Cultivator Speed and Sweep Spacing Effects on Herbicide Incorporation

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ABSTRACT

IN order to improve incorporation of herbicides, the effect of tool speed, sweep spacing, and sweep size on the incorporation of herbicides by a field cultivator was studied. Non-uniform dye placement occurred at narrow sweep spacings and at high tool speeds. Depth of dye placement tended to increase as tool speed increased and decrease as sweep spacing increased. The results indicated that present incorporation procedures can be improved to give more uniform vertical and horizontal herbicide incorporation. Of the variables tested, the most uniform profiles were created by 23 cm sweeps on 15 cm spacings and operated at 6.4 km/h. This is a slower tool speed and narrower sweep spacing than that recommended by previous researchers.

INTRODUCTION

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 herbicide and may reduce crop injury 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 runoff water is also reduced by incorporating the herbicide into 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 in an 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 certain combinations of sweep spacings, tool speeds, and sweep sizes would windrow the herbicide across several sweeps. This phenomena would leave the herbicide concentrated in one area of the incorporation profile (Fig. 1).

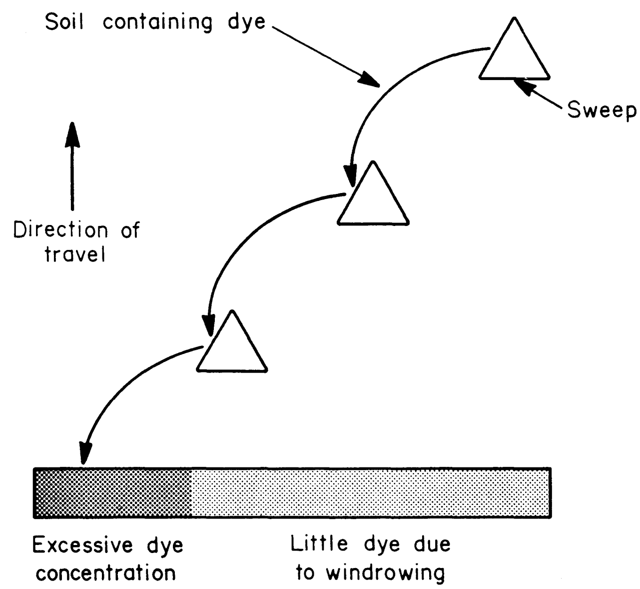

Fig. 1—Dye concentration due to windrowing.

The objective of this research was to determine the effect of tool speed, sweep spacing, and sweep size on herbicide incorporation uniformity and 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 investigated.

LITERATURE REVIEW

Field cultivators are popular incorporation implements among farmers because of their advantages over other equipment. Among these advantages are the ability to create a more desirable seed bed than disk harrows, lower power requirements when compared to powered rotary tillers, and more residue can be 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 high concentrations of herbicides were alleviated by a second incorporation pass at an angle to the first. Bode and Gebhardt (1969) observed nonuniform verticle incorporation with a field cultivator.

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TABLE 1. TESTS USED TO DETERMINE THE EFFECT OF SWEEP SPACING, TOOL SPEED, AND SWEEP SIZE ON HERBICIDE INCORPORATION

Test ID*	Location	Number of sweeps	Spacing, cm	Speed, km/h	Sweep Size, cm
1	Deere & Co. Tech. Center (soil bin)	1, 2, and 3	10, 15, 20	6.4, 9.6, 12.8	15
2	Univ. of Ill. (field)	1	---	6.4, 9.6, 12.8	15
3	Univ. of Ill. (field)	9	15	6.4, 9.6, 12.8	15
4	Univ. of Ill. (field)	9	10, 15, 20	6.4, 9.6, 12.8	15
5	Univ. of Ill. (field)	9	15, 23, 30	6.4, 9.6, 12.8	23

* All tests were conducted with the sweep operated at a depth of 7.6 cm

King (1965) noted that field cultivators require two passes for uniform incorporation. Operating faster than 8 km/h 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/h followed by a drag harrow or other leveling device. Higher 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/h. Horizontal distribution was erratic after one pass, even when followed by a drag harrow. Large sweeps worked better in moist conditions. As sweep width increased from 5 to 30 cm, the largest concentrations of dye tended to be deeper in the soil. A sweep width slightly wider than the sweep spacing is commonly recommended.

