Winter Cereal Canopy Effect on Cereal and Interseeded Legume Productivity

Brock C. Blaser,* Jeremy W. Singer, and Lance R. Gibson

ABSTRACT

Interseeding red clover (Trifolium pratense L.) or alfalfa (Medicago sativa L.) into winter cereals in the North Central United States can provide forage and a green manure crop. We hypothesized that winter cereal canopy traits such as leaf area index (LAI) and whole plant dry matter (DM) would influence interseeded legume establishment and productivity, yet the effect of canopy traits on resource competition in intercropping systems is not well understood. This study was conducted from 2005 to 2007 to evaluate the impact of diverse cereal canopy traits on the establishment of frost-seeded legume intercrops. In March, red clover and alfalfa were frost-seeded into three winter wheat (Triticum aestivum L.) and three triticale (X Triticosecale Wittmack) varieties selected for differences in maximum LAI, plant height, and DM. Across three growing seasons, the cereals produced a range of LAI from 2.1 to 6.2 and whole plant harvest DM of 817 to 2029 g m⁻². In the 2 yr with legume data, densities were influenced by cereal 1 yr and DM was affected by cereal both years. Alfalfa and red clover densities were similar, yet DM production was 42% higher in red clover 40 d after grain harvest. The presence of a legume intercrop did not affect grain yield, but reduced weed densities and weed DM 40 d after harvest. Producers implementing this intercrop may select cereal varieties based on grain yield, but must be cautious of varieties known to produce above normal LAI values because of the potential to reduce legume productivity.

Incorporating winter cereal grains into the North Central U.S. corn (Zea mays L.)–soybean (Glycine max [L.] Merr.) system could extend the rotation and increase yields of subsequent crops (Crookston et al., 1991; Singer and Cox, 1998), build soil tilth (Brady and Weil, 2000), reduce erosion (Zhu et al., 1989), and improve N capture (Nance et al., 2007). Addition of a legume intercrop decreases the fallow period after grain harvest, provides a forage crop to use solar energy (Singer et al., 2007), and provides N to subsequent crops as a green manure (Hesterman et al., 1992). The presence of a forage crop during the traditional fallow period has also been reported to promote populations of beneficial insects (Hartwig and Ammon, 2002) and suppress weed growth (Mutch et al., 2003; Blaser et al., 2006).

Red clover has been successfully frost-seeded into winter cereals (Hesterman et al., 1992; Blaser et al., 2006; Singer et al., 2006). However, winter cereal species effects on the productivity of the interseeded legume has been variable (Blaser et al., 2006; Klebesadel and Smith, 1959; Flanagan and Washko, 1950). Blaser et al. (2006) reported that triticale lowered red clover postharvest plant density 18% compared with wheat in 1 of 2 yr while Klebesadel and Smith (1959) reported 35 and 51% more alfalfa and red clover plants grown under a spring wheat variety compared to a winter wheat variety, respectively. Additionally, interseeded legume effects on grain yields have been inconsistent (Brandt et al., 1989; Hesterman et al., 1992; Thiessen Martens et al., 2001). Winter wheat yields were reduced an average of 43% with interseeded subterranean clover (T. subterraneum L.) compared with wheat alone in 1 of 3 yr, were 48% higher than interseeded plots in another year, and were similar in a third year (Brandt et al., 1989).

Tesar and Marble (1988) claimed that using winter cereals as companion crops for alfalfa establishment was less effective because winter cereals were too competitive compared with spring cereals. To better understand the intercrop relationship and select cereal varieties that are compatible with red clover and alfalfa establishment, canopy traits that impact legume productivity must be quantified. Light transmittance to the legume was reported to be a critical factor limiting legume establishment as an intercrop (Klebesadel and Smith, 1959) and is directly influenced by measurable canopy traits. We hypothesized that as canopy traits such as LAI and whole plant DM increase, interseeded legume productivity would decrease. Therefore our objectives were to (i) quantify the LAI and whole plant DM of six winter cereals exhibiting diverse canopies, and (ii) measure the impact of these traits on interseeded red clover and alfalfa establishment and productivity.

