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CULTIVATOR SPEED AND SWEEP SPACING EFFECTS ON HERBICIDE INCORPORATION

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SUMMARY:

The effect of tool speed, sweep spacing, and sweep size on the incorporation of herbicides was studied. Image processing was used to record the distribution of incorporated fluorescent dye. Incorporation profiles were statistically analyzed. Windrowing, or non-uniform dye placement, occurred at narrow sweep spacings and high tool speeds.

KEYWORDS:

Chemicals, Cultivators, Herbicides, Tillage, Vision

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CULTIVATOR SPEED AND SWEEP SPACING EFFECTS ON HERBICIDE INCOPORRATION

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ABSTRACT

The effect of tool speed, sweep spacing, and sweep size on the incorporation of herbicides by a field cultivator was studied. A system using image processing was developed to quickly and accurately record the distribution of fluorescent dye, which represented the herbicide, after incorporation into the soil. A quantitative statistical procedure was developed to analyze the incorporation profiles. Windrowing, or non-uniform dye placement, occurred at narrow sweep spacings and at high tool speeds.

INTRODUCTION

Herbicides are commonly used to control weeds. However, if herbicides are not used properly, poor weed control and crop injury can occur. Proper use includes uniform application and, for some herbicides, uniform incorporation into the soil. Uniform incorporation maximizes the probability of weeds coming into contact with the herbicide and reduces crop damage due to high concentrations of the herbicide (Whitehead et al., 1968, Talbert and Frans, 1968, Collier et al., 1975). Incorporation minimizes herbicide volatilization and photodecomposition (Savage and Barrentine, 1969). Environmental contamination due to herbicide in rainfall runoff is also reduced by incorporating the herbicide into the soil (Baker and Laflen, 1979).

In 1985, 11.7 million acres of corn and 9 million acres of soybeans were planted in Illinois. Herbicides were applied to 99% of the corn acres, with 39% of these herbicides incorporated once and 14% incorporated twice. Of the soybean acreage, 97% received a herbicide application, with 25% incorporated with one tillage pass and 33% incorporated with two passes (Pike, 1985). Two tillage passes are commonly used to attempt to uniformly incorporate herbicides (Schafer et al., 1984). Single pass incorporation can result in non-uniform placement of herbicide in the soil profile (Thompson et al., 1981).

It was hypothesized that at certain combinations of sweep spacings, tool speeds, and sweep sizes, the herbicide would be windrowed across several sweeps. This phenomena would leave the herbicide concentrated in one area of the incorporation profile (Figure 1).

The objective of this research was to determine if windrowing occurs. If windrowing does occur, operating parameters will be recommended that result in the most uniform incorporation profiles for the variables tested in this research. The effect of tool speed, sweep spacing, and sweep size on herbicide placement was studied by viewing fluorescent dye concentrations after the dye was incorporated. The fluorescent dye simulated the herbicide.

LITERATURE REVIEW

Field cultivators are popular incorporation tools among farmers because of their advantages over other types of tools. Among these advantages are the ability to create a more desirable seed bed than discs, lower power requirements when compared to powered tillers, and more residue can be

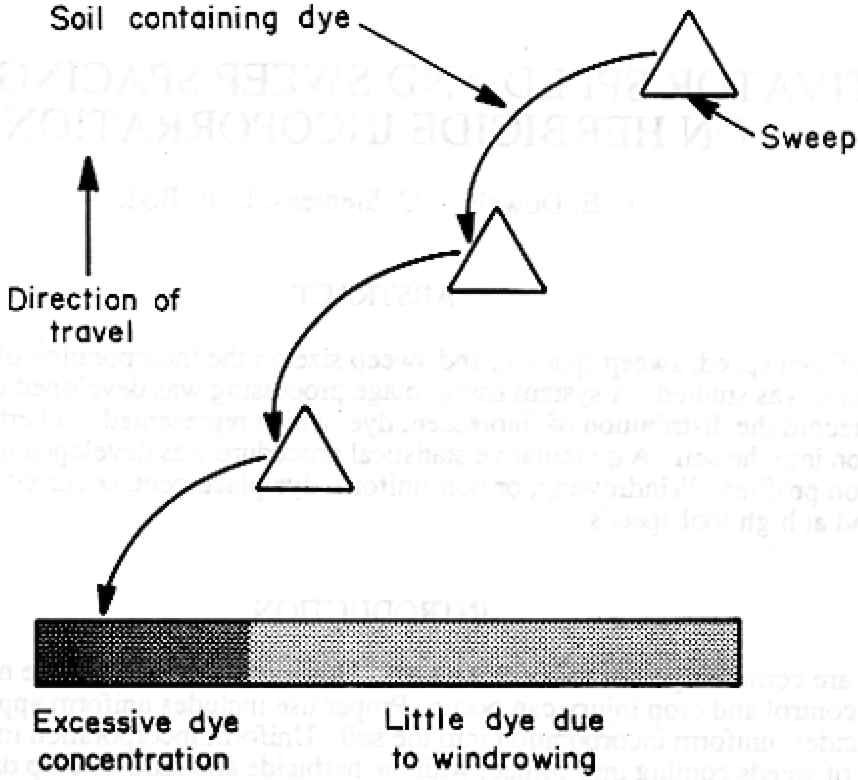


Figure 1. Dye concentration due to windrowing.

handled when compared to harrows. However, field cultivators do not always incorporate herbicides uniformly.

Siemens and McGlamery (1985) reported that poor weed control in their research was probably due to non-uniform herbicide incorporation by one pass of a field cultivator. Bode et al. (1979) showed areas of herbicide concentrations in the field when a cultivator was used to incorporate chemicals. The herbicide concentrations were alleviated by a second incorporation pass at an angle to the first. Bode and Gebhardt (1969) observed nonuniform vertical incorporation with a field cultivator.

King (1965) noted that field cultivators require two passes for uniform incorporation. Operating faster than 8 km/hr tended to concentrate herbicide between the tool sweeps. Hulbert and Menzel (1953) determined that at least two incorporation passes of a field cultivator were required for uniform placement of tracers below the soil surface.

For uniform incorporation with a field cultivator (Kempen, 1981), two passes were needed at 8 to 9.6 km/hr followed by a drag harrow or other leveling device. Faster speeds increased herbicide streaking from a single pass. The optimum incorporation speed range was given by Thompson et al. (1981) as 7 to 12.8 km/hr. Horizontal distribution was erratic after one pass, even when followed by a drag harrow. Large sweeps worked better in moist conditions. As sweep size increased from 5 to 30 cm, the largest concentrations of dye tended to be deeper in the soil. Prior research has shown that uniform incorporation can not be achieved with one pass of a field cultivator. However, a single pass, instead of two passes, is desired to minimize input costs. Additional research is needed to improve the incorporation of herbicides by field cultivators.

PROCEDURES

Fluorescent dye coated granules, representing herbicides, were incorporated in the field and in a soil bin. After incorporation, a cross-section was cut into the soil. The cross-section was then fluoresced and recorded on video tape. The video tape was then analyzed using a computer image analysis system. The profiles were converted to wave forms and analyzed for vertical and horizontal uniformity using the Kolmogorov-Smirnov (K.S.) two sample statistical test. Details of the procedures were discussed by Dowell (1988).

The effects of tool speed and sweep spacing on windrowing was studied in a soil bin by incorporating fluorescent dye with one sweep and examining the incorporation profile. A second sweep, spaced over a specified amount, incorporated dye at the same speed as the first sweep. The incorporation profile was then viewed to see how the selected speed and spacing affected the dye windrowing. A third sweep, run at the same speed and spacing as the second sweep, incorporated additional dye. The profile was then viewed again. This procedure simulated how a three row cultivator incorporated dye.

Windrowing was studied in the field by viewing profiles after incorporating dye with nine sweeps. Tool speed, sweep size, and sweep spacing were the variables analyzed. All tests are listed in Table I.

RESULTS AND DISCUSSION

The effect of tool speed, sweep spacing, and sweep size on deviations from an ideal incorporation profile are reported. An ideal profile has dye perfectly distributed horizontally and vertically in the incorporation profile. It was desirable to find a speed range, spacing range, and sweep size which resulted in a profile that most closely approximated an ideal incorporation profile. Tests were run in a soil bin and in the field.

Table I. Tests used to determine the effect of sweep spacing, tool speed, and sweep size on herbicide incorporation.

