University of Minnesota | Extension

Managing the Rotation from Alfalfa to Corn

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Introduction

Alfalfa provides many benefits to cropping systems. These benefits occur both during alfalfa production and during the subsequent crops that follow. Some of the common benefits during alfalfa production are increased soil organic matter, decreased soil erosion, and decreased soil nitrate leaching loss. Alfalfa also usually requires no nitrogen (N) fertilizer and few herbicide applications. Crops that follow alfalfa usually benefit from: i) reduced or eliminated N requirement from fertilizer or manure, ii) increased yield potential compared to following other crops (Figure 1), and iii) reduced weed, insect, and disease pressure. This bulletin describes management practices for alfalfa termination and the two subsequent corn crops that will help utilize the benefits of alfalfa.

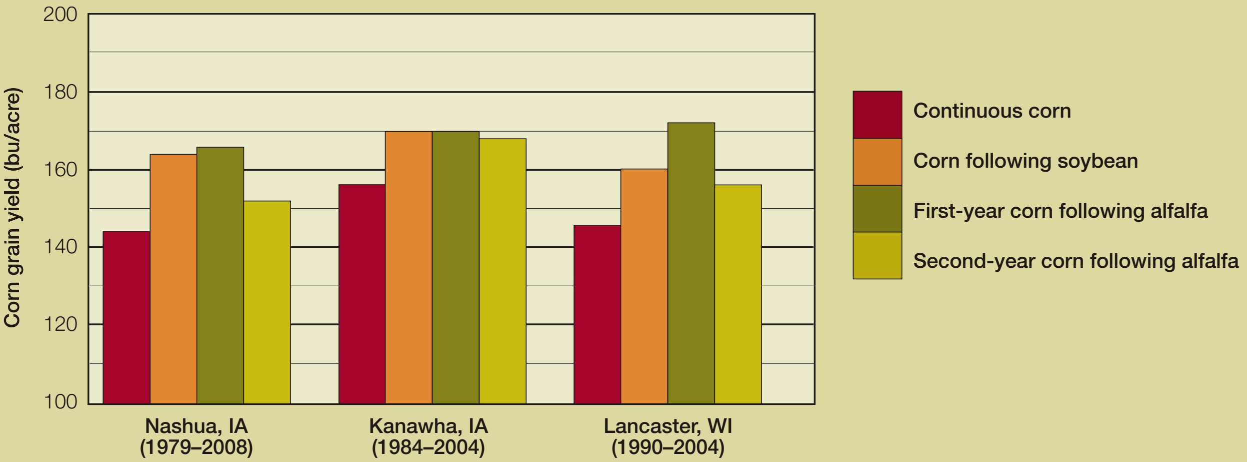

FIGURE 1 Grain yield for N-fertilized corn grown in various rotations. Data adapted from Mallarino and Ortiz-Torres (2006) and Stanger and Lauer (2008).

Alfalfa Termination

Successful termination of alfalfa is essential in order to fully realize the benefits of alfalfa to subsequent corn crops, as volunteer alfalfa competes with corn for water and N.

I. DECIDING TO TERMINATE

When possible, the decision about when to terminate alfalfa should be based on economics. Accurate record-keeping of alfalfa establishment costs, production costs, yields, stand quality, and value (market or feed) are essential. Initial alfalfa establishment costs can usually be recovered during the following one or two production years, but sometimes can be recovered in the establishment year if alfalfa is harvested and its price is high. After the first few production years, alfalfa stand condition and quality can decline at highly variable rates depending on alfalfa genetics, alfalfa management, soil properties, weather conditions, and other factors. This variability makes it difficult to define optimal alfalfa stand lengths across many growing conditions. However, research in Wisconsin, Manitoba, and western Canada suggests that net return to alfalfa production often is maximized by rotating alfalfa after an establishment year plus two to four production years (Zenter et al., 1986; Jeffrey et al., 1993; Undersander and Barnett, 2008).