MATERIALS AND METHODS

This winter cereal grain/legume intercrop study was conducted from 2005 to 2007 at the Iowa State University Agronomy and Agricultural Engineering Farm near Ames, IA (42°’00’ N, 93°’50’ W; elevation 341 m above sea level). Treatments were arranged as a split-block with four replicates with cereal grain varieties as main plots and legume varieties as subplots. ‘Décor’, ‘Lamberto’, and ‘NE426GT’ winter triticale varieties and ‘Ernie’ and ‘Kaskaskia’ soft red and ‘Goodstreak’ hard

Abbreviations: DM, dry matter; FHE, full head extension; LAI, leaf area index.
red winter wheat varieties were no-till planted into recently harvested soybean fields with Nicotlet loam (fine-loamy, mixed, superactive, mesic Aquic Hapludolls) soil in 2004 and 2006 and Webster loam (fine-loamy, mixed, superactive, mesic Typic Endo-aquolls) soil in 2005. Cereal varieties were selected to provide a broad range of canopy characteristics including maximum LAI (3.4–4.7) and plant heights (96–132 cm) based on previous studies (Skrla and Jannink, 2004; Iutzi, 2006). Cereals were planted at 3,000,000 seeds ha\(^{-1}\) on 5 Oct. 2004, 7 Oct. 2005, and 6 Oct. 2006 using a tractor-mounted 3.8-m wide John Deere 1520 grain drill (John Deere Co., Moline, IL) with 15-cm row widths. The planted area for each cereal variety was 7.6 by 30 m.

In 2005, ‘Cherokee’ red clover was frost-seeded in subplots within each cereal grain treatment on 23 March. ‘Marathon’ red clover and ‘Mycogen 4375LH’ alfalfa were frost-seeded on 29 March. In 2006 and 2007 all three legumes were frost-seeded on 15 and 20 March, respectively. Legumes were seeded at 9,000,000 seeds ha\(^{-1}\) using a tractor-mounted, 3.66 m wide Gandy Model no. 1012T-TBM drop spreader (Gandy Co., Owatonna, MN). Due to no seed supply in 2007, Cherokee was replaced with the genetically similar red clover variety ‘Southern Belle’ (Quesenberry et al., 2005). Southern Belle was developed through a combination of recurrent selection processes using Cherokee as the base population and initial production trials reported similar yields between the two varieties. Cherokee and Marathon were selected for high DM production and diversity in origin, below 38° North and Wisconsin, respectively (Singer et al., 2006). Mycogen 4375LH alfalfa (hereafter referred to as alfalfa), a commercially available and locally adapted variety with a fall dormancy rating of 3.8, was included to evaluate frost-seeded alfalfa establishment success under winter cereals managed for grain. A fourth subplot within each cereal grain variety was a check plot with no legume seeded. Each subplot area occupied 7.6 by 7.3 m. All plots were broadcast fertilized with 45 kg N ha\(^{-1}\) in the form of NH\(_4\)\(_2\)NO\(_3\) on 4 Apr. 2005, 29 Mar. 2006, and 9 Apr. 2007. In 2006, 60 kg P ha\(^{-1}\) in the form of NH\(_4\)\(_2\)HPO\(_4\) was also applied on 29 March.

### Cereal Canopy and Dry Matter Measurements

Cereal canopy LAI was measured every 18 d beginning at jointing (growth stage [GS] 30; Zadoks et al., 1974) through grain harvest. These measurements were initiated on 21 Apr. 2005, 24 Apr. 2006, and 4 May 2007. Data were obtained using the LAI-2000 Plant Canopy Analyzer (LI-COR Inc., Lincoln, NE) by placing the light sensor in the interrow of two untrafficked grain rows and just above the legume canopy. One above (incident) and two below (extension) samples were collected on 7 June 2005, 5 June 2006, and 11 June 2007. Time of FHE was determined when the api- head extension samples were collected on 7 June 2005, 5 June 2006, and 11 June 2007. Time of FHE was determined when the api- peak head extension reached the kernel hard stage (GS 92). Plant DM samples at grain maturity were collected on 12 July 2005, 10 July 2006, and 11 July 2007. When both samplings, the cereal DM was clipped at the soil surface from two 0.5 m\(^2\) quadrats per subplot. Samples were oven dried at 60°C until constant weight and a whole sample DM weight was recorded.