Test*	Location	Number of Sweeps	Spacing (cm)	Speed (km/hr)	Sweep Size (cm)
Jan. 5	Deere & Co. Tech. Center	1, 2, and 3	10, 15, 20	6.4, 9.6, 12.8	15
April 9	Univ. of Il.	1	-------	6.4, 9.6, 12.8	15
May 9	Univ. of Il.	9	15	6.4, 9.6, 12.8	15
May 29	Univ. of Il.	9	10, 15, 20	6.4, 9.6, 12.8	15
July 17	Univ. of Il.	9	15, 23, 30	6.4, 9.6, 12.8	23

* All tests were run at a depth of 7.6 cm.

Soil Bin Tests

Figure 2, derived from the January 5 soil bin tests, shows the relationship of the soil and dye displaced by a leading sweep to the spacing of a following sweep for different speeds. It is evident from the figure that as the spacing of the following sweep decreases, less soil and thus, less dye can be moved back into the furrow created by the leading sweep. If the following sweep does not move the soil and dye into the leading sweep furrow, then it is being windrowed over to the next following sweep. Thus, it is expected that windrowing of the dye increases with a decrease in sweep spacing.

The increase in the distance that the dye was displaced, due to an increase in tool speed, is also shown in Figure 2. This increase in displacement results in an increase in the amount of soil that was moved past the center of the following sweep, thus windrowing of the dye is expected to increase with an increase in tool speed.

The percent of the total amount of soil thrown out of the furrow by the leading sweep that can be replaced in the first furrow by the following sweep is shown in Figure 3. This figure indicates how much of the soil and dye can be windrowed over to the next sweep. The graph indicates that there are large differences in the amount of soil that can be replaced in the furrow, and thus not windrowed, as tool speed increased from 6.4 km/hr to 9.6 km/hr or from 6.4 km/hr to 12.8 km/hr. As tool speed was increased from 9.6 km/hr to 12.8 km/hr, little differences in the amount of dye that can be replaced in the furrow occur. Since higher tool speeds were not moving soil and dye back into the previous furrow, the soil and dye was being windrowed over to the following sweep. Figure 3 also shows that as sweep spacing decreases, the amount of soil that can be replaced into the previous furrow decreases. This indicates windrowing increases with a decrease in spacing. Figure 3 was derived from the January 5 and April 9 tests by measuring the amount of soil displaced from the furrow.

The January 5 tests showed that a decrease in spacing caused windrowing to increase. The narrow 10 cm spacings showed dye concentrations in the left half of the profile created by two sweeps (Figure 4). If little or no windrowing occurred, dye would be evident in the right half of the furrow. The wider 20 cm spacing profiles for two sweeps showed dye in the right half of the profiles where the dye from the first furrow was moved back into the first furrow by the second sweep and not windrowed (Figure 5).

The effect of speed on windrowing was seen with the 15 cm spacing in the January 5 tests. At 6.4 km/hr and 9.6 km/hr,the third sweep was able to move soil back into the furrows created by the first and second sweeps (Figure 6). However, as tool speed was increased to 12.8 km/hr, virtually no dye was placed in the profile (Figure 7). This resulted because at high tool speeds, the soil containing the dye was displaced past the center line of the second and third sweeps, causing the dye to be windrowed out of the soil profile. The dye would be concentrated in an area outside of the excavated profile shown.

The 20 cm spacing showed that windrowing did not occur at any speeds tested in the January 5 tests. Differences in the profiles were observed, however. A tool speed of 6.4 km/hr was not fast enough to break out a large enough furrow to ensure an even horizontal placement of the dye. Pockets of dye can be observed corresponding to the furrows formed (Figure 8). Corresponding areas of undisturbed soil containing no dye can also be seen. A larger furrow formed by increasing the tool speed to 12.8 km/hr enables a more even dye distribution (Figure 9).

The January 5 soil bin tests showed the progressive effects of windrowing for one, two, and three sweeps as tool speed increased and sweep spacing decreased. Further testing was done in the field using nine sweeps on a three row cultivator.

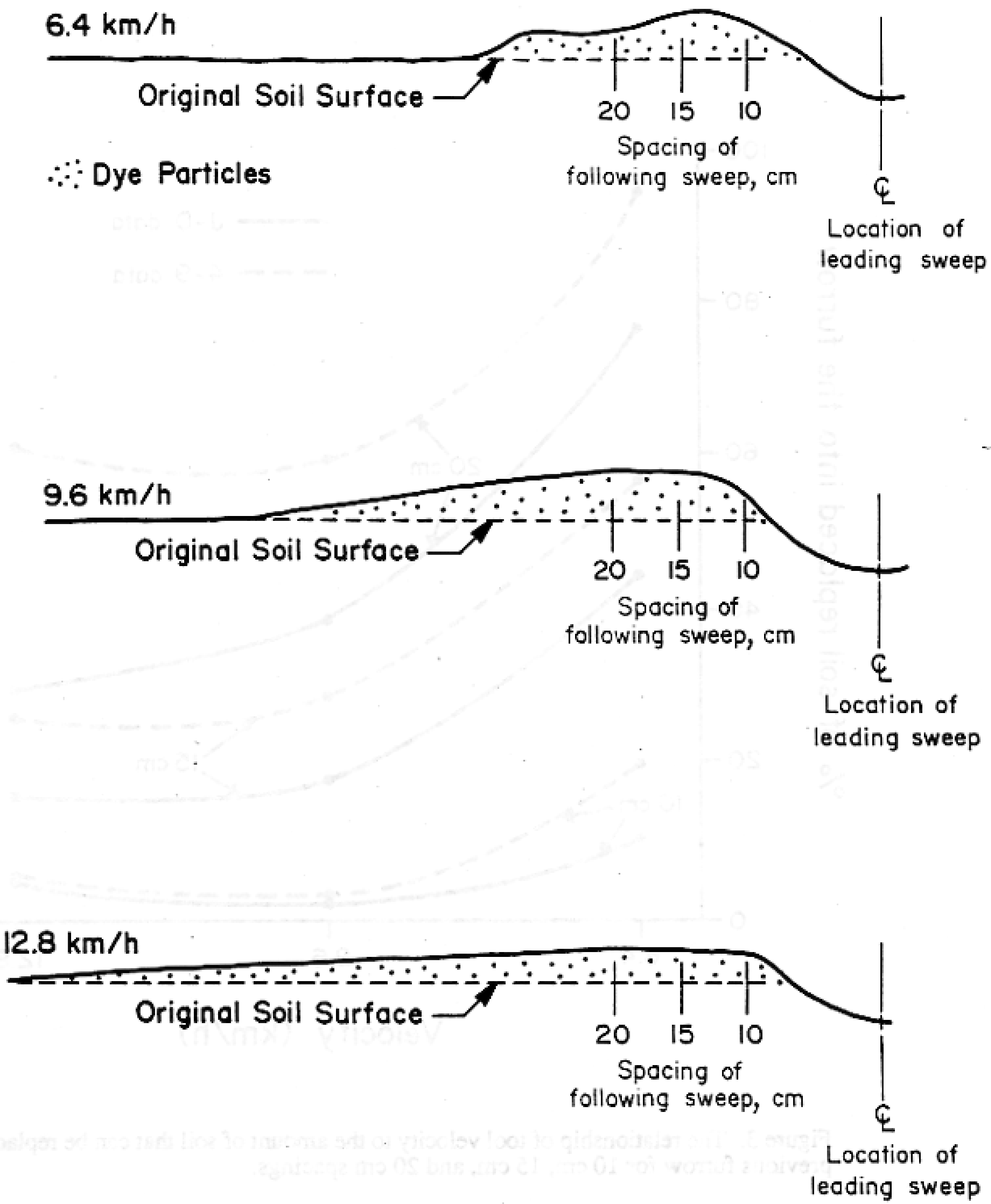


Figure 2. Relationship of the furrow formed by a leading sweep to the spacing of a following sweep.