Planned alfalfa termination based on economics is not always possible. Sometimes alfalfa is rotated due to winterkill, weedy or diseased stands, changes in government programs, competition with commodity crops, land needed for applying manure, or other reasons. A survey of 421 Minnesota growers in 2012 found that growers rarely rotate alfalfa according to a planned schedule and that the most common reason for terminating alfalfa was the need for a place to apply manure; one-half of respondents (52%) selected this as the top reason for terminating alfalfa (Yost et al., 2014a). Therefore, improved manure management options, such as increased storage capacity and

TABLE 1 Alfalfa stand age during 2006-2012, according to combinations of Cropland Data Layers. Establishment year stands were not consistently identified in the data layers, so stand age may reflect only production years in some cases.

State	Alfalfa stand age (years)				
	2	3	4	5	6 or more
	--- % of alfalfa acres ---				
Iowa	43	31	7	3	16
Minnesota	25	24	13	3	35
North Dakota	6	4	2	2	86
Nebraska	15	16	14	6	49
South Dakota	15	13	10	4	58
Wisconsin	19	27	21	5	28

increased dispersion to other fields, may promote longer alfalfa stands. The second most common reason for alfalfa termination was thinning alfalfa stands; one-third (36%) selected this as the top reason. Responses were evenly distributed among the remaining reasons for terminating alfalfa, such as weedy alfalfa stands and winterkill.

The majority of growers across the Upper Midwest rotate alfalfa after an establishment year plus two to three production years according to survey responses from 421 Minnesota growers in 2012 and an analysis of satellite imagery for 2006-2012 (Cropland Data Layers by USDA-National Agricultural Statistics Service) (Yost et al., 2014a,d). However, in some areas of this region, the majority of stands were rotated after six or more years (for example, the western halves of the Dakotas and Nebraska), indicating opportunities for more proactive and frequent rotation of alfalfa to improve net return from alfalfa production (Table 1).

II. HOW AND WHEN TO TERMINATE

Traditionally, alfalfa stand termination relied on tillage implements such as a moldboard plow or a chisel plow with overlapping sweeps to completely cut off alfalfa roots. Although effective at terminating alfalfa, these tillage implements may not be suitable for all fields due to concerns about soil erosion. Tillage implements that do not cut the roots from all plants are ineffective for complete alfalfa termination and therefore herbicides can provide enhanced termination (Figure 2).

Fall

Advantages to fall alfalfa termination include an earlier start to alfalfa residue decomposition, potential for earlier drying and warming of soil and an earlier corn planting date, and potential for earlier N release during first-year corn. These benefits likely have been realized by growers in Minnesota, because two-thirds of 421 growers in 2012 indicated that they terminated alfalfa in the fall. The major disadvantage with fall termination is that it does not allow for the opportunity to assess whether an alfalfa stand will survive the winter and be productive for another year.

Fall herbicide applications to terminate alfalfa should occur before the first killing freeze (28°F or lower for a few hours), but when new alfalfa regrowth since the last cutting is at least 4 to 6 inches. Herbicide applied to plants with less than 4 inches of regrowth or to freeze-damaged plants may result in an ineffective kill due to poor herbicide translocation to roots. To determine if a killing freeze occurred, use the fingerprint test on the morning after a freeze – if your fingerprint remains after squeezing alfalfa leaves between your fingers, the epidermis of the leaves has ruptured due to a killing freeze.

In some fields, fall tillage is desired after an herbicide application for alfalfa termination in order to relieve soil compaction and produce a soil surface that dries more rapidly in the spring. Tillage can generally begin within 3 to 4 days following herbicide application, since the majority of the herbicide is translocated within the plant by this time. Be aware that some labels require a longer interval before tillage. If tillage that completely cuts all alfalfa roots is used to terminate alfalfa, such as a moldboard plow or a chisel plow with overlapping sweeps, herbicides typically are not needed prior to tillage.

