The nutritional value of manures and other organic phosphorus sources and uptake over time

Tim McLaren[1,2], Mike Bell[2], Swarna Shome[1], Maurie Street[3], Ben O'Brien[3] & Peter Kopittke[1]*

[1] School of Agriculture and Food Sustainability, The University of Queensland, St Lucia QLD 4072
[2] School of Agriculture and Food Sustainability, The University of Queensland, Gatton QLD 4343
[3] Grain Orana Alliance, Dubbo NSW 2830

Keywords
chicken manure, crop production, organic amendment, P speciation, soil P

GRDC code
UOQ2203-006RTX

Take home message
- A large proportion of the total phosphorus (P) in livestock manure exists in inorganic forms (on average 78%), and this proportion tends to increase with drying/processing/storage
- Overall, crop responses to P from chicken manure were similar to that of MAP when all other nutrients were non-limiting across multiple years
- In general, the fate of P from chicken manure in soil was similar to that of MAP over time, which largely accumulated in the 0–10 cm soil layer as inorganic P (e.g., pools of sorbed P)
- Crop recovery of 'fresh' MAP in the year of application was higher for canola (40%) compared to wheat (32%), and similar across fertiliser type and rate
- Chicken manure was shown to be an economic type of fertiliser P if acquired relatively close to the source.

Background
Crop production in the grain growing regions of Australia is often limited due to low concentrations of soil phosphorus (P) fertility. The addition of mineral-based fertilisers, such as monoammonium phosphate (MAP), has been an important strategy to increase soil P fertility and reduce the likelihood of a crop P deficiency. Mineral-based fertilisers are primarily derived from naturally occurring phosphate rock, which is a non-renewable resource and predominantly located in geopolitically unstable regions of the world. Consequently, the cost of mineral-based fertilisers is predicted to rise and become increasingly volatile in the future. It is essential that alternative sources of P are investigated, such as the use of organic amendments (e.g., livestock manure), that could be used to meet crop P demand and/or supplement mineral-based fertiliser inputs.

In Australia, it is estimated that around 635 kt of P as livestock manure is produced annually (Cordell et al., 2013). Intensive livestock enterprises (e.g., cattle feedlots, piggeries, and poultry sheds) have the potential to offset a significant portion of crop P requirements that are currently being met by mineral-based fertilisers. However, there is a lack of understanding on the forms of P present in livestock manures, and their fate in soil to improve soil P fertility and meet crop P demand.

In general, concentrations of total P in livestock manure tend to be much lower (i.e., 0.2-3.0 %) than that of mineral-based fertilisers (8-23 %). The forms of P in livestock manure could either be ‘organic’, i.e., associated with carbon (e.g., phytate), or ‘inorganic’, i.e., associated with a cation (e.g., calcium phosphate). Studies outside Australia show that a large portion of the P in livestock manure is that of inorganic forms, but chicken manure can contain a higher proportion of its total P as organic forms (largely as phytate). However, the proportion of inorganic to organic P in livestock manure is highly variable and can depend on the type of animal, its diet, and the processing/storage of manure. The significance of this is that the predominant forms of P in livestock manure are likely to affect its fate in soil and bioavailability.

The aims of this research were to:

1. Assess the forms of P in a variety of livestock manures sourced from eastern Australia (Experiment 1).
2. Determine the crop responses to increasing rates of fertiliser P supplied as either chicken manure or MAP under field conditions (Experiment 2).
3. Assess the fate of fertiliser P in soil supplied as either chicken manure or MAP (Experiment 3).
4. Determine the crop recovery of a ‘fresh’ addition of MAP in the year of application to soils that had been previously fertilised with either chicken manure or MAP under field conditions (Experiment 4).

Materials and methods

Experimental design 1

A total of 24 livestock manure samples were collected from a diversity of locations across NSW and QLD. This included poultry layers, broiler chickens, beef feedlots, pasture raised beef, dairy cattle, and piggeries. Samples were collected fresh/moist and stored at 4 °C. A subsample of each manure was dried and then ground prior to chemical analysis. A variety of nutrients were measured in each manure sample and the chemical forms of organic P determined from NaOH-EDTA extracts using nuclear magnetic resonance (NMR).

