Response of Snap Beans to Tillage and Cover Crop Combinations

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Abstract. Field experiments were conducted on a Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Paleudult) from 1983 through 1985 to determine the effects of tillage method, cover crop, and N fertilization on inorganic soil N and yield, yield components, and N content of snap bean (Phaseolus vulgaris L.). Hairy vetch (Vicia villosa Roth), Austrian winter pea (Pisum sativum ssp. arvense L. Poir), Austrian winter pea plus wheat, wheat, crimson clover (Trifolium incarnatum L.) and no cover were the cover crop treatments. Inorganic N concentrations generally were greater in soil with cover crop treatments containing legumes than in soil with no cover and wheat treatments. The use of Austrian winter pea, hairy vetch, and crimson clover as cover crops without supplemental N resulted in snap bean yields comparable to those obtained when 90 kg ha−1 additional N was supplied. Supplemental N decreased the amount of dry matter partitioned into pods. Inorganic N profiles in the soil indicated that conventional tillage (CT) practices resulted in greater mineralization of N fixed by the legume cover crops than no-tillage (NT) practices. However, snap bean yields for NT were comparable to or greater than those obtained with CT, suggesting that N released from legume residues provided sufficient supplemental N for optimum growth and yield.

Crop production using no-tillage (NT) management has gained widespread acceptance in the United States during the past two decades. Benefits commonly reported for NT crop production include reductions in soil erosion, reductions in fuel and labor requirements, increased land use, flexibility in planting and harvest operations, and improved soil water retention (1, 16, 17). However, more fertilizer N is often unavailable to plants under NT compared to conventional tillage (CT) because of increased immobilization (8, 18), denitrification (17), and leaching (21). Therefore, high rates of N fertilization are often required to obtain optimum yields of crops under NT management.

Although NT management has been used primarily for production of corn and soybeans, considerable work has demonstrated the adaptability of NT techniques to production of other crops, including many vegetables (9, 10, 12, 15). Many of the advantages of NT are dependent on the presence of a mulch from crop residues or a cover crop. Small grains have been the cover crops used most commonly for NT production of vegetables (9, 15). However, recent efforts have been directed toward the use of legume cover crops, because of the added benefit of partial to complete supply of the crop N requirement. Mitchell and Teel (11) reported that NT field corn (Zea mays L.) grown without N fertilization in mulches containing legumes had yields as high as corn grown in small grain stubble fertilized with 112 kg N/ha. Similar results using legumes and no N fertilization have also been obtained for NT grain sorghum [Sorghum bicolor (L.) Moench] (20) and CT cotton (Gossypium hirsutum L.) (22).

Yields of snap bean under NT management have been shown to be equal to (12) or greater than (10) those obtained using CT management. However, N fertilization is still normally required to maximize yield when small grain cover crops are used, since supply of N from N2-fixation is usually insufficient to meet crop requirements. The use of legume cover crops may provide the N necessary for optimum yields without addition of N fertilizers.

The objectives of this study were to evaluate the use of various cover crop combinations for production of snap beans under CT and NT management and to determine whether legume cover crops supply sufficient N during the growing season for snap bean production under the two management regimes.

Materials and Methods

General experimental practices. Field experiments were conducted on two similar sites at the Univ. of Maryland Vegetable Research Farm from 1983 through 1985 on a Norfolk loamy sand. The experimental design was a split-split plot with ran-
Fig. 1. Influence of tillage and cover crop on soil inorganic N profiles in 1984, \(\nabla\) hairy vetch; \(\nabla\) hairy vetch plus wheat; \(\circ\) Austrian winter pea; \(\bullet\) Austrian winter pea plus wheat; \(\square\) wheat; \(\blacksquare\) no cover.

