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RHINO EARTH TILLER
TEST REPORT
AREA REDUCTION IN MIXED MINEFIELDS

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Scope

The Rhino Earth Tiller has been thoroughly evaluated and found to be effective in a variety of environments as a clearance tool against antipersonnel mines. The survivability of the system against a range of explosive threats has also been evaluated through test and under operational conditions. The current philosophy for employing the Rhino allows for use in clearing antipersonnel landmines in situations where the probability of encountering an antitank mine is extremely low. The main rationale for this position is that the risk of causing damage to the tiller from the detonation of an AT mine is too high to permit the tiller to be used for clearing AT mines. While this is a true statement, it overlooks several important factors in considering the use of Rhino for area reduction in the presence of AT mines:

1) Large objects such as AT mines have shown a tendency to be excavated and visibly pushed by the Rhino for a long way before they are drawn into the crusher.

2) Experience has shown that less than half of all working mines drawn into the crushing mechanism are detonated by Rhino.

3) Experience has shown that in long buried minefields of interest, many mines are no longer functional, or hasty clearance operations have left some mines still in place but unfuzed.

4) The area reduction role requires very few total mine encounters since the use of the machine would be to locate the mined area boundary. Use of the Rhino ceases in a given area as soon as the first mine is uncovered.

This test was performed to help examine and quantify the first factor above which may, if combined with the other three conditions, give confidence in assuming the risk of employing the Rhino for area reduction in the presence of antitank mines. The following specific technical objectives were written to focus the conduct of the test on quantifying and evaluating the risk to the Rhino from antitank mines.

Objective 1 – Determine how far a representative AT mine is likely to be moved by the Rhino prior to being crushed by the Rhino system.

Objective 2 – Determine how detectable, visually, a representative AT mine is during the interval between the moment it is encountered by the Rhino and the moment it is crushed by the Rhino.

Objective 3 – Determine whether it is possible to reliably excavate and visually detect the presence of an AT mine, stop the Rhino system before the AT mine is crushed or detonates, and locate the suspect mine.

A three part test designed to meet these objectives as well as to gather incidental information on the use of the Rhino was conducted at an Army test range in Aug. and September 2002.

System Description

The Rhino is a tracked tilling vehicle custom designed and built from the ground up. The working tiller consists of two horizontal drums, stacked one overtop of the other. The drums are studded with commercially available, asphalt shredding chisels. The lower drum counter rotates against the direction of vehicle travel, excavating soil and objects from burial depths of 25 – 35 centimeters. The excavated soil and constituent objects are carried up the face of the lower, digging drum and into the 1 to 5 centimeter gap between the lower and upper drums. The chisels on the two drums mesh with each other as the drums rotate counter to one another. The powerful shredding action this produces will crush objects larger than 5 centimeters in diameter. Testing has shown that the Rhino will detonate between 25% and 50% of the mines it encounters as it crushes them. The undetonated mines are supposed to be shredded into pieces too small to be a threat to personnel and equipment.

Ideally the gap between the drums would be arbitrarily small in order to smash even small components to dust; however, the simple requirement of passing the finite volume of excavated soil through the gap precludes this. The small, but none-the-less finite gap between the drums establishes a minimum size below which crushing action is not guaranteed. The gap on the Rhino fixes the dimensions on the smallest crushable object at 5 centimeters, small enough to reach and destroy all but toe-popper style antipersonnel mines.