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 with field cultivators.

PROCEDURES

Fluorescent dye coated granules, representing herbicides, were incorporated with medium crown field cultivator sweeps in the field and in a soil bin. After incorporation, a cross-section was cut into the soil to reveal the incorporation profile. The profile was then fluoresced and the image 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) and Dowell et al. (1988).

The effects of tool speed 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 laterally a specified distance, 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 and showed the progressive effects of windrowing. 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 1 and specific details of the soil conditions and testing procedures are discussed by Dowell (1988). Similar soil preparation procedures were used and similar soil conditions were maintained in the field and soil bin tests so comparison could be made between tests.

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 uniformly distributed horizontally and vertically in the soil profile. It was desired to find a speed range, spacing range, and sweep size which resulted in a profile that most closely approximated an ideal incorporation profile.

Soil Bin Tests

Fig. 2, derived from the soil bin tests, shows the soil

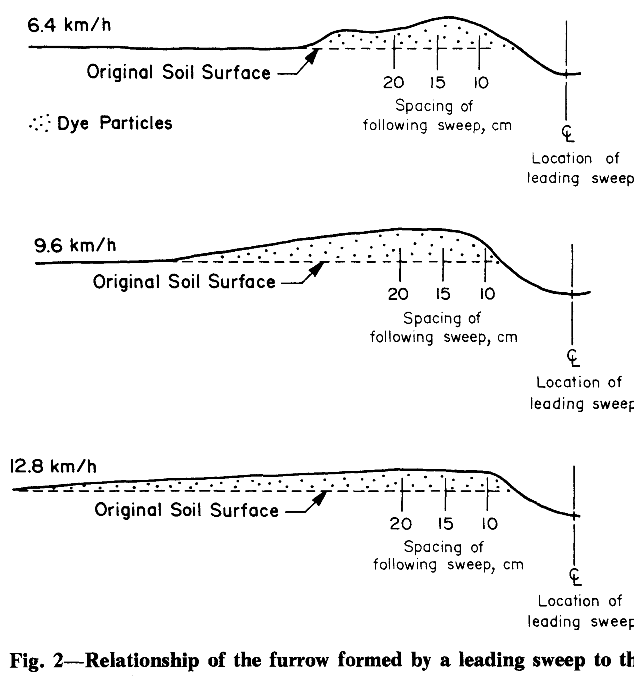


Fig. 2—Relationship of the furrow formed by a leading sweep to the spacing of a following sweep.