Cover crops. The experimental sites were moldboard-plowed and disked prior to planting cover crops. Preplant fertilizer was incorporated at 20N-4P-17K (kg ha\(^{-1}\)) in 1983 and 22N-19P-74K (kg ha\(^{-1}\)) in 1984. Cover crops were planted in late September in both years. The seeding rates in 1983 were hairy vetch, 27 kg ha\(^{-1}\); hairy vetch plus wheat, 18 and 56 kg ha\(^{-1}\), respectively; Austrian winter pea, 101 kg ha\(^{-1}\); Austrian winter pea plus wheat, 67 and 56 kg ha\(^{-1}\), respectively; and wheat, 85 kg ha\(^{-1}\). A no-cover treatment was used in 1983-84. In 1984-85, the no-cover treatment was replaced by crimson clover seeded at 19 kg ha\(^{-1}\). The seeding rate of wheat was increased to 110 kg ha\(^{-1}\) when seeded alone and to 73 kg ha\(^{-1}\) when seeded in a grass-legume mixture in 1985 due to low dry matter yields in 1984. All cover crops were drilled, except crimson clover, which was broadcast by hand. Legume seeds were inoculated with the appropriate \textit{Rhizobium} spp. before planting.

Prior to treatment with herbicides, representative samples of top growth were obtained from 0.25-m\(^2\) sections of plots for estimation of dry matter and total N. The cover crops were killed with N-(phosphonomethyl) glycine (glyphosate) (2.24 kg ha\(^{-1}\)) and 1,1'-dimethyl-4,4'-bipyridinium salts (paraquat) (0.42 kg ha\(^{-1}\)) beginning in late Apr. 1984 and with paraquat (0.56 kg ha\(^{-1}\)) in mid-May 1985. The CT plots were plowed in mid-May each year, followed by disking.

Snap beans. Based on soil test results, 0N-39P-74K (kg ha\(^{-1}\)) in 1984 and 0N-20P-37K (kg ha\(^{-1}\)) in 1985 were broadcast on all plots prior to planting. Ammonium nitrate was broadcast by hand within a few days of planting. Snap beans (\textquoteleft Eagle\textquoteright) were planted at a rate of 33 seeds m\(^{-1}\) into the cover crop residues on the NT plots and into a disked seedbed on CT plots. Four rows per plot were planted 0.76 m apart on 13 June 1984. Five rows per plot were planted 0.73 m apart on 22 May 1985. One day after planting, herbicides were applied for weed control: glyphosate (1.68 kg ha\(^{-1}\)) and 2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl) acetamide (metolachlor) (1.68 kg ha\(^{-1}\)) in 1984, and paraquat (0.28 kg ha\(^{-1}\)) and metolachlor (0.84 kg ha\(^{-1}\)) in 1985. Supplemental irrigation was applied as needed during both growing seasons.

Pods from plants in 2.44-m sections of two inner rows were harvested on 1 Aug. 1984 and 18 July 1985 and then weighed and separated into sieve size grades with a mechanical grader. At harvest, plants in a 0.61-m section of each plot were removed at the soil surface and used to estimate total above-ground dry matter production, harvest index, vegetative N concentration, and pod N concentration. Pods were separated from vegetative tissue and both were dried at 65°C. Harvest index (HI) was calculated as the ratio of the dry pod weight to the total above-ground dry matter.

Soil sampling and N analyses. Soil samples were taken twice in 1984 and five times in 1985 to monitor inorganic N levels. Subsamples were taken randomly from nine different locations per plot at depths of 0 to 7.5, 7.5 to 15, and 15 to 30 cm. All cover and tillage treatments were sampled on 6 and 7 June 1984, before N fertilizer was applied. Plots fertilized with 90 kg N/ha were sampled on 23 and 24 July 1984. In 1985, crimson clover and wheat plots not fertilized with N were sampled at 12-day intervals. The first soil sampling date was 2 days before snap bean planting and the last sampling date occurred during early bloom. Before analysis, samples were air-dried, passed through a 2-mm sieve, and thoroughly mixed. Soil samples were analyzed for inorganic N using a steam distillation procedure (7). Before N analysis, dry leaf and stem tissue was chopped in a hammer mill and ground in a Wiley mill equipped with a 40-mesh sieve. Dry pod tissue was ground in a Wiley mill (40
Subsamples were analyzed for total N using the salicylic acid–thiosulfate modification of a semimicro-Kjeldahl procedure (2). Pod tissue from 1984 was not analyzed for total N.