At the other end of the size scale, survivability becomes the limiting factor in the feasibility of employing the Rhino in mine clearance operations. Extensive testing and field experience have established that explosive charges below 100 grams TNT equivalent produce only very localized and inconsequential damage to the surface of the tilling drum. Operation in the aftermath of a detonation of this order would continue uninterrupted with 5 – 60 minute repairs required during scheduled maintenance intervals. Technical tests and inadvertent encounters with antitank mines in the range of 5-7 kg. of explosive weight have produced more extensive damage which is dependent upon the location of the charge at the time of detonation. In the best of cases detonation occurs at or near the initial impact point of the tiller and mine. In this case more widespread but still localized damage to the drum surface occurs. Loss of chisels, chisel mounting boxes, and slight deformation to the drum surface occurs, requiring 1 day of skilled labor repair. In the more serious cases shock transmitted through the tiller structure is capable of breaking bearing and drive components within the tiller drum and possibly shock-damaging electric components elsewhere in the vehicle. Recovery following this kind of damage would require several days of expert service in the field and possibly return of the tiller unit to the factory and procurement of high dollar, long lead items. Clearly daily or even monthly recovery of the tiller from such damage would not be practical, but recovery or replacement of the tiller unit from less frequent explosions may be feasible and hence the purpose of this test.

The Rhino itself is 10 meters long and produces a 3.5 meter swath. It is capable of tilling at 400 – 600 meters per hour and has a “road speed” of nearly 4 kilometers per hour. It weighs 58 metric tons and is hydrostatically driven (both tracks and tillers). It is designed to be remotely operated from up to one kilometer and there is an option of driving from inside the cab when performing non-hazardous tasks with the system. The system is furnished with a dozer blade which can be installed in place of the tiller unit, and there is a simple grading blade on the rear of the vehicle. A number of automatic systems and sensors are present throughout the vehicle to assist the operators/maintainers and protect the system from operator misuse. A tilling depth sensing system is used to automatically track and control the tilling depth to a specified depth within a –0/+5 centimeter tolerance. The penalty for having these automatic systems is the added complexity and skill level required to service the vehicle, as well as the reliability issues of these features themselves. A 1700 liter diesel fuel tank feeds the 850 horsepower Caterpillar engine. Area coverage rates of 7,000 square meters per day have been reported in some operations (the rate experienced in this test was approximately half that). The lower digging drum spins at 120 rpm and contains on the order of 400 carbide tipped chisels. The upper drum spins at 600 rpm and contains on the order of 200 chisels. Individual chisels can be replaced in 1 to 2 minutes and cost on the order of $1 each. Operation in rocky areas may require replacement of 5-20 chisels per day.

TESTS

Test Conditions

All tests were performed under ambient fair weather conditions. The soil on site is a very dense clay with a significant sand content. The areas tilled were evenly divided between bare soil and short, medium density grass cover. Terrain on site is flat with no obstacles or significant erosion ditches. Recent rainfall had served to keep the dust down for the duration of the test.

Since area reduction deals more with detecting the location of mines in order to define minefield boundaries, the Rhino was outfitted for the tests with two monitoring video cameras for the tilling drums which are in addition to the driving cameras furnished with the system for operator control of the vehicle. One of these cameras was an inexpensive (<$35) wide angle camera placed on the front of the tiller looking rearward at the lower drum. The second was a pan and tilt camera with zoom lens placed on top of a 10 meter mast at the operators station located outside of the minefield. This camera was capable of zooming in on the lower drum at 120 meters for the purpose of monitoring the material moving off of the tiller drums. The operator's station itself was placed inside a mobile camper vehicle along with a separate station for monitoring the tiller cameras. The camper was placed 20 meters beyond the edge of all areas tilled. Additional operators termed "camera spotters" were stationed at each of the tiller video screens, and a "minefield monitor" was stationed on the ground near the tiller.

Test Results Part I

The objective of this phase was to gain a measure of how deeply the Rhino can effectively till in a single pass under the test conditions present at the test site. This information was used to prescribe the tilling depth at which the Rhino operated in the later test sequences and to determine the ranges of interest for burying the test mines. Fifty yard tilling runs were made with the depth control set at 5 centimeter incrementally-increasing settings between 10 centimeters and 25 centimeters. The performance of the Rhino was monitored for these runs with respect to the time required to complete the run, the degree of steering and depth control maintained over the course of the run, the degree to which visual monitoring of the tiller could be maintained, and the degree to which acceptable vehicle engine loading was maintained. At the conclusion of each plowing run, a cross section of each lane was excavated to determine the actual depth at which the area had been tilled, for comparison with the desired depth. Results for these tests are summarized in table 1.