Experimental design 2

In 2022, two field experiments were established near Wongarbon (NSW) and a winter crop grown in 2022, 2023, and 2024 (Figure 1). Each plot was 12 m × 2 m and arranged in a randomised complete block design with four replicates. Treatments included eight fertiliser rates (0, 5, 10, 15, 30, 50, 70, and 90 kg P ha^{-1}) and two fertiliser types (chicken manure and MAP). Fertiliser was spread on the surface and then incorporated using offsets to a depth of about 10 cm. The first field experiment included a wheat (2022)/canola (2023)/wheat (2024) rotation, and the second field experiment included a canola (2022)/wheat (2023)/canola (2024) rotation. The chicken manure and MAP treatments were only applied in 2022, and in subsequent years all plots received 5 kg P ha^{-1} as MAP at planting. Basal additions of nitrogen (N), potassium (K), sulfur (S), and micronutrients were applied throughout the duration of the field experiment when needed.

The topsoil (0-10 cm) had a clay loam texture with a pH (1:5 in H_2O) of 5.7, an initial concentration of Colwell-P of 19 mg kg^{-1}, and an initial PBI value of 62. The average rainfall at this site is about 610 mm yr^{-1}, but the 2022 growing season was well above average, the 2023 growing season was well below average, and the 2024 growing season was closer to the long-term average. The chicken manure was sourced from a poultry shed near Temora, NSW (Figure

1), and had a gravimetric water content at sample collection of 44%, and a concentration of total P and N on a dry-weight basis of 1.8% and 5.5%, respectively.

Figure 1. A subsample of the chicken manure used in this study (left) and the two field experiments located near Wongarbon, NSW (right).

Crop yield was measured each growing season and the grain/seed analysed for total concentrations of various nutrients. Data from the 2024 growing season is still being analysed. Crop P offtake was determined for each growing season and the cumulative P offtake determined for each field site (results for 2022 and 2023 presented below).

Experimental design 3

Soil samples were collected from the 0–10 cm and 10–30 cm layers of the aforementioned field experiments (Experimental design 2), at the beginning of the growing season in 2022. Further soil sampling and testing was carried out in 2023 and 2024. All soil samples were dried and ground prior to chemical analysis. Soil samples were analysed for a diversity of soil P pools (e.g., Colwell P).

Experimental design 4

In 2024, a field 'microplot' experiment was established at the aforementioned field experiments (Experimental design 2) on a subset of treatments (i.e., 0, 30, and 90 kg P ha^{-1} rates, both cropping rotations, and the chicken manure and MAP plots). Three of the four field replicates were chosen and each experimental plot contained two microplots.

Analytical grade MAP solution was labelled with a carrier-free P-33 radionuclide to supply about 13 kg P ha^{-1}. Briefly, a 30 cm long microplot was identified just after germination where there was a consistent plant stand along the row (Figure 2). The labelled MAP solution was added by inserting a total of eight (9 mm diam.) tubes with a removeable rod insert within a defined length of 30 cm and about 2 – 3 cm from the planting row to a depth of ~8 cm below the soil surface as a 'band'. The rod insert was removed and the radiolabelled solution injected into each tube, which was rinsed with H_2O and allowed to diffuse into the soil. The tubes were then removed, and the hole backfilled with topsoil.

Aboveground biomass of wheat within the microplots (and adjacent buffer zones) was harvested at 124 DAS, whereas that of canola was harvested at 132 DAS. Aboveground biomass was dried and ground prior to chemical analysis.

Figure 2. Example of a 30 cm microplot where P-33 labelled MAP solution was injected as a 'band' about 8 cm below the soil surface to supply 13 kg P ha^{-1} (left) and an example of the harvested crop within the microplot (pink) and an adjacent buffer zone (blue) taken 111 days after fertiliser application (right).

Results

Concentrations and forms of P in livestock manure

Concentrations of total P in livestock manure differed greatly between and within types ranging from 0.3–3.4% P across all samples (Table 1). In general, pig manure had the highest concentration of total P (average 2.4% P) followed by chicken manure (average 1.6% P), and beef/dairy manure (average ~0.75% P). The largest variability in concentrations of total P was found in chicken manure (0.8–2.6% P) and pig manure (1.9–3.4% P). The majority of P in fresh/moist manures was present as inorganic forms (average 78% of total P), which generally increased after drying (85 % of total P). The predominant form of organic P that could be identified was phytate or RNA mononucleotides.