### Cereal Yield and Yield Components

All yield and yield components were determined from the DM samples collected at grain maturity. Spikes m\(^{-2}\) was counted before threshing the grain. The threshed grain sample was weighed to determine subplot grain yield and 1000-kernel weight from two random subsamples. Kernels spike\(^{-1}\) for each cereal species was calculated from the total yield, spikes m\(^{-2}\), and 1000-kernel weight data. Whole grain moisture was measured by drying 10 g of grain at 130°C for 19 h and weighing (ASAE Method S352.2). Final subplot grain yield was reported on a 135 g kg\(^{-1}\) moisture basis. The harvest index (HI) was calculated as grain dry weight divided by total aboveground DM.

A 30-g subsample of grain was ground using an Udy cyclone sample mill (Udy Corp., Ft. Collins, CO) to pass a 0.5 mm screen. Moisture content of the ground grain subsample was determined by drying 2 to 3 g of ground grain at 130°C for 1 h and weighing (AACC Method 44-15A). Ground grain samples were analyzed for N concentration using the Dumas combustion method (AOAC Method 990.03). Percent crude protein was calculated from total N multiplied by the factor of 5.7 for wheat or 6.25 for triticale and was adjusted for moisture content.

All six cereal varieties were machine harvested using a Massey Ferguson Model 25 combine (Sampo Rosenlew Ltd., Pori, Finland) on the same day, regardless of maturity date. Harvests occurred on 13 July 2005, 17 July 2006, and 13 July 2007. The straw was baled and removed the day of grain harvest. After the straw was baled in 2005 and 2006, a forage harvester was used to cut excess stubble to 6 cm. In 2007, the stubble height after combining was 6 cm, so no additional stubble management was necessary. Excess stubble and straw were removed to prevent smothering of the underseeded legumes.

### Legume and Weed Density and Dry Matter

Legume plant densities were measured before cereal grain harvest by counting the plants within one 0.5 m\(^2\) quadrat per subplot on 8 July 2005 and 14 July 2006. Legume shoot DM was determined 40 d after grain harvest by clipping plants 6 cm above the soil surface from two 0.25 m\(^2\) quadrats per subplot. These samplings occurred on 22 Aug. 2005, 25 Aug. 2006, and 25 Aug. 2007. Weed density and DM 40 d after grain harvest were assessed at the same time and from the same 0.25 m\(^2\) quadrats as the 40 d legume DM. Both legume and weed DM samples were oven dried at 70°C until constant weight.

### Weather Data

Weather conditions during the study and long-term climatic data were obtained from the Iowa Environmental Mesonet (IEM, 2008). Daily maximum and minimum air temperature and rainfall totals were recorded from a weather station located 0.5 km from the experimental site (Table 1). Growing degree days (GDD) were calculated beginning 1 March of each season using the formula: GDD = Σ {[(daily max. temp. + daily min. temp.)/2] – base temp.} > 0 with base temperature = 0°C. Between frost-seeding on 20 Mar. 2007 and 3 Apr. 2007, observed average daily air temperature was 13°C and total rainfall was 58 mm. These optimum growing conditions resulted in a high percentage of...
Table 1. Average monthly air temperature and rainfall near Ames, IA†, for 2005 to 2007. Thirty-year averages were computed from data collected approximately 0.5 km from the experimental site from 1975 to 2004.