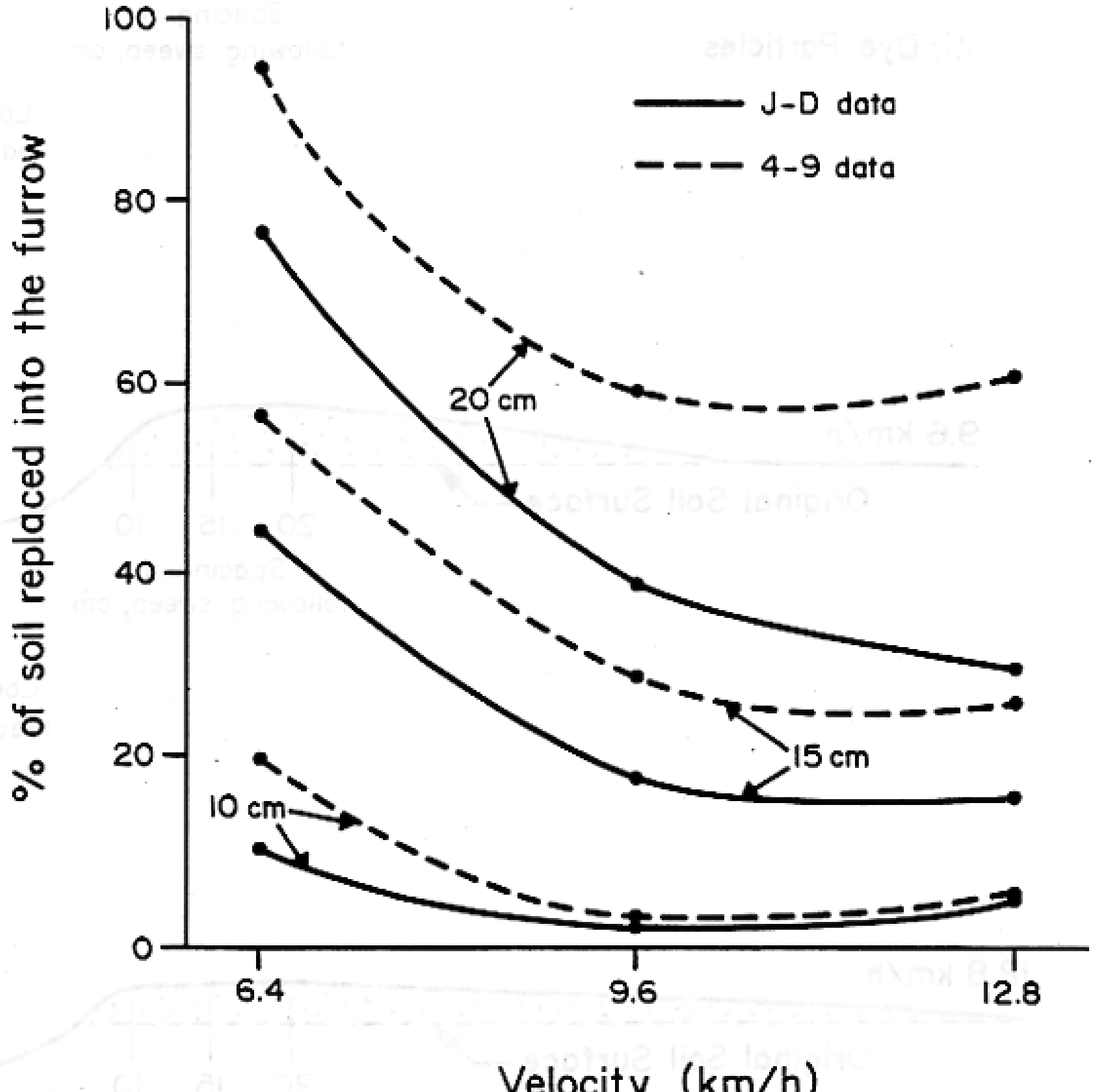
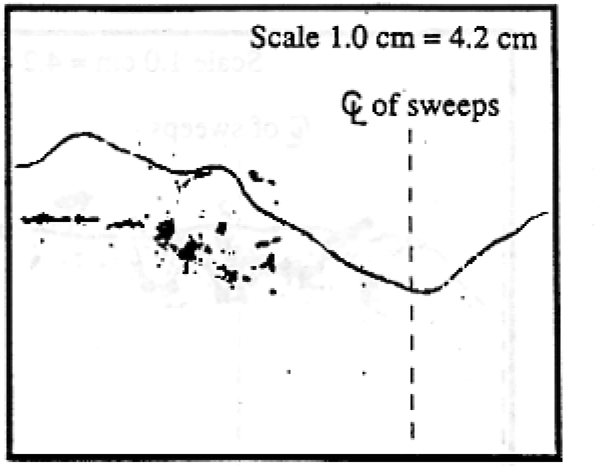
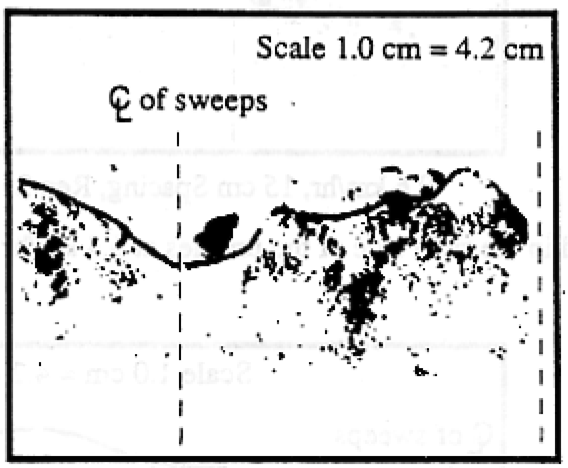


Figure 3. The relationship of tool velocity to the amount of soil that can be replaced into the previous furrow for 10 cm, 15 cm, and 20 cm spacings.



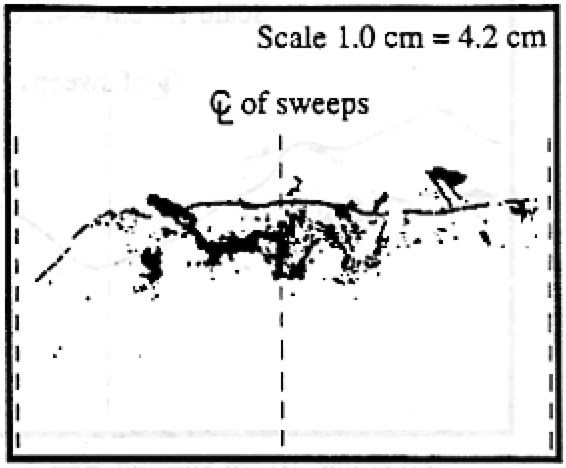
9.6 km/hr, 10 cm Spacing, Rep 2

Figure 4. Dye concentrations in the left sides of the profile due to windrowing (January 5 tests, 2 sweeps).



6.4 km/hr, 20 cm Spacing, Rep 1

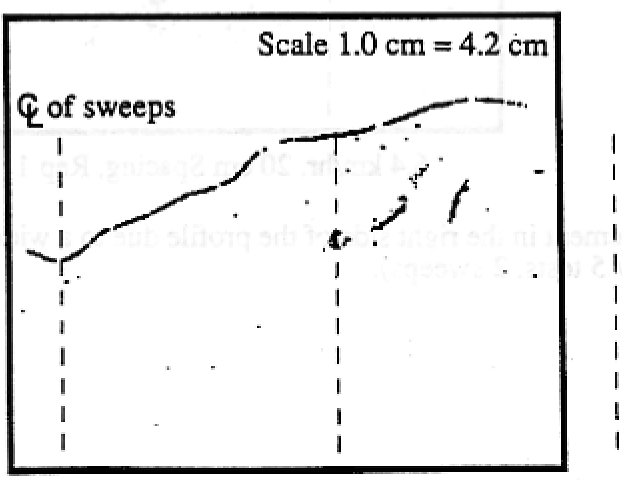
Figure 5. Dye placement in the right side of the profile due to a wide sweep spacing and a slow tool speed (January 5 tests, 2 sweeps).



6.4 km/hr, 15 cm Spacing, Rep 2

9.6 km/hr, 15 cm Spacing, Rep 2

Figure 6. Dye replaced in the right side of the profiles at 6.4 km/hr and 9.6 km/hr (January 5 tests, 3 sweeps).



12.8 km/hr, 15 cm Spacing, Rep 2

Figure 7. Dye windrowed out of the profile at 12.8 km/hr (January 5 tests, 3 sweeps).

Effect of Tool Speed

The effect of tool speed (6.4, 9.6, and 12.8 km/hr) on furrow formation and the uniformity of dye incorporation was studied. Furrow formation effects how the dye will be placed in the incorporation profile and will be discussed first.

