Efficient cover crop management has been shown to increase organic matter, reduce erosion, control moisture, and provide N to agricultural systems. Inputs such as manures and commercially available materials can be difficult to manage because they often have low available N contents and can provide P and micronutrients in excess of crop needs. The use of legume cover crops to fix atmospheric N, through biological nitrogen fixation (BNF) is an established and highly beneficial farming practice. Estimates of the N contribution from legume cover crops vary widely.

Many organic farmers incorporate green manures into the soil two or three weeks before planting. Emphasis on reducing tillage has stimulated an interest in alternative cover crop management systems and implements. The roller-crimper is a tractor-mounted implement with a water-filled rolling drum that terminates a cover crop by crimping the stems while leaving the root system and soil undisturbed. The effectiveness of roll-kill is related to the growth stage of the cover crop, and termination for optimal kill, defined as the date when cover crops could be successfully terminated by the roller-crimper, corresponds to the active flowering period. In many regions of the United States, it has proven difficult to match the peak production of winter annual cover crop species with the preferred planting dates for spring cash crops.

For optimum yield, corn in North Carolina is usually planted before early April to avoid overlap of drought-sensitive growth stages with a historical dry period at the end of June. This early planting date falls before most winter annual cover crops’ point of peak biomass and N accumulation and, because cover crops are often incorporated two to three weeks before planting, could result in a significant loss of potential N delivery to the system. A recent study in Pennsylvania found that peak N production of hairy vetch occurred two weeks after the optimum corn planting time, resulting in a potentially significant loss of cover crop N.

New, underutilized, and early flowering cultivars of winter annual legumes could reach maturity early enough in the season to complement the North Carolina production schedule. The southern-adapted hairy vetch cultivars AU Merit and AU Early Cover reach 50% flowering 15 days earlier than other hairy vetch cultivars or common vetch, and crimson clover cultivars AU Sunrise and AU Robin flower earlier than the traditionally used cultivars Tibbee or Dixie. Biological N fixation of less commonly used species may be important for delivering new N to organic systems; however, few studies have examined the BNF potential of legume candidate species that are appropriate for the roller system, especially regarding their performance in the southeastern United States where cover crop growth may be increased by favorable climatic conditions found in this region.

In a new study published in Agronomy Journal, researchers hypothesized that high total N derived from the atmo-

Abbreviations: BNF, biological nitrogen fixation; Ndfa, nitrogen derived from the atmosphere.
sphere (Ndfa) and total N in cover crops that are sensitive to termination by the roller-crimper will be associated with high grain yields in a succeeding corn crop. This hypothesis was tested by (i) measuring the biomass production and total N accumulation at three potential kill dates, (ii) determining the percentage of Ndfa at the optimal kill date, and (iii) identifying roller-crimper-compatible legume species for North Carolina organic corn production systems.

The study was conducted at two sites in 2009: the Tidewater Research Station in Plymouth, NC on a Portsmouth soil (a fine loamy over sandy or sandy-skeletal, mixed, semiactive, thermic Typic Umbraquult) and the Piedmont Research Center in Salisbury, NC on a Lloyd soil (a fine, kaolinitic, thermic Rhodic Kanhapludult). In 2009–2010, the study was conducted at the Caswell Research Farm in Kinston, NC on a Pocalla loamy sand (a loamy, siliceous, subactive, thermic Urtic Hapludalf). For details on the test design, see the original article in *Agronomy Journal* (cited below).

The natural abundance method calculates the Ndfa percentage based on three values: the proportion of $^{15}$N from a non-fixing reference plant grown in the same field and under the same conditions as the legume and assumed to access the same soil N pool, the field-grown legume, and the isotopic fractionation value of shoot tissue from the same species grown entirely dependent on BNF. The Ndfa percentage is then calculated.

**Results**

Within species, comparisons were made for all cultivars of hairy vetch, crimson clover, and Austrian winter pea; however, no consistent differences among specific cultivars were observed across all site-years. For hairy vetch, AU Merit produced significantly more biomass and N than the other cultivars at the Caswell site in 2010. This could be attributed to a lack of rainfall in early spring when the early cultivars AU Early Cover and Early Cover–Winter Hardy were maturing; beginning in May, this site began receiving modest irrigation, which may have benefited the later-maturing AU Merit. Across all species, hairy vetch had among the highest N contents overall, resulting from its high biomass and low C/N ratio (Fig. 1) relative to the other cover crops.