<table>
<thead>
<tr>
<th>Month</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>30-yr</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>30-yr</th>
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<tr>
<td>Air temperature</td>
<td>°C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>March</td>
<td>3.0</td>
<td>3.3</td>
<td>6.0</td>
<td>2.8</td>
<td>35</td>
<td>74</td>
<td>81</td>
<td>53</td>
</tr>
<tr>
<td>April</td>
<td>12.8</td>
<td>13.1</td>
<td>8.7</td>
<td>10.3</td>
<td>82</td>
<td>109</td>
<td>153</td>
<td>93</td>
</tr>
<tr>
<td>May</td>
<td>15.5</td>
<td>17.0</td>
<td>19.0</td>
<td>16.5</td>
<td>111</td>
<td>55</td>
<td>169</td>
<td>112</td>
</tr>
<tr>
<td>June</td>
<td>23.0</td>
<td>22.1</td>
<td>22.2</td>
<td>21.4</td>
<td>124</td>
<td>21</td>
<td>52</td>
<td>119</td>
</tr>
<tr>
<td>July</td>
<td>24.1</td>
<td>24.4</td>
<td>23.8</td>
<td>23.5</td>
<td>104</td>
<td>141</td>
<td>75</td>
<td>112</td>
</tr>
<tr>
<td>August</td>
<td>22.1</td>
<td>22.6</td>
<td>24.1</td>
<td>22.1</td>
<td>172</td>
<td>156</td>
<td>200</td>
<td>120</td>
</tr>
<tr>
<td>Rainfall</td>
<td>mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Legume germination. From 4 to 9 Apr. 2007, a severe frost event occurred with average daily temperatures of –3.2°C and average low temperatures of –8.1°C. Damage to both cereals and legumes was observed and the few legume plants that survived or germinated after the frost event were not adequate for data analysis. Consequently, no legume data are presented for 2007.

Statistical Design and Analysis

The experimental design was a randomized complete block in a split-block treatment arrangement. Statistical analysis was performed using PROC MIXED of the Statistical Analysis System Version 9.1 (SAS Institute, Cary, NC). A Fisher’s protected LSD (α = 0.05) was used for all mean separation tests. Year, variety, and legume were treated as fixed effects. Initial analyses resulted in a significant year effect, so all data are presented by year. The linear model was $Y_{ijk} = \mu + B_{i} + V_{j} + BV_{ij} + L_{k} + BL_{ik} + VL_{jk} + BVL_{ijk}$, where B represented blocks or replicates, V represented cereal variety, and L represented legume variety.

RESULTS AND DISCUSSION

Cereal Grain Production

Grain yield was affected by cereal variety in all three study years (Table 2). However, no legume or cereal variety × legume interaction effects were observed for grain yield, yield components or grain protein in any study year. In 2005, NE426GT triticale and Kaskaskia wheat were the highest yielding varieties and Décor triticale and Ernie wheat were the lowest. Grain yields were similar among varieties in 2006 with an average of 6.3 Mg ha$^{-1}$. This average was 30% higher than the 2005 average grain yield and 47% higher than the 2007 yields. In 2007, maximum grain yields were observed from Décor and Kaskaskia, but the six varieties averaged only 3.3 Mg ha$^{-1}$. The substantially higher grain yields in 2006 were related to the drier conditions during the grain filling period which was ideal for increased kernel weight and number (Tables 1 and 2). Similar dry conditions occurred in 2007, but yields were limited by cereal grain stands damaged by frost in early April. Average wheat and triticale yields were 1.0 Mg ha$^{-1}$ lower in 2005, 0.9 Mg ha$^{-1}$ higher in 2006, and 2.2 Mg ha$^{-1}$ lower in 2007 compared to 7 and 3 yr wheat and triticale averages recorded in Iowa (Skrdla and Jannink, 2004).

The three wheat varieties averaged 36% more spikes m$^{-2}$ than the three triticale varieties in both 2005 and 2006, while the trend was reversed for kernels spike$^{-1}$ in both years (Table 2). Triticale varieties averaged 38 and 26% more kernels spike$^{-1}$ than wheat varieties in 2005 and 2006. Thousand-kernel weight did not follow a species trend as the highest weights were recorded for Goodstreak and NE426GT in 2005 and Ernie and Décor in 2006. No cereal grain yield component differences were observed in 2007. Décor had the highest grain protein content of all six varieties in 2005 and 2007 with 15.9 and 14.0 g kg$^{-1}$, while 2006 grain protein differences among species were minor (Table 2). When interseeding subterranean clover into winter wheat, Brandt et al. (1989) reported both a grain yield increase and decrease in the presence of the legume in separate years. The legume intercrop also caused a significant increase in kernels spike$^{-1}$ and spike m$^{-2}$ in 1 yr and lower grain N concentration in a separate year. However, the presence of a legume intercrop in this study had no effect on grain yield, yield components, or grain protein.

