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Report on the Mine Clearing Rake Test

October 2006

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Operational Evaluation Test Report on the Mine Clearing Rake

October 2006

EXECUTIVE SUMMARY

1. Background: Interest has been expressed in seeing the Mine Clearing Rake (MCR) included in the tool box offered to organizations for application in humanitarian demining (HD) missions. Given that there is no track record of operational utilization of the MCR by HD organizations, the U.S. Army's Humanitarian Demining Program Manager (HD PM), under the U.S. Army's Night Vision and Electronic Sensors Directorate (NVESD) located at Ft. Belvoir, VA, undertook the task to conduct an operational evaluation test of the MCR.

2. Purpose: The purpose of the operational evaluation test was to assess the ability of the MCR to enhance the effectiveness of a humanitarian demining mission. To this end, the HD PM purchased an MCR and initiated the testing process.

3. Scope and Limitations: The test was designed to assess the ability of the MCR to uncover and lift mines from two different demining environments. The first, designated as Test Site 1, was a vegetation-covered rolling field of sandy loam soil. Test Site 2 was a desert environment of level sand. While there were claims that the MCR would work against anti-tank mines, the test was limited to assess performance against anti-personnel mines, by far the largest threat faced by humanitarian deminers. The two guidelines followed while developing the test protocols were: design the test to assess the MCR's capabilities, and, to remove any obstacle from the test environment that might degrade the MCR's performance, by equipment normally found in a humanitarian demining organization.

4. Operational Demining Tasks Considered for the MCR: Based on the claims made regarding the MCR's performance, three distinct HD phases were considered for assessing the MCR's capabilities. These were the area preparation, demining, and quality assurance phases. Of the three, the area preparation and demining phases were considered poor choices for the MCR since it required driving the primary power source for the MCR, in this case a tractor, over potentially mined ground, creating a significant safety risk for the driver and vehicle. The quality assurance task, while still posing some risk was considered an acceptable risk.

5. Test and Test Results: At Test Site 1, 100 test targets (anti-personnel inert and replica mines) were buried in the test area at a depth of 2 inches (5 cm) to the top of the mines. The area was prepared by mowing and extensive plowing and cultivation before testing the MCR. Eighty-two mines were uncovered during the area preparation, leaving 18 mines to be found by the MCR. At the end of 2½ hours of operating the MCR, not a single mine was uncovered. The test was also impeded by clogging of the MCR with mowing debris and grass roots, which caused the buildup of dirt in a bow wave fashion in front of the MCR resulting in the digging knives being raised out of the ground.

At Test Site 2, the MCR was tested against 10 anti-personnel mines which were engaged by the MCR in a single pass. The result was a bow wave of sand developed at

the front of the MCR within 3 lengths of the MCR from the start of the test. This bow wave persisted until the end of the test run, a distance of approximately 80 m. When the sand buildup in front of the digging knives array was shoveled away, seven of the mines were found buried in the sand against the front edges of the digging knives, having been pushed by the MCR for 145 feet (44 m) from where they were buried to the end of the test run. If these had been live mines, safe demining procedures would call for a deminer to probe the bow wave of sand to find and uncover the mines by hand. One of the remaining mines was found buried in the sand accumulation under the drag mat. Another was found partially uncovered but not lifted out of its original position. The tenth mine was found where it was buried and was later removed using a shovel.

6. Recommendation: Based on the performance of the Mine Clearing Rake during this operational evaluation test, it should not be considered for use in Humanitarian Demining operations.

FOREWORD

The Mine Clearing Rake (MCR) was evaluated in an Operational Evaluation Test in October 2006 at a U.S. Army Countermine Test Facility in central Virginia. The test was conducted by the U.S. Army's Night Vision and Electronic Sensors Directorate (NVESD), Countermine Division, Humanitarian Demining (HD) Program Office, as the result of a request from the Office, Assistant Secretary of Defense, Special Operations and Low-Intensity Conflict (OASD/SOLIC). The MCR was first tested by the Army in 1991 for its potential as a countermine asset. The current test program was to determine to what extent the MCR enhances the effectiveness of a humanitarian demining mission.

