ABSTRACT

Nitrogen from manures and fertilizers requires careful management to maximize efficiency and minimize losses. Cover crops may conserve nutrients from fall-applied manure and cycle N to corn (Zea mays L.). To quantify N benefits from winter cover crops (CC) and poultry litter (PL), fertilizer nitrogen equivalence (FNEQ) was calculated. Cover crop treatments included Rye (Secale cereale L.), Legume (Trifolium incarnatum L. and/or Vicia villosa Roth), LegumeRye, and winter fallow (WF) with and without fall-applied PL (2 Mg ha⁻¹). Corn grain yield and grain N response to fertilizer N rates from 0 to 224 kg N ha⁻¹ served as the basis for calculating FNEQ. Cover crop N content, whole corn plant N content, grain yield, and grain N contents were measured. Across years, N content of Legume residue was 22% greater with PL than without. Without CC, PL failed to result in an N credit to corn. Poultry litter coupled with Legume CC resulted in increasing fertilizer N credit from Year 1 to 3 from 25 to 117 kg N ha⁻¹. Rye resulted in negligible FNEQ for the duration of this study. For biculture, FNEQ ranged from a deficit of -12 to a credit of 75 kg N ha⁻¹. Coupling PL with CC resulted in increasing fertilizer N recovery, while a more immediate and synergistic N benefit was observed when Legume was combined with PL. These results suggest legume may effectively scavenge PL N in low N systems and result in increased residual soil N availability over time.

Core Ideas
- Fall-applied poultry litter and legume cover crop equate to more than 100 kg fertilizer N in corn.
- Without legume cover crop, fall-applied poultry litter failed to result in fertilizer N credit.
- Fertilizer N equivalence of legume/rye biculture was variable between -12 to a credit of 75 kg N ha⁻¹.
- Fertilizer N equivalence of legume cover crops and poultry litter increased across the 3-yr study.

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MANAGING N resources for reduced leaching and greater crop and soil recovery in row crop production is critical to improving long-term agricultural sustainability. Animal manures play an important role in the recycling of nutrients when properly utilized in row crop production systems and can serve as a substitute for inorganic fertilizer inputs. As with fertilizers, manure derived N and P can become environmental pollutants when availability is asynchronous with crop demand or rates are excessive (Andraski et al., 2000; Sharpley et al., 2007; Adeli et al., 2011). Current row crop production practices are heavily reliant on inorganic fertilizer sources (Hera, 1996), which have experienced fluctuations in pricing and an overall increase in cost in recent years causing growers to seek other nutrient source options such as manure. In the mid-South, PL applications may occur following crop harvest in the fall, as it is a period which is operationally favorable and more easily coordinated with logistics of trucking and spreading. Growers are primarily interested in PL benefits of added organic matter, P, and K, while assuming zero credit for PL-derived N due to potential overwinter N losses, especially by leaching (Adeli et al., 2011).

Coupling C and N in animal and green manures improves nutrient cycling (Drinkwater et al., 1998). Non-legume winter CC such as rye are known to reduce leaching losses of nitrate N (NO₃⁻–N) derived from organic sources such as manures and legumes, as well as from inorganic fertilizers (Adeli et al., 2011; Ditsch et al., 1993; Staver and Brinsfield, 1998). Studies on N dynamics in legume cover crop systems have indicated the importance of the associated C in immobilizing legume N in the organic matter fraction of soil (Ladd et al., 1981; Varco et al., 1993; Harris et al., 1994; Seo et al., 2006). In contrast, inorganic fertilizer N application generally results in lower immobilization compared to legume N (Azam et al., 1985). Coupling C and N dynamics by integrating organic N sources into cropping systems has been shown to increase total system recovery of applied N in the crop and soil by 30 to 42%, compared to inorganic fertilizer N sources alone (Gardner and Drinkwater, 2009).

Cover crop benefits vary among species and can be selected based on ecosystem service preferences. Proper selection can help achieve various production and nutrient stewardship goals (Schipanski et al., 2014). Typically, leguminous cover crop species are selected to supplement N through biological N₂ fixation.

Rachel Seman-Varner,* Jac Varco, and Megan O’Rourke

*Corresponding author (rnsvarner@gmail.com).

SOIL FERTILITY & CROP NUTRITION

Nitrogen Benefits of Winter Cover Crop and Fall-Applied Poultry Litter to Corn

R. Seman-Varner and M. O’Rourke, Dep. of Horticulture, Virginia Polytechnic Institute and State Univ., 440 West Campus Drive, Blacksburg, VA 24061; J. Varco, Dep. of Plant and Soil Sciences, Mississippi State Univ., Box 9555 32 Creelman St. Mississippi State, MS 39762. Received 21 Nov. 2016. Accepted 26 June 2017.

