STUDIES OF MACHINES FOR INCORPORATION OF PRE-EMERGENT HERBICIDES

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The depth and uniformity of herbicide incorporation using both granular and liquid forms by several implements is reported. The results indicated substantial differences in the incorporation capabilities of these implements. The disc-type implements provided deeper incorporation because of soil inversion by the discs. The tine-type implements which stirred the soil did not provide deep incorporation. The discer equipped with the Normand spray boom attachment provided a shallow or deep incorporation depending upon the position of the spray boom. The differences in incorporation capabilities of various implements will require proper selection of implement depending on the herbicide and the crop to be treated.

INTRODUCTION

Although not many of the herbicides in use today are pre-emergent, the ones in use are of great significance, particularly for the control of wild oats. The successful use of these herbicides depends on correct application and incorporation. Wasted chemical, damage to crops and poor weed control can result from incorrect application and incorporation procedures.

Pre-emergent herbicides are available in either liquid or granular form; the most common of these is triallate used for wild oats control. The pre-emergent herbicides require incorporation into the soil just after application. The depth of incorporation may vary depending on the kind of weed to be controlled and the crop that is to be grown. For example, trifluralin should be mixed relatively deeply for control of wild oats whereas a shallow incorporation is more satisfactory for control of green foxtail.

According to Ashford (1975), a triallate granule has to be within half a centimeter of a growing wild oat to have any effect. This shows the importance of a uniform application and thorough incorporation of the herbicide. Moreover, a normal application rate of 14 kg/ha of triallate granules when incorporated to a depth of 5 cm means that one part of the herbicide has to be mixed with nearly 26,000 parts of the soil.

Various implements are used to incorporate herbicides. The common ones are discer (common name for one-way disc harrow), tandem disc harrow, drag harrow, and cultivator.

Bode et el. (1969) studied the incorporation of trifluralin with various implements and reported that deeper incorporation was obtained with a tandem disc harrow, while a shallow incorporation resulted from a power rotary cultivator. Hulbert and Menzel (1953) used radioactive tracers and granules to study the soil mixing characteristics of various tillage implements and reported that disc harrowing followed by spring tooth harrows resulted in fairly uniform distribution of granules. Holroyd (1964) studied the incorporation of fluorescent dye with a spring tine harrow, a rotary cultivator and a chain harrow and reported that increasing the depth and frequency of operation increased the depth of incorporation. Matthews (1970) used chloride analysis for incorporation studies and reported that uniform incorporation in both horizontal and vertical directions was obtained with single discing, double discing and cross-discing operations. The cross-discing operation did not seem to improve the distribution over the double disc operation. Butler and Siemens (1972) reported incorporation of pesticides with a tandem disc harrow and a cultivator and observed that incorporation with the tandem disc improved with faster speeds and larger gang angles and a second operation resulted in deeper and more uniform incorporation. Incorporation with the field cultivator was not as good as with the tandem disc harrow and concentration of granules appeared in rows.

There appears to be a considerable difference among various incorporating impements with regard to their ability to incorporate both granular and liquid herbicides to a desired uniformity and depth. Therefore the project was undertaken to evaluate the following:

1. The incorporation capabilities of common farm implements.
2. The effects of speed, mode of incorporation and disc angle on the vertical distribution of granules when incorporated with a tandem disc harrow.
3. The effects of boom position, speed and depth of tillage on the vertical distribution of the liquid when using the Normand attachment on a discer.
4. The effects of the spout position of the Gandy applicator on the vertical distribution of granules when mounted behind a discer.

EQUIPMENT AND PROCEDURES

Description of Incorporating Implements

Common farm implements used for tillage operations were selected for incorporation of granules and liquid spray. These are listed below:

Discer — A 2.75-m Massey Ferguson discer with the disc size of 0.5 m spaced 0.18 m apart. The Normand spray attachment and the Gandy applicator were also attached behind the discer.

Tandem disc harrow — A 6.1-m International Harvestor tandem disc harrow with the disc size of 0.5 m spaced 0.19 m apart and the disc gangs at an angle of 15°.

Field cultivator — A 6.1-m International Harvestor "vibra shank" cultivator, sweep size 0.23 m spaced 0.2 m apart and followed by drag diamond harrows.

Deep tillage cultivator — A 3.05-m Massey Ferguson cultivator, sweep size 0.4 m spaced 0.3 apart and followed by drag diamond harrows.

Spike tooth harrows — Three sections of 0.9-m-wide spike tooth diamond harrows.