Table 1. Summary of Timed Runs to Assess Tilling Depth Capability

Run	**Preset Depth**	**Depth Achieved**	**Elapsed Time**	**Comments**
1	10 cm	10 cm	6:14 m	Tilling was smooth and continuous except one pause to correct vehicle heading.
2	15 cm	15 cm	5:24 m	Tilling was smooth and continuous
3	20 cm	25 cm	7:25 m	Vehicle forward motion stalled several times. Engine overheated near end of run. Still completed the run with out significant interruption or backing up.
4	25 cm	30 cm	10:29 m	Vehicle forward motion difficult to maintain. The amount of soil ejected from the tiller visually occluded the tiller drum. Vehicle overheated quickly and steering adjustments were frequent and required raising the tiller. The tiller drum itself stalled on some occasions.
Soil type and condition				Very dry, very hard clay

All tilling runs produced tilled depths within the tolerance allowed by the automatic depth control system. The 10 and 15 centimeter depth lanes required little operator involvement with the tiller. At 20 centimeters some operator involvement was required, mainly in adjusting the vehicle direction. Forward stall conditions generally were momentary and the tiller was able to work itself free. The engine overheat was experienced near the end of the lane and was a surprise as was the stall of the drum itself on the 25 centimeter lane. These conditions had never been observed with this Rhino and test personnel were unable to find cause other than to attribute it to the very tough soil and high (35 C) ambient temperature. The vehicle motion stalls were much more severe in the 25 centimeter lane as was the amount of soil and dust shielding the tiller drum from view of the monitoring cameras. For these reasons the decision was made to have all remaining mine tests performed with the tilling depth set to 20 centimeters depth.

Test Results Part II

The second phase of the test was performed as a quick and dirty indication of the likely outcome of the more extensive test and for the twofold purpose of determining how far the tiller will push a mine before it is either crushed or detonated and how well the camera spotter perceives the excavated mine versus the minefield monitor. This was desired in order to have a background understanding of how critical it is to visually detect a given mine at the moment it is tilled to the surface, since there are a number of factors beyond the scope of this test program that will probably affect how quickly the mine is visually detected in any given field situation. Four nearly identical tests were performed using M 20 mines configured to give a smoke indication when the mine is triggered. Each mine was buried 10 centimeters (10 centimeter hole) approximately 9 meters down the run of a 45 meter lane. As was determined in part I, the automatic tilling depth was set to 20 centimeters. Each lane was tilled and the location at which the mine first became visible to the minefield spotter and the location at which the mine first became visible to one of the camera spotters were marked and measured. The tilling continued until the mine was either crushed, detonated, or the end of the lane was reached. Table 2 lists these marked distances as measured from the original location of the mines as well, as the total distance each mine was pushed before being destroyed or reaching the end of the lane, and the condition of the mine at the end of the run.

Table 2. Distances AT Mines Pushed by Tiller in Test Lanes

Run	Mine Appearance Location Minefield Spotter Observed	Mine Appearance Location Camera Spotter Observed	Displaced Mine Final Location	Final State Of Mine	Comments
1	1.7 m	1.7 m	42 m	Undetonated Uncrushed	Run required 5:08 minutes Mine still functional at end of test
2	1.7 m	4.5 m	40.8 m	Not fuzed Uncrushed	Test run with mine inadvertently left unfuzed.
3	1.5 m	1.5 m	39.3 m	Undetonated Uncrushed	Mine still functional at end of test
4	.5 m	.5 m	36.8	Undetonated Uncrushed	Mine still functional at end of test. Run completed in 3:55 minutes. The mine popped free and was visible 17 times during this pass.
Soil type and conditions					Dry, sandy clay

