Throwing out mines: effects of a flail

Geneva International Centre for
Humanitarian Demining
Centre International de
Déminage Humanitaire - Genève

The **Geneva International Centre for Humanitarian Demining** (GICHD) supports the efforts of the international community in reducing the impact of mines and unexploded ordnance. The Centre provides operational assistance, is active in research and supports the implementation of the Anti-Personnel Mine Ban Convention.

For further information please contact:

Geneva International Centre for Humanitarian Demining
7bis, avenue de la Paix
P.O. Box 1300
CH-1211 Geneva 1
Switzerland
Tel. (41 22) 906 1660
Fax (41 22) 906 1690
www.gichd.ch
info@gichd.ch

Throwing out mines: effects of a flail, GICHD, Geneva, November 2005

This project was planned by Havard Bach and Johannes Dirscherl, with report preparation and data analysis by Ian McLean and Rebecca Sargisson, bach@gichd.ch.

Contents

Summary **1**

Introduction **2**

Methods **3**

Results **5**

All soil types, 60-mm mines only 6
Distance thrown 6
Angle of throw 6
Visibility of 60-mm mines after flailing 6
All mine sizes 8
Distance thrown 8
Angle of throw 8
Visibility of all mines after flailing 8

Discussion **10**

Acknowledgements

The Geneva International Centre for Humanitarian Demining (GICHD) would like to thank Goran Ericsson, and the rest of the SWEDEC team, for providing equipment and supporting the study in many ways. Funding was provided by the governments of Germany, Norway and Sweden.

Summary

- The test was of throw-out of mine-mimics (hard plastic discs) by a small flail.
- Tested, were: three soil types (Topsoil, Sand, Gravel), four laying depths (0, 5, 10, 15 cm), and 3 mine sizes (60, 90, 110 mm).
- Most mines were left within 2 m of where they had been laid, usually just behind the laying site. However, a small proportion of mines were thrown considerable distances; >9 m: 2.2%, >4 m: 5.6%. The largest distance a mine was thrown was 65 m.
- Mines were thrown further from Topsoil and were more likely to be visible if laid in Topsoil, than for the other two soil types, which were similar to each other.
- Throw patterns were not linked to laying depth or size of mine.
- Mines were mostly thrown either directly forward or directly backward. Very few were thrown laterally forward.
- The flail threw significantly more mines to the right than to the left, which has implications for best deployment procedures.
- Visibility of thrown mines was linked to size, with larger mines being more visible after flailing.

Introduction

Recent tests and trials on the clearance capability of flail machines have shown that if machines are adequately operated and the operating environment is favourable, flails are able to achieve clearance rates approaching 100%[1]. However, some field operators have experienced clearance rates as low as 50-60%. An important reason for the discrepancy is that a proportion of aged mines have faulty detonation mechanisms[2]. Having failed to detonate, some also remain apparently intact after flailing. When found by QA teams, these mines are reported as missed because examining their firing mechanism is time consuming and dangerous. The resulting under-representation of clearance capability suggests that flail machines should only be used as ground preparation for subsequent demining, a conclusion that we believe to be inappropriate.

To satisfy the requirements of statistical analyses, tests on clearance capability of flail machines require a large number of mines. Real mines are scarce, mine mimics are expensive, and tests tend to use too few mines to support statistical analysis. Despite such resource constraints, a continued effort to test machines is desirable and should be prioritized. Clearly, any study designed to explore the proportion of mines that are initiated or broken up by a machine will need to use real mines. However, some research questions allow testing without using real mines (or real mine-mimics).

Here, we investigate the pattern of throw-out for mines that are not broken up or destroyed by a flail. The study used unbreakable “mine-mimics”, so explored issues of throw-out only. The results address issues about the direction and distance at which mines are likely to be thrown and their visibility after flailing, in relation to standard treatment factors in mine clearance (soil type and mine depth).

[1] GICHD, 2004; A study of mechanical application in demining, GICHD, Geneva
[2] Many mines found in Bosnia today in ground where there is regular frost and rainfall are not functional due to age and environmental effects (T. Berntsen, pers. comm.)