Rod weeder — A 3.05-m Morris rod weeder.

Tracer Technique

Various tracer techniques have been used to study the incorporation capabilities of tillage implements. The technique used in this study has been described by Lal and Reed (in prep.).

Attaclay granules dyed with 0.2% uranine dye (sodium fluorescein) were applied with a Gandy applicator at a rate of 34 kg/ha, about twice the normal application rate of triallate granules. For liquid application, 0.2% solution of uranine dye in distilled water was sprayed with different nozzles at a rate of 112 liters/ha.

Granule and Liquid Application

A 3.05-m-wide Gandy applicator was used for spreading granules on the soil surface at a rate of 34 kg/ha. The lateral distribution of granules from the Gandy applicator was determined in both the lab and the field. The distribution in the lab was obtained from the calibration of the applicator, while the field distribution was obtained by taking soil samples after applying the granules but before incorporation. The depth of sampling was very shallow for these samples.

TABLE I EXPERIMENTAL PLAN FOR THE TANDEM DISC HARROW STUDY

Test number	Speed (km/h)	Disc angle (degrees)	Mode of incorporation†
1	5	16	Single
2	8	16	Cross
3	8	16	Single
4	8	20	Single
5	8	20	Cross
6	5	20	Cross

†Single, single pass with harrow in the direction of granules application.
Cross, cross-harrowing, i.e., second pass at right angles to the single pass.

TABLE II EXPERIMENTAL PLAN FOR THE NORMAND AND THE GANDY ATTACHMENT WITH THE DISCER

Test number	Depth (cm)	Speed (km/h)	Nozzle or spout location†		
			Hor.	Vert.	a
Normand attachment					
1	7.5	8	50	50	36°
2	7.5	5	50	50	36°
3	10.0	8	50	50	36°
4	10.0	5	50	50	36°
5	7.5	8	31.5	40	55°
6	7.5	5	12.5	50	65°
Gandy attachment					
7	7.5	8	2.5	63.5	90°
8	7.5	8	15.0	63.5	90°

†Hor. = Horizontal position of nozzle tip or spout opening from the discs in cm.
Vert. = Vertical position of nozzle tip or spout opening from the lowest part of the disc in cm.
a = spray angle or spout angle in degrees.

Floodjet TK 2.5 and Teejet 6502 nozzles were used for spraying liquid for determining their uniformity of distribution patterns in the lab and on the soil surface. However, Teejet 65015 nozzles were used for the Normand spray attachment and Floodjet TK 2.5 nozzles were used for the liquid incorporation study. The nozzles were operated to deliver 112 liters/ha.

The tracer granules and the liquid were applied in front of the tractor. However, with the Normand spray attachment and with the Gandy attachment behind the discer, the spray or granules were directed on to the turning soil. For both granular and liquid applications, a strip of land equal to the width of the applicator (3.05 m) was used. The effective length of the experimental strip was 32 m.

Experimental Procedure

Incorporation of granules and liquid was carried out just after the application or simultaneously with the application, depending upon the kind of experiment. The depth of tillage was maintained close to 7.5 cm for all the implements. However, the penetration of rod weeder and spike tooth harrows was shallower. Where necessary the tillage was also carried out to the 10-cm depth. The speed of operation was maintained at 8 km/h. In each case, a single operation was carried out for incorporation except in the case of spike tooth harrows where incorporation was carried out by cross-harrowing.

Experiments were also conducted to determine the effects of preincorporation tillage depth on the depth of incorporation. The depths of tillage considered were 5 cm and 10 cm.

Tandem disc harrow

The effects of disc angle, single vs. a double-cross operation, and travel speed on incorporation depth were measured. The details are given in Table I.

Discer with Normand and Gandy attachment

The effects of the spray nozzle position with the Normand attachment and the spout position of the Gandy applicator on the depth of incorporation were determined. In addition, the effects of travel speed and tillage depth were included in the study. Table 2 lists specific details.

Soil Sampling and Dye Extraction

Vertical distribution

Soil samples were taken immediately after incorporation. The strip of incorporated land was divided into four sections, each section thus representing one replicate. Three sample locations across the width of incorporation and three along the line of travel were chosen in each section. Positions of wheel tracks were avoided in taking samples. Soil samples were taken at intervals of 3.05 m along the line of travel.