Abbreviations: CC, cover crops; FNEQ, fertilizer nitrogen equivalence; PL, poultry litter.
and subsequent decomposition and mineralization. A reduction in fertilizer N requirements by a row crop following a legume cover crop has been widely demonstrated across crops and environments (Touchton et al., 1982; Hargrove, 1986; Sullivan et al., 1991; Varco et al., 1999; See et al., 2000). In some instances, the combined effects of using a legume cover crop plus fertilization have been shown to result in the greatest yield (Ebelhar et al., 1984; Decker et al., 1994). Legume N may be important to long-term organic matter maintenance (Janzen et al., 1990; Ladd et al., 1981), and combining legumes with fertilizer N management may be an important contribution to reducing inorganic fertilizer and to long-term agricultural sustainability (See et al., 2006). In contrast, grass species of CC are touted for their greater scavenging ability of residual nutrients, especially mobile nutrients such as NO₃⁻–N, compared to legumes (Shipley et al., 1992; Ranells and Wagger, 1997; Thorup-Kristensen, 2001; Dabney et al., 2001).

Bicultures of legume and grass species have been studied to optimize multiple ecosystem services in addition to N₂ fixation, including: controlling erosion, improving water relations, recovering residual nutrients, and building soil organic matter (Ranells and Wagger, 1997). Tradeoffs in residue quantity (Sainju et al., 2005), quality, crop yield (Miguez and Bollero, 2005), and biological N fixation rates (Wortman and Dawson, 2015) must be considered when selecting mixtures. In many instances, these trade-offs can be predicted from the characteristics and proportions of individual component species. For example, total N accumulation of biculture residues and winter rye tissue N concentration have been positively correlated with legume proportions in rye/hairy vetch (Vicia villosa Roth) bicultures (Hayden et al., 2014). Recovery of residual soil NO₃⁻–N by bicultures has been shown to be intermediary between rye and legume monoculture CC (Ranells and Wagger, 1997). However, other functions of CC mixtures may not always be directly predicted by component species. Studies have shown that biological N₂ fixation by legumes may be reduced or enhanced when grown with grass species, with stronger correlations in perennial systems (Brainard et al., 2011; Schipanski and Drinkwater, 2012).

Coupling CC with manure has been suggested as a way to retain applied nutrients in row crop production systems (Cambardella et al., 2010; Singer et al., 2008). Legume, grass, and biculture cover crop systems fertilized with PL may conserve PL N by uptake and retention until spring row crop establishment with later release of nutrients following CC termination, especially when PL is applied in narrow subsurface bands (Tewolde et al., 2015). However, limited research exists examining fall-applied animal manures in narrow subsurface bands (Tewolde et al., 2015). Although rye sequestered PL N applied in the fall and reduced NO₃⁻ leaching, there was little effect on cotton (Gossypium hirsutum L) yield. Rye production responded to increasing levels of residual soil N derived from fertilizer and manure, but generally a subsequent row crop the following season did not benefit from grass–manure systems (Staver and Brinsfield, 1998; Singer et al., 2008). In contrast, legume–manure systems have been shown to potentially decrease the economic optimum N rate for corn to as low as zero (Andraski et al., 2000).

Fertilizer N equivalence has been used to interpret crop response to organic nutrients in animal manures and CC residues by comparing yield to yield following inorganic fertilizer (Ebelhar et al., 1984; Decker et al., 1994). The objective of this study was to quantify the FNEQ of legume, grass, and biculture CC combinations with and without fall-applied PL to potentially reduce inorganic N inputs on conservation-tilled corn systems. We hypothesized that the addition of PL would increase the N availability of CC residues across species. We also expected that the greatest FNEQ would be from the legume monoculture and that the legume rye biculture FNEQ would be intermediate between legume and rye monocultures. This research is important to develop a better understanding of nutrient cycling dynamics and crop productivity of systems that take a multi-process approach to nutrient management by integrating manures, CC, and inorganic fertilizers.

**MATERIALS AND METHODS**

**Study Site**

The study was conducted at the W.B. Andrews Agricultural Research Systems Farm at Mississippi State in Oktibbeha County, Mississippi (33°28’N, 88°45’W) from October 2012 to August 2015. Alluvial soils at the experimental site are primarily a Marietta fine sandy loam (fine-loamy, siliceous, active, thermic Fluvaquentic Eutrudult) and minimally a Leeper silty clay loam (fine, smectitic, nonacid, thermic Vertic Epiaquult). Prior to treatment establishment of the 3-yr study plots, composite soil samples comprised of eight cores were collected using a 2.5-cm diam. soil probe per treatment plot at depths of 0 to 15 cm. Soil samples were air-dried and analyzed for pH in deionized (d.i.) water (1:2 soil/d.i. water) and for extractable nutrients using the Mississippi soil test (Rasberry and Lancaster, 1977). The initial soil pH ranged from 5.27 to 7.32, possibly due to a transition zone on the West side of the field from the sandier Marietta to the more clayey Leeper soil series. To eliminate any potential pH effect, dolomitic lime was applied at a rate of 2240 kg ha⁻¹ as needed to individual plots when pH values were less than 6.0 following corn harvest. Experimental plots were blocked based on initial variation in soil pH and soil series. Initial extractable soil nutrient results were P = 1275 mg kg⁻¹ (very high), K = 127.3 mg kg⁻¹ (high), Mg = 70.6 mg kg⁻¹ (high), Ca = 2050.5 mg kg⁻¹ and an approximate CEC = 10.9 cmol c⁻¹ kg⁻¹.

