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PERFORMANCE OF SENSOR TECHNOLOGIES IN DETECTING AND MAPPING FRESHLY DEPOSITED URINE PATCHES IN THE GRAZED PASTURE SYSTEMS IN AUSTRALIA

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Abstract

Grazing is an integral part of Australia's livestock Industry (4th largest rural industry), where ~60-65% of dairy cattle feed needs originate through grazing pasture. During grazing, the spatial distribution of ruminants and frequency of urinating events over the grazed paddock is uneven. These urine patches act as the hotspots of greenhouse gas emissions (GHG) and leaching losses of nitrogen (N). Identification of the location and size of urine hotspots is central to mitigating N losses by their targeted management.

This study investigated the potential of an advanced ground-based sensing tool, Spikey-R (designed and developed in New Zealand) for detecting the location, shape and size of urine patches. This study verified the capability of Spikey-R in comparison with two other sensors; a thermal sensor camera and an aerial multispectral camera attached to a remotely piloted aircraft system (RPAS). These technologies were tested on a moderately well-drained soil under different soil moisture levels (at 100% field capacity and at 60% below the field capacity) by manually creating the urine patches using 1L, 2L and 3L of artifical urine (heated to ~38°C immediately before application).

The detection of urine patches through Spikey-R, when compared with the thermal and RPAS approaches, resulted in 100% positional detection accuracy. Spikey-R precisely detected the patch shape, size and location for up to 48-hours post urine application. The detection of urine patches through RPAS was more evident after a 14-day post-urine application. Comparatively, the mean patch area assessed through thermal and RPAS sensor camera images were ~15.3% and 20.6%, respectively, higher than the area detected through Spikey-R. Irrespective of soil moisture conditions, the trends in the urine patches shape detected through RPAS and Thermal sensors were not significantly different from each other compared to Spikey-R over time. Therefore, more work under a different set of conditions for the ground-truthing of such innovative sensor tools is recommended.

1. Introduction

On-going market and climate volatility and challenges for developing productivity-enhancing and low emissions technologies have completely changed the Australian dairy and livestock industry by reducing average farm profit. Worldwide, 7.82 Gt of nitrous oxide (N_2O), the third most important greenhouse gas (GHG) were emitted from agriculture with a 0.29 Gt contribution from Australia and New Zealand (FAO, 2017). In agricultural soils, N_2O is produced from transformation of nitrogen (N) containing compounds, either from fertiliser N or from the animal excreted urine and dung. More fertiliser-N and/or animal excreted urine-N, would produce more N_2O emissions. Worldwide nitrogen (N) loss from the dairy and livestock industry is a major concern. In Australia, dairy contributes ~1.6% into Australia's total GHG emissions, where 90-95% contribution directly from farms (Dairy Australia, 2019).

Grazing is an integral part of Australia's 4th largest rural industry: dairy and livestock farming. It accounts for ~60-65% of dairy cattle feed annually (Dairy Australia, 2019). Spatial distribution patterns and frequency of urination in pastures grazed by beef cattle/sheep are uneven and between 70 and 95% of ingested N is returned in urine/dung. These urine patches are the preferred grazing location of livestock in a paddock and also act as hotspots for N loss. Moir et al. (2010) reported that urine patches in dairy-grazed pastures with a high stocking density (4.3 cows ha^{-1}) cover an average 23.1 ± 2.2% of the annually grazed area with urine patch size 0.35 m^2.

These urine hotspots are continually (over)grazed under different grazing management strategies and left with a biased amount of nitrogen load. Under these circumstances, it is easy for growers to compromise the paddock's safe carrying capacity for N loading with blanket N application for optimising the N level between soil and plants. The Australian dairy and livestock industry faces dual challenges if it is to meet rising societal expectations: to reduce both GHG emissions and nutrient leaching to waterways and to continue to improve productivity while remaining economically viable. Therefore, implementing or utilizing available urine nutrients can be a strategic approach considering environmental and farmers' productivity concerns, i.e., nitrogen-use-efficiency and animal health. Until now identifying and determining the shape, size and location of urine patches post-grazing under grazed pasture systems has been a time-consuming and expensive process. However, adopting site-specific management practices like using advanced ground-based sensing tools can improve the fertiliser use efficiency and increase the capacity and capability of dairy and livestock enterprise. This study aims to validate 'Spikey-R' – a ground-based sensing tool for detecting and mapping the location and area of cow urine patches under moderately-well drained soils. It also aims to validate the results of Spikey-R and other proximal sensing tools like Remotely Piloted Aircraft System (RPAS or 'drone') and thermal camera to map the pasture response to urine.

