PERFORMANCE OF "SPIKEY" IN LOCATING AND DETECTING FRESHLY DEPOSITED URINE PATCHES IN LIVESTOCK GRAZED PASTURE SOILS OF IRELAND

Macdara O'Neill [1], Karl Richards[1], Geoffrey Bates [2], Daniel Smith [2] and Patrick Forrestal[1]

[1] Teagasc, Johnstown Castle Research Centre, Co. Wexford, Ireland

[2] Pastoral Robotics Limited, New Zealand

Email: macdara.oneill@teagasc.ie

Abstract

Urine deposition by grazing livestock accounts for 70-95% of the nitrogen (N) returned to pasture, which may lead to increases in N leaching and/or N_2O emissions. Detecting freshly deposited urine patches could potentially inhibit N loss through applying inhibitors that prevent N transformation processes in the soil. In this study, three sensor technologies (Spikey-R, thermal camera and a remotely piloted aircraft system/ drone) were tested for their ability to accurately detect simulated urine patch configurations at three different urine volumes (1, 2 and 3 litres; l) under two soil moisture regimes (below and at field capacity). Each sensor was used to detect patches at varying time periods after urine deposition: Spikey-R (2 to 52 hours), thermal imagery (≤1 minute) and RPAS (9 days).

Patch sizes detected by the Spikey-R and RPAS were greater than those detected by the thermal imagery (p<0.05), with values ranging from 0.17-0.40 m^2 (thermal), 0.23-1.0 m^2 (Spikey-R) and 0.50-1.56 m^2 (RPAS). For both soil moisture conditions, 2 and 3 l urine volumes produced larger patches than 1 l urine volume, consistent with each sensor type. The largest patches occurred on soils at field capacity, however, no significant differences were detected amongst the sensors for equal volumes of deposited urine. The Spikey-R detected urine patches within 2.0 ± 3.7% precision 52 hours after urine was deposited compared to the initial run (2 hours). RPAS flights captured larger patch areas than all of the Spikey-R treatments (p<0.05). This is likely due to the time period between the two sensor measurements (2 days vs. 7 days), whereby the RPAS flight captures the 'effective area'; pasture around the initial wetted area affected by urine-N diffusion and N uptake by peripheral plants via root extension. Thermal imagery was ineffective for detecting urine patch configuration. The limited time period (< 1minute) was too short to account for lateral expansion across the pasture and also suggests that immediately deposited urine was not indicative of future pasture response.

The results indicate the Spikey-R unit and RPAS technologies are reliable techniques for detecting the shape, size and location of urine patches in dairy pastures across two soil moisture gradients. The immediate and accurate detection of urine patches by the Spikey-R is, however, highly advantageous over the RPAS method, which relies on pasture growth response for urine patch detection.

Introduction

Globally, agricultural soils are the main source of nitrous oxide (N_2O) emissions. It is estimated that livestock grazing accounts for 40% of these emissions due to large nitrogen (N) inputs from animal excreta (Oenema et al., 2005). The amount of reactive N in the excreta deposits

often exceeds plant demand and may lead to higher rates of microbial nitrification and denitrification. Thus, grazed pastures exhibit high potential for N_2O emissions from excreta deposited by animals.

Cattle urination events are approximately 2 l in volume (Doak, 1952) with an average surface area 0.24 m^2 (0.14-0.49 m^2), with an estimated effective area of approximately 0.68 m^2 (Selbie et al., 2015). Urine patches are estimated to cover 20-30% of an intensively grazed paddock (Moir et al., 2011). Urine deposition accounts for 70-95% of the N returned to pasture soils (Haynes and Williams, 1993) leading to high N loading rates up to 2000 kg N ha^{-1} (Selbie et al., 2015). Each patch contains 2-3 times the N required by the pasture for maintenance and growth. Urine patches are considered hotspots for reactive N losses through leaching and gaseous emissions, leading to detrimental impacts on the environment (Saggar et al., 2005). Nitrogen losses may be mitigated if N transformation inhibitors are applied to urine patches (Luo et al., 2010). A simultaneous approach of targeted applications of N transformation inhibitors to urine patches and fertiliser application to grazed areas unaffected by urine deposition could provide a low-cost, environmentally-friendly system on dairy farms.