**Experimental Design**

The experimental design of this study was a randomized complete block in a 4 × 2 factorial arrangement of four CC and two PL treatments. Treatments were randomly assigned to plots within a block and repeated each year on the same experimental units. Cover crop treatments included rye (variety Elbon), legume, legume/rye biculture, and winter fallow control (hereafter referred to as Rye, Legume, Legume/Rye, and WF, respectively). In 2013, the legume portion of Legume and Legume/Rye treatments was a combination of hairy vetch and crimson clover (T. incarnatum L.). In 2014 and 2015, only hairy vetch was used in the Legume and Legume/Rye treatments. Cover crop seed was broadcast in 2013 and planted with a grain drill in 2014 and 2015. Prior to planting, legume seeds were inoculated with rhizobia (N-Dure, INTX Microbials, LLC, Kentland, IN). Seeding rate calculations were corrected for any seed coating. Pelletized, minimally composted PL was obtained from Mighty Grow Organics Inc. (Fruitdale, AL). Based on lab analysis, PL average nutrient concentrations...
were: N = 3.33%; P = 1.80%; and K = 3.18% and was labeled as containing less than 0.1% soluble N. Average moisture content was 16.7%, with a range from 22% in 2013 to 11% in 2015. Nutrient concentrations and moisture content were analyzed annually prior to application rate calculations. All CC treatments, including the WF control, were grown with and without PL (CC treatments with PL hereafter denoted as RyePL, LegumePL, LegumeRyePL, and WFPL). Poultry litter was broadcast by hand per row within 4 wk of fall CC planting at a rate of 2 Mg ha\(^{-1}\) on a dry-weight basis and an N rate of 67 kg N ha\(^{-1}\). There were four replicates per treatment. Seedling rates and planting dates are shown in Table 1.

All treatments that did not include PL were amended, based on litter analysis, with approximately equivalent amounts of P and K, in the form of concentrated superphosphate [Ca\((H_2PO_4)\), 0–46–0] and muriate of potash (KCl, 0–0–60) at application rates of 18 kg P ha\(^{-1}\) and 33 kg K ha\(^{-1}\) in 2013, 32 kg P ha\(^{-1}\) and 42 kg K ha\(^{-1}\) in 2014 and 26 kg P ha\(^{-1}\) and 50 kg K ha\(^{-1}\) in 2015.

Plots consisted of four rows including two outside border rows, and with row spacing of 0.97 m and a length of 12.19 m. Seedbeds were initially prepared using a seedbed finisher run across bedded rows in the fall of 2012 and with no subsequent tillage in 2013. The experimental field had been previously managed using conventional tillage for cotton and corn production research. Previous crops were managed with a constant recommended N rate across the area which results in minimal residual soil N due to winter and spring rainfall patterns. Cover crop seed was broadcast onto the minimally tilled beds on 25 Oct. 2012, and drilled into untilled corn residue on 10 Oct. 2013 and on 21 Oct. 2014. Cover crops were terminated with glyphosate [\(N\)-phosphonomethyl]glycine\] as the potassium salt at 1.54 kg a.i. ha\(^{-1}\) on 10 Apr. 2013, 4 Apr. 2014, and 9 Apr. 2015 and immediately following corn planting each year. Immediately prior to termination, four 0.25 m\(^2\) samples of cover crop aboveground biomass were harvested, separated by species, dried at 65°C, ground in a Wiley mill to pass a 0.425-mm sieve and then analyzed for N content with a Carlo Erba NC 1500 dry combustion analyzer (Carlo Erba, Milan, Italy). The percent N of the subsample was multiplied by the harvested biomass (kg ha\(^{-1}\)) to calculate total N content (kg N ha\(^{-1}\)). Remaining residues were returned to the experimental plots.