2. Materials and methods

2.1 Site and experimental description

A field trial was established on a moderately well-drained soil at Menangle, NSW (34°07'30.1"S 150°42'17.5"E). Since October 2017, the experimental area (~≥300m^2) was identified and fenced off from the rest of the field. This site was under permanent dairy pasture for the last 21 years (1996-2018) consisting of Ryegrass (L. *perenne*) and Kikuyu (*Pennisetum clandestinum*). The soil at the site is classified as Eutrophic Red Chromosol (Isbell, 2002), or Haploxeralf (Soil Survey Staff 1999) with a moderately high soil C and N and moderately acidic soil, as shown in **Table.1**.

At the experimental site, two levels of soil moistures i.e., 100% field capacity (FC) and 60% below the field capacity (BFC), were established. The two levels of soil moisture, i.e., at 100% field capacity (FC) and 60% of field capacity (BFC), were established and maintained through irrigation before initiating the urine patches. The moisture content at the field site was achieved by calibrating the soil water-filled pore space (WFPS) in the range of 66–72% at FC and 48–54% at BFC. Before urine application, volumetric moisture content (VMC) (Delta-T HH2 moisture meter) was regularly measured inside each treatment block as an indirect representative of WFPS and was kept in the 38-40% and 25-30% for FC and BFC, respectively, as per Eq. 1.

$$\text{WFPS (\%)} = \left(\frac{\text{VMC}}{\text{Total Porosity}}\right) \times 100 \qquad (1)$$

The field-moist soil samples were estimated from composite soil samples of six soil cores, which were oven-dried at 105°C for 48 hours or until a constant dry weight. Soil bulk density was determined initially from undisturbed soil core samples using the soil core method. The VMC was then calculated by multiplying the GMC by the soil bulk density (g cm^{-3}). Soil total porosity was calculated by assuming a soil particle density of 2.65 t m^{-3} (Luo et al. 2007), according to Eq. 2:

$$\text{Total Porosity (\%)} = \left(1 - \frac{\text{Bulk Density}}{\text{Particle density}}\right) \times 100 \qquad (2)$$

Furthermore, long plastic sheets were used to prevent the established field moisture contents from rainfall events. One week before the artificial urine application herbage was cut to ~0.05 m height (equivalent to 2^{nd} knuckle height of fingertips). The state average annual rainfall was highly variable, in that it was 40% below average up to September 2018. However, in October and November 2018, the total rainfall was above the average, with 562 mm of total annual rainfall at the end of the year (BOM, 2018). The mean temperature was recorded as 1.68 °C above the annual mean temperature (25 °C) on record (BOM, 2018).

Table.1 Key soil Physico-chemical properties at the experimental field site before the commencement of urine application. Samples were analysed using methods described in Rayment and Higginson (1992)

Soil Properties		**Depth (m)**		
		0 - 0.10	**0.10 - 0.20**	**0.20 – 0.30**
Total C (%)		2.36 ± 0.02	1.74 ± 0.01	1.35 ± 0.01
Total N (%)		0.20 ± 0.02	0.12 ± 0.01	0.06 ± 0.01
Total P (%)		0.05 ± 0.01	0.04 ± 0.01	0.02 ± 0.01
pH_w		5.6 ± 0.03	5.6 ± 0.03	6.2 ± 0.02
$EC_{1:5}$ (dS m^{-1})		0.08 ± 0.01	0.05 ± 0.01	0.05 ± 0.01
Bulk Density (Mg m^{-3})		1.09 ± 0.02	1.44 ± 0.03	1.51 ± 0.02
Particle size (%)	Clay	18	14	30
	Sand	62	68	68
	Silt	20	18	2
Soil textural classification		Sandy Loam	Sandy Loam	Sandy Clay Loam

(All the values in the table are the mean values (n=3); values followed by '±' are standard error of means; soil pH_w and $EC_{1:5}$ measured in 1:5 soil/water solution ratio)

