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COVER
The commonly accepted belief of crop and soil scientists and practitioners is that the tie-up or release of N from cover crops is based largely on carbon-to-nitrogen ratios (C:N). Recent research in Wisconsin and North Dakota challenge this long-held belief. See story on page 3. Cover photo shows an experimental strip of radish cover crop planted following winter wheat, Sheboygan County, WI. Photo courtesy of Matt Ruark.
FROM THE EDITOR

New Look for Crops & Soils Magazine

Dear readers: I am delighted to kick off 2020 with a new look for Crops & Soils magazine! We hope you like the change, and we will continue to look for ways to increase its value to you. One thing to look for later this year is the incorporation of some video highlights to select articles. Stay tuned! We’ve worked with our new publishing partner, Wiley, to redesign both the print and online format of this magazine. Let me know what you think (news@sciencesocieties.org) of the change and if there’s anything we can do to improve.

Last issue, we provided some details about our partnership with Wiley and how it will benefit the Societies (http://doi.org/10.2134/cs2019.52.0611). This partnership will be beneficial as it increases worldwide exposure of our publications to institutions and researchers. However, full ownership of our publications remains with ASA, CSSA, and SSSA. The Societies, editors, and editorial boards will retain all control over editorial decisions. Member service support for Society member subscription renewals will also continue to be provided by our Madison, WI headquarters staff.

There’s been a lot of change lately! We also have a new CEO, Nick Goeser. Nick brings great enthusiasm for the mission of our organizations and a desire to grow them to bring value to new and existing members and certified professionals. You can check out his introductory column in the latest issue of CSA News magazine at https://doi.org/10.1002/csan.20003.

“Let me know what you think (news@sciencesocieties.org) of the change and if there’s anything we can do to improve.”

Matt Nilsson, Managing Editor of Magazines for ACSESS

DOI: 10.1002/crso.20009
Nitrogen Availability from Cover Crops: Is It Always about the C:N Ratio?

By M. Ruark, Department of Soil Science, University of Wisconsin–Madison; and D. Franzen, Department of Soil Science, North Dakota State University

The commonly accepted belief of crop and soil scientists and practitioners is that the tie-up or release of N from cover crops is based largely on carbon-to-nitrogen ratios (C:N). Recent research in Wisconsin and North Dakota challenge this long-held belief. Earn 0.5 CEUs in Nutrient Management by reading this article and taking the quiz at www.certifiedcropadviser.org/education/classroom/classes/742.

DOI: 10.1002/crso.20003
The commonly accepted belief of crop and soil scientists and practitioners is that the tie-up or release of N from cover crops is based largely on carbon-to-nitrogen ratios (C:N). Generally, the reasoning is that if cover crop dry matter has a C:N ratio greater than 30, N tie-up is likely, and if the ratio is less than 20, release of N is likely. When the C:N ratio is between 20 and 30, we assume neither N tie-up or release will occur. Recent research in Wisconsin and North Dakota challenge this long-held belief. In this article, we will highlight this research, which demonstrates that not all low C:N ratio cover crops or mixtures lead to more N availability to the subsequent crop.

**Clover and Radish in Wisconsin**

Opportunities for successful cover crop establishment occur when cover crops can be planted in late summer following winter wheat harvest in the upper Midwest. In addition, there is more opportunity for different cover crop species to be planted, especially green manure cover crops that will supply N to the next year’s corn crop (and result in less commercial N needed for optimal production). Two popular cover crops that can be planted after winter wheat harvest are radish and crimson clover. Radish is a brassica that can be drilled at a rate of 10 lb/ac and will winter-kill. Several years of research trials have been conducted in Wisconsin to evaluate whether radish will supply N to the subsequent corn crop. Radish was evaluated across three locations and three years in Wisconsin. The C:N ratio of total radish biomass (above- and belowground biomass) ranged from 10 to 19, and the total N uptake ranged from 20 to 200 lb N/ac. While it would be expected this C:N ratio and the often large amounts of N contained in the radish biomass would be advantageous and lead to a reduction in the optimum N rate for the subsequent corn crop, we never determined a “N credit” resulting from the radish (Ruark et al., 2018).

Figure 1 shows the effect of radish across two different growing seasons in Sheboygan, WI (located in northeast Wisconsin). In 2013, corn following radish appeared to require more N to optimize yield than following no cover crop. In 2014, lack of rainfall suppressed yields, but corn following radish outyielded corn following no cover crop at the higher N rates. In neither case did the radish appear to supply N. In these climates, radish decomposed quickly when the soils warmed up in the spring. The N trapped in the biomass is released quickly—perhaps too quickly—and does not remain available in the surface soil for the corn crop (although actual fate of this N remains unknown). It should be noted that we never saw a negative effect of the radish on corn yield and twice saw slight yield increases (although more N was required to achieve the increase in yield). Thus, while there may be some benefits to radish as a cover crop, there is no evidence that it will supply N to corn, and farmers should not alter their N applications.

Crimson clover is a nitrogen-fixing legume that can be drill-seeded at 15 lb/ac and will winter-kill in Wisconsin. In contrast to radish, crimson clover has been shown to clearly supply N to the next crop. Research trials were also conducted in Sheboygan County, WI to determine the potential N supply from this legume cover crop. Crimson clover was planted after winter wheat harvest in early- to mid-August and corn was planted the following spring. In 2015, crimson clover had a C:N ratio of 16:1 and had 45 lb/ac of N in the aboveground biomass; in the following spring, corn following crimson clover N rates the same as the no-cover crop (Figure 1). In 2016, crimson clover had a C:N ratio of 16:1 and had no N in the aboveground biomass; in the following spring, corn following crimson clover N rates the same as the no-cover crop (Figure 1).
2016, even more biomass was produced (70 lb N/ac) and had a C:N ratio of 11:1. Nitrogen response studies demonstrated that clover supplied N to the corn as evidenced by greater yields at lower N rates (Figure 2). Maximum yields were relatively unaffected, but corn following no cover crop required more N to achieve maximum yield compared with following crimson clover. These results are quite typical across a range of clover cover crops (e.g., red clover and berseem clover) (Stute & Posner, 1995; Gentry et al., 2013).

Cover Crop Mixtures in North Dakota

In North Dakota, a nitrogen response trial was conducted to determine if diverse and intensive cover cropping would supply N to the next season’s corn crop. The research site was located southwest of Rutland, ND, a couple miles north of the North Dakota–South Dakota border. The study was conducted on a farmer field. In early August 2016, a cover crop mixture was seeded into winter wheat stubble in a long-term no-till field (>30 years continuous no-till). The mixture included field pea, flax, forage radish, and volunteer winter wheat. The entire field was planted with cover crops, and after emergence, replicated treatment strips (with and without cover crops) were created by spraying out cover crops about two weeks after planting. The cover crop biomass, residual soil nitrate N to 2 ft in depth, and soil moisture were sampled in the fall before freezing conditions (which caused winterkill of all covers except for winter wheat, which was sprayed out in the spring by the farmer) (Tables 1 and 2). In the spring, N rates at 40 lb/ac increments from 0 to 200 were applied as ammonium nitrate to the soil surface two days after corn planting.

The total N in the cover crop biomass prior to winterkill was 85 lb N/ac. The residual soil nitrate N in the cover crop treatment was only 15 lb N/ac (Table 2) while the residual nitrate N in the no-cover-crop treatment was 114 lb N/ac. The total known N (cover crop N plus residual nitrate N) was 100 lb N/ac for the cover crop treatment. Another cover crop mixture (rye, radish, and camelina) was seeded between the rows of corn on June 22, 2017. On Aug. 16, 2017, the cover crop aboveground portion of plants was sampled in each N treatment. The dry matter weight of the cover crop mixture was 133 lb/ac and was 4% N, resulting in a total uptake of about 5 lb N/ac, which was trivial compared with total corn N uptake. Thus, we wouldn’t expect this interseeded cover crop mixture to have much, if any, effect on the corn yield response to N.

Table 1. Individual cover crop species biomass and C:N ratio and total biomass and weighted C:N ratio of the cover crop mixture sampled on Oct. 21, 2016 at Rutland, ND.

<table>
<thead>
<tr>
<th>Cover crop</th>
<th>Biomass (lb/ac)</th>
<th>C:N ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field pea</td>
<td>1,490</td>
<td>18.1</td>
</tr>
<tr>
<td>Radish top</td>
<td>1,690</td>
<td>15.4</td>
</tr>
<tr>
<td>Radish root</td>
<td>1,370</td>
<td>29.8</td>
</tr>
<tr>
<td>Flax</td>
<td>200</td>
<td>21.0</td>
</tr>
<tr>
<td>Winter wheat</td>
<td>220</td>
<td>14.5</td>
</tr>
<tr>
<td>Total/weighted mean</td>
<td>4,970</td>
<td>18.0</td>
</tr>
</tbody>
</table>

Figure 2. Corn yield following no cover crop or a crimson clover cover crop in 2015 or 2016 in Sheboygan County, WI.
The corn N response equations from Figure 3 indicate that N rate required for maximum yield with cover crops was 162 lb N/ac while the N rate required to maximize yield with no cover crop was 161 lb N/ac. In terms of economic optimum N rate (EONR), assuming $3.50 corn price and $0.40/lb N cost, the EONR for no cover crop was 0 lb N/ac while the EONR with the cover crop was 136 lb N/ac. In terms of residual N plus N rate, the economic optimum N (EON, which includes residual nitrate N plus N rate) is 77 lb N/ac for the no-cover-crop treatment and 178 lb N/ac for the cover crop treatment. The cover crop, therefore, had an N drag of about 100 lb N/ac compared with no cover crop (which was similar to the total difference in available N in the soil profile), and the economic loss from the cover crop was about $57/ac due to lost yield at maximum and the cost of additional N. These data clearly demonstrate that cover crop use will benefit water quality (i.e., preventing nitrate from leaching out during the winter and early spring) but can come at a cost to agronomically available N (i.e., more N may be required following certain cover crops) and agronomic productivity. The reduction in yield due to the cover crop could not be explained by soil moisture differences since there were no significant differences in spring soil moisture at planting between treatments.

Conclusions

In all, it is clear that it is not just the C:N ratio that is affecting whether N in the cover crop biomass will be available to the next corn crop, but a host of factors including the total biomass produced, the structure of the plant biomass, and the time of termination. Grass-only cover crop mixtures were not included in these studies as it has been well documented by others that they will not provide N to the next corn crop (e.g., Pantoja et al., 2015). There are many species of cover crops available to plant between early to late August, and each has its own potential benefit. However, if a grower in the upper Midwest is interested in a cover crop that will supply N, the choices appear to be limited only to legumes.

See [CEU] quiz on page 7.

References


Nitrogen Availability from Cover Crops: Is It Always about the C:N Ratio?

Earn 0.5 CEUs in Nutrient Management by taking the quiz for the article at www.certifiedcropadviser.org/education/classroom/classes/742. For your convenience, the quiz is printed below. The CEU can be purchased individually or you can access as part of your Online Classroom Subscription.

1. The C:N ratio of total radish biomass (above- and below-ground) ranged from
   a. 1–9.     c. 20–29.

2. In what year did corn following radish in Sheboygan, WI appear to require more N to optimize yield than following no cover crop?

3. Which of the given cover crops effectively supplied N to the subsequent corn crop?
   a. Crimson clover.
   b. Radish.
   c. Mixture of field pea, flax, forage radish, and volunteer winter wheat.
   d. Mixture of rye, radish, and camelina.

4. Which of the following is a benefit of radish cover crops?
   a. Agronomic productivity.
   b. Increasing agronomically available N.
   c. Increased soil moisture.
   d. Better water quality.

5. Which of the following factors does not affect whether the N in the cover crop biomass will be available to the next corn crop?
   a. Total biomass produced.
   b. Structure of the biomass.
   c. Soil moisture.
   d. Time of termination.
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Can Winter Canola Be Grown on Wide Row Spacing?

By Don Wysocki, Extension Soil Scientist, Oregon State University, Pendleton

Recent interest in oilseed crushing and biofuels in the Pacific Northwest has heightened interest in canola production. Stand establishment is the most difficult aspect of winter canola (Brassica napus) production in the region. High amounts of crop residues, dry soils, and wide diurnal temperature flux present challenges for stand establishment. If canola stands can be established in the fall, a niche for winter canola exists in the low (<12 inch annual precipitation) and intermediate rainfall (12 to 16 inches of annual precipitation) areas of the Pacific Northwest. Autumn conditions typically are hot and dry during the optimum sowing window for canola, and the seed zone

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water is often marginal. Equipment and methods commonly used to plant wheat have only been marginally successful with canola. Unlike wheat, canola is a much smaller seed (90,000 to 120,000 seeds/lb) and cannot emerge as well from deep soil placement. It is best to plant canola shallow but into firm, moist soil.