In preparation for corn planting in 2014 and 2015, field plots were strip-tilled followed by a bed roller to smooth and firm beds. Corn (Pioneer hybrid 33-N-58 in 2013, Pioneer hybrid 1935 in 2014 and Pioneer hybrid P6637 YHR in 2015) was planted with a vacuum planter at a rate of 74,000 kernels ha\(^{-1}\) on 18 Apr. 2013, 21 Apr. 2014, and 22 Apr. 2015. For pre-emergence weed control, a tank mix of atrazine (2-chloro-4-ethylamino-6-isopropylamino-1,3,5-triazine) at 2.34 kg a.i. ha\(^{-1}\), mesotrione (2-[4-(methylsulfonyl)-2-nitrobensoyl]cyclohexane-1,3-dione) at 0.16 kg a.i. ha\(^{-1}\), and S-metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(1-methoxypropan-2-yl) acetamidine] at 1.22 kg a.i. ha\(^{-1}\) was applied following planting. Post-emergence applications of glyphosate at 1.54 kg a.i. ha\(^{-1}\) were made in 2013 and 2015. At physiological maturity, a 1-m length of whole corn plants were harvested from the center rows of each plot on 8 Aug. 2014 and 10 Aug. 2015, and stover and grain were separated prior to drying at 65°C. Corn grain was also harvested from the center two rows the whole length of each plot.
using an automated plot combine (see Table 1 for harvest dates). Nitrogen content from the whole plot and 1-m grain harvest, and stover from 1-m harvest were analyzed for total N. All reported grain yield was adjusted to 15.5% moisture content. Yield and N content of grain combine harvested from the center two rows of the whole experimental plots were used to determine FNEQ for the cover crop and PL treatments.

**Fertilizer Nitrogen Equivalence**

The experiment included five N rate treatments that were used to calculate grain yield or N content response functions, which were in turn used to calculate fertilizer N equivalence of the CC×PL treatments. Five N fertilizer rates from 0 to 224 kg ha⁻¹ in 56 kg ha⁻¹ increments were broadcast as ammonium nitrate after corn planting on 9 May 2013, 24 Apr. 2014, and 24 Apr. 2015. Fertilizer N rate treatments were managed as winter fallow in randomly assigned plots among the CC and PL treatment plots within the experimental area. Simple linear regression of grain yield and grain N yield from N fertilizer treatments were used to calculate a yield response curves. These responses served as an index to compare grain yield and grain N of CC×PL treatments. Grain yield or grain N content values for CC×PL treatments were substituted for y in the appropriate regression equation to calculate the FNEQ by solving for x or equivalent fertilizer N rate (see Supplemental Table S1 for FNEQ regression equations). Both FNEQ calculations were used to compare the effect of CC×PL treatments on overall yield and specifically the N value transferred to grain. Although manure P and K availability were accounted for in the N fertilizer rate response using whole plot grain yield and grain N yield from N fertilizer treatments were used to calculate FNEQ of CC×PL treatments were based on the predicted linear regressions.

**RESULTS**

**Cover Crop Nitrogen**

Among CC treatments, CC residue N content values were greatest for Legume, intermediate with LegumeRye, and lowest for Rye treatments overall (P < 0.0001; Table 2). There were no significant CC×PL interactions within individual years, or across years at α = 0.05. However, the main effect of poultry litter increased CC residue N content significantly overall (P = 0.0018). The addition of PL to Legume did not increase CC residue N content in 2013, but resulted in 32.6 and 20.8 kg N ha⁻¹ greater residue N content with PL in 2014 and 2015, respectively (Table 3). Across the 3-yr period, addition of PL to Legume CC increased residue N content by 22% or 16.1 kg N ha⁻¹. Apparent N recovery of PL N in Legume residue was 24%, while for Rye the recovery was 21% based on the yearly average PL N application of 67 kg N ha⁻¹. LegumeRye CC residue N content increased by 17.7 kg N ha⁻¹ for an apparent N recovery of PL-derived N of 26%. Winter fallow, based on biomass N content of winter annual weeds, recovered only about 5% of the fall applied PL N for the 2 yr that weeds were monitored (2014 and 2015).

**Corn Nitrogen Content**

Overall, corn plant total N content (grain plus stover N content at physiological maturity) was significantly affected by CC and PL (P < 0.0001 and P = 0.0190, respectively, Table 2). There was also a significant CC×PL interaction (Table 2). Corn plant total N content increased by 24.0 kg N ha⁻¹ in 2014, and 31.5 kg N in 2015 when PL was included with Legume, while a lesser effect was observed with both LegumeRye and LegumeRye

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**Table 2. Test of significance of year, cover crop (CC), poultry litter (PL) and their interaction effects on CC N, Grain N, Stover N and Total plant N at physiological maturity, and Grain yield and grain N from the whole plot harvest from 2013, 2014, and 2015 experimental years.**

