Litterbag decomposition and nutrient change study of poultry litter

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Abstract
Quantifying in-situ patterns of poultry litter (PL) mass decomposition and changes over time in NO_3-N, NH_4-N and Colwell P when applied alone or in combination with urea fertiliser helps farmers to synchronise nutrient additions to the soil with crop requirement. Using a buried litterbag technique in the field, decomposition and nutrient changes followed a two-phase pattern suggesting labile and recalcitrant PL components. Twenty-five days after burial (DAB), PL at 10 cm in loam soil contained64% dry matter (DM), 66% NO_3-N, 16% NH_4-N, and 69% Colwell P compared with initial concentrations at burial. After 27 DAB, PL in a clay loam had 73% DM, 8% NH_4-N and 85% Colwell P remaining compared with initial concentrations, with increases of 6 times in NO_3-N. Using an exponential model to estimate PL remaining values from day of burial until final excavation in the loam, it was determined there was 63% DM, 6% NO_3-N, 5% NH_4-N and 55% Colwell P remaining. After another 43 days buried in the clay loam, there was 63% DM and 2% NH_4-N remaining of initial PL values, a 1.2 increase in NO_3-N, while Colwell P had returned to starting levels. The rate of PL-N:urea-N had significant effect on NH_4-N in phase 2, with greater concentration with higher litter ratio. Since only ~5% of starting PL NH_4-N remained at the end of the experimental period on both soil types, the data indicates timely application of PL is required to synchronise any short-term N fertiliser benefit to a developing crop. The free-draining nature of the loam compared with the heavier clay loam are likely to be the main drivers of difference in PL decomposition and nutrient change observed between soil types. The patterns suggest that PL may better fulfil the expectations of a slow release nutrient source in a clay loam than a loam.

Additional keywords: chicken manure, urea, fertiliser, soil texture.

Introduction
Poultry litter (PL) amended to crop land has been shown to have an effect on nutrient cycling (Warn 2014) and soil biophysical properties (Brye *et al.* 2005) which can can result in improved crop performance (Tewolde *et al.* 2010). Synthetic fertilisers applied in combination with PL have in some cases been reported to have a synergistic effect, improving crop performance and minimising unwanted soil P build-up where PL is applied as the sole N source (Tewolde *et al.* 2007). Matching the supply of PL nutrients with crop demand is crucial to optimise its management and develop recommendations for its use in crop nutrition, either solely or in combination with synthetic fertiliser.

Materials and methods
Litter decomposition and nutrient release studies were carried out using a litterbag technique (Al Chami *et al.* 2016) in southern NSW, Australia; at the Centre for Regional and Rural Futures, Hanwood, NSW (34 .19°S; 146.04°E) and at a commercial cotton field at Widgelli, NSW (34.20 °S; 146.1°E). Located only 10 km apart, weather conditions were considered the same and are presented in Figure 1. Both sites have soils classified as Chromosols according to the Australian Soil Classification (Isbell 2002), with the Hanwood site a loam, and the Widgelli site a clay loam. Sites were irrigated every 7–10 days, at which time 70-90 mm was applied.

Poultry litter (excreta, bedding material, feathers and egg shells) was obtained from local intensive chicken layer production sheds. Non-ground PL was inserted in litterbags with 0.5 mm mesh size and were between 156–520 cm^2. Litter properties at time of burial were; 80% dry matter; 90 mg NO_3-N kg^{-1}; 2590 mg NH_4-N kg^{-1}; 7392 mg Colwell P kg^{-1}; 32000 mg labile C kg^{-1}. A total of 288 litterbags (144 at each field site) were filled with three differing combinations of PL-N:urea-N rates of 30:70; 70:30 and 100:0, to achieve a target N rate of 250 kg available N ha^{-1} based on bag area. The PL was spread thinly inside the bag to maximise contact between the incubated material and urea with soil particles outside the bag, and buried to a depth of 10 cm. The litterbags were laid 60 cm apart in a row on a raised bed in an unplanted area of a cotton field in a randomised complete block design. Excavation of the litterbags occurred pre-watering and then 1, 2 and 3 days after watering over a 50 day period in the loam and over a 70 day period in the clay loam.

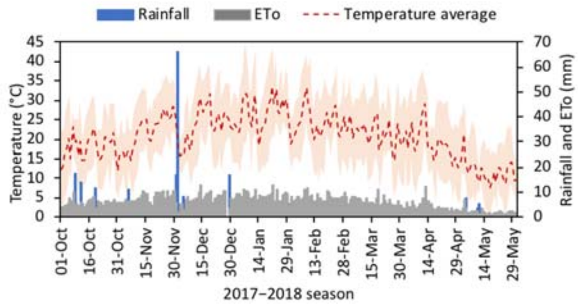

Figure 1. Meteorological conditions the 2017–2018 summer cropping period in Griffith NSW.