Cereal Grain Canopy

Cereal grain whole plant DM was collected when plants reached FHE and maturity just before grain harvest. In 2005, NE426GT and Lamberto produced the greatest DM at FHE while Goodstreak and NE426GT produced the greatest DM in 2007. Décor and Ernie produced the least DM in both 2005 and 2007. No differences among varieties were observed for FHE DM in 2006. Average DM increase from the FHE to maturity DM harvest was 8% in 2005 and 2007 and 47% in 2006 (Table 3). These observed whole plant DM averages for wheat and triticale were similar to average winter triticale DM reported
by Gibson et al. (2007) and Schwarte et al. (2005) who used similar triticale varieties in central Iowa from 2003 to 2005.

Ernie, Kaskaskia, and NE426GT averaged a 19% greater HI compared to the average of Goodstreak, Décor, and Lamberto in 2005 (Table 3). In 2006, Lamberto had a 13% lower HI than all other varieties. More dramatic differences were observed in 2007 because of the variability in crop stands. Ernie and Décor averaged a HI of 0.59 compared with the lowest two varieties, Goodstreak and NE426GT, averaging 0.31. A cereal variety × legume interaction was observed for HI in 2005 when Ernie produced a 0.08 higher HI and NE426GT produced a 0.07 lower HI in subplots containing Marathon red clover compared to the other cereals and legume treatments (data not shown).

Leaf area index measurements were initiated at jointing (GS 31) which occurred in late April in 2005 and 2006 (430 GDD) and early May 2007 (570 GDD; Fig. 1). In 2005, all varieties surpassed a LAI of 4.0 by 630 GDD and obtained maximum values of between 4.5 and 6.2 near the end of May. Lamberto had higher values throughout the season, averaging 0.8 higher LAI than Goodstreak and NE426GT. Average maximum LAI values in 2006 were 3.9 with Lamberto, Ernie, and Goodstreak exceeding 4.0 for a brief period at 980 GDD. Maximum LAI values in 2007 averaged 2.8. Goodstreak had the maximum LAI for the season averaging 0.4 greater LAI than the next closest variety, NE426GT. Due to the crop stand reduction from the spring frost, no varieties produced LAI values comparable to the previous two seasons. Peak LAI values for winter wheat and triticale have been reported between 4.0 and 5.0 which corresponds to LAI observed in 2006 and 2007 (Picard et al., 2010; Ellen, 1993). However, peak LAI values over 6.0, as observed in 2005, are less common and typically associated with cereals used for dual-purpose (grazed by livestock in the winter and then allowed to produce grain for harvest in the summer) or forage (Royo and Blanco, 1999; Royo and Tribo, 1997).

All varieties produced maximum LAI near anthesis (GS 69) each season. Leaf area index started to decline as nutrients were remobilized from vegetative to reproductive growth. However, when comparing the LAI and grain yield in 2005 and 2006, the higher LAI in 2005 did not result in higher grain yields compared with 2006, which could be attributed to rainfall events in both years (Tables 1 and 2; Fig. 1). When compared with optimum irrigation for winter wheat, Day and Intalap (1970) reported a 48% yield loss when water was limited during jointing (GS 30). Below average rainfall in March and April 2005 corresponded to jointing of the cereals in this study and may have limited grain yield potential. Day and Intalap (1970) also reported a 42 and 37% yield loss when water was limited during flowering (GS 69) and soft dough (GS 85), respectively. The time period for flowering and soft dough in 2006 also corresponded to below average rainfall in May and June. However, normal rainfall amounts for central Iowa have been reported to limit winter cereal yield in

### Table 3. Winter cereal whole plant dry matter (DM) at full head extension (FHE) and grain maturity, and harvest index (HI) near Ames, IA, from 2005 to 2007.

<table>
<thead>
<tr>
<th>Cereal variety†</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FHE DM†</td>
<td>Maturity DM§</td>
<td>HI</td>
</tr>
<tr>
<td>Ernie</td>
<td>1029</td>
<td>1069</td>
<td>0.35</td>
</tr>
<tr>
<td>Kaskaskia</td>
<td>1210</td>
<td>1336</td>
<td>0.38</td>
</tr>
<tr>
<td>Goodstreak</td>
<td>1295</td>
<td>1413</td>
<td>0.31</td>
</tr>
<tr>
<td>NE426GT</td>
<td>1416</td>
<td>1619</td>
<td>0.36</td>
</tr>
<tr>
<td>Décor</td>
<td>1163</td>
<td>1309</td>
<td>0.29</td>
</tr>
<tr>
<td>Lamberto</td>
<td>1423</td>
<td>1461</td>
<td>0.28</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>116</td>
<td>150</td>
<td>0.03</td>
</tr>
</tbody>
</table>