Statistical analyses. Analysis of variance, analysis of covariance, and general linear models were conducted according to procedures provided by the SAS Institute (Cary, N.C.). The Waller–Duncan multiple comparison procedure (BLSD) was used to compare means (k = 100). Analysis of variance was conducted on log(x + 1)-transformed soil inorganic N data for each depth on the first sampling data in 1984 and for each depth over time in 1985. Sieve size 4 was used as a covariate in the analysis of covariance for yield in 1984 because maturity was affected by treatment. Planned comparisons were made for certain treatments using single degree-of-freedom contrasts.

Results and Discussion

Cover crops. Hairy vetch produced the highest and wheat the lowest amount of dry matter in 1984 (Table 1). Conversely, wheat and legume–wheat mixtures produced the highest dry matter in 1985. Hairy vetch dry matter production was reduced in 1985 due to water stress (49.4 and 88.6 cm of precipitation during 1984–1985 and 1983–1984, respectively). Dry matter production of Austrian winter pea was reduced in both years by diseases such as Sclerotinia wilt.

Hairy vetch and Austrian winter pea tissues had the highest total N concentrations in both years (Table 1). The N concentration of hairy vetch, hairy vetch plus wheat, and Austrian winter pea tissues was lower in 1985 than in 1984 because the percentage of hairy vetch in the hairy vetch–wheat mixture was visibly reduced and cover crops were more mature when killed in 1985 than in 1984.

Hairy vetch had the highest N content in 1984 and the lowest in 1985 (Table 1). The legume–wheat mixtures had a greater N content than wheat in 1984 and 1985 (P ≤ 0.05 in 1985 calculated from a wheat vs. legume–wheat mixtures contrast).

Soil inorganic N concentration. On 7 June 1984, N concentrations were increased in the 0 to 7.5-cm layer of NT soils (P ≤ 0.01), whereas CT soils had greater N concentrations in the two deep layers (Fig. 1). Higher inorganic N below 7.5 cm in CT soils probably was due to greater mineralization and less loss due to leaching (21) and denitrification than in NT soils (17).

Soil N concentrations on the first sampling date were highest in hairy vetch plots at all depths, but differences were not always significant. Austrian winter pea and legume–wheat mixtures
Table 2. Effect of tillage method and N rate on pod yield, dry matter production, and harvest index (HI) of snap beans in 1984 and 1985.

<table>
<thead>
<tr>
<th>N rate</th>
<th>Tillage</th>
<th>Pod yield (t·ha⁻¹)</th>
<th>Dry matter production (t·ha⁻¹)</th>
<th>HI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1984</td>
<td>1985</td>
<td></td>
</tr>
<tr>
<td>0 kg·ha⁻¹</td>
<td>CT</td>
<td>6.9</td>
<td>2.5</td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td>NT</td>
<td>6.7</td>
<td>1.8</td>
<td>0.31</td>
</tr>
<tr>
<td>90 kg·ha⁻¹</td>
<td>CT</td>
<td>6.5</td>
<td>3.3</td>
<td>0.18</td>
</tr>
<tr>
<td></td>
<td>NT</td>
<td>6.9</td>
<td>2.1</td>
<td>0.22</td>
</tr>
</tbody>
</table>

Significant F value for

C**, N** T × N*

C*, N**

T**, C*

N**

C × N*

*Significant at the 5% or 1% levels, respectively (T = tillage, C = cover crop, N = nitrogen rate).

Table 3. Main effect of cover crop on pod yield, dry matter production, and harvest index (HI) of snap beans in 1984.

