PRELIMINARY EVALUATION OF THREE METHODS FOR DETECTING URINE PATCHES IN THE FIELD

Mike Dodd[1], Andrew Manderson[1,2], Phil Budding[1], Suzanne Dowling[3], Siva Ganesh[1], Chris Hunt[1]

[1] AgResearch, Grasslands Research Centre, Private Bag 11008, Palmerston North
[2] current address: Landcare Research, Private Bag 11052, Palmerston North
[3] AgResearch, Ruakura Research Centre, Private Bag 3123, Hamilton
Email: mike.dodd@agresearch.co.nz

Abstract

We conducted two field experiments to examine the potential of three methods to detect simulated animal urine patches after deposition, by means of soil electrical conductivity (EC) measurements, ammonia (NH_3) volatilisation measurements and soil surface temperature measurements (infrared imaging). All three techniques were successful at distinguishing simulated urine patches from non-patch areas, over varying periods of time post-deposition. Electrical conductivity measurements were effective for at least 7 days, NH_3 volatilisation measurements were effective for at least 3 days, and thermal measurements were effective for up to 140 minutes, under the ambient experimental conditions (soil surface temperatures of ~14°C and soil moisture ~40%). Further experimentation could usefully explore the range of conditions (soil type, pasture cover, moisture and temperature) under which this effectiveness extends. Practical considerations in the application of these approaches will dictate their utility.

Keywords: ammonia volatilisation, electrical conductivity, pasture, soil temperature, urine patch

Introduction

Livestock urine patches are the major source of nitrogenous emissions in grazed pastoral systems (Haynes and Williams, 1993), due to high concentrations of ammonium ions and the associated products of microbial transformation. These emissions include leached nitrate ions (NO_3^-) in soil solution, nitrous oxide gas (N_2O) and ammonia gas (NH_3), all of which have detrimental environmental impacts (Ledgard, 2001; Zaman and Blennerhassett, 2010). Nitrate leaching impacts water quality (PCE, 2012) and N_2O is a powerful greenhouse gas (Forster *et al.*, 2007). It is desirable to mitigate these emissions and one approach involves application of chemical formulations to inhibit those transformation pathways (e.g. dicyandiamide, DCD; urease inhibitor, NBPT). The highly variable distribution of urine patches across a recently grazed paddock, combined with the small-scale nature of the patches, has meant that blanket application of formulations is the only practicable approach (Di *et al.*, 2007; Moir *et al.*, 2011). However, blanket applications to paddocks post-grazing are considered inefficient, particularly where the accumulation of the formulation in soil or products is undesirable. While DCD is currently non-marketable due to food safety concerns it seems reasonable to expect that this will be addressed in time, or alternative formulations emerge.

Ideally, inhibitor formulations would be targeted at the urine patch, as treatment of urine patches within a short time after deposition has been shown to reduce total N losses (Zaman and Nguyen, 2012). This presents us with the problem of identifying urine patches in the field in a timely fashion. Given the potency of urine patches in transforming the localized environment (Williams and Haynes, 1994), there are a number of potential means of identifying distinguishing them from the surrounding soil-pasture matrix:

1) Temperature – urine is deposited at animal body temperature (~38°C) and thus will temporarily elevate soil surface temperatures under most ambient conditions in New Zealand.
2) Optical – urine reflects ultra-violet light which could be detected by an optical sensor at the relevant wavelengths, and pasture growing on a urine patch has elevated chlorophyll levels which will impact light reflectance.
3) Moisture – urination events typically involve from 1-7 L of liquid (Betteridge *et al.*, 2013) which will temporarily elevate soil surface moisture content.
4) Chemical – the N-based contents and products of urine will be temporarily elevated in the soil solution (NO_3^-, nitrite, ammonium).
5) Electrical – the content of salts in urine increases the electrical conductivity of the soil (Corwin and Lesch, 2005).
6) Gaseous – the N-based products of urine are transformed into gaseous compounds (N_2O and NH_3) which volatilise from the patch.