Methods

The study was conducted at the SWEDEC test site in Eksjö, Sweden, in early December 2003.

All tests fields were laid out in the same way: a strip 5 m long and 80 cm wide within a soil platform 3 m wide (*Figure 1*). Twenty mines (hard rubber discs) were laid in a standard array in the strip, giving a standard sample size for each treatment combination of 20 (or slightly less in a few cases of missing data).

The treatment variables were:

- 3 x soil (Sand, Gravel, Topsoil)
- 4 x depth (0, 5, 10, 15 cm)
- 3 x size of mine (60, 90, 110 mm diameter)

Sand and gravel were tested with all mine sizes and depths. Topsoil was tested with 60-mm mines only, although at all treatment depths.

The machine, a DOK-ING MV4, was run once only along the strip in the direction indicated in Figure 1, which is treated as “north” for analyses of throw angle. This machine has a clearance width of 1.725 m^3, thus the test clearance strip of 80 cm gave a margin of error of about 45 cm on each side.

Parameters measured were:

- Distance the mine was thrown
- Direction the mine was thrown
- Visibility of the mine after flailing

Because not all possible treatment combinations were used, two sets of analyses were run:

- For all soil types; 60 mm mines only.
- For all mine sizes; sand and gravel only.

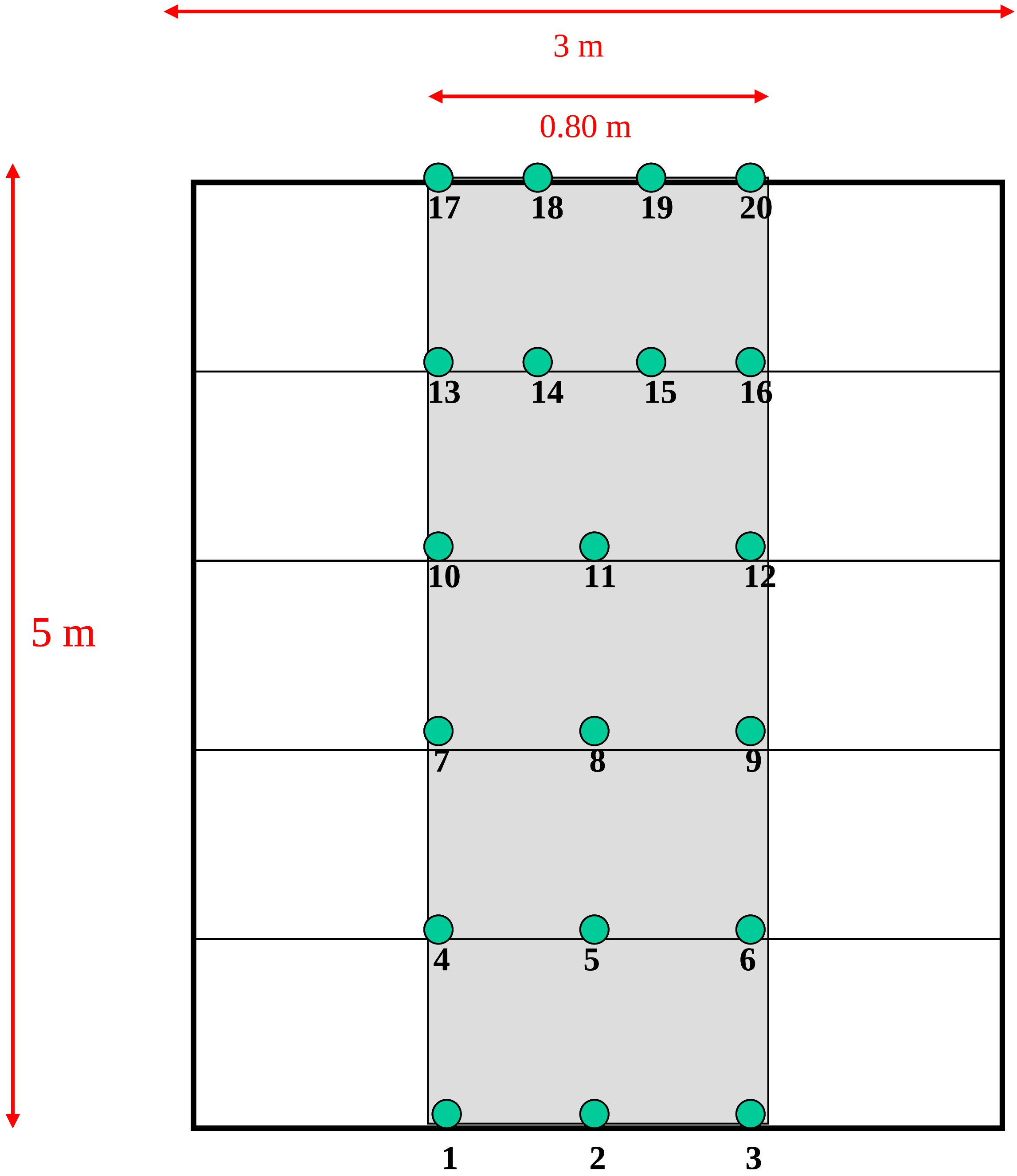
Angle (direction) of throw required some adjustment for statistical analysis and visual representation for the following reasons:

