Nitrogen Fertilizer, Manure, and Compost Effects on Weed Growth and Competition with Spring Wheat

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ABSTRACT

Crop fertilization is an important component of integrated weed management systems. A field experiment was conducted to determine the effect of various application timing—tilleage intensities and N sources on weed growth and spring wheat (Triticum aestivum L.) yield. Timing—tilleage treatments consisted of applying the various N sources in either the previous fall or in spring each under zero-till or tilled conditions. Nitrogen sources consisted of granular ammonium nitrate fertilizer applied either surface broadcast or subsurface banded 10 cm deep between every second wheat row, fresh cattle (Bos taurus) manure, and composted cattle manure. An unfertilized control also was included. Treatments were applied in four consecutive years to determine annual and cumulative effects. Subsurface-banded N compared with broadcast N fertilizer often reduced N uptake by weeds, decreased weed biomass, and increased wheat yield. Weed N uptake and growth with fresh and composted manure tended to be intermediary between banded and broadcast N fertilizer in the initial year but was similar to or greater than that with broadcast N fertilizer in subsequent years. The gradual N release from manure and compost over years appeared to benefit weeds more than spring wheat. The ranking of the weed seedbank at the conclusion of the 4-yr experiment was composted manure = fresh manure ≥ broadcast N fertilizer > banded N fertilizer. Information gained in this study will be utilized to develop more efficient fertilization strategies as components of integrated weed management programs in spring wheat production systems.

H erbicides and fertilizer are major input costs in North American cropping systems (Derkson et al., 2002; Grant et al., 2002; Schlegel et al., 2005). Farmers are cognizant of these costs and thus are interested in alternative approaches to managing weeds and improving soil fertility.

Integrated weed management systems have the potential to reduce herbicide use (and associated costs) and to improve weed control over the long term (Buhler, 1999). Manipulation of crop fertilization may be a means of reducing weed interference in crops (DiTomaso, 1995). Nitrogen is the major nutrient added to increase crop yield (Raun and Johnson, 1999; Camara et al., 2003), but it is not always recognized that altered soil N levels can affect crop—weed competitive interactions. Nitrogen fertilizer can affect weed germination and establishment (Egley and Duke, 1985). Many weeds are high-N consumers (Oasem, 1992; Hans and Johnson, 2002), thus limiting N for crop growth. Weeds not only reduce the amount of N available to crops, but the growth of many weed species also is enhanced by higher soil N levels (Supasiliapa et al., 1992; Blackshaw et al., 2003).

Crop—weed competitive interactions can be altered by N fertilizer dose (Cathcart and Swanton, 2003), application timing (Angonin et al., 1996; Blackshaw et al., 2004), and application method (Rasmussen et al., 1996; Mesbah and Miller, 1999). However, other studies found that N dose (Satorre and Snaydon, 1992; Gonzalez Ponce, 1998) or application method (Cochran et al., 1990) had little effect on crop—weed competition. Additionally, results may be crop and weed specific. Van Delden et al. (2002) reported that common chickweed [Stellaria media (L.) Vill.] interference with potato (Solanum tuberosum L.) was reduced with higher soil N levels, but the opposite result occurred when it was competing with wheat.

There has been renewed interest in recent years in using livestock manure to improve soil fertility and crop production (Janzen et al., 1999; Mooleki et al., 2004). Manure may be utilized directly or it may be composted before being applied to cropland. Composted manure has several advantages over fresh manure, including reduced numbers of viable weed seeds, reduced volume and associated cheaper transportation costs, and smaller particle size that facilitates more uniform application (Richard and Choi, 1999; Larney and Blackshaw, 2003). Livestock manure may affect crop—weed competitive interactions differently than N fertilizer (Davis and Liebman, 2001), perhaps due to speed of N release or form of N. Nitrogen in fresh manure is >90% ammonia while that of compost is >70% nitrate (Hao et al., 2004).

Greater knowledge of inorganic and organic N effects on weed growth and competitive interactions with crops will allow for a better understanding of why differences occurred among previous studies and would aid the development of fertilization strategies as components of integrated weed management programs. A field experiment was conducted to determine the response of selected grass and broadleaf weed species and spring wheat to N fertilizer, fresh cattle manure, and composted cattle manure applied the previous fall or at the time of planting spring wheat under zero-till or tilled conditions. Treatments were applied in four consecutive years to assess both annual and cumulative effects over time.

