11-2005

Detection of Landmines by Dogs: Environmental and Behavioural Determinants

Ian McLean
Geneva International Centre for Humanitarian Demining (GICHD)

Rebecca Sargisson
Geneva International Centre for Humanitarian Demining (GICHD)

Ian Mansfield
Geneva International Centre for Humanitarian Demining (GICHD)

Recommended Citation

McLean, Ian; Sargisson, Rebecca; and Mansfield, Ian, "Detection of Landmines by Dogs: Environmental and Behavioural Determinants" (2005). *Global CWD Repository*. 85.
https://commons.lib.jmu.edu/cisr-globalcwd/85

Detection of landmines by dogs

Environmental and Behavioural determinants

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

Detection of landmines by dogs: environmental and behavioural determinants, GICHD, Geneva, November, 2005.

This project was managed and written by Ian McLean and Rebecca Sargisson, info@gichd.ch. Contributing authors include Jennifer Brown (University of Canterbury, New Zealand, statistical analysis), James Phelan (Sandia, USA, soil chemistry), and Lena Sarholm (FOI, Sweden, soil chemistry).

Contents

Acknowledgements

The Geneva International Centre for Humanitarian Demining (GICHD) thanks Johannes Dirscherl, Candy d'Sa, Paul Ellis, Matts Gustavsson, Asif Khan and Ray Wills for their support for the field work, and especially Matts Gustavsson for his assistance with soil samples and the weather station. Field and logistic support was provided by the Monitoring Evaluation and Training Agency (META): we particularly thank Anaiatulla, Ghulam Rahman, Khair Sharif, Nawabi, Raheem and Rassool, but many others contributed in many ways. The Mine Dog Centre (MDC) provided supervisors, handlers and dogs, and camera operators, without which the study would have been impossible: we particularly thank Shohab Hakimi, Javid Shawali and Zainadeen for administrative support. At the UN Mine Action Centre (UNMACA), essential contributions were made by Farid Hassani, Tammy Hall, Alan Jones, Karim, Dan Kelly, and Noel Spencer. Many other essential contributions were made by Ann Goeth, James Trevelyan, James Phelan, Ann Kjellström, and Lena Sarholm. Funding was provided by the US State Department through the United Nations, and the governments of Sweden, Norway and the United Kingdom.

Summary

- The overall aim of the study was to explore the effects of environmental variables on mine detection by dogs.
- Operational mine detection dogs were used to search for mines in a test mine field, near Kabul, Afghanistan. The minefield had 114 mines laid in 30 strips (40 x 8 m).
- Key trial variables were mines (8 types) and laying depth (surface, 7.5, 15, 20, 25 cm). There were 4 replicates of each depthxmine combination.
- The key variable used in the analysis was whether a mine was found or missed by the dog.
- The field site was designed to ensure that dogs missed some mines, because without missed mines, a key factor in the analysis would not be available. Some mines were buried deep to ensure they were difficult to find, and the dogs did not work strictly to the MDC-Afghanistan SOP. Despite the task being made difficult, the overall find rate was similar to that found in other studies of demining systems.
- In total, 39 dogs were used to search for 539 mines in 5 trials, conducted in October 2002, and April, June, July and September 2003.
- Measured during the study were:
    - Weather patterns through the year of the study.
    - Weather variables (temperature, wind, humidity) at the time the dog crossed the mine.
    - Dog behaviour.
    - Vegetation over the mine.
    - A soil sample was taken from over the mine and from a sample of false indication sites in each box. Analysis for explosive chemicals was by two labs using gas chromatography.
- Find rates differed by trial month, being highest in October 2002 and lowest in April and June 2003.
- Find rates for mines declined with laying depth of the mine.
- Different mines had different find patterns in relation to depth. Larger mines were found at higher rates than smaller mines.
- TC6 AT mines and Type 72 AP mines were particularly difficult for dogs to find. Both these mines had relatively low concentrations of analyte chemicals in soil samples.

- Heavy spring rainfall was linked to reduced find rates, increased contamination in the soil throughout the site, and increased difficulty in pinpointing found mines (particularly in June). Contamination from mines appeared to be carried down runoff channels by heavy rains.
- Find rates through the morning were linked to humidity through the morning, although the relationship was complex. Humidity declined steeply from dawn until about midday. Find rates were high around the time that the sun first hit the ground (when overnight moisture was evaporating from the ground surface). Find rates were lower through the rest of the morning, but increased as humidity declined.
- Find rates were not linked to any other measured weather variable.
- Find rates were reduced when vegetation was present at high density over a mine, but find rates were not linked to the abundance of spiky or smelly vegetation.
- No relationship was found between dog search behaviour and find rates. However, instances were documented of handlers influencing find rates.
- Large numbers of false indications were given during the trials. Many were given at sites where concentrations of explosive chemicals in the soil were similar to those found over mines, and higher than concentrations found over missed mines. Red marks, which appeared on the ground surface between April and June and lasted until September, showed relatively high concentrations of explosive chemicals.
- Although the study site was an old battlefield, it was cleared before the study began, including removal of up to 30 cm of topsoil from much of the site. The high level of contamination remaining there has implications for any attempts to do mine detection using odour-detections technologies in Afghanistan.
- A link was established between detection success and presence of explosive chemicals in the soil. However, detection thresholds of dogs and the gas chromatograph were not the same, and the relationship is not simple.
- TNT, 2,4-DNT, and RDX were the most commonly found chemicals in soil samples.
- Higher find rates were linked to a higher rates and concentrations of TNT being found in the soil, and also to greater numbers of different chemicals being found.
- Of the 16 chemicals reported, four of 10 that could be analysed were significantly higher over found mines than over missed mines (TNT, 2,4-DNT, 4a26DNT, 2a46DNT). Some were too rare for appropriate analyses to be performed. None were significantly more common over missed mines.
- Concentrations of different chemicals in the soil varied in different ways across trials.
- Concentrations of chemicals in the soil varied in different ways over each mine type. However, in general, bigger mines had higher concentrations of chemicals.

- Humidity is a key factor influencing the success of mine detection by dogs. Using the information presented here, it may be possible to predict in which part of the day humidity is likely to cause the greatest difficulty in any operational theatre.
- Dealing with environmental variability will require careful and regular maintenance training of the dogs.

Chapter 1.
Introduction

Background to the study

> "*The technology for clearing minefields remains frustratingly primitive*".

Croll (1998) p. 141.

At the time Croll was writing, the three main methods used to search for or clear landmines were:

1. manual deminers working with simple technology such as hand tools and metal detectors (GICHD, 2005a);
2. machines (GICHD, 2004); and
3. mine detection dogs (GICHD, 2003).

Seven years later in 2005, improvements in equipment design and in deployment style are clearly evident. However, in terms of concept and principle, the technologies have changed little since the initiation of humanitarian demining on a large scale in 1989. Also, the silver-bullet promise of new technologies that were supposedly on the horizon in 1998 is not yet being fulfilled (Lokey, 2003), and is unlikely to be fulfilled in the near future (Bach, 2002).

Reasons for the glacial rate of deployment of new technologies are complex, and have been subjected to some analysis (e.g. Bach, 2002; McLean, 2003; King, 2004). More relevant here is that improved understanding of the "old" technologies is likely to contribute more to productivity and safety in the demining industry in the next few years than will deployment of new technologies. With that point in mind, the GICHD launched a series of studies designed to explore the old technologies, with the primary aim of optimising performance (GICHD, 2003; Bach *et al*., 2003; GICHD, 2004, 2005a). This study of environmental influences on detection of mines by dogs is a part of that series.

Because of the nature of the risk represented by mines, any mine clearance technology must find mines with high reliability. A technology that finds mines with varying (or worse, unknown) reliability is unlikely to be used. It is interesting, therefore, to discover that few independent and comparative analyses of the reliability of the "old" mine detection technologies have been conducted, and most that are available were conducted relatively recently (e.g. for machines: SWEDEC, 2002; GICHD, 2004; McLean *et al*., 2005; for manual: Trevelyan, 2003; GICHD, 2005a); for metal detectors: Mueller *et al*. 2003, 2004, in prep. These trials routinely produce results described as "disappointing", primarily because detection reliabilities are lower than expected or desired. For example, Trevelyan (2003) concluded that even under ideal conditions, prodders were unreliable at target depths of more than 7 cm; Mueller *et al*. (2004) found that reliability of metal detectors declined steeply at much shallower depths than 13 cm; and comparative study of a variety of manual systems reported mines missed by most (GICHD, 2005a).

Response to verbal presentations of these studies is routinely negative, with the main argument being “our experience is that the technology is better than that…” (comments at Eudem conference, Brussels, 2003). These results are forcing a new perspective on IMAS 09.10, which recommends a default minimum clearance depth of 13 cm (based on the perceived reliabilities of most metal detectors in 2003). Clearly, the realities of objective trials conducted under controlled conditions are challenging embedded beliefs about detection reliability (McLean, 2003).

This study of environmental effects on mine detection dogs similarly presents results that some will find disappointing, some will find challenging, and some will find refreshing.

Mines are routinely found in difficult and variable environmental situations and mine clearance agencies therefore prefer to use technologies that are insensitive to environmental variation. Environmental factors affect the reliability of each clearance technology in different ways and with varying sensitivity. For example: i) machines have low sensitivity to soil type, but may have lowered reliability in hard or boggy ground (presence or absence of water affects deployment capability); ii) dogs are affected little by soil compaction, but increasing water in the soil decreases the availability of odour; and iii) metal detectors have limited application in soil with a high iron content.

It is therefore imperative that the environmental influences on any detection technology be understood and the constraints defined. Specifically, for any mine clearance technology it will be valuable to define the environmental conditions under which detection reliability declines, or the limits beyond which the technology should not be used. This study was therefore designed to sample the full range of conditions under which dogs are used in Afghanistan in order to see whether those limits are being reached under normal operating conditions.

Dogs, demining and the International Mine Action Standards (IMAS)

Mine detection dogs were first used during and after World War II (Lemish, 1996), and have been used with increasing frequency since the first humanitarian mine clearance operation began in Afghanistan in 1989 (Hayter, 2003). Today, about 1000 dogs are used in more than 20 countries (http://www.gichd.ch/MDD/database/database.htm). Opinions on the reliability of dogs as detectors vary, and tend to be strongly held and forcefully stated (e.g. Matre, 2003, discussions in the MGM forum). HALO Trust concluded in 2003 that dogs were an unacceptable technology because of their low reliability (HALO Trust, unpublished), although HALO apparently also held this opinion strongly in 1998 as a result of tests conducted in 1992 (Handicap International, 1998). The debate will no doubt continue, but dogs are now an accepted and important member of the mine detection toolbox and will continue to be used by many agencies in the foreseeable future.

Given the long history of use of dogs, it is reasonable to assume that the limitations on their use as mine detectors are thoroughly understood. Unfortunately, the reality is very different. The original training and deployment of dogs as mine detectors was accompanied by little research, and it seems that development was limited to unstructured and unreported testing of different deployment options. There was essentially no published research on the principles underlying detection of mines using dogs before the GICHD began its work in 2000 (Handicap International, 1998, appears to be the first significant review of the use of mine detection dogs for humanitarian purposes, and it concentrates primarily on operational issues). In 1999, a meeting to discuss the use of dogs as mine detectors was convened in Ljubliana, and the general absence of information was formally recognised by the MDD community for the first time. At that time, examples of mines missed by dogs were being reported and the reliability of dogs was being questioned. Some programmes came under threat, and some demining agencies made the strategic decision to stop using dogs.

Despite the problems and arguments, organisations such as the United Nations, Mechem, RONCO and Norwegian People's Aid have persisted with dogs as a core capacity of their demining infrastructure. For example, the use of dogs in Afghanistan has recently been expanded or improved in four ways: i) by a significant increase in the number of dogs used in the field, ii) by a review and overhaul of the training programme used by the NGO that supplies most dogs used, iii) by integration of the dog IMAS into national standards, and iv) by operational use of a poorly-known technology: Remote Explosive Scent Tracing (REST, described in Fjellanger, 2003; Fjellanger *et al*., 2003; McLean *et al.,* 2003; GICHD, in prep.; the version used in Afghanistan is MEDDS, Mechem Explosive and Drug Detection System, described in Fjellanger, 2003; Joynt, 2003).

Several key initiatives flowed from the Ljubliana conference:

- A team of mine dog experts was convened to support the development of UN-approved international standards for use of dogs (the IMAS 09.4x series). That series was approved as draft Standards in 2002, and was fully revised in 2005.
- Procedures were approved for testing and accrediting mine detection dogs.
- Research was initiated on several themes to explore issues that appeared to affect the reliability of dogs.
- Organisations wishing to implement or use procedures outlined in the standards were supported on request by an outreach program supplied by the GICHD (the Standards Implementation and Support Committee, SISC, although SISC has subsequently been shut down).

Many national regulatory organisations now work to IMAS standards, although with varying success and effectiveness. Perhaps more relevant is that many operational mine detection organisations have implemented internal procedures to ensure compliance with IMAS, even if IMAS has not yet been adopted by the national regulatory body. With respect to dogs, IMAS standards are still being introduced in some countries, and implementation has not been entirely successful in others. An important reason is that too little is known about the limits on reliability of dogs for regulatory agencies to make consistent and objective decisions, and standards implemented nationally have varied as a consequence.

If a mine is missed by a clearance operation using dogs, it has been traditional to blame the dog – hence the negative views of some participants at the Ljubliana conference and elsewhere. However, there are other possibilities. For example: the dog was improperly deployed (a procedural failure), the dog was sick (a handler failure), there was a failure in the training process (a system failure), the search pattern was inadequate (a supervision failure), or there was no odour-of-mine available that day due to recent environmental conditions (an environmental effect). Just as with mine detectors or any other technology, if the technology is improperly used or is used in inappropriate conditions, it may be ineffective. In these examples, the failure is due to how or when the detector is used - the detector itself may have been working well. Elsewhere, the GICHD reports on issues related to *how* dogs are used (GICHD, 2005b). Here, we focus on the issue of *when* to use dogs.

When this study was conceived, the IMAS were being written and it was the intention of the UN-run Mine Action Centre in Afghanistan to implement the standards locally as soon as possible. Implementation proceeded more slowly than anticipated, and was continuing in 2005. A central requirement in the dog IMAS is an accreditation system involving external testing and licensing of individual dogs. Significant infrastructure (particularly test fields) is required before such testing can proceed. However, testing also requires introduction, practice and acceptance. A key objective of this study was introduction of the Afghanistan Mine Dog Centre (MDC) to the concept and procedures of testing as part of the process of implementing IMAS accreditation testing.

The two objectives of introducing the MDC to testing, and studying environmental effects on mine detection, were therefore combined into one broad project.

Study Objectives

The study addressed the following broad objectives:

- To investigate the influence of environmental conditions on the reliability of dogs as mine detectors. Key flow-on objectives were:
    - to define the limits of detection reliability for dogs (i.e. to define the conditions under which dogs should not be used);
    - to study the variation in availability of odour from mines under different conditions; and
    - to improve the objectivity and quality of information used to prepare the IMAS.
- To introduce MDD accreditation procedures to Afghanistan.

The originally proposed questions:

- Overall research question: Why do dogs miss some mines?

- The same question framed more specifically: What are the conditions under which dogs are most likely to miss mines?
- What proportion of mines are found by dogs under different conditions?
- What chemical signatures are available above and near a mine?
- How does that chemical signature vary around one mine? At one time? At different times of the year?
- What is the variation in chemical signature among mines of the same type buried at different depths, in different soil types, and at different times of the year?
- How does the training and behaviour of the dog influence the probability of a mine being found?
- How does the training and behaviour of the handler influence the probability of a mine being found?
- Are mines missed because the handler misreads the dog's signals?
- What is the relationship between the location at which the dog first detects the mine, the location at which the dog indicates the mine, and the location of the mine itself?
- What is the rate of false alarms (false indications; mine indicated but none present)?
- What is the cause of false alarms?
- What odours are available to dogs from different types of mines?

In retrospect, most of these questions were addressed to some extent, and some are addressed very well by the study. However, some were too ambitious and were barely touched upon.

Environmental influences on odour availability

Maintaining a reasonably constant detection reliability in a variety of weather conditions requires objective understanding of the effects of environmental parameters on odour availability. Local standards on environmental issues are applied by most if not all demining organisations, sometimes with very specific requirements (e.g. dogs are not to be used at air temperatures below 5°C or above 30°C, NPA-Bosnia SOP), or the requirement may be more general (e.g. dogs should work across the wind, MDC-Afghanistan SOP). Such standards usually flow from operational experience and are therefore sensible and rational. But they may not be based on an objective assessment of the problem.

For example, at low temperatures, it is predicted that odour molecules have low volatility (Phelan and Webb, 2003) and hence dogs should have a reduced ability to detect the TNT or other molecules leaking from the mine. In hot conditions odour availability should be relatively high (Phelan and Webb, 2003), but dogs become fatigued quickly. In reality, the upper and lower temperature limits at which dogs can find mines reliably have not been determined, and may vary with the dogs' recent experience. Thus operational dog teams could be making insufficient use of dogs (the defined limits are too narrow), or they could work in unsuitable conditions (the defined limits are too wide).

Certainly, local conditions must be taken into account when determining limits. The upper limit of 30ºC applied in Bosnia (where dogs mostly work on a mat of vegetation) would potentially prevent several hours of work each day in the dry and sunny climate of Afghanistan, where dogs were still working at 34ºC (breast height in shade) over relatively bare ground (surface temperatures >50ºC; GICHD, 2005b).

The theoretical issues underlying the effects of environmental factors on odour availability have been reviewed in detail by Phelan and Webb (2003), and will not be reviewed here. Phelan and Webb also reviewed all available empirical information on this issue. Unfortunately, most of the available studies are theoretical, with empirical investigations limited to studies of mine leakage in relation to soil characteristics and weather parameters. A direct practical link to detection by dogs has not previously been a component of any published research, probably because mine detection dogs are not generally available as a research resource.

This study aimed to add the dog into the picture painted by Phelan and Webb. Specifically, experienced dogs were used to search for mines in a test minefield under environmental conditions typical of the range of deployment conditions normally experienced by those dogs. The type and placement (location and depth) of mines was known, the search behaviour of the dog was recorded on video, all weather parameters were measured before and during the search (including at the moment that a mine was found or missed), and soil samples were taken from over the mine within a short time of the dog passing over it. The data therefore allowed for an analysis of weather, vegetation, search behaviour, and chemical variables that contributed to the dogs' reliability in relation to type of mine, depth of mine, and recent environmental history.

History of the study, and participants

The study was originally conceived during a visit to Afghanistan by GICHD personnel in 2000, with implementation planned for 2001 and reporting in 2002. Delays were caused initially by the Taliban, and then by the ousting of the Taliban following the events of 11 September, 2001. One test field was eventually completed in May 2002, and the first sampling event took place in October 2002 (6 months after the mines were laid). Four sampling events were completed in 2003 at approximately 6-week intervals (mid April, beginning June, end July, end September), for a total of five including the sampling event of October 2002. The sampling events encompassed the full range of weather conditions under which dogs are used for demining in Afghanistan.

A second test field was planned at a location 2 hours drive south of Kabul. The site was cleared and pegged out, but no mines were laid there. The nearby town of Gardez became a centre of ongoing conflict after the Taliban were ousted, and this site was abandoned for security reasons.

In 2001, the delays caused by the political situation in Afghanistan suggested that the study might never proceed, and a satellite study was initiated in Bosnia. A test field was established in December 2001. Unfortunately, only one sampling event was achieved (in June 2002) due to a combination of poor summer weather and sickness amongst the dogs in that year. The study eventually proceeded in Afghanistan and the study in Bosnia was abandoned.

The involved agencies and their contribution are listed in Table 1.

Table 1. Agencies involved in the study, and their contribution

Agency	Location	Contribution
UNMACA	Pakistan, Afghanistan	Administrative support and funding (through UNOCHA and UNOPS)
Mine Dog Centre (MDC)	Afghanistan	Dog teams
Monitoring Evaluation and Training Agency (META)	Afghanistan	Logistic support in the field. META provided the interface between GICHD and MDC in order to minimise contact between the researchers and MDC
FOI	Sweden	Chemical analysis of soil samples, field support, advice on research design
Sandia	USA	Chemical analysis of soil samples, advice on research design
SRSA	Sweden	Funding, field support, weather equipment
GICHD	Geneva	Project management, gathering of field data, analysis of videos, data analysis and reporting
NPA	Bosnia	Logistic support and dogs in Bosnia
University of Western Aust	Australia	Research support
University of Canterbury	New Zealand	Statistical analysis of data

Finding versus missing mines

An issue in the historical background of this study was the controversial question of whether dogs find mines reliably. We therefore emphasise here that:

- this study was ***not*** designed to investigate the question of whether dog detection systems find mines reliably, and
- the study was designed to ensure that some mines were missed.

For this study to produce useful data, it was essential that some mines be missed by the dogs. Central to the research design was the objective of statistical comparison of data in two general categories: data for ***found*** mines and data for ***missed*** mines. Comparison was of many parameters, but a central concern during the design phase was that the “missed mine” category might contain too little data for statistical analysis to proceed. For example, small sample size in the missed mine category was a problem for some analyses of the data from October 2002, when the highest proportion of mines was found.

In order to ensure that some mines were missed, the task was made difficult for the dogs as follows:

- The dogs did not work to the SOP used by MDC-Afghanistan.
- The dogs worked for longer periods than is their usual operational experience.
- Some mines were buried deeper than the normal depths at which mines are expected to be found reliably, or at which especially AP mines would normally be buried. Depths at which mines were laid in the test minefield (N) were surface (20), 7.5 cm (29), 15 cm (39), 20 cm (8), 25 cm (18). More than half of the mines were therefore buried deeper than the IMAS requirement for reliable detection by metal detectors.
- Some mine types used were known or thought to be difficult for dogs to find.
- The test site was established in a contaminated area.

It is therefore essential that the results of this study are ***not used*** to support arguments about the reliability with which dogs find (or miss) mines. The study focuses on comparison among groups, and does not provide data to address issues of reliability in absolute terms under typical operational situations.

We also take this opportunity to congratulate the Afghanistan MDC on being willing to expose its dogs and its programme to the objectives of the study, which clearly included the future possibility of critical comment on reliability issues.

Chapter 2. Methods

Preparation of the Test Field

The test field was established in a steep-sided valley at Kharga (Q’arga), 15 km north of Kabul just below a reservoir dam (*Figure 1*). The site had originally been established as a 9-hole golf course as part of a larger recreational and commercial development involving a swimming pool, a lake, accommodation, restaurants and a fish farm. Most of the old putting greens could still be seen. It was a battlefield at some point during the Russian occupation or the civil war, presumably after being abandoned as a commercial and recreational facility. When the site was first visited by GICHD in 2001, there was a crater from a large bomb in the middle of the site, some artillery pieces were stored on site, and most of the buildings were destroyed.

The site was initially cleared using dogs from MDC, who treated the deployment as a standard clearance exercise. Some explosive items were found (*Figure 2b*) and a large number of indications at which nothing was found suggested that there was considerable explosive contamination on site. Likely sources were the bomb, which had only partially exploded, runoff from the surrounding hills (on which cluster bomblets were still present) and items or residual explosive remaining deeper in the ground. During the period of the study, dangerous objects such as fuzes and artillery shells appeared regularly on the site, presumably either washed down from the surrounding hills or thrown from passing vehicles. Battlefield clearance was conducted in the hills surrounding the site during early 2003.

Up to 30 cm of topsoil was removed (*Figure 2a*) from about two thirds of the site prior to the test mines being laid, with the aim of removing most of the contamination left by the partially exploded bomb. After removal of topsoil, the site was cleared again using dogs (*Figure 2c*), and the indication rate was considerably reduced. Even so, runoff from the surrounding hills presumably continued to introduce contamination, and subsequent soil chemistry analyses suggested that considerable contamination remained in the ground. Although not ideal for the trials, the site was realistic in that dogs routinely work in highly contaminated situations in Afghanistan. They are also trained at a highly contaminated site (the MDC training area in Kabul).

Figure 1. The Kharga test field in May 2002

a. May 2002. The Kharga site showing an old pond (centre right), a demining clearance site (centre left) and the old golf course clubhouse. Kharga dam in the background.

b. May 2002. Abandoned artillery pieces on the Kharga site (removed in May 2002).

c. April 2003, eastern side of Kharga site from dam. Study test field on right of the central road.

d. April 2003, western side of Kharga site from dam.

Layout of the test field

After soil preparation, the site was laid out into 31 strips, each 40 m (X axis) x 8 m (Y axis). The length of 40 m was chosen to provide a realistic search baseline, and the width of 8 m was the standard line search distance for Afghanistan dogs. Strips were marked in 2-m intervals using wooden pegs, painted blue (corners), red (8-m intervals) and white (2-m intervals; *Figure 3*). These pegs were used both to measure out placement of the mines, and throughout the study to define the location of the searching dog and the mines.

Figure 2. Preparation and clearance of the Kharga test site

a. Raking of topsoil prior to removal offsite.

b. An abandoned arms cache.

c. A dog giving an indication during preliminary clearance.