A method that has been tried by innovative producers is to plant canola using row spacings much wider than used for winter wheat. This allows wide shovel openers to move dry soil to the areas between the rows and creates a seed row that is shallow to moist soil, allowing the seed to be placed relatively shallow with a minimum of soil cover. Going to wider rows can allow for better stand establishment but may also have an adverse effect on yield. Recognizing that the effect of row spacing on yield of winter canola in the Pacific Northwest had not been evaluated, we conducted row width experiments in the 2006–2007, 2007–2008, and 2008 and 2009 crop years.

Several studies have been conducted on row spacing of spring canola in more humid areas. These studies have generally focused on row spacing commonly used for planting cereals, but a few have looked at wider spacings. In Sweden, Ohlsson (1974) found that yields were less when canola was grown on 18-inch spacing versus either 5- or 10-inch spacing. In Alberta, Canada, Kondra (1975) reported statistically similar yields for 6-, 9-, and 12-inch row spacing on spring canola but lower yields with 24-inch spacing. A study by Clarke et al. (1978) in southern Saskatchewan, Canada, reported that canola grown at 12-inch row spacing yielded more than broadcast seeding at equivalent sowing rates. In a study in northwest Alberta, seed yield was 36% higher for canola grown at 3-inch row spacing than on 6- and 9-inch row spacing (Christensen and Drabble, 1984). However, this study found no effect between sowing rates of 3 and 6 lb/ac. Morrison et al. (1990) working in Manitoba, Canada showed that canola yield was greater from stands sown on 6-inch spacing compared with 12-inch spacing. In Ontario, Canada, May et al. (1993) found that row spacings of 4 and 8 inches did not influence yield or oil content of three spring canola cultivars but that yield did increase as sowing rate was increased from 1 to 8 lb/ac. Dosdall et al. (1998) found that flea beetle (Phyllotreta crucifera) damage was less when canola was grown at wider row spacings and higher seeding rates. Johnson and Hansen (2003) in North Dakota reported no difference in yield, oil content, date to flower, or lodging on four spring canola cultivars grown on 6- and 12-inch row spacing. In a drought-affected study in New South Wales, Australia, Haskins (2007) found no difference in yield of canola grow on 6- and 24-inch row spacing.

In summary, various studies in several locations over a 30-year period have shown that row spacing sometimes affects yield. Differences in climatic conditions, soil conditions, weed competition,
planting date, stand establishment, and seed variables make direct comparison of these studies difficult. In those studies where row spacing was shown to affect yield, the difference in yield was attributed to combinations of weed competition, intraspecies competition of plants along the row, or incomplete exploitation of available water and nutrients by rows being too wide. Winter canola in the Pacific Northwest may be able to tolerate wider rows because of the long growing period. Winter canola is a 10-month crop, which allows time for plants to branch more profusely, thus exploiting the wider rows. Wide rows could be an advantage for herbicide-tolerant canola where any weed competition can be eliminated.

The Experiment

Row-spacing experiments on winter canola were conducted at the Columbia Basin Agricultural Research Center near Pendleton, OR. The soil is Walla Walla silt loam, coarse silty, mixed, mesic, hyperactive Typic Haploxerolls. Soil fertility levels for N, S, and P in the trials were adjusted for a seed yield goal of 2,700 lb/ac (Wysocki et al., 2007b) by shank applying 80 lb/ac nitrogen as anhydrous ammonia and 10 lb/ac S as Thiosol in August. Annual grasses and volunteer wheat were controlled in crop with a postemergence application of 11 oz/ac Assure II in November of the crop year.

The experiment was a randomized complete block design with four replications using row spacings of 6, 12, 24, and 30 inches and seeding rates of 5 and 7 lb seed/ac. Athena winter canola was sown on Sept. 14, 2006 and Sept. 12, 2007. Plot dimensions were 5 by 40 ft. Plots were sown into tilled summer fallow that had been pre-irrigated with 1 inch of water five days before planting. This was done to ensure adequate stand establishment when using a small-plot drill. The seedbed was prepared with one pass of a Brillion rolling harrow. Seed was sown 0.75 inches deep using a Hege plot drill equipped with double disk openers and semi-pneumatic press wheels.

In both years of this study, plots were force-lodged with a John Deere 880 swather equipped with a 5-ft-wide “pusher header” (Wysocki et al. 2007a). Plots were forced-lodged on June 21 in 2007 and on July 7 in 2008. Data on yield components of: (1) branches (racemes) per plant, (2) pods per plant, and (3) seed size (1,000-seed weight) were taken in 2008. Because yield component measurement is very time consuming, it was decided that data be collected on only the treatments that had been sown with 5
lb seed/ac. Three representative plants from these treatments were selected immediately after pushing. Harvested plants were collected, dried, and taken to the laboratory. Racemes and pods per plant were counted manually. Pods were clipped from the plants, gathered, and threshed, and seed yield was determined by weighing. Data were averaged from the selected plants. From these data derived yield components of: (1) seeds per raceme and (2) seeds per pod were computed. Pods per raceme were determined by dividing pods per plant by racemes per plant. Seeds per pod were determined using threshed seed weight from sampled plants, pods per plant, and 1,000-seed weight values. Seed weight was determined from three random 1,000-seed counts taken from harvested seed from each plot.

Stand counts were taken for all treatments at both the 5 and 7 lb/ac sowing rates on two 3.3-ft-long row elements in each plot after harvest. Plant stems in each row element were counted. Plants per linear foot of row and plants per square foot were computed using the average of the two row elements.

**Results**

Yields of winter canola at four row spacings and two sowing rates for 2007 and 2008 are presented in Figure 1. In 2007, yields at 6- and 12-inch row spacing were much higher than yield obtained from 24- and 30-inch row spacing. Row spacing of 24- and 30-inch row spacing yielded about 1,000 lb less per acre or only 60% of the narrower spacing. In 2008, 6-, 12-, and 24-inch row spacing yielded nearly the same, and 30-inch row spacing yielded about 300 lb/ac less or about 85 to 90% of the other row spacing.

Data on plant stand for 2008 are presented in Figure 2. As might be expected, plant stand along the row and per unit area changed with row spacing and sowing rate. Plants per square foot for 6-inch row spacing at both sowing rates were nearly double that for wider spacing. Plant density at 12-, 24-, and 30-inch row-spacing was in the range of 4 to 5 plant per ft². The exception was 7.1 plants/ft² at 7 lb seed/ac on 12-inch row-spacing.

Yield component data are presented in Figures 3 and 4. Branching (racemes/plant) increased as row spacing increased; however 1,000-seed weight and seeds per pod were fairly uniform for all row spacings (Figure 3). Pods per plant and pods per raceme increased as row spacing increased (Figure 4).

**Discussion**

Yield results obtained in 2007 and 2008 are somewhat contrasting (Figure 1). In 2007, 24- and 30-inch row spacings yielded 52–60% of the best-yielding treatment that was obtained with 6-inch row spacing and 7 lb seed/ac. In 2008, the highest-yielding treatment was 12-inch row spacing and 7 lb seed/ac, and the wider spacings yielded 73 to 88% of this yield. One possible reason for this difference is that the 2008 growing season was cooler and had more late-season rain. This may have allowed plants in wider rows to compensate better than in 2007. In 2008, yields for both sowing rates at 6-inch spacing were 89 and 94% of the highest yield. Stand counts showed that plant density was nearly 9 plants/ft² on these treatments. It is possible that these densities were high enough for intraspecies competition to limit yield.

As expected, plant stand along the row (plant/foot of row) increased as row spacing and seed rate increased. However, seeding success actually decreased. If success remained constant with row spacing, then plants/foot of row at 6-inch spacing should increase at 2, 4, and 5 times with 12-, 24-, and 30-inch row spacings.
Figure 3. Yield component response of winter canola to four row spacings planted at 5 lb seed/ac, Pendleton, OR 2008.

Figure 4. Effect of row spacing on number of pods per plant and per raceme of winter canola, Pendleton, OR 2008.

**Conclusion**
- Growing canola on wide row spacings is feasible. Plantings should be made in late August and early September.
- Planting in wide rows provides an opportunity to reach deeper into the seed bed for moist soil and yet not bury the seed too deeply.
- More branching and producing more pods is primarily how canola responds to the increased space in wider rows. The same response is seen when plant density is low in areas of the stand. Plants produces more branches and more pods. Winter canola has a tremendous ability to compensate by adding branches and pods as space allows.
- Seedling success decreases with wider rows because more plants are crowded along the row.
- Stands of 4 to 5 plants/ft² are optimum for winter canola.
- Seldom are stands of winter canola uniform across a field. Replanting or overseeding is probably not needed if there is 1 to 2 plants/ft².
- Winter canola should be planted and emerged by mid-September. This date is earlier for areas in Washington and Idaho.

**References**


See [CEU](https://catalog.extension.oregonstate.edu/em8943) quiz on page 15.
Can Winter Canola Be Grown on Wide Row Spacing?

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1. Which of the following was NOT mentioned in the article as a reason it is difficult to establish stands of winter canola in the Pacific Northwest?
   a. High amounts of crop residues.
   b. Heavy precipitation.
   c. Dry soils.
   d. Wide diurnal temperature flux.

2. What is the seed weight of canola?
   a. 9,000 to 12,000 seeds/lb.
   b. 15,000 to 45,000 seeds/lb.
   c. 50,000 to 80,000 seeds/lb.
   d. 90,000 to 120,000 seeds/lb.

3. In a study in northwest Alberta by Christensen and Drabble, seed yield was 36% higher for canola grown at ______ row spacing than on 6- and 9-inch row spacing.
   a. 3-inch
   b. 5-inch
   c. 12-inch
   d. 15-inch

4. In Ontario, Canada, May et al. (1993) found that row spacings of 4 and 8 inches did not influence yield or oil content of three spring canola cultivars but that yield did increase as sowing rate was increased from 1 to
   a. 3 lb/ac.
   b. 5 lb/ac.
   c. 8 lb/ac.
   d. 10 lb/ac.

5. In this experiment, soil N, S, and P were adjusted for a seed yield goal of
   a. 1,300 lb/ac.
   b. 1,900 lb/ac.
   c. 2,300 lb/ac.
   d. 2,700 lb/ac.

6. In 2008, 6-, 12-, and 24-inch row spacing yielded nearly the same and 30-inch row spacing yielded about ______ than the other row spacing.
   a. 100 lb/ac less
   b. 100 lb/ac more
   c. 300 lb/ac less
   d. 300 lb/ac more

7. Plants per square foot for ______ row spacing at both sowing rates were nearly double that for other row spacing.
   a. 6-inch
   b. 12-inch
   c. 24-inch
   d. 30-inch

8. Which treatment had the highest yield in 2008?
   a. 6-inch row spacing.
   b. 12-inch row spacing.
   c. 24-inch row spacing.
   d. 30-inch row spacing.

9. In 2008, stand counts for the 6-inch row spacing were nearly
   a. 5 plants/ft².
   b. 7 plants/ft².
   c. 9 plants/ft².
   d. 11 plants/ft².

10. Recommendations of a 5 lb seed/acre planting density in seeds/foot of row for 6-, 12-, 24-, and 30-inch row spacing is about 5, 10, 20, and 25 seeds, respectively, based on a measured seed weight of
    a. 92,000/lb.
    b. 93,000/lb.
    c. 95,000/lb.
    d. 99,000/lb.
Crop Production and Environmental Impacts under Organic Management with Reduced Tillage and Diversified Cropping

By Myriam R. Fernandez, Robert P. Zentner, Michael P. Schellenberg, and Olanike Aladenola, Swift Current Research and Development Centre, Agriculture and Agri-Food Canada, Swift Current SK, Canada; Julia Y. Leeson, Agriculture and Agri-Food Canada, Research and Development Centre, Saskatoon, SK, Canada; and Mervin St. Luce, Brian G. McConkey, and Herb Cutforth, Swift Current Research and Development Centre, Agriculture and Agri-Food Canada, Swift Current SK, Canada

In the Canadian Prairies, organic agriculture has traditionally relied on summer fallow and mechanical tillage for nutrient and pest management. More recently, there has been a substantial increase in the use of legume green manure, diversified crop rotations, and reduced tillage. The objectives of this study were to determine...
During the past few decades, organic crop production has become increasingly widespread. The global increase in organic demand is attributed to factors such as increasing concerns about food safety and consumer health, environmental issues, rising input costs, and declining soil productivity and quality (Reganold and Wachter, 2016). Studies in the Canadian Prairies have reported that organic cropping systems have higher net returns and are more energy efficient than non-organic systems (Entz et al., 2005; Zentner et al., 2011a, b). Crop yields are often reported to be lower with organic than conventional management (Benaragama et al., 2016a; Berner et al., 2008; Campiglia et al., 2015; Ponisio et al., 2015). However, a survey of organic farms in eastern regions of the Canadian Prairies revealed that grain and forage yields ranged from one-half to almost double conventional yields (Entz et al., 2001). Similarly, studies in the U.S. have reported no consistent differences in the yield of wheat among management systems (Cavigelli et al., 2008) and similar or greater grain productivity and superior quality of organic winter wheat compared with well-fertilized winter wheat grown in a no-till cropping system (Miller et al., 2008). Even so, crops grown under reduced tillage and diversified sequences can maintain soil fertility and quality at adequate levels, keep weed populations at low levels, and foster healthy plants for sustainable and profitable production of annual crops. Earn 1.5 CEUs in Crop Management by reading this article and taking the quiz at https://www.certifiedcropadviser.org/education/classroom/classes/692.