MATERIALS AND METHODS

A field experiment was conducted from 1998 through 2001 at Lethbridge, Alberta, Canada. The soil was a Typic Hapludoll with a sandy clay loam texture, pH 7.8, and 3.4% organic matter. The experiment was established on land that had been in spring wheat production in 1995 and 1996 and was fallowed in 1997. The plot site had very low weed populations due to excellent weed control attained during these preceding years. Available soil N (nitrate and ammonia) to a depth of 60 cm...
at the initiation of the experiment was 32 kg ha\(^{-1}\). Annual precipitation at the site ranged from 176 to 482 mm over the duration of the study (Table 1). Precipitation received was near or above the long-term mean (387 mm) in 1998 and 1999 but well below average in 2000 and 2001.

A set of factorial treatments was applied in four consecutive years to spring wheat. Treatments consisted of (i) N application timing–tillage intensity combinations, (ii) N source, and (iii) weed species. Timing–tillage treatments consisted of applying the various N sources in either the previous fall or in spring at planting each under zero-till or tilled conditions (one operating 8 cm deep). Nitrogen sources consisted of granular ammonium nitrate fertilizer applied either surface broadcast or banded 10 cm deep between every second wheat row, fresh beef cattle manure, and composted beef cattle manure. Nitrogen fertilizer was applied each year at 50 kg ha\(^{-1}\), a dose considered representative for spring wheat production in this semiarid region. Manure and compost were surface-broadcast at commonly recommended rates of 30 t ha\(^{-1}\) on a wet weight basis each year. If tillage was part of the treatment, it was conducted within 1 d of manure application. Composted manure was prepared by placing fresh manure in windrows that were approximately 15 m long, 4 m wide, and 2 m high and turning windrows seven times over 3 mo with a tractor-pulled windrow turner (Fuel Harvesters Equipment, Midland, TX, USA) followed by curing for an additional 3 mo. Selected characteristics of manure and compost applied in each year are given in Table 2. Available N in the year of application as a percentage of total N was expected to be approximately 20% for fresh manure and 5% for composted manure (Larney et al., 2002).

Thus, available N in the application year ranged from 26 to 67 and 12 to 18 kg ha\(^{-1}\) for fresh manure and composted manure, respectively. An unfertilized control also was included. Weed treatments consisted of a combination of the grass weeds green foxtail [Setaria viridis (L.) Beauv.] and wild oat (Avena fatua L.), a combination of the broadleaf weeds common lambsquarters (Chenopodium album L.) and wild mustard (Sinapis arvensis L.), and a weed-free control. Treatments were organized in a split-split-plot design with four replications. Main plots were N application timing–tillage intensity, subplots were N source, and sub-subplots were weed species. Sub-subplot size was 2 m wide by 5 m long.

Fifty viable seeds of each weed species were broadcast by hand on the soil surface of respective plots at the initiation of the experiment immediately before planting spring wheat to ensure adequate weed populations. In each year, glyphosate [N-(phosphonomethyl)glycine] at 450 g a.e. ha\(^{-1}\) was applied 1 wk before seeding wheat to kill any existing vegetation. Spring wheat cultivar Katepwa at 90 kg ha\(^{-1}\) plus 11 kg P ha\(^{-1}\)

was placed 4 cm deep in 23-cm rows in early May with a double-disc zero-till drill capable of simultaneously midrilling a modified N fertilizer. Wheat seed was always treated with a combination of carbasin (5,6-dihydro-2-methyl-1,4-oxathiin-basis each year. If tillage was part of the treatment, it was conducted within 1 d of manure application. Composted manure was prepared by placing fresh manure in windrows that were approximately 15 m long, 4 m wide, and 2 m high and turning windrows seven times over 3 mo with a tractor-pulled windrow turner (Fuel Harvesters Equipment, Midland, TX, USA) followed by curing for an additional 3 mo. Selected characteristics of manure and compost applied in each year are given in Table 2. Available N in the year of application as a percentage of total N was expected to be approximately 20% for fresh manure and 5% for composted manure (Larney et al., 2002).