The results were consistent for all four runs made. When encountering a mine the tiller would excavate and eject the mine about 1 ½ meters in front of the spoils pile carried in front of the lower drum. The ejection was clearly visible to both spotters, and the mine would lie exposed and visible to both spotters for several seconds as the tiller approached it again. Then the spoils pile in front of the tiller would re-cover the mine as the vehicle approached, and the mine would again be ejected from the pile. This cycle continued approximately 18 – 25 times as the mine was carried down the lane. Since none of the mines was detonated or crushed during these tests each was carried in this fashion to the end of the lane and recovered. All of the mines were pretty battered when retrieved, and each was checked to verify that it was still functional. The results of these tests were used to design the mock minefield for the part III testing. The fact that the mines proved to be easily detectable to the video monitors gave confidence in the approach. Even more appreciated was that the mines were each pushed 40 meters and made visible multiple times without inducing detonation. This would seem to relieve the responsibility on the camera spotters somewhat, which may be important as lighting conditions, soil/mine contrast, dust obscuration and other local conditions beyond the scope of this test program alter the camera spotter's perception and ability to detect the mine immediately every time.

Test Results Part III

The part III testing was designed to assess whether the phenomena observed in the part II test could reliably be depended on to serve as the basis for an area reduction role in a more realistic field environment. A 7000 square meter mock minefield was laid out containing 50 antitank mines randomly placed throughout (see figures 1 and 2). Four antitank mines ranging in size from 320 mm dia and 83 mm high to 333 mm diameter and 150 mm high. A range of burial depths was chosen to cover shallow burial up through, and beyond the maximum tilling depth used on the test. Specifically, 10 centimeters, 15 centimeters, 20 centimeters, and 25 centimeter depths (to the bottom of the mine) were used, as the planned tilling depth was 20 centimeters. The minefield included 18 meters of "run up" and 18 meters of "run out" area beyond the edges of the actual mined locations. The run up area was needed for the operator to align the vehicle parallel with adjacent passes and establish proper overlap as well as establish proper and steady tilling depth before entering "hazardous" areas. The run out area was needed to allow the Rhino to push excavated mines near the exit boundary for some distance to ensure they were made visible and to allow (theoretically) AP mines in a given mixed minefield situation time to be drawn in and crushed. 45 of the test mines contained smoke fuzes, as in the part II testing, and the remaining 5 mines did not have any kind of functional fuze. Each mine was given a unique identifying number to assist in recovery and analysis of the movement of the mines in the tilling process, and its initial position within the minefield was surveyed and recorded. The external control station was placed 15 meters beyond the end of the run out space at the minefield border. It was moved once over the course of the tilling operation to keep the external camera viewing angle of the tiller front at 90 degrees plus or minus 30 degrees. The camera boom was kept extended to a height of 10-15 meters for a slightly depressed elevation angle over the landscape which varied 2-3 meters.