A range of techniques exist to quantify urine patches that utilize electromagnetic induction measurements (Rodhe et al., 2010), optical sensing of pasture (Dennis et al., 2013), urine sensors (Misselbrook et al., 2016; Shephard et al., 2017), ground-based sensors (Bates et al. 2015). Spikey-R is a high-precision, ground-based sensing tool that is practical solution for detecting urine patches (Quin et al., 2016; Bates et al., 2017). Spikey-R is a ground-based sensor that uses a soil conductivity approach to measure urine patch size and its spatial configuration. Preliminary test results from the Spikey-R tool illustrate its accuracy in measuring the size and shape of urine patches on moderately drained pasture soils under a cool temperate maritime climate (Bates et al., 2017; Jolly et al., 2019; Quin et al., 2016).

In this study, three sensors technologies: Spikey-R, thermal imaging and remotely piloted aircraft system or drone, were tested for their ability to detect freshly deposited urine on a livestock grazed pasture in Ireland.

Methodology

Experimental setup

The experiment was established on a long-term pasture in Teagasc, Johnstown Castle (52° 18' 33'' N, 6° 30' 1'' W) in southeast Ireland. Livestock were excluded from the field site and nitrogen fertiliser application ceased for three months prior to the experiment. Three urine volumes were examined (1, 2 and 3 l) with six replications. Two soil moisture levels were created: a dry site below field capacity (<FC) and a wet site at field capacity (AFC) separated by a buffer strip. The target water-filled pore space for soils <FC and AFC was 50% and 80%, respectively. Target soil moistures were attained by sheltering the dry soils with tarpaulin or irrigating the wet soils. Grass was cut to approximately 5 cm one-week prior to commencing the study.

Synthetic urine was prepared according to de Klein et al. (2003) using urea (13.65 g l^{-1}), glycine (3.4 g l^{-1}), potassium bicarbonate (16.31 g l^{-1}), potassium sulphate (1.61 g l^{-1}) and potassium chloride (5.68 g l^{-1}). Simulated urine patches were created on the pasture by applying pre-heated (40°C) synthetic urine through a funnel at a height of 135 cm above the soil surface for 15-20 seconds.

Eighteen square (40 cm x 40 cm) stainless steel metal plates were placed on the pasture as ground control points (GCPs) with the coordinates of each GCP recorded using a handheld GPS device (Garmin). Before urine was applied, the RPAS was flown over the site to produce a 'base' image (Jolly et al., 2019). The purpose of this flight was to capture the GCPs for the RPAS and Spikey-R runs. Three sensor-based methods used to detect urine patch shape and size are described below.

Fig. 1 - Modified frame with funnel designed to mimic a natural urination event

Thermal imaging

A thermographic camera, which forms an image using infrared radiation, was used to record the size and shape of each urine patch. The images were taken at a constant height of 1.5 metres, 30 seconds after each application of urine. A 1m x 1m frame was placed on the ground for each urine patch with three discs located in the corners of the frame for georeferencing the images.
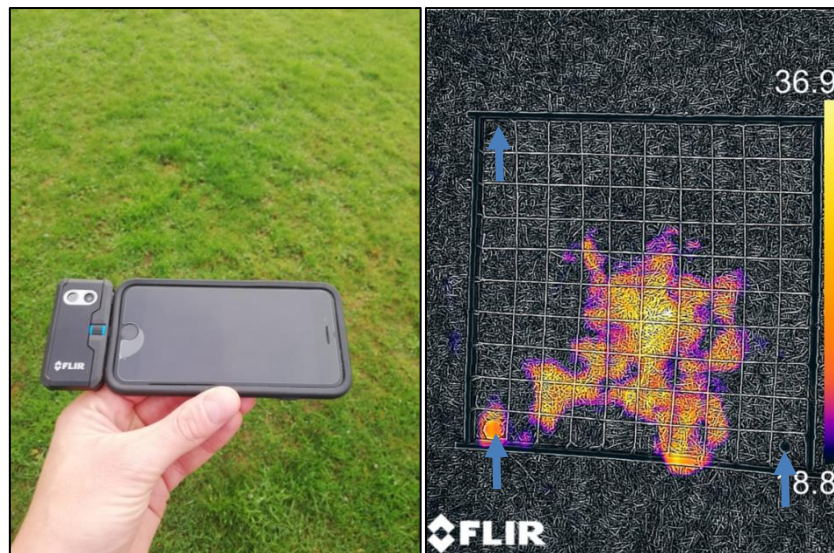