CONTENTS

1	Introduction.....	1
1.1	Background	1
1.2	Purpose.....	1
2	System Description.....	1
3	Test Site Description and Area Preparation	4
3.1	Test Site Weather	6
3.2	Test Targets.....	6
4	MCR Test Preparation	8
5	MCR Operational Performance Test.....	8
5.1	Test Site 1	8
5.2	Sand Test Site	11
6	Test Results.....	13
6.1	Mine Recovery - Test Site 1 (Vegetation-Covered, Sandy Loam Soil)	13
6.2	MCR Operational Efficiency - Test Site 1	13
6.3	Mine Recovery – Test Site 2 (Sand Soil).....	14
6.4	Operational Efficiency – Test Site 2.....	14
7	Recommendation.....	14
	Appendix A Test Support Personnel.....	15
	GLOSSARY.....	16

FIGURES

Figure 1. Mine Clearing Rake.....	1
Figure 2. Fendt 918 Tractor	2
Figure 3. Loftness Vegetation Cutter.....	2
Figure 4. Krause Chisel Plow	2
Figure 5. Unverferth Spring Cultivator.....	2
Figure 6. MCR	2
Figure 7. Unprepared Test Site 1	5
Figure 8. Vegetation Cutting.....	5
Figure 9. Plowing of Site	5
Figure 10. After Plowing	5
Figure 11. Cultivating Site.....	5
Figure 12. Cultivating Completed.....	5
Figure 13. Test Site 2 (Sand Test Site)	6
Figure 14. Layout of Test Site 1 Showing Mine Location and Pattern	7
Figure 15. Layout of Test Site 2 Showing Mine Location and Pattern	7
Figure 16. Ready for MCR Test	8
Figure 17. MCR Bow Wave	9
Figure 18. Knives out of Ground	9
Figure 19. Clearing the MCR.....	10
Figure 20. Cleaning Rake	10
Figure 21. Surface-Laid Mine.....	10
Figure 22. Surface-Laid Mine Remaining on Ground	11
Figure 23. Accumulation at the Digging Tines.....	11
Figure 24. Accumulation within the Drag Mat.....	11
Figure 25. Mine Found in Accumulation Heap	12
Figure 26. Two Mines Found Stacked within Accumulation Heap.....	12
Figure 27. Mine Found within Drag Mat Accumulation	12
Figure 28. Exposed Mine in Original Location	13
Figure 29. Tenth Mine Found After Shoveling	13

TABLES

Table 1. Fendt 918 Vario Tractor	3
Table 2. Mine Clearing Rake	3
Table 3. Loftness Vegetation Cutter	3
Table 4. Krause Chisel Plow.....	3
Table 5. Unverferth Spring Cultivator	4
Table 6. Mines Found During MCR Performance Test.....	13

1 Introduction

1.1 Background

In early 2006, at the request of the Office, Assistant Secretary of Defense (Special Operations & Low-Intensity Conflict) [OASD(SOLIC)], the U.S. Army's Humanitarian Demining (HD) Program Office, initiated a program to procure and perform an operational performance test on the Mine Clearing Rake, hereafter referred to as MCR. The MCR was first tested by the U.S. Army in 1991 at an arid U.S. Army test site. During the intervening years, the MCR, in an earlier configuration, was tested for Army use by the U.S. Army Countermine Division.

1.2 Purpose

The purpose of the operational performance test is to determine to what extent the MCR enhances the effectiveness of a humanitarian demining mission. The test will assess the utility of the MCR as both an area preparation tool leading up to the demining phase, and as a quality assurance tool at the end of the demining phase.