2.2 Field site setup and sensor tool technology

In this experiment, urine patches were established in the morning by manually pouring artificial urine from a purpose-built stand, with a nozzle positioned at 1.5m height ground level, and the flow rate was optimised to mimic a 'typical' natural cattle urination. Artificial urine was prepared as per the protocol used by de Klein et al. (2003). Before creating urine patches, artificial urine was pre-heated to ~38 °C. The preheated artificial urine was applied on the ground at three different volumes (1L, 2L and 3L) in 6 replicates under both soil moisture conditions (FC and BFC). The urine patches were randomly distributed within the defined (2.5 m x 2.5 m) plots in each replicate. Urine was poured inside a metal frame (1 m x 1 m) as a control mechanism for identifying the border of the patch.

Metal ground control points (GCPs) were marked using a Trimble GeoXH 6000 high-accuracy GNSS (Global Navigational Satellite System or 'GPS') receiver with real-time kinematic (RTK) corrections. These GCPs were critical for both the Remotely Piloted Aircraft System (RPAS) and ground sensing tool i.e. Spikey-R. Prior to urine application, the RPAS was flown over the selected site to create a 'base' orthomosaic image for geo-referencing the Spikey-R and thermal images. Specific settings related to sensors tools for capturing urine patches data are described in the following section:

Thermal Camera

A FLIR-C2 handheld thermal camera captured oblique (~70° elevation) thermal and optical images of each urine patch within one minute of urine deposition. Thermal images were captured in 'Thermal MSX' mode, which overlaid the results of an edge-detection algorithm from the optical image over the thermal images. This was essential for identifying urine patches location later. The thermal imagery would require rectification and geo-referencing while keeping RPAS captured as orthomosaic image for overlaying thermal images of the patches captured after deposition. The frame was placed immediately before pouring of the urine followed by an image taken using a thermal camera, after which the frame was moved to the next urine patch location.

Each thermal image was manually rectified using the built-in 'Georeferencer' feature of QGIS with coordinates in x/y space of [0,0] (bottom-left of image), [0,1] (top-left), [1,1] (top-right), and [1,0] (bottom-right). The transformation type used was 'Projective' (linear rotation/translation only), and the resampling method was 'nearest neighbour'. The coordinate reference system (CRS) was set to Universal Transverse Mercator (UTM) zones (WGS 84/UTM zone 56S - Projected) to measure the distance in metres. While using a metal frame as thermal GCP, the rectified thermal images were then georeferenced using the QGIS Georeferencer, where setting 'Transformation type' was chosen as 'Projective'. The processed thermal images were then manually digitised to produce a polygon for each urine patch, from which patch area and perimeter could be extracted for comparison with those from the other sensors using Microsoft Excel.

Remotely Piloted Aircraft System (RPAS)

A XAG C2000 mapping UAV equipped with multi-spectral (*Parrot Sequoia*) camera was flown immediately prior to, and post-urine application with a third follow-up flight on 14-day post-application. As described above, the first two flights were to provide data for the other sensors while the final flight was to detect the pasture response to the urine patches created. Flight altitude was kept at 30 m providing a ground sample distance (GSD) of less than 0.01 m per pixel. Overlap and sidelap were set to 75% each. Individual images were processed using drone deploy to create orthomosaics with a GSD of 0.01 m, georeferenced using the metal plate GCPs as described above.