Some research has already been conducted into the potential for using these effects to locate urine patches, though the publication record is limited. Documented approaches include electromagnetic induction measurements (Rodhe *et al.* Rodhe *et al.* (2010); optical sensing of pasture colour (Mackenzie *et al.* (2011), Dennis *et al.* (2013). To date we are not aware of any documented attempts to detect patches via temperature, electrochemical or gaseous approaches. However, there are obvious limitations to such approaches, in particular that temperature- and optical-based methods are compromised by diurnal variations in the ambient environment.

The objective of this study was to explore the potential of three approaches for the detection of urine patches: temperature, electrical conductivity and gaseous. For each approach we aimed to determine a) if simulated urine patches were distinguishable from the soil/pasture matrix; and b) for how long the difference could be detected after deposition.

Methods

Experiment 1: Soil electrical conductivity and NH_3 volatilisation

This experiment aimed to use a portable electrical conductivity meter (Hanna H993310 Direct Soil Activity and Solution Conductivity Kit, Hanna Instruments, Ann Arbor, MI) and a portable gas analyser (QRAE Plus Four-gas detector, RAE Systems Ltd, San Jose, CA) to measure soil EC and NH_3 volatilisation respectively. The QRAE device was calibrated for an NH_3 detection range of 0-50 ppm. The experiment was conducted at Grasslands Research Centre on a reclaimed lawn, consisting of 30 cm depth of topsoil and oversown with ryegrass in 2013. Initial volumetric soil moisture content was 40%, which increased to 44% after application of the treatments. Two treatments were applied to the soil: 1 L of a 0.75% solution of artificial urine (Ingredients: $CO(NH_2)_2$ - 14.64 g/l; $NH_2CH_2.COOH$ - 3.65 g/l; $KHCO_3$ - 22.4 g/l; KCl - 3.81 g/l; K_2SO_4 - 2.15 g/l) heated to 40°C and a control 1 L of water heated to 40°C. The artificial urine treatment application rate equated to 106 gN/m^2. These treatments were applied to a fresh set of plots the following day (i.e. 2 cohorts). Four replicates of each solution/day treatment were included in a randomised block design. The solutions were poured onto each plot from a height of 1 m over a period of 10 s and contained by a 300 mm diameter PVC ring (although there was substantial seepage under the ring due to variation in soil surface height). The solution was allowed to soak in for 60 s before the first EC and gas analyser readings was taken. The gas analyser was held at a height of 1 m with a 5 mm dia. inlet tube attached to a 80 mm funnel at ground level, which took up to 60 s to register a reading. Measurements of EC, soil temperature and NH_3 were taken prior to treatment application at 8:30 am and subsequently at approx. 30 min, 90 min, 240 min and 420 min afterwards. These four measurements throughout the day were repeated for the following days (day 2, 3, 4, 6 and 7 for cohort 1 and day 2, 3, and 6 for cohort 2).

Experiment 2: Soil surface temperature

This experiment used an infrared camera (ThermaCam S60, FLIR Systems AB, Danderyd, Sweden) to take images of simulated urine patches. The manufacturer's image processing algorithm calculates average surface temperature and maximum surface temperature for the field of view. The experiment was conducted at Ruakura Research Centre on a mild overcast day in May 2014. Soil temperature was 14°C, air temperature was 13°C, and humidity was 70%. We established two levels of pasture cover, bare ground and short grass (<1000 kgDM/ha) in small plots (1 m^2) to simulate post-grazing conditions. Two water treatments were applied to the soil: 2 L of hot water (40°C) and 2 L of tepid water (15°C). Three replicates of each cover/temperature treatment were included in a fully randomised design. The water was poured onto each plot from a height of 1 m over a period of 20 s and contained by a 300 mm diameter PVC ring (although there was substantial seepage under the ring due to variation in soil surface height). The water was allowed to soak in for 60 s before the first image was taken with the infrared camera from a height of 1.5 m. Subsequent images were taken at intervals of 20 min, 40, min, 60 min, 100 min, 140 min, 220 min and 300 min.

