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Midseason application of organic fertilizer improves yield and nitrogen uptake in rice

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Abstract

Organic rice (*Oryza sativa* L.) systems in California utilize a 30-d drain approximately one month into the growing season to control weeds. This drain may result in N losses and reduce yields. Two field trials were initiated to evaluate whether top-dressing fertilizer N following the drain period could mitigate this problem by increasing N uptake and yields. Treatments evaluated rates and sources of commercially available organic fertilizers varying in N content and C to N ratio. The six treatments were a control with no top-dress fertilizer, and top-dress applications of 12–3–0 (applied at 22, 45, and 67 kg N ha^{-1}) and 6–3–2 and 4–1–4 applied at 45 kg N ha^{-1}. Total plant N uptake at harvest increased linearly with increasing N rate at both locations. At both sites, grain yields increased linearly (by 15 to 22 kg ha^{-1} for every kg N ha^{-1} applied) up to 45 kg N ha^{-1} above which yields plateaued at one site but continued to increase linearly at the other site. Application of 12–3–0 increased yields relative to the control at both locations but yields were not significantly different between the three fertilizer sources at the 45 kg N ha^{-1} rate at either location. Total plant N uptake and N recovery were higher in the 12–3–0 treatment compared to the other fertilizer sources at only one location. An economic analysis indicates that at the yield responses reported here, top-dress N fertilizer applications were economical.

1 | INTRODUCTION

Rice is the highest-yielding crop among the organic cereals and can be very profitable for growers (Delmotte, Tittonell, Mouret, Hammond, & Lopez-Ridaura, 2011; Hazra, 2018), achieving up to 94% of the yield of its conventional counterparts (de Ponti, Rijk, & Van Ittersum, 2012). However, as with all organic crops, weed competition is one of the major yield-limiting factors (Delmotte et al., 2011) and often takes precedence over other management considerations. For example, in California, rice is typically grown in a water-seeded system in which land is prepared, fertilizer applied, the field is flooded and then seed is planted aerially. In conventional systems the field remains flooded for the duration of the season; however, in organic systems a common method for weed control is to drain the field roughly 30 d after sowing (DAS) and let the field dry out for approximately 30 d to kill aquatic weeds through drought stress (Sullivan, 2003). Although this water management practice is effective at reducing weed pressure, it reduces crop yields as rice, which is sensitive to dry soil conditions (Bouman & Tuong, 2001; Carrijo, Lundy, & Linquist, 2017), also undergoes drought stress during this period.

In conventional systems, which remain flooded during the season, it is often recommended to apply all the nitrogen (N) fertilizer at planting but assess the crop nutrient status midseason to determine whether a top-dress application is necessary (Linquist et al., 2009; UC ANR, 2018). This practice is efficient as the flooded system ensures that the soil remains anaerobic, and this protects N from denitrification (Buresh, Reddy, & van Kessel, 2008) until it is needed by the growing

Abbreviations: DAS, days after sowing; LSD, Protected Least Significance Difference test; NRE, nitrogen recovery efficiency.

crop. The majority of fertilizer-N is taken up between 25 and 45 DAS (LaHue, Chaney, Adviento-Borbe, & Linquist, 2016) and is utilized for production of dry matter during the reproductive growth stages (Sims & Place, 1968) beginning at 45 to 55 DAS when panicle initiation occurs.

In organic systems, the 30-d weed control drain complicates N management. Typically, organic rice growers apply manure before planting and may decide to add a top-dress of organic fertilizer-N at the end of the drain period, that is, just before reflooding. Previous research indicated that the application of preplant organic manure or fertilizers was effective at increasing yields by 2500 kg ha^{-1} on average across fertilizer types, with and without weed control drains (Wild, van Kessel, Lundbergand, & Linquist, 2011). However, they also found that most of the fertilizer-N taken up by the rice occurred during the first 53 DAS, with relatively little fertilizer-N uptake after that. When comparing organic fields with and without weed control drains, Wild et al. (2011) found that in the drained fields the yield response to preplant organic fertilizer (average 1400 kg ha^{-1} increase across fertilizer types) and nitrogen recover efficiency (NRE) was lower than fields without a drain. They speculated that one reason for the lower NRE in the drained field was the loss of N resulting from nitrification during drying and denitrification on reflooding (Buresh et al., 2008).