The 14-day post-application flight orthomosaic was analysed with the 'ImageJ' free domain software version 1.42 (Rasband, 2012). This orthomosaic image was then loaded into ImageJ, and colour thresholding was applied in the Hue, Saturation, and Brightness (HSB) in order to create a mask (ImageJ menu: Image -> Adjust -> Color Threshold). The general range used was 60 – 80 (Hue), 0 – 255 (Saturation), and 0 – 100 (Brightness), which depend upon multiple factors like soil moisture levels, soil types, and pasture conditions as well as lighting levels and the kind of camera used on the RPAS. After thresholding, several steps from the 'Process -> Binary' menu were used, in the following order: Convert to mask, Dilate -> Fill Holes -> 2- Erode -> 2-Dilate. The multiple 'erode' and 'dilate' steps were used to identify the edges of the urine patches and to eliminate the image 'noise' without biasing the patch area. Finally, the 'Analyze -> Analyze Particles' from the imageJ menu function was chosen to eliminate patches smaller than 1000 pixels (0.10 m^2 or approximately dinner-plate sized), while selecting 'show count masks' option used to output a unique number of each patch. This image from ImageJ was then exported as portable network graphics (PNG) files with corresponding 'world' files – text files containing information which can help GIS tools like QGIS to accurately place this PNG image on a map as per coordinates. The ImageJ output i.e. PNG image, translated to a GeoTIFF with GDAL using QGIS, so a NODATA value of 0 could be set, then Polygonize tool was used to create a polygon per urine patch. The resulting shapefile was edited in QGIS and using 'symbology' feature for each patch then an ID was given that would match IDs used for the thermal imagery polygons and after which data were exported in Microsoft Excel.

Ground-based sensor - Spikey-R

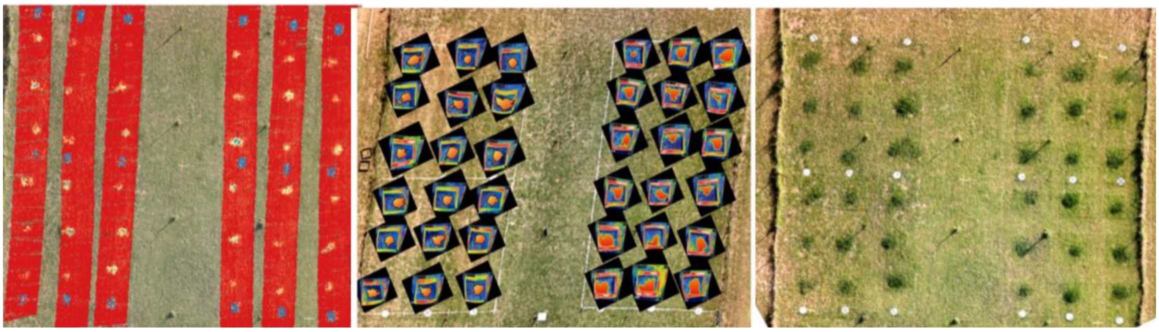
'Spikey-R' is a research-grade and an improved version of the 'Spikey®' equipment. This ground-based sensing tool was developed to detect the urine patches based on the measurement of soil electrical conductivity. It consisted of 75 spiked metal sensor plates that were equally spaced at 25 mm on a 2 m wide axle. Plates were isolated into adjacent pairs, with an electric current passed through the soil between the plates and the voltage drop measured to indicate the conductivity of the soil (spike penetration was typically less than 10 mm). The entire array of discs was split into three blocks for recording/management purposes. Spikey-R was towed at a walking pace (i.e., 5 km hr^{-1}) behind a vehicle, with an on-board 'TracMap' GNSS unit providing location data. Data was downloaded onto a flash drive and processed by Pastoral Robotics Ltd to produce GeoTIFF images of soil conductivity, with areas of higher conductivity theoretically corresponding to urine patches.

Spikey-R was towed over the urine patches at 2, 4, 24, and 48 hours post-application of urine. At every pass of Spikey-R special attention was to taken include the metal GCPs. As the TracMap GNSS is not very accurate, the resulting GeoTIFFs obtained through this system required further georeferencing with the QGIS Georeferencer which accurately placed and scaled them according to the metal GCPs. The final GeoTIFFs were then loaded into ImageJ for further image analysis followed by thresholding the raw images recorded as the difference of voltages. All the images in ImageJ were processed separately for both soil moisture conditions i.e. at field capacity and below field capacity, however, an approximate thresholding range (1100 – 20,000) was used. After thresholding, the mask was converted to binary, and holes were filled before being run through the ImageJ despeckle filter and outliers were removed using noise filters. Finally, the Analyze Particles tool of ImageJ was used with a threshold of 20 pixels (still 0.10 m^2 as pixels were 0.05 m GSD) and similar steps were followed as used for RPAS image processing, i.e. georeferencing and converting each urine patch into polygons.

3. Results

3.1 Identifying sensor technology ability for locating and mapping urine patches

Results (**Fig. 1(a-c)**) are the urine patches location and shape as captured by different proximal sensors i.e. the ground-based sensor, thermal imaging camera and RPAS imaging.