2 System Description

The MCR is comprised of three digging knife units and a drag mat/chain harrow. The MCR, as tested, is shown in Figure 1. This configuration, with the digging knives in a straight line across the front of the MCR, was selected during familiarization runs with the MCR as the one offering the best MCR performance and control of the

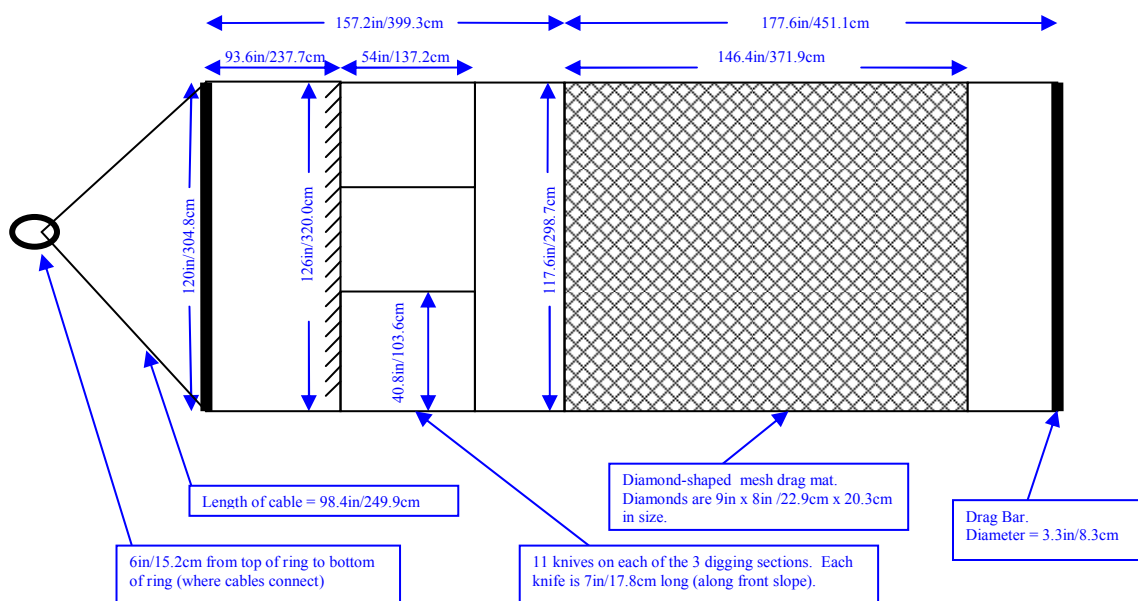


Figure 1. Mine Clearing Rake (MCR)

MCR while towing and turning. The tools used in the MCR test were a Fendt 918 Vario tractor (Figure 2), a Loftness 918 Timber Ax Extreme vegetation cutter (Figure 3), a Krause 4830-730F Chisel Plow (Figure 4), an Unverferth Perfecta II Spring Cultivator (Figure 5), and the MCR (Figure 6).



Figure 2. Fendt 918 Tractor



Figure 3. Loftness Vegetation Cutter



Figure 4. Krause Chisel Plow



Figure 5. Unverferth Spring Cultivator



Figure 6. MCR

Specification information supplied by the manufacturers of each of the tools is presented below in Tables 1 through 5.

Table 1. Fendt 918 Vario Tractor

Item	Measurement / Dimension
Max Height, to top of cab	10.15/3095 ft/mm
Min Working Clearances under axles	1.98/605 ft/mm
Max Width	8.17/2490 ft/mm
Max Length	16.2/4938 ft/mm
Max Shipping Weight	17945/8138 lbs/kg
Fuel Capacity	530 liters
Oil Capacity	24 liters
Hydraulic Fluid Capacity	65 liters

Table 2. Mine Clearing Rake

Item	Measurement / Dimension
Length (overall)	334.8/8504 in/mm
Width (overall)	125.5/3188 in/mm
Mine Lifting Knife Sections/Width	125.5/3188 in/mm
Number of Knives per Section	11
Knife Length	7/177.8 in/mm
Harrow Grid	8x9 / 203x229 in/mm
MCR Fielded Weight	/ lbs/kg

Table 3. Loftness Vegetation Cutter

Item	Measurement / Dimension
Width	117/2972 in/mm
Cutter Fielded Weight	4980/2259 lbs/kg
Width of Cut	93/2362 in/mm
Number of Knives	20