Figure 3. The Kharga site, showing pegs used for boxing

a. September 2003. Line of pegs on right side.

b. October 2002. Adjacent boxes.

The mines were laid in March and May 2002. A total of 120 locations were identified for a planned 120 mines (average 4 per strip). A total of 114 mines were laid because only 6 (of the planned 12) of one type were available.

Mines used

Some confusion occurred over the correct name for the 8 types of mine used. We follow Jane's nomenclature and other assignments (King, 2003), except for a small Pakistan-made AP mine, which is called P3 in Jane's, but is called P4AP here. Where there are AP and AT mines with the same or similar names, AP or AT is added to the name. There were essentially three groups of mines used: 3 small AP mines, 2 medium sized AP mines, and 3 anti-vehicle mines (AT mines) (Table 2).

Table 2. Types, names and size of mines used in the Kharga test field (after King, 2003)

Mine	Origin	Explosive	Weight of explosive	Weight of mine
P4AP	Pakistan	Tetryl	30 gm	140 gm
Type 72 AP	China	TNT	50 gm	140 gm
YM1		RDX	50 gm	190 gm
PMN2	State factories	TNT/RDX	100 gm	420 gm
PMN	State factories	TNT	240 gm	550 gm
P3AT	Pakistan	TNT	5 kg	7 kg
TC-6	Italy, various	TNT/RDX	6 kg	8.4 kg
TM57	State factories	various	6.3 kg	8.5 kg

The following assignment rules were used:

- The number of mines in a strip was randomly assigned using a weighted mean (average of 4 per strip) and restricted range (minimum 2, maximum 5).
- Once a mine had been assigned to a strip, location within the strip was assigned randomly with the limitations that a mine was a minimum of 3 m from any other mine, and 0.5 m from any boundary.
- Having randomly defined 120 locations in 30 strips (one strip was left empty), mine x depth combinations were then randomly assigned to each location in replicates of 4 (= a total of 30 mine x depth assignments for 120 locations) using the following rules:
    - strip number was ignored during the assignment process, thus it was possible (if unlikely) for two replicates to be assigned to the same strip (e.g. two PMN mines at 15 cm depth);
    - mines were laid at five depths (surface, 7.5 cm, 15 cm, 20 cm, 25 cm), although every mine was not laid at every depth;
    - 8 types of mine were used (*anti-personnel*: type 72, PMN, PMN2, YM1, P4AP; *anti-vehicle*: TM57, P3AT, TC6);
    - six of the mines were assigned to 3 depths (for 12 mine x depth replicates) and two were assigned to 5 depths (for 24 mine x depth replicates, including two sets of 8 mines at 15 cm); and
    - details are in Appendix 1.
- Depths were measured to the top of the mine.

- Mines were laid following strict IMAS protocols, involving washing and sterilising the mines three times over several days (see IMAS 09.42). All handling and digging tools were sterilised in boiling water. Once sterilised, mines were handled with plastic gloves. All soil not returned to a hole was removed completely from the site. Details are shown in the GICHD training video: Vapour Detection (available from the GICHD at www.gichd.ch).
- The mines were laid in the last of a series of dry years. At the time of laying (spring), there was little vegetation on site and the ground was hard. It was therefore not possible to remove a cap of soil from the hole and the surface was broken up. Holes were filled in and tamped down, and it was assumed that weathering would remove evidence of the laying before the first trial.
- The individual mines used were as representative of real (or live) mines as possible, within safety constraints. In practice, this meant that some mines were missing caps or seals, allowing them to leak at faster rates than operational mines.

In practice, the above design was not perfectly achieved, as follows:

- Only 6 P4AP mines were available rather than the required 12; thus a total of 114 mines were buried rather than the planned 120.
- Due to randomisation, depths at which the 6 P4AP mines were laid were not matched, with 1 laid at 7.5 cm, 3 at 15 cm and 2 at 25 cm.
- For defuzing, some mines had plugs or other seals removed.
    - Only 5 of the 12 TM57 AT mines had plugs, making these mines more leaky than was normal for a deployed mine.
    - One of the TM57 mines used had a plastic casing (the other 11 were metal).
    - PMN2 mines have a plastic sealing ring which was cut off in some cases in order to ensure the mine was defuzed; the rings were taped back in position before the mine was buried, but the mine was not as well sealed.
    - Some mines, especially the P4AP mines, were cracked or broken, and had lost some explosive content – we considered this to be normal aging as mines in similar condition are often found by deminers (these mines had been removed from minefields).
- When the study had been completed, all the mines were dug up to ensure that they were still in position. All were in place except one, which was displaced 50 cm from its assigned location. We do not know if that was an error in the original placement, or if it had shifted after burial. However, we considered it to be close enough to the assigned position for data associated with that mine to be used normally.

A permanent weather station recording all standard parameters was set up on site in May 2002, and ran continuously throughout the trials (*Figure 4*). Unfortunately, a full data set for the entire period of the trials (October 2002 to September 2003) was not obtained due to data-logger breakdowns, with no data available for the week leading up to the trial of early June 2003. Data were available for the weeks leading up to all other trials in 2003, and qualitative information about weather was obtained from locals for the periods in which data were missing.

Figure 4. Weather station with dog and research teams working in the background

The trial procedure

Principles and background

A request for dogs was made through META ahead of each proposed trial event, and the research team was assigned 8 dogs and handlers and two supervisors for the period of the trial (one working week of six days).

During operational search in Afghanistan, a handler and dog work closely with a supervisor who observes the search and monitors details such as ground missed by the dog (*Figure 4*). This practice allows the handler to concentrate on the details of search behaviour of the dog, while the supervisor has a broader view to ensure complete coverage of ground and safety. The same practice was used for the trials.

The researchers supplied two teams, each of between 2 and 4 people who fulfilled three roles: observing the search, recording data, and soil sampling. The observer operated a video camera used to track the dog throughout the search (in some cases a camera operator was available), and spoke details of the search into a microphone connected to the camera. The datum recorder ensured that weather data were noted when the dog crossed a mine. If a second datum recorder was available, that person recorded weather data exclusively. Once the search of a strip was completed, the datum recorder(s) moved into the strip to take soil samples, sometimes with the help of the observer.

Thus at any one time during a trial two pairs of teams were working: a **dog team** consisting of dog, handler and supervisor; and a **research team** consisting of observer and datum recorder(s) (*Figure 5*).

Figure 5. Research and dog teams in action

a. Dog, handler and supervisor; observer with camera in background

b. datum recorders with portable weather station (the temperature gauge is shaded by the box)

Cross referencing between observer (on tape) and datum recorder (on paper) was achieved using coordinated time records. Both the observer and the datum recorder also held a mapped layout of each trial strip to ensure that weather records, dog behaviour and position of mine could be linked.

Terminology

- A **strip** is a marked box, 40 m x 8 m, containing 2-5 mines.
- A **trial** is one of the five sampling visits made by the research team

The following principles were established at the beginning of the series of trials:

- No entry of any personnel into a strip prior to that strip being searched during a trial (guards were present continuously to ensure that people did not enter the trial area between trials).
- One dog to search 4 strips.
- Video camera to remain focussed on the dog throughout the search.
- Different supervisors, handlers and dogs requested for every trial.
- All 30 strips containing mines to be searched on each trial.
- The dog teams to deploy as they would in a real minefield.

- MDC management staff to remain off-site during the trial (observation from the fence-line was permitted).
- A minimum of interaction or discussion between the researchers and the dog team.
- No feedback on search success given to the dog team at any time.
- META personnel supporting the study were instructed to pass no information on to MDC personnel.
- MDC given a summary only of results of each trial: no information was given to MDC on the details of the layout in the trial field until the full set of trials was completed.
- UNMACA was given a more detailed summary of the results of each trial, which in some cases led to feedback into the operational SOP used by MDC.

In practice, these principles were generally achieved, but with exceptions as follows:

- Due to availability, it was sometimes necessary to use the same supervisors on different trials.
- A few dogs and handlers were used on more than one trial.
- Due to sickness or availability, it was sometimes necessary to have one dog search more or less than 4 strips.
- Only 4 dogs were available for the sampling done in late July 2003, thus each dog did about 8 strips.
- Due to vegetation growth (height, density or excess spiky plants), it was not always possible to complete the search of all strips. The number of mines actually searched for therefore varied between trials, although most mines were searched for in all trials.
- In October 2002, some locations at which mines had been laid 6 months before could still be seen (as scratch marks on the surface). We therefore entered the strips one day before the trials began and made many additional marks on the soil surface (10-15 marks per strip; *Figure 6*) to ensure that the dogs could not locate mines from the marks. All marks disappeared through the 2002/2003 winter.

Dogs used during the trial events

A total of 39 dogs were used in the five trials, of which 22 were male and 17 female. Twenty-eight of the dogs were German Shepherds and 11 were Malinois (Belgian Shepherds). The average operational experience of all 39 dogs was 3.4 years (s.d. = 1.7). The average number of strips searched by one dog was 3.8 (s.d. = 1.9, range 1-11).

None of the 39 dogs shared a handler. All handlers were male, and the average operational experience of the handlers was 5.4 years (s.d. = 3.9).

One dog, Axel, was used in both October 2002 and July 2003 (when 4 dogs were used for the entire trial); this dog searched an unusually high number of strips (11). All other dogs were used for one trial only.

Figure 6. Digging and scratch marks in Trial strips in October 2002


a. Scratch (below) and mine (above) b. scratch (above) and mine (below)

Data gathered during the trial

The research team arrived at a strip before the dog team. The camera was positioned at an angle to the predicted search direction (determined from wind direction). A small portable weather station (a shaded stand, *Figure 5b*) was placed about 15 m from the strip. When the dog team arrived, they established a search direction (*Figure 7*) and went to work.

Search direction was frequently adjusted as the wind changed, and could be from the X or Y axis as a baseline. The observer and camera were moved as necessary to ensure an appropriate camera angle and lighting.

The weather recorder took records every 4 mins, or immediately if the dog crossed a mine at a moment when no data were being recorded. About 2 min were required to make a full set of weather records.

Figure 7. Testing the wind in order to determine search direction

Weather parameters recorded were:

- temperature in the surface layer of soil
- temperature at ground level in exposed sun
- temperature in shade at chest height
- relative humidity in shade at chest height
- soil moisture content (based on conductance)
- mean wind speed over 20 sec (m/s)
- peak wind speed over 20 sec (m/s)

The dog always worked across the wind and down wind and search direction was adjusted frequently, so wind direction was not recorded. The weather record only approximated the few seconds during which the dog was close to a mine, but was representative of that moment - temperature and humidity parameters did not normally vary during the 2 min of data recording. Wind speed was variable over short time intervals, although the 20 sec recording window reduced that variability.

When the dog gave an indication, the site was marked by the supervisor with a flag or rock (*Figure 8*), and then the dog continued to search. The indication was recorded on a map of the strip with a time and number in order to ensure that it could be linked to the weather records and video. A time and number were also noted if a mine was missed.

The distance between the mine and the indication marker was recorded, up to 2 m. Distances greater than 2 m to a mine were ignored and the indication was treated as a false alarm.

The X and Y coordinates of all indications was noted, whether or not a mine was present.

Figure 8. Mine markers placed after indications by the dog

a. Marked mine

b. Marked indications in a strip

In most cases, the dog searched the entire strip in one sequence. A complete search of a strip required between 16 and 77 min of search time (mean = 42, s.d. = 14). It took the dogs significantly longer (mean = 55 min) to search each strip in Trial 2[1] (April 2003) than in any other trial (mean range 33 to 40 min for the other 4 trials). After completing the search of a strip, the dog team left the trial area, returning about 30 min later for the next strip to allow time for the soil sampling team to do their work.

Immediately after the search was completed, the datum recorders entered the strip to take soil and vegetation samples (*Figure 9*).

Figure 9. Soil and vegetation sampling

a. taking a soil sample from over a mine

b. defining a vegetation sampling quadrant

---

[1] F (1, 4) = 16.86, P < .001

Soil Samples

Soil samples were taken in order to do chemical analysis for the presence of explosive substances. Samples were taken using stainless steel scoops (*Figure 9a*) and using sterile handling procedures (plastic gloves, sterile sample bottles). Scoops were cleaned with acetone between each sample.

The sample was taken directly over the mine from the top 2 cm of soil.

Additional soil samples were taken as follows (one sample only in each location):

- From all indication sites at which there was no mine within 2 m (= false alarms; October 2002, April 2003).
- From 2 randomly-chosen indication sites at which there was no mine within 2 m (June, July, September, 2003).
- From all indication sites that were 1-2 m from a mine, as well as from over the mine (all trials); where the indication was ≤ 1 m from the mine, we sampled from over the mine only. Indications >2 m from a mine were treated as false alarms.

Soil samples were placed in a freezer within 8 hrs of being taken, and were maintained in frozen or chilled conditions until chemical analysis up to several months later.

Chemical analysis of soil samples was undertaken at two laboratories, FOI (a government research lab in Sweden) and Sandia (a commercial lab in the USA). The two labs used slightly different procedures and analysed for slightly different chemicals. The details of their analysis protocols are in Appendix 2.

Vegetation samples

A 1-m^2 quadrant was placed around the mine (*Figure 9b*). Within the quadrant, the following was recorded:

- Total vegetation cover; 4 point scale: 0-25%, 25-50%, 50-75%, 75-100%. Cover was viewed as any vegetation that could be a barrier between the dog's nose and the ground, so included all dead vegetation.
- Abundance of smelly vegetation; 4 point scale: 0=absent, 1=present, 2=common, 3=dominant. Two species growing commonly on site gave a strong odour when bruised (*Figure 10*). Odour from the plant in *Figure 10b* could be smelled by humans up to 15 m away as the dog worked through it.
- Abundance of spiky vegetation; 4 point scale: 0=absent, 1=present, 2=common, 3=dominant. There were 4 species growing commonly on site that were spiky enough to prevent effective search by the dogs, *Figures 11, 12*). One formed a broad mat, preventing the dogs from working in parts of some strips during trials in July and September 2003 (*Figure 12a*).
- Smelly and spiky plants in one quadrat could both be recorded as a "2" (=common), but if one was recorded as a "3", then the other must be a "0" or a "1".

Figure 10. Plants that gave off a strong odour when bruised or brushed

a. flowering herb

b. strong smelling leafy plant that could form a broad mat over many square metres; dead spiky vegetation of a different species in lower right of picture

Figure 11. Spiky plants that could prevent dogs from searching small areas

a. broad-leafed flowering herb with spiked leaf tips

b. shrub with spiky branchlets

c. thistles (2 species were present)

The measure of cover was absolute, but the measures of abundance were relative, and were independent of cover. For example, if a quadrat contained one small spiky plant and no other vegetation, cover would be recorded as 0-25%, but abundance of spiky vegetation would be recorded as 3. If spiky and smelly plants were both common in a quadrat, then cover would be high (e.g. 75-100%), but abundance would be 2 for both types.

There was little vegetation on the site in October 2002 (*Figure 6*) due to several dry years. The drought broke in the winter and spring of 2003, resulting in prolific plant growth in some areas (*Figure 12*) which prevented search by dogs in parts of several strips.

Figure 12. Plants that formed a broad mat, in some cases preventing the dog from searching large areas of some strips

a. a spiky herb that was difficult for dogs to walk on in July and September

b. dense herbaceous shrubs which prevented effective search

Behaviour records

The entire search of the dog was recorded on video, with two primary objectives:

- To document the search behaviour of the dog in relation to the location of each mine or indication event.
- As a check to confirm that mines were correctly assigned in the field as "found" or "missed".

With respect to the search behaviour of the dog, the videos were used to determine:

- If the dog passed within 1 m of the mine; if the dog did not pass within 1 m of a mine, data linked to that mine were eliminated from the analysis.
- The number of times, if any, that the dog searched a line on which a mine was present (giving the number of times the mine was crossed before being found).
- The time taken by the dog from the time it left the handler to the time it returned to the handler on the line immediately preceding a line containing a mine (giving a measure of search speed). The line before the line containing the mine was used because it was searched completely, whereas if a mine was present, the search was interrupted when the dog indicated the mine.
- The height of the dog's nose from the ground, giving a measure of search focus. Height was estimated off the video in relation to eye-nose length, where 1 = one eye-nose length. Ten estimates of nose height were taken by pausing the video at random moments while the dog was searching on the line immediately prior to a line containing a mine, with the average of these 10 measures used in the analysis.
- Whether the handler prevented an indication by pulling the dog off a mine.

Other behaviour records

Qualitative observations and records were made on the following:

- the general search behaviour of the dog
- the interaction between the dog and handler
- the role and level of involvement of the supervisor
- if areas in the strip were not searched

Standing Operating Procedures (SOP) during the trial

Although the dog team was instructed to operate as though they were in a minefield during the trial, several differences to the normal SOP were applied:

- Safety distances were ignored (the supervisor and research team were often closer to the dog than the standard 25-m safety distance).
- A one-dog search protocol (normally two dogs search an area before it is declared clear).
- Search from any baseline, allowing stepping inside the strip (in order to ensure searching across the wind).
- Search continued beside an indication site (normally a 5-m exclusion zone is applied if the dog continues to search after giving an indication).

More detailed descriptions of the MDC-Afghanistan operational system can be found in the report of the Operations study (GICHD, 2005) and in the GICHD training video: *Using Animal Detectors* (available from the GICHD at www.gichd.ch).

Checking the test minefield

In late 2003, META was instructed by a local community leader to dig up the test minefield at Kharga, and the deconstruction was achieved with SRSA support in March 2004. The presence, precise location and depth of all mines were therefore checked after the study was completed. All except one were at the assigned location, and at the assigned depth, with only minor variation due to erosion effects. The mine at the wrong place was displaced by only 50 cm, thus it was retained in the data.

Data Analysis

The key category variable used to separate all data was the assignment of a mine as **found** or **missed**. The statistical procedures used are described below.

Distance between indication and mine

In the Afghanistan SOP, the search by a manual deminer extends to 1 m in all directions from an indication site (= 4 m^2), and is based on the assumption that dogs are trained to pinpoint mines. Thus, operationally, if the indication site is more than 1 m from the mine, the mine may not be found by the manual deminer. In October 2002, most finds were marked within 1 m of the mine, supporting this principle.

In April 2003 (and subsequently), we saw a new situation. Dogs that had clearly found a mine (from their behaviour) had trouble pinpointing the mine. As a result and for a variety of reasons (including interference by the handler in some cases), some indications for mines that clearly had been found by the dog were marked more than 1 m from the mine. Applying the 1 m rule resulted in the mine entering the data as "missed", even though the dog had clearly found it. Therefore, in the four trials in 2003, an intermediate "find" category was recognised (indication 1-2 m from the mine, termed **1-2 m mines**). The October 2002 data were reviewed and a small number of mines were re-assigned to this category using the mine-indication distance measures.

We are confident that the pinpointing problem was caused by heavy rains in the week preceding the trials in April and June (see *Figure 14*). The rain thoroughly washed the soil, reduced the concentration of odour immediately over the mine, spread the odour more broadly around the mine as contamination, and eliminated any gradient of odour leading up to the mine. The effects could most clearly be seen where the strip was on a slope. All of the following were seen (also see *Figure 13*):

- the dog searched intensively down-slope of the mine,
- the search concentrated in runoff trenches that were created by the rain or along the edges of vegetation barriers that trapped runoff,
- the dog walked right over the mine with no change in search behaviour,
- the dog continued searching the same small area for some time (up to 5 minutes),
- in many cases the handler eventually encouraged the dog to indicate (using the lead), and it did so at an arbitrary location in relation to the area of intensive search, and
- the dog did not indicate and moved on, either spontaneously or with encouragement by the handler.

We note that 2 m is an arbitrary cutoff for dealing with this problem, and in a few instances (as in *Figure 13b*) it appeared that there was a "find" more than 2 m from the mine. However, the 2 m cutoff was applied rigidly to the data.

Analysis of the data could have proceeded using 1-2 m indications as a third assignment category (found, missed, intermediate), or with the 1-2 m mines removed from the data. However, either approach reduced sample sizes to small values for some analyses, and was also incompatible with the broader objective of looking specifically at the relationship between environmental factors and whether mines were found or missed. We therefore dealt with this issue in two ways:

- All mines for which there was an indication within 2 m were treated as found mines in the analyses.
- Once the trials were completed in April, we demonstrated the problem to UNMACA who responded immediately by requesting that MDC adjust its operational SOP to make clearance more inclusive in situations where nothing was found in the standard 4 m^2 clearance area.

Figure 13. Drainage lines, erosion channels and indication sites

a. indication markers along drainage lines downhill from a mine

b. mine (yellow tape head), indication (flag) and drainage flow (red rope); distance from mine to indication: 2.3 m

Statistical Analysis

The following description is provided for readers who wish to understand the procedural approach to data analysis used in this report. However, understanding the statistical procedures is not critical to understanding the results.

In essence, if a result is **significant** (as determined by a statistical test returning a P value of **<0.05**, see below), then it will be interpreted as a factor influencing detection probability. If a result is **not significant** (the statistical test returned a P value **>0.1**), then it will be interpreted as not influencing detection probability. If the P value was in the range 0.1 to 0.05, then the result will be interpreted as **suggesting** some influence on detection probability, because it is close to the key decision probability for significance of P=0.05.

We used EXCEL, the statistical software package R (version 2.1.0, 2005, The R Foundation for Statistical Computing), or the statistical package Statistica®, to analyse all data. The detection probability (chance that a mine was detected) was modelled using logistic regression. The method is used to help understand the factors that influence detection success.

Logistic regression is a statistical procedure used when the primary variable with which all other variables are to be linked has two outcomes - in this case a mine was either found or it was missed. Thus, the data for one variable (e.g. humidity) are sorted into two categories (humidity when mine found, humidity when mine missed).

We began with a complex model using all the possible factors that could influence mine detection – the treatment variables (mine type, depth at which the mine was buried, month of the trial), and the measured variables (weather, vegetation and soil chemistry).

The statistical procedure used to decide which factor has an important influence on mine detection is to systematically remove each factor one-by-one from the model.

The model without the current factor of interest (e.g., with TNT removed) is compared with the model where that explanatory factor is included. If the model without the factor is just as good at predicting the chance of a mine being detected as the model containing the factor, then that factor is not important in determining detection probability.

To decide if a reduced model (a model with a factor removed) is as good as a model with the factor included, an objective, statistical test is needed. For logistic regression the test is based on the change in the residual deviance **between the two models**. Deviance is a measurement of how well the model predicts detection probability, and is based on the difference between the number of mines that the model predicts would be found and the number actually found. The residual deviance measures how poorly the model predicts detection success. The term "residual" suggests that there are still some remaining, and unexplained, influences on detection probability.

The notion of deviance used in logistic regression is analogous to the notion of variance used in regression analysis or analysis of variance, but they are not calculated in the same way.

The formal statistical test is called the **likelihood ratio test (LRT)** which returns a value estimating the change in the residual deviance of the model with and without the explanatory factor, and is the test statistic reported here. If the change in residual deviance is small, then the factor is not important in determining detection probability. The LRT uses the chi-squared (χ^2) distribution. The probability (P)predicted by that distribution is used to decide if the factor is important or not.

Some analyses in this report used standard analysis of variance (ANOVA) or regression procedures. In analysis of variance, the response variable (e.g. nose-height) is a continuous measurement (i.e., it can take any value and accuracy is only limited by measurement technology). In a multivariate ANOVA, the diagnostic statistic used to decide if a factor is important in predicting nose-height uses the difference in residual variance between models with and without the factor, and is called an F-statistic. The probability (P) predicted by that F-statistic is used to decide if the factor is important or not.

By convention, a P-value smaller than 0.05 (P is obtained from tables of the LRT or F distributions, which are available as tables) is considered to be evidence that the factor is important.

The tests used are identified wherever test statistics are reported.

Chapter 3.
Results

The full data set from the Kharga site is available from the GICHD as an excel file "Kharga data for web".

General weather patterns

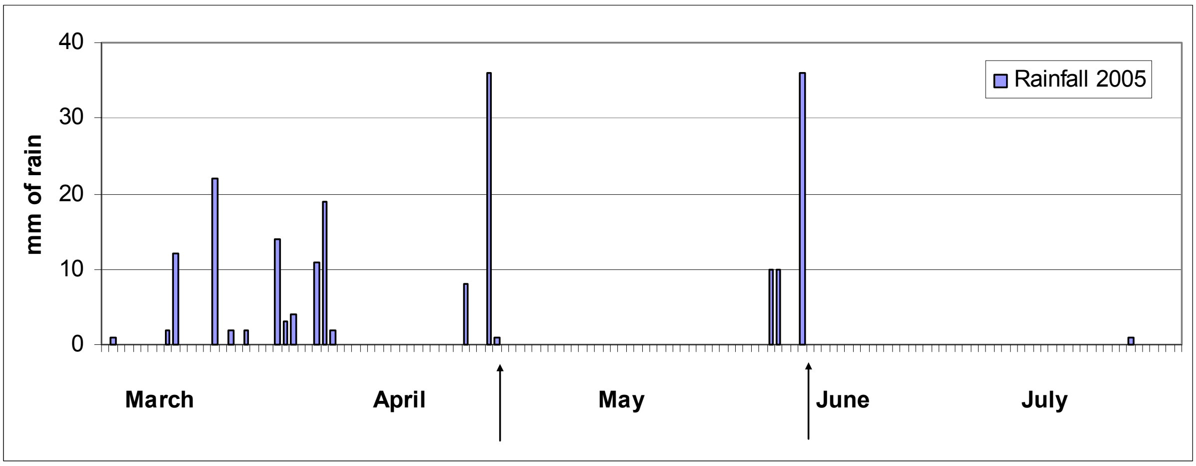
No detailed weather data are available for the years before this study, but the winter of 2002/3 was the first for some years in which there was significant precipitation. Drought conditions prevailed to a greater or lesser extent for at least the 4 previous years. Significant snow fell during the 2002/3 winter, there was considerable rain during March, and two major rainfall events immediately preceded the field visits in April and June (*Figures 14, 15*; the rainfall measures for end May are estimated in this figure, due to failure of the weather station during that week). There was no rain in June and none fell between the small rain event on 9 July and end of September (when records end).