The data from both experiments were analysed by repeated measures ANOVA. In experiment 1, each cohort was analysed separately. The factors were treatment (urine or water), day and sample time (of day), with a natural log transformation being required for the EC data and a square root transformation required for the NH_3 data. Soil temperature was included in the statistical model as a covariate for both response variables. In experiment 2 the factors were treatment (warm or tepid water), grass cover (bare or short) and time after deposition.

Results

Experiment 1: Soil electrical conductivity and NH_3 volatilisation

The electrical conductivity of the soil increased within an hour after application of artificial urine with no immediate change upon application of water (Fig. 1). In addition, EC increased in the urine treatment over subsequent days to a peak on day 4. There was also a slight increase in EC under the water treatment on day 4. The statistical analysis showed that the main treatment effect was significant ($p<0.01$), as were the day effect and the interaction between treatment and day. However the sample time (of day) effect was not significant.

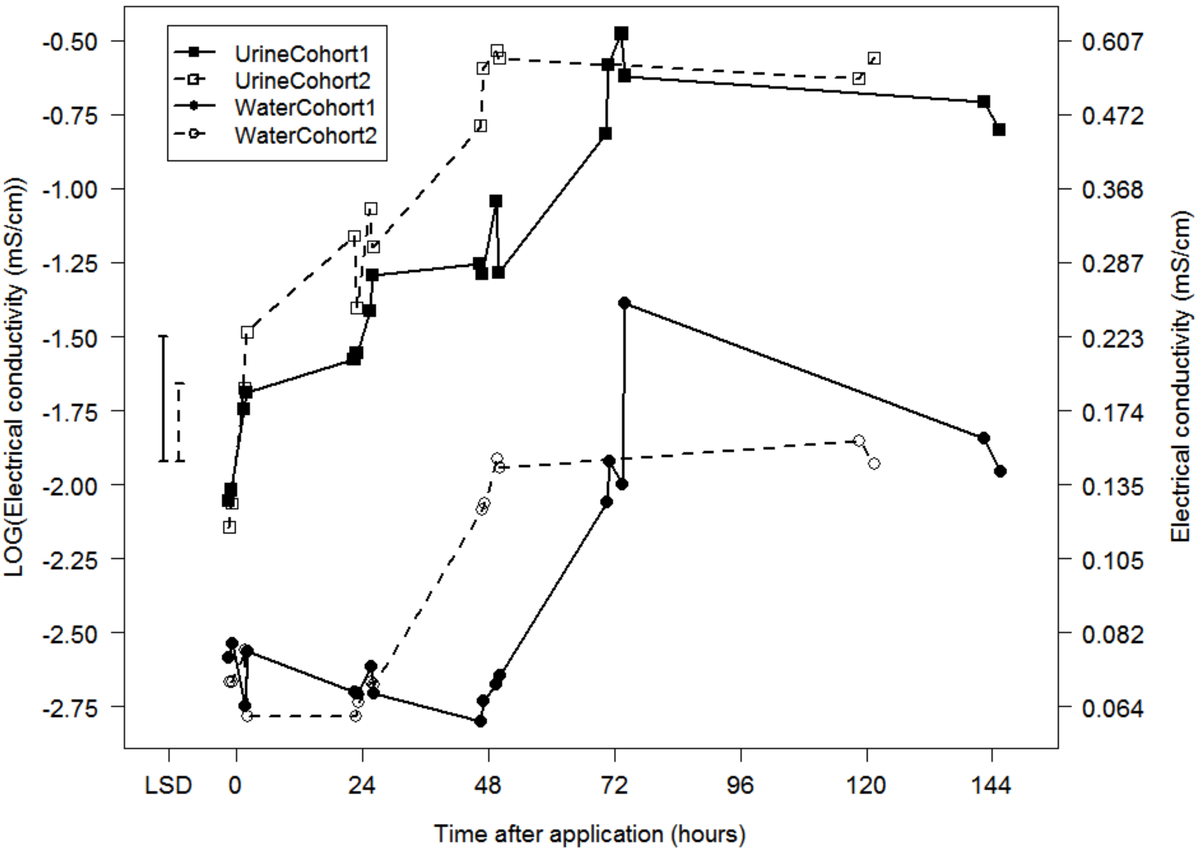

Fig. 1: Mean soil electrical conductivity (mS cm^{-1}) in urine and water patches over time after application (hours) for two application dates. Average LSD (5%) bars for the log transformed data of each cohort are shown together, with a second y-axis to indicate back-transformed values on the raw data scale.