<table>
<thead>
<tr>
<th>Effect</th>
<th>CC N</th>
<th>Grain N</th>
<th>Stover N</th>
<th>Total N</th>
<th>Grain yield</th>
<th>FNEQ</th>
<th>Grain yield</th>
<th>FNEQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>0.0002</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>CC</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>PL</td>
<td>0.0018</td>
<td>0.0880</td>
<td>0.0015</td>
<td>0.0190</td>
<td>0.2646</td>
<td>0.2310</td>
<td>0.0251</td>
<td>0.0487</td>
</tr>
<tr>
<td>CC×PL</td>
<td>0.9486</td>
<td>0.0219</td>
<td>0.0520</td>
<td>0.0147</td>
<td>0.0810</td>
<td>0.0367</td>
<td>0.0673</td>
<td>0.1548</td>
</tr>
<tr>
<td>Year×CC</td>
<td>0.2196</td>
<td>0.2335</td>
<td>0.4559</td>
<td>0.2309</td>
<td>0.4282</td>
<td>0.2019</td>
<td>0.0131</td>
<td>0.1499</td>
</tr>
<tr>
<td>Year×PL</td>
<td>0.3259</td>
<td>0.5320</td>
<td>0.8373</td>
<td>0.5835</td>
<td>0.2152</td>
<td>0.1459</td>
<td>0.0502</td>
<td>0.1277</td>
</tr>
<tr>
<td>Year×CC×PL</td>
<td>0.5321</td>
<td>0.5426</td>
<td>0.8806</td>
<td>0.6101</td>
<td>0.8513</td>
<td>0.6233</td>
<td>0.7398</td>
<td>0.8106</td>
</tr>
</tbody>
</table>

2884  
Agronomy Journal • Volume 109, Issue 6 • 2017
In both years, corn plant total N content of Rye, RyePL, and WFPL did not differ significantly.

Main effects of CC and PL influenced stover N content as well \( (P < 0.0001 \text{ and } P = 0.005, \text{ respectively; Table 2}) \), while the interaction effect was significant \( P = 0.052 \). Stover N for LegumePL was 35 and 23% greater than following Legume in 2014 and 2015, respectively (Table 4). Similarly, in 2014 and 2015, LegumePL grain N content at physiological maturity was 32 and 33% greater than Legume. There were no other significant differences in stover N or grain N among CC treatments due to PL at \( \alpha = 0.05 \).

### Grain Yield and Nitrogen Content

Cover crops influenced grain yield from the combine harvest each year (2013 \( P = 0.048 \), 2014, and 2015 and overall \( P < 0.0001 \); Table 5). The main effect of PL on grain yield was not significant across years, however there was a significant CC \( \times \) PL interaction \( (P = 0.0367; \text{Table 2}) \). Corn grain yield was greatest in Legume, followed by LegumeRye, and the least in Rye. LegumePL grain yield was 23, 35, and 25% greater than Legume in 2013, 2014, and 2015, respectively. Poultry litter did not significantly increase grain yield in Rye or LegumeRye treatments. While differences were not significant, Rye and RyePL yield were less than or equal to WF and WFPL across years.

Trends in whole plot grain N content were similar to grain yield with respect to treatments. Cover crop was significant \( (P < 0.0001) \) and overall the PL effect was not \( (P = 0.2646; \text{Table 2}) \). In 2014 and 2015, LegumePL had 30 and 25% more grain N than Legume, respectively. Grain N content in Rye and RyePL treatment were similar to the grain N of WFPL and WF treatments. Across years, grain N content was 15.0 kg N ha\(^{-1}\) greater for LegumePL than Legume, and only 2.8 kg N ha\(^{-1}\) greater for RyePL than Rye.

### Fertilizer Nitrogen Equivalence

Yearly calculated FNEQ for CC \( \times \) PL treatments based on grain yield and derived from WF grain yield N response functions are shown in Table 6. In 2013, the FNEQ of LegumePL was almost four times the 6.7 kg FN ha\(^{-1}\) of Legume without PL based on grain yield \( (\text{FN} = \text{fertilizer N based on FNEQ}; \text{LegumeRyePL, Rye, and RyePL}) \). LegumeRyePL, Rye, and RyePL had negative FNEQ values based on grain yield. In 2014, the FNEQ value for LegumePL equaled 84.2 kg FN ha\(^{-1}\) and Legume alone was equal to 32.9 kg FN ha\(^{-1}\). The greatest FNEQ value of 117 kg FN ha\(^{-1}\) occurred with the LegumePL treatment in 2015, which was nearly twice that of the Legume without PL. Results suggest a synergistic effect of the combined LegumePL treatment as FNEQ was 82% greater than the sum of the individual FNEQ values for Legume and PL treatments. The enhanced effect of the combined LegumePL on FNEQ as compared to Legume alone is at least partially due to a negative FNEQ resulting with WFPL. By the third year of the study, The FNEQ of LegumeRyePL was not significantly different from the greatest FNEQ (LegumePL) and was 50% greater than LegumeRye. Rye, and RyePL FNEQ based on grain yield were negative all 3 yr.