Figure 14. Water runoff and erosion effects during heavy rain at the Kharga site

The field visit in October 2002 therefore came at the end of some years of drought. Conditions at that time were very dry and there was little vegetation on the site.

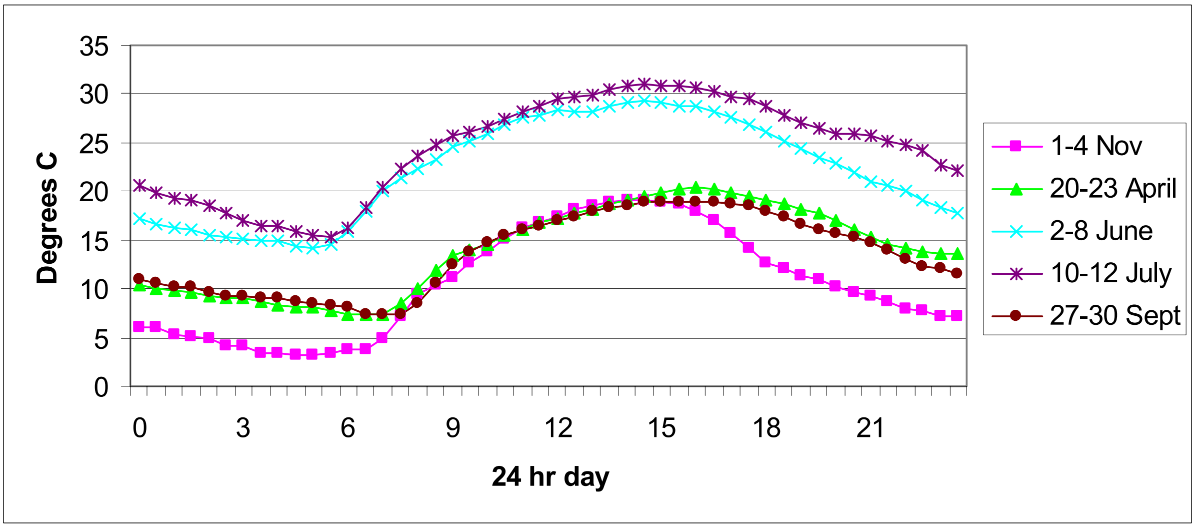
In contrast, the site was well watered in the spring of 2003, with much evidence of water runoff from snowmelt and heavy rains (*Figure 13, 14*). Vegetation growth was prolific in some parts of the site (*Figure 12*), resulting in a requirement to clear vegetation out of some boxes (removed off site), and parts of some boxes not being searched in some months.

Figure 15. Rainfall at the Kharga field site in spring and summer of 2003. First day of April and June field trials are marked by arrows.



Temperatures were surprisingly similar during the different field visits, with the 5 trials undertaken during essentially two temperature regimes (*Figure 16*; note that trials each day began about 1 hour after dawn, and ceased about 4 hours later). Due to problems with the weather station, these temperature data overlap only partially with the exact days of the trials, but they are close enough to be representative. In general, these temperatures are not too high for work by dogs, although exposure to the sun did result in dogs beginning to overheat by mid morning in June and July.

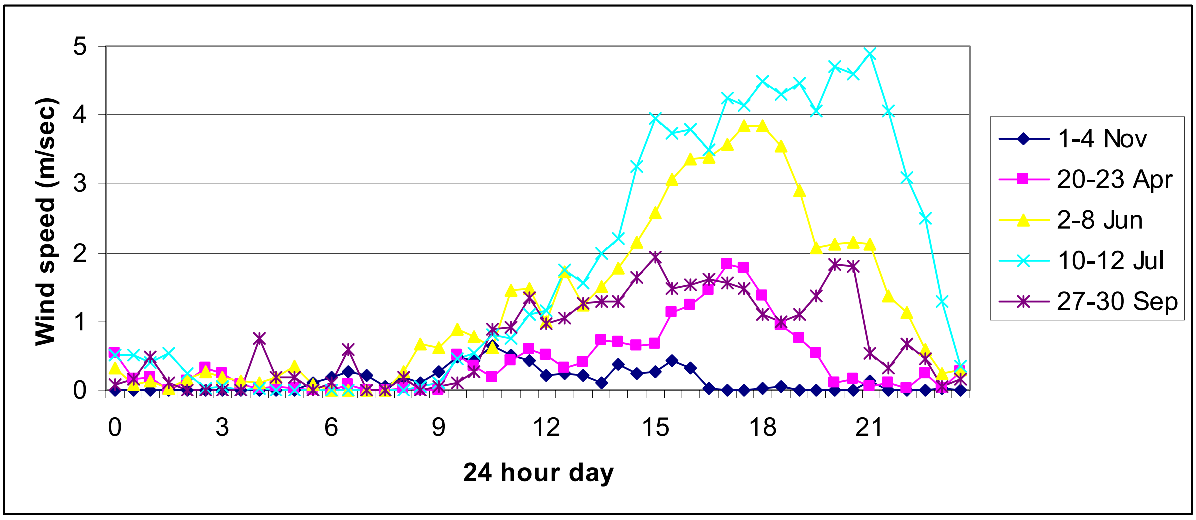
Figure 16. Average 24 hour temperature patterns at the Kharga site at the approximate time of each field visit. Dates given in the figure are for when weather data were taken, and are not the trial dates.



The Kharga site was well-sheltered, with relatively little wind. Wind prevented the dogs from working on only one occasion during the study (for about 15 mins, in July).

Wind speed was generally low at night, increasing slowly through the morning, and usually peaking in mid to late afternoon (*Figure 17*). Winds were generally low in the autumn and spring, and were strongest in summer. Although the dogs did not work in strong winds, wind was not a constraint during the morning at Kharga, including in July. Work usually stopped around 1030 hrs in July, but because of temperature rather than wind.

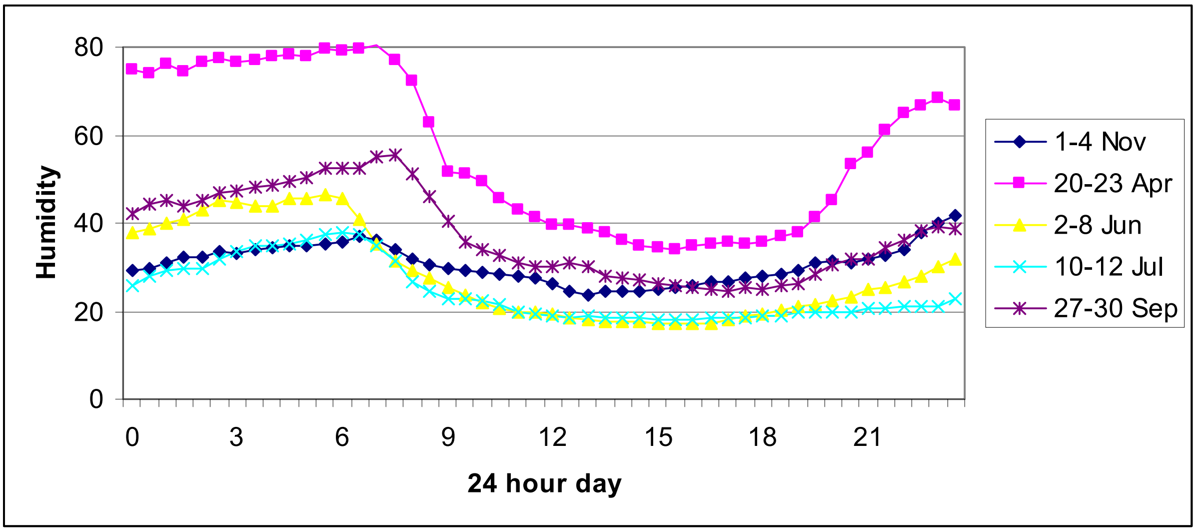
Figure 17. Average 24 hour wind speed patterns at the Kharga site at the approximate time of each field visit. Dates given in the figure are for when the weather data were taken, and are not the trial dates.



Humidity (at 1.5 m in the shade) was highest in April, and low at most other times, including in June (despite the heavy rain immediately before the trial) (*Figure 18*). Humidity dropped steeply through the morning period when the dogs were working, particularly in April and September. The surprisingly high levels of humidity in September were presumably due to overnight dew as a result of cooler nights, as no rainfall was recorded after 9 July in 2003.

Overall, although wind speed is the most likely parameter to vary during short time intervals, wind speeds were generally so low at Kharga when the dogs were working that they contributed little variation to the working conditions. The precipitous drop in humidity through the morning was a big change during the main work period, and was the most likely parameter to have influenced detection success on a short-term basis.

Figure 18. Average 24 hour humidity patterns at the Kharga site at the approximate time of each field visit. Dates given in the figure are for when weather data were taken, and are not the trial dates.



Finding mines

Due to the heavy rain experienced in the spring of 2003, and the consequence that dogs indicated some mines up to several m from the mine's actual location, MDC changed its SOP to require clearance of a 4-m square box around each indication (16 m^2) if nothing was found within the standard 2x2 m clearance box. Given this SOP change, all mines reported as "found" in this section include indications given by the dogs up to 2 m from the mine.

The find rate was calculated as the proportion of mines found by the dogs. Mines were found most successfully in October 2002, least successfully in April and June 2003 (when trials were conducted immediately after heavy rains), and increased again after the rain stopped (*Figure 19*)[2]. The find rate achieved in October 2002 is most representative of the drought conditions typical in recent years in Afghanistan.

Find rates in relation to mine type

Mines of different types were found at different rates (Figure 20)[3]. The general pattern was for larger mines to be found at higher rates, seen in the increasing height of the bars from left to right. The dogs had more difficulty with TC6 AT mines than TM or P3AT mines, and the most difficult mine to find was the Type 72 AP mine (this mine was laid at all 5 depths). Relevant points are:

- Some of the TM mines were very leaky, as they did not have plugs.
- The P3AT and TC6 mines are both plastic, whereas the TM mines are metal.

---

[2] Differences among trial months were significant, *LRT* = 23.37, 4 df, N = 539, P = 0.0001

[3] The difference in find rates among mines was significant, *LRT* = 19.83, 7 df, N = 539, P=0.006

- The Type 72 AP mines have a rubber cap, which tends to break down as the mines age. Some were already corroding when they were laid.
- Most of the P4AP mines had cracked casings when they were laid, and some had already lost significant portions of explosive.
- All of the PMN2 mines were opened prior to being laid to ensure that detonators were removed, and so were not fully sealed.

Figure 19. Proportion of mines found in each trial

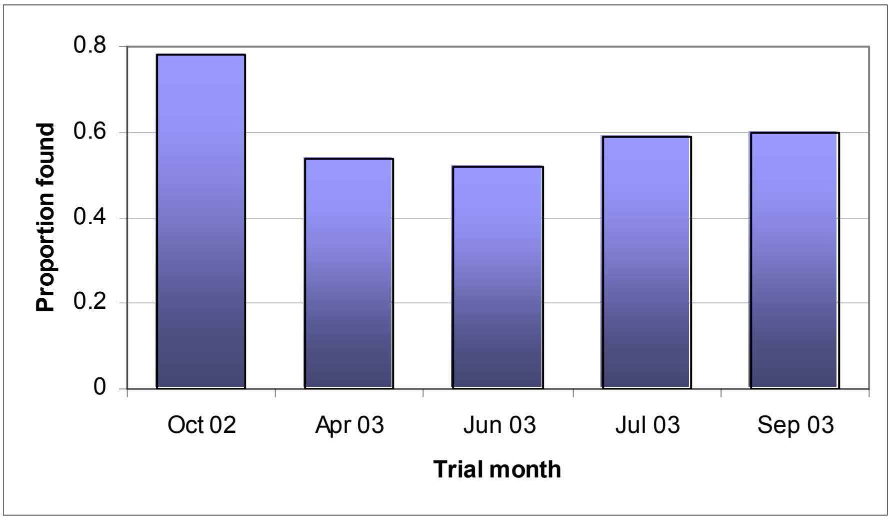
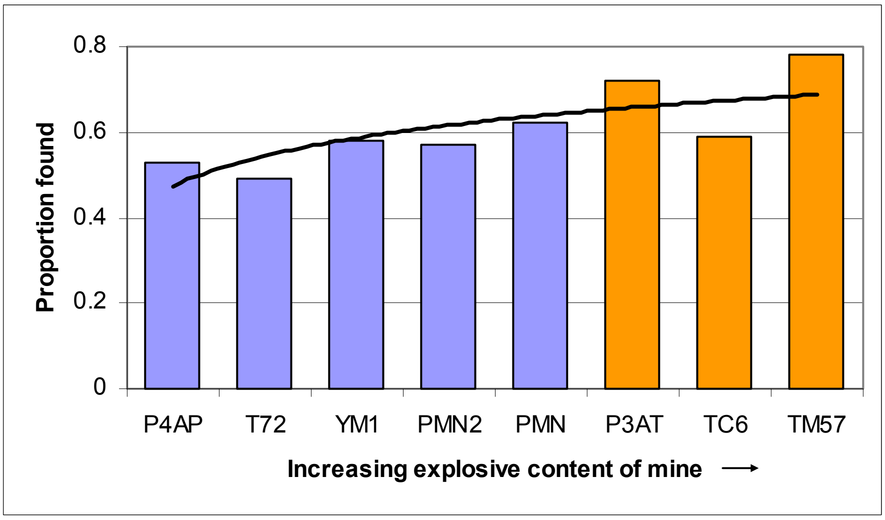


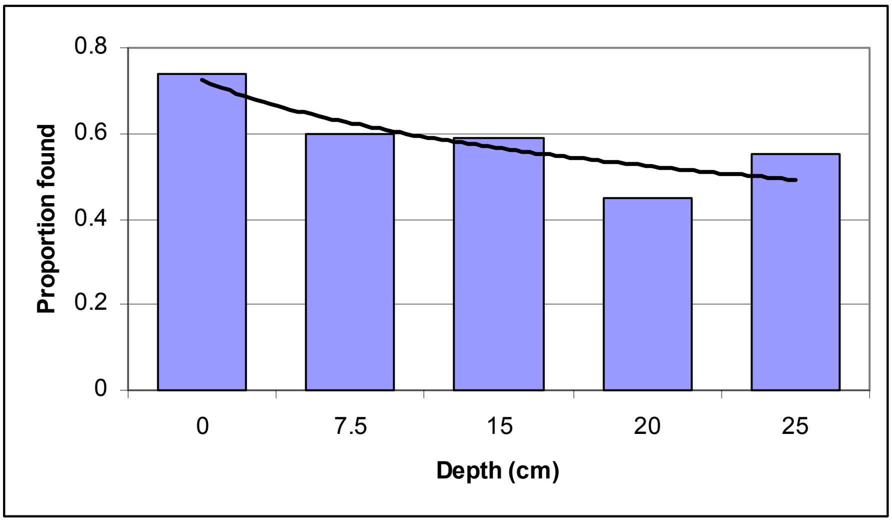
Figure 20. Proportion found of mines of each type. AP mines (blue), AT mines (orange).



Find rates in relation to depth of mine

Find rates decreased with depth (*Figure 21*)[4], indicated by the trend line in the figure. Note that different types of mine were laid at different depths, and different mines were found at different rates (*Figure 20*). The low value at 20 cm should be interpreted cautiously, as it is calculated only from T72 and PMN mines, both of which had low find rates at deeper depths. Overall, the figure is best interpreted to show that sub-surface mines were found at lower but similar rates, relative to surface-laid mines.

Figure 21. Proportion of mines found in relation to laying depth



Interaction between mine type and laying depth

Figure 22 provides a breakdown of the data in Figures 20 and 21. Note that different mines were laid at different depths, with six mine types laid at 3 depths, and two laid at 5 depths. Of the six laid at three depths, three were all relatively shallow, and three were all relatively deep.

For the mines laid at 5 depths, one (PMN) showed a strong decline in proportion found with depth, whereas the other (T72) showed little relationship with depth (and was difficult to find at any depth).

For the mines laid at 3 relatively shallow depths, two (PMN2, TC6) showed a decline from surface to subsurface, but no difference for subsurface mines; one (P3AT) showed little relationship with depth.

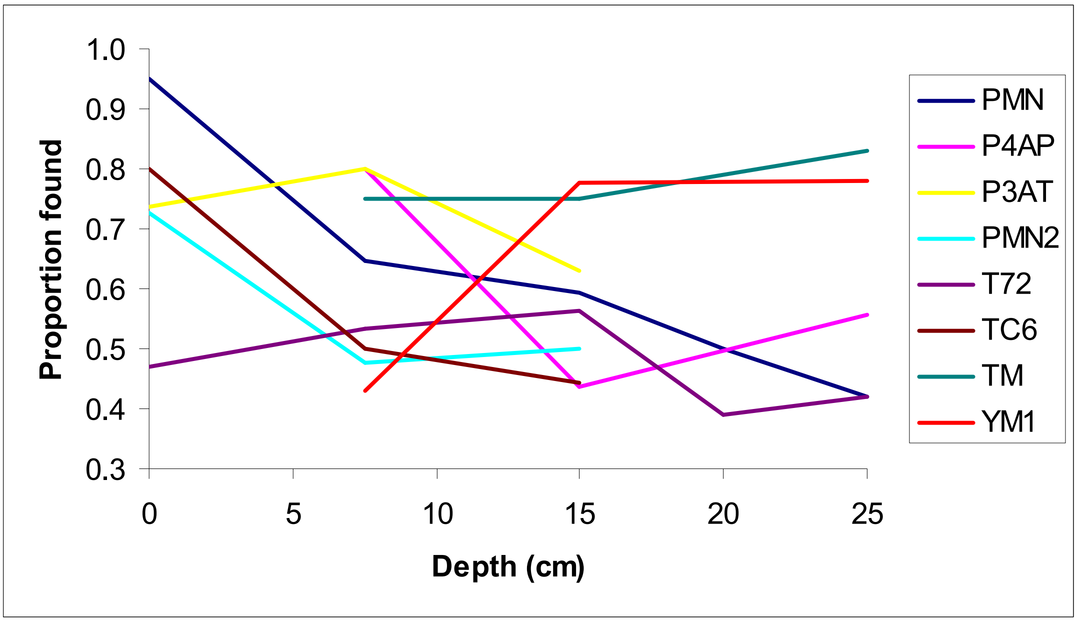
For the mines laid at 3 relatively deep depths, one (TM) showed no relationship with depth, one (P4AP) showed a decline with depth, and one (YM1) showed an increase with depth.

---

[4] The decline in find rates with depth was significant, LRT=10.31, 1 df, N=539, P=0.001

Despite the result reported in Figure 21, in general terms, it is not appropriate to conclude that deeper laid mines are always more difficult to find than shallow mines. More important is the differences among mines, with the significant effect in Figure 21 being due to a small number of mines only. Clearly, deeper-laid PMN mines are more difficult to find, and subsurface PMN2 and TC6 are more difficult to find than when on the surface. Three mines showed little or no relationship with depth (T72, P3AT and the leaky TM). Very deep P4AP mines were more difficult to find, but very deep YM1 mines were easier to find.

Figure 22. Interaction between mine type and depth in relation to proportion of mines found



False Indications (alarms)

Typically, false indication (or false alarm, FA) rates are calculated as the percentage of available negative stimuli identified as positive. In the current study, the “negative stimuli” were any patch of ground that was more than 2 m from a mine. It was therefore impossible to calculate the FA rate in the usual manner.

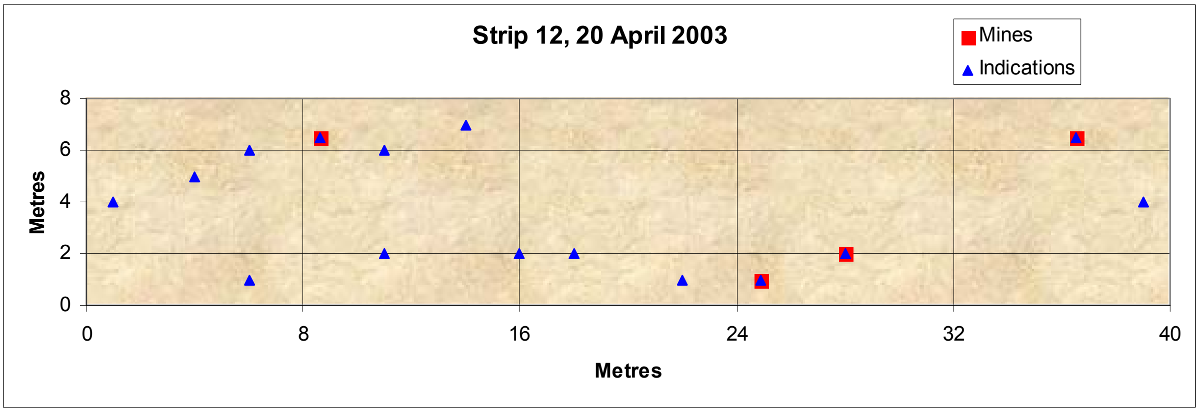
The FA rate was therefore calculated as the proportion of total indications that were more than 2 m from a mine. For example, if a dog gave 10 indications in a strip, and 5 of those indications were >2 m from a mine, this dog’s FA rate would be 0.5 (50%), because half of the indications given by the dog were false (more than 2 m from a mine).

It was likely that at least some FAs were real for the dog, in that appropriate odour was available at the location where the indication was given, even though no mine was present. Soil chemistry analyses (below) support the view that some FAs were at sites containing levels of contamination equivalent to those found above mines.

Figure 23 shows the result for one strip in April, 2003. In this example, all 4 mines were found (indicated by a blue triangle placed over the red square), but there were also 11 false alarms. If a 2x2 m clearance box was placed around every indication, then 60 m^2 of this strip would be cleared manually. If the adjusted clearance requirement was applied (of an expanded 4x4 m box around any indication where nothing was found in the core 2x2 m zone), up to 192 m^2 would be cleared. As the entire box is 320 m^2, these are extremely demanding clearance requirements, suggesting that the dog could be a liability rather than asset in terms of mine clearance in this system.

However, comparison of the figure with the topography of the site suggests a different perspective on the problem. This site slopes downhill from right to left along the long axis of the box. Most of the indications are placed along two lines, one containing one mine near the uphill end of the line, and the other containing two mines at the uphill end. There were obvious drainage channels produced by heavy rainfall along those lines (see *Figure 13a*). The upper line of indications was along a drainage channel that flowed originally from an adjacent box, also containing mines. A reasonable and sensible interpretation of this figure is that most of the indications are of contaminated sites along the drainage channels downstream of the mine or mines. In effect, each mine was found several times, although at increasing distances from the mine, and the true number of FAs was considerably less than was recorded using the 2 m criterion.

Figure 23. Lines of false alarms, potentially caused by water runoff along drainage lines with mines placed at or near the uphill end of the channel.
Drainage pattern is from right to left.



However, large numbers of FAs were recorded during the trials, and many cannot be attributed to contamination due to water runoff (especially for October 2002). *Figure 24* shows an example where runoff and contamination are not the cause of multiple FAs. In this example, two mines were found and one was missed, and there were many FAs uphill of the mines. This example was a situation where the handler pushed the dog to give an indication on almost every search line. Unfortunately, some handlers misunderstood the nature of the trial, believing that finding every mine was the primary objective. As a result, they sometimes worked the dog too intensively on each line. The dog gave indications because it had few options.