Poultry litter remaining dry matter (RDM) and remaining nutrients (RN) at the end of the first 25 days after burial (DAB) in the loam and at 27 DAB in the clay loam (phase 1) was calculated using the percentage change between time of burial and litterbag excavation at 25/27 DAB. This was followed by a slower decomposition process (phase 2) which utilised an exponential model to estimate PL changes in the following 25–43 days. This was calculated using the equation; $RDM\ and\ RN(t)=A_0e^{kt}$. Where A_0 is equal to the RDM or RN value (%) at time zero, *e* is Euler's constant, and *k* is a positive or negative constant that reflects the rate of growth or decay per day, and *t* is time. The **exponential decay** function was used to estimate half-life ($t_{1/2}$), the time until 50% of the compartment is decomposed. Analysis of variation (ANOVA) and post-hoc Tukey Honest Significant Difference tests were conducted using SPSS software (SPSS 24, SPSS Inc., Chicago, USA) using a significance level of 0.05. Where means are referred to the standard error has been provided.

Results

Phase 1 mass decomposition and nutrient changes

Soil type had a significant effect on PL RDM, NO_3-N, NH_4-N and Colwell P concentrations during phase 1, and a fertiliser treatment effect was observed on PL RDM. In the loam, the mean reduction in PL DM mass in the first 25 DAB across all treatments was 36.3 ± 2.4%, compared with a 27.3 ± 1.2% reduction of DM mass in the first 27 DAB in the clay loam (Table 1). The 30:70 treatment had greatest RDM (71.8 ± 2.3% in the loam and 76.1 ± 0.5% on the clay loam), significantly higher than both 70:30 and 100:0 treatments. Initial PL NO_3-N concentration at burial decreased from 90 mg kg^{-1} to 63 ± 29.1 mg kg^{-1} in the loam and increased to 549 ± 80.1 mg kg^{-1} in the clay loam. This equated to 66.2 ± 37.2% PL NO_3-N remaining in the loam, and 6 times the starting level in the clay loam (Table 1). Ammonium-N concentrations in the litterbag PL contents reduced in both soil types and all treatments from an initial concentration of 2590 mg kg^{-1} to 411.7 ± 44.3 mg kg^{-1} between 0–25 DAB in the loam, and to 195.2 ± 22.7 mg kg^{-1} between 0–27 DAB in the clay loam. There was 16 ± 1.7% of the initial PL NH_4-N remaining after 25 DAB in the loam, and only 8 ± 0.9% NH_4-N remaining after 27 DAB in the clay loam (Table 1). There was 19% greater PL Colwell P concentration remaining in the clay loam than the loam litterbags. In the loam, there was 69.1 ± 10.8% PL Colwell P remaining of initial concentrations, and 85.2 PL Colwell P 3.8% in the clay loam (Table 1).

Phase 2 mass decomposition and nutrient changes

Soil type had a significant effect on PL NO_3-N, NH_4-N and Colwell P at phase 2 final observations, and there was a fertiliser treatment effect on PL RDM and NH_4-N. Using the exponential model, there was a relatively strong relationship for the PL DM decomposition in the loam for the 100:0 treatment (R^2=0.4, P=0.022) and in the clay loam for the 70:30 (R^2=0.8, P<0.001) and 100:0 (R^2=0.5, P=0.009) treatments (Table 1). There was 58% of the initial PL DM remaining in the 100:0 treatment in the loam 50 DAB, and 61% and 63% PL DM remaining in the higher PL combinations (70:30 and 100:0) treatments respectively in the clay loam 70 DAB. At the end of the phase 2 observation period, treatment differences over both soil types were significant (p<0.001), with the 70:30 treatment having significantly less RDM (7.11 ± 0.3 g) compared with the 100:0 (9.9 ± 0.3g) and 30:70 (11.3 ± 0.7g) treatments.

The relationship for PL NO_3-N concentration changes in treatments during the second observation period in the loam were weak (R^2<0.2, p>0.05), unlike the clay loam (R_2>0.6, p<0.01) (Table 1). At the end of the second observation period there was a mean of 119.7 ± 14.9 mg kg^{-1} more PL NO_3-N measured in the samples buried in the clay loam than in the loam (p≤0.001). Poultry litter NH_4-N declined exponentially in both soil types with R^2 values of >0.5 in the loam and >0.8 in the clay loam (Table 1). There was 43% PL NH_4-N remaining in the loam and 27% PL NH_4-N remaining in the clay loam after 50/70 DAB compared with the starting phase 2 concentrations (at 25/27 DAB). Combining soil types, the 30:70 treatment had significantly less remaining PL NH_4-N compared with the 100:0 treatment at final extraction (2.7% versus 4.2% respectively) with the 70:30 treatment not significantly different to either.