- The mean of several angles might not portray a sensible conceptual pattern. For example, if one mine is thrown forward (20 degrees) and another is thrown backwards (160 degrees), the average throw direction for these two mines (90 degrees) does not portray a sensible direction in absolute terms. The data given in Table 2 are means, and are useful for statistical comparison between treatments, but they should not be used to represent typical throw angles.

A similar problem applies to mines thrown to left or right. Mines thrown at 20 degrees and 340 degrees are thrown at equivalent angles in terms of forward direction, but the mean (180 degrees) is clearly inappropriate. To address this problem, the data were adjusted for analysis so that all mines were thrown on one side only.

[3] GICHD, 2004; Mechanical Demining Equipment Catalogue, GICHD, Geneva

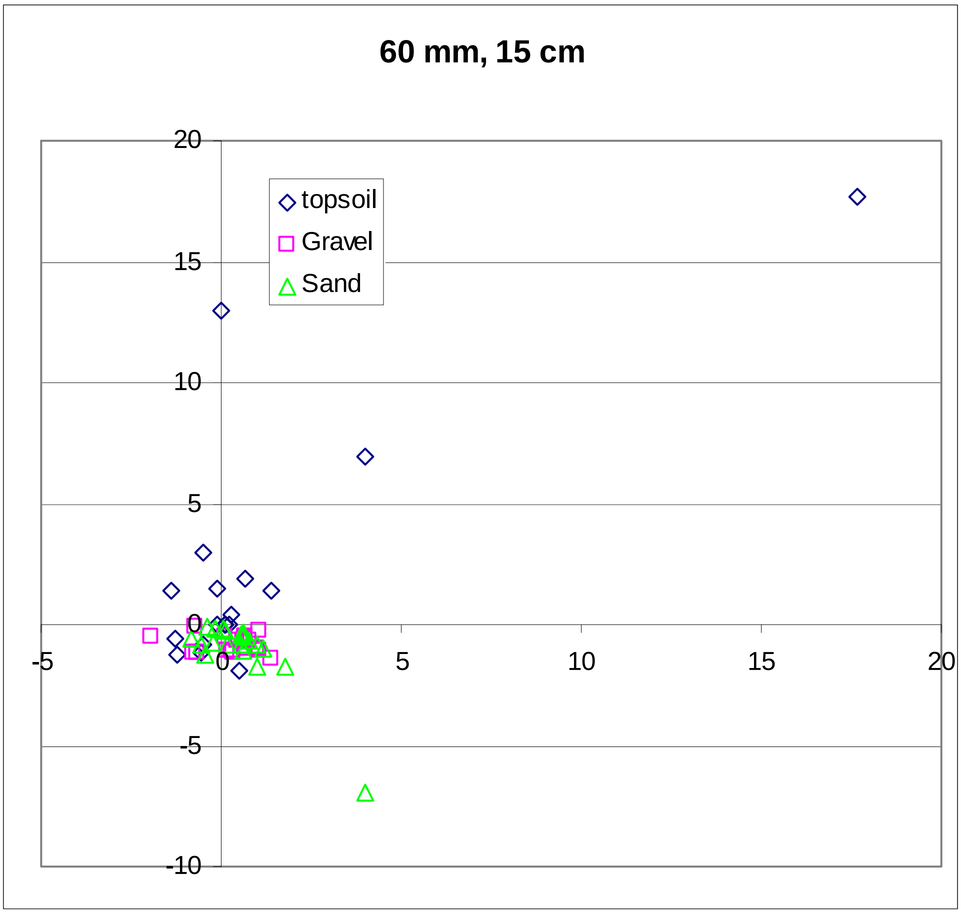
Figure 1. The standard layout of test strips for the throw-out tests