Table 1. Average concentration of total P in fresh/moist and dry livestock manure, and the proportion of inorganic and organic P in NaOH-EDTA extracts. CM = chicken manure, BM = beef cattle manure, DM = dairy cattle manure, and PM = pig manure. The number of manure samples within each type is provided (n). Values in parentheses are standard errors.

Manure	**Fresh manure**			**Dry manure**		
	Total P (g P kg^{-1})	Inorganic P (%)	Organic P (%)	Total P (g P kg^{-1})	Inorganic P (%)	Organic P (%)
CM (n=9)	15.6 (1.6)	77 (3)	23 (3)	11.2 (0.7)	82 (3)	18 (3)
BM (n=8)	6.5 (0.5)	75 (4)	25 (4)	5.7 (0.7)	86 (3)	14 (3)
DM (n=3)	7.7 (0.9)	86 (4)	14 (4)	7.6 (1.1)	92 (3)	8 (3)
PM (n=4)	23.6 (3.5)	80 (5)	20 (5)	19.8 (1.8)	85 (5)	15 (5)

Crop responses to the addition of chicken manure and MAP with increasing rate over time

Overall, canola seed yield was relatively high ranging from 2.7–4.0 t ha^{-1} and very high for wheat grain yield ranging from 6.7–8.0 t ha^{-1} in 2022, which increased with the addition of fertiliser P (Figure 3). Crop yield for both crops was lower in 2023 compared to 2022, but there was still an additional 0.8 t ha^{-1} of canola seed yield and 0.6 t ha^{-1} of wheat grain yield at the highest rates of fertiliser P compared to the non-fertilised treatment in 2023. Nevertheless, crop yields were generally similar between the chicken manure and MAP treatments.