The tool sweeps were staggered on three rows (Figure 10), thus the depth of the furrow formed by the leading sweeps (sweeps 1, 4, and 7) influenced how deep soil and dye displaced from the

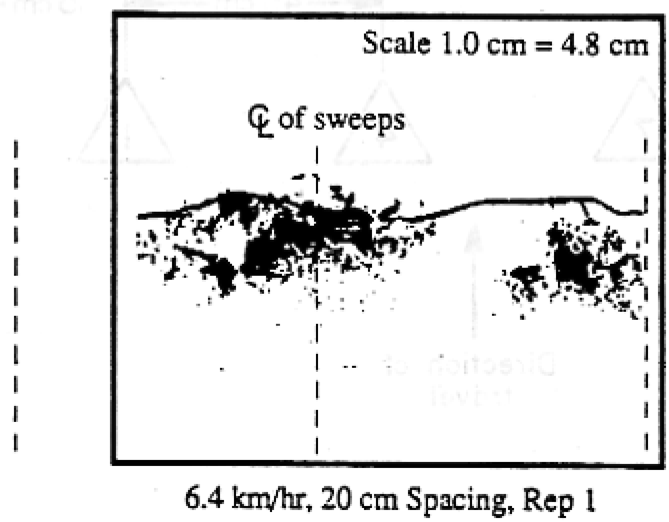


Figure 8. Dye concentrations at slow speeds corresponding to sweep furrows (January 5 tests, 3 sweeps).

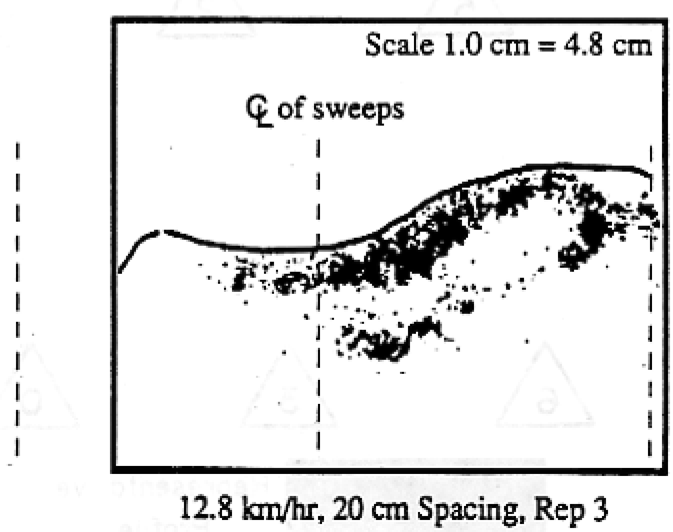


Figure 9. Dye incorporated at 12.8 km/hr which is more uniformly distributed than dye incorporated at 6.4 km/hr (January 5 tests, 3 sweeps).

following sweeps will be placed in the profile. Furrow formation was studied by taking measurements in the field and from video tape. Figure 11 shows the measurements recorded in Table II.

Measurements from the single sweep tests showed that most peak to peak, peak to furrow bottom, and furrow depth from the original ground surface measurements increased with tool speed. Thus, as tool speed increased, a larger furrow was formed due to more soil being displaced by the tool. The increased velocity imparted to the soil as tool speed increased displaced the soil further from the furrow, not allowing the soil to fall back into the furrow. The resulting furrow is deeper, and as trailing sweeps move soil and dye back into the furrow, the soil and dye will be placed deeper in the soil profile. Deeper placement of dye is shown in actual cross-sections taken from the field and is discussed below.

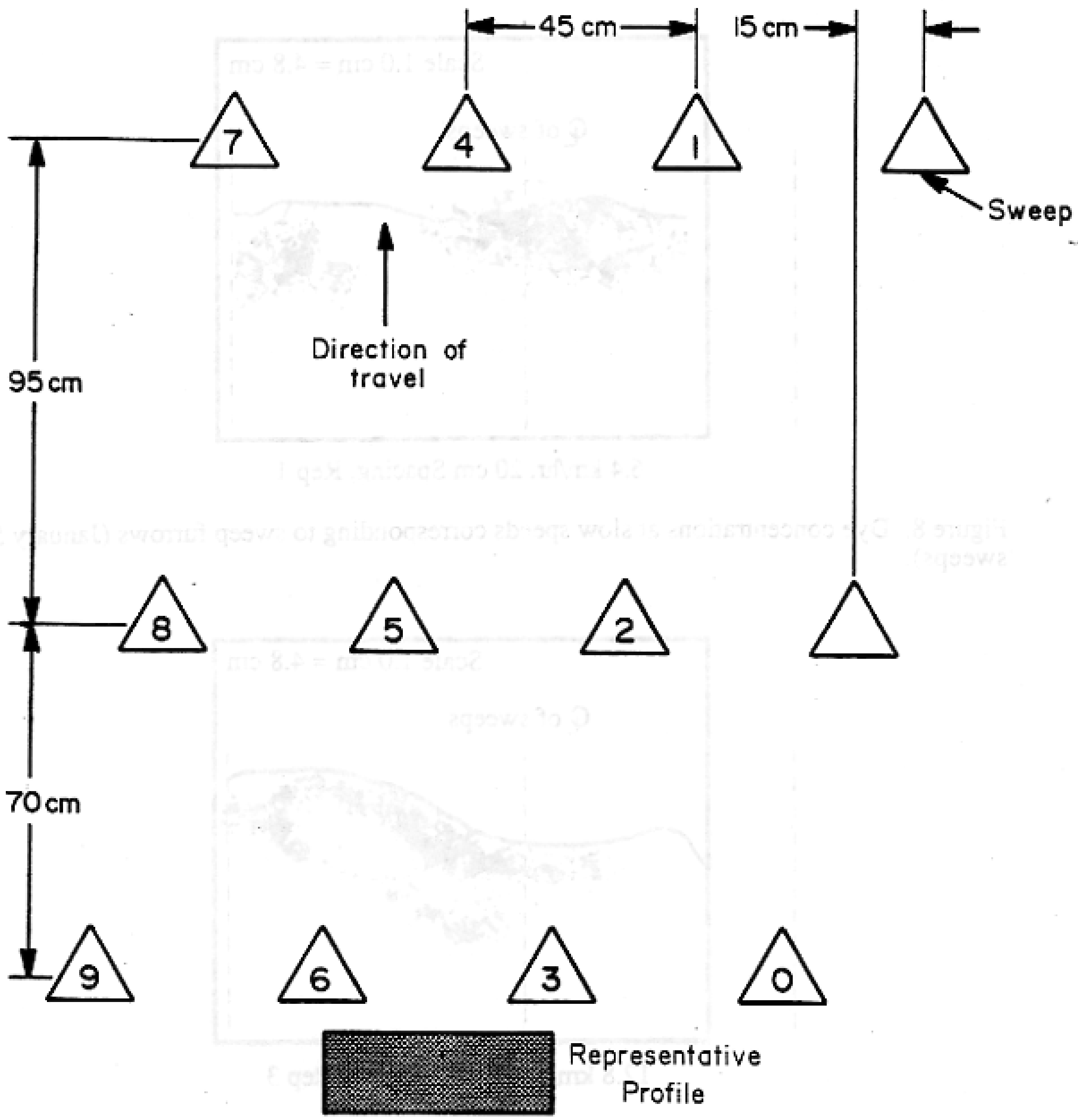


Figure 10. Sweeps 15 cm wide on 15 cm centers and the representative profile that was recorded.

The effect of speed on dye incorporation was studied by statistically analyzing complete incorporation profiles of 15 cm and 23 cm sweeps on a field cultivator. A complete profile is one which has a sufficient number of sweeps in the area treated with dye to represent a field cultivator. Since only complete profiles were statistically analyzed, only the May 29 and July 17 field tests were examined. The January 5 and April 9 tests did not have a sufficient number of sweeps on the incorporation tool and the May 9 tests did not have a large enough area of dye applied to the soil surface to give an adequate representation of the incorporation characteristics of a field cultivator. The distance to the centroid of the total amount of dye in each incorporation profile, for the May 29 and the July 17 tests, was calculated from the surface of the soil after incorporation. Table III shows that as speed increased, the distance to the centroid of the dye moved further from the soil