Corn grain yields for all cover crop and planting date treatments are reported in Table 1 (next page). Nitrogen response curves varied widely, with a significant interaction with the cover crop termination (corn planting) date at Piedmont in 2009 and Caswell in 2010, probably as a result of water stress.

Cover crop treatment and the cover crop × termination date interaction had significant effects on the corn yield for all site-years ($P < 0.001$; Table 1). In 2009, hairy vetch treatments were among the highest yielding for corn grain at the late termination dates. The lowest yield was seen at Piedmont in 2009 for the early termination date of berseem clover. Of all cover crops tested, hairy vetch treatments were the most consistent in producing high corn grain yields. Between-species contrasts indicated that the hairy vetch treatments produced more grain than crimson clover for all site-years except Tidewater ($P < 0.05$), with a significant interaction with termination date for all site-years except Piedmont in 2010 (Table 1). Corn planted in hairy vetch cultivars yielded more grain than in common vetch in 2009 ($P < 0.01$), but this difference was nonsignificant in 2010. The hairy vetch bicultures, AU Early Cover + Wrens Abruzzi and AU Merit + Wrens Abruzzi, had higher grain yields in 2010 at both Caswell and Piedmont than the hairy vetch monocultures AU Early Cover, AU Merit, Early Cover–Winter Hardy, and Purple Prosperity ($P < 0.05$).

Within-species comparisons of hairy vetch show greater yields from the AU Early Cover treatment than all

**Fig. 1.** Carbon/nitrogen ratios of winter annual cover crops grown in North Carolina in 2009 and 2010. Crops were harvested in late April (mid termination) and mid-May (late termination). Cover crops included hairy vetch cultivars AU Early Cover (AUE), AU Merit (AUM), and Purple Prosperity (PRO); common vetch (VET); Austrian winter pea cv. Whistler (WHI) and unstated cultivar (PEA); crimson clover cultivars AU Robin (AUR), AU Sunrise (AUS), Dixie (DIX), and Tibbee (TIB); Balansa clover cv. Frontier (FRO); berseem clover cv. Bigbee (BIG); subterranean clover cv. Denmark (DEN); and bicultures rye plus AUE (MXE), rye plus AUM (MXM), and rye plus Austrian winter pea (MXP).
Table 1. Grain yields of corn planted into roll-killed cover crop residues at four locations in North Carolina. In 2009, corn was planted on April 16, April 29, and May 13 at Tidewater for early, mid, and late, respectively, and on April 23, May 8, and May 21 at Piedmont for early, mid, and late, respectively. In 2010, corn was planted on April 23 and May 6 at Caswell for mid and late, respectively, and on April 28 and May 28 at Piedmont for mid and late, respectively. Corn planting was preceded by cover crop roll-kill operations on the same day. Reported yields are least squared means.

<table>
<thead>
<tr>
<th>Treatment†</th>
<th>Grain yield</th>
<th>Tidewater 2009</th>
<th>Piedmont 2009</th>
<th>Caswell 2010</th>
<th>Piedmont 2010</th>
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† AUE, AU Early Cover; AUM, AU Merit; EAR, Early Cover–Winter Hardy; PRO, Purple Prosperity; VET, unstated cultivar; AUR, AU Robin; AUS, AU Sunrise; DIX, Dixie; TIB, Tibbee; FRO, Frontier; BIG, Bigbee; DEN, Denmark; PEA, unstated cultivar; WHI, Whis-tler; MXE, AU Early Cover + Wrens Abruzzi; MXM, AU Merit + Wrens Abruzzi; MXP, unstated cultivar + Wrens Abruzzi.

‡ Missing data are a result of corn not being planted in treatment combinations at particular site-years.
other cultivars at Tidewater ($P < 0.05$), with a cultivar ×
termination date interaction being significant at Piedmont
in 2009 ($P < 0.05$), indicating that AU Early Cover treat-
ments had greater yields at earlier termination dates. In
2010, AU Early Cover grain yields were not significantly
greater than other hairy vetch cultivars, although AU Merit
had greater yields at Caswell at the late termination date.
Within-species comparisons of Austrian winter pea and
crimson clover were nonsignificant. Apart from late-termi-
nated hairy vetch, most cover crop treatments resulted in
lower yields than the highest-yielding N-fertilized control
treatments. In 2009, corn yields from late-terminated hairy
vetch treatments were equal to or greater than the highest-
yielding late-planted, N-fertilized corn.