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threshold and dried at 27°C for 2 wk. Grain protein content was determined using a near-infrared transmission spectrophotometer (Foss Electric Multispec Division, Brampton, ON, Canada).

Weed seed in the soil seedbank was determined at the conclusion of this 4-yr experiment. Nine soil cores (8 cm diam. by 10 cm deep) were randomly collected from each plot, bulked, air-dried, placed in polyethylene bags, and stored for 3 mo at 1°C. Seed determinations were conducted using the greenhouse emergence method (Cardina and Sparrow, 1996). Soil was spread onto plastic trays, placed in a greenhouse with a day/night temperature of 24/17°C, and watered as necessary to keep moist. Weed emergence counts were made twice weekly for 1 mo. Soil was then air-dried, remixed, placed in polyethylene bags, and stored at 1°C for a minimum of 1 mo before conducting the second cycle of emergence counts. The cycle of cool storage/emergence counts was conducted three times, and emergence values were combined.

Data collected over the 4 yr were statistically analyzed as a split-split-split plot design (Steel and Torrie, 1980) with N application timing–tillage intensity as the main plot, N source as the split plot, weed species as the split-split plot, and year as the split-split-split plot factor. All interactions among these four factors also were included in the model. Analyses were performed using the MIXED procedure in SAS (1999), and year was treated as a repeated measure. The UNIVARIATE procedure within SAS was used to examine the residuals for normality and to check for outliers in the data. Any outliers in the data were deleted and the remaining data reanalyzed. A number of variance–covariance structures were modeled for each variable to account for differences in variance and possible correlations among years, and the best model was selected on the basis of the smallest Akaike’s Information Criterion (AIC) value (SAS Inst., 1999). Weed seedbank data collected at the end of the study were highly variable and thus were log-transformed to stabilize the variance among treatments before conducting the analysis. Least squares means were generated for significant effects, and treatment means were compared using Fisher’s Protected LSD test at the 5% level (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Weed Nitrogen Concentration

Weed shoot N concentration was affected by N source in all years \((P < 0.05)\). The unfertilized control was always among treatments having the lowest N concentration in all weed species (Fig. 1), indicating that N uptake by weeds increased with added N. Common lambsquarters and wild mustard shoot N concentrations were greater than those of green foxtail or wild oat \((P < 0.05)\), indicating that broadleaf, as well as grass weeds, potentially are serious competitors with crops for soil N.

Surface-broadcast N fertilizer was among treatments giving the highest shoot N concentration in wild oat in all years, in green foxtail and wild mustard in 3 of 4 yr, and in common lambsquarters in 2 of 3 yr (insufficient plants precluded data collection in 2001) (Fig. 1). In contrast, banded N fertilizer was among N treatments with the lowest shoot N concentration in green foxtail in 2 of 4 yr, in wild oat in 3 of 4 yr, and in common lambsquarters and wild mustard in all years. A previous study similarly documented that shoot N concentration of several annual weeds was often greater with surface broad-

Fig. 1. Weed shoot N concentration response to N source in four consecutive years. Common lambsquarters data were not collected in 2001 due to insufficient plants being present in the plots. Bars on the graph within a weed species and year with the same letter are not significantly different according to Fisher’s Protected LSD test at the 5% probability level.
Table 3. Weed shoot N concentration response to N application timing–tillage intensity averaged over 4 yr.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Green foxtail†</th>
<th>Wild oat</th>
<th>Common lambsquarters‡</th>
<th>Wild mustard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall–zero till</td>
<td>1.3 b</td>
<td>1.4 a</td>
<td>2.5 a</td>
<td>3.6 a</td>
</tr>
<tr>
<td>Fall–tilled</td>
<td>1.4 a</td>
<td>1.4 a</td>
<td>2.6 a</td>
<td>3.5 a</td>
</tr>
<tr>
<td>Spring–zero till</td>
<td>1.2 c</td>
<td>1.1 c</td>
<td>2.6 a</td>
<td>3.2 b</td>
</tr>
<tr>
<td>Spring–tilled</td>
<td>1.2 c</td>
<td>1.2 b</td>
<td>2.5 a</td>
<td>3.3 b</td>
</tr>
</tbody>
</table>

† Means within a species with the same letter are not significantly different according to Fisher’s Protected LSD test at the 5% probability level.
‡ Common lambsquarters data was averaged over 3 yr; insufficient plants prevented data collection in 2001.

cast than with banded N fertilizer (Blackshaw et al., 2004). Kirkland and Beckie (1998) reported that N uptake by wild oat, but not green foxtail, was greater with surface-broadcast compared with banded N fertilizer.