A highly effective herbicide option for fall termination of alfalfa is 2,4-D amine or ester used alone or tank mixed with dicamba products. If grasses are present

FIGURE 2 Incomplete alfalfa termination by a chisel plow without overlapping sweeps (top left); and effective alfalfa termination by: fall-applied herbicide followed by chisel plowing (top right); fall moldboard plow tillage (bottom left); fall-applied herbicide without tillage followed by no-tillage corn (bottom right).

with alfalfa, a good option is to tank-mix glyphosate with 2,4-D. The use of high rates of glyphosate alone for alfalfa termination often results in only partial kill (60 to 90% kill with fall applications, or 40 to 80% kill with spring applications). Glyphosate will not control alfalfa that is tolerant to glyphosate.

Spring

Advantages to spring termination of alfalfa include the ability to assess alfalfa winter survival and the opportunity for an additional harvest of alfalfa in late May followed by delayed planting of short-season silage or grain corn. Another advantage is soil cover to prevent erosion during winter months. Disadvantages to spring termination of alfalfa include delayed decomposition of alfalfa residue and N release during growth of first-year corn, the potential for delayed corn planting, and increased difficulty in terminating alfalfa with the use of herbicides.

Spring termination of alfalfa with herbicide can be challenging because the optimal time to plant corn typically occurs before alfalfa regrowth is greater than 4 to 6 inches. Tillage alone or in combination with herbicide can be used to terminate alfalfa in the spring. When herbicides are used preemergence, glyphosate tank mixed with dicamba and 2,4-D provides consistent control. However, typical dicamba or 2,4-D rates require 2 weeks or more after application before planting corn to reduce the chance of crop injury during emergence. To control alfalfa postemergence in corn, products containing 2,4-D or dicamba can effectively control volunteer alfalfa. Products that contain clopyralid also can be used for suppression before or after corn planting. Be aware that the time available for application is short and corn injury can occur if the herbicide labels are not followed. Also, injury to non-target crops such as soybean can occur from volatilization of many postemergence growth-regulator herbicides. Relying solely on a postemergence herbicide program to terminate alfalfa is discouraged due to increased risk of crop injury and incomplete alfalfa kill.

First-Year Corn Following Alfalfa

Corn often is planted as the first crop following alfalfa in the Upper Midwest. It was the first-year crop on about 50% of the acres in the Dakotas and on 75 to 92% of the acres in Iowa, Minnesota, Nebraska, and Wisconsin during 2008–2012 (Figure 3) (Yost et al., 2014d). This section provides suggestions for optimal management of first-year corn.

PLANTING

Due to high water use by alfalfa relative to other crops, soil moisture following alfalfa can be limiting in areas of low precipitation or low soil water holding capacity. This should be a consideration for deciding whether and when to plant corn. On the other hand, if precipitation is adequate for growing corn, water use by alfalfa may allow for earlier corn planting. For fields where anticipated in-season soil moisture is limited, consider: a) terminating alfalfa earlier, b) planting corn early, c) planting drought-tolerant corn hybrids, d) planting shorter-season crops such as wheat, and e) utilizing irrigation.

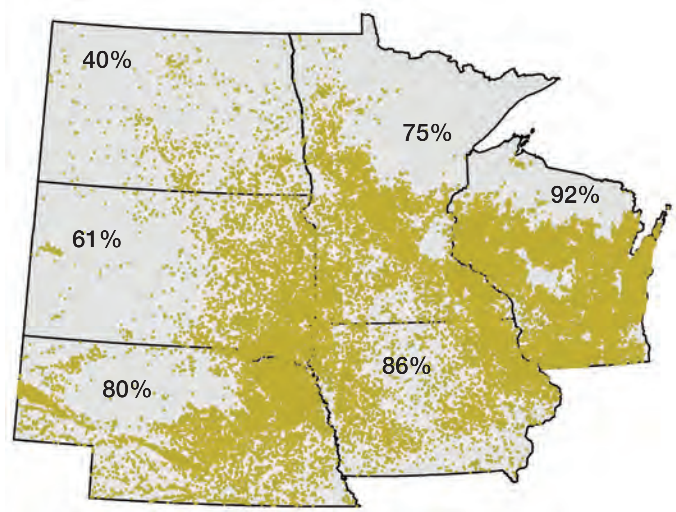

FIGURE 3 First-year corn following alfalfa during 2008–2012 according to combinations of Cropland Data Layers. Percentages indicate percent of total first-year crop that was corn in each state.