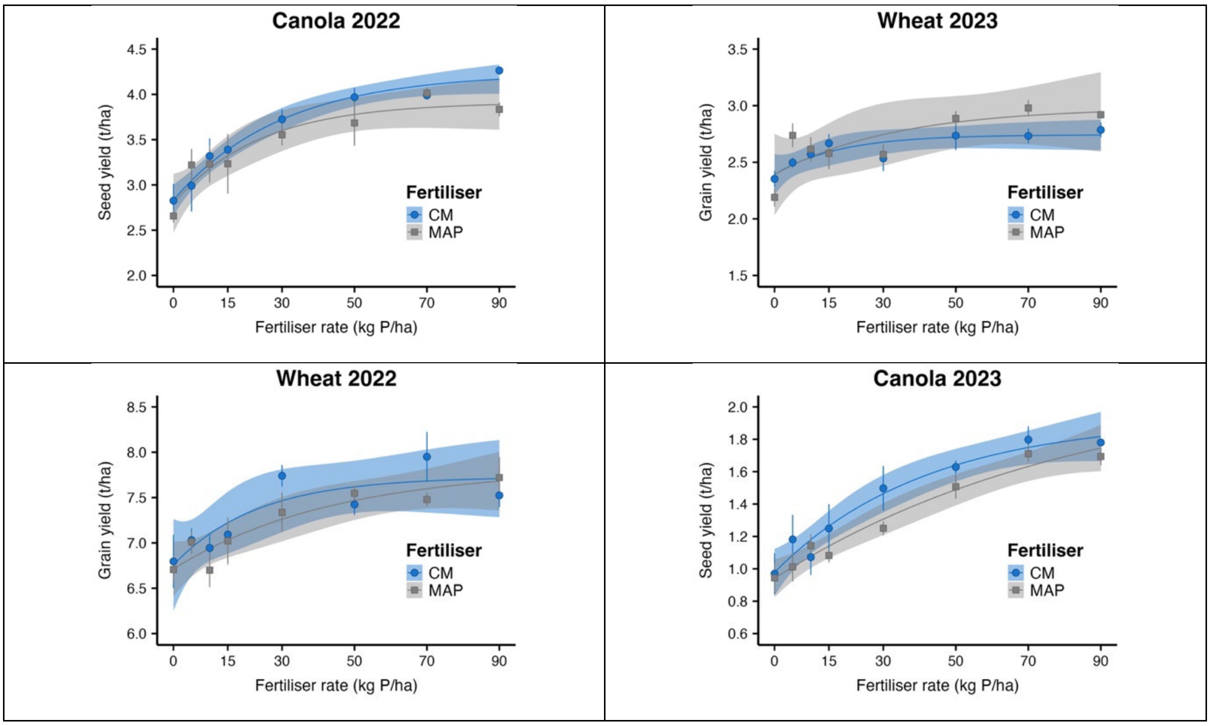

Figure 3. The seed/grain yield for the canola (2022)/wheat (2023) rotation (top) and the wheat (2022)/canola (2023) rotation (bottom). Fertiliser treatments include type (chicken manure and MAP) and rate (0, 5, 10, 15, 30, 50, 70, and 90 kg P ha^{-1}), which was applied in 2022.

Figure 4 shows the cumulative crop P offtake for the different crop rotations across the 2022 and 2023 growing seasons with increasing addition of fertiliser P. Cumulative crop P offtake increased with the addition of fertiliser P, but there was no significant difference between the chicken manure and MAP treatments. Therefore, it appears that crops were accessing similar amounts of P from both P sources at this site.

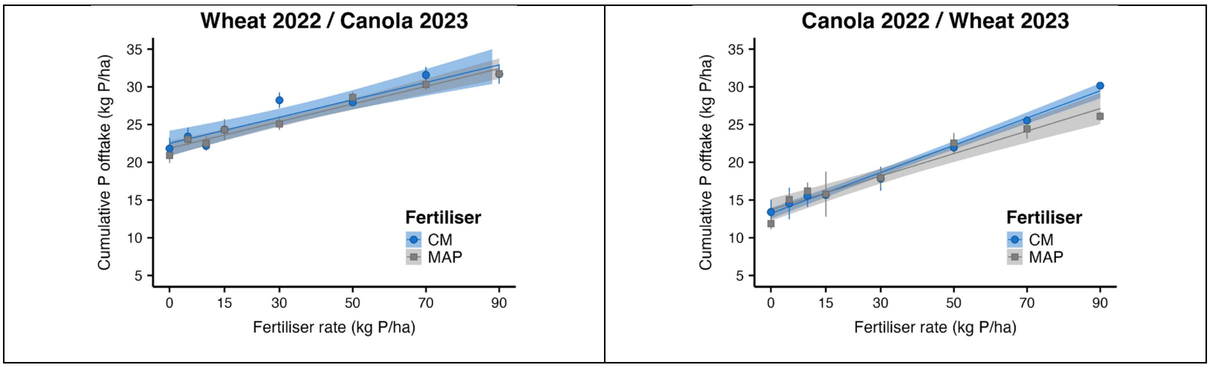

Figure 4. The cumulative P offtake for the wheat (2022)/canola (2023) rotation (left) and the canola (2022)/wheat (2023) rotation (right). Fertiliser treatments include type (chicken manure and MAP) and rate (0, 5, 10, 15, 30, 50, 70, and 90 kg P ha^{-1}), which was applied in 2022.

The fate of P from chicken manure and MAP in soil over time

In general, concentrations of plant-available P (Colwell-P) in the 0–10 cm soil layer increased with the addition of fertiliser P for both the chicken manure and MAP treatments, which ranged from 25 to 60 mg P kg^{-1} in 2022 (Figure 5). Concentrations of Colwell-P were typically higher in the MAP treatments compared to the chicken manure treatments at the highest fertiliser rates. Furthermore, concentrations of Colwell-P in the 0–10 cm soil layer generally decreased over time in fertilised soil (i.e., for both chicken manure and MAP), which ranged from 20 to 40 mg P kg^{-1} in 2024. Concentrations of Colwell-P in the 10–30 cm soil layer were consistently low (5–10 mg P kg^{-1}) over time and did not increase with the addition of fertiliser P (data not shown).