Figure 24. False alarms caused by a handler working the dog too intensively on each search line

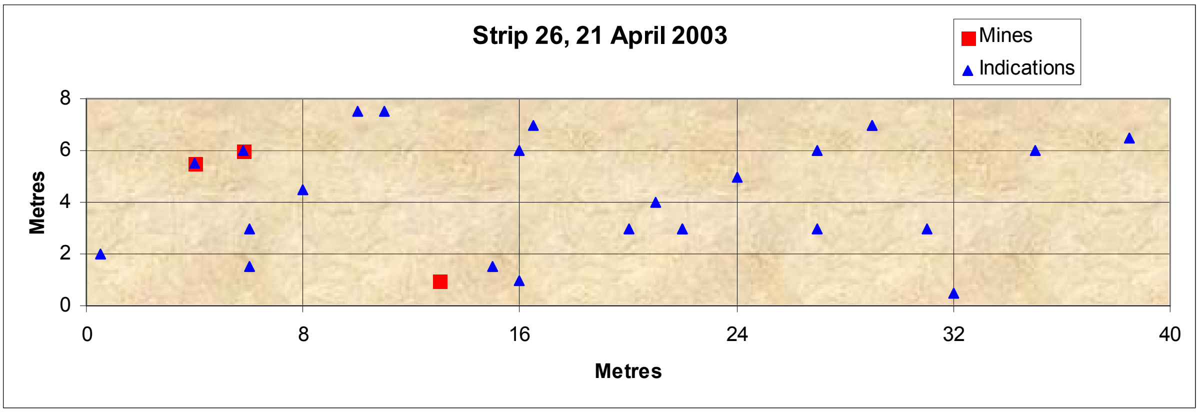
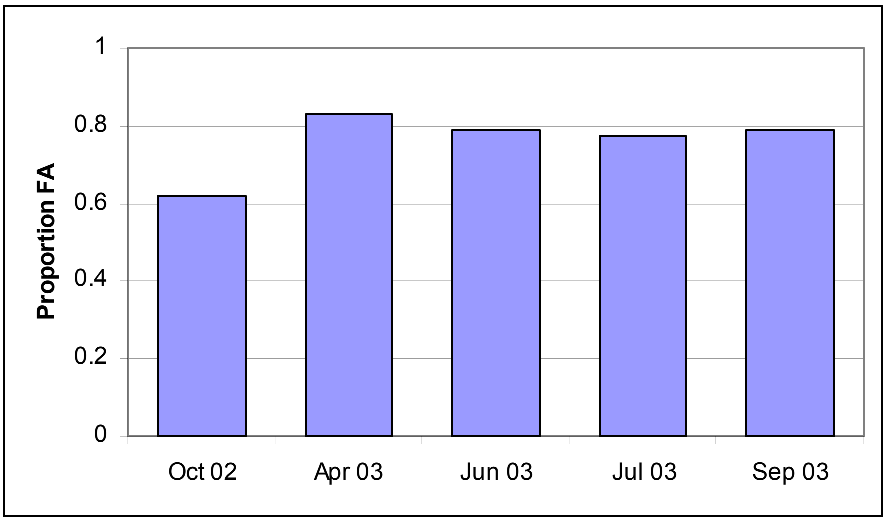


Figure 25 shows the proportion of indications that were FAs across the five trials. The highest rate of FAs was in April 2003, when 83% of all indications were false; the lowest was in October 2002, with 62%. FA rates were around 80% through all trials in 2005. These FA rates are likely to be higher than normally expected of field-search mine-detection dogs, due to the issues described above.

Figure 25. Proportion of total indications that were false (FA) for the five trials



Influence of weather variables on find and miss rates

Heavy rainfall prior to the trials clearly had an effect on the ability of dogs to find mines, and also on the ability of a dog to pinpoint a mine after it had detected that the mine was nearby (reviewed above). Assuming that the result for October 2002 (78% find rate) is representative of find rates for individual dogs in drought conditions, then recovery of the find rate after heavy rains is a long term process (see *Figure 16*), as the find rate was 60% in late September 2003, almost 4 months after the last heavy rain. This result confirms theoretical projections made by Webb and Phelan (2003).

Many weather variables were measured at the time that a dog crossed a mine (reviewed in Methods). A difficulty with analysis of weather data is that weather variables tend to be highly correlated (e.g. typically as temperature goes up, relative humidity goes down and wind speed goes up, see *Figures 16-18*). Two options are normally used to avoid the problem of correlated variables resulting in spurious results:

- Each variable is analysed separately – the problem with this approach is that it often requires a very large number of analyses, introducing the likelihood of obtaining chance significant effects.
- All the variables are combined into an overall exploratory (or descriptive) analysis, which identifies the variable(s) that contribute the most explanatory power to the data. That (or those) variables are then analysed specifically for significant effects.

The second approach is preferred, although it is statistically more sophisticated and the results are not always easy to interpret. Both approaches were used here. The results from the first analysis were consistent with the results of the second analysis, and only the results of the second analysis are reported.

Analysis of the data using Principal Components Analysis (PCA, a descriptive statistical procedure) indicated that the variable which contributed most explanatory power to the data was **humidity**.

Humidity was measured as relative humidity in the shade at breast height, and was taken every time a dog crossed a mine. An estimate of soil water content based on conductance was also taken each time a dog worked a strip. The soil water measurement did not change during the period that the dog was working, and one or a few measures were taken when the dog finished).

The PCA analysis explored how the probability of a mine being found was influenced by weather variables at the time the dog crossed the mine in relation to trial month, mine type and mine depth.

Using the language of PCA, the humidity and soil water content measures together contributed 68% of the variation in the first principal component, and 24% variation in the second principal component.

In plain language, this result means that of the weather variables, humidity and/or soil water content gave the strongest predictive power in relation to the probability of a mine being found for a particular month, type of mine and depth. Note that this result does not mean that the probability varied significantly with these two factors - only that they were a better predictor of a mine being found than temperature or wind speed.

Using follow-up univariate analysis, humidity at breast height was significant[5] and soil water content was not[6]. However, the effect of humidity was due primarily to month – because humidity varied with month (*Figure 18*). When humidity was included in a logistic regression analysis involving month, mine type, and depth, humidity did not explain significantly more variance than was already explained by month – the P value for humidity was 0.15.

In other words, the probability of a mine being detected was not significantly influenced by the weather variable predicted by PCA to be the most likely to affect detection success.

Overall, none of the weather variables measured at the time a dog crossed a mine had any effect on the probability of that mine being found.

We conclude that the probability of dogs finding mines was robust with respect to the general weather patterns experienced during these five trials. That weather variation encompassed most of the conditions under which dogs normally work in Afghanistan. Dogs therefore worked with similar effectiveness under all these conditions.

Find rates through the working day

Although humidity was not significantly linked to find rates in the overall analysis, it was possible that a large drop in relative humidity through the morning could influence find rates on a fine time scale (i.e. at short intervals through the morning). Two approaches were taken:

1. Visually compare the relationship between find rate through the morning, and humidity.
2. Link the data for find rate and humidity through time from all trials using regression analysis.

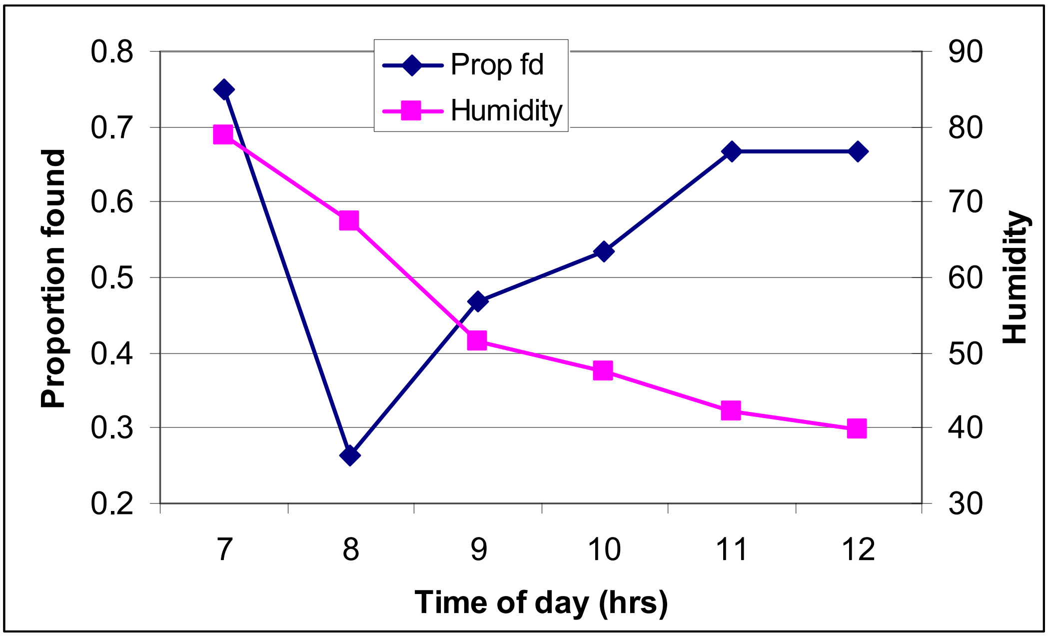
The find rate was calculated for each half hour and hour period from the time at which the dogs began work (0730 in October, 0700 in April and September, 0600 in June and July). The widest range of humidity values was recorded in April (*Figure 18*), so the April graph was used for the first approach, seen in *Figure 26*. Humidity declined rapidly through the work period. The find rate was initially high, and declined rapidly to a minimum during the second hour of work. Find rate then increased through the rest of the morning as humidity continued to decline.

---

[5] LRT=4.04, df=1, P=0.04

[6] LRT=2.21, df=1, P=0.15

Figure 26. Proportion of mines found in April in relation to humidity and time of day at which the search was conducted



The following interpretation of Figure 26 is necessarily speculative, and we note further that the equivalent graphs for the other trials (not reported) did not show the same pattern as was found in April. However, humidity was much lower at the start of the work day in all the other trials (Figure 18).

We believe that two effects are operating here, as described in Phelan and Webb (2003).

- First, in April there was a heavy overnight dew, wetting the surface of the soil and displacing surface odour. There is little movement of air overnight, thus displaced odour tends to concentrate immediately above the ground. When the sun first hits the ground (the time at which the dogs begin working), there is a short period during which evaporation of surface moisture and overnight accumulation of odour together provide an increased concentration of odour-of-mine near the ground surface. The mines were therefore relatively easy for dogs to detect in the first hour, giving the initial high detection rate.
- Second, once the odour described above has dispersed, humidity begins interacting antagonistically with detection success. Relatively high humidity makes detection difficult, and detection improves as humidity declines. This effect is predicted because, when sniffing, the dog rapidly alternates exhalation and inhalation of moist air over the ground surface (the process is portrayed in the GICHD video: *The Dangerous Journey*, available from www.gichd.ch). This moist air displaces molecules of odour-of-mine attached to surface dust into the vapour, allowing them to be inhaled. When humidity is high, the process is less effective than when humidity is low, because the key

factor influencing release of odour molecules is the high moisture content of the dogs' exhaled breath.

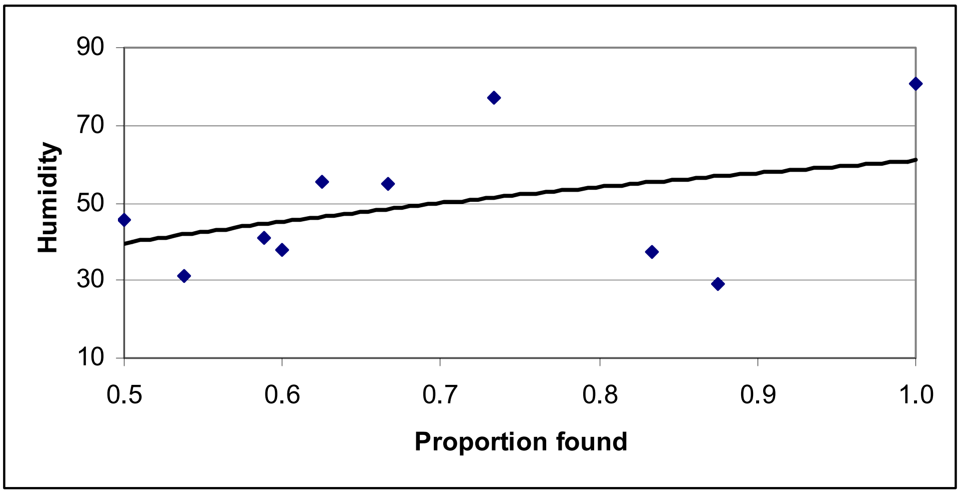
Two effects are predicted from this theoretical perspective.

1. During the first hour, detection success should be relatively high. Detection is enhanced by evaporating surface moisture and displaced odour from overnight wetting, or, if there is little overnight dew and humidity near the surface is low, because the dogs' detection system is using the humidity differential effectively. Detection success should therefore be **relatively high** and **independent of humidity** during the first hour. Technically, this means that the regression relationship between the two should not be significant.
2. During the rest of the day, humidity and detection success should interact antagonistically: detection success should be relatively **poor when humidity is high** and relatively **good when humidity is low**. Technically, this means that the regression relationship between the two should be negative, and significant.

Data from all trials were lumped to explore these two relationships. To improve sample size, humidity and find rate were calculated for half hour intervals.

During the first hour, the relationship between humidity and find rates was slightly positive, but was not significant (as predicted, *Figure 27*)[7].

Figure 27. Relationship between proportion of mines found and humidity during the first hour of work in all trial months



During the rest of the work period, the relationship between humidity and find rates was significant and negative (as predicted, *Figure 28*)[8].

---

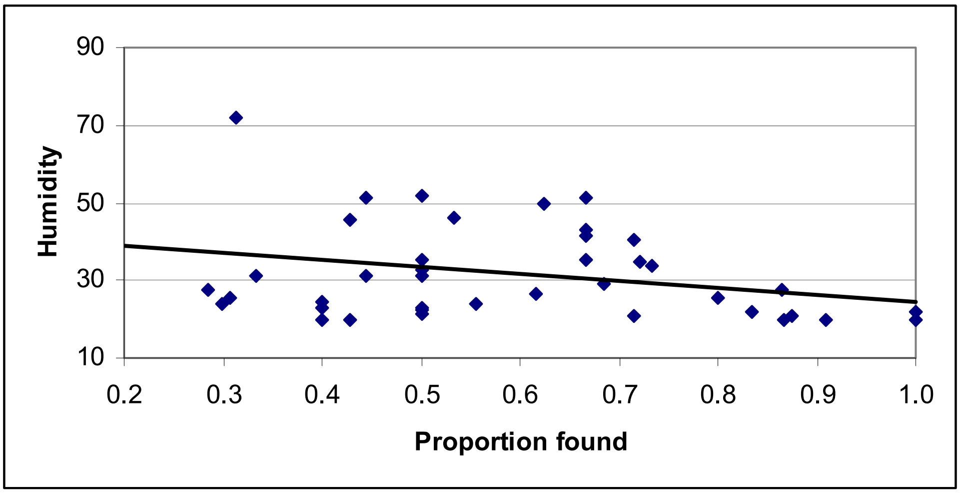
[7] R^2=0.16, d.f. = 1,8, P=0.26

[8] R^2=-0.11, d.f. = 1,40, P<0.03

Also as predicted, the average find rate during the first work hour was higher (X±s.e.=0.70±0.13, N=10) than during subsequent hours (X±s.e.=0.56±0.07, N=42). The difference was significant using a one-tailed t-test[9]. This effect is not due to the dogs being fresh early in the morning, because we worked only two dogs at a time of the four available. The dog working in the second hour was just as fresh as the dog working in the first hour, as both were doing their first search of the day.

Although preliminary, these results provide the first empirical support linking predictions about the relationship between odour availability and environmental moisture (summarised in Phelan and Webb 2003) and current views about the odour detection mechanism used by dogs. They raise the question of whether dogs should be trained to deal with significant changes in humidity during normal work periods.

Figure 28. Relationship between proportion of mines found and humidity after the first hour of work in all trial months



Vegetation

At least two mines were required in a category for the data to be used in these analyses. An absent point in a figure means that 1 or 0 mines were recorded in that category in that month.

In general terms, the proportion of mines found decreased with increasing amounts of vegetation in the vicinity of the mine (*Figure 29*). The decline was significant[10] when the main trial variables of mine type, depth and month were ignored. However, vegetation cover did not add significantly to the main effects when mine type, depth and trial were retained in a multivariate logistic regression[11], suggesting that the effect, while real, is fairly weak.

---

[9] t=1.7, P<0.05

[10] LRT=10.09, df=3, P=0.18, N=527

[11] LRT=2.96, df=3, P=0.40, N=539

It is sensible to conclude that considerable vegetation cover (categories 3 and 4) is a problem for these dogs, which are accustomed to working in relatively arid zones with patchy vegetation. We note that these results were obtained despite searches of some patches being cancelled in some months because of dense vegetation. In other words, the proportion of mines available with vegetation cover of 4 was higher, but the dogs did not search for some of them because the vegetation was too dense.

A breakdown of the vegetation cover data by trial month shows why the effects are weak (*Figure 30*). Some decline is found in most curves, but it is small.

Figure 29. Proportion of mines found in relation to vegetation cover. The four vegetation categories are 1: 0-25%, 2: 25-50%, 3: 50-75% and 4:75-100%.

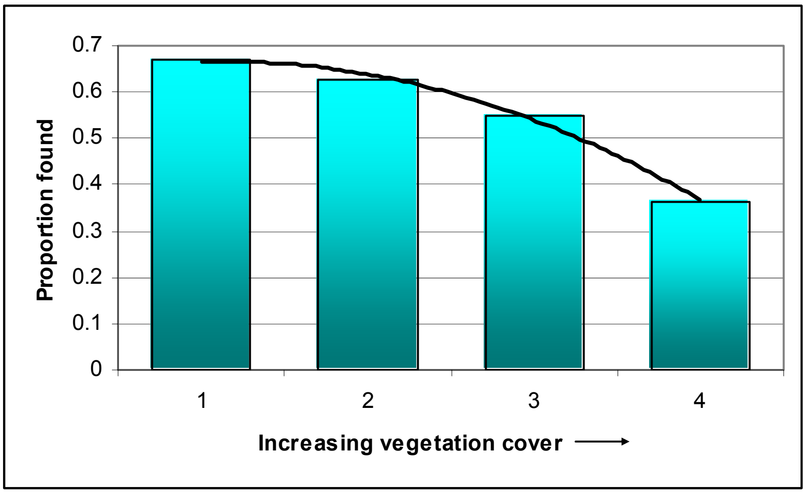
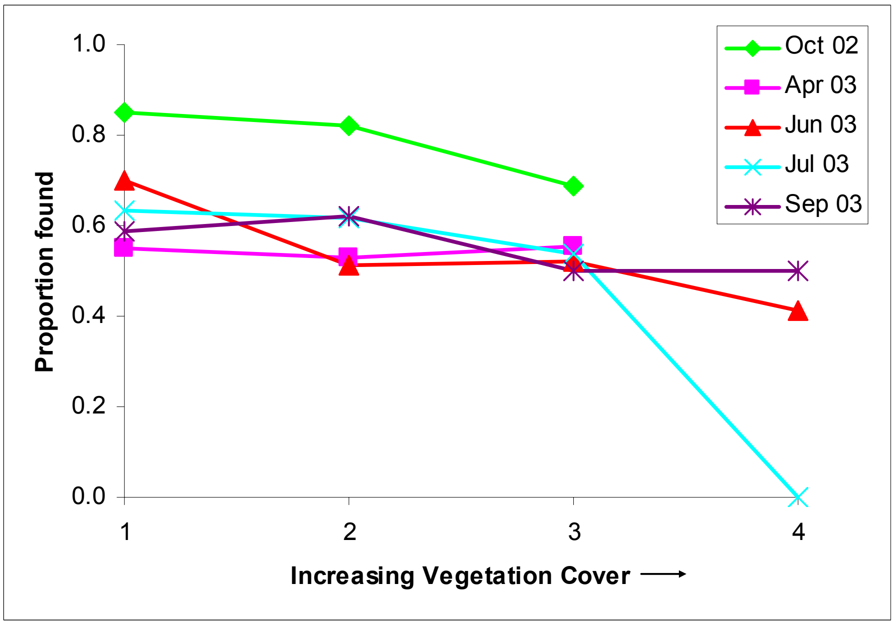


Figure 30. Breakdown of find rate as a function of vegetation cover for all trials. Vegetation categories as in *Figure 29*.



Neither of the vegetation variables: proportion of spiky plants (*Figure 31*), or proportion of smelly plants (*Figure 32*), significantly influenced the probability of mines being found whether or not month, mine type and depth were included in the analysis.

Figure 31. Relationship between spiky vegetation and proportion of mines found for each trial month

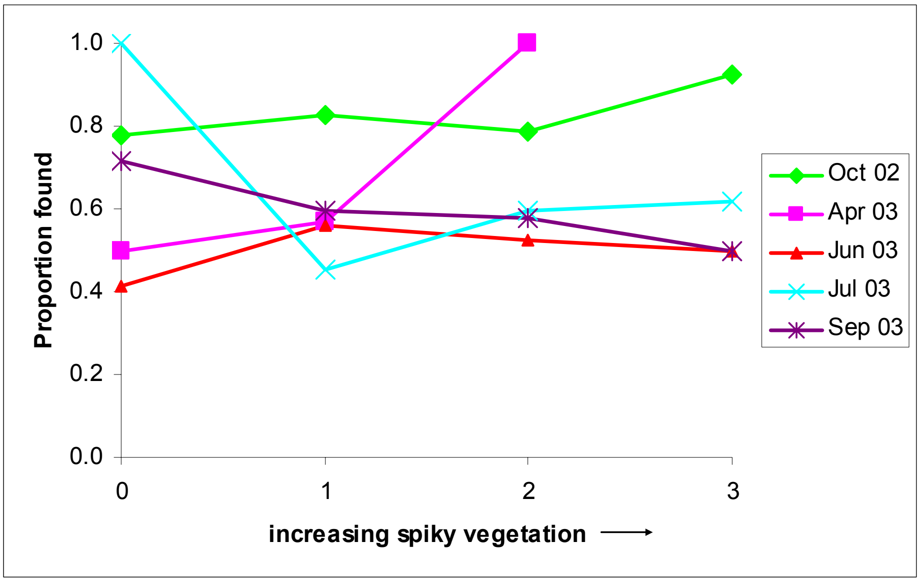
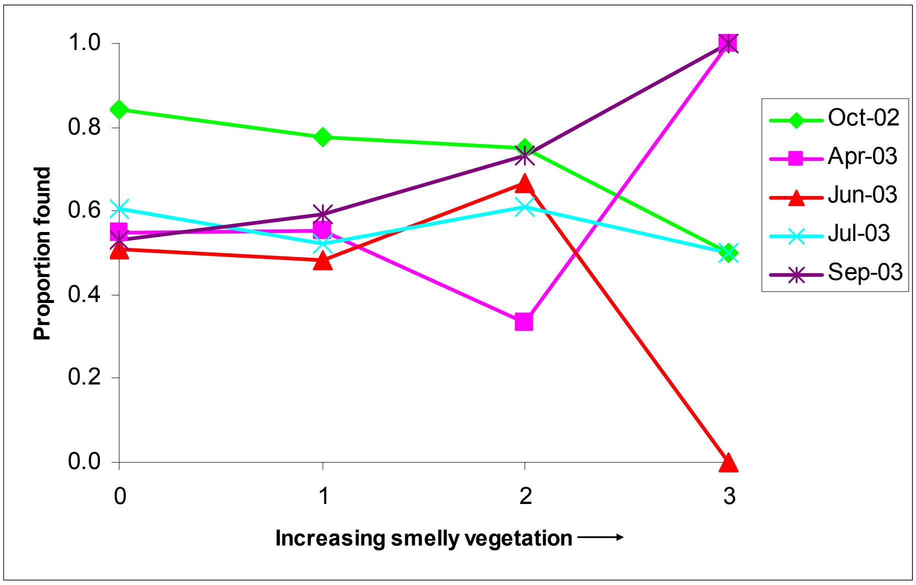


Figure 32. Relationship between smelly vegetation and proportion of mines found for each trial month



In general, the curves in Figures 31 and 32 were flat, with small sample sizes causing some extreme values (e.g. the proportion found of 1 for category 0 spiky plants in July is obtained from 4 mines). Note that there were a few areas not searched because of dense spiky vegetation in July and September. However, the dogs searched through dense smelly vegetation without difficulty. Spiky and smelly plants are described in the Methods.

Overall, we conclude that increasing vegetation cover had some influence on the probability of mines being found, with the strongest effect being reduced find rates when cover was high. The occurrence of spiky and smelly plants had no effect on the probability of mines being found.

Search behaviour of the dogs

Video recordings were used to determine if search behaviour was linked to mines being found or missed. Three behavioural parameters were measured:

- number of times the mine was crossed,
- search speed (measured as time on the search line immediately preceding the line on which the mine was found; or time on the search line when the mine was missed), and
- height of the nose above-ground (measured off the video in relative nose length).

Details are in the Methods.

Number of times the mine was crossed

If the dog indicates on a mine, then the search for that mine is over and the dog is withdrawn. However, if it passes over the mine, then it may have several more opportunities to find it: i) on the return, and ii) if the handler sends it out on that line again. During operations, handlers frequently send the dog out on a line several times (GICHD, 2005).

For mines that were found, 43% were found when the dog first crossed the mine on the way out, and another 20% were found on the return (*Figure 33*). The other 37% were found on the second or subsequent lines.