(a) (b) (c)

Fig. 1 *Georeferenced post-urine application images of urine patches detected by: (a) Spikey-R at 48-hour (identified in yellow patches), (b) thermal imaging camera at 30-seconds, and (c) 14-day orthomosaic image captured through Remote Piloted Aircraft System (RPAS). The left and right side of the image representing 'at 60% below the field capacity (BFC)' and 'at 100% field capacity', respectively.*

Ground-based sensing technology - Spikey-R

When the Spikey-R passed over the manually created urine patches at different time intervals (2, 4, 24, 48-hours), the sensors (a.k.a., spikes) of Spikey-R detected the urine patch locations **(Fig. 1a)** and also estimated the shape and size of the urine patches. Results indicated that there was no difference in the size **(Fig. 2)** and shape **(Fig. 3)** of the urine patch measured by Spikey-R under both the soil moisture conditions. Whereas, the size of the urine patches measured through Spikey-R indicated that size of urine patch varies with the different volume of urine applied **(Fig. 2)**. Specifically, when considering the sensitivity of the Spikey-R in detecting the urine patches, it was found that the estimated size of the urine patch at 48-hour was ~2-fold larger in the U3 (3L) compared to size under U1 (1L) treatment. These results suggested that Spikey-R was not only able to detect the freshly (2-hour) deposited urine patches but also precisely identify urine patches spatial configuration up to 48-hours post-urine deposition.

Remotely Piloted Aircraft System (RPAS)

Urine patches, when monitored using the RPAS system equipped with a multispectral camera, were not evident during 2, 24, 48-hours and 7th day of post-urine application. Whereas urine patches were highly evident on the 14th day of the post-urine application, as shown in **Fig. 1c**. Results indicated that the estimated sizes of the urine patches were comparatively similar under both the soil moisture conditions (FC and BFC). In addition, irrespective of the soil moisture conditions, it was also found that the size of the urine patches under U3 (3L) treatment was ~2-fold larger than the size of urine patches under U1 treatments **(Fig. 4).**

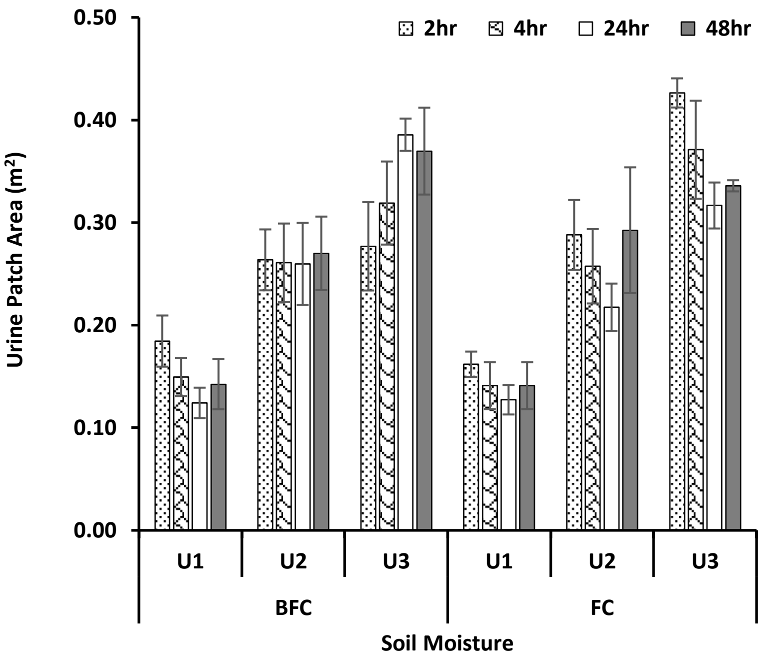


Fig.2 *Urine patches area detected and measured by Spikey-R from both soil moisture conditions (FC and BFC) at 2, 4, 24, and 48 hours post-application of artifical urine. All the values are the mean values with standard error bars, where U1 (1L); U2 (2L); U3 (3L) is the amount of artifical urine poured as treatment; BFC – at 60% below the field capacity (BFC), FC – at 100% field capacity (FC).*