At each sample location, three samples were taken adjacent to each other down to the depth of incorporation. Each of these samples was divided into three parts for depths of 0—2.5 cm, 2.5—5.0 cm, and 5.0—7.5 cm. Thus, at each location, nine samples of approximately 16.4 cm^3 of soil were collected. A total of 81 samples were taken for each replicate for 7.5-cm depth of incorporation.

Lateral distribution

Soil samples for lateral distribution were taken at three random locations along the line of travel. For the granular experiment, a total of 54 samples were taken at each location along the middle for a width of 1.6 m between the tractor wheels. The width of 1.3 m between the front wheels of the MF 1150 tractor was a limiting factor.

For the lateral distribution of liquid with Teejet 6502 and Floodjet TK 2.5 nozzles, soil samples were taken after spraying the liquid on the soil surface and after incorporation by two passes perpendicular to each other with a spike tooth harrow. A total of 39 samples were taken along the middle of 1.16-m width in order to avoid wheel tracks.

The procedure for extracting dye and determining the fluorescence level for each sample has been described by Lal and Reed (in prep.).

Data Analysis

For a vertical distribution of the granules and the liquid, a total of 27 fluorescence readings obtained in a replicate were averaged for each soil layer. Each of these values was transformed to the percentage of the sum of the fluorescence values of the replicate. These percent values represented the quantity of the granules or the liquid incorporated at various depth levels. A further average of these percentages of four replicates represented the quantity of the granules or the liquid for each soil layer which was incorporated in that layer for a test trial. Thus, a total of 108 fluorescence readings were averaged for each depth level for every test. The uniformity of incorporation at different depths was estimated from the coefficients of variation which were calculated with 108 values from all the replicates at each depth level.

Analysis of variance and Duncan's new multiple range test were applied to various test trials at individual depth level. Similar treatments were also paired for this analysis for determining the effect of a single variable on incorporation.

The fluorescence readings were averaged over the three replicates for the lateral distribution of the granules and the liquid. These average values for each sample were then transformed to the percentage of the sum of all the values of a test. This procedure resulted in a common mean for similar treatments for the purpose of comparison of distribution pattern. The range of values was calculated as the percentage of the mean which showed the minimum and the maximum quantity of the granules or the liquid at any location in the test strip. The coefficients of variation were calculated as the measure of the uniformity of incorporation.

RESULTS AND DISCUSSION

Vertical Distribution of Granules

Figure 1 shows that the best mixing of granules to 7.5-cm depth in the soil was obtained with the disc-type implements. Similar results have been reported earlier (Hulbert et al. 1953; Bode et al. 1969; Matthews 1970; Butler et al. 1972). There was no significant difference in the distribution between the tandem disc harrow and the discer.

Both cultivators followed by spike tooth harrows appeared to be quite similar in their ability to incorporate the granules. A higher

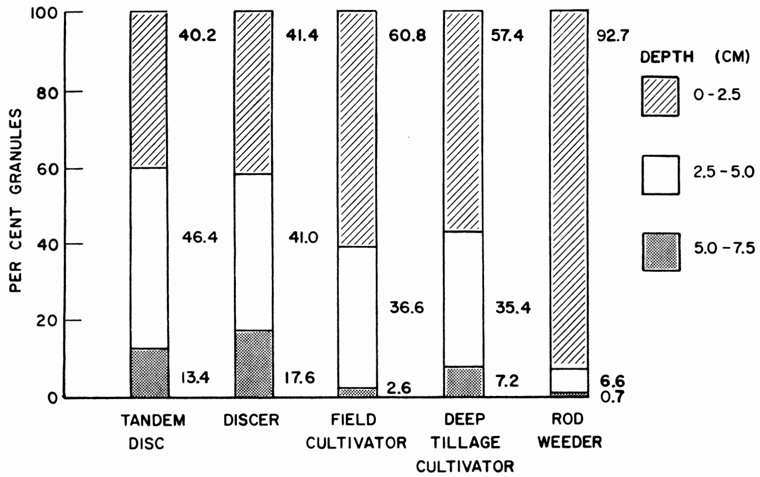

Figure 1. Incorporation of granules with various implements.