Given that most fertilizer N was taken up within 53 d and that NRE was lower in the drained fields (NRE: 26 vs. 34%), top-dress N applications just before reflooding may provide the additional N needed to increase yields. However, unlike in conventional systems where inorganic N is available immediately for plant uptake (Peng & Cassman, 1998), the availability of organic fertilizer-N is less predictable due to variable mineralization rates, which are dependent on the organic fertilizer properties and other factors such as temperature and moisture (Hadas, Baryosef, Davidov, & Sofer, 1983; Wild et al., 2011). Furthermore, top-dress fertilizer-N is used less efficiently to increase yield the later it is applied after panicle initiation (Linquist & Sengxua, 2003; Reddy & Patrick, 1976). In organic rice systems the reflooding of the field following the weed control drain, coupled with the top-dress fertilizer-N application, occurs around the panicle initiation growth stage. The period of mineralization required for top-dress organic fertilizer-N will delay crop N uptake and thus may limit the fertilizer's ability to increase grain yields. In laboratory incubation studies, organic N mineralization of organic manure or fertilizer has been shown to occur in two phases: a rapid mineralization during the first 7 to 10 d followed by a slower mineralization phase after that (Hadas et al., 1983; Wild et al., 2011). Given the slower availability of mineralized N from organic fertilizer products, it is questionable whether the top-dress organic fertilizer-N will be available in time to be effectively utilized by the crop to increase yield. The C to N ratio of organic materials affect mineralization rates (Chaves, De Neve, Hofman, Boeckx, & Van Cleemput, 2004; Zhu, 2007) and lower C to N ratio organic fertilizers might be expected to mineralize faster and be used more efficiently. Therefore, our broad objective was to test the efficacy of top-dress applications in organic rice systems. Specifically, we wanted to (i) determine the appropriate rates for top-dress organic fertilizers; and (ii) test the hypothesis that lower C to N ratio organic fertilizers would be more effective at increasing rice yields than higher C to N ratio fertilizers.

Core Ideas

- Effects of midseason pelletized fertilizer applications using different organic products were evaluated.
- Yield response to top-dress applications varied by site and rate.
- The nitrogen recovery efficiency ranged from 28 to 49%.
- Top-dress applications of rapid mineralizing organic fertilizers were economically viable.

2 | MATERIALS AND METHODS

2.1 | Site description

Two field trials were conducted in commercial organic rice fields in 2017: one trial in Woodland, CA (38°36′15″ N, 121°39′54″ W) and the other trial in Richvale, CA (39°3153″ N, 121°44′40″ W). The Woodland site was in its second year of organic rice production and the Richvale site in its fourth year of organic rice production. Both sites were fallow for at least 2 yr prior to the start of organic rice production. The soil at the Woodland site is a Capay silty clay (22% sand, 24% silt, and 54% clay) with a pH of 6.9 and at the Richvale site an Esquon-Neerdobe clay (23% sand, 28% silt, 49% clay) with a pH of 5.9. At both sites, straw residue from the 2016 crop was incorporated into the soil and the fields were flooded during the winter to facilitate straw decomposition (Linquist, Brouder, & Hill, 2006), a practice that is common in both organic and conventional rice systems in California.