† Ernie and Kaskaskia are soft red winter wheat, Goodstreak is hard red winter wheat, and NE426GT, Décor, and Lamberto are winter triticale varieties.
¶ ns, not significant.
Table 4. Frost-seeded Cherokee and Marathon red clover (RC) and Mycogen 4375LH alfalfa densities at grain harvest and legume dry matter (DM), weed densities and DM 40 d after grain harvest near Ames, IA, from 2005 to 2006.

<table>
<thead>
<tr>
<th></th>
<th>2005</th>
<th></th>
<th></th>
<th></th>
<th>2006</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Legume density †</td>
<td>Legume DM ‡</td>
<td>Weed density</td>
<td>Weed DM</td>
<td>Legume density</td>
<td>Legume DM</td>
<td>Weed density</td>
<td>Weed DM</td>
</tr>
<tr>
<td></td>
<td>plants m⁻²</td>
<td>g m⁻²</td>
<td>plants m⁻²</td>
<td>g m⁻²</td>
<td>plants m⁻²</td>
<td>g m⁻²</td>
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<tr>
<td>Cereal variety §</td>
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<td></td>
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<tr>
<td>Ernie</td>
<td>53</td>
<td>191</td>
<td>12</td>
<td>59</td>
<td>148</td>
<td>185</td>
<td>5</td>
<td>28</td>
</tr>
<tr>
<td>Kaskaskia</td>
<td>61</td>
<td>190</td>
<td>13</td>
<td>47</td>
<td>147</td>
<td>198</td>
<td>4</td>
<td>13</td>
</tr>
<tr>
<td>Goodstreak</td>
<td>57</td>
<td>122</td>
<td>13</td>
<td>43</td>
<td>158</td>
<td>187</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>NE426GT</td>
<td>53</td>
<td>141</td>
<td>16</td>
<td>50</td>
<td>169</td>
<td>167</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>Décor</td>
<td>60</td>
<td>199</td>
<td>13</td>
<td>39</td>
<td>140</td>
<td>188</td>
<td>5</td>
<td>22</td>
</tr>
<tr>
<td>Lamberto</td>
<td>35</td>
<td>101</td>
<td>17</td>
<td>45</td>
<td>105</td>
<td>123</td>
<td>5</td>
<td>17</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>15</td>
<td>52</td>
<td>ns ¶</td>
<td>ns</td>
<td>ns</td>
<td>47</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Legume Alfalfa</td>
<td>55</td>
<td>106</td>
<td>13</td>
<td>42</td>
<td>140</td>
<td>151</td>
<td>4</td>
<td>13</td>
</tr>
<tr>
<td>Cherokee RC</td>
<td>43</td>
<td>195</td>
<td>6</td>
<td>25</td>
<td>100</td>
<td>185</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>Marathon RC</td>
<td>62</td>
<td>171</td>
<td>10</td>
<td>26</td>
<td>194</td>
<td>188</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Check</td>
<td>–</td>
<td>–</td>
<td>26</td>
<td>97</td>
<td>–</td>
<td>–</td>
<td>8</td>
<td>42</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>13</td>
<td>23</td>
<td>10</td>
<td>27</td>
<td>50</td>
<td>ns</td>
<td>2</td>
<td>16</td>
</tr>
</tbody>
</table>

† Legume densities counted on 8 and 14 July 2005 and 2006.
§ Ernie and Kaskaskia are soft red winter wheat. Goodstreak is hard red winter wheat, and NE426GT, Décor, and Lamberto are winter triticale varieties.
¶ ns, not significant.

other years (Skrdla and Jannink, 2004; Schwarte et al., 2005; Blaser et al., 2006). Therefore, below normal rainfall in May and June, combined with 15 and 28% above normal rainfall in March and April, may have provided sufficient soil moisture for cereal growth without limiting cereal yields in 2006.