Results

A typical throw-out result, seen in *Figure 2*, is for 60-mm mines buried at 15 cm in the three soil types. In this figure, the (0,0) point is the original site at which the mine was laid, and the datum points indicate where the mine was thrown to after flailing. Most mines remained close to and slightly behind where they were laid. If these were real mines, they would likely be: i) compressed into the soil (although they might be exposed due to soil disruption), ii) initiated, or iii) broken up. A small number of mines were thrown several metres, and a very small number were thrown a considerable distance, which in this case included a mine thrown 25 m. Mines thrown several or more metres were generally thrown forward.

Figure 2. Throw-out effect after flailing for 60-mm mines laid at 15 cm in three soil types. X and Y axes are distance in metres.



Summaries of all data are in Tables 1 and 2. In order to eliminate bias in the means due to extreme values, all throw distances >10 m were removed for calculation of means and variances in these tables. The extreme values are noted in the ranges, but the N's are those used to calculate the means.

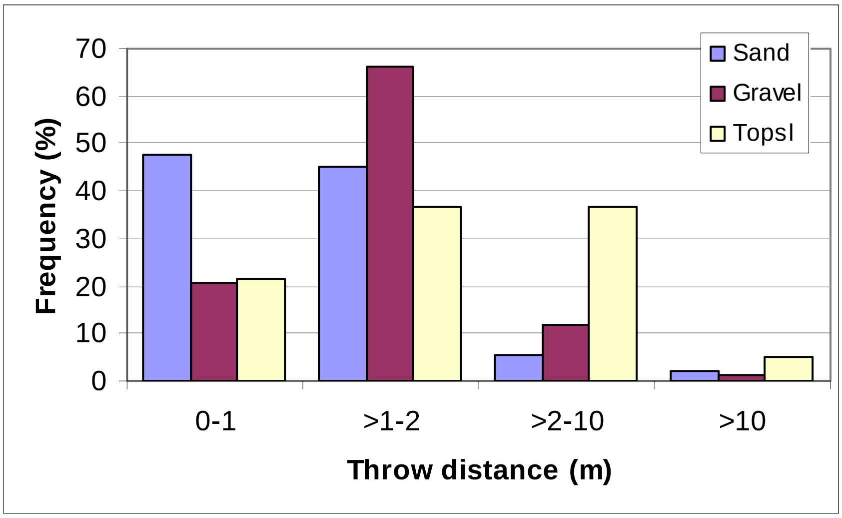
Extreme throw distances include the following values (in m): 65, 50, 2 x 25, 2 x 15. Of a total of 555 mines for which data were available, 2.2% (12) were thrown >9 m, and 5.6% (31) were thrown >4 m.

All soil types, 60-mm mines only

Distance thrown

Significant variation was found for distance thrown in different soils, with mines thrown greater distances in Topsoil, relative to Sand and Gravel (*Figure 3*, $F_{2,227} = 10.7$, $P = 0.00$). There was no significant difference between Sand and Gravel.

Figure 3. Distances mines were thrown in three soil types



Angle of throw

Side (laterality) of throw was investigated across all soils and depths for the 60-mm mines. Mines thrown directly forward (0±9 degrees) or backward (180±9 degrees) were removed from this analysis.

Ignoring soil type and depth, significantly more mines were thrown to the right (136) than to the left (79) ($X^2=7.6$, $P<0.01$), indicating that the flail had an asymmetric action.