This article was adapted from two companion articles in Agronomy Journal—“Soil Fertility and Quality Response to Reduced Tillage and Diversified Cropping under Organic Management” and “Grain Yield and Quality of Organic Crops Grown under Reduced Tillage and Diversified Sequences.” For the full text, including the References (omitted here due to space constraints), view the original articles at https://doi.org/10.2134/agronj2018.01.0028 and https://doi.org/10.2134/agronj2018.01.0029.
al., 2008). These highly variable yield and quality differences reported between organic and non-organic systems appear to depend on the specific management practices employed and the site characteristics (Campiglia et al., 2015; Seufert et al., 2012).

Compared with conventional high-input management systems for annual crops, soil fertility is often considered to be lower under organic management. Deficiencies in available N, P, and S in organic cropping systems have been reported in Manitoba and Saskatchewan (Entz et al., 2005; Knight et al., 2010). However, in a U.S. study, N increased significantly after 22 years in organic animal and legume systems (Pimentel et al., 2005). Soil C has also been reported to be higher in organic than conventional plots (Gadermaier et al., 2011; Pimentel et al., 2005) attributable to the higher amounts of plant residues being returned to the soil.

Weed management is reported as one of the most difficult challenges under organic conditions. However, organic systems may be able to tolerate a greater abundance of weeds compared with conventional systems due to differing weed species compositions and differences in weed-crop competition influenced by fertility management (Ryan et al., 2009). Benaragama et al. (2016b) also showed that in the absence of weeds, the organic systems still produced 44% lower yields than the conventional systems, suggesting that the effect on yields could not be attributed to weed competition but was mostly attributable to lower soil productivity. Armengot et al. (2015) also reported that despite weed increases in the reduced-tillage treatments in an organic trial, yields of various crops were similar for reduced and conventional tillage.

In the Canadian Prairies, organic agriculture has traditionally relied on summer fallow and mechanical tillage to provide enhanced soil moisture and nutrients, mitigate the impact of weeds, and reduce crop diseases; however, in recent years, there has been a substantial increase in the use of legume green manure, diversified crop rotations, and reduced-tillage management. Conservation tillage has been shown to improve soil quality and lower the environmental impact of crop production. Under organic management, reduced tillage could help improve soil fertility and increase water retention, yields, and nutrient uptake (Krauss et al., 2010). Other benefits of reducing the frequency of tillage in organic systems include higher soil organic C and microbial biomass (Carr et al., 2013). However, adoption of reduced tillage by organic farmers has been slow due mostly to concerns about nutrient supply and weeds that may limit crop yields (Cooper et al., 2016; Peigne et al., 2007).
The inability of organic no-till cropping systems to control perennial weeds has been identified as their greatest shortcoming (Carr et al., 2013; Mirsky et al., 2012). According to a meta-analysis of organic systems by Cooper et al. (2016), weeds were about 50% higher when tillage intensity was reduced although this did not always impact yields. The lower yields with reduced-tillage organic systems have been correlated with higher weed pressure as well as lower N availability in spring and early summer due to retarded mineralization (Sans et al., 2011). However, several studies have found that weeds might be managed in organic no-tillage systems through suppression by surface crop residues and weed seed exposure to environmental extremes (Anderson, 2005; Halde et al., 2015; Vaisman et al., 2011).

Diverse crop rotations can reduce weeds by disrupting their life cycles. In a study in the Central Great Plains, Anderson (2010) reported lower weed density when there were more than two crop types being rotated. In a meta-analysis, Ponisio et al. (2015) found that yields under organic management were 19% lower than under conventional management, but through the use of multiple crop types and rotations, the yield gap could be reduced to 8 to 9%.

The objectives of this multi-year study conducted in the Brown soil zone of Western Canada were to determine if diversified crop rotations and reduced tillage under organic management can maintain soil fertility and quality at adequate levels, keep weed populations at low levels, and foster healthy plants for sustainable and profitable production of annual crops. Results from this study will also be of benefit to non-organic producers, who are increasingly interested in reducing their reliance on non-renewable energy inputs, lowering input costs, reducing greenhouse gas emissions, and finding alternate methods to control herbicide-resistant weeds.

**Materials and Methods**

This study was conducted near Swift Current, SK on an Orthic Brown Chernozem with silt-loam texture (Fernandez et al., 2016). The land had been organically managed under green manure (GM) for two years prior to the initiation of the study in 2010.

The experiment included two crop sequences × two tillage systems. Cropping sequences were simplified rotation (SR): GM–spring wheat; and diversified rotation (DR): GM–oilseed–pulse–spring wheat. In the DR rotation, the oilseed crop alternated between flax and mustard while the pulse crop alternated between field pea and lentil. All phases of the rotations were

**Green manure termination with a tandem disc. YouTube screenshot courtesy of the Natural Systems Agriculture Lab at the University of Manitoba (https://youtu.be/F2nU86lQgfw).**
Results and Discussion

The total precipitation ranged from above average in the 2010 and 2011 crop years (>140% of long-term mean) to slightly below average in 2013 and 2015 (95 and 90%, respectively). In May–June of 2015, the area received less than 40% of normal precipitation; however, the July precipitation was 150% of normal. In contrast, in 2012, precipitation during May–June was 165% of normal, whereas precipitation during July was only 41% of the long-term mean. Except for 2015, June precipitation was favorable for crop growth (greater than 140% of the long-term mean). Average temperatures from May to July were lowest in 2010 (56.5°F) and highest in 2015 (59.9°F). Overall, crop growth stress was rated as high in 2015, average in 2013 and 2014, moderate in 2012, and low in 2010 and 2011.

Nitrogen content tended to be lowest in the last few years of the trial (Table 1). In most years, there were significant differences in soil NO3–N among the tillage-rotation systems. For all years combined, soil NO3–N levels in the plots to be seeded to wheat were significantly higher under HT than LT for the SR only and were significantly higher in SR than DR under HT only. Whenever there was a significant difference between HT and LT in the other crops, the NO3–N levels were higher under HT than LT (data not presented). Crop residue incorporation in the soil with HT likely increased microbial activity, which in turn, increased residue decomposition and N mineralization. Reduced tillage has been previously associated with lower soil NO3–N levels (Burgess et al., 2014; Peigne et al., 2007; Vaisman et al., 2011).

There were few differences in soil PO4–P in the 0- to 15-cm depth among individual years (data not presented). Overall, soil PO4–P content was higher in the first three years than in the last three years of this trial. Contrasts among tillage-rotation combinations also revealed that there were significantly higher soil PO4–P levels in plots following a pulse crop in LT-SR than in HT-SR. Higher soil-available PO4–P under LT than HT agrees with the findings of Gademaier et al. (2011).

Soil organic C in the 0- to 15-cm depth changed between the springs of 2013 and 2016 (data not presented). For all treatments combined, there was a 2.2% decrease under HT, mostly due to a decrease in the GM plots in the SR of 15.3%. Overall, for all treatments under LT, there was a mean increase of 2.1% between the two years. Increasing organic C in the LT over time was expected since conservation tillage enhances C sequestration by reducing the rate of soil organic matter decomposition (Berner et al., 2008; Emmerling, 2007).

In both 2013 and 2016, there were overall no significant differences in soil organic C among tillage-rotation systems. However, in 2013, there was significantly higher organic C in HT than LT following wheat in the SR (21.1%). For the treatments combined in 2013, organic C was significantly higher in the DR than the SR under LT by 14.7%. The greater diversity of crop residues and root exudates in the DR than in the SR treatment may result in greater C inputs (McDaniel et al., 2014). In 2016, soil organic C tended to be higher under LT; however, the difference was not significant.

Soil aggregate distribution differed for most fractions between LT and HT (data not presented). The fine fractions were present at lower levels, and the large fractions at higher levels, under LT than HT in the DR. Higher fine fractions of dry soil aggregates under HT indicate a higher potential for soil erosion under more intensive tillage management and agrees with the findings of Malhi et al. (2009). The wet aggregate stability was significantly higher in LT than HT in the DR. Previous studies have also shown that conservation tillage provides greater wet soil aggregate stability in the surface layer than conventional tillage (Emmerling, 2007; Peigne et al., 2007).

Higher-than-average moisture conditions in most years of this study resulted in high weed biomass (data not presented). Overall, this was highest in 2012 and 2014 and lowest in 2013. The weed biomass was significantly lower under HT than LT in 2012, 2014, and 2015. The opposite was true in 2011 in SR. Comparison between SR and DR showed no differences in

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### TABLE 1. Soil NO₃–N in the spring before seeding the crops in an organic tillage-cropping sequence trial at Swift Current, SK.

<table>
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<tbody>
<tr>
<td>High simplified, GMb wheat</td>
<td>10.3de 29.2bc 18.9ab 16.1c 18.6bc 14.7ab 15.9cd 20.1b 17.9b</td>
<td>25.4</td>
<td>30.5</td>
<td>25.5</td>
<td>23.3</td>
</tr>
<tr>
<td>High diversified, GM wheat</td>
<td>9.4e 23.1c 8.5b 15.5c 20.1bc 19.6ab 12.7d 19.4b 16.0b</td>
<td>25.4</td>
<td>30.5</td>
<td>25.5</td>
<td>23.3</td>
</tr>
<tr>
<td>High simplified, GM wheat GM</td>
<td>59.8a 85.0a 42.9a 37.1a 37.5ab 24.4a 46.8a 49.0a 47.8a</td>
<td>25.4</td>
<td>30.5</td>
<td>25.5</td>
<td>23.3</td>
</tr>
<tr>
<td>High diversified, wheat pulse</td>
<td>38.5a-c 31.8bc 36.2ab 18.0bc 29.3a-c 15.3ab 34.7a-c 21.7ab 28.2b</td>
<td>25.4</td>
<td>30.5</td>
<td>25.5</td>
<td>23.3</td>
</tr>
<tr>
<td>High, lentil flax</td>
<td>12.6c-e 17.8ab 15.8bc 15.3cd</td>
<td>25.4</td>
<td>30.5</td>
<td>25.5</td>
<td>23.3</td>
</tr>
<tr>
<td>High, mustard GM</td>
<td>42.6ab 35.2ab 45.4a 41.1ab</td>
<td>25.4</td>
<td>30.5</td>
<td>25.5</td>
<td>23.3</td>
</tr>
<tr>
<td>High, field pea mustard</td>
<td>32.7bc 25.6a-c 13.4ab 23.9ab</td>
<td>25.4</td>
<td>30.5</td>
<td>25.5</td>
<td>23.3</td>
</tr>
<tr>
<td>High, flax GM</td>
<td>56.3b 37.1a 19.0ab 37.5ab</td>
<td>25.4</td>
<td>30.5</td>
<td>25.5</td>
<td>23.3</td>
</tr>
<tr>
<td>Low simplified, GM wheat</td>
<td>9.8de 13.5c 21.9ab 18.1bc 12.7c 6.9b 14.7cd 12.8b 13.8b</td>
<td>25.4</td>
<td>30.5</td>
<td>25.5</td>
<td>23.3</td>
</tr>
<tr>
<td>Low diversified, GM wheat</td>
<td>7.9e 10.9c 25.1ab 15.3c 16.0bc 9.8b 16.2cd 12.0b 14.1b</td>
<td>25.4</td>
<td>30.5</td>
<td>25.5</td>
<td>23.3</td>
</tr>
<tr>
<td>Low simplified, wheat GM</td>
<td>37.6a-d 33.5bc 19.7ab 24.9a-c 18.0bc 7.9b 25.1b-d 22.1ab 23.6b</td>
<td>25.4</td>
<td>30.5</td>
<td>25.5</td>
<td>23.3</td>
</tr>
<tr>
<td>Low diversified, wheat pulse</td>
<td>24.2b-e 11.2c 25.2ab 21.8bc 37.2a 7.6b 28.9a-d 13.5b 21.2b</td>
<td>25.4</td>
<td>30.5</td>
<td>25.5</td>
<td>23.3</td>
</tr>
<tr>
<td>Low, lentil flax</td>
<td>21.5b-e 20.6ab 16.2bc 19.4cd</td>
<td>25.4</td>
<td>30.5</td>
<td>25.5</td>
<td>23.3</td>
</tr>
<tr>
<td>Low, mustard GM</td>
<td>30.6b-e 33.8ab 18.9bc 27.7a-d</td>
<td>25.4</td>
<td>30.5</td>
<td>25.5</td>
<td>23.3</td>
</tr>
<tr>
<td>Low, field pea mustard</td>
<td>18.8c 19.8bc 8.7b 15.7b</td>
<td>25.4</td>
<td>30.5</td>
<td>25.5</td>
<td>23.3</td>
</tr>
<tr>
<td>Low, flax GM</td>
<td>19.9c 29.7ab 20.0ab 23.1ab</td>
<td>25.4</td>
<td>30.5</td>
<td>25.5</td>
<td>23.3</td>
</tr>
</tbody>
</table>