The six winter cereals combined with the three unique growing seasons produced a wide range of canopies. Maximum LAI values ranged from 6.2 in 2005 to 2.1 in 2007 (Fig. 1) and whole plant DM at harvest averaged 1136, 2029, and 817 g DM m⁻² in 2005–2007. This broad range of LAI and cereal DM provided diverse canopies where it was possible to evaluate the impact of these traits on legume establishment and productivity.

**Legume Establishment and Dry Matter**

Legume density at grain harvest was only different among cereal varieties in 2005 and was caused by lower densities recorded under Lamberto (Table 4). This observation corresponded to higher FHE DM and LAI produced by Lamberto throughout the season (Table 3 and Fig. 1). Legume densities were affected by legume species and variety in 2005 and 2006 (Table 4). Marathon red clover had 31 and 48% higher densities than Cherokee red clover in both years. Average alfalfa densities were similar to both red clover varieties in 2005 and only to Cherokee in 2006.

Cereal variety affected legume DM production 40 d after grain harvest in 2005 and 2006. This residual effect of the cereal crop on legume production is most likely attributed to the cereal canopy which affected legume shoot size during the intercrop period. In 2005, legume DM from treatments previously containing Lamberto, Goodstreak, and NE426GT was lower than the other cereals (Table 4). This response corresponds to the higher LAI values produced by these three varieties throughout the season (Fig. 1). Higher LAI canopies permit less light transmittance to the legume seedlings and result in less plant growth and root development. A similar pattern was observed in 2006 when Lamberto produced the same or higher LAI relative to Ernie, Kaskaskia, Goodstreak, and Décor, and legume DM collected after Lamberto produced an average of 35% less DM relative to those four cereals (Table 4). Leaf area index for NE426GT was similar to Lamberto for over half of the season, which corresponded to similar 40 d legume DM under those two varieties (Fig. 1; Table 4).

Legume shoot DM production was also affected by legume variety and species in 2005, yet legume density did not directly influence DM production. Cherokee had the lowest density of the three legumes but produced the greatest DM with 195 g m⁻² (Table 4). Marathon produced 12% less DM than Cherokee and on average, the two red clovers produced 42% more DM than alfalfa. Legume DM production independent of density was also observed by Singer et al. (2006). They reported that the relationship between red clover plant number and DM at cereal harvest was not significant in a year with high red clover plant counts (average of 229 plants m⁻²), but was highly significant in a year with low red clover plant counts (average of 30 plants m⁻²) at cereal harvest. Likewise, the lower alfalfa DM in the establishment year may carry over into the second year. Therefore, legume density may not be as critical to the DM of the intercrop as is the legume species or variety.

Previous reports claiming using winter cereals as companion crops for alfalfa to be less effective because winter cereals were too competitive compared to spring cereals (Tesar and Marble, 1988). Results from this study demonstrate that alfalfa is as competitive in stand establishment as Cherokee and Marathon red clover varieties and can be successfully frost-seeded into winter cereals grown for optimum grain production. However, the lower alfalfa DM in 2005, a year with high LAI for an extended period of time (Fig. 1), and the trend toward lower alfalfa DM in 2006 (P = 0.27), may be attributed to the higher light compensation point of 13% required by alfalfa compared to only 6% for red clover (McKee, 1962; Taylor and Smith, 1995). Given the different light compensation points, this study verifies that alfalfa DM production in the establishment year will likely be lower than red clover within the range of LAI’s measured in this study.
CONCLUSIONS

Winter cereal LAI values ranged from 3.5 to 6.2 for 2005 and 2006 and affected legume establishment densities when LAI values were sustained over 5.6 for nearly 40 consecutive days. Legume DM was affected by cereal variety 40 d after grain harvest, but responses were not always related to legume density. Alfalfa frost-seeded into winter cereal grains in the North Central United States can achieve similar establishment densities as red clover, but may experience slightly lower DM yields in the establishment year. Weed density and DM are consistently suppressed in the presence of legumes in fields typically fallow after grain harvest. Plant breeders developing cereals compatible with interseeded legumes and producers using this intercrop may continue to focus on high grain yield in their cultivars and varieties. However, attention must be given to varieties known to produce maximum LAI values above those typically found in grain-types for extensive periods of time because of the potential to reduce legume productivity.

REFERENCES