The treatment trends in FNEQ values based on grain N were similar to those FNEQ values based on grain yield. The range of FNEQ values based on grain N was from –15 to 101 kg FN ha\(^{-1}\), while the range of FNEQ values based on grain yield was from –31 to 117 kg FN ha\(^{-1}\). In 2013, based on grain N content, LegumePL.

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### Table 4

Yearly grain, stover, and total plant N content of cover crop \( \times \) poultry litter treatment combinations at physiological maturity. PL = poultry litter, WF = winter fallow, and WFPL = winter fallow poultry litter.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grain N</td>
<td>Stover N</td>
</tr>
<tr>
<td></td>
<td>kg N ha(^{-1})</td>
<td>kg N ha(^{-1})</td>
</tr>
<tr>
<td>Legume</td>
<td>45.3</td>
<td>26.2</td>
</tr>
<tr>
<td>LegumePL</td>
<td>60.0</td>
<td>35.4</td>
</tr>
<tr>
<td>Rye</td>
<td>30.2</td>
<td>17.3</td>
</tr>
<tr>
<td>RyePL</td>
<td>31.0</td>
<td>22.0</td>
</tr>
<tr>
<td>LegumeRye</td>
<td>37.8</td>
<td>24.4</td>
</tr>
<tr>
<td>LegumeRyePL</td>
<td>40.4</td>
<td>27.8</td>
</tr>
<tr>
<td>WF</td>
<td>30.0</td>
<td>24.3</td>
</tr>
<tr>
<td>WFPL</td>
<td>26.0</td>
<td>23.8</td>
</tr>
<tr>
<td>LSD</td>
<td>16.1</td>
<td>7.3</td>
</tr>
</tbody>
</table>

### Table 5

Yearly whole plot grain yield and grain N content of cover crop \( \times \) poultry litter treatment combinations at harvest. PL = poultry litter, WF = winter fallow, and WFPL = winter fallow poultry litter.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mg ha(^{-1})</td>
<td>Mg ha(^{-1})</td>
<td>Mg ha(^{-1})</td>
</tr>
<tr>
<td>Legume</td>
<td>3.5</td>
<td>4.9</td>
<td>5.6</td>
</tr>
<tr>
<td>Legume PL</td>
<td>4.3</td>
<td>6.6</td>
<td>7.0</td>
</tr>
<tr>
<td>Rye</td>
<td>1.9</td>
<td>2.9</td>
<td>3.6</td>
</tr>
<tr>
<td>Rye PL</td>
<td>1.9</td>
<td>3.0</td>
<td>4.0</td>
</tr>
<tr>
<td>LegumeRye</td>
<td>4.4</td>
<td>3.8</td>
<td>5.0</td>
</tr>
<tr>
<td>LegumeRye PL</td>
<td>2.6</td>
<td>3.9</td>
<td>6.1</td>
</tr>
<tr>
<td>WF</td>
<td>3.3</td>
<td>3.6</td>
<td>4.2</td>
</tr>
<tr>
<td>WFPL</td>
<td>3.0</td>
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</tr>
<tr>
<td>LSD</td>
<td>2.2</td>
<td>1.3</td>
<td>1.6</td>
</tr>
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Agronomy Journal • Volume 109, Issue 6 • 2017
treatment was equivalent to 32 kg N ha⁻¹, followed by LegumeRye (25 kg N ha⁻¹), and Legume (13 kg N ha⁻¹). LegumeRyePL and WFPL had negligible FNEQ. Rye and RyePL treatments both yielded less corn grain than WF and resulted in negative FNEQ values. In 2014, all CC × PL treatments had positive values of FNEQ based on grain N content. As in 2013, the greatest FNEQ in 2014 was observed for LegumePL. Poultry litter without any cover crop (WFPL) resulted in an FNEQ of 6 kg N ha⁻¹ and had a synergistic benefit when combined with legume CC, which resulted in 44% greater FNEQ compared to the additive FNEQ values of PL and Legume in 2014. In 2015, LegumePL had the greatest FNEQ (101 kg N ha⁻¹), which was almost twice that of Legume alone. Again in 2015, PL resulted in an apparent synergistic effect on FNEQ when combined with Legume. Once again, WFPL resulted in a negative FNEQ value for WFPL (−6 kg N ha⁻¹). The FNEQ of LegumeRyePL was 51% greater compared to LegumeRye. RyePL resulted in an equivalence of 13 kg N ha⁻¹, a slight but positive effect compared to the negative FNEQ observed the first year. As in 2013, Rye resulted in less grain N content than WF, and a negative FNEQ in 2015.