Ammonia volatilisation was also detected in urine patches but not water patches, at the earliest, two hours after application (Fig. 2). Levels increased during the first and second days after application, but declined after that to be undetectable by day 6. The statistical analysis showed that the main treatment effect was significant ($p<0.01$), as were the day effect, the sample time (of day) effect and the interaction between treatment and day. There was an apparent difference between the two cohorts in that mean peak levels were approx. 20 ppm for the first application date (at midday on day 2), but up to 50 ppm for the second application date (in early morning on day 2), though this was not statistically verified.

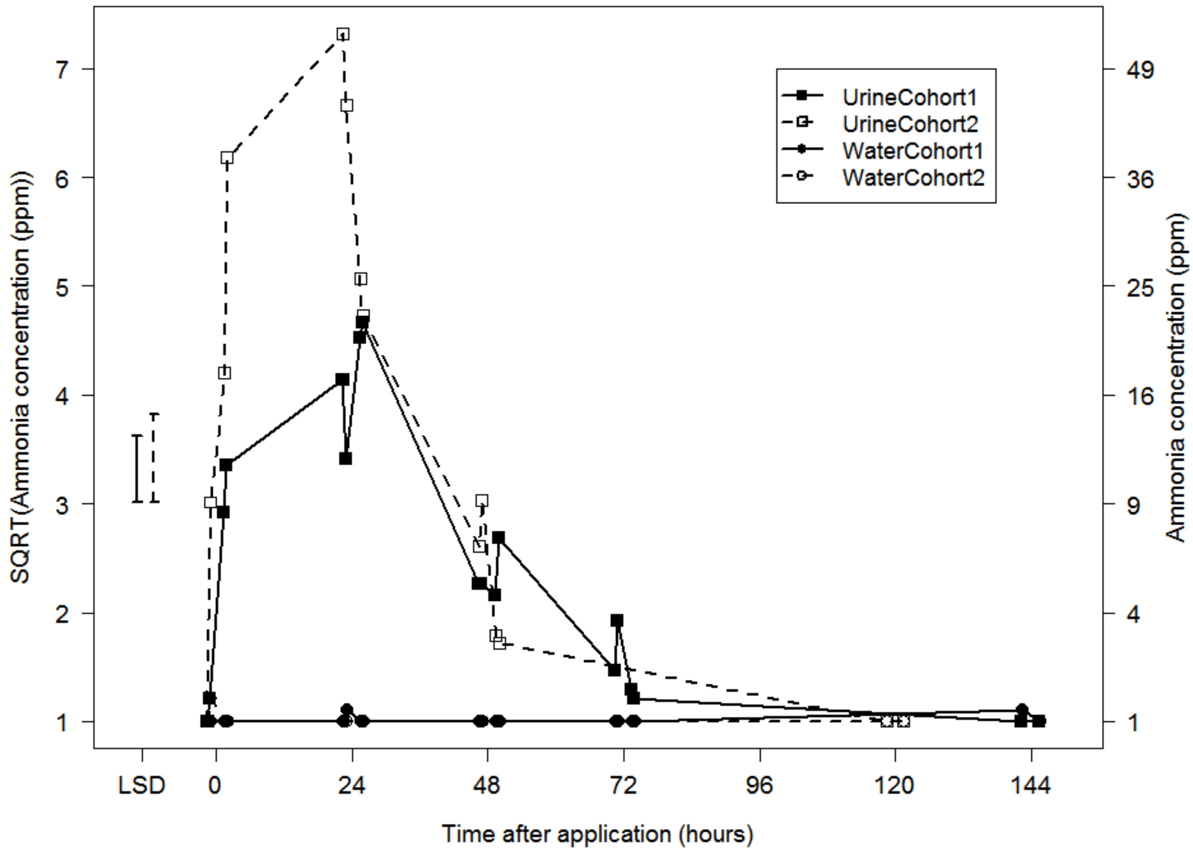

Fig. 2: Mean NH_3 volatilisation (ppm) in urine and water patches over time after application (hours) on two application dates. Average LSD (5%) bars for the log transformed data of each cohort are shown together, with a second y-axis to indicate back-transformed values on the raw data scale.

Experiment 2: Soil surface temperature