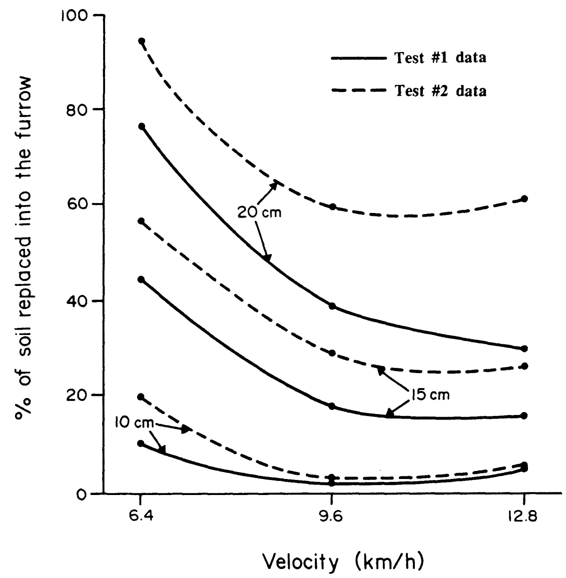
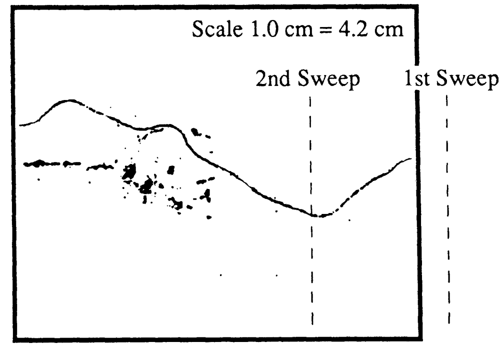
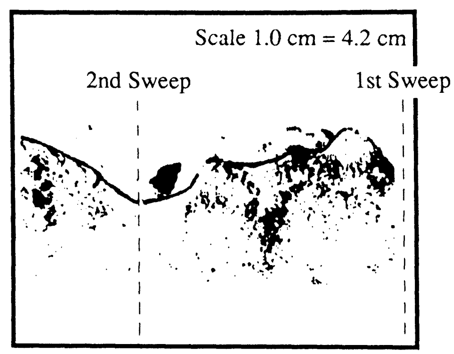


Fig. 3—The relationship of tool velocity to the amount of soil that can be replaced into the previous furrow if the following sweep is placed at a spacing of 10 cm, 15 cm, or 20 cm.



9.6 km/hr, 10 cm Spacing, Rep 2

Fig. 4—Dye concentrations in the left side of the profile due to windrowing (Test #1, 2 sweeps).



6.4 km/hr, 20 cm Spacing, Rep 1

Fig. 5—Dye placement in the right side of the profile due to a wide sweep spacing and a slow tool speed (Test #1, 2 sweeps).

profile formed by a leading sweep and the potential location of a following sweep, at spacings of 10, 15, or 20 cm. This figure shows 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 Fig. 2. A greater 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 soil moved from the furrow by the leading sweep that can be replaced by the following sweep is shown in Fig. 3. This figure indicates how much soil and dye can be windrowed to the next sweep. The graph shows that the amount of soil that can be replaced in the furrow, and thus not windrowed, decreased as tool speed increased from 6.4 km/h to 9.6 km/h or from 6.4 km/h to 12.8 km/h. However, as tool speed increased from 9.6 km/h to 12.8 km/h, little differences occurred in the soil that can be replaced in the furrow. Since faster tool speeds can not move soil and dye back into the previous furrow, the soil and dye must be windrowed over to the following sweep. Fig. 3 also shows that as sweep spacing decreases, the amount of soil that can be replaced into the previous furrow decreases indicating that windrowing increases with a decrease in spacing. Fig. 3 was derived from the #1 soil bin tests and the #2 single shank tests by measuring the amount of soil displaced from the furrow in relation to the spacing of a following sweep.

The #1 soil bin multiple shank tests showed that a decrease in spacing caused windrowing to increase. The narrow 10 cm spacings produced dye concentrations in the left half of the profile created by two sweeps (Fig. 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 (Fig. 5).

The effect of speed on windrowing with the 15 cm spacing is shown in the results of the soil bin tests. At 6.4 km/h and 9.6 km/h, the third sweep was able to move soil back into the furrows created by the first and second sweeps (Fig. 6). However, as tool speed was increased to 12.8 km/h, virtually no dye was placed in the profile (Fig. 7). 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 the excavated profile.

At the 20 cm spacing, windrowing did not occur at any speeds tested in the soil bin tests. However, differences in the profiles were observed. A tool speed of 6.4 km/h was not fast enough to break out a large enough furrow to ensure an even horizontal distribution of dye. Concentrations of dye were observed corresponding to the furrows formed. A larger furrow formed by increasing the tool speed to 12.8 km/h provided a more even dye distribution.