Table 4. Krause Chisel Plow

Item	Measurement / Dimension
Width	210/5334 in/mm
Plow Shipping Weight	5364/2433 lbs/kg
Number of Shanks	7
Row Spacing	30/762 in/mm

Table 5. Unverferth Spring Cultivator

Item	Measurement / Dimension
Width (collapsed)	150/3810 in/mm
Width (extended)	240/6096 in/mm
Folded Height	87/2210 in/mm
Cultivator Fielded Weight	2545/1154.4 lbs/kg
Number of S-Tines	37
Number of Leveling Bar Teeth	40

3 Test Site Description and Area Preparation

The MCR operational performance test was conducted at a U.S. Army countermine testing facility in late October 2006. Two test sites were selected. Test Site 1, laid out to replicate an anti-personnel minefield, was 9922 m² (141m x 70m) of gently rolling terrain made up of sandy loam soil heavily covered with field grass, small shrubs and young trees. Test Site 2 was a 2100 m² (92m x 23m) sand area. Both sites were considered suitable for assessing the mine-lifting capability of the MCR and assessing the utility that the MCR might add to Humanitarian Demining missions.

During the familiarization phase of the test, while towing the MCR on a lightly sodded, previously tilled field, it became readily evident that the digging knives at the front of the MCR became clogged with grass and roots which then caused dirt to quickly build up into a bow wave along the front of the mounting bar for the digging knives. The build-up of dirt created additional drag (resistive) forces which caused the digging knives to come out of the ground. This situation continued even after the 6 inch anchoring chains were attached to the back-end of the rake section. As a result, the decision was made that the MCR would be tested only in soil that had been repeatedly plowed and cultivated, resulting in soil conditions that might be more representative of a quality assurance phase.

Test Site 1 (141m x 70m) allowed 25 - 30 meters at each end for 180° turns with the MCR between successive passes over the test area. While the vegetation in the total 141m x 70m area was cut with the Loftness vegetation cutter, only the central 70m x 70m MCR test area was plowed and cultivated prior to testing the MCR. Photos of the area preparation process of the first test site are presented in Figures 7 through 12. By the time the test site was considered ready for MCR testing, the test site surface was primarily powdered loam, free of surface grass and shrubs, ready for crop planting. However, the soil still contained pieces of shredded grass and root systems mixed into the soil by the plow and cultivator.



Figure 7. Unprepared Test Site 1



Figure 8. Vegetation Cutting



Figure 9. Plowing of Site



Figure 10. After Plowing



Figure 11. Cultivating Site



Figure 12. Cultivating Complete

There was no need for any preparation of the sand test area (see Figure 13).



Figure 13. Test Site 2 (Sand Test Site)

3.1 Test Site Weather

Weather for the MCR test at both test sites was moderate in temperature 55° to 60° F (13° to 15° C), with a light, drying breeze. Humidity was low, with a very light early-morning dew which was gone by 0830 hrs due to the breeze. There was no rain for at least 72 hours before testing.

3.2 Test Targets

A total of 100 test mines were buried in the center of the Test Site 1 before any area preparation (cutting, plowing, cultivating) was done. The mines were buried at a depth of 5cm to the top of each mine, with 50 mines at 1m intervals in each of two staggered rows. There was a 1m separation between the rows. There was a 10m unmined area between the end of each row and the sides of the test area. All mines were models of actual AP mines. The types and numbers of each mine were:

PMA2	20
PMD6	24
VS50	24
PMN	32

A layout of Test Site 1 is shown in Figure 14.