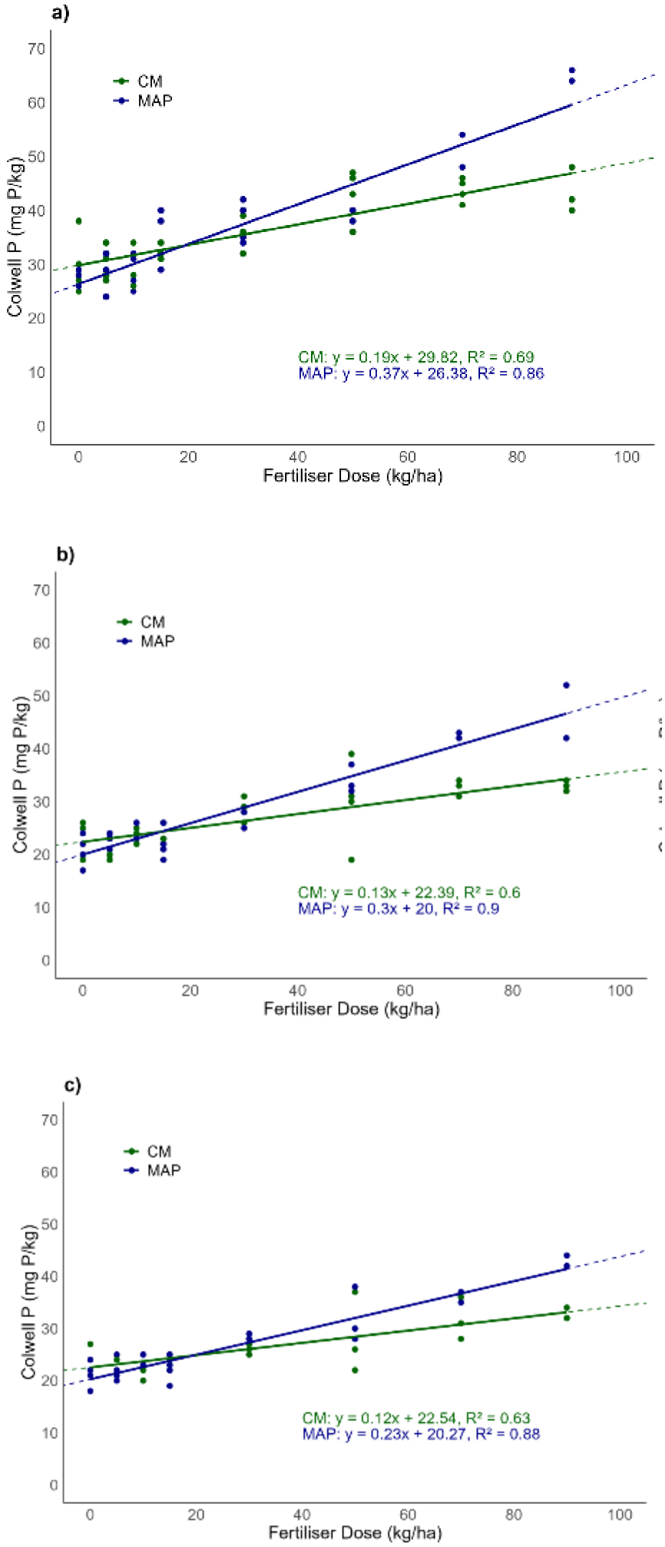

Figure 5. Relationship between the concentration of Colwell-P in the topsoil (0–10 cm layer) and fertiliser P rate for chicken manure and MAP after (a) 1 month (b) 12 months and (c) 24 months since application in 2022. Data from the wheat (2022)/canola (2023)/wheat (2024) rotation is shown.

In general, concentrations of extractable inorganic P in the 0–10 cm soil layer increased with the addition of fertiliser P for both the chicken manure and MAP treatments ranging from about 75 to 145 mg P kg^{-1} in 2022 (Figure 6). There was no difference in the concentration of extractable inorganic P between the chicken manure and MAP treatments across all growing seasons. Furthermore, concentrations of extractable organic P in the 0–10 cm soil layer remained unchanged with the addition of fertiliser P, but did tend to decrease overall by about 15 mg P kg^{-1} after each growing season (data not shown).