FIGURE 4 Current alfalfa N credit guidelines are based on alfalfa stand density measurements at alfalfa termination.

NITROGEN

Through a symbiotic relationship with soil bacteria, alfalfa can gather N from the atmosphere for its own growth and production. During its lifetime, alfalfa sheds and regenerates fine roots, which add N to the soil. The N content of alfalfa herbage and roots combined can be as high as 200 lb N/acre. When alfalfa is terminated, the N in alfalfa residue along with increased soil N and other soil quality improvements that occur during alfalfa production typically supply large quantities of N to one to more years of subsequent crops. This increased N supply often causes first-year corn to require little or no N as fertilizer or manure. The size of the reduction in N rate for first-year corn compared to continuous corn (corn following two or more years of corn) is commonly known as the 'alfalfa N credit.'

Alfalfa N credit guidelines

Guidelines in Minnesota and several other Midwest states indicate that N credits of 150, 75, and 50 lb N/acre should be used for first-year corn following good, fair, and poor alfalfa stands, respectively (Figure 4). When these credits are subtracted from the guideline N rates for continuous corn in Minnesota, first-year corn guideline rates range from 0 to 115 lb N/acre (Table 2).

Adoption of first-year corn N rate guidelines

Across Minnesota, only 35% of respondents followed Extension guidelines for first-year corn, but adoption ranged from 22 to 67% among regions (Figure 5). Adoption rates were slightly higher when manure was not applied to first-year corn (40%) than when it was applied (30%), but the majority of respondents (67%) applied manure. By not fully accounting for alfalfa N credits for first-year corn, growers without manure who exceeded Extension guidelines often (62% of cases) applied 100 to 150 lb N/acre above guidelines (Figure 6). When the combined N credits for manure and alfalfa were not fully accounted for, excessive N rates were even higher; one-third of respondents exceeded guidelines by more than 150 lb N/acre.

TABLE 2 University of Minnesota Extension N rate guidelines for first-year corn following alfalfa.

Soil productivity[a]	Alfalfa stand density	N cost ÷ corn grain price[b]			
		0.05	0.10	0.15	0.20
	--- plants/ft² ---	---------- lb N/acre ----------			
High	4 or more	5	0	0	0
	2 to 3	55	40	30	20
	1 or fewer	115	100	90	80
Medium	4 or more	0	0	0	0
	2 to 3	30	20	10	0
	1 or fewer	90	80	70	60
Low	4 or more	0	0	0	0
	2 to 3	0	0	0	0
	1 or fewer	60	50	40	30

[a] High- and medium-productivity soils should have at least 3% organic matter. Irrigated sandy soils are in the high-productivity category.

[b] Ratio is calculated as N fertilizer cost ($/lb N) ÷ corn grain price ($/bu). For example, for urea that costs $460 per ton, the N cost is $0.50 per pound. If grain is worth $5.00 per bushel, then the fertilizer N cost ÷ corn grain price ratio is $0.50 ÷ $5.00 = 0.10.

To gain confidence in alfalfa N credits, consider using an 'N-rich' strip (a strip with a high N rate applied) in fields where alfalfa N credits are adopted. If significant differences in plant color or tissue tests occur between the N-rich strip and adjacent corn, a sidedressed N application may be warranted. If sidedressed N is applied, consider leaving a zero-N strip and then compare yields with a yield monitor or weigh wagon to determine whether sidedressed N increased yield.