In 2017, both sites received an initial application of poultry manure of 11.2 t ha^{-1}, applied during land preparation and worked into the soil before planting. The poultry litter applied at the Woodland contained 3.2% N, 1.6% phosphorus (P) and 1.7% potassium (K), and at Richvale 1.56% N, 0.91% P, and 1.7% K on a dry weight basis. Thus, Woodland and Richvale received 173 and 91 kg N ha^{-1}, respectively from the preplant manure application. Woodland also received a gypsum

TABLE 1 Field management and conditions prior to treatments and reflood

				Pre-plant manure		Reflood				Plants	
		Plant	Drain	Rate	Date	Reflood	Soil NO_3–N[a]	Soil NH_4–N[a]	Dead weeds N[a]	Rice N[a]	Mean biomass[a]
Site	Variety	date	date	kg N ha^{-1}		date	— kg ha^{-1} —				
Woodland	S–102	May 20	June 21	173	April 25	July 15	0.3 ± 0.1	1.7 ± 0.5	14 ± 6	68 ± 18	4616 ± 500
Richvale	A–202	May 19	June 13	91	May 2	July 20	0.2 ± 0.1	5.2 ± 1.4	6 ± 2	41 ± 7	2898 ± 334

[a]Errors are standard deviations.

application of 1905 kg ha^{-1}. Following land preparation and fertilizer application, the fields were flooded and soaked seed was flown on by airplane. The variety S-102 (short grain) was seeded on May 20 at the Woodland site and the variety A-202 (aromatic long grain) was seeded on May 19 at the Richvale site. Both varieties are early maturing with high yield potential. For the weed control drain, the Woodland site was drained at 32 DAS for 24 d and the Richvale site at 25 DAS for 37 d (Table 1).

2.2 | Experimental design

Within each field, a location for the top-dress trial was selected during the dry down period in a uniform area with respect to weeds and stand establishment. At each site, the treatments were set up in a randomized block design with six treatments replicated four times. Plot size was 3.05 m by 9.14 m (27.87 m^2). The treatments evaluated three different commercial pelletized organic fertilizer products varying in N content at a single rate (45 kg N ha^{-1}) and different rates of top-dress N fertilizer of a single fertilizer relative to a control which received no top-dress N (Table 2). The five fertilizer treatments were 12–3–0 (True Organic Products, Inc.) applied at three different rates (22, 45, and 67 kg N ha^{-1}), and 6–3–2 (True Organic Products, Inc.) and 4–1–4 (Petaluma's Finest), both applied at a rate of 45 kg N ha^{-1}. Despite the variation of P and K in the treatments, this did not affect results as the P and K applied in the preplant manure was sufficient for optimal plant growth. Woodland received 179 and 190 kg ha^{-1} of P and K, respectively, and Richvale 102 and 190 kg ha^{-1} of P and K, respectively from the preplant manure. Furthermore, soil extractable P (Olsen-P) and K were considered sufficient (Linquist & Ruark, 2011; Williams, 2010). At Woodland, Olsen-P and 1N NH_4OAc-extractable K were 22 and 356 ppm, respectively, and 22 and 160 ppm at Richvale, respectively. The organic top-dress fertilizers were broadcast by hand onto the plots just before reflooding the fields on 14 July 2017 and 19 July 2017 at the Woodland and Richvale sites, respectively. The application rates for the fertilizers were based on the listed N content of each fertilizer. We independently tested the N content of each fertilizer and found that the N content of the 12–3–0, 6–3–2, and 4–1–4 was 12.1, 5.3, and 4.2%, respectively (Table 2). The 12–3–0 fertilizer was derived from feather meal, meat and bone meal; the 6–3–2 was derived from poultry manure, feather meal and meat and bone meal; and the 4–1–4 was pelletized dehydrated chicken manure.

2.3 | Sampling and data collection

Total aboveground biomass and plant N concentration were determined from plant samples taken prior to fertilizer application and at harvest. Prior to the top-dress N application and before reflooding, plant samples (cut at ground level) were taken from a randomly placed 1-m^2 quadrat in each block. Weeds from within the quadrat were also collected at this time and separated from the rice biomass. At harvest, approximately 20 random plants were taken from each plot before the combine harvest described below. Plant samples taken at harvest were separated into straw and grain fractions for determination of harvest index and for N analysis. All plant samples were dried at 60°C, weighed and ground to prepare for N analysis. Yields from each plot were determined from measured areas averaging 15.8 m^2 using a small plot combine harvester, which provided grain weight and moisture. The grain yield (paddy or unprocessed grain) is reported at 140 g kg^{-1} moisture. Plots were harvested on October 9 (86 d after reflood) at Woodland and on October 18 (90 d after reflood) at Richvale.