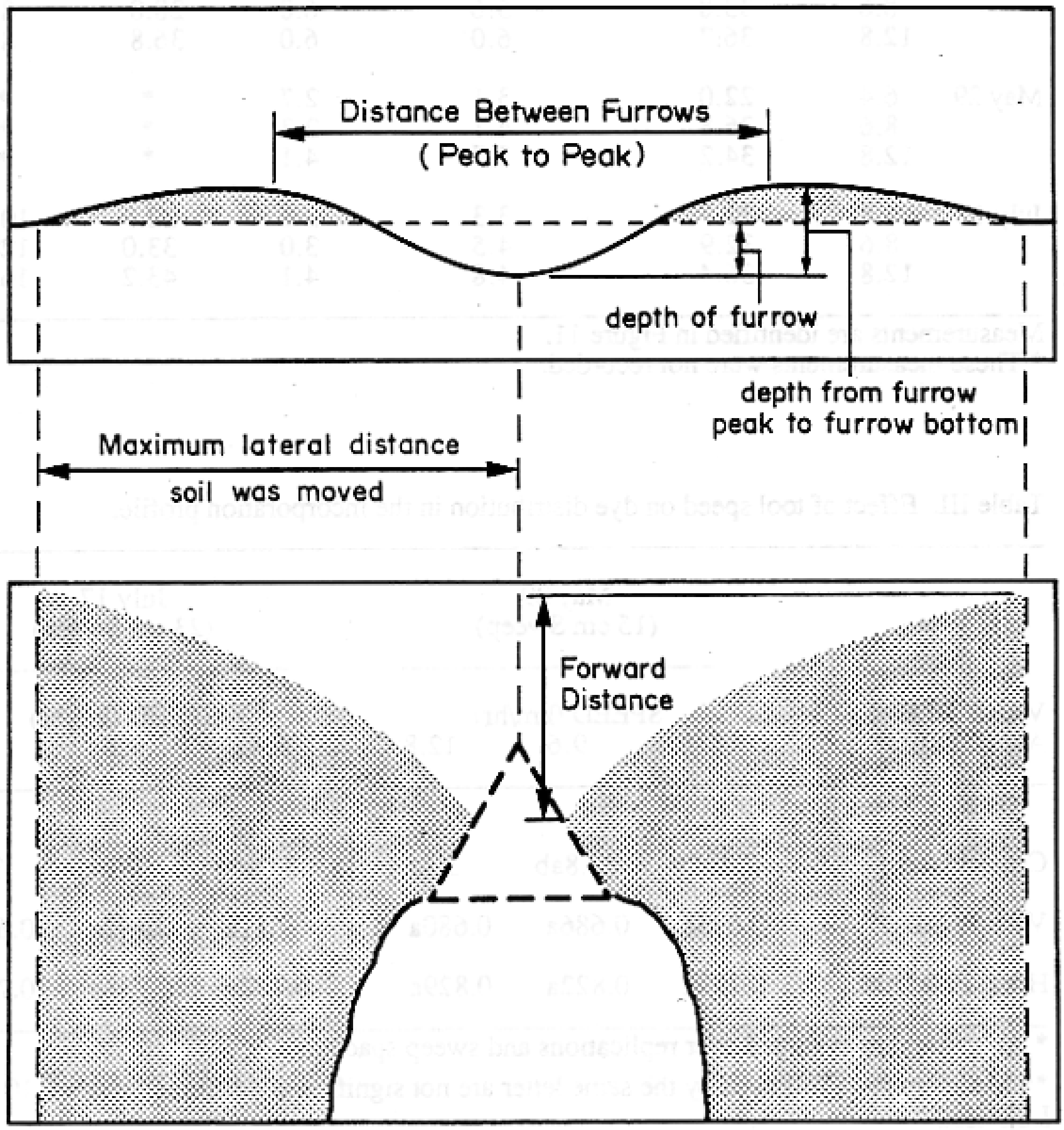


Figure 11. Measurements recorded in the field and in the soil bin.

Table II. Dimensions of furrows formed in tests.

Test	Speed (km/hr)	Peak to Peak (cm)	Peak to Bottom (cm)	Depth (cm)	Lateral (cm)	Forward (cm)
Jan. 5	6.4	25.5	5.9	2.5	25.4	81
	8.6	26.6	7.7	3.6	44.5	89
	12.8	22.1	5.6	2.9	66.0	132
April 9	6.4	30.3	5.0	2.2	21.6	49
	8.6	33.8	5.6	6.8	28.0	81
	12.8	36.7	6.0	6.0	36.8	81
May 29	6.4	22.0	3.1	2.7	*	*
	8.6	26.8	4.1	2.3	*	*
	12.8	34.2	5.7	4.1	*	*
July 17	6.4	22.9	3.3	2.5	22.9	101
	8.6	32.9	4.5	3.0	33.0	127
	12.8	36.4	4.8	4.1	43.2	163

Measurements are identified in Figure 11.
* These measurements were not recorded.

Table III. Effect of tool speed on dye distribution in the incorporation profile.

VARIABLE ANALYZED*	May 29 (15 cm Sweep) SPEED (km/hr) 6.4	9.6	12.8	July 17 (23 cm Sweep) SPEED (km/hr) 6.4	9.6	12.8
Centroid (cm)	2.4b**	2.8ab	3.3a	3.0a**	3.6a	3.8a
Vert. FNMAX	0.673a	0.686a	0.680a	0.611a	0.592a	0.624a
Horz. FNMAX	0.799a	0.822a	0.829a	0.732a	0.736a	0.772a

* All values are averaged over replications and sweep spacings.

** Means in rows followed by the same letter are not significantly different at $\alpha = 0.10$ using the LSD test.

surface, which agrees with the furrow formation analysis which concluded that furrow depth increased with tool speed. Tool speed was shown to have a significant (α=.05) linear effect on the location of the centroid (Table IV).

The Kolmogorov-Smirnov test was used to compare the horizontal and vertical wave forms with the average of each wave form. The average of each wave form would represent the distribution of the dye if it was incorporated uniformly. The smaller the maximum difference (FNMAX) in the functions representing the wave forms, the more uniform the actual incorporation profiles. The horizontal distribution trends for the May 29 and July 17 tests indicated that the most uniform incorporation profiles were created at slower speeds and became increasingly less uniform as tool speed increased (Table III). However, there was no statistically significant effect of tool speed on either the vertical or horizontal FNMAX values except for the July 17 horizontal tests (Table IV).

The effect of tool speed on the May 29 wave form comparisons are shown in Table V. The 20 cm spacing horizontal wave forms derived from profiles incorporated at higher tool speeds were significantly different from the slower tool speeds. The horizontal wave forms incorporated at 9.6 km/hr with either the 10 and 15 cm sweep spacings were significantly different than profiles incorporated at 6.4 km/hr. These horizontal analysis differences support the concept that windrowing occurred at slower speeds for narrower sweep spacings, that is spacings at 10 cm and 15 cm.

The July 17 horizontal wave form data (Table VI) shows that the 15 cm and 30 cm spacings were most similar at low speeds and the 23 cm spacing comparisons were most similar at high speeds. However, at a given sweep spacing, statistical comparisons of horizontal wave forms derived from profiles incorporated at different tool speeds were very similar. This indicates that increasing speed from 6.4 km/hr to 12.8 km/hr creates similar differences in the profiles, or no differences in the profiles. Inspection of the July 17 profiles (Figure 12) reveals that the 15 cm spacing tests have a gradual increase in windrowing as tool speed increased. The 23 cm and 30 cm spacing profiles show little windrowing occurred.

The 23 cm sweep spacing profiles of the July 17 tests showed concentrations in the left and right sides of the profiles at 12.8 km/hr indicating windrowing at high tool speeds. The 30 cm sweep spacing profiles showed dye concentrations between all four sweeps of the profile at slow speeds. Table VII summarizes the effect of tool speed on windrowing. As tool speed increases windrowing of the dye increases.

Effect of Sweep Spacing

The effect of sweep spacing on dye incorporation was studied to determine the optimum spacing for uniform placement of the dye. Sweep widths of 15 cm (January 5, May 9 and May 29 tests) and 23 cm (July 17 tests) were used on spacings of .67, 1.0, and 1.33 times the sweep size. The spacings are listed in Table I.

The May 29 field tests showed increased amounts of windrowing in the 20 cm spacing profiles (Figure 13) as tool speed increased. The 20 cm spacing showed dye concentrations in the right side of the profile at slow speeds. As tool speed increased, this concentration moves to the left side due to windrowing. No dye was observed to move back into the right side of the profile, which indicated the dye was not windrowed past the third sweep. The narrower 10 cm and 15 cm spacings showed windrowing at all speeds. The 10 cm spacing windrowed the dye into the center of the profiles at all tool speeds. The 15 cm spacings moved the dye to the left of the profile at all speeds.

Table IV. Analysis of variance of dye distribution in the incorporation profile.