Maximum patch temperature immediately after hot water application was 36°C, which rapidly declined within the first 20 minutes and was indistinguishable from the control tepid water application by 140 minutes and for the rest of the measurement period (Fig. 3). There was a slight increase in maximum patch temperature over the first 40 minutes after application of tepid water followed by a decline after 240 minutes. Average patch temperature immediately after hot water application was 28°C, which rapidly declined and was indistinguishable from the control tepid water application by 100 minutes and for the rest of the measurement period. The temperature effect and temperature by time interaction effects were significant ($p<0.001$) for both maximum and average patch temperature data, but the grass cover effect was not significant in either case and thus is not shown in Fig 3.

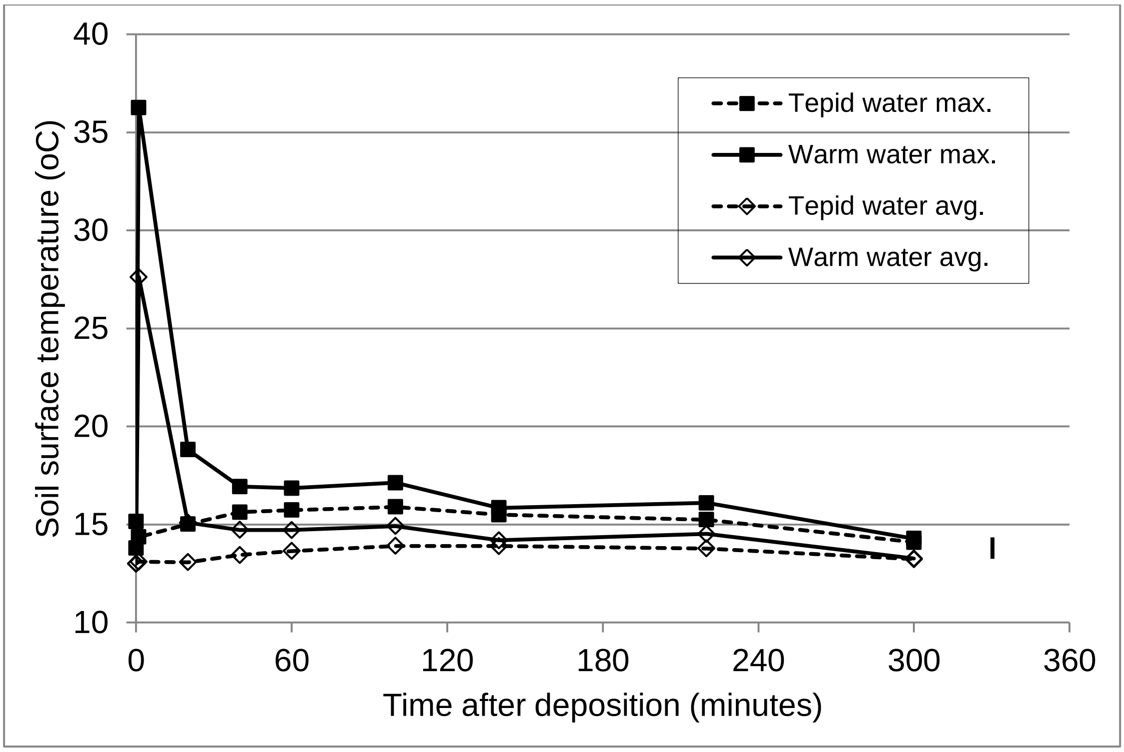

Fig. 3: Maximum and average patch soil surface temperature over time after warm (40°C) and tepid (15°C) water application. Average LSD (5%) bar shown on right = 1°C.

