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Establishing soil nutrient distribution zones across free range egg farms to guide practical nutrient management strategies

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ABSTRACT

Little is known regarding manure nutrient deposition in free range egg layer facilities. Consequently, a significant knowledge gap exists regarding how to best manage soil nutrient loading on these farms. Here, we report on soil nutrient properties across 14 Australian free range farms. Electromagnetic-induction (EM) mapping was performed at each farm to select soil sample locations which were collected at an average depth of 30 cm. EM data exhibited promising relationships with key soil properties. Measured soil properties were highly variable between and within farms. Soil nitrate-N (NO_3-N) and Colwell-P (Col-P) concentrations ranged from 1 to 529 mg N kg^{-1} and 11 to 1856 mg P kg^{-1}. Average NO_3-N and Col-P concentrations across farms were 100 mg N kg^{-1} and 250 mg P kg^{-1} which exceed typical background nutrient levels and exceed requirements for dryland crop or pasture production. Farms with trees exhibited 2.6 × and 2.1 × greater NO_3-N and Col-P concentrations than farms with no trees ($P < 0.05$), indicating trees attract birds to range areas resulting in higher manure deposition rates. Generalised nonlinear models were derived to describe soil nutrient concentrations with respect to shed location. These models revealed sharp nitrate and Col–P concentration decreases with increasing distance from sheds, with 50% of the NO_3-N and Col-P concentration gradients restricted to a radius of < 6 m (equating to an area of 0.05 ha) from the nearest shed ($P < 0.05$). Encouragingly for farms that pose a nutrient accumulation risk, these relatively small impacted areas can be managed with several options which we discuss in this paper.

1. Introduction

Free range egg farming has expanded substantially in developed countries in response to consumer demand (Piskorska-Pliszczynska et al., 2014; Parisi et al., 2015). In Australia, the retail turnover of free range eggs in 2014 surpassed all other egg categories for the first time since industrialisation (Singh et al., 2015). Australian free range egg producers are required to provide the hens with a range area sufficient to maintain stocking densities of 10,000 hens per hectare (Aus-Govt, 2017), or 1500 birds per hectare (RSPCA, 2015) for certain kinds of accreditation. Standard free range management in Australia utilises a shed where feed, water, roosting and laying occurs. Sheds are typically fixed in one location, with a study of two free-range flocks showing that birds on average spend 14% of their time on the range area (Larsen et al., 2017). From this it is inferred that the majority of manure is deposited in the shed, with smaller amounts deposited in the range area. Some systems have been developed with movable shelters with slatted floors where manure can be deposited directly to the range but these represent only a small proportion of the flock in Australia (G. Runge, pers. comm.).

As a result of regulation requirements as well as industry drivers, Australia's egg industry identifies maintaining environmental sustainability as an important goal. One important issue is the sustainable management of nutrients excreted by the birds in manure (Kijlstra et al., 2009), yet detailed information in this area is critically lacking. Very little published information exists regarding manure deposition quantities, manure deposition patterns, and resulting manure nutrient soil profiles in range areas globally. With insufficient information available to determine nutrient risks, the regulatory requirements for controlling nutrient losses are not standardised. However, some nutrient control strategies are less favourable for free range poultry than other intensive livestock operations. For example, the use of retention dams to withhold potentially nutrient-rich runoff water is common in beef cattle feedlots (Woodbury et al., 2003; Andersen et al., 2009) but is

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disadvantageous for free range poultry because open water sources attract wild birds, which are vectors for a number of serious poultry diseases (Berhane et al., 2009). To establish suitable nutrient control or management mechanisms, a clear understanding of the nutrient source and risk in the system is required.

Regarding nutrient densities in free range areas, Singh et al. (2015) measured soil (top 10 cm) nitrogen and phosphorus concentrations within the range areas of 14 free range layer farms across Australia. They reported 14-fold higher nitrogen and 8-fold higher phosphorus levels in range area soils relative to background areas, but did not provide information on the distribution of these nutrients in the range area. European research has indicated that free range farming can produce worse environmental outcomes than conventional intensive poultry egg farms (Hermansen et al., 2004). This is largely because the birds may not range very far from the sheds, leading to higher manure deposition in these areas resulting in soil nutrient hotpots which are prone to negative downstream environmental impacts (Hirt et al., 2000). Even if nutrients are reasonably evenly distributed across the range area, there is no guarantee that this will alleviate environmental concerns. As Hermansen et al. (2004) note, typical free range stocking densities adopted in Europe result in nitrogen supplies of > 200 kg ha^{-1} within 100 days, which is more than optimal for most crops.

The relative environmental risks of excessive nutrient loading in range area soils appear to be site-specific and probably depend on a combination of interacting environmental factors. For example, while Jones et al. (2007) detected no change in groundwater nitrate and phosphate concentrations associated with an expansion in a free range layer enterprise in the UK, Lee et al. (2010) concluded that concentrated soil nutrient zones in poultry range areas are highly susceptible to environmental problems via leaching and runoff. Similarly, Kratz et al. (2004) reported 'excessive' mineral nitrogen and available-phosphorus concentrations in range area soils for broiler in Europe and posited environmental risks associated with nutrient volatilisation, leaching and runoff.