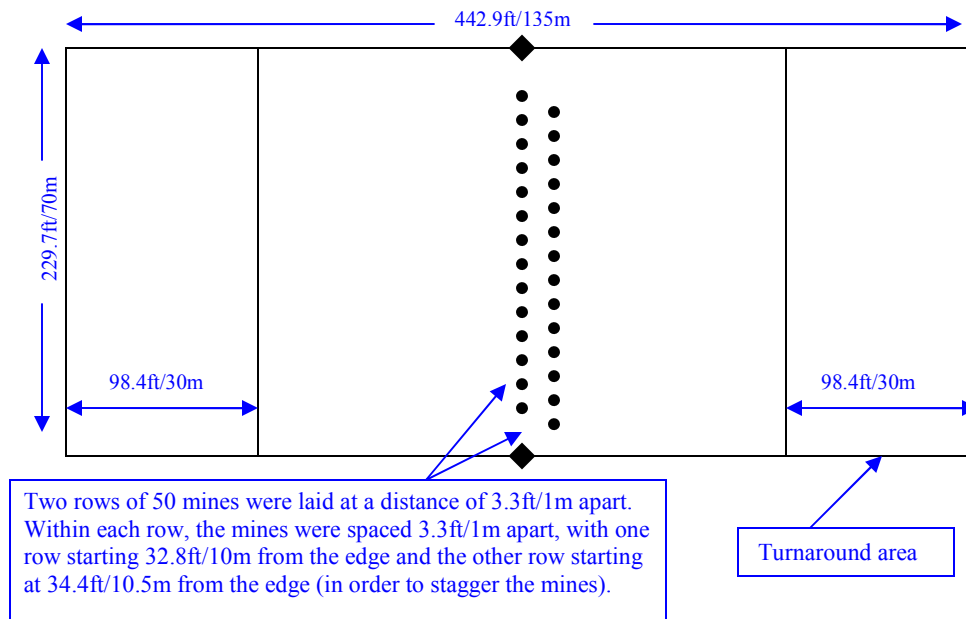


Figure 14. Layout of Test Site 1 Showing Mine Location and Pattern

At Test Site 2, the sand site, ten mines were buried. These mines were of the same size and type as those used in Test Site 1. The mines were buried in a scattered pattern along a 1.5 m strip in the center of the field to a depth of 5 cm to the top of the mine. A layout of the Test Site 2 is shown in Figure 15.

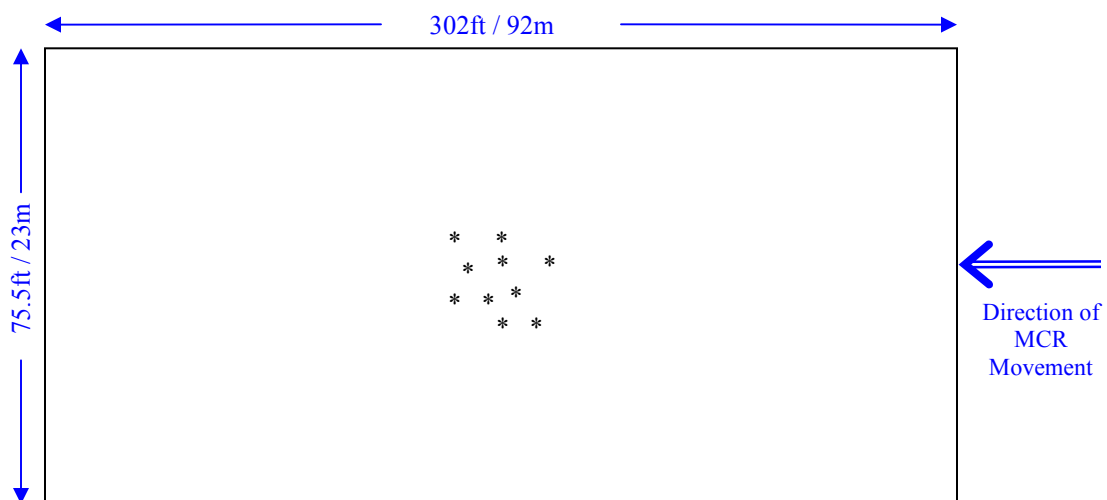


Figure 15. Layout of Test Site 2 Showing Mine Location and Pattern

4 MCR Test Preparation

A drawing of Test Site 1 area is shown in Figure 14. The area devoted to the actual test of the MCR was 75m x 70m, with 30m at each end set aside to allow adequate room to perform 180° turns without tipping the MCR between successive passes through the prepared test area.