The 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

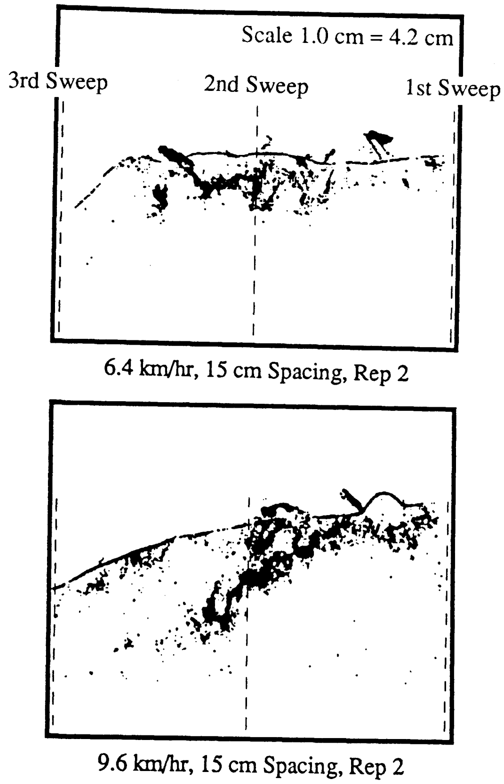


Fig. 6—Dye placment in the right side of the profiles at 6.4 km/h and 9.6 km/h (Test #1, 3 sweeps).

was done in the field using nine sweeps on a three row cultivator.

Field Tests

Effect of Tool Speed: The effect of tool speed (6.4, 9.6, and 12.8 km/h) on furrow formation and the uniformity of dye incorporation was studied. Furrow formation affects how the dye will be placed in the soil profile and will be discussed first.

The tool sweeps were staggered on three rows (Fig. 8), thus the depth of the furrow formed by the leading sweeps (sweeps 1, 4, and 7) influenced the depth at which soil and dye were placed in the profile by the following sweeps. Furrow formation was studied by taking measurements in the field and from the video tape images. Fig. 9 shows the dimensions recorded in Table 2.

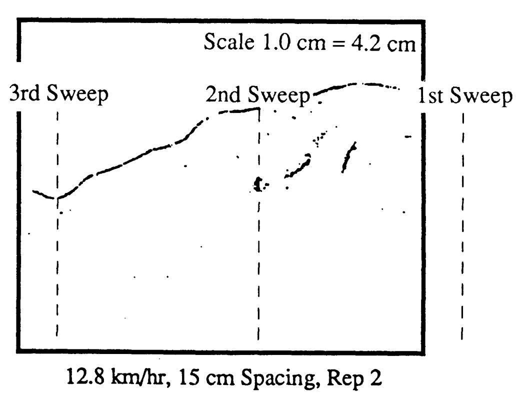


Fig. 7—Dye windrowed out of the profile at 12.8 km/h (Test #1, 3 sweeps).