Fig. 3. *Urine patches detected by Spikey-R at 2-hour (Turquoise), 4-hour (Red), 24-hour (Green), and 48-hour (Blue) post-urine application. The left and right sides of the image represent 'at 60% below the field capacity (BFC)' and 'at 100% field capacity', respectively.*

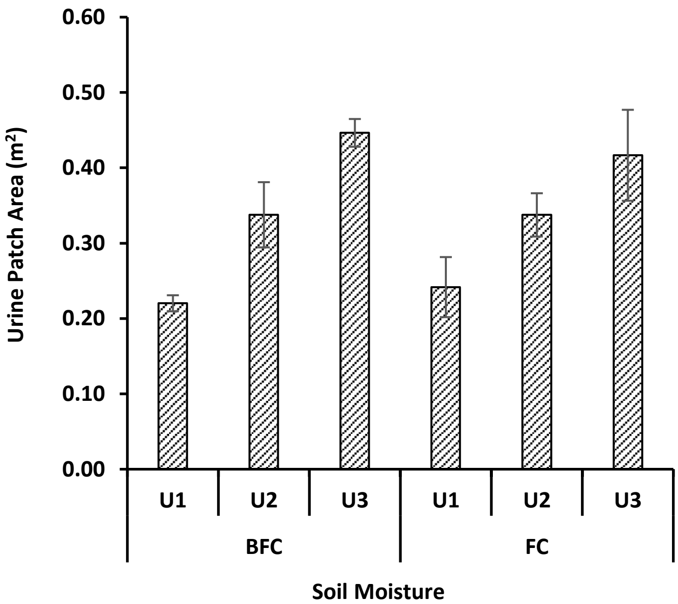


Fig. 4. *Urine patch areas measured from 14-day post-urine application RPAS orthomosaic image under two different soil moisture conditions at 60% below the field capacity (BFC) and at 100% field capacity. All the values are the mean values with standard error bars, where U1 (1L); U2 (2L); U3 (3L) is the amount of artifical urine poured as treatments.*

(a) (b)

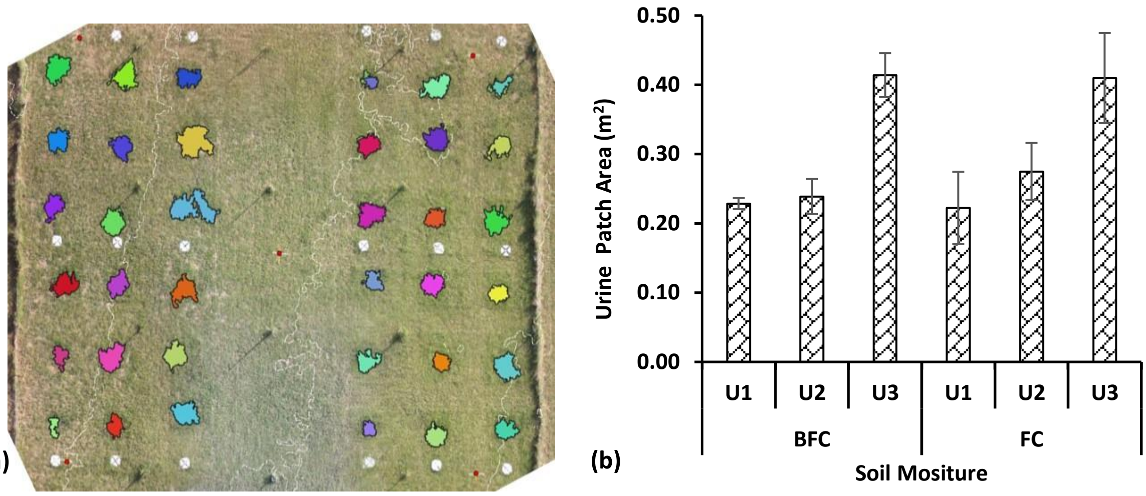


Fig. 5 *(a) Urine patch areas estimated through the thermal images recorded 30-seconds post-urine application under two different soil moisture conditions i.e., 'at 60% below the field capacity' (BFC) and 'at 100% field capacity' (FC) using a thermal sensor; (b) The estimated urine patch area from the thermal images using QGIS software, where all values are the mean values with standard error bars, where U1 (1L); U2 (2L); U3 (3L) is the amount of artifical urine poured as treatments.*