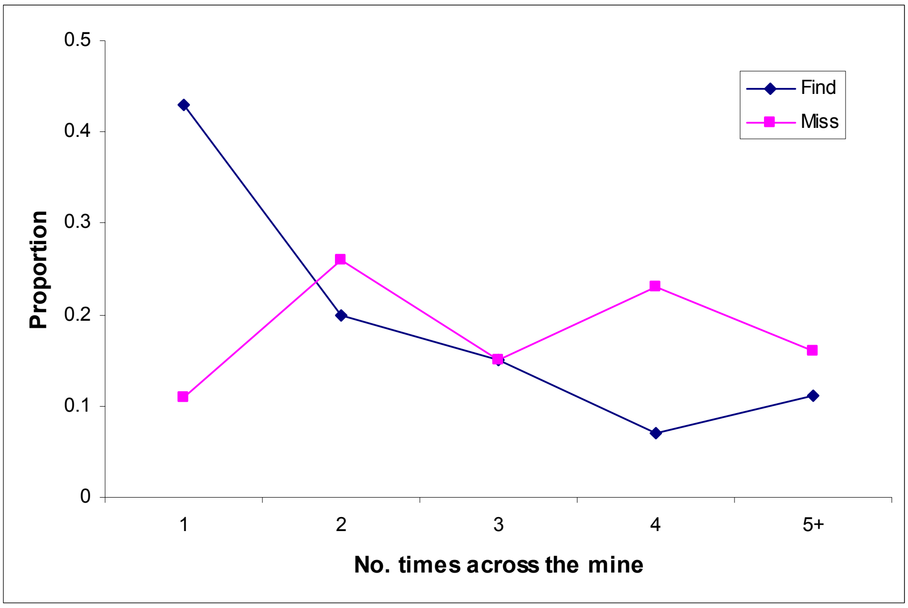
For mines that were missed, the number of times crossed indicates the number of times the dog worked that line. Not surprisingly, 2 (one time out and back) and 4 (two times out and back) were the most frequent categories. More than two searches on a line was rare.

Overall, these data indicate that if a mine was going to be found, it was most likely to be found on the first encounter. But additional searching did result in some extra mines being found, suggesting that the handlers were making sensible assessments about the quality of the search.

Search speed

Search speed showed no relationship with the probability of a mine being found or missed (*Figure 34*). The dogs searched at about the same speed in all of the trials (no significant effect for month), and at about the same speed for found and missed mines. There were no significant effects[12], indicating that search speed did not predict whether mines would be found or missed. Dogs did not miss mines because they were moving too fast.

Figure 33. Number of times a mine was crossed in relation to whether it was found or missed



Nose height

In *Figure 35*, relative nose height is an estimate of height of the nose above-ground using the distance between the eyes and tip of the nose for the individual dog doing the search (thus, e.g., 0.5 = half the distance between the nose tip and eyes of that dog).

The height of the nose was similar whether or not the mine was found (*Figure 35*)[13]. A significant effect for trial can be seen in the higher bars for June through September - the head was held about twice as far off the ground in the summer months[14], perhaps because of vegetation and/or heat, or because more dust is available. In absolute terms, the difference between April and June is 4-5 cm.

Overall, there was no suggestion of any relationship between height of nose above-ground and find and miss rates.

---

[12] LRT=0.29, df=1, P=0.6

[13] F=3.26, df=1,509, P=0.3

[14] F=17.30, df=4, 509, P<0.0001

Figure 34. Search speed in relation to whether mines were found or missed

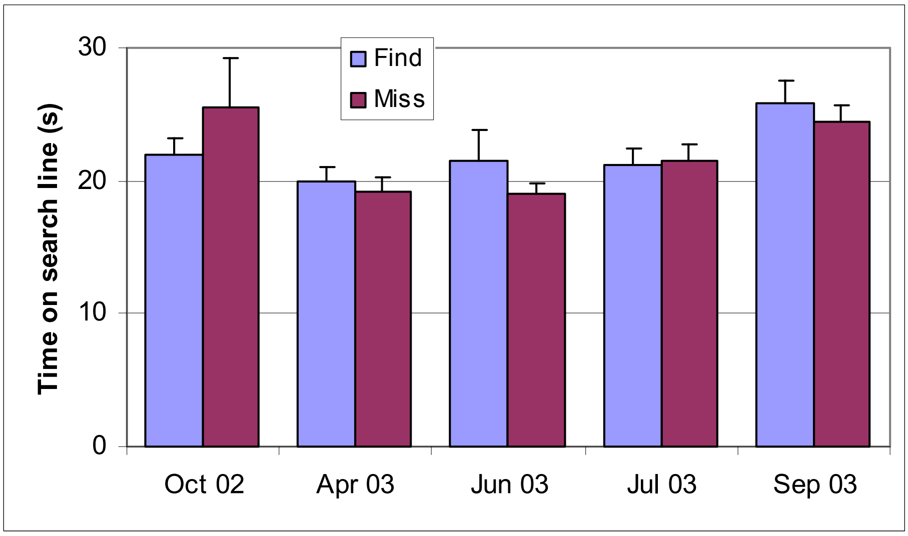
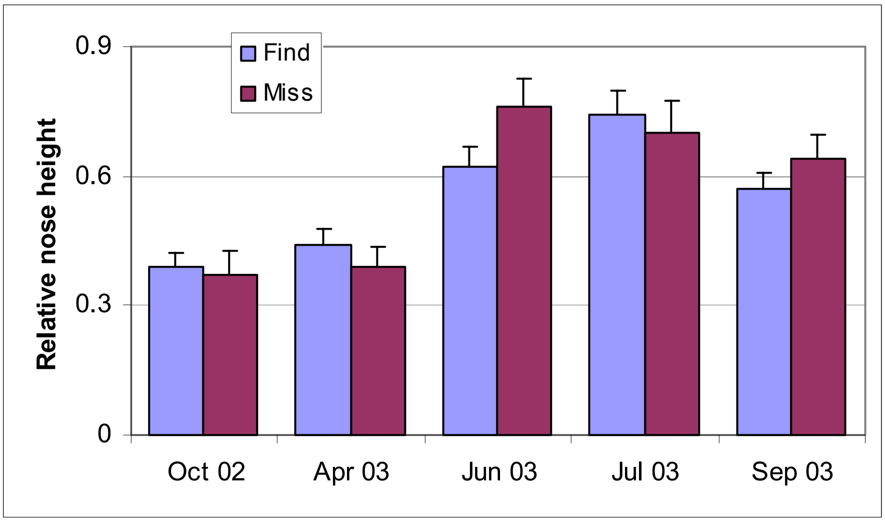


Figure 35. Height of the nose above ground during searches for found and missed mines. In absolute terms, the difference between April and June is 4-5 cm.



Soil chemicals

Chemical concentrations in this section are reported using the units **nanograms/gm (= parts per billion)**.

In this analysis, “chemicals” refers to any analyte reported by either laboratory, which are likely to have leaked from the mine laid directly underneath where the sample was taken. However, there was additional contamination on the site, and the analyte results simply report what was present in the soil, whatever its source.

The primary sample size used in this section was 489 (= no of mines for which soil sample analysis was available).

The data returned by the two labs were difficult to deal with for the following reasons:

- The two labs used slightly different procedures and returned results on slightly different sets of chemicals (although both labs returned results on the key chemicals of TNT and DNT). FOI (Sweden) returned results on 11 chemicals, whereas Sandia returned results on 10. FOI returned results on some rare aminos that Sandia did not report, gave presence/absence only for RDX, and did not detect tetryl. Sandia returned a concentration for RDX, and detected tetryl. Details are in Appendix 2, Table 1.
- The labs returned an absolute value which estimated the quantity of a chemical present in the soil sample. Due to differences in sensitivity and procedure between the labs, these values were not directly comparable. There also appeared to be differences in detection sensitivity for different chemicals. For example, samples were assigned randomly to the labs, but FOI (Sweden) detected TNT in 178 of 244 samples (73%) whereas Sandia (USA) detected TNT in 99 of 248 samples (40%). On average, FOI also reported higher values for TNT when it was found. Overall, FOI reported the following chemicals more frequently: TNT, 24-DNT, 25-DNT, 26-a-DNT, 4,6-a-DNT, whereas Sandia reported the following more frequently: 2,6-DNT, 4-a-DNT, 2-a-DNT, RDX, TNB, DNB. We were unable to compensate for differences in frequency of reporting or absolute values between the labs, so ignored those differences. However, in order to compensate for differences in absolute values (and also to avoid statistical bias in the data), all values >1000 were used in the analyses as 1000.
- Even for the same mine type, different chemicals could be reported as present or absent. To give a specific example, the following scenario was possible: for two found PMN mines, TNT was present over the first and absent over the second, whereas DNT24 was present over the second and absent over the first. These differences in availability may be of no consequence to the dogs, who potentially can use either chemical to find the mine. Thus any analysis that looks specifically at one chemical is potentially confounded in relation to find and miss rates.
- It is impossible to know the relationship between the absolute values reported by the labs, and detection threshold for a dog.
- Large numbers of zero values (chemical not detected) for even the most commonly found chemicals, confound attempts to do single-chemical analyses.

There is no straightforward analytical solution to these issues. We took two approaches:

1) We developed a simple categorical variable assigned as “present” if any chemical was found (at any concentration), or “absent” if no chemical was found. Analysis of this variable was in relation to whether the dog found or missed the mine.

2) The most common chemicals were analysed individually, using the absolute value returned by the lab (or 1000 if the value was >1000). Log values were used for both analysis and reporting in order to normalise the data.

Detection frequencies in soil samples taken over mines

The detection frequency for each chemical for each trial is in Annex 3. In summary, the most frequent chemicals detected were TNT (56.6% of samples taken over mines), 2,4-DNT (27.4%) and RDX (17.3%), with most others <10%.

The detection frequency for each chemical over each mine is in Annex 4. The counts in this table give the number of times each chemical was detected by the gas chromatograph. The chemicals found do not link well to the explosives reported in Jane's as being used in each mine (Table 2). For example, the P4AP mine is reported to contain tetryl, but no tetryl was reported over this mine, whereas TNT and various DNTs were found many times.

Chemicals present or absent

Detection of chemicals in the soil was extremely variable at different times of year (*Figure 36*). In October 2002, chemicals were detected over 46% of the mines. In April 2003, detection of chemicals was extremely low at 20%, whereas for the rest of the summer detection was high, and almost 100% in June. Note that this analysis refers to availability of chemicals in the soil, and is independent of whether mines were found or missed by the dogs.

Figure 36. Proportion of soil samples in which chemicals were detected, taken from over mines for each trial.

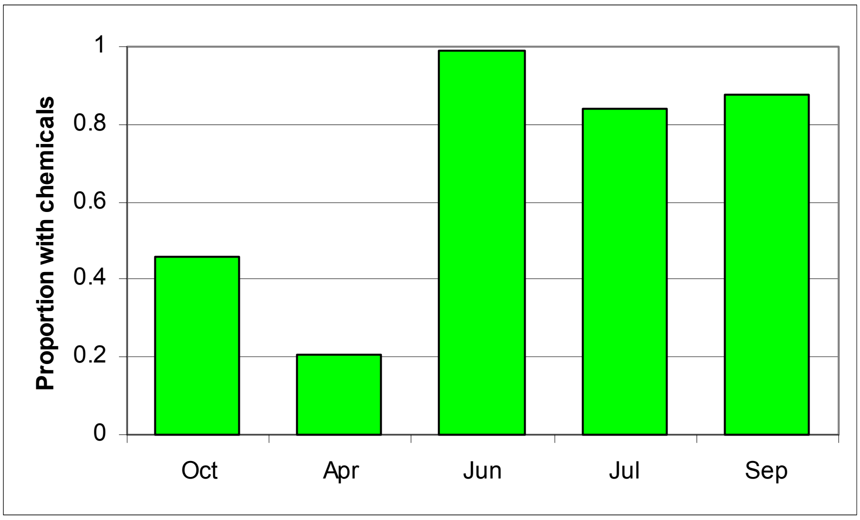
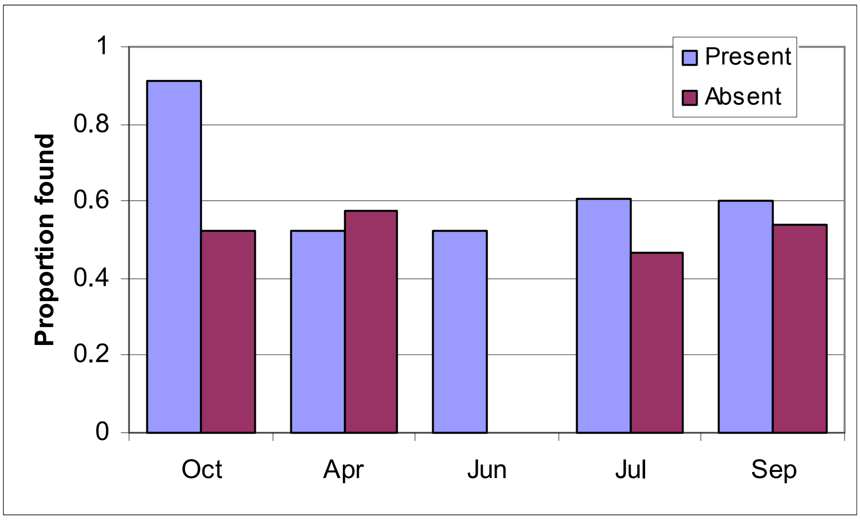


Figure 37 shows the proportion of mines that were found in relation to whether chemicals were present or absent in the soil over the mine. In general, mines were more likely to be found if chemicals were present, but the relationship varied significantly with month[15]. Chemicals were found over all except one mine in June 2003, hence the zero bar for chemicals "absent".

In October 2002, significantly more mines were found when a chemical was detected than when no chemicals were detected[16]. Slightly more mines were found in July and September and slightly less were found in April when a chemical was present, but none of the differences in 2003 was significant. This variability between months is the cause of the significant overall result in the paragraph above.

Figure 37. Proportion of mines found in relation to whether chemicals were present or absent over mines for each trial.



Overall, these results mean that in October 2002, mines were more likely to be found if chemicals were detected in the soil, but in 2003, availability of chemicals did not predict whether mines were found or missed. The rate at which mines were found when no chemicals were detected in the soil was similar in all trials, at around 50% (purple bars in *Figure 37*).

If more individual chemicals were available, mines were significantly more likely to be found (*Figure 38*)[17]. However, the proportion of these soil samples in which TNT was found was high, and increased with total number of chemicals found (**1 chemical found**: 73% contained TNT, **2 chemicals found**: 78% contained TNT, **3**: 89%, **4**: 97%, **5+:**100%. Thus, although having more chemicals present appears to improve the probability of a mine being found, we cannot exclude the alternative explanation that the dogs are detecting TNT primarily or exclusively.

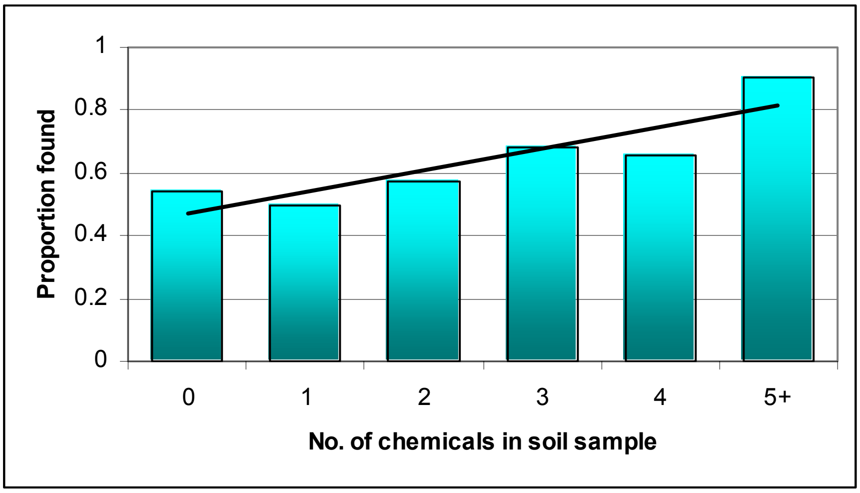
---

[15] LRT = 11.99, 4 df, P = 0.017, N=488

[16] X^2=13.2, P=0.0003

[17] LRT = 6.74, df=1, P = 0.0094, N = 277; note that this effect adds significant in addition to the effects of depth, month and mine type.

Figure 38. Proportion of mines found in relation to the number of chemicals detected in the soil over the mine.



Soil chemicals at 1-2 m from the mine

For mines where the indication was 1-2 m from the mine, two soil samples were taken:

- One from over the mine
- One from the indication site.

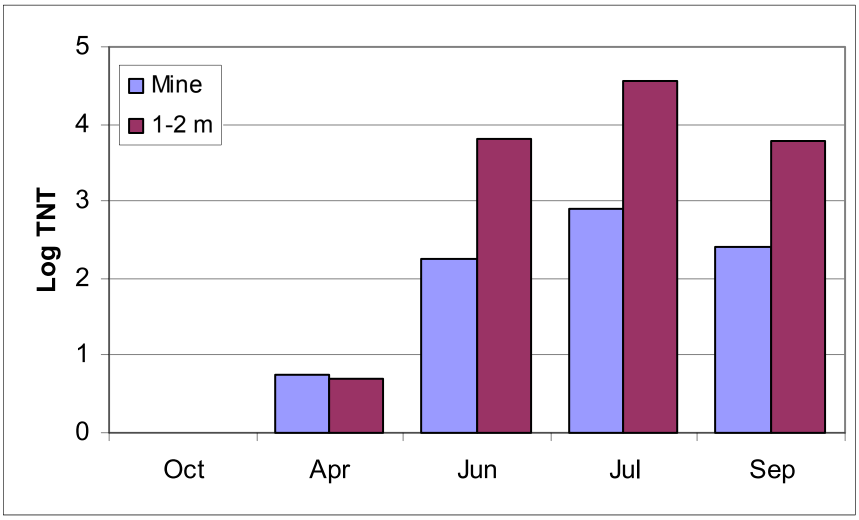
For this analysis, TNT only was used (as the most commonly found chemical). The soil samples used were only those where both samples were analysed (both samples of a pair were always analysed by the same lab). Seventy pairs of samples where at least one contained TNT were available. TNT was detected in 43 of the samples from over the mine, and 48 of the samples taken 1-2 m from the mine (i.e. at the indication site). The statistical analysis used only those soil samples where a non-zero concentration of TNT was reported.

The concentration of TNT was significantly higher in samples taken where the dog gave the indication (1-2 m from the mine) than in samples taken over the mine[18] (*Figure 39*). The effect was due to results from June, July and September. No TNT was found in the two samples available for October and for most of the 13 samples in April. Note that the Log scale means that the difference between the absolute values of the means in this figure are very big (e.g. for July, the means are 808 and 36907).

---

[18] ANOVA, df=1, P = 0.007, N = 91

Figure 39. Amount of TNT detected in soil samples taken over a mine, and at an indication site 1-2 m from the mine.



Individual Chemicals

Details for all individual chemicals, including box and whisker plots (box plots) as shown here for TNT and 2,4-DNT, are given in Appendix 5. A box plot displays the spread of data, and is read as follows:

- the line in the middle of the box is the median (50th percentile) – i.e. half the data are above it and half are below it;
- the box defines 25% and 75% of the data – i.e. half the data fall within the box;
- the whiskers extend out to the data point distance that is about 1.5 times the length of the box; and
- any "o" markers are extreme outlier values.

Zero values (which more correctly should be referred to as "below the minimum detection threshold for the Gas Chromatograph") dominated the data for even the most commonly found chemical (TNT), and so were excluded in the following analyses. The analyses are therefore of the relative concentration of the chemical over found and missed mines when the chemical was present. All analyses and figures used data transformed to natural logarithms[19].

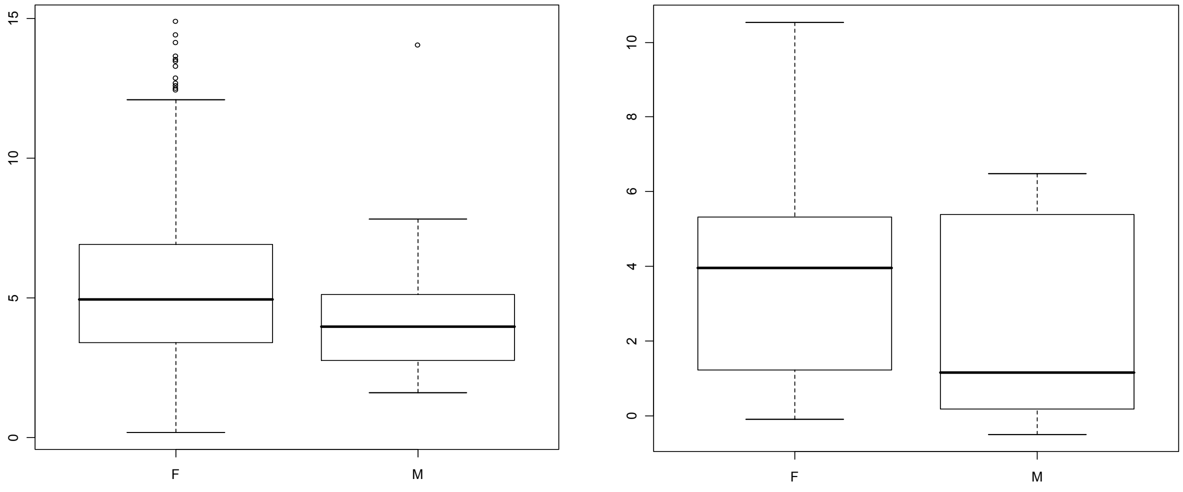
---

[19] Transformation of data from a distribution that is strongly asymmetric, as here, to a distribution that is closer to symmetric (= a normal distribution), is a standard statistical procedure used to improve the effectiveness of the statistical analysis. The absolute values in the data are changed, but the distribution of values in the data is not. Statistical tests such as regression and analysis of variance are concerned with distributions, and are not influenced by absolute values in any way.

Chemicals over found and missed mines

Enough data were available for three chemicals to be tested using logistic regression: TNT, 24DNT and RDX. Enormous variance in the reported values for concentration of these chemicals combined with small sample sizes for some categories (especially for April), made it extremely unlikely that any effect would be significant. However, with month, mine type, and mine depth included as factors in the analysis, TNT was significantly more abundant over found mines than over missed mines (*Figure 40a*)[20]. At P=0.087, the higher concentration of 2,4-DNT over found mines approached significance (*Figure 40b*). RDX occurred in similar concentrations over found and missed mines (Appendix 5).

Figure 40. Concentration of analyte in soil samples taken over found and missed mines (all data combined from all trials). Y axis = concentration in ng/gm.



a. TNT

b. 2,4-DNT

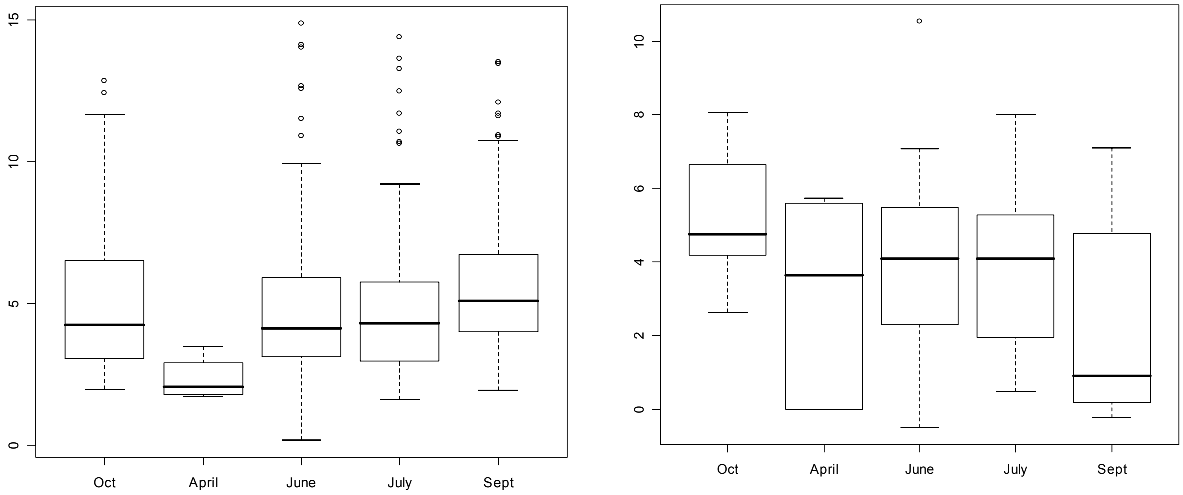
The patterns across trials for TNT (*Figure 41a*) and 2,4-DNT (*Figure 41b*) were quite different. TNT was relatively low in April and relatively high in September. 2,4-DNT was high in October, intermediate in April, June and July, and low in September. The low value for TNT for April is consistent with the pattern for detection of chemicals overall (*Figure 36*).

Too few data were available for most chemicals to run the logistic regression. However, a simpler comparison of chemical concentration over found versus missed mines was run as a t-test, using data lumped for mine type, depth, and month (Table 3). In Table 3, a positive value for t indicates that the concentration was higher over found mines, and a negative value indicates it was higher over missed mines.