### DISCUSSION

Fall-applied PL and CC management schemes have the potential to reduce spring inorganic fertilizer N inputs. Uncoupled PL (applied without CC) did not significantly supply spring N to corn, even though approximately 67 kg N ha⁻¹ was applied each fall. Cover crop N content, corn total N content, grain yield, grain N content and FNEQ indicate fall-applied PL coupled with a legume CC resulted in a fertilizer credit of approximately 100 kg N ha⁻¹ or more by the third year of this study. Fertilizer credit attributable to rye was negligible across the 3-yr period, which is in agreement with previous work on rye (Clark et al., 1997; Huntington et al., 1985). Cover crop N content, grain yield, and FNEQs of LegumeRye biculture were variable across the 3-yr period, but by the end of the study FNEQ of LegumeRye biculture was not significantly different from the maximum FNEQ value, which occurred with the LegumePL treatment. The FNEQ of Legume, LegumePL, and LegumeRyePL CC systems increased across the experimental period, suggesting a buildup of residual effects on soil N and availability, while the FNEQ trends of Rye, RyePL, WF, and WFPL suggest no residual effect on soil N availability within the 3-yr study.

Based on grain yield and grain N content, the application of PL to winter fallow suggests some residual N availability, but the fertilizer N credit was minimal and no greater than 6 kg N ha⁻¹. There was no difference between WFPL and WF alone in stover N content, grain yield, grain N content, or FNEQ. Fall-applied PL N dynamics in the soil were not studied, but since it was not ultimately recovered by next year’s corn crop, some was likely lost through leaching, denitrification or both as winters are mild and with high rainfall. Also, as principally an organic form of N some may have been immobilized and incorporated in soil organic matter (Seo et al., 2006). Without the potential to recover mineralized PL N by a CC, the risk of nutrient loss is high with fall-applied litter (Meisinger et al., 1991). Although the application rate of PL in this study was below rates typically applied as compared to other studies, the rate used was reasonable for fertilizing CCs, and supplying P and K for the next year corn crop, while lessening the risk of N loss by leaching and avoiding soil P buildup or loss by runoff (Brink et al., 2008).

The combined benefit of Legume CC plus fall-applied PL was greater than the addition of their individual effects on grain yield based FNEQ. Each year the FNEQ of LegumePL was greater, by as much as nine times, compared to the additive FNEQ of Legume and WFPL treatments, partly due to the negative FNEQ values of uncoupled PL (WFPL). Increased corn grain productivity of legume treatments was correlated with an increase in total CC N content, which was 41% greater with the application of PL. There was no significant effect of PL on legume CC residue quantity (p = 0.71, data not shown); however, PL did increase the N content significantly. Therefore, greater N content, greater N mineralization rates (Kuo and Sainju, 1998), and possibly greater synchrony of nutrient release with crop uptake (Stute and Posner, 1995), may have contributed to increased grain productivity of the LegumePL treatment compared to Legume, Rye, RyePL, and biculture treatments. The apparent synergistic effect also suggests the ability of a legume CC to recover and retain nutrients in the fall and effectively release and supply N to corn as residue decomposition proceeds.

The effect of rye CC on grain productivity was slightly negative or neutral with and without PL. The lowest FNEQ, based on grain N content, occurred the first year of the study in 2013 (−15 kg N ha⁻¹) when residues were greatest (3200–5200 kg ha⁻¹), and corn stand was reduced by 26% for the RyePL treatments (data not shown). However, despite managing for less residue (maximum 2700 kg ha⁻¹), strip-tilling in 2014 and 2015, and the resulting excellent corn stands, FNEQ of rye treatments remained negligible (−5 to 14 kg N ha⁻¹). The CC N yield of RyePL was greater than Rye by 27 to 54% across the 3-yr period, but the effect of RyePL on grain production was detrimental or only minimally positive. These results confirm

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Table 6. Average fertilizer nitrogen equivalents (FNEQ) for cover crop × poultry litter treatment combinations based on corn grain yield and grain N content is 2013, 2014, and 2015. LSD values present to separate means.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>FNEQ based on grain yield</th>
<th>FNEQ based on grain N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legume</td>
<td>6.7</td>
<td>32.9</td>
</tr>
<tr>
<td>LegumePL</td>
<td>25.4</td>
<td>85.2</td>
</tr>
<tr>
<td>Rye</td>
<td>−27.6</td>
<td>−30.6</td>
</tr>
<tr>
<td>RyePL</td>
<td>−29.3</td>
<td>−26.8</td>
</tr>
<tr>
<td>LegumeRye</td>
<td>26.2</td>
<td>−2.9</td>
</tr>
<tr>
<td>LegumeRyePL</td>
<td>−12.5</td>
<td>2.5</td>
</tr>
<tr>
<td>WFPL</td>
<td>−4.2</td>
<td>−17.6</td>
</tr>
<tr>
<td>LSD</td>
<td>47.3</td>
<td>36.9</td>
</tr>
</tbody>
</table>