Green foxtail shoot N concentration was lower with fresh cattle manure than with broadcast N fertilizer in 2 of 4 yr and was similar to that of banded N fertilizer in 3 of 4 yr (Fig. 1). Wild oat shoot N concentration was lower with fresh cattle manure than with broadcast N fertilizer in all years and was always similar to that of banded N fertilizer. However, shoot N concentration of common lambsquarters and wild mustard was similar with fresh manure and broadcast N fertilizer in all years and was higher than that attained with banded N fertilizer in common lambsquarters in 1 of 3 yr and in wild mustard in 3 of 4 yr. Eghball and Power (1999) found that plant available N is often lower with manure than with inorganic fertilizer in the year of application, and this appeared to be the case with the grass weeds in our study.

In contrast to fresh manure, composted manure resulted in similarly high green foxtail N levels in 2000, and higher N levels in 2001, compared with those attained with broadcast N fertilizer (Fig. 1). Wild oat N levels were similar with composted manure and broadcast N fertilizer in the latter 3 yr. Shoot N concentration of common lambsquarters and wild mustard was at similarly high levels with compost manure compared with surface broadcast N fertilizer in all years and was actually higher a couple of years. Nitrogen release is slower from composted manure than from fresh manure, resulting in lower plant available N in the application year but greater available N in succeeding years (Eghball and Power, 1999; Eghball et al., 2004).

Nitrogen application timing–tillage intensity affected shoot N concentration in some weed species (P < 0.05). Averaged over years, shoot N concentration of green foxtail, wild oat, and wild mustard was lower with spring-applied than with fall-applied N treatments (in zero-till or tilled conditions) (Table 3). Additionally, shoot N concentration was lower with zero-tillage than with tillage in green foxtail and wild oat with fall-applied and spring-applied N treatments, respectively.

Wheat Nitrogen Concentration

Spring wheat shoot N concentration was affected by the interaction of N source by weed treatment in all years (P < 0.05). However, further examination of the data revealed that there were no differences among weed species in their effect on wheat shoot N concentration; differences only occurred between the weed-free control and the weed-infested treatments.

Wheat shoot N concentration was greater with banded than with broadcast N fertilizer in 1 of 4 yr under weed-free conditions and in all 4 yr when competing with weeds (Fig. 2). Rao and Dao (1996) previously reported higher winter wheat leaf N content with banded than with broadcast N fertilizer. It is noteworthy that broadcast N fertilizer did not increase weed-infested wheat N concentration above that of the unfertilized control in 2 of 4 yr, indicating that this is an inefficient method of applying fertilizer when competitive weeds are present. Mason (1987) reported that wheat N uptake was often reduced by competing weeds.

Manure increased weed-free wheat shoot N levels above that of the unfertilized control but rarely did so in the presence of competing weeds (Fig. 2). Wheat N concentration was higher with fresh manure than with composted manure in the initial year (1998) under either weed-free or weed-infested conditions. However, in subsequent years, wheat N levels were as high or higher with compost manure compared with fresh manure. Previous studies have documented higher wheat shoot N concen-
Table 4. Weed-free wheat shoot N concentration response to N application timing–tillage intensity.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>1998†</th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
</tr>
</thead>
<tbody>
<tr>
<td>N, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fall–zero till</td>
<td>1.4 c</td>
<td>1.6 c</td>
<td>1.6 a</td>
<td>1.9 c</td>
</tr>
<tr>
<td>Fall–tilled</td>
<td>1.5 b</td>
<td>1.6 c</td>
<td>1.6 a</td>
<td>1.9 c</td>
</tr>
<tr>
<td>Spring–zero till</td>
<td>1.6 a</td>
<td>1.8 a</td>
<td>1.7 a</td>
<td>2.1 a</td>
</tr>
<tr>
<td>Spring–tilled</td>
<td>1.6 a</td>
<td>1.7 b</td>
<td>1.6 a</td>
<td>2.0 b</td>
</tr>
</tbody>
</table>

† Means within a species with the same letter are not significantly different according to Fisher’s Protected LSD test at the 5% probability level.