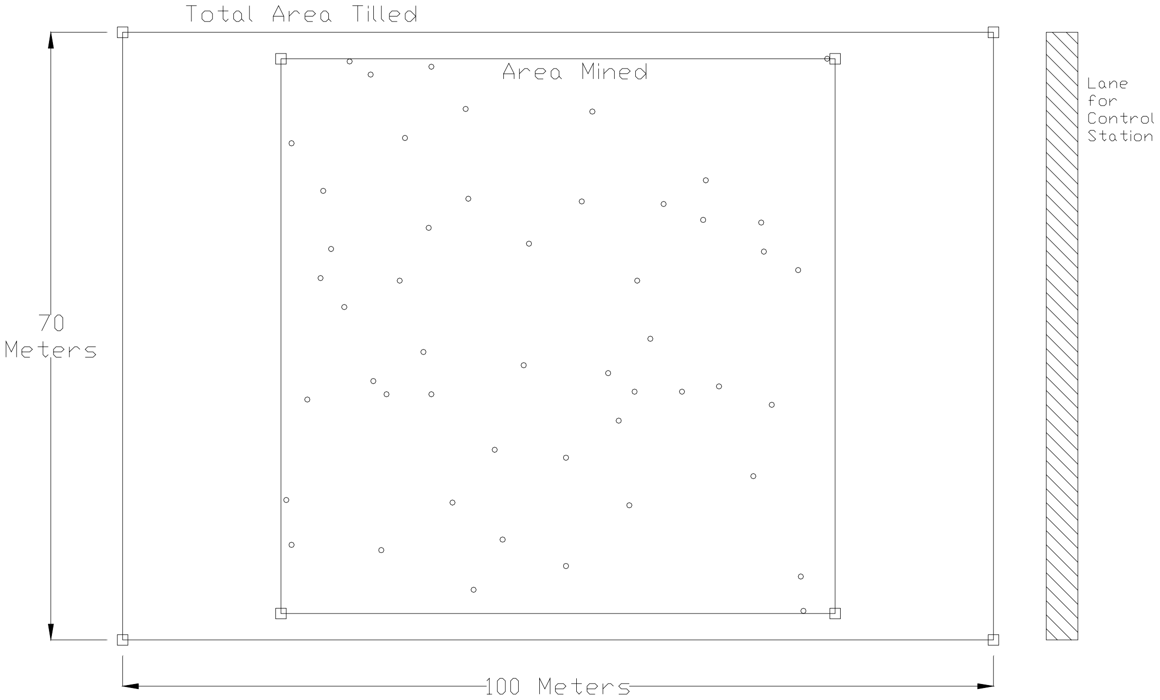

Figure 1 Test Area Layout and Mine Locations

The test was run such that parallel, overlapping runs were made across the long dimension of the minefield. Each overlap varied between 0.30 meters and 1.50 meters dependent upon the operators ability to perceive and control the path of the Rhino. The purpose of the overlaps was to ensure complete coverage of the test area rather than any attempt to double till the field. During the tilling passes the operator was only permitted to communicate with the camera spotters inside the control station. No instructions or information from witnesses on the ground was permitted to influence the operator. When a mine became visible to either of the camera spotters, the operator would stop the Rhino as quickly as possible and back up 5 meters. The ground crew was notified by radio and sent into the test minefield to investigate and recover the object spotted. At the end of each pass the Rhino was backed over the lane just cleared and repositioned outside the test boundaries to begin the next pass. The tilling times where reported do not include the time required to investigate the detections. The location where each mine was recovered was surveyed and recorded, and its trigger condition was examined, as was its physical integrity.

Figure 2. Rhino Entering Mock Minefield

Twenty nine passes of the tiller were required in order to complete tilling of the entire 7000 square meters test area (see figure 3). The average forward speed maintained during the test was 0.53 km/hr. The working time required to complete the area was 5.5 hours of tilling plus 1.4 hours of repositioning time between passes, for a total of 6.9 hours or 1015 square meters per hour of operation.

Figure 3. Tilled Area at Test Conclusion

Each of the 50 mines buried for this test was "spotted" by one or both of the camera spotters during the course of the test. Table 3 lists each mine by serial number, initial burial depth, and whether or not it was fuzed (5 of the mines had non functional fuzes) . For each mine the distance it traveled to the point at which it was recovered is given along with the conditions (physical and trigger condition) it was recovered in and information as to which of the two camera spotters detected the presence of the mine before the Rhino operation was halted.

