K.S. method. First, each wave form can be compared with its mean. The mean of the wave form represents how the wave form would look if the dye were perfectly distributed. The resulting test statistic gives an indication of the variability in an incorporation profile. Second, each wave form can be compared with another wave form. The probability that both of these wave forms came from the same distribution can be calculated. This test can be performed separately on the wave forms resulting from the horizontal and vertical distributions of dye.

The procedure used in the K.S. test is to first rank all observations together. Sample cumulative distribution functions are then calculated and the maximum difference (Dmax) in the sample distribution functions computed. Dmax is then compared to a calculated critical value at a chosen level of significance to determine if there is evidence to support the null hypothesis that the two samples come from the same parent distribution. Sample comparisons are shown in Table 1.

TABLE 1. KOLMOGOROV-SMIRNOV, TWO-SAMPLE STATISTICAL TEST RESULTS FOR PROFILES INCORPORATED WITH 15 cm SWEEPS ON 15 cm SWEEP SPACINGS

| Speed, km/h | Comparison rep | vs speed, km/h | Rep | Dmax | Critical value at $\alpha = 0.01$ |
|---|---|---|---|---|---|
| 6.4 | 1 | 6.4 | 2 | 0.033 | 0.075 |
| 6.4 | 1 | 6.4 | 3 | 0.042 | 0.075 |
| 6.4 | 2 | 6.4 | 3 | 0.051 | 0.075 |
| 9.6 | 1 | 9.6 | 2 | 0.038 | 0.077 |
| 9.6 | 1 | 9.6 | 3 | 0.063 | 0.076 |
| 9.6 | 2 | 9.6 | 3 | 0.028 | 0.075 |
| 12.9 | 1 | 12.9 | 2 | 0.036 | 0.074 |
| 12.9 | 1 | 12.9 | 3 | 0.042 | 0.074 |
| 12.9 | 2 | 12.9 | 3 | 0.054 | 0.074 |
| 6.4* | | 9.6 | 1 | 0.084† | 0.076 |
| | | 9.6 | 2 | 0.095† | 0.075 |
| | | 9.6 | 3 | 0.089† | 0.075 |
| 9.6* | | 12.9 | 1 | 0.067 | 0.075 |
| | | 12.9 | 2 | 0.053 | 0.075 |
| | | 12.9 | 3 | 0.072 | 0.075 |

*Values averaged over replications.
†Comparisons are significantly different at $\alpha = 0.01$

The data in Table 1 shows that the replications came from the same parent distribution, which is expected if measurements are within experimental error. Further analysis shows that there is little difference in the 9.6 km/h and 12.9 km/h profiles, but that there are differences in the 6.4 km/h and 9.6 km/h profiles. These results indicate that tool speed has a highly significant ($\alpha = 0.01$) effect on herbicide incorporation as speed is increased from 6.4 km/h to 12.9 km/h. A similar analysis can be conducted to determine the effect of sweep spacing on the uniformity of herbicide incorporation.

The K.S. method appears to be the best method for comparing the incorporation profiles of tillage tools. With this method, all incorporation profiles can be compared against an ideal incorporation profile and a test of significance performed. Also, two incorporation profiles can be compared to see if the profiles are the same, within a specified level of significance. Additional details of these procedures are given in Dowell (1988).

## SUMMARY AND CONCLUSIONS

A procedure was developed to determine the location of a fluorescent dye when incorporated into the soil by a tillage tool. A video camera was used to determine the location of a surface applied dye after being incorporated. It was assumed that the fluorescent dye represented herbicide and would be displaced in a similar manner as herbicide applied to soil. Image processing was used to store and analyze the incorporation profiles. The procedure was very quick and accurate and will be used in subsequent incorporation tests.

Several statistical procedures were examined to analyze the incorporation profiles. The Kolmogorov-Smirnov statistical test provides a quantitative method for comparing the profiles.

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