Mowing of the 135m x 70m area took 2 hours 10 minutes. Average mowing speed was 1.5 mph (2.5 kph). Plowing the MCR test area (75m x 70m) took 3 hours 4 minutes until the soil was judged to be sufficiently broken up to be ready for working with the spring cultivator. Plowing speeds ranged from very slow to a maximum of 5 mph (8.3 kph). The MCR test area was worked with the spring cultivator for 3 hours 21 minutes to insure that the test area was free clumps of sod at speeds of 1.5 to 5 mph (2.5 to 8.3 kph). At this point in the preparation process, the test area resembled mine-cleared areas ready for final quality assurance testing. Figure 16 shows the prepared Test Site 1 field.



Figure 16. Field Ready for MCR Test

Test Site 2, the sand soil test area, required no preparation before MCR testing. While there was spotty evidence of wild grass seed having germinated in the sand, the lack of nutrients in the sand caused the grass shoots to quickly die.

5 MCR Operational Performance Test

5.1 Test Site 1

Testing of the MCR at Test Site 1 started about mid-day and continued for approximately 2½ hours. The weather was mild (~60° F [15.5 ° C]), spotty clouds, low humidity, and a slight breeze. Soil in the test area was dry, powdery, and well cultivated to a depth of 6-8 inches (15-20 cm). Soil did contain a mixture of mowing debris and field grass roots.

Since the test mines were buried in the test area prior to the preparation of the test area, it was anticipated that some of the mines would be uncovered by the plowing and the cultivating. This, in fact, did happen. After each pass of the equipment (this included vegetation cutter, plow, cultivator, and MCR passes), the test area was visually scanned for exposed mines. Any mines found were removed from the test field. Of the 100 mines buried, one was exposed and crushed by the vegetation cutter when the cutter scalped a high spot. Forty-eight mines were uncovered and exposed during the plowing cycle. An additional 33 mines were brought to the surface by the spring cultivator. This left 18 out of the original 100 mines buried in the test area for the MCR to uncover.

The MCR was towed through the test area by the Fendt Tractor at speeds varying from about 3 mph (5 kph) to 6 mph (10 kph). Regardless of the speed, a bow wave of dirt formed along the front edge of the rake (in front of the knives). (The higher speeds were tried to see if the dirt would flow over the rake structure rather than build up into a bow wave. Very slow speeds, 1 to 1.5 mph (1.4 to 2.5 kph), were tried but only resulted in the rake portion of the MCR coming totally out of the ground.) Smaller buildups of dirt formed in front of the front tow bar, the rear drag bar, and at various spots under the drag mat. The drag caused by the MCR's buildup of dirt required that the tractor be operated in 4-wheel drive. Maximum dirt buildup was achieved within 3-4 MCR lengths from start of towing. The bow wave in front of the knives achieved a height that consistently measured $\sim 19\frac{1}{2}$ inches (49.5 cm) at which point the dirt cascaded down the backside of the wave and was processed by the agricultural drag mat. The amount and weight of the dirt accumulated in front of the knives was so great that the easiest way to clean the MCR, thus allowing a fresh restart of the test, was with the assistance of a front end loader. When it was observed that the bow wave of dirt caused the knives to come out of the ground, the tow chain attachment points were moved back to the second set of attachment holes. However, the knives still came out of the ground. Pictures of the dirt buildup in the MCR and the knives out-of-the-ground are shown in Figures 17 and 18.