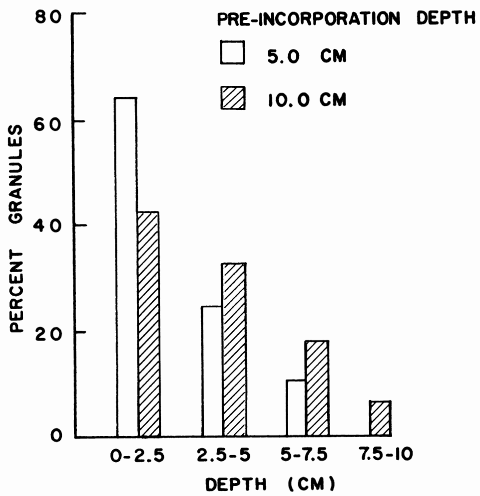

Figure 2. Effect of pre-cultivation depth on granule distribution.

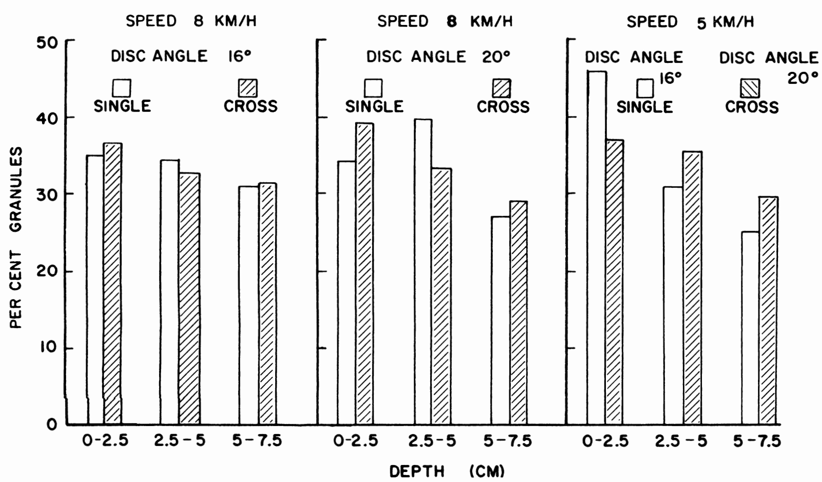

Figure 3. Granule incorporation with the tandem disc harrow.

percentage of granules was found in the top 2.5-cm layer and a lower percentage in the third 2.5-cm layer. This difference between cultivators and disc-type implements is thought to be due to the fact that discs cause soil inversion, whereas the cultivators only stir the soil.

Another effect of secondary distribution of granules was also observed with cultivators followed by harrows. The combined action of both the implements tends to place granules in ridges and leave furrows with few or no granules. This row effect was also observed in another experiment using triallate granules on Harmon oats (Lal and Reed 1976). Butler and Siemens (1972) also observed a similar row effect with a field cultivator.

The rod weeder caused little mixing and a very high percentage of granules remained in the top layer of soil with only a trace reaching the third layer.

Effect of Pre-incorporation Tillage Depth

Figure 2 shows the percentage of granules mixed at various intervals of depth for 5.0-cm and 10.0-cm depths of tillage prior to the application of granules.

There were nearly 22% more granules in the top 2.5-cm layer where the soil was tilled 5.0 cm deep rather than 10.0 cm deep. This difference reversed in both the 2.5 — 5.0-cm layer and the 5.0 — 7.5-cm layer where nearly 8% more granules were deposited for the 10.0-cm deep tillage. Statistically, the difference of 22% of the two treatments in the top layer was significant, while at other depth levels, the difference in the amount of granules deposited was not significant. When the soil samples were taken to a depth of 10.0 cm, nearly 6% granules were found in the 7.5 — 10.0-cm layer when the pre-incorporation tillage was 10.0 cm deep.

These results indicate that tilling of soil deeper prior to application and incorporation of granules will result in deeper incorporation of the herbicide. This is likely the result of the deeper penetraion of the harrow teeth which leave a deeper furrow and subsequently, the top soil falls into it carrying the granules with it to the furrow bottom. Where the harrow penetration was not as deep as in the case of 5.0-cm-deep tillage, the majority of granules remained nearer the surface.

Incorporation with the Tandem Disc Harrow

Figure 3 shows the percent of granules mixed at various depths for different treatments with the tandem disc harrow. Statistically, there was no significant difference among various incorporation techniques of the tandem disc harrow.

Disc angle

Little or no difference was observed in the concentration of granules at various depth intervals between 16° and 20° disc angles either with a single or double pass.