Prior to the top-dress fertilizer application a soil sample (0–15 cm) from each plot was taken using a soil sampling probe and bulk density was determined from the same depth. Soil samples were pooled by block. At harvest, five soil samples were taken and pooled together for each plot. Soils were placed in a cooler and stored in a refrigerated room and extracted within 48 h with 2 M KCl and analyzed for ammonium and nitrate (Doane & Horwath, 2003; Forster, 1995). Soil extractable N was converted to kilograms of N per hectare using bulk density (Table 1).

Following grinding in a ball mill, all soil, fertilizer, weeds and plant samples were analyzed for total N and carbon content at the UC Davis Stable Isotope Facility using an elemental analyzer interfaced to a continuous flow isotope ratio mass spectrometer (Sharp, 2005). Total plant N uptake was determined by multiplying the grain and straw biomass by the N

TABLE 2 Fertilizer products used in the study and the determined N concentration, C to N ratio and application rates of each

Fertilizer	Measured N %	C to N ratio	Application rate kg N ha^{-1}
12–3–0 True Organic Products	12.1	4.0:1	22, 45, 67
6–3–2 True Organic Products	5.3	5.6:1	45
4–1–4 Petaluma's Finest	4.2	7.9:1	45

concentration of each. Using these data, the N recovery efficiency (NRE) was calculated as follows:

$$\mathrm{NRE} = \frac{\text{Total plant } \mathrm{N_{fertilized}} - \text{Total plant } \mathrm{N_{unfertilized}}}{\text{N fertilizer applied}} \times 100$$

2.4 | Statistical analysis

To evaluate the relationship of different rates of 12–3–0 fertilizer on yield and N uptake, we used a regression analysis. Effects of treatments on yield, N uptake and NRE were evaluated using a standard ANOVA in RStudio version 1.1.453 (R Core Team, 2018). Mean separations for significant ANOVA results were determined using a Protected Least Significant Difference test (LSD) and differences were considered significant at $P \leq .05$ (Fisher, 1935).

2.5 | Economic analysis

An economic analysis was conducted to determine if the application of top-dress organic fertilizers were profitable given the yield responses we observed in this study. This analysis assumed a top-dress N rate of 45 kg N ha^{-1} and considered the cost of fertilizer (\$253 Mg^{-1}, \$413 Mg^{-1} and \$930 Mg^{-1} for the 4–1–4, 6–3–2, and 12–3–0, respectively), the cost of application (\$7.7 per ton of material applied; pers. comm. with farmer) and the price of rice which varied by the variety (S-102 was \$0.73 kg^{-1} and A-202 was \$0.88 kg^{-1}).

3 | RESULTS AND DISCUSSION

3.1 | Application rates

Without the application of top-dress N, yields were 7378 and 7412 kg ha^{-1} for Woodland and Richvale, respectively. In response to top-dress N applications, yields increased to 8770 and 8195 kg ha^{-1}, respectively. To put these yields in perspective, 2017 California statewide rice yields, which represents mostly conventionally grown rice, averaged 9426 kg ha^{-1} (USDA, 2017).

Using the 12–3–0 fertilizer, the yield response was linear throughout the range of N rates applied at Woodland (up to 67 kg N ha^{-1}); while at Richvale, the response was linear to 45 kg N ha^{-1} after which yields plateaued (Figure 1). Yields increased by 1392 and 783 kg ha^{-1} at Woodland and Richvale, respectively in response to top-dress N fertilizer. In the linear range of the response curve, yields increased by 22 and 15 kg ha^{-1} for every kg N ha^{-1} applied at Woodland and Richvale, respectively (Figure 1).