Figure 17. MCR Bow Wave



Figure 18. Knives out of the Ground

To clean the MCR, the towing ring of the MCR was removed from the Fendt tractor and looped over one of the teeth of a standard digging bucket attached to an Army front end loader. The bucket was then raised to pull the rake clear of the dirt bow wave

and the front end loader was backed away so that the MCR could be pulled out of and away from the debris heap. After the rake was cleared from the heap, people manually cleaned any remaining grass or roots from the tines and detached the MCR from the front end loader. The procedures used to clean the rake involve, at a minimum, two personnel (equipment operator and person on foot to attach/detach/clean the MCR) and a front loader. In this test, three personnel were used to clean the MCR (Fendt operator, front loader operator, attach/detach personnel), taking a total of 5min, 40 sec to complete the cleaning process. Pictures of the movement of the MCR by the front end loader and the manual cleaning of the rake are presented in Figures 19 and 20.



Figure 19. Clearing the MCR



Figure 20. Cleaning the MCR

After 16 passes through the test area over a 2½ hour period, including 4 cleanings of the MCR utilizing the front loader, the MCR did not uncover a single mine with either the digging knives at the front end or the trailing agricultural drag harrow. At this point, testing for the buried mines at Test Site 1 was terminated.

After testing the MCR on buried mines, a test of surface-laid anti-personnel mines was performed within the Test Site 1 field. Two mines were laid on top of the prepared field and within the path of the MCR, cleaned of debris prior to this test. The mines were placed at a point 40m and at 50m from the start of the MCR run. Figure 21 shows the condition of the field and the placement of the mines in the field.



Figure 21. Surface-Laid Mine

As the tractor and MCR passed over the mines, one mine was covered with dirt by the MCR and the other remained in place as the MCR drag mat moved across the top of the mine. The mine that remained in place was captured by photograph as the drag mat crossed over the top, as shown in Figure 22.



Figure 22. Surface-Laid Mine Remaining on Ground

5.2 Sand Test Site

As in Test 1, the MCR was towed through the sand area by the Fendt Tractor at speeds varying from 3 to 5 mph (5 to 8.3 kph). Sand accumulated along the front edge of the digging tines, in locations under the drag mat during MCR movement, and in front of the rear drag bar. When the MCR reached the end of the test area, the bow wave in front had reached a height of 19in (48.2 cm) along the front of the digging tines. This accumulation prevented the tines, 17.8 cm in length, from fully penetrating the ground. The maximum digging depth of the tines by the end of the test run was measured to be 7.6 cm. Pictures of the sand accumulation are shown in Figures 23 and 24.



Figure 23. Accumulation at the Digging Tines



Figure 24. Accumulation within the Drag Mat

After one pass of the MCR, the field and the MCR accumulation mounds were closely examined for mines. This investigation found seven mines within the accumulation in front of the digging knives, one under the drag mat, one mine slightly exposed in its original location, and the last mine buried in its original location. Of the seven mines found within the sand accumulation in front of the digging knives, none were visible by the tractor operator during or after the test. The locations of these mines were not discovered until the buildups in front of the digging knives and within the drag mat were shoveled away. The final orientation of the mines within the front buildup varied from their original (burial) orientations indicating that they had been tumbled and rolled within the sand. Pictures of the mines discovered within the MCR sand accumulation are shown in Figures 25, 26, and 27.



Figure 25. Mine Found in Accumulation Heap



Figure 26. Two Mines Found Stacked within Accumulation Heap



Figure27. Mine Found within Drag Mat Accumulation

The remaining two mines were left in their original burial location. The uncovered mine was not shifted from its original burial location and was only visible due to its bright blue paint color and after close inspection of the area. The second mine

appeared untouched by the MCR and was uncovered by shovel after the test was complete. Pictures of these two mines are found in Figures 28 and 29.



Figure 28. Exposed Mine in Original Location



Figure 29. Tenth Mine Found after Shoveling

6 Test Results

6.1 Mine Recovery - Test Site 1 (Vegetation-Covered, Sandy Loam Soil)

The MCR performance test was conducted in a field in which 100 test mines had been buried to a depth of 5cm to the top of the mine prior to any area preparation work taking place. During the mowing, plowing, and cultivation of the field, 80 mines were uncovered and removed and 2 mines were destroyed leaving a total of 18 mines to be uncovered by the MCR. After 2½ hours of towing the MCR through the prepared area, the MCR did not uncover a single mine. A recap of the mine recovery at Test Site 1 is presented in Table 6. Results are presented in the order that the tool was used