Fig. 2 - Handheld FLIR camera attachment (left) for taking infrared images of heated synthetic urine (right) 1-minute after simulated urine deposition. Discs (blue arrows) were placed in the corners of the 1 m x 1 m grid to serve as additional GCPs

Remotely Piloted Aircraft System (RPAS)

The field GPS data were ground-truth corrected through the geographic information system (GIS) tool/software before the RPAS i.e., drone flights were performed to capture optical imagery ($\approx$ 1 cm per pixel). The drone flights were performed on 9 and 20 day of post-application of urine, whilst taking ~10 minutes to complete the image capturing operation. Imagery from SD cards, along with coordinates of each reference plate (including altitude component and estimation of accuracy), were georeferenced using QGIS software

Fig. 3 - DJI Phantom 4 Pro drone (left) was used to capture urine patches of the dry and wet sites (right) 9-days after simulated urine deposition

Spikey-R

The Spikey-R was connected with a Trackmap system (similar to Global Navigation Satellite System (GNSS)) to detect and map the location of each urine patch and reference square metal plates. A map was produced showing the distribution and morphologies of the reference disks and urine patches using Python software.

The Spikey-R device developed in Milestone-2 was towed over the urine treated areas and metal-square plates at 2 h, 4 h, 16 h, 28 h and 52 h post-urine application (Fig. 4). Each pass of the Spikey-R pass was conducted at 1+/- 0.1 m s^{-1} (3.6 km h^{-1}) in a straight line over the field treatment blocks (<FC and AFC) where each urine patch through different urine volume inputs was randomly assigned. Data records of voltage drop between each electrode pair, at approximately 25 mm intervals and linked to on-board data controller, were taken for each pass. Data were presented as a georeferenced map of voltage levels, with GCPs clearly visible as areas of high conductivity. This was essential to enable the re-georeferencing of each individual Spikey-R pass from the less-accurate on-board unit to the more accurate positions of each GCP obtained from the Trimble unit, without which the accurate comparison to RPAS and thermal data would be difficult.

Fig. 4 - Spikey-R instrument towed behind the Kubota vehicle over each metal GCP (left) and (right) the processed PNG files of three side-by-side Spikey-R runs on the wet soil 2 hour simulated urine deposition, illustrating each urine patch (light blue) and GCP (red/yellow/green) against the background pasture.

Post processing

Each image was imported into the ImageJ software. Imported images were first calibrated to the correct scale using a known object length using a 1 m x 1 m square grid placed over the patches (thermal imaging) or the metal GCPs (Spikey-R). The perimeter of each urine patch was then traced which subsequently calculated the area within.

Statistical analysis was conducted using SAS 9.4 (Cary, NC, U.S.A.). Normality was checked with residual and student panels. Log and square root transformations were applied to data which was not normally distributed. The PROC GLIMMIX procedure was used to test for areal differences between the sensors. Significant differences were determined according to the *simulate* post-hoc test ($p < 0.05$).

3. Results

Thermal Camera

The thermal camera captured the immediate patch configuration and area ranging 0.17-0.40 m^2 (Fig. 6a and 6b). These areas were on average 32% and 55% smaller than the areas calculated by the RPAS and Spikey-R methods, respectively. Larger patches were detected at 2 and 3 l of urine applied for both soil moisture levels, whilst the method also detected larger patches in the soil AFC compared to <FC (Fig. 6a and b).