The smaller response to top-dress N fertilizer at Richvale may be due to several factors. First, at the end of the drain period and prior to top-dress application, the Richvale site had more soil extractable N (Table 1); thus, added N may be expected to have had less of a benefit. Total soil extractable N (NO_3–N + NH_4–N) at Richvale averaged 5.4 kg N ha^{-1} compared to 1.9 kg N ha^{-1} at Woodland (Table 1). At both sites, the mineral N was predominately NH_4–N, which would be plant available and not susceptible to denitrification losses on reflooding the field (Linquist, Koffler, Hill, & van Kessel, 2011; Patrick & Wyatt, 1964). The importance of available soil N at reflood is also supported by the fact that N uptake in the zero N treatments was higher at Richvale (53 kg N ha^{-1}) than at Woodland (23 kg N ha^{-1}) between reflood and harvest (compare Table 1 to Table 3). That said, total seasonal N uptake values in the zero top-dress N plots were similar and averaged 92 kg N ha^{-1} (Table 3). Second, the Woodland site was drained at 32 DAS for 24 d while at Richvale the drain began at 25 DAS and lasted for 37 d. The extra week of flood time at Woodland may have increased the early season N uptake, lowering the overall soil N. In water-seeded conventional systems, rice takes up all the applied preplant fertilizer N between 25 and 45 DAS (LaHue et al., 2016; Linquist & Sengxua, 2003; Sims & Place, 1968). Thus, by draining earlier, the rice at the Richvale site may have been stressed earlier and not been able to take up as much preplant N. Finally, the longer drain period at Richvale may have resulted in greater stress and reduced the yield potential relative to the Woodland site.

The N uptake response was linear at both sites with increasing rates of 12–3–0 (Figure 1). Applications of top-dress fertilizer at high rates resulted in a N uptake of 124 and 119 kg N ha^{-1} at Woodland and Richvale, respectively, increasing N uptake by 36% and 28% compared to the unfertilized control, respectively. The NRE for the 12–3–0 was similar across N rates and averaged 43% (Table 3). Nitrogen recovery efficiencies of this magnitude are high for organic fertilizers. In conventional rice systems using inorganic fertilizer, NRE can range from 20 to 78% (Cassman, Kropff, Gaunt, & Peng, 1993; Peng & Cassman, 1998; Wilson, Wells, & Norman, 1989) and average globally about 49%