**Discussion**

The roller-crimper is a popular new tool being evaluat-
ed for cover crop termination in organic corn production.
This study sought to identify cover crop species compat-
ible with the roller-crimper system in North Carolina
using defined criteria of high biomass and N production,
susceptibility to termination by the roller-crimper in mid-
April, and high grain yield from corn planted into roll-
killed mulch. None of the cover crops tested fulfilled all
criteria. Earlier-flowering crimson clover, while suscep-
tible to termination in April, failed to produce adequate
corn yields. Hairy and common vetch matured late and
thus could not be killed in time to achieve the desired
corn planting for this region, although corn yields from
late cover crop plantings were surprisingly high at some site-years.

This study suggests that the agronomics of a roller-
crimper-based organic no-till system are substantially
different from either a conventional management or tillage
system. In particular, cover crop species selection, the
degree of cover crop biomass and total N produced, and
successful termination of the cover crop to avoid competi-
tion with corn growth appear to be the most important
factors affecting corn yields.

All species derived a majority of their tissue N from
BNF, with most having more than 70% of the N derived
from N$_2$ fixation. Research on hairy vetch has shown that
peak N$_2$ fixation occurs between late April and early May.
This study supports the idea that roll-killing vetch during
this peak N period may result in both successful termina-
tion of legume cover crops and greater input of fixed N to
the agroecosystem. The high proportion of N derived from
BNF in legume tissues was consistent with previous find-
ings for other forage and cover crop legumes.

In the conventionally managed, N-fertilized control
plots, corn grain yield rarely responded to N applications
greater than 100 lb N/ac, suggesting that N was not the
limiting factor beyond this threshold. Two probable causes
for yield reductions at high N rates were weed competi-
tion and water stress. Despite herbicide application at
planting, increased weed populations were often observed.
in the highest N rate plots, suggesting that excess N led to increased weed competition.

The roller-crimper failed to kill all hairy vetch cultivars, common vetch, berseem clover, and Austrian winter pea at the early roll date in 2009. Even after attempted termination at these dates, cover crops continued to show vigorous growth and competition with the corn, resulting in severely decreased corn grain yields that were lower ($P < 0.05$) than the 0 N control plot yields. Table 1 shows that as termination dates progressed later in the season, corn yields from hairy vetch treatments increased and yields from corn planted into all hairy vetch cultivars (AU Early Cover, AU Merit, and Early Cover–Winter Hardy) at the late planting date in 2009 were comparable to the controls.

In 2010, the corn yields were greater following biculture mulches than following the individual legume stands ($P < 0.05$). An additional reason for the yield increase could be related to the mulch weed suppression ability. Research on rolled rye cover crops in soybean production has shown reduced weed populations under rolled rye leading to an increase in soybean yields.

**Conclusions**

From the data and observations collected in this study, it is clear that the ecology and agronomics of a no-till organic system in North Carolina are distinctly different from either a conventional no-till system or a more traditional organic system. The researchers hypothesized that cover crop treatments producing high amounts of biomass and acquiring significant N through BNF would be predictive of high corn grain yields. This was true for some cover crop × termination date combinations. In addition, corn yields from many cover crop treatments were less than or equal to those of the 0 N controls, regardless of termination date or biomass. This suggests that in a roller-crimper system, the choice of cover crop species, followed by biomass production, are the most important factors determining the success of the succeeding crop. While some data suggest that early maturing cultivars of hairy vetch result in increased yield over later-maturing cultivars, overall the cover crop treatments that resulted in higher corn yields required a later termination date than is traditionally used in this state, suggesting that producers who wish to use a roller-crimper system for organic corn production will have to adjust planting schedules to accommodate this late termination.

Cover crop biomass also appears to have an important effect on controlling weed populations as well as providing adequate N to the corn crop, but additional information on how rolled biomass and cover crop species affect weed interactions, soil N dynamics, and soil–water relations is needed. Before it can be recommended to farmers, there is still much to be investigated about the roller-crimper system. In the immediate future, however, farmers choosing to use a roller-crimper as a legume cover crop termination and N delivery tool should choose cover crops with low C/N ratios, such as hairy vetch, that are known to produce high amounts of biomass. Further studies investigating the potential pest management and drought risks that producers may face by shifting planting dates later in the season, and how these risks compare with those in a fertilized, conventionally managed, or more traditional organic system, are necessary before this system could be recommended for adoption.

This study examined the impact of roll-killing specific cover crop cultivars on a single season of corn but did not investigate how long-term use of a roller-crimper would affect an agroecosystem. Studies investigating how the long-term use of a roller-crimper in organic agriculture would affect soil C and N pools, soil structure and respiration, and other parameters known to be affected by no-till agriculture are also important for understanding how this system could be optimized.