Table 3. Results of Tilling Mock Minefield

MINE	FUZED	DEPTH OF MINE (CM)	SEEN ON TILLER CAMERA (Y/N ?)	SEEN ON TOWER CAMERA (Y/N ?)	DISTANCE MINE MOVED (METERS)	PHYSICAL CONDITION OF MINE (SHREDDED /INTACT)	TRIGGER CONDITION OF MINE (FIRED / NOT FIRED)
1	Y	20	N	Y	0.18	SHREDDED	FIRED
2	Y	10	Y	Y	2.10	INTACT	NOT FIRED
3	Y	20	Y	Y	2.12	INTACT	NOT FIRED
4	Y	25	Y	Y	2.59	INTACT	NOT FIRED
5	Y	25	Y	Y	1.26	INTACT	NOT FIRED
6	Y	25	Y	Y	0.03	INTACT	FIRED
7	Y	10	Y	N	0.62	INTACT	NOT FIRED
8	N	20	N	Y	2.55	INTACT	
9	Y	15	Y	Y	3.84	INTACT	NOT FIRED
10	Y	15	Y	Y	1.92	INTACT	NOT FIRED
11	Y	20	Y	Y	1.43	INTACT	NOT FIRED
12	Y	10	N	Y	0.85	INTACT	NOT FIRED
13	Y	20	Y	Y	1.87	SHREDDED	NOT FIRED
14	Y	15	Y	Y	0.89	INTACT	NOT FIRED
15	Y	15	Y	Y	0.94	INTACT	NOT FIRED
16	Y	20	Y	Y	2.19	INTACT	NOT FIRED
17	Y	15	Y	Y	2.60	INTACT	NOT FIRED
18	Y	25	Y	Y	1.06	SHREDDED	FIRED
19	Y	25	Y	Y	2.24	INTACT	NOT FIRED
20	Y	15	Y	N	1.07	INTACT	NOT FIRED
21	N	20	Y	Y	2.35	INTACT	
22	Y	10	Y	Y	0.96	INTACT	NOT FIRED
23	Y	10	Y	Y	1.29	INTACT	NOT FIRED
24	Y	15	Y	N	1.56	INTACT	NOT FIRED
25	Y	10	Y	Y	3.69	INTACT	NOT FIRED
26	Y	15	Y	Y	1.48	INTACT	NOT FIRED
27	N	20	N	Y	1.54	SHREDDED	
28	Y	15	Y	Y	4.07	INTACT	NOT FIRED
29	Y	20	Y	Y	2.12	INTACT	NOT FIRED
30	Y	15	Y	Y	3.46	INTACT	NOT FIRED
31	Y	25	Y	Y	0.35	SHREDDED	FIRED
32	Y	25	N	Y	2.14	INTACT	NOT FIRED

33	N	15	Y	Y		INTACT	
34	Y	25	Y	Y	2.47	INTACT	NOT FIRED
35	Y	20	N	Y	2.89	INTACT	NOT FIRED
36	Y	10	Y	Y	1.64	INTACT	NOT FIRED
37	Y	15	N	Y	1.21	INTACT	NOT FIRED
38	Y	25	Y	N	2.75	INTACT	NOT FIRED
39	Y	20	Y	Y	1.14	INTACT	NOT FIRED
40	Y	20	Y	Y	1.07	INTACT	NOT FIRED
41	N	15	Y	Y	2.33	INTACT	
42	Y	15	N	Y	2.75	SHREDDED	FIRED
43	Y	10	Y	N	1.17	SHREDDED	FIRED
44	Y	20	N	Y	1.78	INTACT	NOT FIRED
45	Y	25	Y	Y	4.89	INTACT	NOT FIRED
46	Y	10	N	Y	2.33	INTACT	NOT FIRED
47	Y	20	Y	N	1.48	INTACT	NOT FIRED
48	Y	10	Y	N	5.34	INTACT	NOT FIRED
49	Y	15	Y	Y	1.39	INTACT	NOT FIRED
50	Y	20	Y	Y	1.27	INTACT	NOT FIRED
SUMMARY			40 / 50	43 / 50	AVERAGE 1.94 M	INTACT 43/50	NOT FIRED 39/45