**F value** | 7.26 | 12.36 | 2.16 | 7.08 | 4.09 | 3.87 | 6.81 | 3.09 | 7.32 |

**P value** | <.001 | <.001 | .043 | <.001 | .001 | <.001 | .012 | <.001 |
## Table 1. Continued.

<table>
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<tbody>
<tr>
<td>Tillage by rotation by crop</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GM: Simplified, high vs. low</td>
<td>.952</td>
<td>.077</td>
<td>.751</td>
<td>.645</td>
</tr>
<tr>
<td>GM: Diversified, high vs. low</td>
<td>.863</td>
<td>.164</td>
<td>.086</td>
<td>.970</td>
</tr>
<tr>
<td>Wheat: Simplified, high vs. low</td>
<td>.016</td>
<td>&lt;.001</td>
<td>.018</td>
<td>.006</td>
</tr>
<tr>
<td>Wheat: Diversified, high vs. low</td>
<td>.111</td>
<td>.022</td>
<td>.248</td>
<td>.361</td>
</tr>
<tr>
<td>Tillage by crop</td>
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<td></td>
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<tr>
<td>Lentil: High vs. low</td>
<td>.315</td>
<td>.761</td>
<td>.960</td>
<td>.511</td>
</tr>
<tr>
<td>Mustard: High vs. low</td>
<td>.180</td>
<td>.880</td>
<td>.001</td>
<td>.038</td>
</tr>
<tr>
<td>Field pea: High vs. low</td>
<td>.116</td>
<td>.175</td>
<td>.272</td>
<td>.359</td>
</tr>
<tr>
<td>Flax: High vs. low</td>
<td>&lt;.001</td>
<td>.082</td>
<td>.816</td>
<td>.111</td>
</tr>
<tr>
<td>Rotation by tillage by crop</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheat: High, simplified vs. diversified</td>
<td>.020</td>
<td>&lt;.001</td>
<td>.478</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Wheat: Low, simplified vs. diversified</td>
<td>.136</td>
<td>.014</td>
<td>.560</td>
<td>.460</td>
</tr>
</tbody>
</table>

$^a$To convert kg/ha to lb/ac, multiply the value by 0.893.

$^b$High: high tillage; low: low tillage. Crop sequences: simplified: forage pea green manure (GM)–wheat; diversified: GM–oilseed (flax or mustard)–pulse (field pea or lentil)–wheat, with all phases of the rotation present each year.

$^c$Values in a column followed by the same letter are not significantly different according to the Tukey–Kramer mean separation (P ≤ .10).
weed biomass under LT while under HT, it was lower in SR than DR in 2012 and 2014.

Perennial thistles, first noted in 2012, became more pronounced in 2013 (data not presented). Overall, there was an increase of 12 times their density from 2013 to 2014. Combined thistle density was significantly higher for LT than HT. The increase in perennial thistles, especially under LT, agrees with Armengot et al. (2015) who reported they almost doubled over time under reduced tillage. In contrast to weed biomass, which varied with environmental conditions and competitiveness of the crops, perennial weeds were affected most by tillage.

Wheat yield decreased steadily over the years (Table 2). Wheat yield was lowest in 2015, the least favorable year due to a dry spring/early summer. In the first year, the organic wheat yield was higher than wheat yields in similar cropping sequences in a nearby conventional no-till study. Although yields were lower in the organic than in the conventional wheat in the following years, initially, the differences were not large even though the latter had fertilizer and herbicides applied. Similarly, comparison of yields with those of the same cultivar in commercial fields in the region revealed an initial higher yield of the organic wheat (131% in 2011) followed by lower yields that differed increasingly over time from the commercial wheat (88, 83, 65, and 61% in each subsequent year, respectively). Because of lower performance of the organic wheat in the last years, over the full period, yields were an average of 75% of the conventional no-till wheat and 85% of the commercial crops.

Although yields varied among years, wheat in HT-SR displayed the most stable yields (Table 2). There were significant differences among tillage-rotation systems in all years, except 2013. Over all years, yields were significantly higher in

**TABLE 2. Grain yield of wheat in an organic tillage-cropping sequence trial at Swift Current, SK.**

<table>
<thead>
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<tbody>
<tr>
<td>High simplified</td>
<td>3420.5</td>
<td>2671.8</td>
<td>2345.7</td>
<td>2302.5</td>
<td>1972.4</td>
<td>2542.7</td>
</tr>
<tr>
<td>High diversified</td>
<td>3171.9</td>
<td>1927.9</td>
<td>2460.4</td>
<td>1424.7</td>
<td>1129.4</td>
<td>2023.0</td>
</tr>
<tr>
<td>Low simplified</td>
<td>3534.0</td>
<td>1805.4</td>
<td>2015.2</td>
<td>1532.6</td>
<td>825.5</td>
<td>1942.3</td>
</tr>
<tr>
<td>Low diversified</td>
<td>2493.0</td>
<td>957.6</td>
<td>1947.4</td>
<td>1190.0</td>
<td>920.4bc</td>
<td>1501.6</td>
</tr>
<tr>
<td>Mean</td>
<td>3154.9</td>
<td>1840.7</td>
<td>2192.2</td>
<td>1612.5</td>
<td>1211.9</td>
<td>2002.4</td>
</tr>
<tr>
<td>F value</td>
<td>.001</td>
<td>&lt;.001</td>
<td>.137</td>
<td>.001</td>
<td>&lt;.001</td>
<td>.001</td>
</tr>
<tr>
<td>P value</td>
<td>.008</td>
<td>.018</td>
<td>.039</td>
<td>.004</td>
<td>.001</td>
<td></td>
</tr>
</tbody>
</table>

| Tillage by rotation  | Simplified: High vs. low | .546 | <.001 | .182 | .002 | <.001 | .008 |
|                      | Diversified: High vs. low | .005 | <.001 | .051 | .228 | .076 | .018 |
| Rotation by tillage  | High: Simplified vs. diversified | .202 | <.001 | .628 | .001 | <.001 | .018 |
|                      | Low: Simplified vs. diversified | <.001 | <.001 | .773 | .092 | .386 | .039 |
| Rotation (both tillage treatments) | Simplified vs. diversified | .001 | <.001 | .888 | .001 | .001 | .004 |
|                      | High vs. low | .054 | <.001 | .028 | .004 | <.001 | .001 |

*To convert kg/ha to lb/ac, multiply the value by 0.893. To convert kg/ha to 60-lb bu/ac, multiply by 0.0149.
*High: high tillage; low: low tillage. Crop sequences: simplified: forage pea green manure (GM)—wheat; diversified: GM–oilseed (flax or mustard)—pulse (field pea or lentil)—wheat, with all phases of the rotation present each year.
*Values in a column followed by the same letter are not significantly different according to the Tukey–Kramer mean separation (P ≤ .10).
HT-SR than in LT-SR and HT-DR with the lowest yield in LT-DR. The latter represented only 59.1% of the yield in HT-SR. While the overall differences in weed biomass between SR and DR were not significant, yields were significantly higher under SR than DR, regardless of tillage, in most years and for all years combined. Similarly, regardless of crop rotation, wheat in HT had higher yields than in LT. Even though tillage was increased in LT starting in 2013, yields were consistently highest, and in most cases weed biomass was lowest, under HT. The lower yields under LT coincided with lower soil NO$_3$-N, and/or higher weed biomass.

Average grain protein in the organic trial was 14.2% (data not presented). In 2011, the highest mean protein coincided with the highest yield (Table 2) while 2014 had the lowest protein and the second lowest yield. In 2013, average protein was also lower than the five-year average, and yield was near average. In 2012 and 2015, protein was above average but yield was below average. There was no negative association between yield and protein among years. This might be explained by the release of mineralized N throughout the season from the previous GM or pulse crop. Low temperatures and water deficits after flowering have been reported to negatively affect protein in organic winter wheat (Casagrande et al., 2009); this might help explain the lower protein in 2014 (below-average temperature) and higher protein in 2015 (high July temperature and precipitation).

Comparison of grain protein in our trial to commercial wheat in the region showed that levels in organic wheat were higher by 9 to 26% in most years. However, in 2014, the organic wheat protein averaged 10% lower than in commercial fields. In comparison to the nearby conventional no-till study, protein in organic wheat was higher in the first three years and slightly lower (by 3%) over the full period. The observation that protein in organic wheat was higher than in the conventional zero-till wheat suggests that the former was more efficient at producing higher protein grain.

For individual years or years combined, there were no significant differences in protein among tillage-rotation systems or these were not consistent (data not presented). In 2013, for both rotations combined, average protein was significantly lower under LT than HT while in 2015, it was higher under LT than HT. Similar protein in LT and HT, despite lower spring soil NO$_3$-N under LT than HT, suggests that there might have been further N uptake by the crop later in the season.

According to linear regressions, precipitation in the growing season and previous 12 months explained 13 and 35%, respectively, of the yield variation while spring soil NO$_3$-N explained 22%. In contrast, weed biomass explained only 5% of the yield variability. Cavagelli et al. (2008) also reported that N availability explained more of the variation in yield than weed competition. Other factors also likely affected yields, including crop management, non-N factors, and crop diseases (Fernandez et al., 2014a, b).

Conclusions

Although intensive tillage (HT) and a two-year rotation of wheat with GM (SR) promoted higher N availability resulting in greater yields, a depletion of N over time was apparent. The decrease in yield, whether due to nutrient levels and/or weed infestations, suggests that growing wheat organically alternated with GM, although resulting in acceptable yields in the short term, might not be enough to maintain productivity in the longer term. More diversified rotations with GM every four years would be even more inefficient at achieving yields compared with conventional production. However, the lower-yielding LT and DR tended to have higher soil organic C in addition to fewer erodible particles, and more water-stable aggregates, increasing the soil’s resistance to wind and water erosion and contributing to the environmental sustainability of organic production under reduced tillage. Thus, a different strategy for increasing soil NO$_3$-N would be needed without compromising soil quality.

This study was conducted in the Brown soil where precipitation is traditionally limited and variable but coincided with above-average precipitation. Low tillage did not appear to be viable under those conditions for more than a few years, after which intensive tillage would be needed for adequate perennial weed control. Under reduced tillage, the occasional use of more intensive and frequent tillage could help mitigate the potential adverse effects of perennial weeds before their levels become unmanageable, in addition to contributing to increased N mineralization. Therefore, flexibility remains necessary regarding reduced tillage in organic systems when perennial weeds need to be better controlled to minimize their effect on crop growth.

Acknowledgments

We gratefully acknowledge funding by the Western Grains Research Foundation and the Agri-Innovation Program of Agriculture and Agri-Food Canada’s Growing Forward 2 through the Organic Science Cluster II, initiated by the Organic Agriculture Centre of Canada in collaboration with the Organic Federation of Canada. This study was designed with input from G. Johnson, M. Meinert, D. Smith, S. Wells, and other members of the Advisory Committee on Organic Research for the Swift Current Research and Development Centre. We thank K. Deobald, E. Powell, P. Spetz, B. Nybo, D. Sluth, W. Galecki, and G. Ford for technical assistance.

See [CEU] quiz on page 25.

American Society of Agronomy
Crop Production and Environmental Impacts under Organic Management with Reduced Tillage and Diversified Cropping

Earn 1.5 CEUs in Crop Management by taking the quiz for the article at www.certifiedcropadviser.org/education/classroom/classes/692. For your convenience, the quiz is printed below. The CEU can be purchased individually or you can access as part of your Online Classroom Subscription.

1. The authors cite Benaragama et al. (2016b), which demonstrated that in the absence of weeds, the organic systems still produced _______ lower yields than the conventional systems.
   a. 25%
   b. 31%
   c. 44%
   d. 47%

2. Which of the following was NOT mentioned in the article as a benefit of reducing tillage under organic management?
   a. Improved soil fertility.
   b. Increased weed suppression.
   c. Increased water retention.
   d. Increased nutrient uptake.