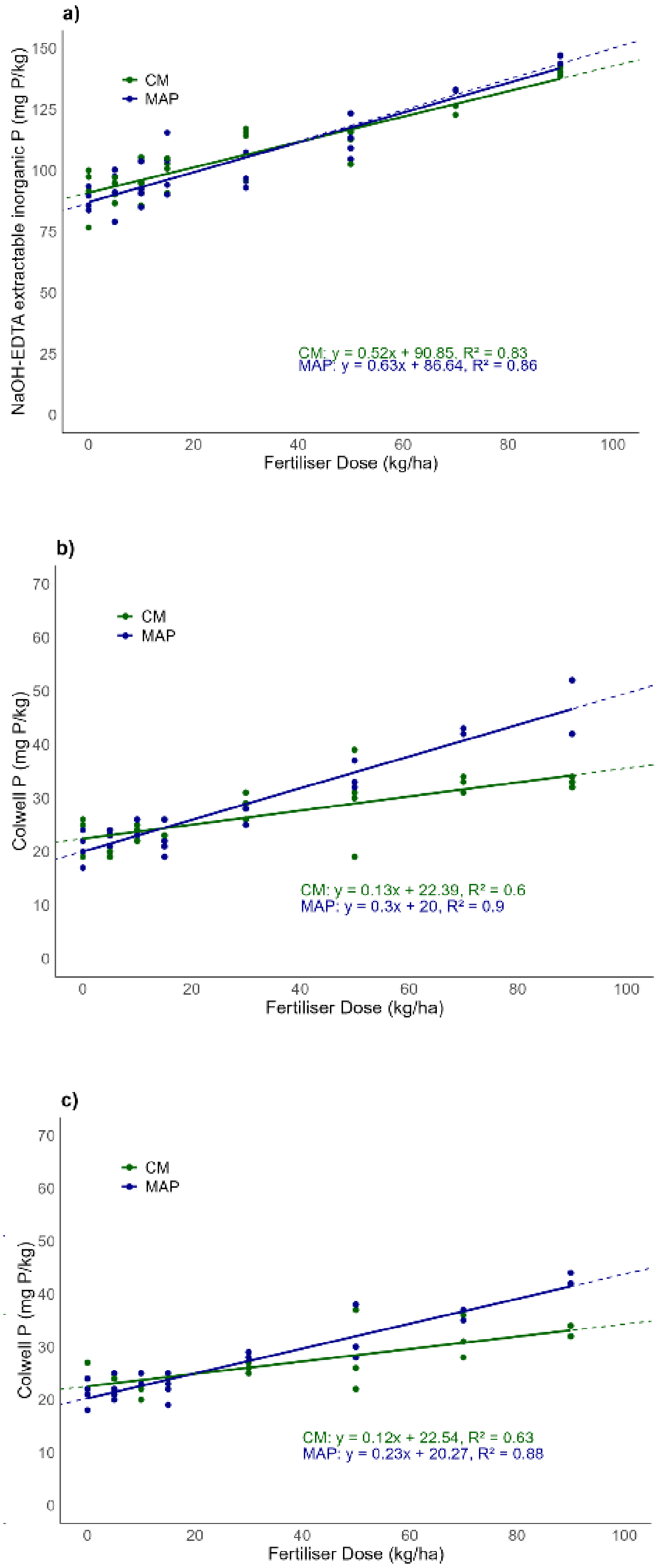

Figure 6. Relationship between the concentration of inorganic P in the topsoil (0–10 cm layer) and fertiliser rate for chicken manure and MAP after (a) 1 month (b) 12 months and (c) 24 months since application in 2022. Data from the wheat (2022)/canola (2023)/wheat (2024) rotation is shown.

A relatively large portion of the added fertiliser P (chicken manure and MAP) appears to be recovered in the 0–10 cm soil layer after application in 2022, and most of the P in fertilised soil accumulates in the sorbed P pool (i.e., orthophosphate associated with clay mineral surfaces), which becomes less plant-available over time. This was the case for both the chicken manure and MAP treatments.

Crop recovery of 'fresh' MAP in the year of application on previously fertilised plots

In general, crop responses to the addition of 'fresh' MAP in 2024 were largely consistent among treatments that had received fertiliser P as either chicken manure or MAP in 2022 (Table 2). However, crop responses tended to be higher in the 90 kg P ha^{-1} fertilised plots compared to the non-fertilised plots. Overall, crop responses were more variable for canola compared to wheat.