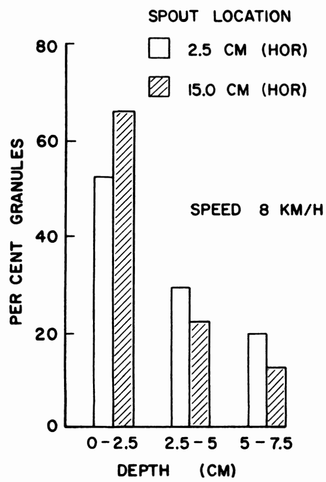

Figure 4. Granule distribution with the Gandy attachment behind the discer. Spouts positioned 63.5 cm above ground level.

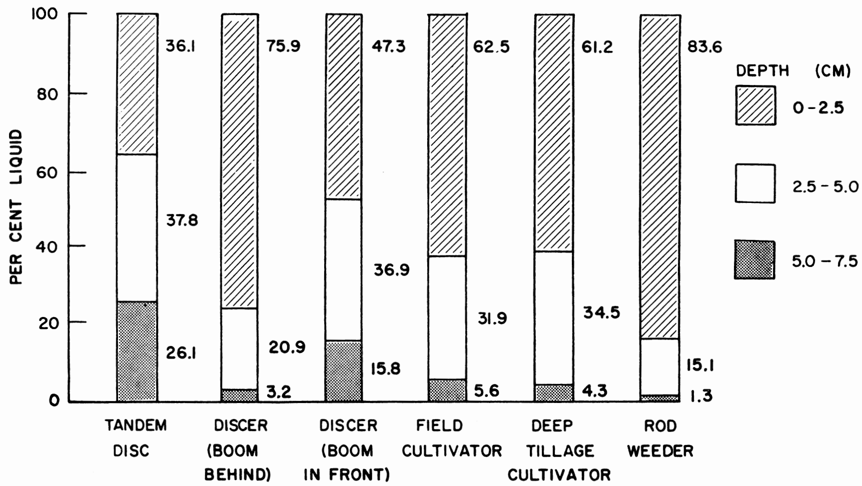

Figure 5. Incorporation of liquid with various implements.

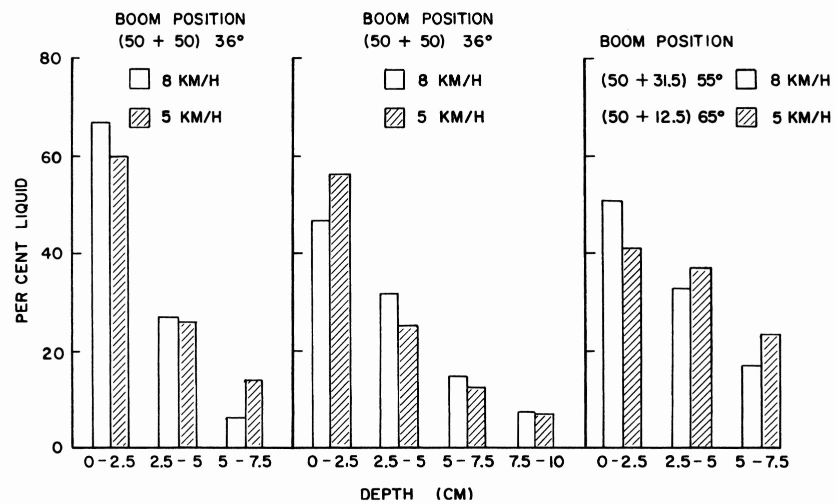

Figure 6. Liquid incorporation with the Normand attachment on the discer.

However, the uniformity of incorporation was improved significantly at the larger disc angles.

Speed of travel

Increasing the speed from 5 km/h to 8 km/h provided deeper incorporation of granules when a single pass was made. Comparisons after two passes showed no difference in the depth of incorporation or in quantitity of granules deposited at various depth intervals. The uniformity of incorporation was improved at the higher speed.

Mode of incorporation

There was little or no change in the depth of incorporation at higher speeds between a single and a cross operation of the tandem disc harrow. The cross operation was two passes at right angles to each other. The single pass at alower speed of 5 km/h resulted in a shallower incorporation. The cross operation improved the uniformity of incorporation slightly but not sufficiently to justify the time and expense required for the second pass.

Thus, it is evident that the granules distribution in various layers of soil is not affected by normal variations in the speed, disc angle, and the mode of incorporation when incorporated with a tandem disc harrow. However, the uniformity of incorporation was improved with the larger disc angle, higher speeds, and cross operation. This confirms the results reported by Butler and Siemens (1972).

Distribution with the Gandy Attachment behind a Discer

Figure 1 shows the percentage of the granules deposited at various depth levels for two positions of the Gandy applicator at the rear of the discer. Statistically, there was a significant difference in the quantity of granules deposited at various depth levels.