Application timing–tillage intensity affected shoot N concentration of weed-free wheat (P < 0.05) but not weed-infested wheat (P > 0.05). Wheat N levels were greater with spring-applied than with fall-applied N treatments, under either zero-till or tilled conditions, in 3 of 4 yr (Table 4). Additionally, wheat N levels within spring-applied treatments were greater with zero-tillage than with tillage in 1999 and 2001.

Weed Biomass

Nitrogen source affected weed shoot biomass in all years (P < 0.05), and grass weeds were found to respond differently than broadleaf weeds to these various N treatments (P < 0.05). The unfertilized control was among treatments with the lowest weed biomass (Fig. 3), indicating that weed growth responded positively to higher soil N levels.

The combined biomass of green foxtail and wild oat was lower with banded N than with surface-broadcast N fertilizer in all years and was lower than all other N treatments in the latter 3 yr (Fig. 3). Previous studies have similarly documented that weed biomass is often lower with subsurface-banded compared with surface-broadcast N fertilizer (Kirkland and Beckie, 1998; Mesbah and Miller, 1999; Rasmussen et al., 1996).

Grass weed biomass was similarly high with broadcast fertilizer and manure in the first 3 yr but greater with manure in the fourth year. Weed biomass was similar with compost manure and banded N fertilizer in the initial year. However, in subsequent years, grass weed biomass with compost manure was similar to or greater than that attained with broadcast N fertilizer or fresh manure. Eghball and Power (1999) found that weed biomass in corn (Zea mays L.) was usually similar with broadcast fertilizer, manure, and composted manure. Similar to the findings with grass weeds, the combined biomass of common lambsquarters and wild mustard was lower with banded N than with surface-broadcast N fertilizer in all 4 yr and was lower than all other N treatments in the latter 3 yr (Fig. 3). However, unlike the findings with grass weeds, broadleaf weed biomass was lower with fresh and compost manure than with broadcast N fertilizer in the first 2 yr. Broadleaf weed biomass was similar with the two manure treatments and broadcast N fertilizer in 2000 but higher with the manure treatments in 2001.

Application timing–tillage intensity also affected weed biomass (P < 0.05). Spring compared with fall-applied N treatments reduced grass weed biomass in 1999 and 2001 and broadleaf weed biomass in 1999 and 2000 (Fig. 4). Blackshaw et al. (2004) similarly reported that weed biomass in spring wheat was sometimes lower with spring-applied than with fall-applied N fertilizer. Grass weed biomass was lower with zero-tillage than with tillage with spring-applied N treatments in 2000 and with both spring-applied and fall-applied N treatments in 2001. Similarly, broadleaf weed biomass was lower with zero-tillage than with tillage with fall-applied N treatments in 1998 and 1999. Tillage is known to stimulate germination of some weed species (Roberts, 1981; Mohler, 2001), and this may have been a contributing factor to greater weed biomass in tilled treatments in some instances.
Weed Seedbank

The weed seedbank was estimated at the conclusion of the 4-yr experiment as a measure of the cumulative effects of weed growth and competitive ability with spring wheat. Nitrogen source affected the seedbank of both grass and broadleaf weeds ($P < 0.05$). The unfertilized control was among treatments with the lowest seedbank, again indicating that weeds responded positively to higher soil N levels (Fig. 5).

Comparison of the various N sources indicated that banded N fertilizer resulted in the lowest seedbank numbers of both grass and broadleaf weeds (Fig. 5). Indeed, the broadleaf weed seedbank was not greater with banded N fertilizer than with the unfertilized control. A previous study found that the seedbank of various weed species was reduced by 19 to 50% with subsurface-banded compared with surface-broadcast N fertilizer (Blackshaw et al., 2004).