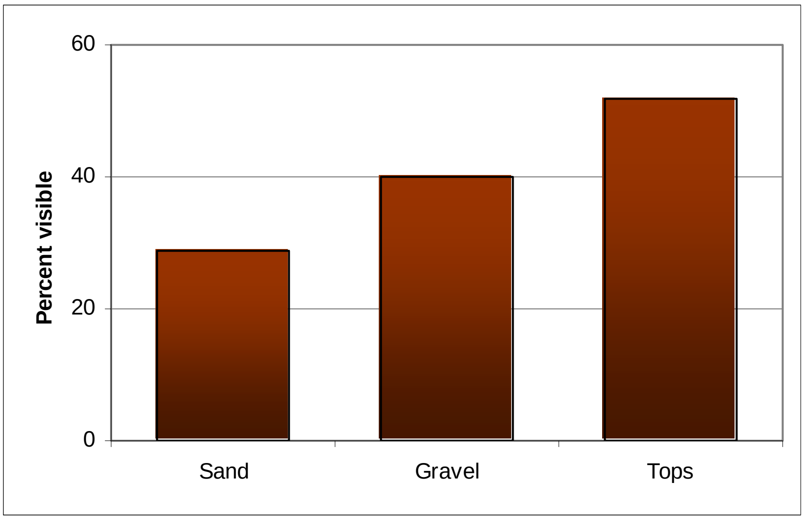
No significant effects were found for angle of throw in relation to soil type or depth for the 60-mm mines. The data for angle were therefore lumped across all soil and mine types, and are reported below.

Visibility of 60-mm mines after flailing

About 40% of the 60-mm mines were visible after the flail had been through.

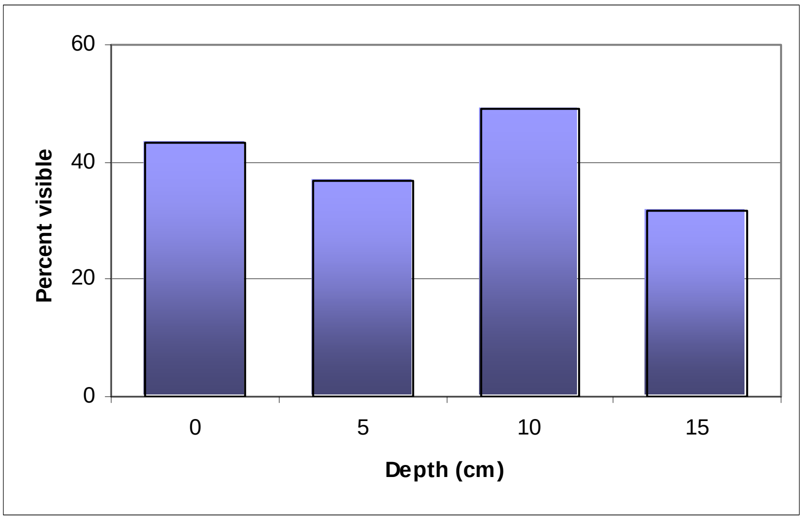
After flailing, most mines were visible in Topsoil and fewest were visible in Sand (*Figure 4*), although the pattern was not quite statistically significant (X^2=5.3, P=0.07). One reason for the greater visibility in Topsoil is that mines were thrown farther from Topsoil, and were therefore more likely to be thrown outside the test strip where they would not be covered by the machine. This effect is less likely in a minefield, where a large area is flailed. The greater visibility of mines in gravel is likely due to the coarse texture of gravel relative to sand.

Figure 4. Proportion of 60-mm mines visible after flailing in relation to soil type



The proportion of 60-mm mines visible after flailing did not vary significantly in relation to depth (X^2 = 2.6, d.f.=3, P=0.45; *Figure 5*).

Figure 5. Proportion of mines visible after flailing in relation to original burial depth



All mine sizes

Distance thrown

In sand and gravel, there were no significant effects on throw distance of either mine size ($F_{2,464}$ = 0.37, NS) or mine depth ($F_{2,464}$ = 1.19, NS). The interaction between size and depth was not significant ($F_{6,464}$ = 1.07, NS). Thus mines of all sizes and depths were thrown similar distances in sand and gravel.