<table>
<thead>
<tr>
<th>Cover crop</th>
<th>Pod yield (t·ha⁻¹)</th>
<th>Dry matter production (t·ha⁻¹)</th>
<th>HI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hairy vetch</td>
<td>7.3</td>
<td>2.9 a</td>
<td>0.22 b</td>
</tr>
<tr>
<td>Hairy vetch plus wheat</td>
<td>6.8</td>
<td>2.3 bc</td>
<td>0.21 b</td>
</tr>
<tr>
<td>Austrian winter pea</td>
<td>7.0</td>
<td>2.5 a</td>
<td>0.24 ab</td>
</tr>
<tr>
<td>Austrian winter pea plus wheat</td>
<td>7.3</td>
<td>2.9 a</td>
<td>0.23 b</td>
</tr>
<tr>
<td>Wheat</td>
<td>6.6</td>
<td>2.0 c</td>
<td>0.24 ab</td>
</tr>
<tr>
<td>No cover</td>
<td>5.7</td>
<td>1.9 c</td>
<td>0.27 a</td>
</tr>
</tbody>
</table>

*Mean separation in columns by the Waller-Duncan Bayesian k-ratio t test (k = 100). Mean separation given only if cover crop was significant at the 5% level or less.

Table 4. Effect of cover crop and N rate on pod yield and dry matter production of snap beans in 1985.

<table>
<thead>
<tr>
<th>Cover crop</th>
<th>Pod yield (t·ha⁻¹)</th>
<th>Dry matter production (t·ha⁻¹)</th>
<th>N rate (kg·ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hairy vetch</td>
<td>10.6 a</td>
<td>0.6 ab</td>
<td>0.6 ab</td>
</tr>
<tr>
<td>Hairy vetch plus wheat</td>
<td>9.7 b</td>
<td>0.6 ab</td>
<td>0.3 ab</td>
</tr>
<tr>
<td>Austrian winter pea</td>
<td>13.0 a</td>
<td>0.6 ab</td>
<td>0.6 ab</td>
</tr>
<tr>
<td>Austrian winter pea plus wheat</td>
<td>10.0</td>
<td>0.6 ab</td>
<td>0.6 ab</td>
</tr>
<tr>
<td>Wheat</td>
<td>7.8 b</td>
<td>0.6 ab</td>
<td>0.6 ab</td>
</tr>
<tr>
<td>Crimson clover</td>
<td>9.7 b</td>
<td>0.6 ab</td>
<td>0.6 ab</td>
</tr>
</tbody>
</table>

*Mean separation in columns by the Waller-Duncan Bayesian k-ratio t test (k = 100).

Generally had intermediate N concentrations and wheat and no cover the lowest. Ebelhar et al. (4) also found that the hairy vetch treatment had a greater N concentration than rye, crimson clover, big flower vetch, and corn residue treatments in the 0 to 7.5-cm layer 2 to 4 weeks after killing the cover crops and applying N fertilizer.

On 24 July 1984, NT soils had greater N concentrations in the 0 to 7.5-cm layer than CT soils (P ≤ 0.05) (Fig. 1). All other main effects and interactions were nonsignificant. Ebelhar et al. (4) also observed that N levels were similar for all cover treatments under NT by the end of July in plots fertilized with 100 kg N/ha. The highest concentrations of N occurred in the 15- to 30-cm layer under CT and in the 7.5- to 15- and 15- to 30-cm layers under NT, apparently due to the leaching of nitrate into the soil profile and plant uptake.

In 1985, higher concentrations of soil N generally occurred under CT than under NT, although differences were significant only in the 15- to 30-cm layer (P ≤ 0.05) (Fig. 2). Crimson clover was killed following seed set, which enabled self-seeding and establishment of a living mulch. Therefore, CT soils probably had higher concentrations of N than NT soils due to greater levels of mineralization and less plant uptake. There was a significant tillage × time interaction at all depths (P ≤ 0.01 for the 0- to 7.5- and 15- to 30-cm depths, P ≤ 0.05 for the 7.5- to 15-cm depth). Under CT, the concentration of N was lower in the 0- to 7.5-cm layer than in the other layers 12 and 24 days after the initial sampling date (P ≤ 0.05), and this low concentration on day 24 coincided with a large increase in N at the 15- to 30-cm depth (6.4 cm of precipitation was received between day 12 and day 24). The 0- to 7.5-cm layer in CT and NT soils had lower N concentrations than the other layers on the final sampling date (P ≤ 0.01), apparently due to leaching of nitrate and plant uptake.