Table 2. Crop responses to the addition of 'fresh' MAP that had been radiolabelled with P-33 and applied in 2024 in two different crop rotations. A subset of treatments from Experimental design 2 (see Materials and methods), which included field plots that had originally received fertiliser P in 2022 as chicken manure or MAP at 0, 30, or 90 kg P ha^{-1}. Values in parentheses are standard errors. Pdff = proportion of crop P uptake derived from the 'fresh' MAP added. Pdfs = proportion of crop P uptake derived from the soil. Fertiliser recovery refers to the percentage of applied fertiliser (i.e., 'fresh' MAP) that was recovered in the aboveground biomass of either wheat or canola in 2024.

Crop type	**Treatment field plot established in 2022**	**Treatment microplot with 'fresh' MAP added in 2024 (kg P ha^{-1})**	**Dry matter (g $microplot^{-1}$)**	**Crop P uptake (mg P $microplot^{-1}$)**	**Pdfs (%)**	**Pdff (%)**	**Fertiliser ('fresh' MAP) recovery (% applied)**
Wheat (2024)	Control (0 kg P ha^{-1})	13	67.2 (4.8)	95.1 (7.4)	68.7 (1.6)	31.3 (1.6)	29.5 (1.3)
	MAP (30 kg P ha^{-1})	13	68.4 (3.0)	105.3 (8.9)	68.2 (1.5)	31.8 (1.5)	33.2 (1.3)
	MAP (90 kg P ha^{-1})	13	76.9 (4.3)	127.7 (6.4)	73.9 (1.9)	26.1 (1.9)	33.4 (2.0)
	CM (30 kg P ha^{-1})	13	74.4 (6.5)	120.0 (7.2)	73.6 (1.8)	26.4 (1.8)	32.0 (2.8)
	CM (90 kg P ha^{-1})	13	71.3 (3.8)	127.6 (11.0)	75.5 (1.9)	24.5 (1.9)	30.6 (0.7)
Canola (2024)	Control (0 kg P ha^{-1})	13	140.2 (12.4)	224.4 (30.7)	79.3 (2.8)	20.7 (2.8)	43.6 (1.5)
	MAP (30 kg P ha^{-1})	13	158.6 (20.0)	273.9 (44.6)	84.8 (2.4)	15.2 (2.4)	38.0 (3.0)
	MAP (90 kg P ha^{-1})	13	145.2 (24.6)	302.7 (55.3)	84.7 (2.7)	15.3 (2.7)	41.0 (1.5)
	CM (30 kg P ha^{-1})	13	113.9 (13.8)	182.9 (25.2)	78.1 (3.0)	21.9 (3.0)	37.1 (2.0)
	CM (90 kg P ha^{-1})	13	133.6 (11.9)	261.5 (39.8)	82.7 (2.4)	17.3 (2.4)	42.6 (3.0)

The proportion of crop P uptake that was derived from the added fresh MAP (Pdff %) tended to be higher in the non-fertilised plots (31% for wheat and 21% for canola) compared to the 90 kg P ha^{-1} plots (on average 25 % for wheat and 16 % for canola). Therefore, pools of soil P were the most important source of P for crop growth (on average 72% for wheat and 82% for canola). Crop recovery of fresh MAP in the year of application was around 32% for wheat and 40% for canola and was similar among treatments based on previous additions of fertiliser type and rate.

Economics of chicken manure vs MAP

An economic analysis was carried out based on information provided from the aforementioned field experiments, in consultation with primary producers, and a chicken manure supplier. Two scenarios were investigated, including one where only P was considered, and the other where P and N was taken into account to balance the N added in the chicken manure. Furthermore, since the application of chicken manure is typically applied at a high rate once every 4–5 years, a target rate of 50 kg P ha^{-1} was used for calculations. The distance from the source for chicken manure is also an important consideration, and here we assume that a farm was located within 50 km from the source.

A target P input of 50 kg P ha^{-1} would require 2.85 t ha^{-1} of chicken manure (dry-weight basis). This equates to 5.07 m^{3} ha^{-1} of chicken manure (wet-weight basis). The cost of chicken manure (wet-weight basis) supplied and delivered to the farm is estimated at \$27 m^{-3} within a 50 km radius of the of chicken manure. The application of chicken manure to the field is estimated at \$7 m^{-3}, which equates to a cost of \$35.52 ha^{-1}. Therefore, the overall cost is \$172.50 ha^{-1} or \$3.45 kg^{-1} P. A target P input of 50 kg P ha^{-1} would require 225.86 kg ha^{-1} of MAP. The cost of MAP supplied and delivered to the farm is estimated at \$1200 t^{-1}. The application of MAP to the field as a broadcast is estimated at \$10 ha^{-1}. Therefore, the overall cost is \$281.03 ha^{-1} or \$5.62 kg^{-1} P.