The lack of published range area soil nutrient data makes it difficult to predict environmental risk with confidence (Xin et al., 2011). Moreover, obstacles exist in seeking to fill this knowledge gap because range areas can be extensive, thereby presenting logistical challenges for targeted and representative soil sampling. The use of electromagnetic induction (EM) soil surveying might help in this regard. EM yields apparent electrical conductivity (ECa) readings in soil and may be used to inform targeted soil sampling campaigns based on mapped variability in ECa across a soil landscape. EM might also be used to spatially quantify other specific properties of interest in soils (Eigenberg and Nienaber, 1998; Eigenberg et al., 2002; Corwin and Lesch, 2005a,b; Eigenberg et al., 2006) as well as other substrates such as stored manure (Eigenberg and Nienaber, 2003; Woodbury et al., 2009). Provided non-related soil parameters such as texture, moisture, temperature and innate salinity are consistent across a site, strong regression relationships between ECa and manure nutrients have been found (Wiedemann, 2015).

The aims of this project were to: 1) perform an EM mapping exercise to inform optimal soil core sampling locations across the range areas of 14 free range layer farms in southern Queensland; 2) investigate any effects of on-farm factors – specifically, presence of fenced areas and Trees – on nutrient accumulation in the range areas; 3) resolve range area nutrient soil concentrations with respect to distance from sheds using generalised nonlinear statistical models; and 4) use the data from these models to propose practical management recommendations for high-risk operations. To the best of our knowledge, this is the first study to seek to quantify soil nutrient accumulation with respect to shed location across poultry range areas.

2. Materials and methods

2.1. Farm characteristics

The study was conducted across 14 free-range egg farms in the Darling Downs region of southern Queensland. The coordinates of the studied area are −27.10 to −28.50 Latitude, −148.95 to −151.96 Longitude. The farms varied in overall bird numbers, stocking density, farm age, and underlying soil type – shown here according to the World Reference Base for Soil Resources (WRB, 2015). Soils are also presented as their type under the Australian classification system (in brackets). Key farm characteristics are shown in Table 1. The range areas of some farms were fenced while others had no restriction on bird ranging behaviour. Farm age varied substantially, with some farms having been in operation for more than 50 years. These farms typically expanded from 'back yard' egg production to small-scale commercial production in the past 20–30 years. All of the farms are located in a region characterised by sub-humid, dry (< 700 mm annual rainfall), subtropical climate (Beckmann et al., 1974).

Table 1
Characteristics of the studied farms.

Farm ID	Farm age, yrs	No. birds	Underlying soil type (WRB)	Corresponding soil type (Australian Soil Classification system)
1	8	20,000	Vertisol	(Vertosol)
2	10	8000	Vertisol	(Vertosol)
3	9	5000	Solonetz	(Sodosol)
4	12	5000	Vertisol	(Vertosol)
5	8	20,000	Luvisol	(Dermosol)
6	2	5000	Leptosol	(Lithosol)
7	> 50	9000	Vertisol	(Vertosol)
8	15	Not reported	Vertisol	(Vertosol)
9	20	Not reported	Vertisol	(Vertosol)
10	25	2500	Vertisol	(Vertosol)
11	7	16,000	Vertisol	(Vertosol)
12	14	22,000	Leptosol	(Lithosol)
13	> 50	2500	Vertisol	(Vertosol)
14	6	2500	Solonetz	(Sodosol)

2.2. Electromagnetic mapping survey and soil sampling

The EM soil surveys were carried out using an EM38-MK2 (Geonics Ltd), towed by an all-terrain vehicle (ATV) with a trailer. The EM38 and GPS were both connected to a handheld computer, enabling the GPS coordinate to be matched with an EM reading (units = ECa, representing apparent electrical conductivity). Following the survey, soil samples were collected from the survey area to validate the ECa results. The soil sampling locations were determined using the ESAP software package to best cover the range in ECa observed (Lesch et al., 2000). At each site, the sampling design consisted of six soil sampling points. Soil samples were collected from the 0–30 cm depth. At some sites soil conditions prevented sampling to 30 cm and in these cases samples were collected at either 0–20 cm or 0–15 cm.

2.3. Soil chemical analysis

Soil pH and EC were measured using an integrated sensor following a 1:5 solid:water extraction, following the International Organization for Standardization Methods (ISO, 2015) and (ISO, 2016a), respectively. Soil chlorine levels were also measured in these extracts using an ion selective electrode according to the method outlined by Frankenberger et al. (1996). NO_3-N was analysed following extraction with 1 M KCl, subsequent oxidation and colorimetric measurement by atomic adsorption spectrophotometry (ISO, 2016b). Colwell phosphorus (P) was determined by shaking samples for 16 h end-over-end at a 1:20 ratio with deionised water, adjusted to pH 8.5 with 0.5 M sodium hydrogen carbonate; extracts were then filtered and analysed for orthophosphate (Saggar et al., 1999). Soil cation exchange capacity was measured using the unbuffered NH_4Cl extraction method by Sumner and Miller (1996). Exchangeable sodium potential was determined by