Overall, there were greater concentrations of soil N in crimson clover plots than in wheat plots (Fig. 3). Low N concentration in the surface layer of crimson clover plots on day 24 coincided with a large increase in N at the 15- to 30-cm depth. Nitrogen concentrations of crimson clover and wheat treatments were not significantly different 48 days after the initial sampling date.

Pod yield. In 1984, pod yields were not affected by tillage
Table 6. Tillage × N rate and Cover × N rate interactions for snap bean N content in 1984 and 1985.

<table>
<thead>
<tr>
<th>N rate (kg ha⁻¹)</th>
<th>1984</th>
<th>1985</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatments</td>
<td>≤3</td>
<td>4</td>
</tr>
<tr>
<td>CT</td>
<td>56</td>
<td>42</td>
</tr>
<tr>
<td>NT</td>
<td>59</td>
<td>40</td>
</tr>
<tr>
<td>90</td>
<td>56</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td>67</td>
<td>32</td>
</tr>
</tbody>
</table>

Significant F value for

- **T x N**
- **T x N**
- **T x C**

*Significant at the 5% or 1% levels, respectively (T = tillage, C = cover crop, N = nitrogen rate).

Table 5. Effect of tillage method and N rate on snap bean size in 1984 and 1985.

<table>
<thead>
<tr>
<th>N rate (kg ha⁻¹)</th>
<th>1984</th>
<th>1985</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tillage treatment</td>
<td>≤3</td>
<td>4</td>
</tr>
<tr>
<td>CT</td>
<td>56</td>
<td>42</td>
</tr>
<tr>
<td>NT</td>
<td>59</td>
<td>40</td>
</tr>
<tr>
<td>90</td>
<td>56</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td>67</td>
<td>32</td>
</tr>
</tbody>
</table>

Significant F value for

- **T x N**
- **T x N**
- **T x C**

*Significant at the 5% or 1% levels, respectively (T = tillage, C = cover crop, N = nitrogen rate).

Method or N fertilization (Table 2), although yields were 7% lower in wheat plots than in legume-containing cover crop plots (Table 3). Yields were higher with cover than without cover (P ≤ 0.05), presumably due to greater moisture and nutrient conservation.

In 1985, there was a yield response to NT that was enhanced further by N fertilization (Table 2). The 1985 growing season was drier than the 1984 growing season. Moreover, snap beans were planted 33 days after incorporating the cover crops in CT method or N fertilization (Table 2), although yields were 7% lower in wheat plots than in legume-containing cover crop plots (Table 3). Yields were higher with cover than without cover (P ≤ 0.05), presumably due to greater moisture and nutrient conservation.

In 1985, there was a yield response to NT that was enhanced further by N fertilization (Table 2). The 1985 growing season was drier than the 1984 growing season. Moreover, snap beans were planted 33 days after incorporating the cover crops in CT plots in 1984 compared to 8 days in 1985, so fertilizer N may have been immobilized to a greater extent in 1985 than in 1984. Therefore, leaching of nitrate and denitrification may have lessened during the 1985 growing season, providing a possible explanation for the response to fertilizer N. In addition, snap bean yields are reduced at low soil moisture tensions in sandy soils (19), so increased yields in 1985 with NT were possibly attributable to the increased soil water content of NT soils (1, 17).