Fig. 5 - Thermal imagery of the urine patches on the dry site (left) and wet site (right) overlaid on the aerial imagery (Day 1).

RPAS

Artificial urine patch shape and configuration were clearly distinguishable from the RPAS flight at day 9 (Fig. 3). Patch sizes ranged from 0.50-1.56 m^2 and were larger than those detected by the thermal imagery and the Spikey-R methods ($p < 0.05$, Fig. 6a and 6b). Depending on soil moisture, mean patch areas calculated from the RPAS were at least 1.71-2.13 (<FC) and 1.38-1.59 (AFC) times those detected by the Spikey-R ($p < 0.05$). The RPAS flight also detected greater patch areas from 2 and 3 l urine deposited on soil AFC than <FC, though the differences were not statistically significant.

Spikey-R

The Spikey-R instrument detected urine patch size and configuration with high accuracy (Fig. 3 and 4). Patches receiving 2 and 3 l were found to be 1.61-2.41 times greater (<FC and AFC) than the 1 l urine treatments. Similar to the thermal and RPAS methods, larger patches produced in the soil AFC were also detected by the Spikey-R (Fig. 6a and 6b). Patch areas measured by the Spikey-R were on average 52% (<FC) and 67% (AFC) the size of patches measured by the RPAS. Regression analysis indicates a close agreement in the calculated values between the two methods ($r^2 = 0.82$) but less so between the Spikey-R and thermal imaging methods ($r^2 = 0.46$).
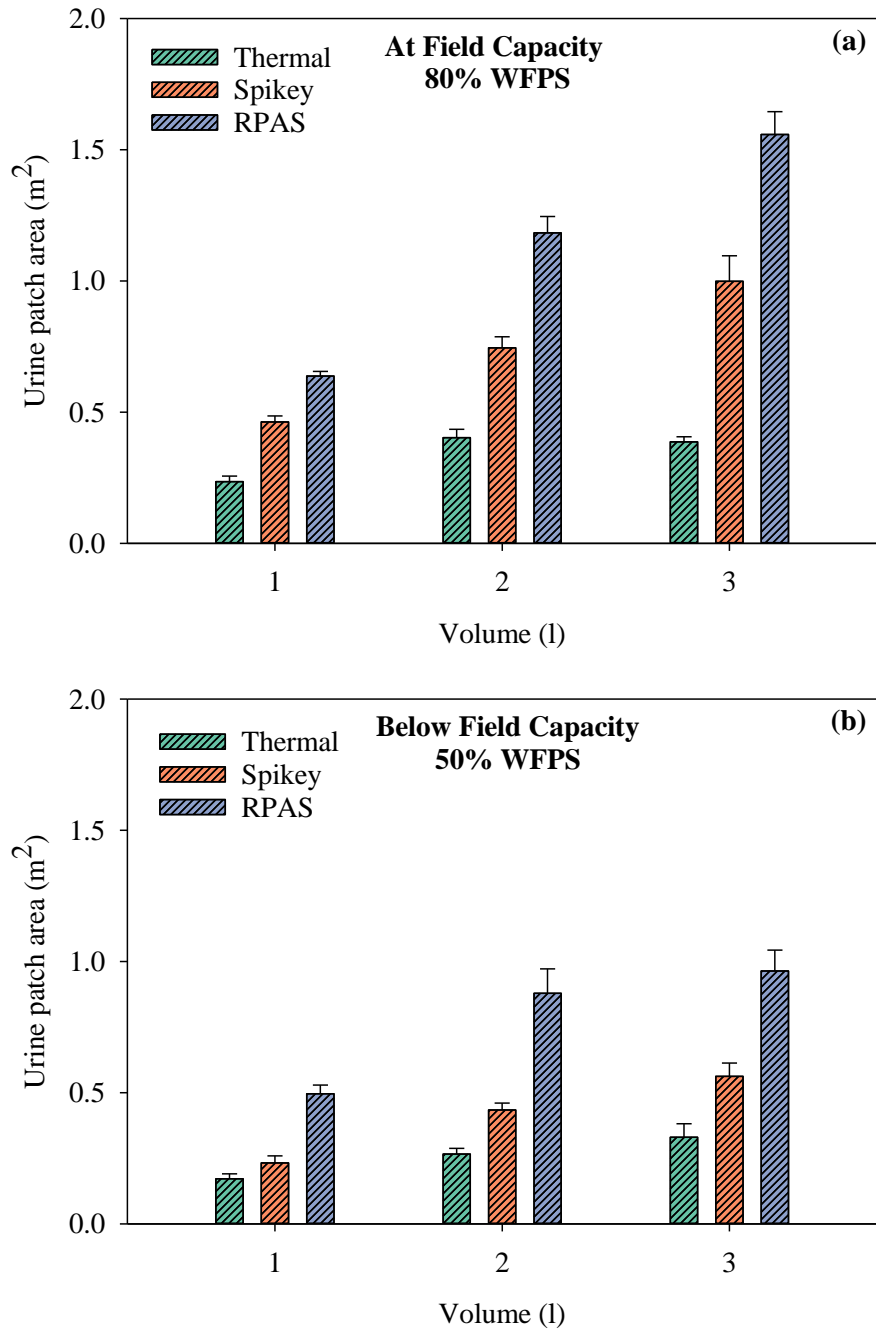
Fig. 6 - Urine patch size measured for soils (a) below field capacity (<FC) and (b) at field capacity (AFC) at three urine volumes (1, 2 and 3 l). Vertical bars represent the standard error of the means (n=6).
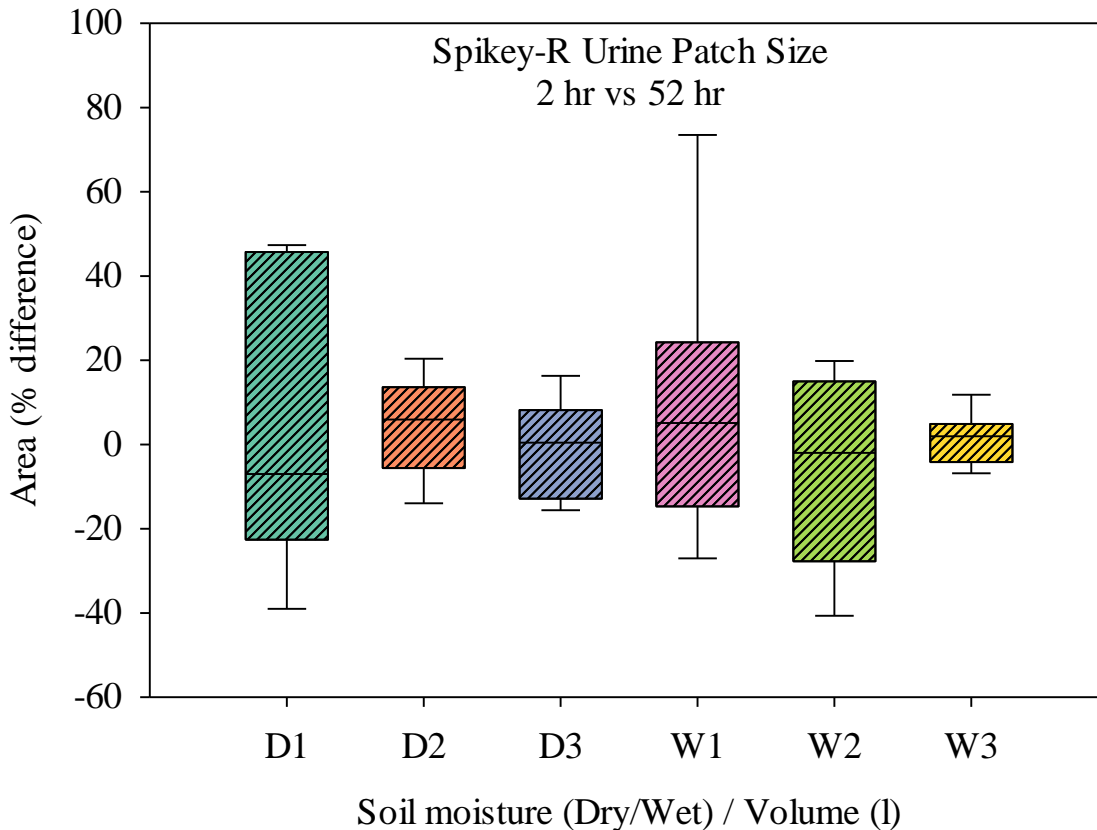
Fig. 7 - Boxplot showing the difference in urine patch area size detected by Spikey after 2 and 52 hours.