Table 3. Mock minefield tilling results

Figure 4 Intact Mine Recovered

Figure 5. Shredded Mine

At the test conclusion, 43 of the 50 mines emplaced were recovered intact (86%), and the remaining 7 were shredded (see figures 4 and 5). The 7 mines that were shredded became visible to the camera spotters as they were being shredded. In all cases this was an immediate effect. The tiller either grabs the mine while it is held immobile in the settled soil and draws it straight into the crushing gap, or as happens most often, the tiller pops the mine cleanly from the hole. The average distance the mine was recovered from its burial location, 1.94 meters, simply represents the distance the mine generally is thrown or rolls down the spoils pile on the first encounter with the tiller. Once the mine has been popped free, there seems to be very little chance that it will be drawn to the crushing gap. 39 of the fuzed mines survived the tilling process without detonating (86%). Of the six that fired, 5 were among the mines that were shredded completely. Only one mine fired without being crushed, and only two mines were shredded without firing. If the results are further broken down by initial burial depth, some further separation in the risk to the tiller appears (see table 4). .

Table 4. Mine Excavation and Recovery Results at Each Burial Depth

BURIAL DEPTH	MINES SHREDDED	PERCENT SHREDDED	MINES FIRED	PERCENT FIRED
10 cm	1/10	10%	1/10	10%
15 cm	1/15	6.7%	0/13	0%
20 cm	3/15	20%	3/12	25%
25 cm	2/10	20%	3/10	30%

With burial less than 20 centimeters, the combined detonation rate of 4.35% is significantly lower than for burials at 20 centimeters and deeper, which was 27.27%.

The combined rate at which the camera spotters were able to detect the mine was 100%. In about 20% of the cases only one of the camera spotters had detected a given mine by the time the second camera spotter had alerted the operator to stop the vehicle.

Conclusions

Caution is advised in reading too much accuracy into the results of the tilling process when broken down by burial depth since the percentages reported are based on a very small total number of mines shredded or detonated at any one depth. Nevertheless the trend of increasing risk of shredding and detonating mines shown experimentally is plausible and the overall rates of clearance are a good representation of the clearance efficiency to be expected with the approach used for the test.

The higher efficiency at the shallower depths is attributed to less soil pressure on the fuze and less structural support for the mine as each tiller chisel attempts to spear and grab the mine case. Lighter and less cohesive soils and sands would likely provide a more conducive medium to avoid grabbing the mine and drawing it into the shredding gap between the drums.

It is interesting that the tiller was able to clear the mines buried 5 cm deeper (25 cm) than the tilling depth set for the Rhino on these tests. It would be worthwhile to repeat the testing with other tilling depths used to see if the increased risk from deeper buried mines can be mitigated by operating the tiller at a deeper setting. The effective rate in a live mine area is likely to tend more toward the higher efficiency numbers reported due to the greater distribution of the mine threat to the shallower burials in most real world situations.

The monitoring of the tilling surfaces on the Rhino during operation was adequate in these tests. None of the detonated or shredded mines is attributed to being unable to see or perceive the mines tumbling in the spoils pile with sufficient clarity to notify the operator. Those mines that were shredded were grabbed immediately and shredded within a few meters of the original placement. The results in these cases would have been no different if the operator had been controlling the Rhino from 1 meter away and directly observing the tiller. A potential problem–keeping the camera spotters diligent with the monitoring task in an area reduction role-is foreseen. The average time between mine encounters on this test was just over eight minutes. The longest interval between successive mine encounters on this test was almost 29 minutes. The spotters reported some concentration problems during the longer “dry spells”.

The overall rate at which mines were safely excavated (87% and 96% for shallow buried mines) probably leaves too much risk to the Rhino system for reliance on this concept alone for clearance or area reduction. Developing a process in which areas are prescreened or conditioned for AT mines is necessary. Ideas for accomplishing this include first treating a suspect area with a heavy mine flail to reduce the exposure of Rhino to only those AT mines which the flail fails to trigger. A second possibility in areas in which large metallic AT mines are the predominant threat is to sweep the area first with a vehicle-based detector array.