3. According to a meta-analysis of organic systems by Cooper et al. (2016), weeds were about _______ higher when tillage intensity was reduced.
   a. 15%
   b. 25%
   c. 40%
   d. 50%

4. In a meta-analysis, Ponisio et al. (2015) found that yields under organic management were _______ lower than under conventional management.
   a. 10%
   b. 14%
   c. 17%
   d. 19%

5. In the experiment, in May–June of 2015, the area received less than 40% of normal precipitation; however, the July precipitation was _______ of normal.
   a. 80%
   b. 120%
   c. 150%
   d. 175%

6. During the experiment, average temperatures from May to June were highest in
   a. 2010.
   b. 2012.
   c. 2014.
   d. 2015.

7. For all treatments combined, there was a 2.2% decrease under
   a. HT.
   b. GM.
   c. SR.
   d. LT.

8. For the treatments combined in 2013, organic C was significantly higher in
   a. DR under LT.
   b. DR under HT.
   c. SR under LT.
   d. SR under HT.

9. The wet aggregate stability was significantly higher in
   a. LT in DR.
   b. HT in DR.
   c. LT in SR.
   d. HT in SR.

10. Perennial thistles increased _______ their density from 2013 to 2014.
    a. 5 times
    b. 8 times
    c. 12 times
    d. 15 times

11. Comparison of yields with those of the same wheat cultivar in commercial fields in the region revealed that in 2015, yields were _______ those of the commercial fields.
    a. 61%
    b. 65%
    c. 83%
    d. 88%

12. Overall, the lowest yields occurred in which treatment?
    a. LT-SR.
    b. HT-SR.
    c. LT-DR.
    d. HT-DR.

13. Average grain protein in the organic trial was
    a. 12.4%.
    b. 14.2%.
    c. 15.0%.
    d. 15.5%.

14. In 2014, the organic wheat protein averaged _______ lower than in commercial fields.
    a. 5%
    b. 10%
    c. 15%
    d. 20%

15. According to linear regressions, precipitation in the growing season and previous 12 months explained 13 and 35%, respectively, of the yield variation while spring soil NO₃-N explained
    a. 18%.
    b. 20%.
    c. 22%.
    d. 24%.
Sunflower Response to Nitrification Inhibitor Application

By A. Chatterjee, Department of Soil Science, North Dakota State University, Fargo

Adding a nitrification inhibitor to fertilizer nitrogen (N) has potential to reduce N loss and increase N use efficiency. On-farm trials were conducted to determine sunflower seed yield and soil inorganic N responses to spring-applied urea N rates (100, 75, and 50% of the recommended N rate) and nitrification inhibitor (nitrapyrin) addition in eastern North Dakota. Earn 0.5 CEUs in Nutrient Management by reading this article and taking the quiz at www.certifiedcropadviser.org/education/classroom/classes/731.

Sunflower has become an important crop in the Northern Great Plains. Nitrogen (N) plays a pivotal role in sunflower yield and oil content. Excess supply of fertilizer N can increase yield but reduce the oil content due to dilution of oil in heavier seeds produced (Blamey and Chapman, 1980). However, shortage of N supply, particularly at an early growth stage, could reduce yield due to suppression of physiological attributes (plant height, total number of florets, and seed vigor) (Connor et al., 1993). For dryland and irrigated sunflower, Zubriski and Moraghan (1983) reported yields of 1,553 and 2,117 lb/ac with 25 lb N/ac and 2,369 and 3,266 lb/ac with 150 lb N/ac, respectively. Current fertilizer N recommendation for eastern conventional till oilseed sunflower N recommendation ranges between 47 and 150 lb N/ac based on the cost of fertilizer N and sunflower price (Franzen, 2016). Recently, Schultz et al. (2018) reported that 14 out of 21 sites responded to fertilizer N additions with the yield response curve in response to incremental fertilizer N application rates following a quadratic relationship in North Dakota and South Dakota.

DOI: 10.1002/crso.20004
Adding a nitrification inhibitor to fertilizer N has the potential to reduce fertilizer N loss through denitrification and leaching, and hence increase fertilizer N use efficiency (Thapa et al., 2016). Some researchers reported toxicity of 6-chloropicolinic acid, a principal metabolite of nitrapyrin on sunflower seedling growth; and the suppressing influence of nitrapyrin was controlled by the form of fertilizer N (Maftoun et al., 1982). The main goal of this research was to find out the potential of inhibitor addition to increase yield by increasing N use efficiency. On-farm trials were conducted to determine the effects of urea N rate and inhibitor addition on sunflower seed yield and soil N availability.

**Research Experiment and Analyses**

During 2018 growing season, two growers’ fields located at Buffalo and Chaffee in eastern North Dakota were selected for this experiment. Details of the experimental sites are presented in Table 1. Monthly average of maximum air temperature and rainfall during the growing season (April through October) from the Prosper, ND weather station of the North Dakota Agriculture Weather Network (https://ndawn.ndsu.nodak.edu/) close to the two sites are presented in Fig. 1. The early to middle part of the growing season (May through July) had lower rainfall than normal; and maximum air temperature was also higher than normal in May. Seven treatments consisted of three fertilizer N (in the form of urea) application rates: 100% (150 lb N/ac), 75% (110 lb N/ac), and 50% (75 lb N/ac) of recommended N, with and without nitrapyrin (Instinct HL, Corteva AgriSciences, 2.5 lb a.i./gal), at the rate of 24 fl oz/ac along with a control (no fertilizer N). Treatments were laid out in randomized block design with four replications. Plot size was 25 ft long and 11 ft wide. Fertilizer N was hand-broadcast just before planting and incorporated to surface soil using tillage equipment. Phosphorus and potassium fertilizers were not applied due to high soil test values according to the current recommendation (Franzen, 2016). Sunflower (oilseed-type cultivar) was planted and growers were responsible for in-season cultural operations. Surface soil samples 0 to 1 ft deep were collected from each plot two and four weeks after planting. Soil samples were analyzed for inorganic N (NH₄⁺ and NO₃⁻) concentration by extracting with 2 M KCl and subsequently analyzed with a Timberline ammonia analyzer (TL-2800, Timberline Instruments, Boulder, CO). At maturity, sunflower heads of the middle two rows of each plot were harvested by hand by clipping the head from the stalk as close to the head as possible and putting it into burlap bags. Sunflower heads were oven-dried at 104°F to a moisture between 8 and 10% prior to being threshed. Threshing of sunflower heads was conducted using an Almaco low-profile plot thresher (Almaco, Nevada, IA). Sunflower seed grain yield was weighed; moisture and test weight were determined on a seed grain subsample using a Dickey-John GAX500XT moisture and test weight meter.

---

**Table 1. Site location, soil properties, and management information of experimental sites used to determine influence of fertilizer nitrogen rate and nitrification inhibitor addition on sunflower yield.**

<table>
<thead>
<tr>
<th></th>
<th>Buffalo, ND</th>
<th>Wheatland, ND</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>N46°51'40.9&quot; W97°18'12.4&quot;</td>
<td>N47°04'46.9&quot; W97°35'01.4&quot;</td>
</tr>
<tr>
<td>Soil organic matter (%)</td>
<td>5.1</td>
<td>4.3</td>
</tr>
<tr>
<td>Available N (0-6 inches) (lb/ac)</td>
<td>40</td>
<td>22</td>
</tr>
<tr>
<td>Olsen-phosphorus (ppm)</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td>Potassium (ppm)</td>
<td>445</td>
<td>447</td>
</tr>
<tr>
<td>Previous crop</td>
<td>corn</td>
<td>hull less barley</td>
</tr>
<tr>
<td>Planting date</td>
<td>May 29</td>
<td>May 23</td>
</tr>
<tr>
<td>Harvesting date</td>
<td>October 5</td>
<td>October 5</td>
</tr>
</tbody>
</table>

---

Figure 1. Normal and 2018 growing season (a) maximum air temperature (°F) and (b) monthly rainfall (inch) data from weather station close to two experimental sites.
(Dickey-John, Auburn, IL). Yields were adjusted to 10% moisture. Statistical analysis of seed yield and soil inorganic N after two and four weeks was conducted using a randomized block design using PROC GLM procedure under SAS 9.4 software (SAS Institute Inc., Cary, NC). Mean separation of treatments was performed using the LSD at 95% significance level.

Seed Yield and Soil Inorganic N

Sunflower seed yields in response to fertilizer N application rate and inhibitor addition at two sites are presented in Table 2. At the Buffalo site, the highest seed yield (4,236 lb/ac) was observed with 100% of recommended N without nitrapyrin addition; whereas, the 75% of recommend N with nitrapyrin addition had the highest seed yield (3,841 lb/ac) at Wheatland. However, these treatments were not significantly different from the control. Schultz et al. (2018) also found that sunflower yield increased with N rate until reaching the critical level and the required N rate to maximize the yield at the conventional tillage site of eastern North Dakota was 200 lb N/ac. For this study, total soil available N (initial soil N + fertilizer N) for the 100% of recommended fertilizer N treatment was close to 190 lb N/ac. Application of fertilizer N additives, nitrification, and/or urease inhibitors could reduce the loss of N but had hardly any effect on yield and quality (Thapa and Chatterjee, 2017).

Soil inorganic N concentration was lowest for the control after two weeks for both sites (Table 2). At the Buffalo site, 100% of recommended N without nitrapyrin had the highest soil N availability (81.5 ppm) after the second week of planting, and it was significantly higher than 50% of recommended N with (17.2 ppm) and without (13.1 ppm) nitrapyrin and the control (8.06 ppm). At Wheatland, 75% of recommended N without nitrapyrin had the highest soil N availability (20.2 ppm) after the second week of planting, and it was significantly higher than 50% of recommended N with nitrapyrin (8.11 ppm) and the control (6.44 ppm). Application of 50% of recommended N without nitrapyrin (19.9 ppm) had higher soil N availability than 50% of recommended N with nitrapyrin (8.11 ppm) at Wheatland after the second week of planting. At Buffalo, 100% of recommended N with nitrapyrin had the highest soil N availability (32.1 ppm) after the fourth week; but it was not significantly different than without nitrapyrin (26.9 ppm). At Wheatland, soil N availability after the fourth week did not vary among treatments. Nitrapyrin effect on soil N availability probably varied with soil type irrespective of urea N rate. Only for Wheatland at the second week did 50% of the recommended N rate show significant difference between with and without inhibitor addition; however, the difference in soil N availability did not result in any difference

<table>
<thead>
<tr>
<th>Site</th>
<th>N rate</th>
<th>Inhibitor</th>
<th>Yield (lb/ac)</th>
<th>Inorganic N (ppm)</th>
<th>Second week</th>
<th>Fourth week</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buffalo</td>
<td>50%</td>
<td>No</td>
<td>4032 (710)AB</td>
<td>13.1 (6.50)B</td>
<td>4.51 (1.21)C</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>3424 (432)C</td>
<td>17.2 (12.1)B</td>
<td>15.9 (14.9)ABC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>75%</td>
<td>No</td>
<td>3582 (728)BC</td>
<td>21.6 (13.2)AB</td>
<td>23.5 (9.81)ABC</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>3632 (400)BC</td>
<td>24.4 (9.79)AB</td>
<td>10.6 (7.37)BC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>No</td>
<td>4236 (593)A</td>
<td>81.5 (78.5)A</td>
<td>26.9 (17.7)AB</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>4090 (335)AB</td>
<td>48.6 (74.0)AB</td>
<td>32.1 (22.6)A</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td></td>
<td>4044 (194)AB</td>
<td>8.06 (1.44)B</td>
<td>6.86 (4.84)C</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LSD (P=0.05)</td>
<td>571</td>
<td></td>
<td>63.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheatland</td>
<td>50%</td>
<td>No</td>
<td>3164 (223)A</td>
<td>19.9 (13.7)A</td>
<td>9.19 (2.69)A</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>3147 (337)A</td>
<td>8.11 (3.18)B</td>
<td>17.4 (21.4)A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>75%</td>
<td>No</td>
<td>3704 (574)A</td>
<td>20.2 (13.9)A</td>
<td>11.8 (8.38)A</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>3841 (771)A</td>
<td>12.9 (8.97)AB</td>
<td>13.3 (9.67)A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>No</td>
<td>3487 (511)A</td>
<td>10.1 (2.99)AB</td>
<td>7.53 (2.90)A</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>3367 (255)A</td>
<td>9.20 (1.94)AB</td>
<td>15.7 (17.4)A</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td></td>
<td>3097 (489)A</td>
<td>6.44 (1.84)B</td>
<td>5.69 (1.65)A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LSD (P=0.05)</td>
<td>772</td>
<td></td>
<td>11.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Standard deviation of mean
in yield. Duration of nitrification inhibition by nitrapyrin varied with location and year due to differences in soil moisture, temperature, and precipitation (Omonde and Vyn, 2013).

**Conclusion**

Optimizing the supply of N is critical for the sunflower seed yield, and the full recommended N rate is necessary to optimize the yield. The addition of an inhibitor did not influence yield or soil N availability. The growing season of 2018 was relatively dry and not an ideal environment for denitrification and leaching losses; hence, spring application of a nitrification inhibitor had hardly any effect on soil N dynamics under sunflower production.