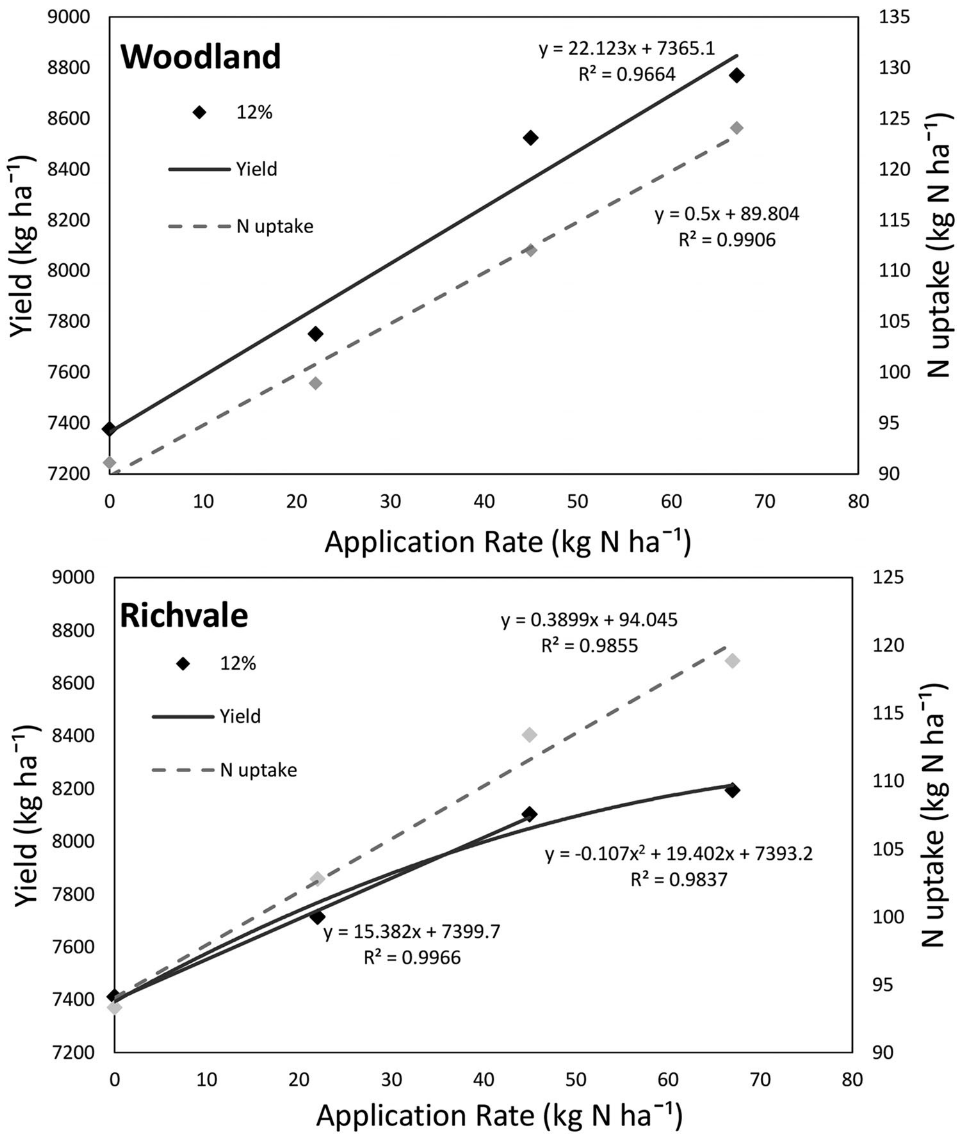

FIGURE 1 Grain yield (14% moisture) and N uptake response to organic N fertilizers. At Woodland, regression lines show the yield and N uptake response to 12–3–0 fertilizer. At Richvale, a best-fit quadratic line shows the yield response for all treatments, and (since the yield response to fertilizer N plateaued at the higher N rate) a linear regression was also included for yield but only through the first three N rates

for irrigated systems (Krupnik, Six, Ladha, Paine, & van Kessel, 2004). In organic systems, NRE is typically lower. For example, Crews and Peoples (2005) found that between 10 and 30% of legume cover crop N was taken up in the subsequent crop. Similarly, Reed et al. (2006) reported that only 27% of applied organic N was utilized in an organic corn-tomato rotation. In rice systems, Wild et al. (2011) reported a 20% NRE using organic poultry manure and 35% using pelletized organic fertilizers (as used in this study) when these fertilizers were applied prior to planting.

3.2 | Organic fertilizer sources

All fertilizer sources significantly increased N uptake compared to the control when applied at the same rate of 45 kg N ha^{-1}. Yields, relative to the control, also increased but only significantly for the 12–3–0 fertilizer across both locations (Table 4). In all cases N uptake and NRE were higher with 12–3–0 than when either the 4–1–4 or 6–3–2 were applied at the same rate, although this was only significant at the Richvale site (Table 4). There were no consistent differences between the 6–3–2 and 4–1–4 fertilizers. We hypothesized that 12–3–0 fertilizer would mineralize rapidly leading to greater N uptake compared to 6–3–2 and 4–1–4 because organic amendments with low C to N ratios have been shown to mineralize faster (Chaves et al., 2004; Gutser, Ebertseder, Weber, Schraml, & Schmidhalter, 2005; Zhu, 2007). We found that 12–3–0 had the lowest C to N ratio of 4.0, while the 6–3–2 and 4–1–4 had C to N ratios of 5.6 and 7.9, respectively (Table 2). This