Variable Analyzed	Source of Variation	May 29 F Value	July 17 F Value
Centroid	Sweep spacing	7.846 *	4.972 *
	Linear effect		6.758 *
	Quadratic		3.185 **
	Tool speed	2.749 *	2.579 *
	Linear effect	5.455*	4.844 *
	Interaction	1.540	1.314
Vert. FNMAX	Sweep spacing	0.716	0.878
	Tool speed	0.144	0.944
	Interaction	2.623 *	0.538
Horz. FNMAX	Sweep spacing	1.739	2.458
	Tool speed	0.488	2.518
	Linear	1.012	3.780 *
	Interaction	0.525	1.629

[a] Where appropriate, data was analyzed to see if a linear or quadratic effect influenced results.

* Value statistically significant at $\alpha = 0.05$

** Value statistically significant at $\alpha = 0.01$

Table V. Results for May 29 profiles incorporated with 15 cm sweeps and compared at constant spacings.

Horz. Distribution Comparison[a]	FNMAX[b]	Vert. Distribution Comparison[a]	FNMAX[b]
6.4,10 vs 12.8,10	0.065	6.4,10 vs 12.8,10	0.213
9.6,10 vs 12.8,10	0.101	6.4,10 vs 9.6,10	0.247
6.4,10 vs 9.6,10	0.112*	9.6,10 vs 12.8,10	0.253
6.4,15 vs 12.8,15	0.049	9.6,15 vs 12.8,15	0.192
9.6,15 vs 12.8,15	0.083	6.4,15 vs 12.8,15	0.285*
6.4,15 vs 9.6,15	0.089*	6.4,15 vs 9.6,15	0.307*
6.4,20 vs 12.8,20	0.098*	6.4,20 vs 9.6,20	0.201
6.4,20 vs 9.6,20	0.131*	6.4,20 vs 12.8,20	0.290*
9.6,20 vs 12.8,20	0.235*	9.6,20 vs 12.8,20	0.319*

[a] speed (km/hr), spacing (cm) vs speed (km/hr), spacing (cm).

[b] Values averaged over replications and sorted in ascending order.

* Values are significantly different at $\alpha = 0.01$

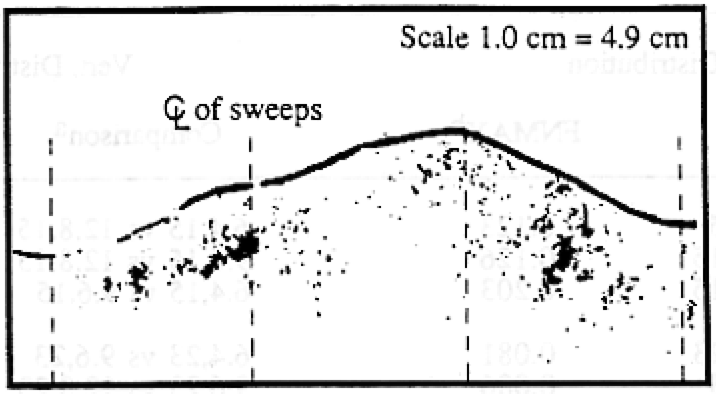
Table VI. Results for July 17 profiles incorporated with 23 cm sweeps and compared at constant spacings.

Horz. Distribution		Vert. Distribution	
Comparison[a]	FNMAX[b]	Comparison[a]	FNMAX[b]
6.4,15 vs 9.6,15	0.123	6.4,15 vs 12.8,15	0.253
9.6,15 vs 12.8,15	0.126	9.6,15 vs 12.8,15	0.257
6.4,15 vs 12.8,15	0.203	6.4,15 vs 9.6,15	0.288
9.6,23 vs 12.8,23	0.081	6.4,23 vs 9.6,23	0.229
6.4,23 vs 9.6,23	0.086	9.6,23 vs 12.8,23	0.263
6.4,23 vs 12.8,23	0.128	6.4,23 vs 12.8,23	0.237
6.4,30 vs 9.6,30	0.097	6.4,30 vs 9.6,30	0.260
6.4,30 vs 12.8,30	0.122	6.4,30 vs 12.8,30	0.338
9.6,30 vs 12.8,30	0.190	9.6,30 vs 12.8,30	0.392

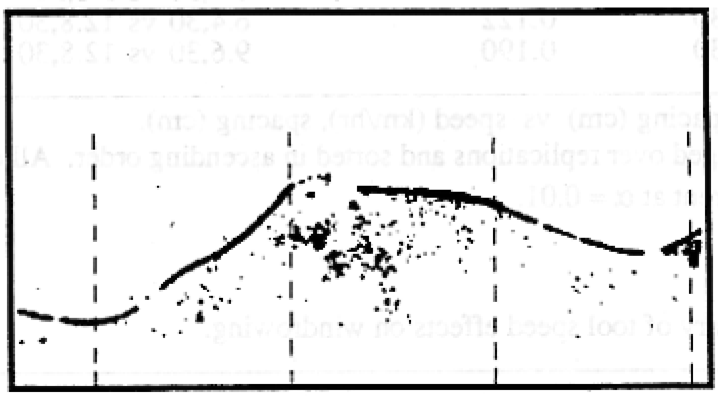
[a] speed (km/hr), spacing (cm) vs speed (km/hr), spacing (cm).
[b] Values are averaged over replications and sorted in ascending order. All comparisons are significantly different at $\alpha = 0.01$.

Table VII. Summary of tool speed effects on windrowing.

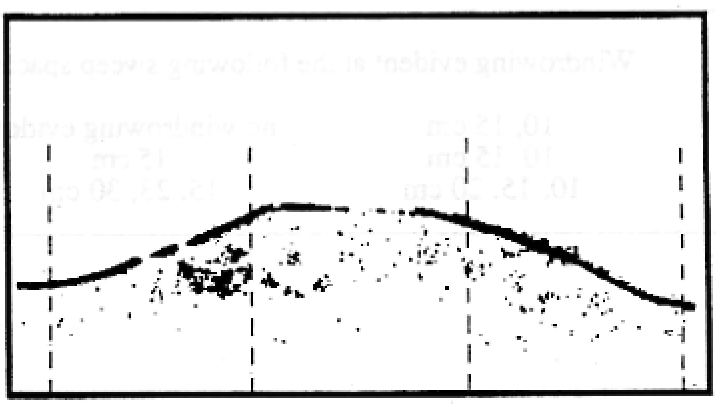
Speed (km/hr)	May 29 (15 cm Sweeps)	July 17 (23 cm Sweeps)
	Windrowing evident at the following sweep spacings	
6.4	10, 15 cm	no windrowing evident
9.6	10, 15 cm	15 cm
12.8	10, 15, 20 cm	15, 23, 30 cm



6.4 km/hr, 15 cm Spacing, Rep 2



9.6 km/hr, 15 cm Spacing, Rep 1



12.8 km/hr, 15 cm Spacing, Rep 2

Figure 12. Windrowing of dye from the right to the left of the profile as tool speed increases (July 17 tests).