In 1985, pod yields from NT plots were higher than those from CT plots, and yields were further enhanced by N fertilization. However, N fertilization did not increase yields from plots containing legumes alone (Table 4), but did increase yields from the legume–wheat and wheat plots (single degree of freedom contrasts). Thus, the use of legume cover crops apparently provided sufficient N to achieve optimum yields of snap beans, and this likelihood is supported by the quantities of N released by the cover crops (Figs. 1 and 3). Yields from crimson clover plots were lowest among the legume and legume–wheat cover combinations, yet were nearly 20% higher than those obtained from wheat cover when no supplemental N was supplied. Others also have observed lower crop yields in crimson clover plots than in hairy vetch plots, possibly attributable to the higher C:N ratio of crimson clover (3, 4). No-tillage snap bean yields probably were reduced in crimson clover plots compared to other legumes due to competition for water between crimson clover plants that self-reseeded and snap bean plants. Reseeding crimson clover has been used successfully as a source of N for grain sorghum production (20), and also may have potential for commercial snap bean production if soil moisture stress can be avoided.

Sieve size. In 1984, N fertilization had little effect on maturity in CT plots, but, in NT plots, applied N lowered the percentage of sieve size 4 pods (Table 5). Peck and MacDonald (14) found that fertilizer N decreased the yield of sieve size 6 pods at an early harvest date, but at a later harvest date there were few differences in large pod yields due to fertilizer N. They attributed the reduced yield of sieve size 6 pods on an early harvest date to decreased seedling growth. Snap bean development may have been delayed with NT because surface temperatures are usually greater in CT soils than in NT soils early in the growing season (5, 6). Conversely, plots fertilized with N in 1985 had an increased percentage of pods that were sieve size 5 and greater, but the reason for this increase was not apparent.

Dry matter production and partitioning. In both years, total dry matter production of snap beans was increased by N fertilization for both CT and NT treatments (Table 2), in contrast to the findings of Peck and MacDonald (14). Also, partitioning of dry matter into pods (HI) was decreased with N fertilization, which agrees with the findings of Nichols (13). Greater dry matter production occurred on CT than on NT plots in 1984, but did not translate into higher pod yields. This result was attributed to greater partitioning of dry matter into vegetative growth on CT plots and was reflected in the overall lower HI than on NT plots. In 1985, the drier of the two seasons, partitioning of dry matter into pods (HI) was 1.5 to 2.0 times greater than in 1984, but was nearly the same on CT and NT plots.
However, the greater quantity of source (dry matter production) from NT plots resulted in higher pod yields than from CT. In general, cover crop had little influence on partitioning of dry matter, except in 1984, when the no cover treatment resulted in the highest HI.

Nitrogen content of snap bean tissues. There was a significant tillage method × N rate interaction for the N content of leaf and stem tissue in 1984 (Table 6). The N content of leaf and stem tissue was greatest in hairy vetch and Austrian winter pea plus wheat treatments in 1984 and lowest in hairy vetch plus wheat, wheat, and no cover treatments (BLSD, k = 100). In 1985, there was little difference between tillage methods in terms of N accumulation, but N fertilization significantly increased the N content of pods, leaves, and stems (Table 6). Peck and MacDonald (14) also found that the N content of snap bean tissues increased as N fertilization rates increased. However, snap bean leaf, stem, and pod tissues from Austrian winter pea and crimson clover treatments showed little or no response to N fertilization. In addition, legume-containing cover crops, with the exception of hairy vetch plus wheat, had the highest N content in stem and leaf tissues when no N was applied, but, when N was applied, N content followed the same trends as yield and dry matter production with fertilization.

In summary, NT management of snap beans was shown to have strong commercial potential for a range of cover crop combinations. Fertilizer N was not required when hairy vetch and Austrian winter pea were used as cover crops; yet, these two cover crops did not provide consistent protection from soil erosion. The use of crimson clover as a cover crop may provide additional benefits of reseeding itself, possibly eliminating the need for land preparation and planting steps for this cover crop in late summer or early fall. To maximize N2-fixation and dry matter production of legume cover crops, further work needs to be done to a) develop and evaluate disease resistant, drought tolerant cultivars, and b) determine optimum seeding rates for legumes grown in monocultures and mixtures.

Literature Cited