---

[20] For TNT, LRT=23.84, df=1, P<0.001, N=277; for 2,4-DNT, LRT = 2.93, df=1, P = 0.087, N = 134; for RDX, LRT = 0.014, df=1, P = 0.9, N = 85.

Figure 41. Concentration of analyte during each trial month, for all soil samples in which it was detected (i.e. combining data for find and miss). Y axis = concentration in ng/gm.



a. TNT **b. 2,4-DNT**

This analysis confirmed the previously reported result for TNT and 2,4-DNT, and in total, 4 out of 10 chemicals were significantly higher over found mines than over missed mines using a 1-tailed test[21] (the two additional chemicals were both DNTs). No chemicals were significantly higher over missed mines, although three chemicals had slightly higher concentrations over missed mines.

Table 3. Comparison of chemical concentrations over found and missed mines. Means are of log values (P values for t are for 1-tailed tests)

Chemical	**t**	**df**	**P**	**Mean for Find**	**Mean for Miss**
TNT	5.7	270	**<0.0001**	5.8	4.1
24DNT	2.7	78	**0.004**	3.6	2.3
26DNT	-0.9	22	0.2	4.0	4.6
25DNT	-0.1	6	0.5	1.9	2.0
4aminoDNT	0.1	27	0.5	3.4	3.3
RDX	0.5	83	0.3	4.4	4.0
4a26DNT	1.9	22	**0.035**	5.0	4.2
2a46DNT	1.8	35	**0.045**	4.1	3.4
TNB	0.8	10	0.2	6.1	4.8
DNB	-0.6	19	0.3	5.0	5.3

As already reported for TNT and 2,4-DNT, availability of different chemicals was quite variable in different months (Appendix 5). For example, the concentrations of the two aminos were highest in April, when chemical concentrations were generally

---

[21] A 1-tailed test is used where the direction of difference is predicted before the test is conducted. P values for 1-tailed tests are half the values for 2-tailed tests.

low and were most frequently reported as zero. In contrast, RDX was at the lowest concentration in June, when chemicals generally were most likely to be detected.

Analytes over each type of mine

Counts of the chemicals found over each type of mine are in Appendix 4. The best way to read this Table is to compare the count for any chemical with the count for TNT, as TNT was usually present if any other chemicals were found. In general, all of the more common explosive chemicals were found over all of the mines, and there is little apparent link to the explosives reported in Jane's to be in each mine (Table 2). For example, no tetryl was found over P4AP mines, and RDX was rare over YM1 mines whereas TNT was common. As expected, TNT and 2,4-DNT were found most commonly. Most of the aminos and DNTs were found only rarely.

In terms of availability of analyte over each type of mine, TNT, 2,4-DNT, and RDX showed different patterns and concentrations (*Figure 42*). In this figure, pattern is shown by shape of the graph and abundance is shown as absolute value on the Y axis. In terms of concentration, TNT and RDX were fairly similar, whereas 2,4-DNT occurred at consistently lower concentrations. Although concentrations were different, the patterns for TNT and 2,4-DNT were remarkably similar, whereas the pattern for RDX was quite different. The log scale has flattened these graphs, however, there is a general trend of increasing concentrations of each analyte with size of mine. Exceptions were:

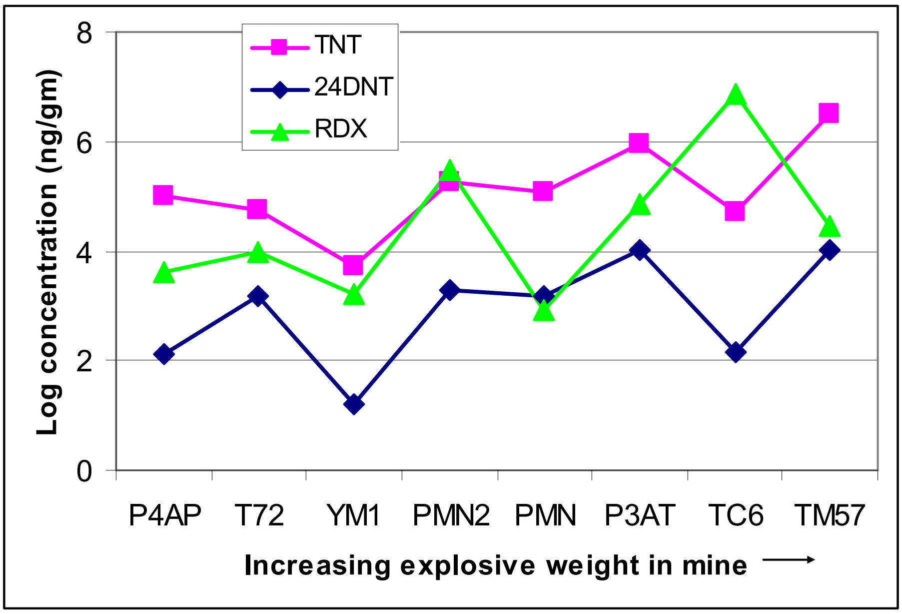
- YM1 mines, which had lower concentrations of all chemicals than either the similar-sized Type 72 mines or the smaller P4AP mines;
- TC6 mines, for which concentrations were similar to the smallest AP mines and were much lower for TNT and 2,4-DNT than for the other two AT mines; and
- PMN mines, which contain more explosive than PMN2 mines, but had similar or lower concentrations of all chemicals relative to PMN2 mines.

Soil chemistry at the sites of False Alarms

A large number of false alarms (FA, false indications) were recorded during each trial (described above). In October 2002 and April 2003, the cause of these FAs was unknown, although many were attributed to handler and training issues. But in June, July and September, the dogs appeared to be using visual cues for some FAs, caused by red marks (*Figure 43*). The marks appeared on the site between the trials in April and early June. By September, they were bleaching out, although some were still visible. In total, more than 100 red marks appeared on the site, and the dogs indicated more than half on each trial. A small proportion (about 8) were over a mine, but most were not associated with mines.

Because zero values were excluded from all calculations of means of chemical concentrations, the means given here are only for those soil samples where the relevant chemical was reported in measurable quantities. The patterns found here could therefore be biased by the excluded zero values if the proportion of zeros was very different among categories. We checked the proportion of zeros in each category, and they were approximately similar in all.

Figure 42. Availability (as concentration in the soil) of the three most commonly found analytes over each type of mine



Although the marks provided a visual cue, clearly they were the result of a chemical process in the soil. Also, although some FAs were linked to red marks, many FAs were given where there were no marks.

Here, we explore the TNT and 2,4-DNT content at all indication sites in order to provide better insight into the causes of FAs. As the red marks appeared to be an important complicating factor, they are included as a variable in the analysis. The data are from June, July and September (when the red marks were visible, and when chemicals were most frequently detected in the soil samples).

Both TNT and 2,4-DNT were more abundant in soil samples that were taken from red marks, in all indication categories (*Figures 44, 45*). Note that, with the log scale, the differences between bars are extremely large. Also, the N for missed mines with red marks was very small (2, across 3 trials).

Clearly, the red marks were caused by explosive contamination in the soil on the site, possibly linked to the heavy rainfall in the spring of 2003. Indicating those marks was therefore the correct response for the dogs, and may not have been done using visual cues.

In the absence of red marks, the TNT and 2,4-DNT content was higher over mines, and higher at indication sites 1-2 m from a mine, than over missed mines or over the mine that was close to the 1-2 m indication site (called M1 in *Figures 44 and 45;* this result is described above in more detail, see *Figure 39*). The overall lower concentration of explosive chemicals over missed mines helps to explain why the mine was missed.

The concentration of TNT and 2,4-DNT at FA sites was similar to concentrations of each chemical at sites where a mine was found, and higher than at missed mine sites. This result suggests that many of the FAs were actually correct indications of contaminated sites, although no mine was present.

Figure 43. Red marks on the Kharga site in early June 2003. The mark on left is disturbed by an ant nest. Both were indicated by the dogs, shown by the site markers.

Figure 44. Concentration of TNT at indication sites over mines (Find, Miss, M1), >2 m from a mine (FA) and 1-2 m from a mine that was not indicated (1-2). M1 mines are the mines that were close to the 1-2 indication sites.

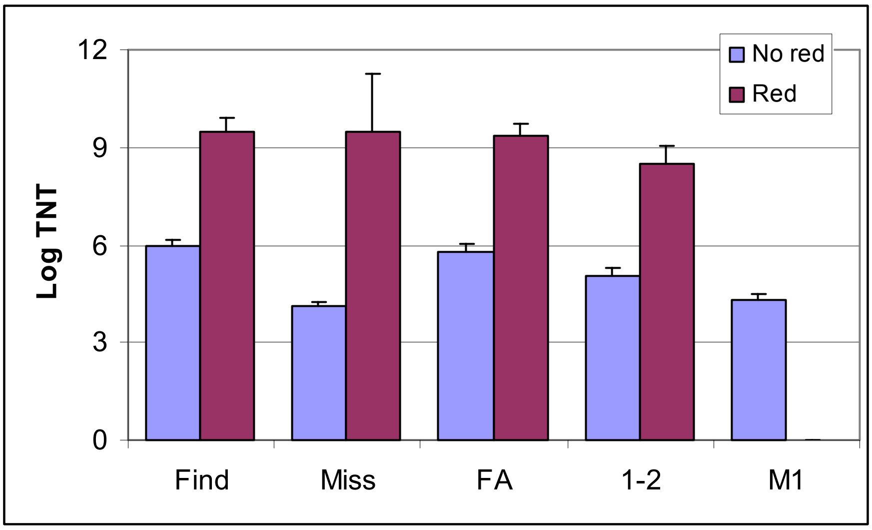
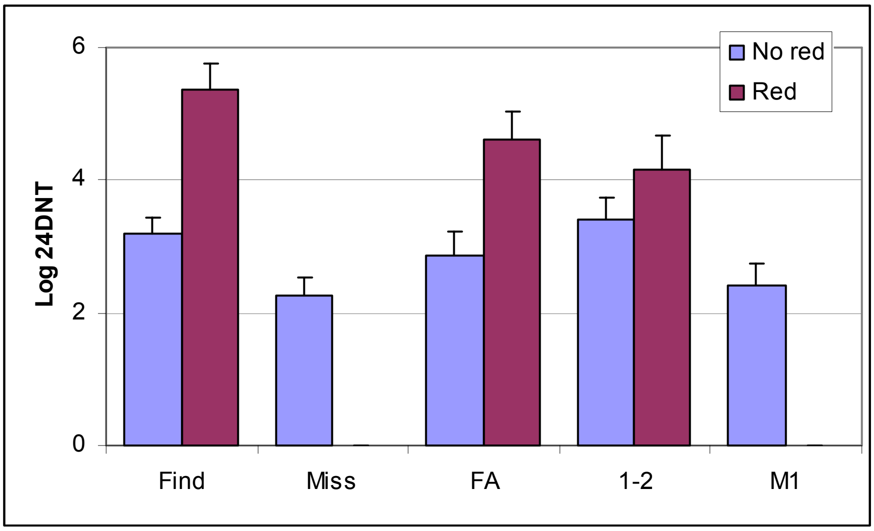


Figure 45. Concentration of 2,4-DNT at indication sites. X axis labels as in Figure 44.



Chapter 4.
Discussion

Factors that affect detection of mines by dogs

This study was designed to address the overall question: “why do dogs miss some mines?”. Just asking this question is provocative. Some agencies insist that dogs do not reliably find mines, and should therefore not be used. Other agencies argue that dogs can find mines reliably, and it all depends on how they are trained and deployed. Two fundamental problems with this disagreement are: i) that it involves no agreed definition of the notion of reliability, and ii) it ignores or avoids the possibility that the dogs might be reliable, whereas odour availability is not.

Considerable variation in systems for using dogs have been documented (GICHD, 2005b), although there have been no studies designed to test whether the different systems differ in detection reliability. Most systems compensate for an assumed miss rate by individual dogs by using redundancy (more than one dog searches an area). Unfortunately, there have been no studies showing that the standard deployment procedure - two dogs search each area - results in an improved detection rate relative to that obtained with one dog. The decision to use only two dogs is essentially an economic decision, and is really based on the assumption that each dog is a reliable mine detector.

In principle, while it may be acceptable for one dog to miss a mine, it is not usually acceptable for the dog detection system to miss a mine. When they disagree about the reliability of dogs as mine detectors, agencies are essentially applying different standards in relation to this distinction between the dog and the system.

The reality is that a dog missing a mine is probably one of the best predictors that the next dog will also miss the same mine, because an important cause of the miss is factors external to the dog. This study clearly demonstrates that the odour-environment in which mine detection dogs work is unpredictable. After heavy spring rains in 2003, Afghanistan dogs accustomed to working in dry desert conditions had difficulty finding mines which they found successfully only a few months before. One cause of that difficulty was low odour availability in April (assumed from the low concentrations of chemicals in the soil). Thus in April, the likely problem was **detection**. However, only 6 weeks later in early June, chemical concentrations in the soil had massively increased and contamination was widespread. In early June, the dogs were clearly having difficulty **locating** mines that had been detected, although it was also likely that some mines were missed because they were not distinguishable from the surrounding contamination. Under these conditions, interference from handlers resulted in some mines being missed, and some mines were indicated at distances such that follow-up clearance would likely have missed them.

Although detection rates improved through the rest of the 2003 summer, they never returned to those achieved under the drought conditions of October 2002. Thus the wet spring appeared to have long–term consequences, as predicted by Webb and Phelan (2003, in Phelan and Webb, 2003).

In addition, one short-term weather-related issue was identified. In April, detection success was initially high, then dropped considerably before increasing through the rest of the morning. We hypothesise that this effect was due to overnight wetting of the soil surface, evaporation when the sun first hits the ground, and a large and rapid decline in humidity through the morning in April. Follow-up analyses using data from all trial months confirmed a negative relationship between humidity and find rates after the first hour, and also that find rates were higher in the first hour than in subsequent parts of the morning. This effect was not due to dogs being fresh in the first hour, because half the dogs used began their first search in the second hour. The results support theoretical predictions about the interaction between moisture and surface odour, and the detection mechanism used by dogs.

The relationship between find rates and humidity was only discovered when it was explored on a fine time scale - humidity did not give significant effects on the general logistic regression analysis. The reason is that the general analysis did not take time of day into account, and high find rates were associated with both high humidity (early in the morning) and low humidity (late in the morning).

It appears that environmental variation is a key determinant of why mines are missed, with the main factor identified in this study being moisture, which affects detection success on two time scales:

- in the long-term, as a result of winter precipitation and/or heavy spring rains; and
- in the short-term, as a result of changes in humidity.

Other weather factors measured in this study (temperature, wind) did not exceed the conditions at which dogs detected mines at consistent rates. No very cold conditions were experienced, and heat likely prevented the dogs from working before it began affecting detection success (if it was going to). The site was relatively sheltered, and the strongest winds were measured during parts of the day when dogs would not normally be working anyway.

Vegetation cover affected detection success, but prickly or smelly vegetation did not. Handlers, very sensibly, would not work dogs through very prickly areas. But the ability of dogs to find mines even when working through highly aromatic vegetation was extraordinary. In general, we doubt that vegetation cover is a significant problem in Afghanistan; first, because the handlers did not like working dogs in dense vegetation, and second, because dense vegetation is encountered relatively rarely during mine detection work.

However, this study shows that dense vegetation can reduce detection success, and that result should be born in mind wherever dogs are used for mine detection.

None of the dog behaviours measured in this study influenced detection success. However, there was some influence of handler and supervisor behaviour under certain conditions. We saw instances where dogs that were taking too long to locate a mine were moved on. In effect, a "found" mine became a missed mine because of handler interference, although the dog was taking considerably longer than was normal in the handlers' experience (due, we believe, to contamination issues). The opposite also occurred, where dogs were encouraged to sit by the handler (tugging on the line) because they were taking too long to pinpoint an obviously found mine. The dog immediately sat wherever it was, and in some instances that location was too far from the mine for it to count as "found". Our discussions with handlers and supervisors showed that most had little understanding of the possibility that contamination could be carried down runoff channels. That is perhaps hardly surprising, as they had not experienced a spring as wet as 2003 for some years.

More than half the mines in this study, including some very small mines, were buried at 15 to 25 cm, depths at which dogs are not expected to find all mines. As expected, find rates decreased with depth, despite the high find rates for the leaky TM AT mines (most of which were deeply laid).

The find-rate pattern in relation to depth was complex, because different mines showed different find-rate patterns. Larger mines were found at higher rates overall, but TC6 AT mines were found at lower rates than the other two AT mines in the study. Analyte concentrations over TC6 mines were much lower than over other AT mines, and TC6 mines are the most frequent mine mentioned in the missed mine reports from clearance of the Kabul-Kandahar road in 2003 (UNMACA records show that 22 of 31 missed mine incidents involved TC6 mines). The road was searched by several odour-detection systems, and it is sensible to conclude that this mine is more difficult for dogs to find than other AT mines.

With respect to small mines, the dogs had considerable difficulty with the small Type 72 mines at all depths, and this mine should also be treated as one that is difficult for dogs to find. Most of the other AP mines showed the expected decline with depth. However, the link between find rates and soil chemistry for the two small mines, YM1 and Type 72, gave anomalous results. Although explosive concentrations in the soil were lowest over YM1 mines, find rates for YM1 mines (most of which were deeply laid) increased with depth, and were considerably higher overall than for Type 72 mines.

Issues arising

Arguably, if dogs miss mines during normal working conditions, then they are not effective mine detectors. But this superficial conclusion ignores the important reality that dogs can and do find many mines, and are therefore a valuable member of the demining toolbox. As well, under test conditions (as in this study), researchers regularly find that demining techniques return disappointing results (reviewed in the introduction). The research design used here required the dogs to search for mines that were difficult to find, and yet returned find rates that were as good as those found in studies of other demining techniques.

The most appropriate response to this study is to ask how these results can contribute to improving the reliability of mine detection by dogs.

The key mechanisms for dealing with these issues are:

- to train for the most difficult conditions likely to be encountered; and
- to operate a high rate of maintenance training within the operational environment, so that the dogs are constantly being challenged to perform well under current conditions.

An obvious third option, of having mine detection agencies monitor soil chemistry, environmental variability and odour availability, is unrealistic.

The first point is essentially impossible to achieve if the “most difficult conditions” have not been defined. This study has identified odour availability and moisture as significant issues in desert environments. While any dog operator would likely agree with those as important issues, we predict that those operators have little understanding of how they vary on either a long- or short-term basis, and no understanding of how detection success varies with them. For example, it is rare for a mine detection agency to operate any kind of weather monitoring system.

The second point requires considerable training resources, and commitment of a significant amount of time to training on a daily or weekly basis. Establishing the required resources in operational environments is difficult, and potentially impossible in some situations. This study identifies the second working hour of the morning as the time when humidity is of greatest concern. Scheduling training at that time could affect work productivity, particularly in desert countries where work at other times of day is frequently impossible (e.g. due to high temperatures or strong winds in the afternoon). However, with the second point in mind, some demining programmes do schedule significant amounts of training during each deployment cycle. Presumably some productivity cost is involved, but the benefit is an assurance that the dogs are maintaining their detection skills under current operational conditions.

Another option is to review the toolbox approach. For example, in the heavy clay soils and frequent wet conditions of the Balkans, a machine is required to work the land before dogs are used. Thus the primary role of the dogs is QA/QC after the machine, and they never work as primary detectors as in Afghanistan and some other places. Combining two different detection systems is likely to give a better detection rate than using the same detection system several times.

Soil Chemistry

This study did not directly address the question of the link between availability of soil chemicals, and odour detection by dogs, although it assumed that such a link exists. A strong link was found in the October 2002 trial, when soil chemicals were found over almost all of the mines found by the dogs, and over only half of the mines missed by the dogs.

However, the link is clearly not a simple one. Find rates by the dogs were essentially the same in April and June. In April, chemicals in the soil were at very low concentrations, and were frequently below the detection threshold of the GC. In

June, chemicals were measured at much higher concentrations, and were found in every soil sample. We believe that the odour environment in which the dogs were working was very different in those two trials, due to the combined effects of very different concentrations of chemicals over mines, and widespread contamination in June. It is possible that the similar find rates reported at both times were coincidental.

TC6 mines were difficult to find, and lower concentrations of chemicals were found over TC6 than for other AT mines. Lower concentrations of chemicals were found over smaller mines, and smaller mines were more difficult to find overall. Overall detection success improved with increasing availability of TNT and/or of all chemicals in the soil. It appears that the assumption of a link between soil chemicals and odour detection is justified.

Apart from the cost, at least five limitations were identified when dealing with the soil chemistry data.

- The enormous variance in measured analyte concentrations over even the same type of mine reduced the power of any analysis attempting to link analyte concentrations to another variable. In effect, any possible influence of the other variable on the issue being addressed was overwhelmed in the statistical analyses. We addressed this issue to some extent by simplifying the data (reducing all large values to 1000, and using natural logs of the data).
- The chemical detection threshold of the GC may **not** be strongly linked to minimum odour requirements for dog detection. We dealt with this issue by ignoring zero values in any analysis using analyte concentrations. However, it is possible that important effects in the data were not found because they have their strongest influence at threshold concentrations. If the minimum for the dog is below the minimum for the GC, then any such effects would be hidden in the zero values.
- It has been demonstrated elsewhere that chemical concentrations in soil are extremely variable on small spatial scales around and above a mine (reviewed in Phelan and Webb, 2003). Our samples were taken from directly over the mine. However, measurement limitations meant that we were not assured of being precisely over the centre of the mine for every sample, especially for small mines. Thus there are two sources of error due to spatial variation in the soil chemistry data presented here: i) variability in sampling location in relation to position of mine, and ii) variability in chemical concentrations in the vicinity of the mine. These factors will have introduced additional variability into the soil chemistry data.
- Different chemicals were found over mines of the same type at the same time. We do not know if this variability is due to local environmental effects around the mine, or to differences in the chemicals in the individual mines (e.g. due to different production sources). Both factors were probably operating.
- The two labs had different detection thresholds for different chemicals.

Taken together, these issues constrain the ability of a statistical procedure to find links between the factors being addressed, and soil chemistry. It should therefore be assumed that any effects found are extremely robust. For example, the finding that an indication given 1-2 m from a mine was at a site containing higher concentrations of chemicals than over the mine itself is a robust result.

Dogs as mine detectors

Despite the missed mines in this study, results such as the high levels of chemicals in the soil at sites of FAs, the 1-2 m result (above), and the negative link between find rates and depth, give confidence in the effectiveness of mine detection dogs.

Results such as different detection patterns for different mines, variability in availability of soil chemicals through time, the complex relationship between humidity and detection on short time scales, and the long-term effect of spring precipitation, are issues of concern requiring careful attention by agencies that use dogs.

Clearly, dogs are faced with a complex and varying odour environment. It is therefore essential that:

- agencies using dogs consider that complexity when deploying dogs, and
- discussions about the reliability of dogs are linked to the influence of factors external to the dog itself.

Clearly, these issues will not be addressed by having mine detection agencies monitor local environmental issues, or conduct studies on chemicals in the soil. **The primary mechanism available is continuous maintenance training of dogs.** Such training will ensure that the dogs are tracking local environmental conditions as closely as possible, whatever those conditions are. This study gives the time of day when humidity creates the biggest problem (1-2 hours after the sun hits the ground) in a desert environment. Although it is possible that the problem is restricted to dry environments, it is more likely that it applies in any situation where humidity is varying strongly. For example, in a situation where there is heavy morning fog, the problem could arise considerably later in the morning, 1-2 hours after the fog lifts.

The dogs used in this study were all experienced operational dogs which had long-since completed their original training, although some were undergoing refresher training at the mine dog school at the time of the study. Although originally imprinted on TNT (and presumably therefore on the associated breakdown and contamination products), a major component of the original training of these dogs uses mines in the ground. All of their subsequent maintenance training uses mines, and not TNT. They are therefore potentially capable of finding mines using any or all of the chemicals documented here. For example, having TNT present and 2,4-DNT absent over a PMN in one location, and 2,4-DNT present and TNT absent over a PMN in another location, may make no difference to the dog in terms of detection capability.

The most likely influence on their detection success during the trials was their recent operational and training experiences, and not their original training. This study documents that odour availability varies with current environmental conditions. Ensuring that dogs are maintaining detection reliability under current environmental conditions might not require maintenance training every day, but it should involve significant amounts of training conducted at least weekly. Some agencies conduct such training, and some do not. This study has demonstrated that it is not just desirable, but essential.

Bibliography

Bach, H. (2002)
Mine action technology now and in the future: is it realistic to expect great leaps forward in technology? Journal of Mine Action 6.1, 46-49.

Bach, H., McLean, I.G., Aakerblom, C., Sargisson, R. (2003)
Improving mine detection dogs: an overview of the GICHD dog program. In: Sahli, H., Bottoms, A.M., and Cornelis, J., (eds) Proceedings of Eudem2-Scot conference, Brussels, 149-155.

Croll, M. (1998)
The history of landmines. Leo Cooper, Great Britain.

Fjellanger, R. (2003)
The REST concept. In (GICHD, ed.) *Mine Detection Dogs: training operations and odour detection*, GICHD, Geneva, 53-108.