TABLE 3 Total plant N uptake and fertilizer N recovery efficiency (NRE) of top-dress 12–3–0 applied at different rates at two sites

	Rate	N uptake	NRE	N uptake	NRE
		Woodland		Richvale	
Fertilizer	kg N ha^{-1}		%	kg N ha^{-1}	%
Control	0	91 a[a]	–	93 a	–
12–3–0	22	99 a	35 a	103 b	43 a
12–3–0	45	112 b	47 a	113 c	45 a
12–3–0	67	124 c	49 a	119 c	38 a
***P*-values**					
ANOVA		< .001	0.334	< .001	0.773

[a]Within each column, values not followed by a common letter are significantly different ($p < .05$).

hypothesis was supported at the Richvale location where N uptake and NRE were higher using 12–3–0 (Table 4). However, at the Woodland location, while the general trend supported this hypothesis, differences were not significant. The 12–3–0 had the lowest C to N ratio because it did not contain manure but was derived from feather meal, meat and bone meal, which typically have higher N content than manure and have been shown to mineralize rapidly (Mikkelsen & Hartz, 2008). The 6–3–2 contained poultry manure, feather meal and meat, and bone meal; and the 4–1–4 was poultry manure.

This study examined the effect of C to N ratio within a relatively narrow range (between 4.0 and 7.9). In the short-term, C to N ratios greater than 20 to 25 result in net immobilization, while below this value there is net mineralization (Probert, Delve, Kimani, & Dimes, 2005). While the fertilizers used in this study had C to N ratios well below 20; the important question for rice growers is whether, given a narrow C to N range of organic fertilizer options, there is any benefit to choosing the lowest C to N ratio fertilizer available (the 12–3–0, in this study). Our data suggests that at some sites, there is a benefit as N uptake was greater in the 12–3–0 at the Richvale site. Castellanos and Pratt (1981) studied the mineralization of different manures which had C to N ratios ranging from 6.5 to 15.9 and found that while the C to N ratio was a factor in determining short term mineralization, other indices were better correlated (i.e., C released as CO_2 and a pepsin extraction). Since our results are inconclusive on the effects of C to N ratio on the rate of mineralization, further studies in this area would be useful, especially when applying N fertilizers during periods when rapid uptake is necessary.

3.3 | Organic N mineralization and timing

The concern when applying top-dress organic fertilizers is whether sufficient amounts of organic N can be mineralized fast enough to allow for adequate N uptake to increase grain yields. Others have found that delaying top-dress N applications beyond panicle initiation results in increasingly reduced yield benefits (Linquist & Sengxua, 2003; Reddy & Patrick, 1976). In continuously flooded systems, the varieties used in this study reach panicle initiation about 45 to 55 DAS. In systems where fields are not flooded early in the season, crop development is delayed (Sharifi, Hijmans, Hill, & Linquist, 2018). Using the severe dry downs implemented in this study, organic growers report that the time from planting to harvest is delayed by about 2 to 3 wk compared to when fields remain flooded. The weed control drains at these sites began 25 to 32 DAS (i.e., before panicle initiation) and the fields were reflooded at 56 to 62 DAS. Given the development delay caused by the drain, the crop was likely at or just before panicle initiation at reflood. Thus, in this system where the reflooding and top-dress application is close to panicle initiation, rapid mineralization of organic fertilizers is imperative.