prior research in which rye biomass production and N uptake increased quadratically with up to 9 Mg ha$^{-1}$ of PL, with no effect on cotton (Gossypium hirsutum L.) lint (Adeli et al., 2011). In potato (Solanum tuberosum L.), rye had lower N use efficiency compared to forage radish (Raphanus sativus L.) and winter pea (Pisum sativum L.) (Jahanzad et al., 2017). Immunization of N is likely an overriding factor in these studies, due to the high C/N of rye residues (Allison 1966; Clark et al., 1997), but other factors such as those related to reduced stand, decreased soil moisture content, or allelopathy of rye residues may also affect crop productivity (Burgos et al., 1999). It is possible that rye is capable of increasing overall N use efficiency of this system by scavenging residual and PL N, increasing SOM, and potentially creating a “slow-release” N source (McSwiney et al., 2010), but a fertilizer N credit was not apparent during the 3-yr study period. Although grain yield for both Rye and RyePL significantly increased by 2015, the greatest yield was only 4 Mg ha$^{-1}$, or about 30% of the maximum yield in this study. Longer experimental studies may reveal greater N benefits from a RyePL combination.

The effect of PL on CC bicultures was variable across the 3-yr period. Biculture residue N was not consistently affected by PL application. Previous studies have suggested that mixed CC N yields do not necessarily follow the same over-yielding pattern as shown in biomass yield because N content is directly related to legume proportion of a mix (Sainju et al., 2005; Smith et al., 2014). There were also inconsistent trends in grain productivity for the biculture treatments across the 3-yr period. However, the biculture residue N content, grain yield, stover N, and grain N tended to fall between those values for Legume and Rye and ultimately resulted in an FNEQ similar with that of LegumePL by Year 3. While grass–legume biculture with PL may not consistently have as high FNEQ as LegumePL, there are benefits and tradeoffs when managing bicultures including N retention, weed suppression, and management costs (Brainard et al., 2011; Hayden et al., 2014).

The full benefits of these cover crop and PL management schemes may take several years to be realized. The greatest positive trend emerged in the LegumePL treatment by the third year of the study. There was also a positive effect on grain yield and FNEQ for Legume and LegumeRyePL across the experimental period. This suggests a cumulative effect on organic N and supply of plant available N from the legume residues in this low disturbance system (McSwiney et al., 2010). These results are consistent with previous work on FNEQ of other legume CC, which also show increasing trends (Reeves et al., 1993; Torbert et al., 1996). The effects of Rye and RyePL on grain yield also increased slightly across years, but the FNEQ was either slightly negative (2013) or positive (2014 and 2015). Inclusion of rye in production systems has resulted in prediction of greater fertilizer N rates to realize economically optimum yield compared to no winter CC (Varco et al., 1999). Comparing the rate of development of benefits from legumes, bicultures, and rye CC in this experiment, it appears that with lower N concentrations of CC residues, such as that of small grain rye, may require a longer period of time to maximize FNEQ.

CONCLUSIONS

The effects of legume, grass, or biculture winter CC on crop productivity have been studied in many agronomic systems, but the combined effect of fall-applied PL coupled with these CC has not. Our results indicate the inclusion of a legume CC fertilized with PL can improve grain yield productivity and suggests substitutability for inorganic fertilizer N up to 117 kg N ha$^{-1}$ for minimally tilled corn. Rye with and without PL did not result in a substantial fertilizer N credit to corn within the 3 yr of this study. Compared to monocultures, the biculture resulted in an intermediate and variable FNEQ based on grain N content and yield. By the third year of the study, Legume Rye PL resulted in a substantial fertilizer N credit similar to legume with PL. Furthermore, the FNEQ based on grain yield of legume, legume with PL, and biculture with PL increased substantially across the 3-yr period, while the FNEQ of rye with and without PL and biculture without PL did not. Additionally, the application of PL to winter fallow resulted in zero N credit, but when coupled with CC, nearly 30% PL N was assimilated in CC residues. Our results suggest the combination of a legume CC with fall-applied PL can result in an effect much greater than either input used alone which results in a substantial fertilizer N credit to corn. The long-term effects and N stability of management schemes that combine organic and inorganic N sources warrant further study.

SUPPLEMENTAL MATERIAL

Table S1. Regression equations, P-value, and adjusted r$^2$ values for N rate plots used to develop the FNEQ index based on corn grain N and grain yield response. These FNEQ values quantified the fertilizer equivalence of winter cover crop and fall-applied poultry litter treatments in corn. Total corrected degrees of freedom for each regression = 19.

REFERENCES


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