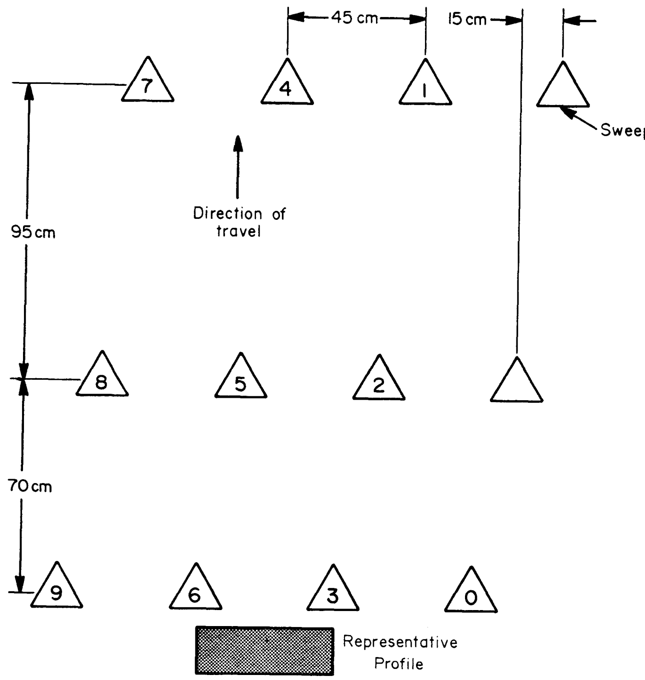


Fig. 8—Sweeps 15 cm wide on 15 cm centers and the representative profile that was recorded.

Measurements from the single sweep tests showed that most peak to peak, peak to furrow bottom, and furrow depth from the original ground surface dimensions increased with tool speed. Deeper placement of dye was shown by the dye concentration in actual cross-sections taken from the field and is discussed below.

The effect of speed on dye incorporation was studied by statistically analyzing complete profiles incorporated with 15 cm or 23 cm sweeps on a field cultivator. Due to field and machinery limitations, only the #4 and #5 field tests had complete profiles which were statistically

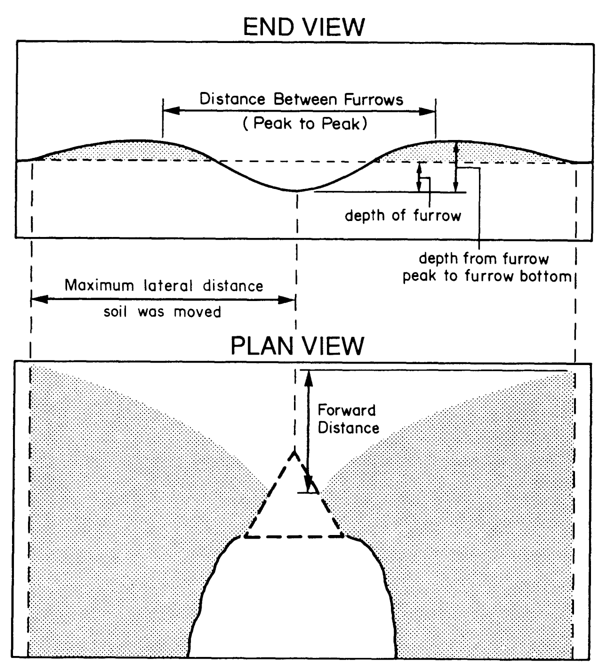


Fig. 9—Measurements recorded in the field and in the soil bin.

TABLE 2. DIMENSIONS OF FURROWS FORMED

Test	Speed, km/h	Peak to peak, cm	Peak to bottom, cm	Depth, cm	Lateral, cm	Forward, cm
#1	6.4	25.5	5.9	2.5	25.4	81
	9.6	26.6	7.7	3.6	44.5	89
	12.8	22.1	5.6	2.9	66.0	132
#2	6.4	30.3	5.0	2.2	21.6	49
	9.6	33.8	5.6	6.8	28.0	81
	12.8	36.7	6.0	6.0	36.8	81
#4	6.4	22.0	3.1	2.7	*	*
	9.6	26.8	4.1	2.3	*	*
	12.8	34.2	5.7	4.1	*	*
#5	6.4	22.9	3.3	2.5	22.9	101
	9.6	32.9	4.5	3.0	33.0	127
	12.8	36.4	4.8	4.1	43.2	163

Dimensions are identified in Fig. 9
* These dimensions were not recorded.

TABLE 3. EFFECT OF TOOL SPEED ON DYE DISTRIBUTION IN THE SOIL PROFILE

Variable analyzed*	Test #4 (15 cm sweep) Speed, km/h 6.4	9.6	12.8	Test #5 (23 cm sweep) Speed, km/h 6.4	9.6	12.8
Vert. 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 α=0.10 using the LSD test.
‡ FNMAX is the maximum difference in the dye distributions as determined by the Kolmogorov-Smirnov statistical test.