The most economic option of supplying P to the field appears to be chicken manure under the aforementioned conditions. Indeed, the cost of chicken manure (wet-weight basis) supplied and delivered to the farm would need to increase to \$48.39 m^{-3} to be similar to the overall cost of MAP. Alternatively, if the cost of MAP decreased to \$719.50 t^{-1} then the overall cost would approximate that of chicken manure. Furthermore, distances greater than 50 km from the source would also significantly increase the overall cost of chicken manure.

The addition of N in the CM was also taken into consideration. At a target P input of 50 kg P ha^{-1} chicken manure and MAP would also provide 157.45 kg N ha^{-1} and 23.63 kg N ha^{-1}, respectively. Therefore, an additional 133.83 kg N ha^{-1} is required to supplement the N in the MAP and balance the N added in the chicken manure. If the additional N was added as urea, then 290.93 kg ha^{-1} of urea would be required. The cost of urea supplied and delivered to the farm is estimated at \$850 t^{-1}. The application of urea to the field as a broadcast is estimated at \$30 ha^{-1} (i.e., \$10 ha^{-1} x three passes). Therefore, the overall cost for MAP (and urea) is \$558.31 ha^{-1} or \$11.17 kg^{-1} P.

In 2022, the addition of fertiliser P (and basal nutrients) resulted in about 1.09 t ha^{-1} extra wheat grain yield and 1.26 t ha^{-1} canola seed yield compared to the non-fertilised control. In 2023, there was about 0.59 t ha^{-1} extra wheat grain yield and 0.80 t ha^{-1} canola seed yield compared to the non-fertilised control. Therefore, the addition of fertiliser P resulted in an extra 1.68 t ha^{-1} of wheat grain yield and 2.06 tha^{-1} of canola seed yield across the two years.

Assuming a price of \$350 t^{-1} for wheat and \$550 t^{-1} for canola, the additional yield alone would result in an increased return of \$588 ha^{-1} and \$1133 ha^{-1} for wheat and canola, respectively. The return on the extra yield alone is considerably more than the overall cost of chicken manure, and still more than the overall cost of MAP (and urea). Further research is needed to better understand crop responses to the residual value of fertiliser P (animal manures and mineral-based fertiliser) over longer timeframes. For the latter, this is being investigated as part of GRDC investment UOQ2303-005RTX.

Conclusion

Mineral-based fertilisers (e.g., MAP) are an important source of P for crop production in Australia. However, prices for mineral-based fertiliser P are forecast to rise and price volatility is expected to increase in the future. Livestock manure is an alternative source of P that has the potential to significantly offset the input of mineral-based fertiliser in some regions. Overall, concentration of total P in livestock manure can vary considerably and is typically much lower than that of mineral-based fertilisers. The majority of P in livestock manure is that of inorganic forms, which appears to be readily soluble.

Crop responses increased with the addition of fertiliser P across multiple years, with little difference between chicken manure and MAP. This suggests that chicken manure can be used to offset P inputs from mineral-based fertilisers with similar results in crop yield, providing that other nutrients are non-limiting. Furthermore, grain growers can more directly compare the cost of using chicken manure to that of MAP on a P-basis. Finally, the residual value of chicken manure appears to be similar to that of MAP, with crop recoveries of 'fresh' additions of MAP being similar in the year of application regardless of fertiliser history at this site.

Acknowledgements

The authors greatly appreciate the significant contributions made by grain growers, livestock animal producers, and the Grain Orana Alliance. We also acknowledge the financial support of the GRDC (Project code: UOQ2203-006RTX), and The University of Queensland.

Contact details

Tim McLaren
School of Agriculture and Food Sustainability
The University of Queensland
St Lucia 4072 QLD
Email: tim.mclaren@uq.edu.au
Ph: 0403 961 012

Date published

February 2025