Fjellanger, R., McLean, I.G., Bach, H. (2003a)
Vapour sensing using dogs in Bosnia: a test of detection capability. In: Sahli, H., Bottoms, A.M., and Cornelis, J., (eds) Proceedings of Eudem2-Scot conference, Brussels, 162-165.

Fjellanger, R., McLean, I.G., Bach, H. (2003b).
REST in Bosnia: a pilot test of detection capability. Journal of Mine Action 7.3, http://maic.jmu.edu/journal/7.3/focus/fjellanger/fjellanger.htm.

GICHD (2003)
Mine Detection Dogs: Training, Operations, and Odour Detection, GICHD, Geneva.

____ (2004)
A study of mechanical application in demining. GICHD, Geneva

____ (2005a)
A study of manual mine clearance. GICHD, Geneva.

____ (2005b)
Mine detection dogs: Operations. www.gichd.ch/research.

Handicap International (1998)
The use of dogs for operations related to humanitarian mine clearance. Handicap international, Lyon, France.

Hayter, D. (2003)
Training dogs to detect tripwires. In (GICHD, ed.) *Mine Detection Dogs: training operations and odour detection*, GICHD, Geneva, 109-138.

King, C. (2003)
Jane's Mines and Mine Clearance, 2003-2004. Jane's, Surrey, UK.

King, C. (2004)
Demining: enhancing the process. In: *Landmines and Human Security*, Matthew, R.A., McDonald, B., & Rutherford, K.R. (eds), State University of New York Press, New York.

Lemish, M.G. (1996)
War dogs – a history of loyalty and heroism. Brassey's, Virginia.

Lokey, J. (2003)
The R&D requirements workshop. Journal of Mine Action 7.3, 9-11.

Matre, P.J. (2003)
Training, organisation and skills: case studies of practice using mine detection dogs. In (GICHD, ed.) *Mine Detection Dogs: training operations and odour detection*, 139-164.

McLean, I.G. (2003)
Scientific contributions to demining technology: beliefs, perceptions and realities. Journal of Mine Action 7.3, 40-42.

McLean, I.G., Bach, H., Fjellanger, R., Åkerblom, C. (2003)
Bringing the minefield to the detector: updating the REST concept. In: Sahli, H., Bottoms, A.M., and Cornelis, J., (eds) Proceedings of Eudem2-Scot conference, Brussels, 156-161.

McLean, I.G., Sargisson, R.J., Dirscherl, J., Bach, H. (2005)
Throwing out mines: effects of a flail. http://www.gichd.ch/7.0.html#828

Mueller, C., Gaal, M., Guelle, D., Lewis, A., Schmarch, M., Sieber, A. (2003)
Proposals for performance demonstration and modular reliability assessment for humanitarian demining. In: Sahli, H., Bottoms, A.M., and Cornelis, J., (eds) Proceedings of Eudem2-Scot conference, Brussels, 233-241.

Mueller, C., Gaal, M., Schmarch, M., Bär, S. (2004)
ITEP test trials for detection reliability assessment of metal detectors. Journal of Mine Action 8.2, 86-90.

Phelan, J.M., Webb, S. W. (2003)
Chemical sensing for buried landmines: fundamental processes influencing trace chemical detection. In (GICHD, ed.) *Mine Detection Dogs: training operations and odour detection*, 209-286.

SWEDEC (2002)
Test of Mineguzzler, Scanjack, Hydrema. Internal report, Sweden (Summary of results in GICHD, 2004, and translation available from ITEP).

Trevelyan, J. (2003)
Statistical analysis and experiments in manual demining. In: Sahli, H., Bottoms, A.M., and Cornelis, J., (eds) Proceedings of Eudem2-Scot conference, Brussels, 242-248.

Joynt, V. (2003)
The Mechem Explosive and Drug Detection System (MEDDS). In (GICHD, ed.) *Mine Detection Dogs: training operations and odour detection*, GICHD, Geneva, 165-174.

Appendix 1.

Location and type of mines in the Kharga test field

x = not used because mine not available

Sorted by mine			Sorted by Depth		
Mine	**Depth**	**strip**	**Mine**	**Depth**	**strip**
P4 (AP)	7.5	6	P3 (AT)	Surf	17
P4 (AP)	15	8	TC-6	Surf	7
P4 (AP)	15	24	PMN-2	Surf	30
P4 (AP)	15	30	PMN	Surf	8
P4 (AP)	25	17	PMN-2	Surf	24
P4 (AP)	25	23	PMN	Surf	10
P4 (AP)x	7.5x	11x	P3 (AT)	Surf	2
P4 (AP)x	7.5x	23x	PMN-2	Surf	11
P4 (AP)x	7.5x	8x	TC-6	Surf	28
P4 (AP)x	15x	27x	TC-6	Surf	9
P4 (AP)x	25x	18x	PMN-2	Surf	13
P4 (AP)x	25x	2x	P3 (AT)	Surf	14
P3 (AT)	7.5	4	PMN	Surf	22
P3 (AT)	7.5	10	PMN	Surf	23
P3 (AT)	7.5	19	P3 (AT)	Surf	13
P3 (AT)	7.5	21	Type 72	Surf	30
P3 (AT)	15	5	TC-6	Surf	14
P3 (AT)	15	7	Type 72	Surf	20
P3 (AT)	15	15	Type 72	Surf	22
P3 (AT)	15	23	Type 72	Surf	29
P3 (AT)	Surf	2	PMN-2	7.5	6
P3 (AT)	Surf	13	P4 (AP)x	7.5x	11x
P3 (AT)	Surf	14	P4 (AP)x	7.5x	23x
P3 (AT)	Surf	17	P4 (AP)x	7.5x	8x
PMN	7.5	1	P3 (AT)	7.5	4
PMN	7.5	6	PMN	7.5	6
PMN	7.5	18	Type 72	7.5	26
PMN	7.5	26	P4 (AP)	7.5	6
PMN	15	5	PMN-2	7.5	11
PMN	15	8	P3 (AT)	7.5	10
PMN	15	9	TM	7.5	12
PMN	15	9	Type 72	7.5	25
PMN	15	15	PMN	7.5	26
PMN	15	20	YM1	7.5	5
PMN	15	21	P3 (AT)	7.5	21
PMN	15	29	YM1	7.5	30
PMN	20	2	TM	7.5	7
PMN	20	21	TC-6	7.5	15
PMN	20	22	Type 72	7.5	20
PMN	20	29	TC-6	7.5	16
PMN	25	1	PMN	7.5	18

PMN	25	2	P3 (AT)	7.5	19
PMN	25	3	Type 72	7.5	12
PMN	25	16	YM1	7.5	21
PMN	Surf	8	PMN	7.5	1
PMN	Surf	10	PMN-2	7.5	27
PMN	Surf	22	TM (pl)	7.5	28
PMN	Surf	23	PMN-2	7.5	29
PMN-2	7.5	6	TC-6	7.5	17
PMN-2	7.5	11	TC-6	7.5	3
PMN-2	7.5	27	TM	7.5	10
PMN-2	7.5	29	YM1	7.5	24
PMN-2	15	3	PMN-2	15	19
PMN-2	15	16	Type 72	15	1
PMN-2	15	18	PMN-2	15	18
PMN-2	15	19	TC-6	15	27
PMN-2	Surf	11	P3 (AT)	15	15
PMN-2	Surf	13	Type 72	15	28
PMN-2	Surf	24	TC-6	15	12
PMN-2	Surf	30	P4 (AP)	15	8
TC-6	7.5	3	TC-6	15	24
TC-6	7.5	15	P4 (AP)x	15x	27x
TC-6	7.5	16	P3 (AT)	15	5
TC-6	7.5	17	PMN	15	5
TC-6	15	4	PMN	15	15
TC-6	15	12	PMN	15	21
TC-6	15	24	PMN	15	29
TC-6	15	27	PMN-2	15	3
TC-6	Surf	7	TC-6	15	4
TC-6	Surf	9	TM	15	23
TC-6	Surf	14	TM	15	30
TC-6	Surf	28	Type 72	15	12
TM	7.5	7	YM1	15	13
TM	7.5	10	YM1	15	17
TM	7.5	12	YM1	15	19
TM	15	10	YM1	15	28
TM	15	21	TM	15	21
TM	15	23	Type 72	15	27
TM	15	30	P3 (AT)	15	23
TM	25	1	PMN-2	15	16
TM	25	9	PMN	15	9
TM	25	9	PMN	15	20
TM	25	20	TM	15	10
TM (pl)	7.5	28	P4 (AP)	15	24
Type 72	7.5	12	Type 72	15	25
Type 72	7.5	20	Type 72	15	2
Type 72	7.5	25	PMN	15	8
Type 72	7.5	26	Type 72	15	11
Type 72	15	1	P3 (AT)	15	7
Type 72	15	2	PMN	15	9
Type 72	15	11	Type 72	15	28
Type 72	15	12	P4 (AP)	15	30
Type 72	15	25	PMN	20	21
Type 72	15	27	PMN	20	29
Type 72	15	28	Type 72	20	3
Type 72	15	28	Type 72	20	27
Type 72	20	3	PMN	20	2
Type 72	20	17	PMN	20	22

Type 72	20	25
Type 72	20	27
Type 72	25	1
Type 72	25	3
Type 72	25	13
Type 72	25	19
Type 72	Surf	20
Type 72	Surf	22
Type 72	Surf	29
Type 72	Surf	30
YM1	7.5	5
YM1	7.5	21
YM1	7.5	24
YM1	7.5	30
YM1	15	13
YM1	15	17
YM1	15	19
YM1	15	28
YM1	25	10
YM1	25	20
YM1	25	24
YM1	25	25
Type 72	20	17
Type 72	20	25
YM1	25	10
PMN	25	16
TM	25	20
YM1	25	24
P4 (AP)	25	23
TM	25	9
TM	25	9
YM1	25	25
Type 72	25	3
P4 (AP)x	25x	18x
P4 (AP)x	25x	2x
PMN	25	1
PMN	25	2
TM	25	1
Type 72	25	1
PMN	25	3
Type 72	25	19
YM1	25	20
Type 72	25	13
P4 (AP)	25	17

Appendix 2.
Soil chemistry analysis Methodology

FOI (Sweden)

Sample Storage

The samples arrived at FOI in Styrofoam boxes with freezer packs, in order to be kept cooled during the transport. The samples were then stored frozen, at –18°C, until analyzed. 12 hours prior to analysis, the samples were transferred into 4°C to thaw.

Dry Content

In order to determine the dry content (dryness) of the sample, 1- 2 grams of soil were weighed and gently dried in an oven at 110°C for at least 18 hours. The sample was then weighed again in order to determine the weight loss.

Extraction

One gram of soil was weighed and transferred to a plastic tube. An internal standard (for quantitative analysis) as well as 25 ml of an aqueous buffer solution was added to the sample tube. The sample tube was then subjected to a 20 minute long microwave assisted treatment at 80°C, in order to desorb the explosives from the soil particles.

The samples were then filtered and subjected to an enrichment using Solid Phase Extraction (SPE). Subsequently, the samples were eluted on SPE-cartridges and further enriched by Nitrogen assisted evaporation.

The enriched samples were analyzed using gas chromatography (GC) using a nitrogen-specific detector probe (GC-NPD). Based on the detector response of the added internal standard, the concentration of TNT and related compounds in the sample could be calculated.

The TNT-content has been presented as nano grams of TNT per gram of dry soil (ng/g d.s).

Verification

In order to verify that peaks detected in the GC analysis corresponded to TNT and related compounds, the samples were re-analyzed using Liquid Chromatography-Mass Spectrometry (LC-MS)[22]. In cases where the GC analysis indicated very low concentrations of TNT and related compounds in the samples, 'pooling' of several samples was performed in order to ascertain that the concentration of relevant analytes were above the limit of detection (LOD) of the LC-MS method.

Good Laboratory Practise Statement

All samples received at the Grindsjön Research Centre, FOI, have been subjected to identical routines regarding storage, sample work-up and extraction as well as chemical analysis according to the internal FOI Standard Operating Procedures (SOPs), developed in compliance with ISO 9001.

Analytes

The analytes reported by FOI are in Table 1.

Table 1. Analyte List reported by the two laboratories

Analyte	Acronym	Sandia	FOI
1,3-Dinitrobenzene	DNB	X	
2,3-Dinitrotoluene	2,3-DNT		X
2,6-Dinitrotoluene	2,6-DNT	X	X
2,4-Dinitrotoluene	2,4-DNT	X	X
2,5-Dinitrotoluene	2,5-DNT		X
3,4-Dinitrotoluene (surrogate)	3,4-DNT	X	X
2,4,6-Trinitrobenzene	TNB	X	X
2,4,6-Trinitrotoluene	TNT	X	X
Hexahydro-1,3,5-trinitro-s-triazine	RDX	X	
4-Amino-2,6-Dinitrotoluene	4A-DNT	X	X
2-Amino-4,6-Dinitrotoluene	2A-DNT	X	X
	2,4dia-6-NT		X
	2,6dia-4-NT		X
Tetryl	Tetryl	X	

---

[22] Chromatographic technique similar to GC, where retention time and mass-to-charge ratio for each component of the sample can be measured independently.

Sandia (United States)

Chemical residues of explosive related compounds in soils were analyzed using EPA Method 8095. The soil samples were received in 40 mL amber screw cap vials. The samples were mixed by vigorously shaking each vial. A 0.8 g (± 0. 01 g) aliquot was removed from each vial and placed into a 5 mL amber screw cap vial with care to avoid stones and organic material. Acetonitrile (4 mL) was added by pipetting (± 0.01 mL) to create a 4:1 solvent to soil ratio. A surrogate (3,4-dinitrotoluene, 25 µL aliquot of 10 mg/L) was placed into each extraction vial as a quality control check on extraction efficiency. A batch containing 20 samples was placed into a water bath cooled (10°C) ultrasonicator for 18 hours. The samples were then syringe filtered (0.45 µm nylon) and placed into an autosampler vial.

The filtered soil extracts were analyzed by gas chromatography with a one (1) µL autoinjection into a split/splitless injector containing a single taper liner (4 mm i.d. x 78 mm long) using a primary and a confirmation column. Primary column analyte separation used an RTX-5 column (Restek, 0.53 µm i.d., 15 m long, 0.1 µm film thickness) with a programmed temperature profile set for 70°C for 2 minutes, 10°C/min ramp to 200°C and then held constant at 200°C for 7 minutes. Confirmation analyses were performed using an RTX-225 column (Restek, 0.53 µm i.d., 15 m long, 0.1 µm film thickness). The temperature profile for the RTX-225 was programmed for 100°C for 2 minutes, 10°C/min ramp to 200°C and then held constant at 200°C for 7 minutes. The electron capture detector was operated at 225°C for both column types with a nitrogen makeup of 60 mL/min.

For each set of samples prepared an autosampler run schedule included the following vials:

1 each: inlet passivation, 1000 pg/µL (all analytes),

3 each: blank,

1 each: continuing calibration verification (CCV),

1 each: laboratory method blank (LMB),

1 each: laboratory control standard (LCS),

1 each: matrix spike (MS),

1 each: matrix spike duplicate (MSD),

10 each: soil extract samples,

1 each: continuing calibration verification (CCV),

10 each: soil extract samples and 1 each CCV until complete.

Calibration standards of 5, 10, 25, 50, and 75, 100 pg/µL were prepared for each batch of samples. Table 1 shows a list of the analytes quantified. Quadratic fit calibration equations were used to quantify the peak area of the sample chromatograms. *Figure 1* shows a calibration standard using the RTX-5 column and *Figure 2* shows the same standard on an RTX-225 column.

The Laboratory Method Blank (LMB) is an acetonitrile extract of an uncontaminated soil to evaluate the presence of naturally occurring interferents. The Laboratory Control Spike (LCS) is an uncontaminated soil spiked with the full list of analytes at 250 ng/g to evaluate bias in the soil extraction process. Both the LMB and the LCS used clean soil from Sandia National Laboratories. The Matrix Spike (MS) is similar to the LCS but uses a randomly chosen sample from the suite of samples collected for analysis from the actual site. The Matrix Spike Duplicate (MSD) is used to assess variability of the analyte recoveries from the actual site matrix. The Continuing Calibration Verification (CCV) is a mid point calibration (50 pg/μL) standard placed every ten samples in the autoinjection run to monitor instrument drift.

The analytes reported by Sandia are in Table 1.

Figure 1. RTX-5 Column Chromatogram - 50 pg standard

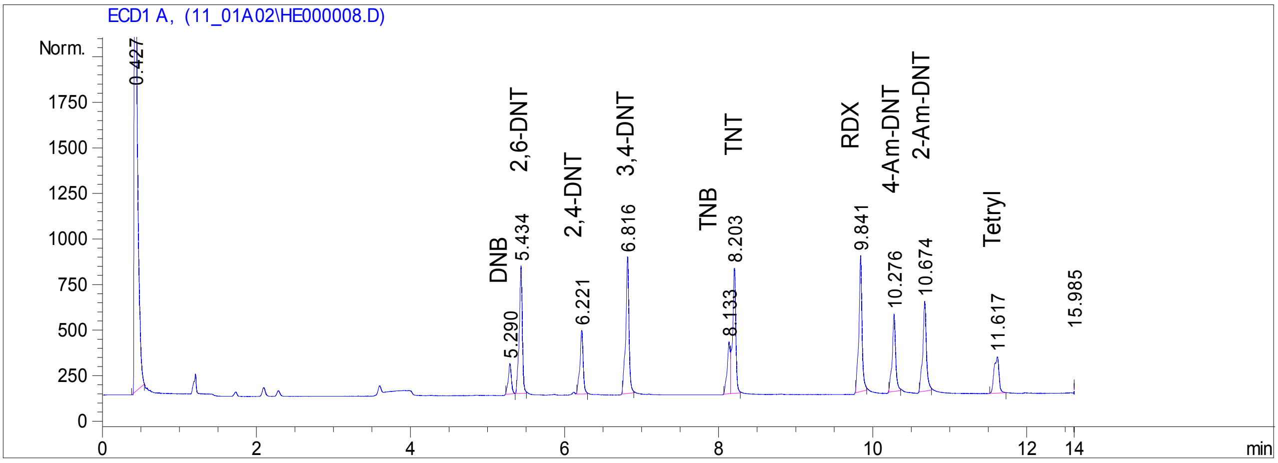
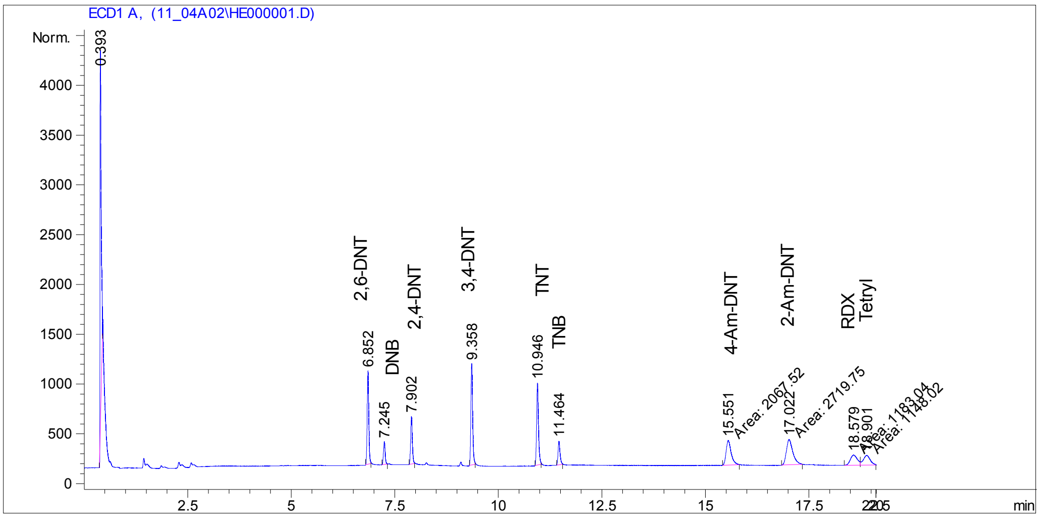


Figure 2. RTX-225 Column Chromatogram – 50 pg standard



Appendix 3. Frequency of detection of each chemical in soil samples taken over mines for each trial

Date		TNT	2,4-DNT	2,6-DNT	2,5-DNT	4-a-DNT	2-a-DNT	RDX	DNT4a26	DNT2a46	3,4-DNT	2,3-DNT	TNB	Tetryl	NT24dia6	NT26dia4	DNB
Oct 02	F	28	11	3	4	2	2	4	7	7	0	2	1	0	1	2	2
	M	3	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0
Total		31	12	3	4	3	2	5	7	7	0	2	1	0	1	2	2
Apr 03	F	6	4	0	0	1	1	4	3	3	0	0	0	0	0	0	0
	M	6	4	2	0	4	4	4	2	2	0	0	1	0	0	0	1
Total		12	8	2	0	5	5	8	5	5	0	0	1	0	0	0	1
Jun 03	F	35	27	17	7	3	2	12	11	15	0	0	12	7	1	0	7
	M	35	15	7	2	0	0	2	3	7	0	0	6	0	0	0	8
Total		70	42	24	9	3	2	14	14	22	0	0	18	7	1	0	15
Jul 03	F	47	14	3	2	2	2	17	9	10	0	0	7	0	0	0	0
	M	30	5	0	1	1	1	4	2	2	0	0	1	0	0	0	0
Total		76	19	3	3	3	3	21	11	12	0	0	8	0	0	0	0
Sep 03	F	54	36	16	6	13	9	29	9	11	0	3	5	0	0	1	3
	M	34	17	1	2	6	4	8	4	4	0	0	0	0	0	0	0
Total		88	53	17	8	19	13	37	13	15	0	3	5	0	0	1	3
Overall		**277**	**134**	**49**	**24**	**33**	**25**	**85**	**50**	**61**	**0**	**5**	**33**	**7**	**2**	**3**	**21**
% Overall		**51.4**	**24.9**	**9.1**	**4.5**	**6.1**	**4.6**	**15.8**	**9.3**	**11.3**	**0**	**0.9**	**6.1**	**1.299**	**0.4**	**0.6**	**3.9**

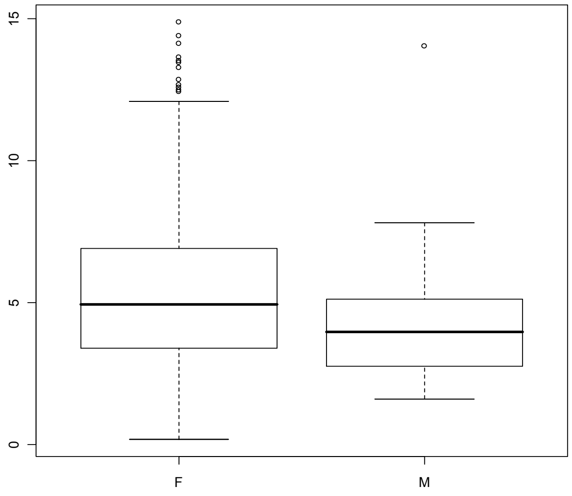
Appendix 4. Counts of chemicals found in soil samples taken over each type of mine

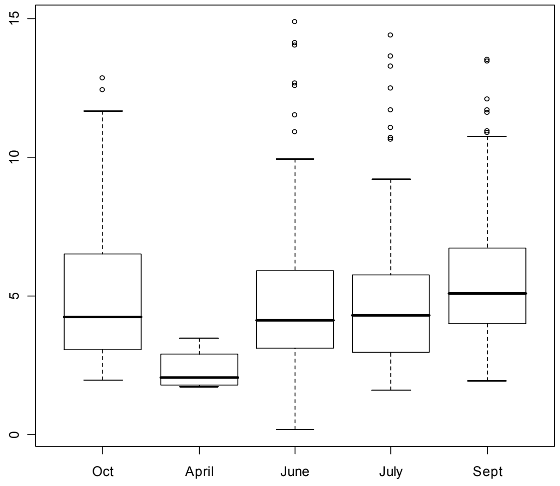
Mine	F/M	TNT	2,4-DNT	2,6-DNT	2,5-DNT	4-a-DNT	2-a-DNT	RDX	DNT4a26	DNT2a46	3,4-DNT	2,3-DNT	TNB	Tetryl	NT24dia6	NT26dia4	DNB
P4AP	F	9	4	2	2	1	0	4	1	2	0	0	1	0	0	0	1
	M	6	2	1	0	1	1	2	2	2	0	0	1	0	0	0	1
Total		**15**	**6**	**3**	**2**	**2**	**1**	**6**	**3**	**4**	**0**	**0**	**2**	**0**	**0**	**0**	**2**
P3AT	F	24	15	11	1	2	3	12	5	5	0	2	8	0	0	0	2
	M	12	6	2	1	1	1	1	1	1	0	0	1	0	0	0	2
Total		**36**	**21**	**13**	**2**	**3**	**4**	**13**	**6**	**6**	**0**	**2**	**9**	**0**	**0**	**0**	**4**
PMN	F	46	29	12	11	7	6	17	19	19	0	2	8	1	2	2	5
	M	21	10	1	0	5	4	3	4	4	0	0	1	0	0	0	2
Total		**67**	**39**	**13**	**11**	**12**	**10**	**20**	**23**	**23**	**0**	**2**	**9**	**1**	**2**	**2**	**7**
PMN2	F	21	11	2	3	2	2	7	5	7	0	0	0	1	0	1	0
	M	12	4	1	0	2	1	4	1	1	0	0	0	0	0	0	2
Total		**33**	**15**	**3**	**3**	**4**	**3**	**11**	**6**	**8**	**0**	**0**	**0**	**1**	**0**	**1**	**2**
T72	F	23	8	3	1	4	3	7	4	5	0	1	3	1	0	0	0
	M	26	14	3	3	2	2	4	2	4	0	0	3	0	0	0	2
Total		**49**	**22**	**6**	**4**	**6**	**5**	**11**	**6**	**9**	**0**	**1**	**6**	**1**	**0**	**0**	**2**
TC6	F	13	4	3	0	3	1	6	0	1	0	0	3	1	0	0	0
	M	15	2	0	0	0	0	0	1	2	0	0	0	0	0	0	0
Total		**28**	**6**	**3**	**0**	**3**	**1**	**6**	**1**	**3**	**0**	**0**	**3**	**1**	**0**	**0**	**0**
TM57	F	21	17	6	1	1	0	12	5	6	0	0	1	3	0	0	2
	M	7	1	0	0	0	0	2	0	0	0	0	2	0	0	0	0
Total		**28**	**18**	**6**	**1**	**1**	**0**	**14**	**5**	**6**	**0**	**0**	**3**	**3**	**0**	**0**	**2**
YM1	F	12	4	0	0	1	1	1	0	1	0	0	1	0	0	0	2
	M	9	3	2	1	1	0	3	0	1	0	0	0	0	0	0	0
Total		**21**	**7**	**2**	**1**	**2**	**1**	**4**	**0**	**2**	**0**	**0**	**1**	**0**	**0**	**0**	**2**

Appendix 5. Occurrence of each chemical over found and missed mines, and across trials.