3.2 Comparative evaluation of sensor tools in mapping urine patches area

Urine patch results i.e. shape and area, estimated through all sensory tools indicated that urine patch configuration varied with the volume of urine deposited **(Fig. 6)**. Whereas, as shown in **Fig. 6,** the results highlighted no significant impact of the soil moisture status i.e., FC and BFC on the urine patch areas. Irrespective of the moisture conditions, the comparative analysis of the patch size area estimated through all sensor tools revealed a significant linear correlation coefficient between Spikey-R and RPAS (r=0.60, P<0.05) followed by Spikey-R and thermal (r=0.53, P<0.05) as shown in **Table 2**. Whereas, there was no significant impact on the urine patch area between Thermal and RPAS (r=0.60, P<0.05) urine patch area comparison (**Table 2)**. On the contrary, when the estimated urine patch area was evaluated from both soil moisture conditions, a higher urine patch area was found through RPAS (0.33 m^2) and thermal imagery (0.30 m^2) compared to Spikey-R (0.26 m^2). Though area estimated through thermal and RPAS imagery was not significantly different from each other, it was found that these areas were ~15.3% and ~26.9% larger than the areas estimated through Spikey-R, respectively, as shown in **Fig. 6**. The positive covariance values, as shown in **Table 3,** indicated that the average urine patch areas estimated by Spikey-R at 2, 4, 24, 48-hour were highly associated and showed a lower variation with a difference of only 0.002 unit between the variance value of Spikey-R at each time.

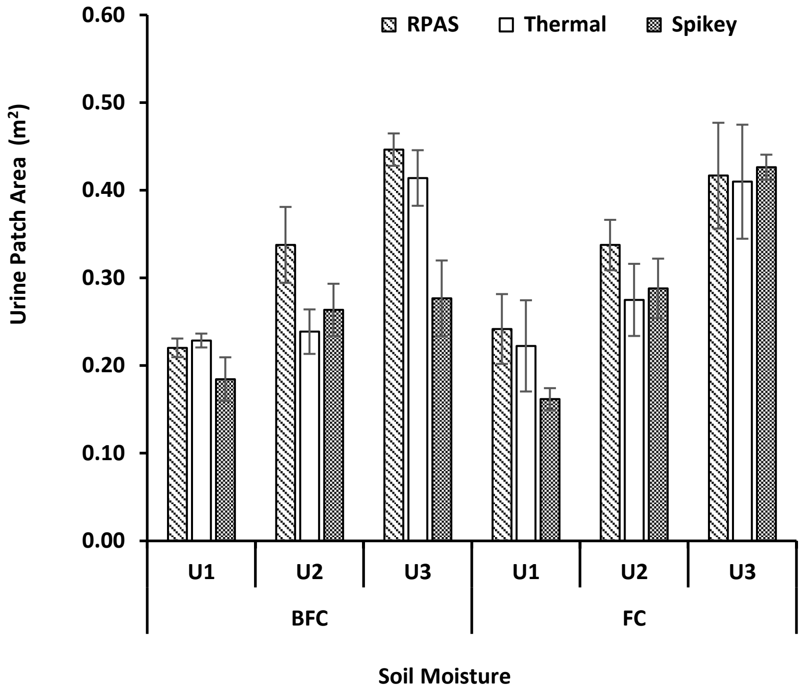


Fig. 6. *Comparison of urine patch areas estimated by all sensors from the soils at 60% below the field capacity (BFC) and at100% field capacity (FC). All values are the mean values with standard error bars, where U1 (1L); U2 (2L); U3 (3L) is the amount of artifical urine poured as treatment*

Table 2 Multiple regression analysis of the urine patch size area detected through different sensing tools

	Spikey and Thermal	Spikey and RPAS	Thermal and RPAS
Multiple-R (r)	0.54	0.58	0.39
R^2	0.29	0.34	0.16
Adjusted R^2	0.27	0.32	0.13
Standard Error of R	0.11	0.10	0.11
Significance	$P < 0.05$	$P < 0.05$	$P > 0.05$

Table 3 Covariance of the urine patch areas estimated from the images detected by Spikey-R at different time intervals