Deeper incorporation of granules was obtained as the spouts were moved closer to the disc. Nearly 52% of granules were deposited in the top 2.5-cm layer at the spout position of 2.5 cm away from the disc in comparison to 66% for the 15-cm position. The uniformity of incorporation was also better at the closer spout position. However, there was a difference of only 7% granules in the top 5 cm of soil between the two positions of spout location.

The spout position change showed a similar trend of incorporation as did the boom position change of the Normand attachment. The spout position of 15 cm from the discs incorporated nearly the same amount of granules in the top 2.5-cm soil as the boom position of 50 cm for the Normand attachment.

It was also observed that with a slight wind, granules were blown either toward the discs or away from the discs, depending upon the direction of wind and the direcion of operation. Wind velocities suitable for liquid spray are likely not suitable for granules application because going with the wind will result in deeper incorporation, while going against the wind will result in nearly all the granules being deposited on the surface.

Vertical Distribution of Liquid

Figure 5 shows the distribution of liquid spray for various implements at three depth intervals. The distribution of liquid within the soil was quite similar to that obtained with the granules. The disc-type implements mixed to a greater depth than the cultivators or rod weeder.

One additional method included the use of a Normand spray attachment for the discer or the one-way-disc harrow mounted behind the disc gang. This unit directs the spray into the turning or moving soil thrown up by the discs. In this case about 75% of the liquid remained in the top layer and a very small amount reached the third layer. This method appeared to give close to the same results as the rod weeder, but there is one important difference. This difference is that the top 1-inch layer of soil from the discer is quite moist, while the same layer with the

TABLE III RANGE AND COEFFICIENTS OF VARIATION IN LATERAL DISTRIBUTION OF GRANULES WITH VARIOUS IMPLEMENTS

Treatment	Range % of mean	Coefficient of variation (%)
Gandy - calibration	59.5-165.4	25.4
Gandy - in the field	65.9-151.4	17.8
Cross-harrowing (2 passes)	67.0-189.2	19.8
Tandem disc harrow (one pass)	61.1-154.6	20.4
Discer	55.0-175.2	27.3
Cultivator with harrows	55.7-207.6	35.0

TABLE IV RANGE AND COEFFICIENTS OF VARIATION IN LATERAL DISTRIBUTION OF LIQUID WITH TEEJET 6502 AND FLOODJET TK 2.5 NOZZLES

Treatment	Range % of mean	Coefficient of variation (%)
Teejet 6502		
Calibration	62.1-120.7	17.3
Before incorporation	60.1-141.7	18.9
After incorporation by cross-harrowing	71.9-192.5	25.3
Floodjet TK 2.5		
Calibration	51.6-157.0	31.3
Before incorporation	52.0-208.9	30.2
After incorporation by cross-harrowing	47.3-177.3	41.0

rod weeder is considerably drier under most circumstances. This difference in moisture could have a profound effect on the activity of the actual chemical utilization.

Distribution with the Normand Attachment on a Discer

Figure 6 shows the percentage of liquid found at various depths for different treatments with the Normand attachment on the discer. Statistically, a highly significant difference was observed in the quantity of liquid deposited at each depth interval for all the treatments.

Boom position and spray nozzle

Bringing the boom closer to the discs increased the concentration of liquid at lower depth intervals, thus increasing the depth of incorporation. When the position of the spray boom of the Normand attachment was changed, the spray angle was also changed. Three different horizontal positions of the boom in this experiment resulted in threee different angles of spray. The percentage of liquid incorporated at different depth intervals at these positions and the angles of spray are shown in Figure 6.

Comparing the concentration of liquid in the top 5-cm layer, nearly 94% was incorporated at the boom position of 50 cm, 83% at 31.5 cm and 76.8% at 12.5 cm. The tendency of the liquid distribution among three depth intervals was toward a greater amount of liquid at lower depths as the boom was brought closer to the discs. However, the uniformity of incorporation decreased successively at each boom position.

Thus, the position of the boom was very important in determining the distribution of liquid and the depth of incorporation. For shallow incorporation it is important to maintain the boom in the further away position. It is also interesting to note that the closest position resulted in incorporation nearly equivalent to cross operation with the tandem disc harrow.