TABLE 4. ANALYSIS OF VARIANCE OF DYE DISTRIBUTION IN THE SOIL PROFILE

Variable Analyzed	Source of variation	Test #4	Test #5
Vert. Centroid	Sweep spacing	‡	‡
	Linear effect*		‡
	Quadratic effect	‡	§
	Tool speed		‡
	Linear effect	‡	‡
	Interaction	NS†	NS
Vert FNMAX#	Sweep spacing	NS	NS
	Tool speed	NS	NS
	Interaction	‡	NS
Horz. FNMAX	Sweep spacing	NS	NS
	Tool speed	NS	NS
	Linear	NS	‡
	Interaction	NS	NS

* Where appropriate, data were analyzed to see if a linear or quadratic effect influenced results.
† NS = not significant
‡ Value statistically significant at α=0.05
§ Value statistically significant at α=0.01
# FNMAX is the maximum difference in the dye distributions as determined by the Kolmogorov-Smirnov statistical test.

analyzed. The distance from the surface of the soil after incorporation to the centroid of the total amount of dye in each incorporation profile was calculated for the #4 and the #5 field tests. Table 3 shows that as speed increased, the distance to the centroid of dye moved further from the soil surface, which agrees with the furrow formation analysis which concluded that furrow depth increased with the tool speed. Tool speed was shown to have a significant ($\alpha=.05$) linear effect on the location of the centroid (Table 4).

The Kolmogorov-Smirnov (K.S.) test was used to compare the horizontal and vertical wave forms with the average of each wave form for each replication. The wave forms were derived by summing the dye particles in horizontal or vertical increments in the soil profile (Dowell et al., 1988). The horizontal and vertical wave forms represent the horizontal and vertical distributions of dye in the profile. The average of each wave form represents 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 distributions. The horizontal distribution trends for the #4 and #5 field tests indicated that the most uniform incorporation profiles were created at slower speeds (Table 3). However, there was no statistically significant effect of tool speed on either the vertical or horizontal FNMAX values except for the #5 horizontal tests (Table 4).

The effect of tool speed on the #4 wave form comparisons are shown in Table 5. 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/h with either the 10 or 15 cm sweep spacings were significantly different than profiles incorporated at 6.4 km/h. 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 test #5 horizontal wave form data (Table 6) 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, indicated by lower FNMAX values. 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/h to 12.8 km/h creates similar or no differences in the distributions. Inspection of the test #5 profiles revealed 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 #5 field tests

TABLE 5. RESULTS FOR TEST #4 PROFILES INCORPORATED WITH 15 cm SWEEPS AND COMPARED AT CONSTANT SPACINGS

Horz. distribution Comparison*	FNMAX†	Vert. distribution Comparison*	FNMAX†
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‡

* speed (km/h), spacing (cm) vs. speed (km/h), spacing (cm)
† Values averaged over replications and sorted in ascending order. FNMAX is the maximum difference in the dye distributions as determined by the Kolmogorov-Smirnov statistical test.
‡ Values are significantly different at α=0.01

TABLE 6. RESULTS FOR TEST #5 PROFILES INCORPORATED WITH 23 cm SWEEPS AND COMPARED AT CONSTANT SPACINGS

Horz. distribution Comparison*	FNMAX†	Vert. distribution Comparison*	FNMAX†
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

* speed (km/h), spacing (cm) vs. speed (km/h), spacing (cm)
† Values are averaged over replications and sorted in ascending order. All comparisons are significantly different at α=0.01. FNMAX is the maximum difference in the dye distributions as determined by the Kolmogorov-Smirnov statistical test.

showed concentrations in the left and right sides of the profiles at 12.8 km/h 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.

The #4 field tests showed increased amounts of windrowing in the 20 cm spacing profiles 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 moved 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. The #3 field tests also showed windrowing as tool speed increased.