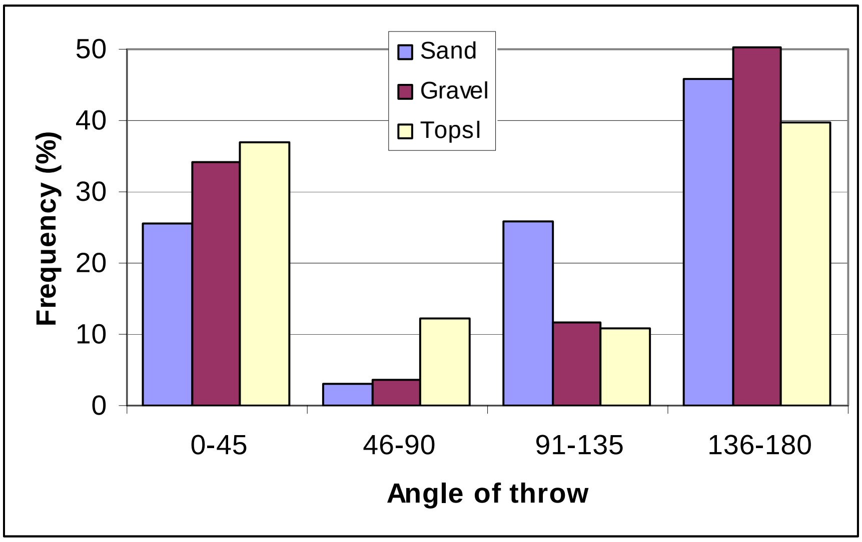
Angle of throw

As already reported for 60-mm mines in all three soil types, mines of all sizes were thrown more to the right than to the left in Sand (L:R, 65:148; X^2=16.8, P=0.00) and in Gravel (L:R, 85:136; X^2=5.8, P=0.016).

The angle of throw for all mines is summarized in *Figure 6*. Included in Sand and Gravel are mines of 3 sizes (60, 90, 110 mm), whereas only 60-mm mines were included with Topsoil. Adjusted data (all mines thrown to one side) were used for this analysis.

In general, most mines were thrown either directly forward (0-45) or directly backward (136-180), with a higher proportion of mines thrown backward overall. Very few mines were thrown laterally forward (46-90). The highest proportion of mines thrown forward was from Topsoil.

Figure 6. Summary of angle of throw using the data converted to one side of a compass only (i.e. ignoring laterality of throw), for mines in three soil types



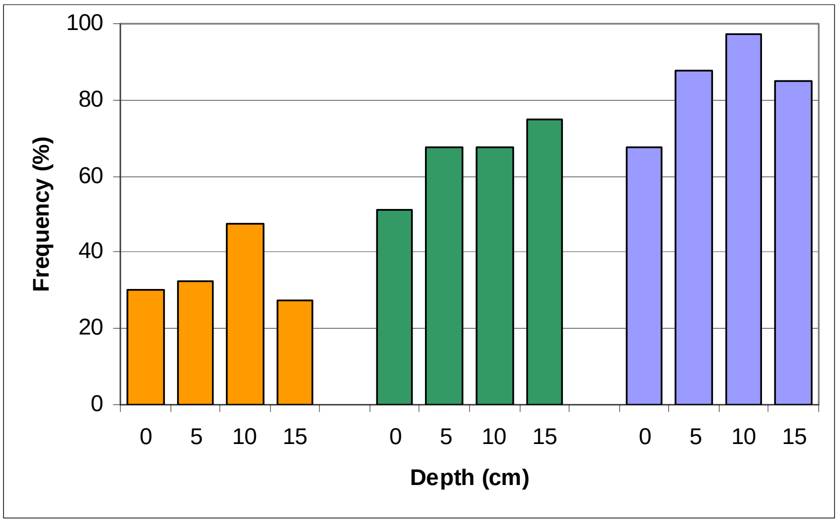
No relationship between angle of throw and soil type was found for 60-mm mines (above). However, when data for all mine sizes were used (Sand and Gravel only), mines were thrown behind significantly more in Sand than in Gravel ($F_{1,452}$ = 4.21, P=0.04; data in Table 2).