Validation of N rate guidelines

On-farm research trials were conducted between 2009-2012 to determine economic optimum N fertilizer rates for first-year corn and to confirm alfalfa N credits for modern, high-yielding corn hybrids. The results of 31 on-farm trials showed that **alfalfa N credits are reliable and often are LARGER than current guidelines suggest.** For example, only 3 of 31 fields required N fertilizer to increase corn grain yield (Figure 7). These three responsive fields had good alfalfa stands at termination, while some non-responsive fields had average stands. These results led to the preliminary conclusions that: i) first-year corn rarely responds to N fertilizer, ii) the response to N is poorly related to final alfalfa stand density, and iii) research needs to identify when first-year corn requires N fertilizer.

Potential field-specific N rate guidelines

In order to identify when corn following alfalfa requires N fertilizer and how much N is needed on responsive fields, results from the 31 on-farm trials were combined with data from all other trials available in the literature and from other researchers (Yost et al., 2014c). With the resulting 259 first-year corn trials, combinations of soil textural class (fine, medium, or coarse), age of alfalfa at termination, alfalfa termination timing (fall vs. spring), and weather conditions between alfalfa termination and corn planting were found to affect the frequency and level of N response in corn (Table 3). These factors were used in predictive equations to estimate when corn will respond to N and what the economic optimum N rate will be. We found that **first-year corn rarely responds to N** except on:

- sandy soils
- fine-textured soils when there are prolonged wet early-season conditions
- medium-textured soils when following 1-year-old alfalfa that was direct seeded
- medium-textured soils when following 2-year-old alfalfa (including the establishment year) seeded with a small grain companion crop
- medium-textured soils when following spring-terminated alfalfa

These predictive equations are being validated with on-farm trials across Minnesota beginning in 2014. Current guidelines based on alfalfa stand density (Table 2) should be used until more site-specific

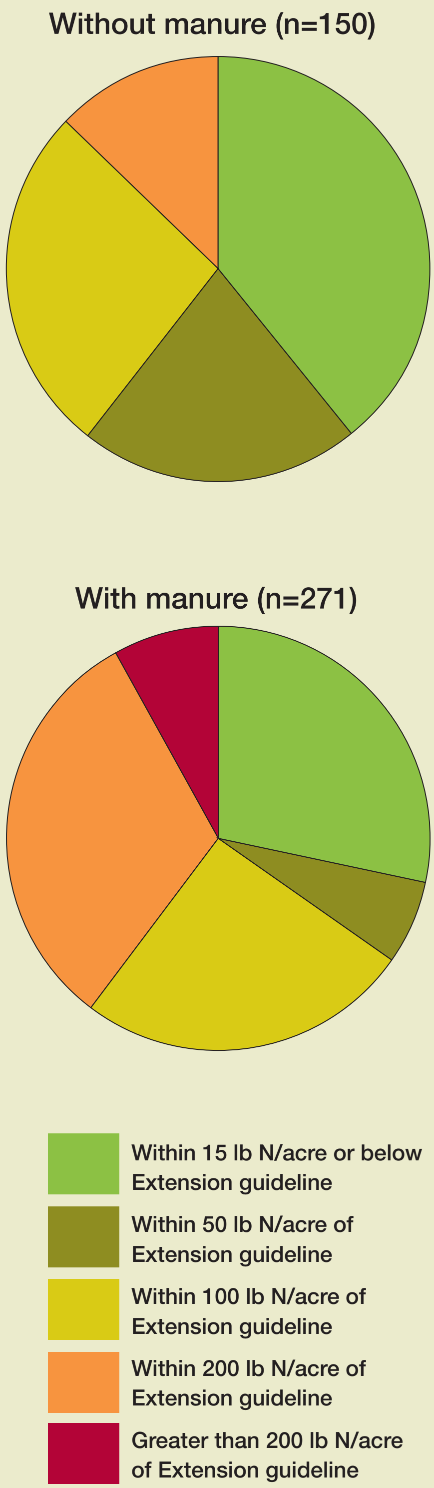

FIGURE 6 Reported rates of N application by survey respondents who use fertilizer only or fertilizer plus manure for first-year corn following alfalfa.