Considering the relatively good yield increase and high NRE when the top-dress was applied near panicle initiation, our results suggest that the organic fertilizers were rapidly mineralized. Rapid mineralization was due to at least a couple of factors. First, the fertilizers used in this experiment were pelletized. Both Hadas et al. (1983) and Wild et al. (2011) show an initial rapid release of available N fertilizer from pelletized manures in the first 7 to 10 d and this is followed by a slower period of release. Furthermore, Hadas et al. (1983) found that pelletizing organic manures further increased the amount of rapidly mineralized N in manures. Second, all the

TABLE 4 Yield, N uptake and N recovery efficiency (NRE) for organic fertilizer sources with varying N content (4–1–4, 6–3–2, and 12–3–0) at 45 kg N ha^{-1} and a control with no top-dress N applied

		Treatment				ANOVA
		0	4–1–4	6–3–2	12–3–0	*P*–values
Woodland	Yield (kg ha^{-1})	7378 a[a]	8349 b	8169 ab	8524 b	.025
	N uptake (kg N ha^{-1})	91 a	112 b	106 b	112 b	.010
	NRE (%)	–	46 a	32 a	47 a	.651
Richvale	Yield (kg ha^{-1})	7412 a	7715 ab	7959 b	8103 b	.003
	N uptake (kg N ha^{-1})	93 a	103 b	106 b	113 c	< .001
	NRE (%)	–	21 a	28 a	45 b	.009

[a]Within each row, values not followed by a common letter are significantly different ($p < .05$).

TABLE 5 Economic analysis of return on investment for top-dress application at 45 kg N ha^{-1} for two rice varieties. Since the yield response to each fertilizer was not significantly different from each other, the average yield increase across fertilizers within each site was used. Cost was analyzed per unit of N applied based on the listed N content of the fertilizer

Location	Variety	Rice price $ kg^{-1}	Fertilizer	Fertilizer cost $, at 45 kg N^{-1}	Application cost $, at 45 kg N^{-1} ha^{-1}	Break even yield kg ha^{-1}	Average yield increase	Profit $ ha^{-1}
Woodland	S−102	0.73	12−3−0	348	2.9	481	969	356
			6−3−2	310	5.8	433	969	392
			4−1−4	285	8.7	402	969	414
Richvale	A−202	0.88	12−3−0	348	2.9	399	514	101
			6−3−2	310	5.8	359	514	137
			4−1−4	285	8.7	334	514	159

fertilizers had a relatively low C to N ratio. At question is if lower C to N ratio fertilizers like the 12–3–0 increase mineralization rates and plant N uptake. While this was supported at one location, the higher N uptake did not translate into significantly higher yields.

3.4 | Economics

While our data generally show an increase in yields using organic N sources for top-dress applications (Table 4), is it an economical practice? Pelletized organic fertilizers are costly and for the fertilizers used here, the cost per unit of N was higher with increasing N concentration of the fertilizer (Table 5). Using an application rate of 45 kg N ha^{-1}, the fertilizer cost ranged from $285 (4–1–4) to $348 (12–3–0). Assuming similar yield increases from the application of different N sources, it was profitable to apply all top-dress fertilizers and profits ranged from $101 to $414 per ha. At the Woodland site it was more profitable due to the greater yield response to the top-dress N application. Despite the fact that the 12–3–0 was cheaper to apply due to a more concentrated form of N, it was less profitable due to its higher cost per unit of N. Our data indicate that N uptake is sometimes higher when 12–3–0 is applied (Table 4). If greater N uptake can translate into higher yields, the 12–3–0 could be more profitable.

4 | CONCLUSION

In this study, we evaluated whether midseason organic fertilizer N could be mineralized fast enough to become available when applied close to panicle initiation in rice. Top-dress applications using pelletized fertilizers improved N uptake, yield and NRE when applied at the end of a weed control drain. Furthermore, the responses seen in this trail indicated that these applications were economically feasible. While results from this experiment show trends consistent with our hypothesis that lower C to N ratio fertilizers would mineralize faster resulting in greater N uptake, this did not necessarily translate into higher yields. Given the higher cost of organic fertilizers with higher N concentrations, future research should continue to evaluate the effect of different fertilizer sources under different site and management conditions, especially when rapid N uptake is required.

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