**References**


High Soil Test Phosphorus Effect on Corn Yield

By Susan Winsor

Low corn prices have farmers scrutinizing their nutrient dollar return on investment (ROI). A recent University of Nebraska–Lincoln study examines phosphorus (P) application level ROI in continuous corn over six years. The most cost-effective method of fertilizer P use proved to be a P-replacement approach with the P rate equal to the P removed from the previous harvest. The research also found that maintaining soil P availability levels above 25 ppm (Bray-1) wasn’t justified. Earn 0.5 CEUs in Nutrient Management by reading this article and taking the quiz at www.certifiedcropadviser.org/education/classroom/classes/706.

Phosphorus (P) is the second most commonly applied nutrient in corn production after nitrogen (N) for the U.S. Corn Belt and Great Plains. Applied P is not subject to as many loss mechanisms as N, but loss of P to erosion and runoff, leaching to tile drains, and eventually movement to surface waters is of environmental concern. Researchers from the University of Nebraska–Lincoln (UNL) examined P application strategies across 12 irrigated and five Nebraska rainfed site-years with and without tillage. The sites had silt loam and silty clay loam soils with initial Bray-1 P below 11 ppm. All sites had a history of conservation tillage. The research was conducted at Haskell Agricultural Laboratory (HAL) near Concord, Eastern Nebraska Research and Development Center (ENREC) near Mead, and

This article was adapted from the Soil Science Society of America Journal article, “High Soil Test Phosphorus Effect on Corn Yield.” For the full text, including References (omitted here due to space constraints), view the original article: https://doi.org/10.2136/sssaj2018.02.0068.

Source: Flickr/Richard Hurd (https://creativecommons.org/licenses/by/2.0/).

DOI: 10.1002/crso.20002
Western Central Research and Development Center (WCREC) near North Platte. The research objective was to determine whether another fertilizer P management strategy is superior to the currently recommended deficiency correction strategy and whether there’s a yield benefit to maintaining soil test P above 25 ppm.

Below are the five P application levels and approaches evaluated. The third one proved to be the most cost effective:

1. **0P**: No P applied.
2. **UNL_P**: P applied according to the UNL deficiency correction recommendation. Corn yield was 3.3% less on average with UNL_P compared with Replace_P and Bray_35 (below).
3. **Replace_P**: P applied to replace P removed in the previous harvest.
4. **Bray_25**: Bray-1 P increased and maintained at 25 ppm.
5. **Bray_35**: Bray-1 P increased and maintained at 35 ppm.

Corn yield was similar for Replace_P, Bray_25, and Bray_35 methods. These had 9.6% higher yields than the control (Table 1). Replace_P was the most cost-effective choice overall. Replace_P had 3.4% and 5.6 bu/ac higher corn yield than UNL_P with 30% or 15 lb/ac more P₂O₅ applied (see Table 2). It had an agronomy efficiency ratio of 26 lb grain yield increase per pound of P₂O₅ applied. This method was economically justified only for Bray1-P below 20 ppm. Study results don’t justify maintaining soil-test P for the 0- to 8-inch depth above 20 ppm Bray-1 P for high continuous corn yield production. For Bray-P above 20 ppm, the P rate should be reduced or Replace_P should be withheld in some years to save money and to avoid excessive surface soil-test P (STP) and P-runoff losses.

**Yield Hit without P Applied**

Not applying any P (0P) cut corn yields by 9.3% (14 bu/ac) compared with the other P application treatments. Fertilizer P application for continuous corn should use the Replace_P method rather than the current UNL P when Bray-1 P is below 20 ppm for the 0- to 8-inch soil depth. Approximately 26% of plant

### TABLE 1. Corn grain yield (bu/ac) as affected by the year × tillage interaction at Haskell Agricultural Laboratory.

<table>
<thead>
<tr>
<th>Tillage</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disk</td>
<td>186</td>
<td>39</td>
<td>156</td>
<td>144</td>
<td>184</td>
</tr>
<tr>
<td>No-till</td>
<td>168</td>
<td>60</td>
<td>152</td>
<td>105</td>
<td>174</td>
</tr>
</tbody>
</table>

Note: Over all trials, grain yield was 2.5% more with disk compared with no-till.
TABLE 2. Bray-1 P initially and after five years of treatment application as affected by soil depth, location, and P application according to 0P with no P applied, University of Nebraska–Lincoln recommendation (UNL_P), to replace harvest P (Replace_P), and to build and maintain Bray-1 P at about 25 ppm (Bray_25) and 35 ppm (Bray_35). Bray-1 P in 2011 was from soil sampling in the spring before application of fertilizer P practices. Location × P practice × soil depth interaction (LSD_{0.05} = 11.8)

<table>
<thead>
<tr>
<th>Soil depth, inches</th>
<th>2011</th>
<th>2015^a</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-2</td>
<td>10.5</td>
<td>14.6</td>
</tr>
<tr>
<td>2-4</td>
<td>7.1</td>
<td>9.8</td>
</tr>
<tr>
<td>4-6</td>
<td>6.1</td>
<td>7.9</td>
</tr>
<tr>
<td>6-8</td>
<td>7</td>
<td>11.2</td>
</tr>
</tbody>
</table>

Eastern Nebraska Research and Extension Center

<table>
<thead>
<tr>
<th>0P</th>
<th>UNL_P</th>
<th>Replace_P</th>
<th>Bray_25</th>
<th>Bray_35</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-2</td>
<td>14.6</td>
<td>29.7</td>
<td>32.2</td>
<td>48.5</td>
</tr>
<tr>
<td>2-4</td>
<td>9.8</td>
<td>16.4</td>
<td>13.7</td>
<td>16.2</td>
</tr>
<tr>
<td>4-6</td>
<td>7.9</td>
<td>9.9</td>
<td>14.4</td>
<td>11.6</td>
</tr>
<tr>
<td>6-8</td>
<td>11.2</td>
<td>9.2</td>
<td>8.4</td>
<td>10.5</td>
</tr>
</tbody>
</table>

Haskell Agricultural Laboratory

| 0-2               | 17.9  | 14.2     | 78.7    | 59.7    |
| 2-4               | 7     | 6.2      | 19.5    | 13.8    |
| 4-6               | 4.5   | 4.4      | 5.9     | 4.8     |
| 6-8               | 4.2   | 4.6      | 5.5     | 4.6     |

West Central Research and Extension Center (WCREC)^b

| 0-2               | 18.3  | 21.8     | 36.1    | 59      |
| 2-4               | 10.6  | 9.1      | 12.9    | 15.1    |
| 4-6               | 8     | 6.4      | 7       | 8       |
| 6-8               | 6.6   | 5.7      | 6.3     | 7.6     |

^aThe location × P practice × soil depth interaction affected Bray-1 P. The tillage × soil depth interaction was significant for the 0- to 2-inch and 2- to 4-inch depth where the respective Bray-1 P was 41.0 and 12.9 ppm for no-till compared with 33.8 and 15.5 ppm for disk tillage.

^bThe WCREC results were from 2013 sampling.

Why Revisit P Rates?

Public scrutiny of P loss to erosion, runoff, and contaminating surface waters brings renewed interest to efficient P management and corn yields. And P removal has increased since many land grant university recommendations were formed. However, high-yielding crops typically have well-developed root systems and mycorrhizal associations for efficient P uptake (Marschner and Dell, 1994; Baligar et al., 1998).

For more than 50 years, fertilizer P recommendations were based upon a soil P availability test (STP) calibrated with crop response to applied P (Olson et al., 1954). Land grant universities differed in how they interpreted and calibrated results. Some states’ P recommendation strategy is deficiency correction, and others advocate building STP well above the critical value and then supplementing at harvest P-removal rates. This build-and-maintain approach ensures adequate P in exceptional years with a yield benefit from STP above the critical level. It also allows skipping P application when P is costly (Leikam et al., 2010).

The build-and-maintain approach delays returns on the build investment, and more P is lost to runoff, erosion, and leaching into surface waters (Sharpley et al., 2001; Wortmann et al., 2013). In Nebraska and some other states, the build approach had less profit potential than basing P rates on deficiency-correction calibrations (McCallister et al., 1987; Olson et al., 1987; Wortmann et al., 2008).

Applied P efficiency is less than for N during the application year (Baligar et al., 2007). However, the eventual recovery of applied P equivalent can be high in the long term as indicated by soil test P increases with application rates near the P removal rates (McCallister et al., 1987). Applied P contributes to various P pools’ equilibrium.
**TABLE 3.** Corn grain P concentration (%) as affected by the location × P practice (L × P), the year × P practice (Y × P), and location × year × tillage interactions (L × Y × T) for three Nebraska locations.

<table>
<thead>
<tr>
<th>Location</th>
<th>Location × P practice</th>
<th>Year × P practice</th>
<th>Year × location × tillage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0P⁺, no P applied. UNL_P, Replace_P, Bray_25, and Bray_35 are annual fertilizer P applications according to the University of Nebraska–Lincoln recommendation, to replace harvest P, to increase or maintain Bray-1 P at 25 ppm, and to increase or maintain Bray-1 P at 35 ppm, respectively.</td>
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<tr>
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<td>0P⁺, no P applied. UNL_P, Replace_P, Bray_25, and Bray_35 are annual fertilizer P applications according to the University of Nebraska–Lincoln recommendation, to replace harvest P, to increase or maintain Bray-1 P at 25 ppm, and to increase or maintain Bray-1 P at 35 ppm, respectively.</td>
<td></td>
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</tr>
</tbody>
</table>

P uptake appears to be from below the 8-inch depth. Gradual depletion of this P source may eventually require higher STP maintenance at the 8-inch soil depth.

Corn yield response to P practices was similar for all site-years. There were no site-years with greater response to Bray_25 and Bray_35 compared with Replace_P, including with the unusually 2011 cool and wet spring conditions at ENREC.

**Latitude and Other Considerations**

There’s no economic justification for maintaining high soil-test P for corn at the Nebraska sites studied. More northern latitudes, and maybe higher elevations, may justify maintaining high STP (Wagar et al., 1986). At Waseca, MN, corn and soybean yields were 14 and 28% higher, respectively, with Bray-1 P of 25 ppm compared with 7 ppm, coupled with P applied as recommended for the lower STP. On calcareous western Canada soils, large infrequent P applications had higher wheat yields than did annual P applications had higher wheat yields (Wager et al., 1986).
The importance of conservation-minded agricultural practices has brought together the USDA-NRCS, Agriculture Retailers Association, American Society of Agronomy, CropLife America, Crop Science Society of America, National Association of State Departments of Agriculture, Soil Science Society of America, Syngenta, and The Fertilizer Institute in support of a new award celebrating CCAs who work to advance environmental stewardship within agriculture.

The CCA Conservationist of the Year Award recognizes a CCA who is an innovative leader in conservation, delivers exceptional conservation advice and results, and contributes substantially to the exchange of conservation ideas and knowledge within the agriculture industry.

Agriculture and environmental stewardship must proceed hand in hand believes the inaugural award recipient, Nick Guilette. Quick to give credit to his grandfather, Guilette’s love and respect for the land took root on the family farm in Casco, WI. Graduating with a general resource management degree and minor in soil science from the University of Wisconsin–Stevens Point furthered Guilette’s passion for agriculture.

Nick Guilette (center) is the inaugural recipient of the CCA Conservationist of the Year Award. Source: USDA-NRCS Wisconsin.
and commitment to conservation. He now works as a nutrient manager for Ebert Enterprises where he enjoys extensive time in the field and working side by side with producers.

Guilette previously worked as a nutrient plan writer and GPS soil sampler at AgSource Laboratories in Bonduel, WI for nine years, advising local dairy farmers on proper manure application on nearly 30,000 acres. Chis Clark, fellow CCA at AgSource who nominated Guilette for the award, says, “Nick has always looked to the future for innovations that will further conservation efforts within agriculture.”

Guilette’s area of northeastern Wisconsin is an environmentally sensitive area with extensive agricultural production. This area has particular water quality challenges due to considerable quantities of manure, shallow soil depths, fractured bedrock that makes groundwater susceptible to contamination, and proximity to the bay of Green Bay and Lake Michigan, Clark explains. However, CCAs in the area are providing advice to maximize nutrient availability and minimize nutrient loss with best management practices.

**Committed, Proactive Involvement in the Community**

Guilette’s commitment to environmental stewardship and proactive conservation solutions are evident in his community involvement. He serves as co-crop adviser for two farmer-led groups concentrating on water quality solutions, Peninsula Pride Farms (PPF) and the Door-Kewaunee Demonstration Farm Network (DK Demo Farms).