Depth of tillage

Increasing the tillage depth of 7.5 cm to 10 cm reduced the amount of liquid deposited in the upper layer. At a speed of 8 km/h, nearly 94% of the liquid was located in the top 5 cm when tilling 7.5 cm deep compared to 78% when tilling 10 cm deep. As expected, the differences in the upper layer resulted in similar differences at the lower levels.

At a slower travel speed of 5 km/h, the difference was less marked with 86% of the liquid located in the top 5-cm layer while tilling at 7.5-cm depth and 81% when tilling at 10-cm depth.

Although the depth of incorporation increased with the depth of tillage, the uniformity of incorporation decreased and was much less uniform with the greater depth of tillage.

Speed of travel

Little or no difference was observed in the concentration of liquid at various depth intervals between 5 km/h and 8 km/h speed of travel either at 7.5-cm or 10-cm tillage depth. However, a shallower incorporation was noticed at higher speed, increasing the concentration of liquid in the top 2.5-cm layer at 7.5 cm tillage depth; but for 10-cm tillage depth, this trend was reversed at the top 2.5-cm layer although the difference was less marked, with nearly 78% liquid deposited in the top 5-cm layer at 8 km/h speed and 81% at 5 km/h speed. The uniformity of incorporation was better at higher speed.

Thus, in general, the depth of incorporation with the Normand attachment will depend on the boom position, depth of tillage and the speed of travel. In most cases, the depth of tillage is adjusted to give proper seeding depth with a discer and it is seldom that the seeding depth is the same as the tillage depth. So when applying and incorporating triallate while seeding, precautions must be taken to avoid deeper incorporation of chemical in order to prevent any crop damage.

Lateral Distribution of Granules

Table 3 shows the range of the amount of granules expressed as the percent of the mean over the sampling width of 1.6 m, along with the coefficient of variation for each treatment. From the comparison of the coefficient of variation, the field distribution of the Gandy applicator was more even than that in the lab. This may be the result of the granules being bounced and dispersed more evenly when falling to the ground. The light wind always present during the field experiments may also have helped in making the distribution more even.

Comparing the distribution of the Gandy applicator in the field with the distribution of the four implements, their order may be arranged according to the degree of uniformity as follows: cross-harrowing, tandem disc harrow, discer, cultivator with harrows.

The minimum and maximum number of granules at any location depended on the applicator and incorporation implement. As shown in Table 3, the range varied from 55% to 207.6% of the average value after incorporation, while the range for the applicator was 65.9 — 151.4 % before incorporation.

This indicated the variation in concentration of granules which at the lower concentration may not be sufficient for controlling wild oats, and at higher levels may damage the crop. The range of concentration nearest to that of the Gandy attachment was obtained with the tandem disc harrow, followed by the discer, cross-harrowing and the cultivator with harrows. Although the distribution of granules was more even with incorporation by cross-harrowing, the range of granules was higher than that of the tandem disc harrow and the discer. This may have been caused by the concentration of granules in the rows.

Lateral Distribution of Liquid

The objectives behind these trials were to compare distribution patterns of liquid at various stages of nozzle operation, i.e.,

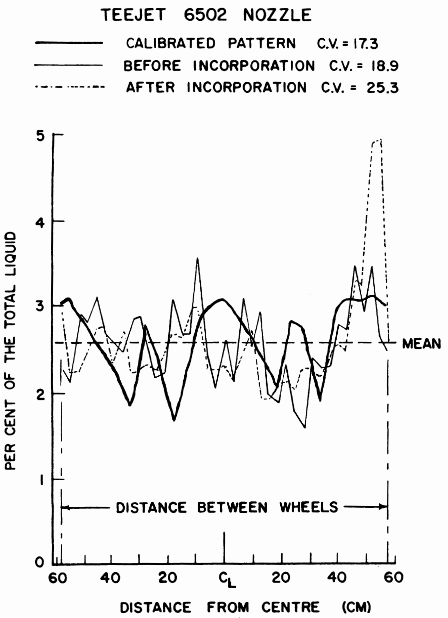

Figure 7. Lateral distribution of liquid with Teejet 6502 nozzle.

calibration, field application before incorporation and after incorporation. The similarity of patterns and degree of dispersion were estimated from the range expressed as the percent of mean value and coefficients of variation which are given in Table 4.