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. The #5 field test means for the location of the centroid of dye in Table 7 show that the more shallow centroids tend to be associated with the widest spacings. The shallow centroids were caused by the sweep spacing being wider than the distance that most of the soil can be moved. Spacing did have a significant effect on the dye centroid (Table 4). The 15 cm spacing centroid of the #5 test data was significantly deeper than other spacings (Table 7).

The #5 test 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 distributions (Table 7).

TABLE 7. EFFECT OF SWEEP SPACING ON DYE DISTRIBUTION IN THE SOIL PROFILE

Variable analyzed	Test #4 (15 cm sweep) Spacings, cm 10	15	20	Test #5 (23 cm sweep) Spacings, 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	0.754

* 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.
‡ FNMAX is the maximum difference in the dye distributions as determined by the Kolmogorov-Smirnov statistical test.

TABLE 8. RESULTS FOR TEST #4 PROFILES INCORPORATED WITH 15 cm SWEEPS AND COMPARED AT CONSTANT SPEEDS

Horz. distribution Comparison*	FNMAX†	Vert. distribution Comparison*	FNMAX†
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‡

* speed (km/h), spacing (cm) vs. speed (km/h), spacing (cm)
† Values are averaged over replications and sorted in ascending order. FNMAX is the maximum difference in the dye distributions as determined by the Kolmogorov-Smirnov statistical test.
‡ Values are significantly different at α=0.01

The FNMAX values for the #4 field tests with the 15 cm sweeps on 10 cm spacings showed that the narrow spacings had the most nonuniform distributions.

The K.S. test of the #4 field data shows spacing had a significant effect on the vertical and horizontal incorporation profiles for all speeds. The greatest differences occurred as spacing was increased from 10 cm to 15 cm or 10 cm to 20 cm (Table 8). Little difference in the incorporation profiles occurred when spacing was increased from 15 to 20 cm.

The horizontal K.S. analysis of the #5 field data (Table 9) showed the distributions were most similar when incorporated at high speeds. However, the earlier speed analysis showed windrowing occurred at high speeds. The vertical analysis showed that all spacings had similar vertical distributions at 12.8 km/h.

Effect of Sweep Size: Two medium crown sweeps of 15 and 23 cm widths were used in this study. The 15 cm sweep, under similar soil conditions did not move the soil as far laterally or forward as the 23 cm sweep. Side and forward movement of soil increase with speed for all tests.

Table 7 shows that FNMAX means derived from the vertical and horizontal analysis were generally lower for the 23 cm sweep (#5 tests) than for the 15 cm sweeps (#4 tests) indicating a more uniform profile. The tool speed analysis showed windrowing was evident at all sweep spacings as speed increased. Thus, slower tool speeds created a more uniform profile. The spacing analysis showed that 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 and operated at 6.4 km/h.

TABLE 9. RESULTS FOR TEST #5 PROFILES INCORPORATED WITH 23 cm SWEEPS AND COMPARED AT CONSTANT SPEEDS

Horz. distribution Comparison*	FNMAX†	Vert. distribution 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/h), spacing (cm) vs. speed (km/h), spacing (cm)
† Values are averaged over replications and sorted in ascending order. FNMAX is the maximum difference in the dye distributions as determined by the Kolmogorov-Smirnov statistical test.

SUMMARY

The Kolmogorov-Smirnov statistical test indicated that the most uniform profiles were created at slower tool speeds. Narrow spacings with 23 cm sweeps and the wide spacings with 15 cm sweeps were shown to give the most uniform incorporation when compared to other spacings. Depth of dye placement tended to increase as tool speed increased and decrease as sweep spacing increased. The 23 cm sweeps created more uniform profiles than the 15 cm sweeps. The most uniform profiles were created by the 23 cm sweeps on 15 cm spacings and operated at 6.4 km/h.

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