“PPF’s vision is to demonstrate that clean water and a prosperous dairy community can co-exist,” says Dr. Don Niles, DVM and PPF President. Created in 2016, PPF now consists of 50 farmers, representing half the cows and tillable acres within two counties and 10 business members. As a farmer-led nonprofit, PPF focuses on improving surface water quality and protecting groundwater by improving soil health, reducing pathogens, and decreasing phosphorus and nitrogen loss. “Nick is often the public face of PPF, whether it involves speaking to reporters or with our newly elected governor, in a farm field, where each were [recently] holding clumps of soil and root mass, discussing soil health,” Niles says. “There is no doubt in my mind that Nick’s ideas and leadership have led to a healthier and more balanced agricultural community in northeast Wisconsin.”

**Improving Water Quality using Soil Health Principles, Sustainable Ag**

The Door-Kewaunee Demo Farm Network consists of four farms committed to the testing and sharing of the best conservation practices for protecting water quality in the Great Lakes Basin. The Wisconsin Department of Agriculture, Trade, and Consumer Protection, the USDA-NRCS, and PPF are working in unison through the DK Demo Farm Network to find innovative solutions, sharing not only their successes but also their failures with other farmers through field days and conferences. NRCS representative and CCA Barry Bubolz, working alongside the farmers, Guilette, and others at the Demo Farms states, “We are utilizing soil health principles and sustainable agriculture practices to improve water quality.”

Proof that the innovative efforts of this team are working came with the deluge of rain that hung over Wisconsin this past year. The Demo Farms led the way for low-disturbance manure applicators to be used in the area. “This type of applicator allows manure to be applied in tiny slits into winter rye, other cover crops, and alfalfa, reducing runoff and potential contamination,” Bubolz explains. “The success of these types of applicators has led to more producers utilizing the management and local manure applicators, adding these types of applicators to their lineup of available equipment.”

Beginning in fall of 2018 and continuing through 2019, the area received 10 to 18 inches above the normal precipitation. The saturated ground presents multiple problems, but a new management style of “planting green,” demonstrated at the DK Farms, is showing promise. “Planting green, planting into a growing cover crop, enabled planting to continue this year despite excessive moisture,” Bubolz says. “The green cover crop taking up water and the root systems holding soils helped reduce soil erosion, reduce nutrient runoff, and dramatically improved harvesting conditions in a very wet and difficult fall.”

“Three years ago, we began participating in the DK Demo Farm Network, exploring better conservation practices,” says Aaron Augustian of Augustian Farms LLC, owned and operated by Todd and Aaron Augustian. “I wanted to try some
out-of-the-box thinking.” The farm is home to 1,250 milking and dry cows housed in freestall barns and milked three times a day. Corn, wheat, and alfalfa are grown on 1,300 acres. The Augustian farm is 1.5 miles off the shores of Lake Michigan, which underscores the importance of keeping nutrients in the fields. “With Nick’s assistance, we are using more cover crops to prevent soil and nutrient loss.” Planting corn into growing rye, applying manure to a growing crop to reduce nutrient runoff, seeding a cover crop with manure application, reshaping grass waterways, and planting native grasses for wildlife and bee habitat represent some of the innovations being tested at the Augustian Farm.

“Under Nick’s guidance, the DK Demo Farms have been testing how specific conservation practice systems reduce erosion and sedimentation, control phosphorus runoff, and increase organic matter and improve soil health. The scientific data collected is then used to explain the results of experiments taking place and shared through a wide range of educational opportunities for the public and all those involved in agriculture,” Clark states.

“Nick is a strong promoter of the 4R practices of nutrient application; right source, right rate, right time, and right place. He conveys and presents his recommendations for conservation practices with a personal approach that garners trust,” notes Vice President of Laboratory Services at AgSource Laboratories, Steve Peterson.

“He pushes his clients to be better and has a great ability to describe agricultural principles to people with little prior knowledge of farming,” Niles says. Guilette is an educator at heart, sharing his wealth of knowledge and the lessons learned through PPF and the DK Demo Farms with all those involved in agriculture and those outside of agriculture. His commitment to environmental stewardship and belief that the path to the future necessitates that agriculture and conservation proceed hand in hand confirms the CCA Conservationist of the Year Award couldn’t be in more capable hands.
Newly Certified

The following list includes newly certified individuals and those who have added additional certifications since the last issue of *Crops & Soils* magazine.

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- Quiroz Vidal, Claudia Alejandra (CCA-MEXICO)

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- Thompson, Steven, Irondale, AL (CCA-SE)

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Managing at a System Level—Considering 4R Nutrient Stewardship and Soil Health Together

By Sally Flis, Ph.D. and CCA, Senior Director of Agronomy, The Fertilizer Institute; Todd Peterson, Ph.D., CEO, Cottonwood Ag Services, LLC; and Carrie Vollmer-Sanders, Director of Ag Engagement Strategy, The Nature Conservancy.

While it might not be easy to define soil health, soils with little erosion, higher water stable aggregation, higher organic matter, and incorporated nutrients can function differently than other, less healthy soils. Understanding how the soil functions at a chemical, physical, and biological level is critical to making effective system-level management decisions. Earn 0.5 CEUs in Nutrient Management by reading this article and taking the quiz at www.certifiedcropadviser.org/education/classroom/classes/753.

The USDA-NRCS defines soil health as the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans. While this definition speaks to the importance of managing soils so they are sustainable for future generations, it does not tell agronomists how to see or measure soil health. In 1964, the U.S. Supreme Court considered a case on whether certain pictures or movies could be banned as obscene. Justice Potter Stewart famously wrote that it may not be possible to define what is profane, “but I know it when I see it.” Soil health is like that; as agronomists, we know it when we see it. Soils that are healthy are just different than some of the agricultural soils we encounter. They look, smell, and feel different and function differently than soils that have been degraded. Understanding how the soil functions at a chemical, physical, and biological level is critical to making effective system-level management decisions. Testing soils for chemical and biological indicators can be useful to track changes in the soil over time as practices change. However, the idea of scoring a soil for “good” soil health is being re-evaluated as individual soil health indicators are being tested in relation to crop yield, 4R nutrient management, conservation practices, and nutrient losses.

DOI: 10.1002/crso.20005
Soil Health Testing

Farmers, university scientists, and soil laboratory researchers have been trying to describe and measure soil health for a long time. Previous generations may have called it soil tilth or soil quality (Doran et al, 1994), but these terms attempted to communicate how soil physical properties improve its ability to produce a crop. Soil organic matter (OM) is often discussed as a simple indicator of soil health. Many standard soil tests include an analysis for OM that is determined by loss on ignition when a soil sample is placed in a 500°C (932°F) muffle furnace for two hours. This measure is effective at quantifying the total amount of organic-based material in a sample, but it is also a very coarse measure of the material. It includes any material that will burn, yet research is finding that crop yields have stronger relationships to measures of OM quality versus quantity (van Es & Karlen, 2019). The quality of OM in the soil is related to the rate or potential for decomposition of OM and the impact of that decomposition on the labile pools of carbon and nitrogen in the soil.

Soil health cannot be measured by a single set of properties but rather includes physical, chemical, and biological properties. As with conventional soil testing, for soil health assessments, it is recommended that samples be taken at consistent field and weather conditions each time and in the same segment of a crop rotation, the same laboratory is used over time, and progress is tracked over time versus using a snapshot score. The challenges of measuring soil health by soil OM alone has led to an expansion of the types of soil health indicators, and there are a few variations of soil health assessments available through commercial and university laboratories (see box).

With the variety of testing options for soil health, recent research has focused on the interpretation of the results and their relationship to management practices and crop yield. Re-analysis of the 15 soil health indicators measured in the CASH assessment conducted on three long-term sites in North Carolina found that eight of the soil health indicators had a significant relationship to mean yields of corn and soybeans (van Es & Karlen, 2019). Specifically, water-stable aggregation of the soil, OM measured by loss on ignition, citrate-extractable protein, soil respiration of CO₂, active carbon, and the mineral concentrations of phosphorus, magnesium, and manganese measured with the Modified Morgan extraction were positively correlated to corn yield, where yield increased when correlated to each measure individually (van Es & Karlen, 2019). Interpreting soil health testing through a single score has been the path for results so far, but further analysis is showing that there are better relationships between yield and individual indicators.

Bavougian et al. (2019) evaluated aspects of the Haney soil health assessment on a long-term research site in Nebraska and concluded that interpretation of the results should shift away from a set threshold to indicate a “good” soil health score and instead measure and track the soil health indicators over time for a specific site. Individual indicators and corn grain yield were impacted by differences in tillage and nitrogen management practices, and the soil health calculation index values were above the previously set good score for all management combinations (Bavougian et al., 2019). Soil OM was shown to be impacted by tillage practices as lower OM concentrations were reported with higher intensities of tillage (Bavougain et al., 2019). When corn grain yield and soil health indicators for the Haney test were measured in the same year, there was no correlation (Bavougian et al., 2019). Both reports found relationships of soil health measures to field management practices, and van ES and Karlen (2019) were able to demonstrate that individual tests versus scores are related to corn grain yields, indicting there is value to testing soil health indicators, but interpreting results based on a score of all measurements may not be the best use of the data.

While there is value to laboratory testing for the quality of OM and the fractions of nitrogen and carbon that can be
related to crop yield, other benefits of improving soil health are reduced sediment loss, increased water infiltration, and the potential for reduced nutrient losses from the field. Often these environmental impacts can be observed by watching how a field responds to a 2-inch rainfall. Observations on the amount of sediment suspended in the runoff, volume of runoff from the field, and flow patterns can be insightful to a grower and a consultant. However, just observing water leaving the field with less sediment does not always mean that all environmental goals were met.

Research has shown that the ability of conservation tillage and cover crops to reduce dissolved reactive phosphorus, which drives algal blooms, in runoff varies (Duncan et al., 2019). This can be from increased soil phosphorus concentrations in the soil surface, not incorporating manure or fertilizer phosphorus applications, or the breakdown of organic materials left on the surface of the soil. Implementing 4R practices along with conservation practices, like cover crops and reduced tillage, results in lower phosphorus losses (Qian & Harmel, 2015). Smith et al. (2017) reported that knifing in liquid phosphorus fertilizer compared with surface application in a no-till system reduced both dissolved reactive phosphorus and total phosphorus losses. When considering soil health practices, it is critical to discuss the potential nutrient and management trade-offs and make practice decisions based on the whole system.

Conclusions

In general, soils that show high levels of biological activity tend to supply more nutrients to a growing crop, but there is little data and much debate about whether fertilizer rates should be adjusted based on soil health indicators and the relationship of those factors to crop yield. There can be trade-offs between soil health practices like no-till and cover crops with environmental goals like reduced phosphorus loss, making it important to consider all the pros and cons of a management system before changing practices. While it might not be easy to define soil health, soils with little erosion, higher water stable aggregation, higher OM, and incorporated nutrients can function differently than other, less healthy soils.

See CEU quiz on page 43.

References


Soil Health Assessments

Here are some of the soil health assessments available through commercial and university laboratories:

- Cornell University began offering its Comprehensive Assessment of Soil Health (CASH) in 2006. CASH consists of three levels of soil health analysis, which include laboratory and in-field measurements along with a combined soil health score.
- The Haney test evaluates multiple biological and chemical aspects of a soil sample and is available through a few soil-testing laboratories in the United States. Reports from this test also include a soil health score.
- Solvita has a laboratory-testing option where soil samples are re-wetted and CO₂ respiration from the sample is measured over a 24-hour incubation period.
- A phospholipid fatty acid or PFLA test can provide a snapshot estimate of total microbial biomass and give some clues on what categories of microorganisms are active in a fresh soil sample.
- Trace Genomics characterizes soil biology by extracting and sequencing DNA from microorganisms in the soil to characterize what species are active. This information identifies which beneficial or detrimental organisms may be active in the soil.

Soil Health Assessments

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See CEU quiz on page 43.

References


1. How is soil organic matter commonly measured by laboratories?
   a. Loss on ignition at 500°C.
   b. Soil texture measurement.
   c. Soil density.
   d. Loss on freezing at −500°C.

2. For soil health assessments, it is recommended that
   a. samples be taken over a wide range of field and weather conditions.
   b. samples be taken at varying segments of a crop rotation.
   c. the same laboratory is used over time.
   d. progress is tracked using a snapshot score.

3. In recent research, individual soil health indicators have been positively correlated to
   a. nutrient loss.
   b. soil quality.
   c. corn yield.
   d. soil moisture.

4. The measure of soil organic matter from soil samples can be impacted by
   a. rainfall.
   b. seed type.
   c. planting date.
   d. tillage practices.

5. Subsurface placement of phosphorus fertilizer
   a. can reduce dissolved reactive and total phosphorus loss.
   b. can decrease phosphorus availability to the crop.
   c. does not change phosphorus loss.
   d. cannot be done in no-till systems.