Large variability was observed between the patch sizes detected by Spikey-R at the initial and final runs, however, the level of accuracy tended to improve as the volume of urine applied increased. Overall, a $2.0 \pm 3.7\%$ difference was found across all treatments and soil moisture conditions with no significant difference detected between the two time points.

Discussion

Thermal Imagery

The thermal imagery was successful in its ability to capture deposited urine but did not produce accurate urine patch shape or size. Although the method identified variation between urine volumes, congruent with the RPAS and Spikey-R methods, the final calculated patch areas was considerably lower. With thermal imaging, the newly formed urine patch must be captured in less than a minute. This limitation may have lead to an underestimation in patch size whereby: (i) a longer duration is needed to allow lateral expansion of deposited urine across the soil surface, and (ii) urine cooling on contact with the soil surface may not be accurately estimated against background radiation. Jolly et al. (2019) found larger time windows for effectively capturing patches under cold ambient conditions (7-10 °C). Although the study was conducted during peak summer months (~16°C), urine could clearly be differentiated from pasture in the majority of plots. Therefore, in this study, one minute was too short a time window to observe full lateral movement of urine after its deposition.

RPAS

The RPAS method was essential for providing the base map of the experimental area and allowed the metal plates (Spikey-R) and additional GCPs (thermal imaging) to be georeferenced. In addition, the RPAS flight detected urine patches on dry and wet pastures with success, further validating the efficiency of this optical sensing technique (Maire et al., 2018; Jolly et al., 2019). Larger patches sizes surveyed from the RPAS flight indicate that the ability to capture the 'effective area' from the initial 'wetted area' (Selbie et al., 2015). Plant roots grow laterally as well as downwards which means plants adjacent the diffusive edge of the urine can access the nutrient pool via root extension. The difference in patch areas calculated by RPAS and Spikey-R may provide a quantifiable estimate of pasture growth response along the edges of the urine patch perimeter.

Spikey-R

The Spikey-R demonstrated its ability to identify patch size and shape. Moreover, the instrument can successfully detect urine patches up to 2 days after urine deposition to a high level of accuracy ($2.0 \pm 3.7\%$), irrespective of soil moisture. In the majority of plots, the 2 m width of the Spikey-R metal plates was sufficient for a single pass to sample the whole patch. Discrepancy in patch size between the Spikey-R and RPAS are due to the shorter duration between measurements ($\leq$ 2 days to > 7days). The close agreement between the Spikey-R and RPAS methods illustrates that urine patches increase in size due to either increased surface flow from 2 to 7 days and/or increased pasture growth at the patch periphery. This may influence when and where nitrification inhibitors can be applied on the pasture to retain N in the system.

A significant interaction between soil moisture and sensor was detected for all techniques ($p<0.05$). This indicates that urine deposition on wetter soils produced larger patch sizes. The result also indicates that each sensor was equally capable of detecting areal differences across contrasting soil moistures.

Conclusion

The results of this study indicate that the Spikey-R tool can reliably detect urine patch size and configuration across two soil moisture gradients. Patches were detected up to two days after urine application. The RPAS method was very effective for capturing urine size and configuration. The Spikey-R tool is, however, advantageous over the RPAS method, where the latter relies on pasture growth response for urine patch detection.

Acknowledgements

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