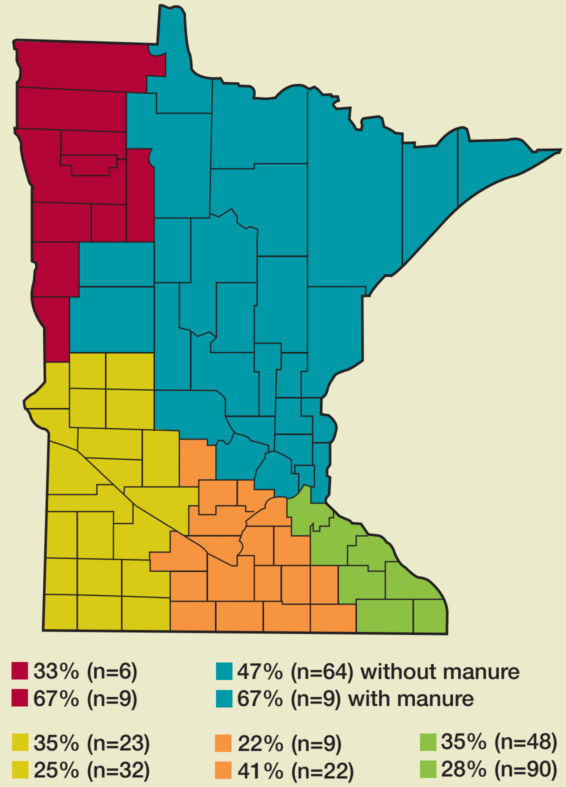

FIGURE 5 Percent adoption (number of respondents) of N guidelines for first-year corn following alfalfa in Minnesota by region when manure was not (top value in each pair) or was (bottom value) applied.

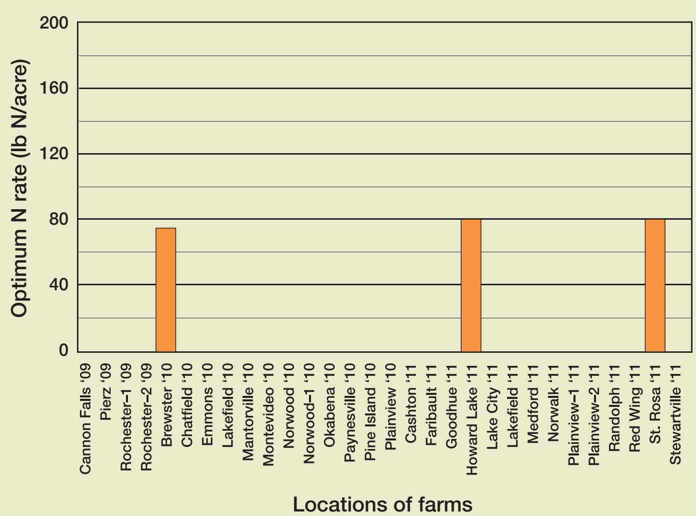

FIGURE 7 Economically optimum N rates at the N fertilizer cost ($/lb N) ÷ corn grain price ($/bu) ratio of 0.10 for 31 on-farm trials conducted in Minnesota during 2009-2011.

TABLE 3 Summary of grain yield response to N fertilizer in 259 trials of first-year corn following alfalfa.

Soil texture[a]	Alfalfa seeding method[b]	Alfalfa age[c]	Alfalfa termination time	Sites responsive to N fertilizer	Total sites	Range in EONR[d]
		--- years ---		--- % ---		-- lb N/acre --
Coarse	D or C	1-3	Fall or spring	96	11	90–210
Medium	D	1	Fall	56	16	50–200
Medium	C	2	Fall	35	54	50–240
Medium	D	2	Fall	8	25	50–150
Medium	D or C	3+	Fall	5	86	80–155
Medium	D or C	3+	Spring	17	48	40–160
Fine	D or C	1-7	Fall or spring	53	19	20–150

[a] Coarse = loamy sand; medium = loam, sandy loam, silt loam, fine sandy loam; fine = clay loam, silty clay loam.