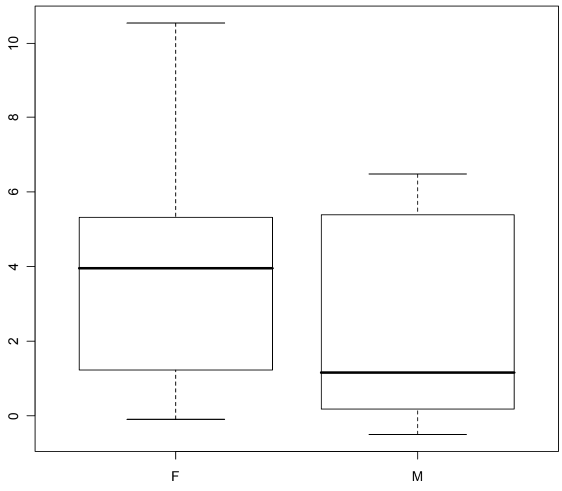
Each pair of figures is the occurrence of the chemical over found and missed mines (left) and across trials (right, lumped for found and missed). Y axis in all cases is concentration of analyte (ng/gm, or parts per billion).

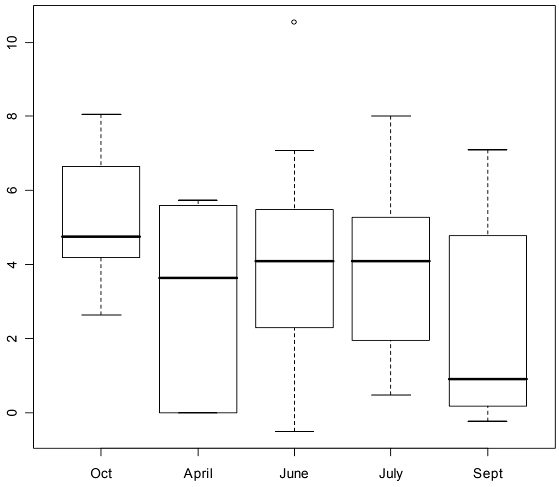
TNT



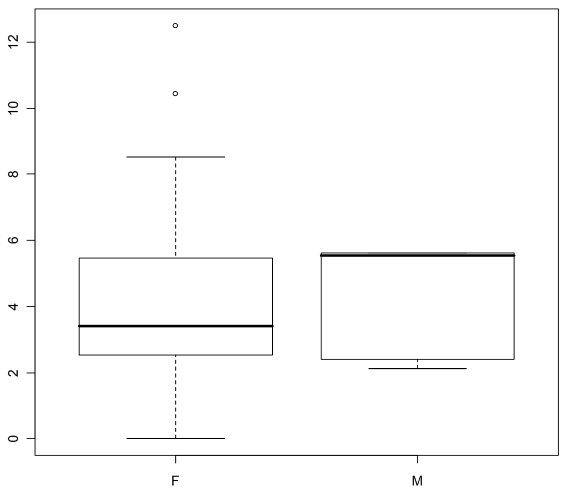


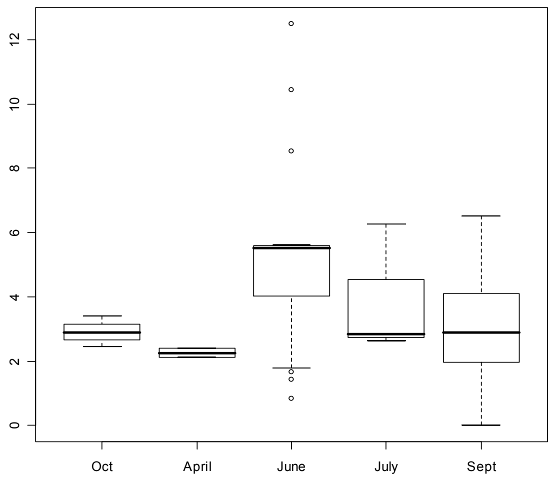
2,4-DNT



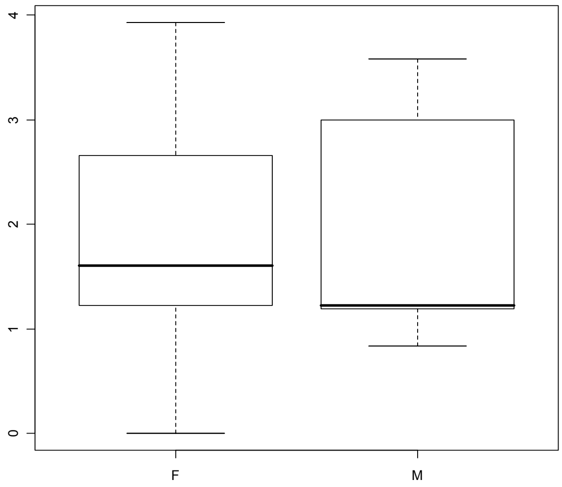


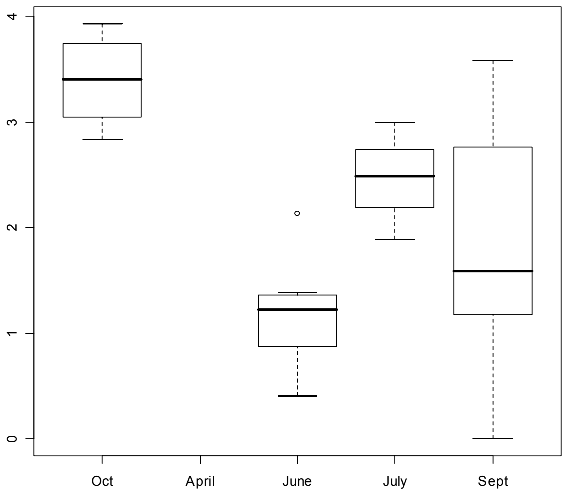
2,6-DNT


0
2
4
6
8
10
12
F
M

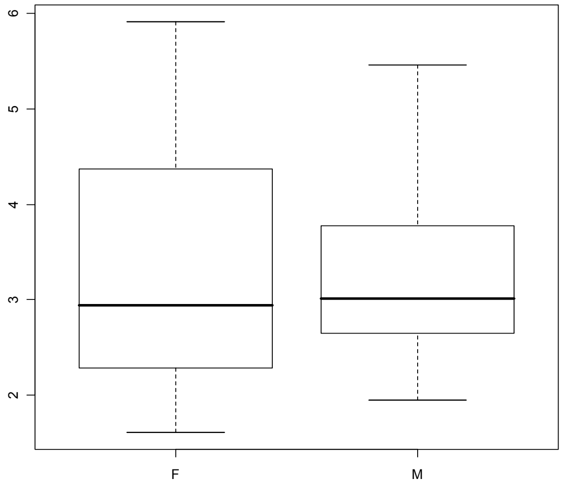

0
2
4
6
8
10
12
Oct
April
June
July
Sept

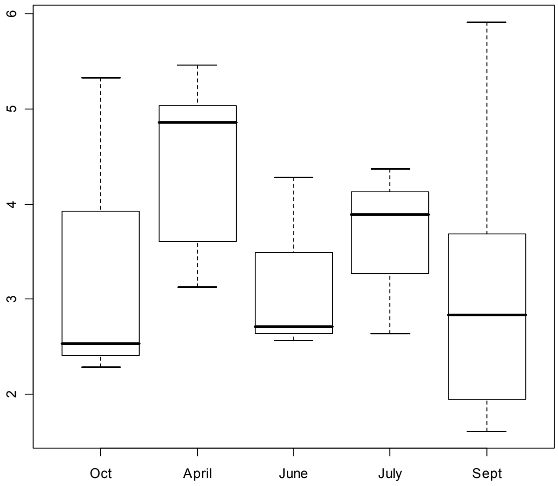
2,5-DNT


0
1
2
3
4
F
M

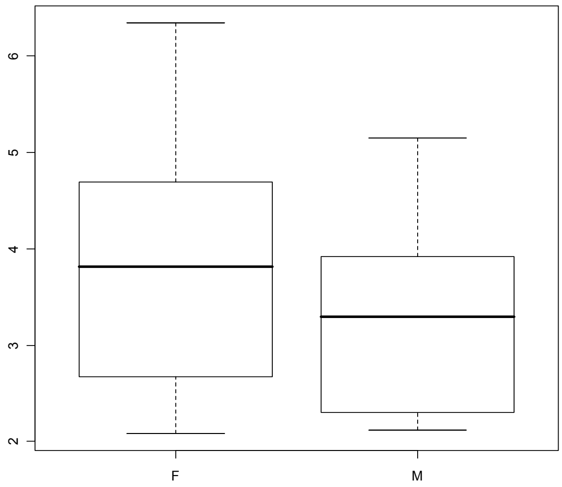

0
1
2
3
4
Oct
April
June
July
Sept

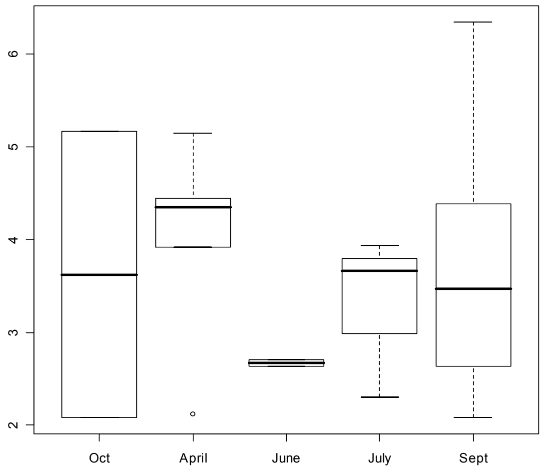
4-a-DNT


6
5
4
3
2
F
M

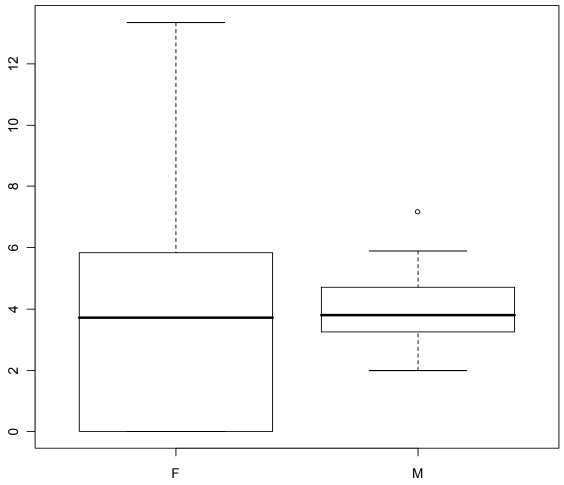

6
5
4
3
2
Oct
April
June
July
Sept

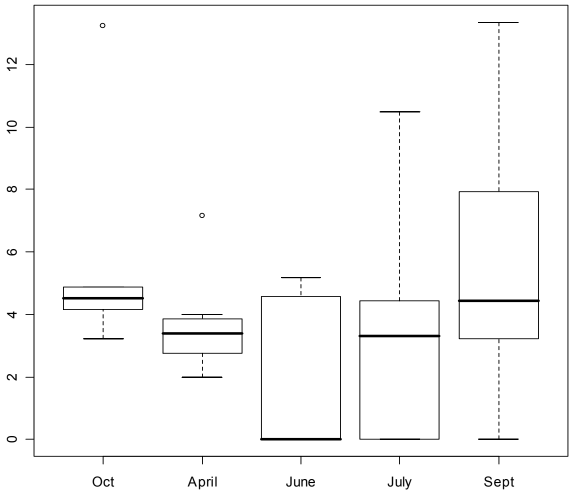
2-a-DNT


6
5
4
3
2
F
M

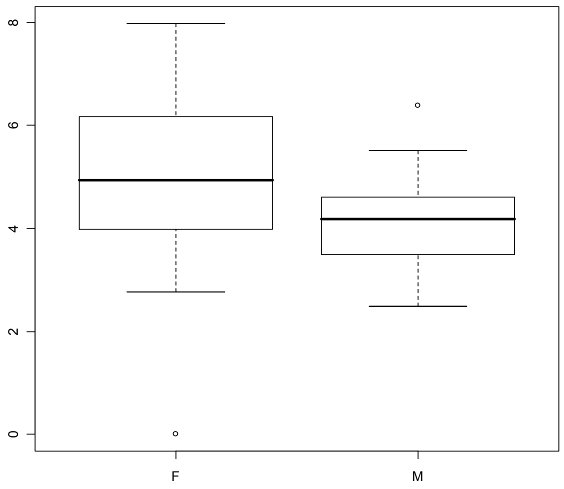

6
5
4
3
2
Oct
April
June
July
Sept

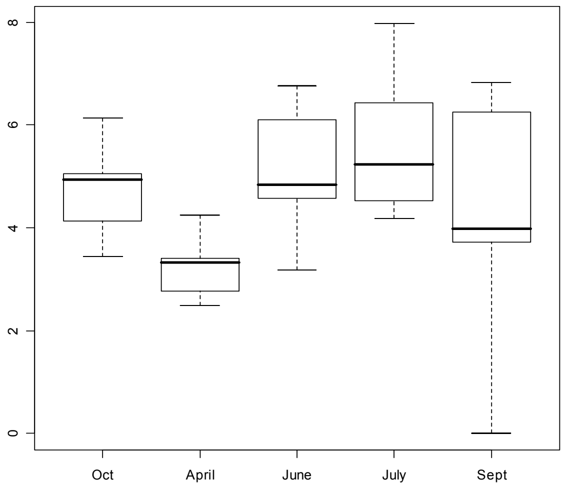
RDX


0
2
4
6
8
10
12
F
M

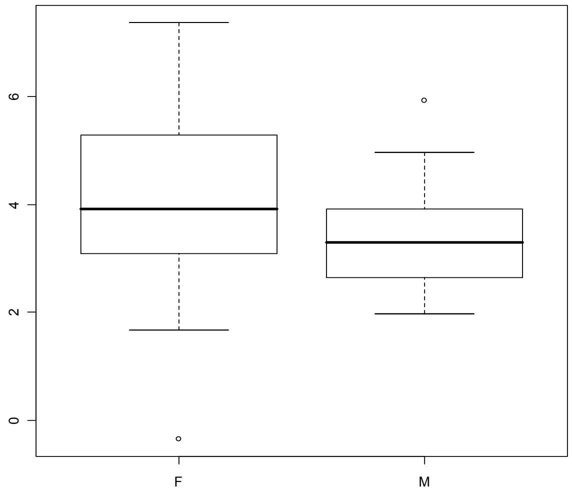

0
2
4
6
8
10
12
Oct
April
June
July
Sept

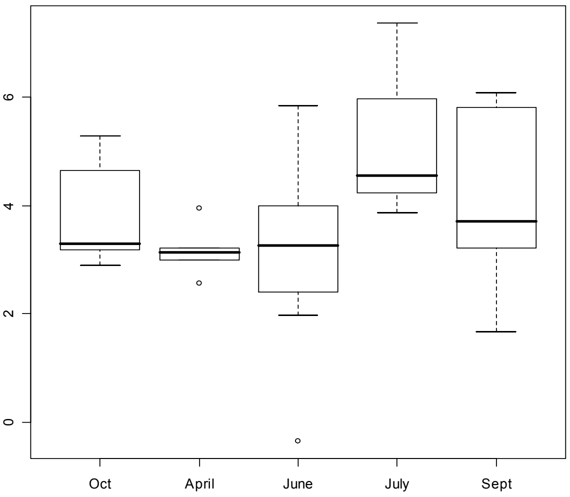
4-a-2,6-DNT


0
2
4
6
8
F
M


0
2
4
6
8
Oct
April
June
July
Sept

2-a-4,6-DNT

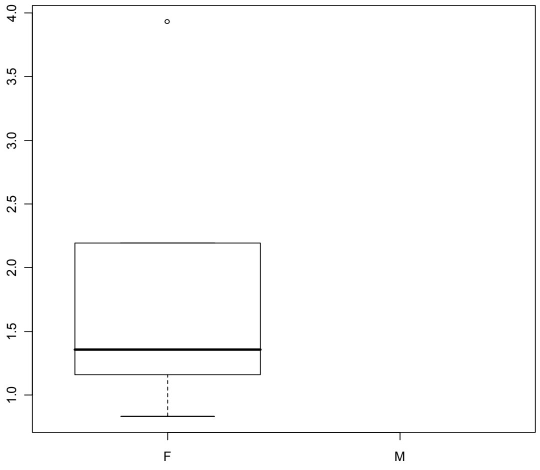


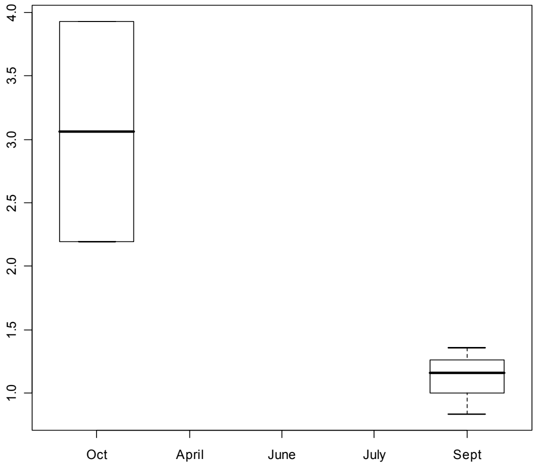


3,4-DNT

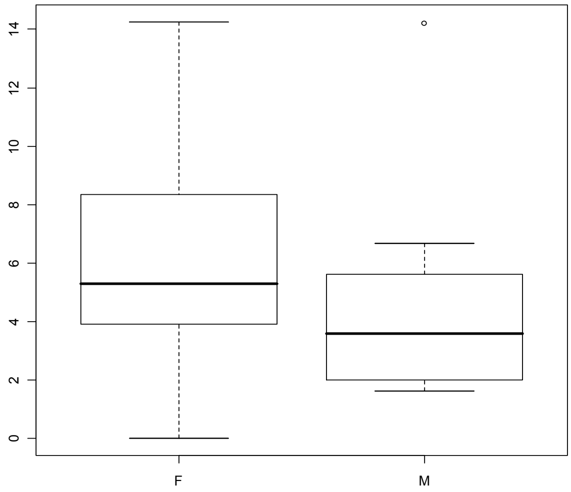
Only found in samples taken over False Alarms

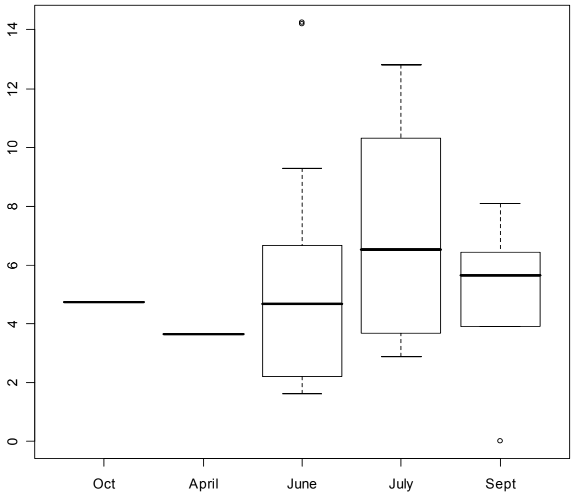
2,3-DNT



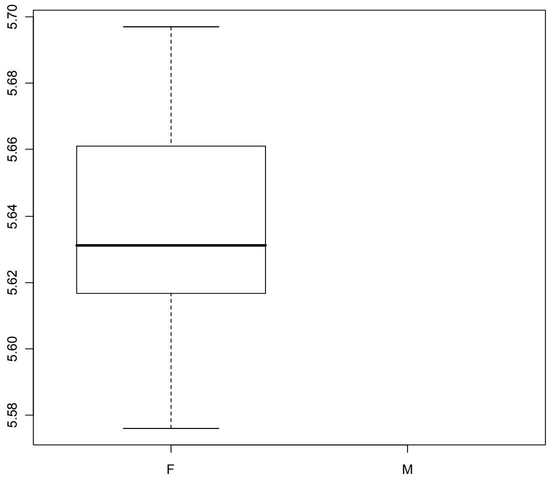


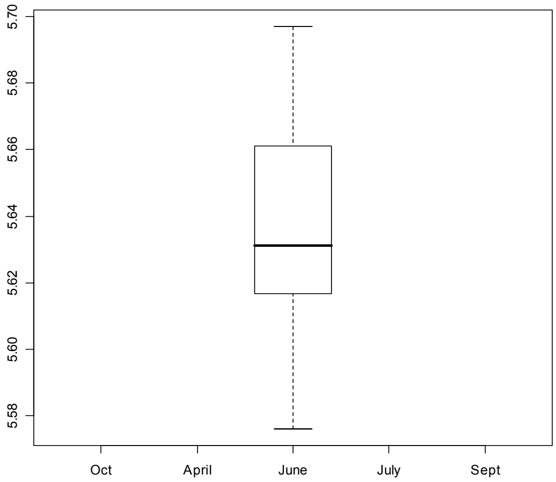
TNB


0
2
4
6
8
10
12
14
F
M


0
2
4
6
8
10
12
14
Oct
April
June
July
Sept

Tetryl

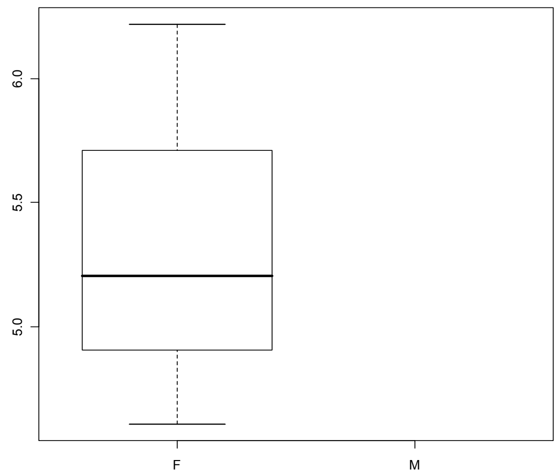

5.58
5.60
5.62
5.64
5.66
5.68
5.70
F
M

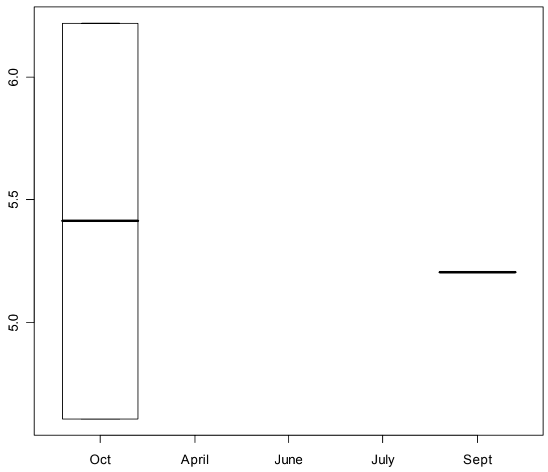

5.58
5.60
5.62
5.64
5.66
5.68
5.70
Oct
April
June
July
Sept

2,4-dia-6-NT

N small. Detected in October and June over Found mines only.

2,6-dia-4-NT





DNB