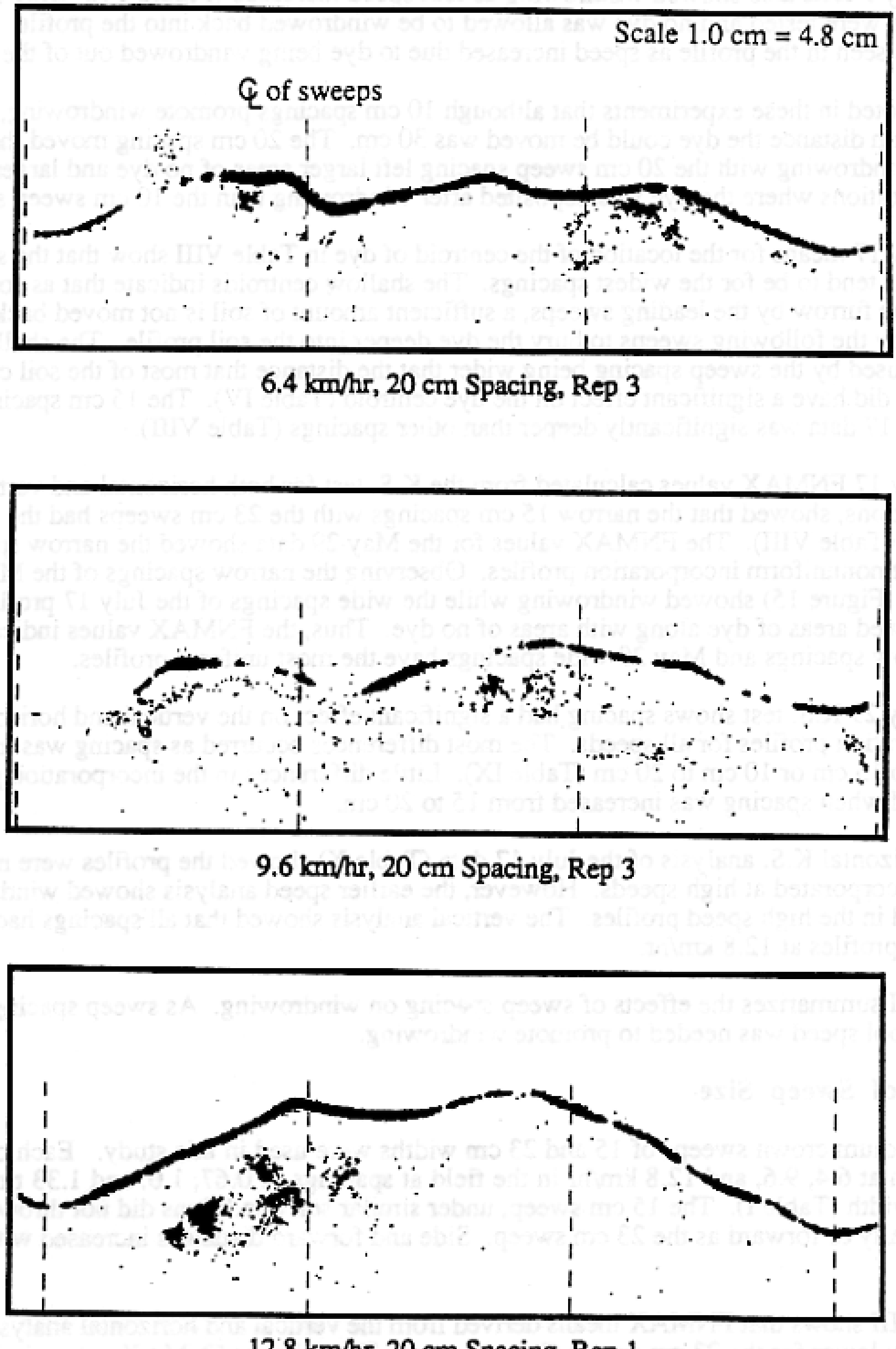


Figure 13. Increase in dye windrowing due to an increase in tool speed (May 29 tests).

The May 9 tests also showed windrowing as tool speed increased (Figure 14). Only the 15 cm spacings were tested and no dye was allowed to be windrowed back into the profile. Thus, less dye was seen in the profile as speed increased due to dye being windrowed out of the profile.

It was noted in these experiments that although 10 cm spacings promote windrowing, the maximum distance the dye could be moved was 30 cm. The 20 cm spacing moved the dye 60 cm. Thus, windrowing with the 20 cm sweep spacing left larger areas of no dye and larger dye concentrations where the dye was deposited after windrowing than the 10 cm sweep spacing.

The July 17 means for the location of the centroid of dye in Table VIII show that the shallowest centroids tend to be for the widest spacings. The shallow centroids indicate that as soil was moved out of the furrow by the leading sweeps, a sufficient amount of soil is not moved back into the furrow by the following sweeps to bury the dye deeper into the soil profile. The shallow centroids were caused by the sweep spacing being wider that the distance that most of the soil can be moved. Spacing did have a significant effect on the dye centroid (Table IV). The 15 cm spacing centroid of the July 17 data was significantly deeper than other spacings (Table VIII).

The July 17 FNMAX values calculated from the K.S. test for both horizontal and vertical distributions, showed that the narrow 15 cm spacings with the 23 cm sweeps had the most uniform profiles (Table VIII). The FNMAX values for the May 29 data showed the narrow spacings had the most nonuniform incorporation profiles. Observing the narrow spacings of the May 29 profiles (Figure 15) showed windrowing while the wide spacings of the July 17 profiles (Figure 16) showed areas of dye along with areas of no dye. Thus, the FNMAX values indicate that July 17 narrow spacings and May 29 wide spacings have the most uniform profiles.

The May 29 K.S. test shows spacing had a significant effect on the vertical and horizontal incorporation profiles for all speeds. The most differences occurred as spacing was increased from 10 cm to 15 cm or 10 cm to 20 cm (Table IX). Little differences in the incorporation profiles occurred when spacing was increased from 15 to 20 cm.

The horizontal K.S. analysis of the July 17 data (Table X) showed the profiles were most similar when incorporated at high speeds. However, the earlier speed analysis showed windrowing occurred in the high speed profiles. The vertical analysis showed that all spacings had similar vertical profiles at 12.8 km/hr.

Table XI summarizes the effects of sweep spacing on windrowing. As sweep spacing increased, a higher tool speed was needed to promote windrowing.

Effect of Sweep Size

Two medium crown sweeps of 15 and 23 cm widths were used in this study. Each of the sweeps were run at 6.4, 9.6, and 12.8 km/hr in the field at spacings of 0.67, 1.0, and 1.33 times the sweep width (Table I). The 15 cm sweep, under similar soil conditions did not throw the soil as far laterally or forward as the 23 cm sweep. Side and forward distances increased with speed for all tests.

Table VIII shows that FNMAX means derived from the vertical and horizontal analysis were generally lower for the 23 cm sweep (July 17 tests). These lower FNMAX values indicate that incorporation with the 23 cm sweeps created a more uniform profile than the 15 cm sweeps. The tool speed analysis showed windrowing was evident at all sweep spacings as speed increased. Thus, the slower tool speeds created a more uniform profile. The spacing analysis showed that

Table VIII. Effect of sweep spacing on dye distribution in the incorporation profile.

VARIABLE ANALYZED	May 29 (15 cm Sweep) SPACING (cm) 10	15	20	July 17 (23 cm Sweep) SPACING (cm) 15	23	30
Centroid (cm)	2.4b*	3.6a	2.5b	4.1a	3.1b	3.2b
Vert. FNMAX	0.677a	0.666a	0.696a	0.595a	0.605a	0.627a
Horz. FNMAX	0.841a	0.826a	0.784a	0.721a	0.765a	0.754a

* All values are averaged over replications and tool speeds.

* Means in rows followed by the same letter are not significantly different at α = 0.01 by the LSD test.

Table IX. Results for May 29 profiles incorporated with 23 cm sweeps and compared at constant speeds.

Horz. Distribution Comparison[a]	FNMAX[b]	Vert. Distribution Comparison[a]	FNMAX[b]
6.4,15 vs 6.4,20	0.066	6.4,15 vs 6.4,20	0.175
12.8,15 vs 12.8,20	0.080	12.8,10 vs 12.8,15	0.264
9.6,15 vs 9.6,20	0.208*	9.6,15 vs 9.6,20	0.266*
6.4,10 vs 6.4,15	0.407*	12.8,15 vs 12.8,20	0.348*
9.6,10 vs 9.6,15	0.410*	9.6,10 vs 9.6,15	0.361*
6.4,10 vs 6.4,20	0.426*	12.8,10 vs 12.8,20	0.381*
12.8,10 vs 12.8,15	0.427*	9.6,10 vs 9.6,20	0.450*
9.6,10 vs 9.6,20	0.429*	6.4,10 vs 6.4,20	0.499*
12.8,10 vs 12.8,20	0.430*	6.4,10 vs 6.4,15	0.523*

[a] speed (km/hr), spacing (cm) vs speed (km/hr), spacing (cm).

[b] Values are averaged over replications and sorted in ascending order.

* Values are significantly different at α = 0.01

Table X. Results for July 17 profiles incorporated with 23 cm sweeps and compared at constant speeds.