Fresh and composted manure were among treatments with the greatest seedbank of both grass and broadleaf species (Fig. 5). The broadleaf weed seedbank was much lower with surface-broadcast N fertilizer than with either fresh or composted manure. However, the grass weed seedbank was only lower with broadcast fertilizer than with compost manure (not fresh manure), and the magnitude of the difference was considerably less than that noted with broadleaf weeds.

Application timing–tillage intensity affected the seedbank of grass weeds ($P < 0.05$) but not broadleaf weeds ($P > 0.05$). Averaged over both tillage treatments, the grass weed seedbank was lower with the spring-applied than with the fall-applied N treatments (3368 vs. 4570 seeds m$^{-2}$). A previous study found that spring-applied compared with fall-applied N fertilizer reduced the seedbank of wild oat and common lambsquarters but not green foxtail or wild mustard (Blackshaw et al., 2004).

Wheat Yield and Protein Content

Nitrogen source and weed treatments interacted to affect spring wheat yield ($P < 0.05$). Weed-free wheat yield was higher with all fertilizer and manure treatments compared with the unfertilized control in all years (Fig. 6). This was an expected finding as wheat is known to respond positively to higher soil N levels (Raun and Johnson, 1999; Schlegel et al., 2005).

Banded N fertilizer was among treatments with the highest weed-free wheat yield in all years, and yields were higher with banded than with surface-broadcast N fertilizer in 2 of 4 yr (Fig. 6). However, Roberts et al. (1992) found that broadcast and banded N fertilizer usually gave similar spring wheat yields. Blackshaw et al. (2004) documented that banded compared with broadcast N fertilizer increased weed-free spring wheat yield in 1 of 4 yr. Studies with winter wheat have reported higher yields with banded than with broadcast N fertilizer (Cochran et al., 1990; Rao and Dao, 1996).

Weed-free wheat yield was lower with fresh or composted manure than with either of the N fertilizer treatments in the first year (1998). However, wheat yield was greater with compost manure than with either broadcast N fertilizer or fresh manure in 1999. Wheat yield was similar among both manure treatments and the broadcast fertilizer treatment in the latter 2 yr. Reider et al. (2000) documented that corn yields were usually similar.
method. Kirkland and Beckie (1998) documented that weed-infested spring wheat yield averaged over six experiments was 12% greater with banded than with broadcast N fertilizer.

Unlike the findings with grass weeds, wheat infested with broadleaf weeds had higher yields with all N treatments compared with the unfertilized control in all years (Fig. 6). Banded N fertilizer was always among treatments with the highest wheat yield when competing with broadleaf weeds, but yields were only higher with banded N fertilizer than with broadcast fertilizer or either manure treatment in 2 of 4 yr. These results may indicate that broadleaf weeds are less affected by N source and placement compared with grass weeds. The extensive taproots of common lambsquarters and wild mustard facilitate N extraction from deep portions of the soil profile, and thus they may be less affected by fertilizer or manure applied on or within 10 cm of the soil surface compared with grass weeds that have greater concentration of roots in the upper regions of the soil profile.

Wheat infested with broadleaf weeds had similar or higher yields with fresh and composted manure compared with broadcast N fertilizer in the latter 3 yr (Fig. 6). Indeed, the two manure treatments had similar wheat yields to those of banded N fertilizer in 2 of 4 yr.

Spring compared with fall-applied N resulted in higher yield of weed-free wheat in 1998, grass-infested wheat in 1999 and 2000, and broadleaf-infested wheat in 1998 and 1999 (Fig. 7). Spring-applied treatments also were better than the fall-tilled N treatment within broadleaf-infested wheat in 2000. A previous study found that weed-infested spring wheat yield was greater with spring-applied than with fall-applied N fertilizer in about 50% of the cases (Blackshaw et al., 2004).