Time Interval	*2hrs*	*4hrs*	*24hrs*	*48hrs*
2hrs	**0.011**			
4hrs	0.008	**0.013**		
24hrs	0.007	0.008	**0.012**	
48hrs	0.006	0.011	0.008	**0.014**

4. Discussion

The proximal sensor technology used in this study signifies the reliability of urine patch location and morphology (i.e., size and shape), which were effectively detected, and delineating the urine patches from non-treated locations. The average urine patch area estimated from all treatments by all sensors in this study varied considerably, i.e. from 0.26 to 0.33m^2 **(Fig. 6)**. These urine patches were manually created while mimicking with the natural conditions, resulting in patch areas between the range from 0.16 to 0.49 m^2 (Moir et al. 2011; Selbie et al. 2015; Williams and Haynes, 1994) determined from natural urine patches deposited from dairy cows. The main difference under the current study was the adopted methodology i.e. using advanced sensor technology, to measure the patch area, which was different from the methodologies employed by other researchers. For example, the study conducted by Ravera et al. (2015) harnessed the dairy cows urine, while grazing and thereafter dispersing urine naturally on bare soil, therefore also estimated the urine patch size in the range of 0.19 and 0.24 m^2.

As expected, the results from this study proved that with the increase in the volume of urine applied (U1, U2, and U3), the urine patch size increases. Thus, results are in agreement with the results reported by Betteridge et al. (2013); Li et al. (2012) and O'Connell et al. (2016), which indicated that larger urine volumes resulted in a larger surface area of urine patches. In contrast, under the current study, no significant difference was found when the patch area was compared between both soil moisture conditions (FC and BFC) **(Fig.6)**. These results could be attributed to the pasture cover and the site history, which was under pasture management for a long-time. Consequently, this becomes a possible reason for the presence of a higher and thicker density of stolon, which would have impacted the potential of urine flow and limits the expansion of the urine patch area.

The positional accuracy in detecting the urine patches by Spikey-R in this study proved it as an effective tool for detecting and mapping the urine patches based on soil electrical conductivity. The cross-validation of the regression analysis between all sensor tool findings, in particular the adjusted-R^2 and standard error of regression analysis, validate the claim that Spikey-R is an effective tool for detecting and mapping urine patches. These regression results also imply that the urine patch area estimated by Spikey-R had more reliability than the urine patch area determined through thermal and RPAS sensors **(Table 2)**. The 14-day RPAS imagery hinted that the pasture herbage response over the urine patch area was easily distinguished from the background pasture in this study. Therefore, if rainfall events are frequent, it is likely that distinguishing the urine patches herbage response to the background pasture through RPAS would be difficult. In addition to these, natural pasture variability might have also influenced the results. Under the current scenario, though thermal image acquisition was 100% for all the manually created urine patches. However, under ideal conditions or typical farm type conditions, environmental conditions like cool air and soil temperature at the time of urine application could cool down the temperature of the urine quickly.

Consequently, thermal imagery may fail to capture urine temperature, resulting in a loss of patch detection. The likelihood of human variabilities in processing the images also cannot be ignored. For example, the non-significant regression analysis of patch area between thermal and RPAS might have occurred due to the contribution from the 'edge effect' of urine patches during the image analysis. The results from the current study suggest future studies should trial diurnal urine patch impacts under different seasons, pasture coverage in a way to identify the pasture diversity and to predict the spatio-temporal variations of urine patches. The urine patch area is an essential factor in the estimation of the factors contributing to environmental (N losses) and economic losses from a dairy farming system.

5. Conclusion

In this evaluation of sensing technologies to measure the spatial configuration of deposited urine patches, Spikey-R was shown to be an effective tool in accurately detecting and adequately mapping the urine patch size between 2 to 48 hours post-urine deposition. Further improvements such as hydraulically controlled spikes with a better GNSS unit would improve its efficiency and remove the need for the GCPs. Among the other two methods used, thermal imaging was also successful in accurately mapping urine patches and needed appropriate referencing tools to improve the efficiency of this method. However, it is labour-intensive and can only be applied within minutes of urine deposition that restricts its use in detecting and mapping urine patches deposited by grazing livestock provided RPAS based thermal cameras are used. The RPAS provided mixed results, which were more sensitive to background soil fertility and environmental conditions.

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