Over the period from 25–50 DAB in the loam and 27–70 DAB in the clay loam, PL Colwell P remained relatively constant with no significant regression relationship ($R^2 \leq 0.2$; $p>0.05$, Table 1). From the start of phase 2 period to final extraction, PL Colwell P in litterbags in the loam had increased by 1.2 ± 2.1% and by 10 ± 3.2% in the clay loam. At final excavation, there was 47% greater Colwell P concentration in litterbags averaged by treatment retrieved from the clay loam compared with the loam ($p<0.001$).

Table 1. Remaining dry matter (%, mean ± SE, n=4) and NO_3-N, NH_4-N and Colwell P (%, mean ± SE, n=four) in the poultry litter at the end of phase 1 observation period (0 DAB–25/27 DAB), and at the end of phase 2 (50/70 DAB) compared with initial values with half-life ($t_{1/2}$).

	PL-N: urea-N (%)	Loam			Clay loam		
		Remaining at 25 DAB compared with 0 DAB	Remaining at 50 DAB compared with 25 DAB	t1/2 days	Remaining at 27 DAB compared with 0 DAB	Remaining at 70 DAB compared with 27 DAB	t1/2 days
Dry matter	30:70	71.8	70.8	173	76.1	65.6	693
	70:30	61.7	60.5	231	71.9	60.8	231
	100:0	57.1	58.3	99	70.6	62.7	347
NO_3-N	30:70	20.3	11.5	#	729.5	117.3	20
	70:30	43.5	4.3	30	663.3	109.2	21
	100:0	134.8	2.5	12	436.3	141.4	23
NH_4-N	30:70	15.1	4.2	15	6.1	1.2	21
	70:30	15.8	5.1	18	8.7	2.4	28
	100:0	16.7	6.7	18	7.8	1.7	20
Colwell P	30:70	59.6	53.5	#	77.1	91.8	#
	70:30	74.1	50.3	#	99	109.7	#
	100:0	73.6	59.8	693	79.6	107.5	#

 # Half-life cannot be estimated due to growth phase.

Discussion and conclusion

The decomposition and nutrient release from PL buried in litterbags alone and in combination with urea occurred as a two-phase process. Decomposition in the initial period of burial was rapid, likely due to mass loss and a rapid increase in the soil microbial population soon after application (Pitta *et al.* 2012). This was followed by a slower decomposition phase of DM and mineral-N possibly caused by recalcitrant components remaining, attributed to substrate resistance to most forms of microbial attack. Since commercial broadacre farmers typically apply PL to fields in Autumn to early winter at rates of 4–5 t ha^{-1}, the data indicate that in both soil types approximately 30–40 % of the physical material had been lost within 2–3 months of application. However, the $t_{1/2}$ calculated from the exponential decay curves of the recalcitrant component indicated that a % of dry mass of the 100:0 amendment would last in the loam for 99 days, which was approximately one third that in the clay loam $t_{1/2}$=347 days. The results indicate that applying PL DM at a rate of 10 t ha^{-1} (with no synthetic N addition) on an annual basis to clay loam soil would likely lead to a slow build-up of residue. The rate of DM decomposition was significantly lower when applied in a 70:30 PL-N:urea-N ratio. This knowledge may benefit crop growers looking to increase soil organic matter.

Nitrate associated with the PL buried in the loam soil initially increased in the 100:0 treatment (though not other treatments) and then diminished to minor amounts by the end of the 50 day period. In the clay loam, PL NO_3-N increased corresponding to substantial declines in NH_4-N reflecting in-situ nitrification processes. The patterns suggest that PL may better fulfil the expectations of a slow release source of nutrients in a clay loam than a loam. We consider that differences observed in the two soil textures were likely caused by lower clay content and greater water infiltration of the loam soil type compared with the clay loam. Since only ~5%

of starting PL NH_4-N remained at the end of the experimental period on both soil types, the data indicates timely application of PL is required to synchronise any short-term N fertiliser benefit to a developing crop. A significant ($p=0.01$) fertiliser effect indicated 100:0 application results in 50% greater NH_4-N compared with 30:70 after 2–3 months. The maintenance of Colwell P in PL over the 50–70 day burial period and extended $t_{1/2}$ suggests that PL may be able to replace synthetic P fertilizer in irrigated summer crops in southern NSW whilst being mindful of P nutrient build-up. The litterbag technique offers a useful method to investigate PL decomposition and nutrient changes, however to further substantiate pedo-climatic effects future experiments require longer-term observations and replication over consecutive growing seasons.

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