Visibility of all mines after flailing

Figure 7 shows the proportion of mines visible in Sand and Gravel after the flail had completed its run for three mine sizes. Mines were increasingly likely to be visible with increasing size, with small mines being mostly buried and large mines being mostly visible. The pattern was highly significant using data lumped by original burial depth (X^2=31.3, 2 d.f., P=0.00).

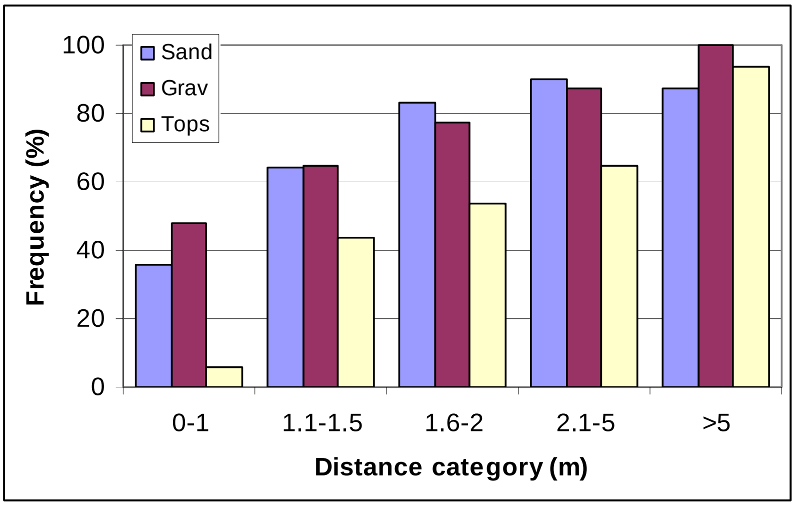
There is a suggestion in *Figure 7* that original depth of burial affected visibility, with deeper buried mines being more visible after the flail. The effect was not significant using data lumped across mine size (X^2=3.9, 3 d.f., P=0.27).

Figure 7. Visibility of mines of different sizes after flailing (60 mm: orange; 90 mm: green; 110 mm: blue)



Visibility of mines increased with distance thrown (*Figure 8*). This effect was expected for mines thrown bigger distances, as those mines were thrown outside the clearance strip. Many of the mines that moved 1 m or less were likely compressed into the soil, whereas mines that moved several metres were more likely to have been lifted out of the ground before being deflected back downwards by components of the flail.

Figure 8. Visibility of mines after flailing in relation to distance thrown



Discussion

The flail is designed to prevent mines being thrown big distances, and the effectiveness of that design can be seen in the high proportion of mines left close to their original laying site. A proportion of those mines would likely be compressed into the soil without being initiated or broken up. However, repeated passes with the flail should ensure that essentially all of them are rendered safe.

Mines that were thrown up to several metres are likely to have been pulled out of the ground by the chains, and then deflected back downwards by the deflector plate or other components of the flail. Although many remained in the clearance strip, such mines are more likely to be visible than mines that were compressed, because they were lifted rather than beaten. Mines that are pulled out of the ground are less likely to be broken up or initiated, and might therefore be in better condition after flailing.

A small proportion of mines were thrown big distances, presumably because the chains hooked the mine past the deflector plate. Clearly, the flail design is not entirely effective at preventing long-distance throws. Mines were more likely to be thrown forward, presumably due to the forward rotation of the chains and the protection behind the chains. Such mines could be thrown into previously cleared strips, or even outside the mine field. Repeated passes are less likely to re-process such mines, particularly if the field is flailed in sectors. This is a small machine, and it seems likely that larger machines could throw mines even greater distances than the maximum seen here of 65 m.

This flail tended to throw mines to the right. Given that it is impossible to prevent such throw completely, it might be possible to adjust the action of the chains and design of the deflector plate to force an even higher proportion of mines to one side. Whether the laterality of throw is a characteristic of this individual flail, or of the model generally, does not matter. What matters is that with laterality of throw known, the machine can be deployed to ensure that the main direction of throw is into areas that are not yet processed. This machine would be best deployed either in a clockwise direction from the perimeter of the minefield, or an anti-clockwise direction from the centre. With respect to mine throw, working the machine back and forth along parallel lines would not be a good way to use this machine.