The range of variation of chemical in the sampling width increased after incorporation by cross-harrowing, but there is a similarity in the distribution patterns, as shown in Figure 7 for the Teejet 6502 nozzle. The peaks seem to occur at relatively the same positions for the calibrated pattern and the field patterns. Stirring the top soil by cross-harrowing did not seem to eliminate the original applied pattern. However, the uniformity decreased, as indicated by the increased coeffcient of variation. Since the distributions of chemical between the patterns obtained before incorporation and after incorporation are similar, it is best to apply the chemical uniformly over the field.

CONCLUSIONS

The results from the soil incorporation studies indicated substantial differences in the incorporation capabilities of various machines as to both depth and uniformity. In terms of uniformity of incorporation, the descending order was as follows: (1) harrows (two passes perpendicular to each other) (2) rod weeder, (3) tandem disc harrow, (4) one-way disc harrow or discer, (5) light duty cultivator with harrows and (6) heavy duty cultivator with harrows.

In terms of depth of incorporation the descending order was as follows. (1) tandem disc harrow, (2) discer, (3) light duty cultivator, (4) heavy duty cultivator, (5) harrows, and (6) rod weeder.

The disc-type implements provided deepest incorporation because the soil was inverted or turned over by the disc action. Tine-type implements which stirred the soil did not tend to give deep incorporation. The wider the spacing of the tines or shanks, the less uniform will be the results. The rod weeder apparently did little as far as incorporation was concerned, with over 80% of liquid or granules remaining in the top layer.

The vertical distribution of granules was influenced considerably by the depth of preincorporation tillage. Doubling the depth of cultivation resulted in nearly 22% fewer granules in the top 2.5-cm layer.

These results indicate that if granular herbicides are incorporated with spike tooth harrows, the depth of loose soil prior to incorporation influences the depth of incorporation and the distribution of granules. It is expected that the results would be similar with the liquid form of the herbicide.

The tandem disc harrow provided the deepest incorporation with only one pass over the field. There was practically no change in the depth of incorporation (vertical distribution) by the second pass or operation with the tandem disc harrow, but uniformity of incorporation was improved. Speed of travel and disc angle of the tandem disc harrow likewise had little effect on the depth of incorporation. Increasing the speed of travel and the disc angle resulted in more uniform incorporation. Since higher speeds, larger disc angles, and double operation all tend to pulverize the soil, serious problems with soil erosion could develop. Too high a speed will also cause soil ridging.

The discer equipped with the Normand spray boom attachment could be positioned to provide shallow or deeper incorporation nearly equivalent to two operations with the tandem disc harrow. The deeper incorporation was less uniform than the shallow incorporation. The higher speed of travel tended to give shallower but more uniform incorporation. As with other implements, the depth of incorporation is controlled to some extent by the depth of tillage; for those herbicides requiring shallow incorporation, the depth of tillage and position of the spray boom is important.

The discer with a rear-mounted attachment for granule application resulted in satisfactory incorporation provided the spouts were positioned properly or the granules were directed correctly. The position determined the depth of incorporation if there was no wind. Moderately windy conditions could result in an erratic incorporation, since the granules are very easily blown about.

Uniformity of the application of liquid herbicides from spray nozzle onto the soil and granules from granule applicators is important. The lateral distribution patterns from individual nozzles and granular applicators in the laboratory were similar in shape to the patterns of the lateral distribution in the soil after incorporation by harrows. In most cases the distribution after incorporation by harrows was less uniform than the distribution before incorporation.

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ASHFORD, R. 1975. Triallate granule spacing effect on oat. Weed Sci. 23: 470-472.

BODE, L.E., K.H. REED, M.R. GEBHARDT, and C.L. DAY, 1969. An evaluation of herbicide incorporation equipment. Res. Bull. 946, Columbia Agric. Exp. Sta., Mo.

BUTLER, B.J. and J.C. SIEMENS. 1972. Incorporation of surface applied pesticides. Proc. 24th Illinois Custom Spray Operators Training School. pp. 22-26.

HOLROYD, J. 1964. Field investigations concerning the selective phytotoxicity of Di-Allate to *Avena* spp. in wheat and barley. Weed. Res. 4: 142-166.

HULBERT, W.C. and R.G. MENZEL. 1953. Soil mixing characteristics of tillage implements. Agric. Eng. 34: 702-708.

LAL, R. and W.B. REED. 1976. Report on engineering study of wild oats control 1975-76. Unpublished Research Report, Agricultural Engineering Department, University of Saskatchewan, Saskatoon, Sask.

MATTHEWS, E.J. 1970. Chloride tracer evaluation of herbicides incorporation tools. Trans. Amer. Soc. Agric. Eng. 13: 64—66.