Table 6. Mines Found During MCR Performance Test

TOOL	Number of Mines Uncovered/Destroyed	Operating (Test) Time (hours)
Loftness Vegetation Cutter	1	2.17
Krause Chisel Plow	48	3.07
Unverferth Spring Cultivator	33	3.63
Wattenburg MCR	0	2.5

6.2 MCR Operational Efficiency - Test Site 1

Established demining procedures do not allow area preparation equipment to operate on ground that is known or suspected to contain land mines. Area preparation is accomplished by reaching into the area with the preparation tool (not the prime mover),

prepare an area or swath of land for demining, and withdrawing from the area until the demining has been completed. The area preparation equipment is then allowed on the mine-free land and another area or swath of land is prepared for demining. The sequence of events followed in the MCR performance test more closely mimicked the events of a quality assurance phase of a demining operation. However, the amount of time spent in preparing the soil to a point where the MCR could reasonably be expected to operate trouble free was excessive for the area involved (5250 m²) (1+ hectare). Even after the extensive preparation, the MCR became clogged with mowing debris and dirt and did not uncover a single mine.

6.3 Mine Recovery – Test Site 2 (Sand Soil)

Ten mines were buried in the sand soil test area in an array that would allow the all ten mines to be exposed or surfaced by the MCR in a single pass. While the MCR did stay in the soil to some extent for the entire sand soil test, the buildup of sand in front of the digging knives limited the penetration to half the length of the digging knives.

Only one mine was exposed, but not moved or brought to the surface by the MCR during the sand soil test. When the sand buildup in front of the digging knives array was shoveled away, seven of the mines were found buried in the sand against the front edges of the digging knives and one was found buried in the sand accumulation under the drag mat. An analysis of the location of where the mines were found showed that once the mines were engaged by the rake-portion of the MCR, the mines were pushed along in front of the rake rather than flowing up the front of the knives and being deposited on the surface. The distance from the point of burial to where the sand buildup was removed by shovel was 145 feet (44 m). After the test, the last mine was uncovered with a shovel at its original burial position.

6.4 Operational Efficiency – Test Site 2

The carrying along of the engaged mines in the bow wave of sand in front of the digging knives is an undesirable event. The location of the mines in relation to the digging knives would require that any soil buildup be removed by hand tools before the MCR is removed from the soil. Due to the metal content of the MCR, which precludes the use of a metal detector, mines would have to be located by using probes and then removed by hand. Physically lifting the MCR free of the sand could detonate mines that are next to or near the digging knives as the knives pass through the sand. Any efficiency that might accrue by having the MCR carry the mines along to a stopping point would be lost by the need to probe and dig for mines in the sand buildup.

7 Recommendation

Based on its performance during this test, it is recommended that the Wattenburg Mine Clearing Rake not be considered as a Humanitarian Demining tool.

Appendix A. Test Support Personnel

Test Director/ Test Engineer: Mr. J. Michael Collins, Fibertek, Inc.

Logistical Support Team/Data Collectors: Mr. Gregory Bullock and Ms. Sarah Heaton

Test Range Support: Mr. Arthur Limerick and Mr. John Snellings

Tractor Drivers: Mr. Daniel Chichester, Mr. William Collins, and Mr. J. Michael Collins .

HD Program Manager's on-site representative: Mr. Ronald Collins.

Test Plan and Report Authors: Mr. Harold Bertrand and Ms. Jennifer Ledford, Institute for Defense Analyses

GLOSSARY

AP	Anti-Personnel
C	Celsius
cm	centimeter
F	Fahrenheit
ft	feet
HD	Humanitarian Demining
IDA	Institute for Defense Analyses
in	inch
kg	kilogram
kph	kilometers per hour
lb	pound
m	meter
MCR	Mine Clearing Rake
mm	millimeter
mph	miles per hour
NVESD	Night Vision and Electronic Sensors Directorate
PM	Program Manager