Soil type was the primary factor determining throw patterns. Mine size and depth of laying were relatively unimportant. The depth setting of the flail is likely to affect some values in the data, but the overall patterns found for mine size and depth should be similar.

Clearly, given the results here, tests of this sort on different makes and sizes of flails are desirable. The GICHD plans to continue with these tests, but they should perhaps also be done by the manufacturers so that advice can be given to purchasers on laterality of throw, proportion of mines thrown beyond the flail, and likely maximum throw distance.

Table 1. Summary of data for throw distance (Dist), in metres. S.E. = standard error.

Soil	Depth (cm)	Size (mm)	Mean Dist	S.E.	N	Range
Sand	0	60	2.0	0.44	20	0.3-15
Sand	0	90	2.2	0.54	19	0.3-25
Sand	0	110	1.0	0.15	20	0.2-2
Sand	5	60	1.2	0.19	20	0.5-3
Sand	5	90	1.6	0.24	20	0.6-5
Sand	5	110	2.0	0.28	20	0.4-4
Sand	10	60	1.6	0.40	20	0.3-15
Sand	10	90	0.9	0.15	20	0.2-1.8
Sand	10	110	1.4	0.17	17	0.5-1.8
Sand	15	60	1.3	0.29	20	0.2-8
Sand	15	90	1.1	0.24	20	0.3-1.4
Sand	15	110	1.9	0.38	20	0.2-14
Gravel	0	60	3.8	0.74	20	0.4-50
Gravel	0	90	1.5	0.13	20	1-2.3
Gravel	0	110	2.0	0.18	20	1.1-3.4
Gravel	5	60	1.6	0.26	20	0.4-7
Gravel	5	90	1.4	0.18	20	0.2-3
Gravel	5	110	1.5	0.19	20	0.3-3
Gravel	10	60	1.9	0.33	20	0.5-11
Gravel	10	90	1.3	0.14	20	0.5-2
Gravel	10	110	1.3	0.17	20	0.1-2.4
Gravel	15	60	1.2	0.14	20	0.5-2
Gravel	15	90	2.7	0.40	20	0.3-8
Gravel	15	110	1.6	0.28	20	0.4-8
Topsoil	0	60	4.0	0.40	20	0.3-9
Topsoil	5	60	5.8	0.84	20	0.5-65
Topsoil	10	60	3.0	0.42	19	0.1-10
Topsoil	15	60	3.3	0.55	20	0.1-25

Table 2. Summary of data for throw direction (adjusted data for one side of the compass only).
The flail moved in direction north; thus 0º = N, 180º = S.

Soil	Depth (cm)	Size (mm)	Mean Angle	S.E.	N
Sand	0	60	97.0	1.65	20
Sand	0	90	116.3	1.47	19
Sand	0	110	120.5	1.59	20
Sand	5	60	127.0	1.49	20
Sand	5	90	118.5	1.79	20
Sand	5	110	125.5	1.60	20
Sand	10	60	92.8	1.77	20
Sand	10	90	127.3	1.56	20
Sand	10	110	117.1	1.90	17
Sand	15	60	112.0	1.59	20
Sand	15	90	122.0	1.68	20
Sand	15	110	107.0	1.83	20
Gravel	0	60	97.8	1.89	20
Gravel	0	90	92.0	1.79	20
Gravel	0	110	113.0	1.81	20
Gravel	5	60	100.3	1.76	20
Gravel	5	90	114.5	1.66	20
Gravel	5	110	102.5	1.84	20
Gravel	10	60	100.3	1.81	20
Gravel	10	90	97.8	1.87	20
Gravel	10	110	79.5	1.85	20
Gravel	15	60	123.5	1.41	20
Gravel	15	90	120.8	1.72	20
Gravel	15	110	107.3	1.78	20
Topsoil	0	60	103.8	1.86	20
Topsoil	5	60	107.5	1.70	20
Topsoil	10	60	95.3	1.77	19
Topsoil	15	60	75.3	1.62	20