Spring wheat grain protein was affected by weed treatment in some years ($P < 0.05$). Wheat protein was greater when grown weed-free than when weed-infested in 1998 (13.4 vs. 12.9%) and in 2001 (13.2 vs. 12.5%). Nitrogen source affected wheat grain protein in all years ($P < 0.05$). In 1998, only surface-broadcast N fertilizer increased wheat protein above that of the unfertilized control (Fig. 8). However, in the latter 3 yr, all N treatments increased wheat protein above that of the unfertilized control. Wheat protein levels were similar with broadcast N fertilizer, banded N fertilizer, and compost manure (and all were higher than with fresh manure) in the latter 3 yr. Rao and Dao (1996) reported that wheat grain N content often was greater with banded than broadcast N fertilizer, but Karamanos et al. (2003) found no differences in wheat protein between banded and broadcast N fertilizer treatments.

Wheat protein content was affected by application timing–tillage intensity treatments in 2 of 4 yr ($P < 0.05$). Wheat protein was higher in fall-tilled than in all other N timing–tillage intensity treatments by 0.9 and 0.5% in 1999 and 2001, respectively (data not shown). This result may have been due to slower N release from spring-applied manure and compost and/or from greater N immobilization in zero-till than in tilled treatments (Grant et al., 2002).
SUMMARY AND CONCLUSIONS

Fresh and composted cattle manure exhibited good potential as N sources for spring wheat production. Weed-free wheat yield and grain protein content with manure and composted manure was often similar to N fertilizer. An additional long-term benefit of manure and compost is improved soil quality (DeLuca and DeLuca, 1997; Eghball et al., 2004).

Results support the findings of previous studies indicating that many agricultural weeds are highly responsive to increased soil N levels (Lintell-Smith et al., 1992; Supasilapa et al., 1992; Blackshaw et al., 2003). Thus, indiscriminate N additions have the potential to benefit weeds at the expense of crops. Subsurface-banded N was often better than surface-broadcast N fertilizer in terms of N uptake by wheat vs. weeds, weed biomass production, and wheat yield. Weeds often germinate at or near the soil surface, especially in zero-tillage systems (Yenish et al., 1992; Hoffman et al., 1998), and it is in this situation that the greatest benefits may be realized by physically placing N in an area of the soil profile where crops, but not weeds, are germinating.

Nitrogen uptake and growth of weeds with fresh and composted manure tended to be intermediary between broadcast and banded N fertilizer in the first couple of years. However, with repeated annual applications, weed shoot N concentration and biomass with the manure treatments were similar to or greater than values attained with broadcast N fertilizer. This was likely due to gradual N release from manure and compost over years (Eghball et al., 2004). Weed-infested wheat yield with fresh and composted manure was usually similar to that with broadcast N fertilizer and was often lower than that attained with banded N fertilizer. The ranking of the weed seedbank at the conclusion of this 4-yr experiment was compost manure = fresh manure ≥ broadcast N fertilizer > banded N fertilizer, indicating that the two manure treatments were the least desirable N treatments in terms of weed management.

Weed N concentration and weed biomass were sometimes greater with fall-applied than with spring-applied N. Nitrogen is mobile in the soil, and any placement effects of N amendments may be somewhat diminished by high amounts of precipitation. Fall- compared with spring-applied N may have more opportunity for movement within the soil profile because of snowmelt and/or early spring rains.

The present study indicates that fresh and composted manure have the potential to increase spring wheat yield but also the level of weed competition. Menalled et al. (2004) similarly documented that composted swine manure increased the competitive ability of common waterhemp (Amaranthus rudis Sauer) without increasing soybean (Glycine max (L.) Merr.) yield. Alterna-
tive application methods may be required to maximize manure benefits to crops and minimize any inadvertent benefits to weeds. For example, Petersen (2003) reported that weed N uptake and weed biomass were 50% lower with subsurface-banded compared with surface-broad- cast liquid swine manure. Rasmussen (2002) similarly documented lower weed biomass and higher crop yield with injected than with surface-broadcast liquid swine manure. Integrated weed management programs that emphasize crop rotation, competitive crops, and timely herbicide use also would help achieve the many advantages of manure application to crop production.

Manipulation of soil fertility, whether using organic or inorganic amendments, should be considered an important component of long-term weed management programs. Information gained in the current study will be used to develop more integrated programs for weed management in spring wheat production systems.

REFERENCES


Rodd, A.V., P.R. Warman, P. Hicklenton, and K. Webb. 2002. Compari-son of N fertilizer, source-separated municipal solid waste compost...