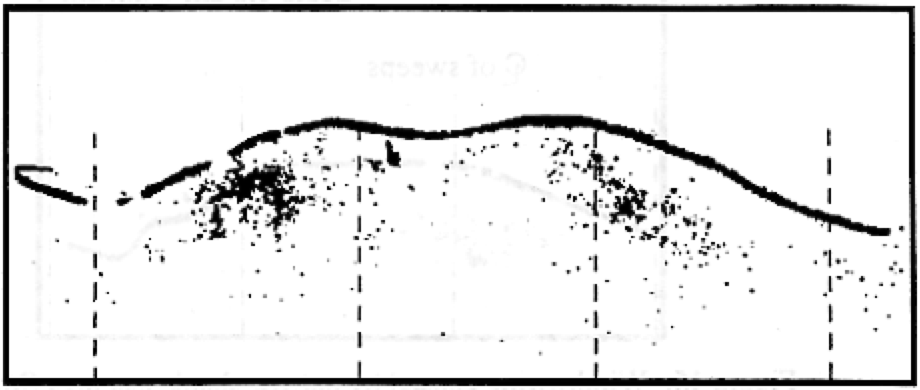
Horz. Distribution		Vert. Distribution	
Comparison*	FNMAX**	Comparison*	FNMAX**
12.8,15 vs 12.8,23	0.058	12.8,15 vs 12.8,23	0.196
9.6,15 vs 9.6,23	0.165	12.8,15 vs 12.8,30	0.201
6.4,15 vs 6.4,23	0.303	6.4,15 vs 6.4,30	0.251
12.8,23 vs 12.8,30	0.215	12.8,23 vs 12.8,30	0.272
12.8,15 vs 12.8,30	0.225	9.6,15 vs 9.6,23	0.278
9.6,23 vs 9.6,30	0.239	6.4,15 vs 6.4,23	0.289
6.4,15 vs 6.4,30	0.249	6.4,23 vs 6.4,30	0.306
9.6,15 vs 9.6,30	0.193	9.6,15 vs 9.6,30	0.365
6.4,23 vs 6.4,30	0.259	9.6,23 vs 9.6,30	0.427

* speed (km/hr), spacing (cm) vs speed (km/hr), spacing (cm)
** Values are averaged over replications and sorted in ascending order.

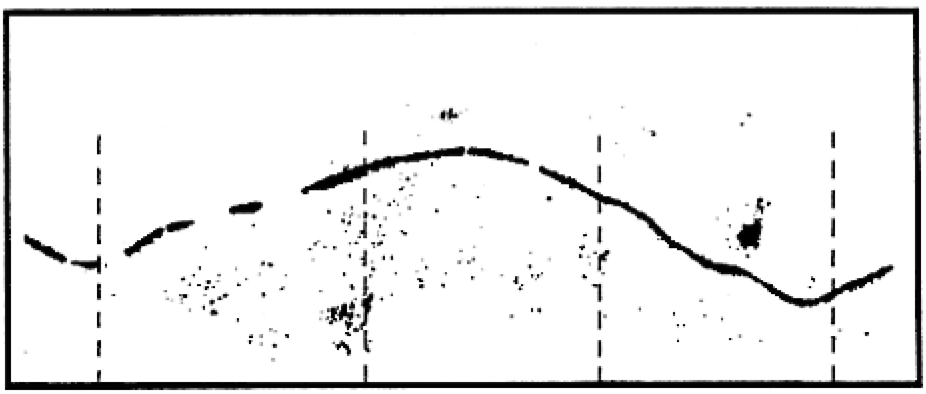
Table XI. Summary of shank spacing effects on windrowing.

Spacing (cm)	May-29 (15 cm Sweeps)	July-17 (23 cm Sweeps)
	Windrowing evident at the following speeds	
10	6.4, 9.6, 12.8 km/hr	*
15	6.4, 9.6, 12.8 km/hr	9.6, 12.8 km/hr
20	12.8 km/hr	*
23	*	12.8
30	*	12.8

* This spacing was not used for these tests.



6.4 km/hr, 15 cm Spacing, Rep 2



9.6 km/hr, 15 cm Spacing, Rep 2

12.8 km/hr, 15 cm Spacing, Rep 3

Figure 14. Increase in dye windrowing due to an increase in tool speed (May 9 tests).

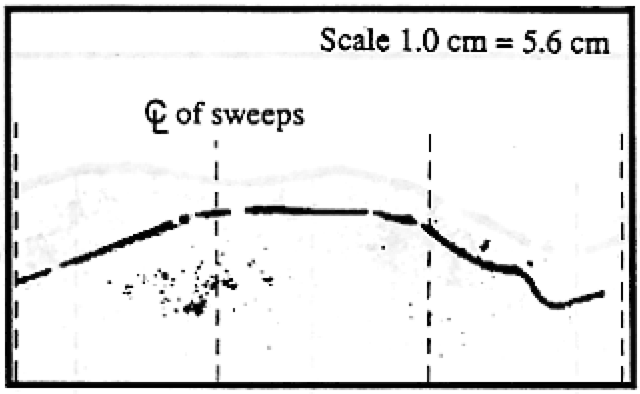


Figure 15. Windrowing caused by narrow shank spacings (May 29 tests).

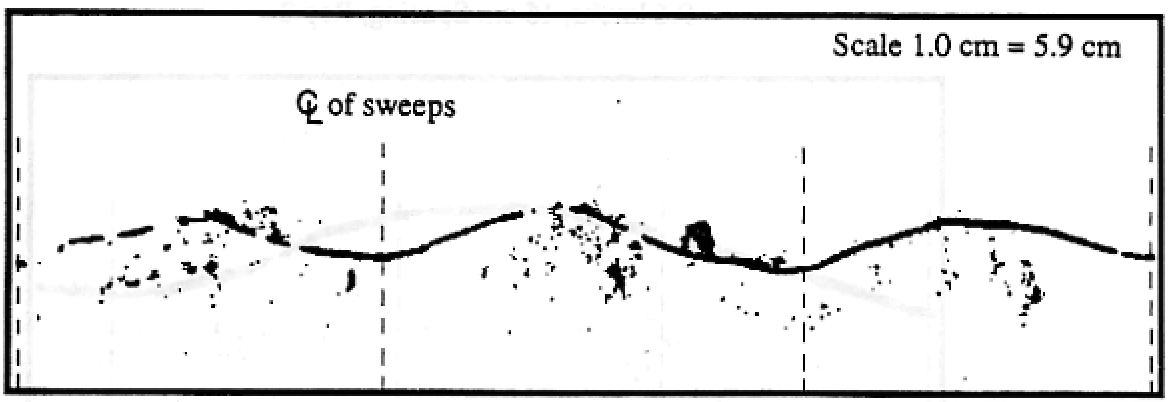


Figure 16. Dye concentrations caused by wide shank spacings (July 17 tests).

areas containing no dye were seen with the wider spacings. Thus, the most uniform incorporation profiles were created with 23 cm sweeps on 15 cm spacings at 6.4 km/hr.

SUMMARY

A procedure was developed to determine the location of a fluorescent dye after incorporation 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 Kolmogorov-Smirnov statistical test was used to compare the incorporation profiles of field cultivator. 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.

The incorporation profiles were analyzed to determine the effects of tool speed and sweep spacing on the incorporation of dye in the soil. As spacing decreased and tool speed increased, the amount of soil and dye that was windrowed increased.

Windrowing occurred when 15 cm sweeps were used on 10 cm and 15 cm sweep spacings at all tool speeds and with the 20 cm sweep spacings at a tool speed of 12.8 km/hr.

A visual and statistical analysis of the 23 cm sweep tests showed windrowing with the 15 cm spacing profiles at 9.6 km/hr and 12.8 km/hr. Windrowing was evident in the 23 cm and 30 cm sweep spacings only at a tool speed of 12.8 km/hr.

Tool speed influenced furrow formation, creating larger, deeper furrows at higher speeds. This, in turn, influenced the depth of incorporation. The vertical centroid of dye in the profile increased in depth as tool speed increased. Increasing sweep spacing was shown to decrease the depth at which the dye was placed in the soil profile.

The Kolmogorov-Smirnov test indicated that the most uniform profiles were created at slower tool speeds for the May 29 and July 17 tests. The narrow spacings with 23 cm sweeps and the wide spacings with 15 cm sweeps were shown to give the most uniform incorporation profiles when compared to other spacings. The 23 cm sweeps created more uniform profiles than the 15 cm sweeps. Thus, the most uniform profiles were created by the 23 cm sweeps on 15 cm spacings and incorporated at 6.4 km/hr.

Research Limitations

Results clearly indicate that windrowing occurred at narrow sweep spacings and high speeds. However, results may vary for different soil types, soil moisture contents, amounts of residue present, etc. Additional testing is needed to determine if results from the experiments can be applied to other field conditions.

Possible sources of experimental error in this research are: non-homogeneity of the soil in the field plots, differences in soil moisture contents of the field plots, differences in soil moisture content during the tests, variations in the distance that the video camera was placed from the profiles, variation in light intensity, variations in subjectivity in choosing a threshold level, tool speed variations due to tractor tire slippage in the field, and tool depth variations. The effects of these errors were not considered in this research.

CONCLUSIONS

Of the parameters tested in this research, those that resulted in the most uniform profiles were recommended. The dye was incorporated most uniformly with a 23 cm sweep on 15 cm spacings at a tool speed of 6.4 km/hr.

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