Earn 0.5 CEUs in Nutrient Management by taking the quiz for the article at www.certifiedcropadviser.org/education/classroom/classes/753. For your convenience, the quiz is printed below. The CEU can be purchased individually or you can access as part of your Online Classroom Subscription.
Tree-to-Tree Nutrient Variability in Pecan Orchards

By James L. Walworth, Professor and Associate Head, Department of Environmental Science, University of Arizona, Tucson

Tree-to-tree uniformity is desirable for nutrient management in orchards, particularly with the prevalence of nutrient application via fertigation, which makes it very difficult to tailor nutrient distribution for individual trees. The goals of this study were to measure the degree of variability of foliar nutrient concentrations exhibited by pecan trees in an Arizona orchard as well as to determine the importance of different sources of variation. Earn 0.5 CEUs in Nutrient Management by reading this article and taking the quiz at www.certifiedcropadviser.org/education/classroom/classes/757.

This article was prepared by the Western Region Nutrient Management Coordinating Committee (WERA-103).

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Tree-to-tree uniformity is desirable for nutrient management in orchards, particularly with the prevalence of nutrient application via fertigation, which makes it very difficult to tailor nutrient distribution for individual trees. Fertigation through drip or sprinkler irrigation systems is generally restricted to a single-rate, uniform nutrient distribution across the irrigated orchard block.

In practice, therefore, fertilizer applications are usually targeted to orchard blocks rather than individual trees. Processes for selecting appropriate fertilization targets may not be obvious and can be affected by the level of variability inherent in an orchard block. In a hypothetical orchard block with no variability, the average tree nutrient demand would be equal to the nutrient demand of each individual tree, but real orchards do exhibit considerable tree-to-tree variability. Variability may result from differences in soil properties; microclimate variations; irregular weed, disease, or insect pest pressures; non-uniform irrigation and fertilizer distribution; and genetic variability. Genetic variability in orchards is often minimized by the use of cloned root stocks and scions. Orchard species that are not commercially cloned are likely to exhibit greater genetic variability than cloned species. Pecan \( \textit{Carya illinoinensis} \) (Wangenh.) K. Koch scions of named cultivars are typically grafted onto open-pollinated root stocks of known maternal parentage, but the variability of these half-siblings can be large. Orchard variability is likely a combination of all of these sources.

In previous studies (Heerema et al., 2017), we determined that photosynthesis rates of individual pecan trees declined when foliar zinc concentrations were below approximately 14 ppm and did not increase when foliar zinc concentrations were elevated above 14 to 22 ppm, establishing this range as a reasonable minimum foliar zinc target. These findings agree with those of Hu and Sparks (1991) who observed declines in photosynthesis rate when pecan leaf zinc concentrations were below 14 ppm. It is notable that these values are far below currently recommended minimum leaf zinc levels for commercial pecan production of 40 to 50 ppm (Heerema, 2013; Jones et al., 1991; Pond et al., 2006; Sparks, 1993).

Individual Tree vs. Block-Scale Measurements

What is the reason for this large discrepancy? In part, these differences reflect different targets. Whereas individual trees exhibit diminished photosynthesis rates associated with foliar zinc levels below 14 to 22 ppm, a reasonable orchard block minimum target must be greater, owing to tree-to-tree variability. A higher target (such as the frequently cited 40 to 50 ppm zinc minimum for pecans) may be a reasonable orchard block target to ensure that trees with the lowest foliar zinc concentrations within a block are not restricted by lack of zinc. This is an important consideration when applying individual tree response data such as those reported by Heerema et al (2017) to whole-orchard blocks. In contrast to orchard-wide measurements of nut yield and quality or tree growth rates, physiological measurements such as photosynthesis rate conducted on individual trees can provide very sensitive measurements of tree performance. It is therefore desirable to convert these individual tree data to pecan orchard management blocks.

Individual tree data arise from coupled physiological measurements (such as photosynthesis rate) and leaf analyses conducted on individual trees, resulting in pairs of single-tree nutrient concentrations and physiological parameters. Field- or block-scale measurements, on the other hand, consist of yield or other measurements collected from a
group of trees, which are coupled with composite leaf samples collected from that group of trees.

Field-scale measurements of nutrient response from multiple trees (entire orchard blocks, rows, or groups of rows) can be directly applied to orchard blocks because composite leaf samples collected from multiple trees within the treatment area provide average nutrient concentrations for that group of trees. For example, Sparks (1993) combined vegetative growth and nut yield data collected from field studies conducted in several locations to develop a 50 ppm minimum leaf zinc threshold from pecan orchards. Because these response data already account for tree-to-tree variability, this value can be directly applied to whole-orchard blocks. In other words, a study that evaluates response on an orchard-block basis will inherently identify average nutrient concentrations associated with tree responses.

Typical leaf-sampling protocols recommend collecting leaves from numerous trees within a sampled area, which are combined into a composite sample for analysis (Heerema, 2013). Composite sampling measures average nutrient concentrations for the sampled area but does not provide estimates of variability statistics or identify minimum or maximum nutrient concentrations. Development of orchard block standards based on individual tree data and applied to averaged nutrient levels will depend on the degree of tree-to-tree variability exhibited within a block. It is therefore necessary to understand the extent of tree-to-tree variability within pecan orchards.

2018 Pecan Orchard Study

To that end, in 2018, we began a study in a commercial microsprinkler-irrigated pecan orchard in southeastern Arizona. The selected orchard block appeared to be very uniform with the exception of a few replanted trees that were slightly younger than the original plantings. The orchard block was established in 2011 with trees grafted on rootstock of the cultivar Ideal (also known as Bradley). The primary scion cultivar is Wichita, and every fifth row consists of Western (also known as Western Schley) pollinizers. Trees are planted in a 20- by 39-ft spacing. All trees have received identical management. In 2018, 6.0 lb/ac zinc in the form of Zn-EDTA was injected into the irrigation system in three separate in-season applications. No zinc was foliar-applied.

In each of seven contiguous rows (six Wichita and one Western row), 17 adjacent trees were selected for sampling. Foliar samples were collected from each of the 119 trees in this area on July 18, 2018. Samples were collected according to standard sampling protocol (Heerema, 2013). Samples were collected only from fruiting branches. Leaves were thoroughly washed, dried, and analyzed for nutrient concentrations. Soil below each tree was individually sampled in February 2019 and analyzed to determine available nutrient levels, pH, salinity, sodicity, and cation exchange capacity. The goals of this study were to measure the degree of variability of foliar nutrient concentrations exhibited by these trees as well as to determine the importance of different sources of variation. This discussion will focus solely on the degree of observed variability of foliar zinc concentrations.

Leaf zinc concentrations within the sampled area exhibited a high degree of variability (Figure 1). The average of the measured foliar zinc concentrations was 19.9 ppm. Within the sampled area, the lowest measured foliar zinc concentration was 11.9 ppm, and the highest was 31.9 ppm. Ten individuals (8.4% of the trees) contained less than 15 ppm (Figure 2). Only 57 of the sampled trees contained in excess of 20 ppm of zinc. None of the trees reached recommended orchard foliar zinc levels of 40 to 50 ppm. Visible zinc deficiency symptoms were nearly absent in the sampled area and considered normal for well-managed orchards in the area (some minor zinc deficiency is almost always visible in local pecan orchards).

Although the average of measured zinc concentrations within the sampled area (19.9 ppm) exceeded the minimum level known to limit photosynthesis (about 15 ppm), some trees were well below this limit. Photosynthesis rate, vegetative growth, and nut production of the trees containing lower levels of zinc are potentially limited by lack of zinc. It is desirable to manage zinc such that trees in each orchard block with the

![Figure 2. Pecan tree foliar zinc distribution, 2018.](image-url)
lowest concentrations exceed a minimal acceptable zinc level. Because it is not practical or economically feasible to sample each tree individually, it is necessary to establish orchard-wide minimum nutrient concentration recommendations. We propose to do this by using estimates of tree-to-tree variability to convert individual tree response data into commercially applicable orchard standards.

Utilizing statistical variability parameters from our 2018 data, we have attempted to determine the minimum average foliar zinc concentration that would ensure that most or all individual trees contain at least 15 ppm. Preliminary analyses indicate that an orchard block average of approximately 24 to 27 ppm (depending on the specific statistical interpretation methods used) would result in no more than 1% of trees containing less than 15 ppm foliar zinc. Additional data are needed to verify the acceptable average foliar zinc concentration for a pecan orchard block. To this end, the study was repeated in 2019.

**Unrealistically High Pecan Foliar Zinc Standard?**

There is a considerable difference between the 24 to 27 ppm threshold identified in the current work versus the 40 to 50 ppm commercial standard. Reasons for the higher commercial standard include lack of resolution in orchard-scale field data and the regression models used to relate foliar zinc concentration to pecan growth and nut yield that make precise threshold identification very difficult. Additionally, most pecan zinc response studies rely on foliar zinc applications that can result in contamination of leaf samples with residual foliar fertilizer. The combination of these effects may be an unrealistically high pecan foliar zinc standard of 40 to 50 ppm. Standards developed from more precise physiological measurements may be more accurate although thorough field validation is needed.

This strategy could be adopted for other nutrients for which physiologically derived nutrient concentration minima based on individual tree data are available. For example, Sherman et al. (2017) determined that the leaf tissue manganese concentration needed to maximize photosynthesis rates in immature pecan trees was approximately 152 ppm. Similarly, Heerema et al. (2014) estimated that pecan tree photosynthesis was maximized when foliar nitrogen concentrations exceeded 3.1%. Knowledge of manganese and nitrogen distributions in pecan orchards could be applied to convert these individual tree thresholds into values that can be applied to averaged orchard block nutrient concentrations. This approach could also be used to develop orchard-scale recommendations from precise individual tree measurements made in controlled environments such as greenhouses or growth chambers.

It is important to recognize the difference between nutrient concentration optima based on research data relating nutrient concentrations to single-tree physiological measurements versus the orchard-block average nutrient concentrations that form the basis of commercial fertilizer recommendations. Single-tree measurements can be more precise and repeatable than orchard-block-scale measurements but do not yield information that is directly applicable in commercial orchard management. Measurements of tree-to-tree variability can be used to “convert” individual tree data into usable nutrient recommendations.

**Acknowledgements**

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See [CEU] quiz on page 48.

**References**


Tree-to-Tree Nutrient Variability in Pecan Orchards

Earn 0.5 CEUs in Nutrient Management by taking the quiz for the article at www.certifiedcropadviser.org/education/classroom/classes/757. For your convenience, the quiz is printed below. The CEU can be purchased individually or you can access as part of your Online Classroom Subscription.

1. Which of the following factors does NOT contribute to tree-to-tree variability within an orchard?
   a. Differences in soil properties.
   b. Genetic variability.
   c. Microclimate variations.
   d. Use of cloned root stocks and scions.

2. What is the measured optimum rate of foliar zinc applications on pecan trees for peak photosynthesis?
   a. 10–12 ppm.
   b. 14–22 ppm.
   c. 25–30 ppm.
   d. 40–50 ppm.

3. What is the minimum concentration of leaf tissue manganese needed to maximize photosynthesis in immature pecan trees?
   a. 122 ppm.
   b. 132 ppm.
   c. 142 ppm.
   d. 152 ppm.

4. Which of the following soil measurements were NOT taken from the pecan orchard in Southeast Arizona in February 2019?
   a. Soil organic matter.
   b. Salinity.
   c. Sodicity.
   d. Cation exchange capacity.

5. Which measurements are used to calculate field- or block-scale parameters?
   a. Physiological measurements from individual trees.
   b. Pairing single-tree nutrient concentrations and physiological parameters.
   c. Yield or other measurements coupled with composite leaf samples collected from a group of trees.
   d. Soil nutrient measurements from trees across the orchard.

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High Soil Test Phosphorus Effect on Corn Yield

Earn 0.5 CEUs in Nutrient Management by taking the quiz for the article at www.certifiedcropadviser.org/education/classroom/classes/706. For your convenience, the quiz is printed below. The CEU can be purchased individually or you can access as part of your Online Classroom Subscription.

1. The research objective was to determine whether another fertilizer P management strategy is superior to the currently recommended deficiency correction strategy and whether there's a yield benefit to maintaining soil test P
   a. below 15 ppm.
   b. between 15 and 20 ppm.
   c. between 20 and 25 ppm.
   d. above 25 ppm.

2. Which of the approaches evaluated proved to be the most cost effective?
   a. UNL_P.
   b. Replace_P.
   c. Bray_25.
   d. Bray_35.

3. The article states that fertilizer P application for continuous corn should use the Replace_P method rather than the current UNL P when Bray-1 P is _______ for the 0- to 8-inch soil depth.
   a. below 10 ppm
   b. between 15 and 20 ppm
   c. below 20 ppm
   d. above 25 ppm

4. At Waseca, MN, corn yields were _______ higher with Bray-1 P of 25 ppm vs. 7 ppm.
   a. 8%
   b. 14%
   c. 22%
   d. 28%

5. Over all trials, grain yield was _______ higher with disk compared with no-till.
   a. 1.0%
   b. 1.5%
   c. 2.0%
   d. 2.5%