Discussion

While there has been considerable research on the dynamic characteristics and spatial distribution of urine patches (e.g., Williams and Haynes, 1994; Moir *et al.*, 2011), documented approaches for the automated detection of urine patches are limited. They include the use of electromagnetic induction (EM) measurements, electrical conductivity (EC) measurements and optical sensing. Rodhe *et al.* (2010) have demonstrated that EM measurements can detect areas of high NO_3^- content on grassland up to 8 days after application of at least 620 kgN/ha. By contrast a urine patch has equivalent rates of ~1000 kgN/ha, (Haynes and Williams, 1993). Their sensor was towed on skids behind a tractor. Mackenzie *et al.* (2011) have developed an optical sensor based on near infra-red that detects patches via “greenness” with the intent of avoiding nitrogen fertiliser applications to such sites and/or applying inhibitors. Similarly Dennis *et al.* (2013) and Petersen *et al.* (http://www.darcof.dk/enews/april04/urine.html) have used digital photograph image analysis to measure excreta patch distribution post grazing. The limitation with these optical approaches is that it takes a period of days-weeks for the green patch to be distinguishable, and given that the colour reflects uptake of NO_3^-, it seems likely that a substantial proportion of the emissions have already been lost. Petersen *et al.* also reported the use of time domain reflectrometry to measure soil impedance/EC, which requires direct soil contact with probes.

Our experiments were designed simply to demonstrate proof of concept for simulated urine patch detection, using previously undocumented approaches, under a limited set of ambient conditions. These experiments were performed at a time of year critical for mitigating urine deposition to minimise NO_3^- leaching over winter. The results of Experiment 1 show that urine patches can readily be detected from the surrounding soil by means of either EC measurements over a period of at least 7 days, or NH_3 volatilisation measurements over a period of up to 3 days. The results of Experiment 2 show that a urine patch can also be detected from the surrounding soil by infrared temperature sensing. However, under the conditions of this study, the window of opportunity to do this was very short. The data in Fig. 3 indicate that while statistically significant differences were detected for up to 100 minutes, reliable detection may be limited to the first 40 minutes. Higher ambient soil temperatures, either later in the day or in the warm season, will presumably make detection even more difficult in the 40-100 minute period.

The conditions under which these experiments were conducted were quite limited, in terms of soil types, pasture covers, ambient moisture and temperature conditions. Having demonstrated proof-of-concept for all three approaches, further experiments would be valuable to determine the range of conditions under which the approaches remain effective. For example, how soil surface temperature and moisture conditions impact the rate of temperature decline after urine application and the level of NH_3 volatilisation; and how soil moisture and anion/cation content impacts soil EC.

It is also worth considering the practical limitations with the techniques we used. The EC measurements require soil contact, and thus a robust contact-based device would need to be developed. Such a device, developed by Pastoral Robotics, was demonstrated at the 2015 FLRC workshop (Geoff Bates, *pers. comm.*), intended to be towed behind an ATV or a remotely operated vehicle (Bates and Quin, 2013). The volatilisation measurements have a significant time lag of up to 60 seconds to register a reading, after which the sensor must be evacuated for approx. 30 sec in preparation for detecting the next patch. This might require multiple sensors and relatively slow search speed. The short window for proximal temperature sensing indicates that a better approach may be to upscale the imagery to the paddock scale to enable a time series of images to capture urination events as the livestock graze. There is also the challenge of distinguishing between fresh urine and fresh dung patches where conductivity, gaseous and temperature approaches are used. Finally, temperature and optical sensors that are compromised by diurnal variation in ambient temperature and radiation may be better employed at night, particularly on ROVs which require no manual control.

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