[b] D = direct seeded without a companion crop, C = seeded with a small grain companion crop.

[c] Alfalfa age at termination includes seeding year.

[d] The range in economically optimum N rate (EONR) for the N cost ÷ corn grain price ratio of 0.10 in fields that needed additional N.

guidelines can be developed. Soil tests, such as the pre-sidedress soil nitrate test (PSNT), have low accuracy in first-year corn, as only 60% of 114 trials in Minnesota and the literature were correctly predicted as being responsive or nonresponsive to fertilizer N (Walker et al., 2014).

PHOSPHORUS AND POTASSIUM

It is important to monitor soil-test potassium (K) towards the end of an alfalfa stand because harvested alfalfa can remove about 160 to 300 lb K_2O/acre each year. If K is needed for first-year corn following alfalfa, applying K ahead of corn rather than ahead of last-year alfalfa will reduce luxury consumption of K by alfalfa and maximize K use efficiency for first-year corn (Yost et al., 2011). University of Minnesota Extension guidelines suggest that 0 to 255 lb K_2O/acre should be applied to corn according to soil-test K concentration in the topsoil and expected corn yield. First-year corn should be fertilized with 0 to 160 lb P_2O_5/acre according to soil-test phosphorus (P) concentration in the topsoil and expected corn yield. Be sure to credit N that may be applied with P fertilizers when determining N rates for corn.

Manure

Manure often is applied to first-year corn following alfalfa for several reasons, including the need to replenish nutrients removed during alfalfa production, insufficient manure storage capacity, inadequate land area for spreading manure in other crop rotations, and/or inability to distribute or sell manure. However, **if possible, avoid manure application for first-year corn following alfalfa** because additional N often does not increase corn yield and can cause N loss to the environment. Many fields with a manure history may have adequate or more than adequate soil-test P and K levels at the end of alfalfa stands, but be sure to soil test. If manure is needed to replenish soil P or K at the end of an alfalfa stand, **apply only the minimum rate (based on a manure nutrient analysis) needed to meet P or K requirements.** Consider applying solid manure if the P need is greater than K, but liquid manure if the K need is greater than P, because solid manure usually has higher P concentration and liquid manure usually has higher K concentration. Also, consider using P or K fertilizer instead of manure to meet needs of first-year corn so that manure nutrients can be utilized for corn in other rotations or for other crops that need N.

INSECTS, WEEDS, AND DISEASES

The potential for soil- and residue-borne insects and pathogens that impact corn is usually lower for first-year corn following alfalfa than corn in other rotations. Bt corn hybrids or soil-applied insecticides for protection against corn rootworm are not necessary when following alfalfa because the lifecycle of corn rootworm is disrupted by alfalfa. Healthy alfalfa stands typically suppress many annual weeds that plague corn grown in crop rotations with only annual crops. This can lead to reduced weed pressure in first-year corn, and less need for herbicide.

Second-Year Corn Following Alfalfa

Corn often is planted as the second crop following alfalfa in the Upper Midwest. It was the second-year crop on 50 to 75% of the acres during 2009–2012 in Iowa, Minnesota, Nebraska, South Dakota, and Wisconsin, and on 30% of the acres in North Dakota during this time (Figure 8) (Yost et al., 2014d). Corn can be an excellent second-year crop following alfalfa termination because the grain yield can be equivalent to corn following soybean or about 10% higher than continuous corn (Figure 1).

PLANTING

Planting second-year corn following alfalfa requires attention to residue management. If tillage is used and first-year corn is harvested for grain rather than silage, stalks from first-year corn generally should be shredded prior to tillage. The choice of tillage system typically affects the yield of second-year corn following alfalfa more than that for first-year corn. Full-width tillage systems often produce greater yield than strip-till or no-till systems for second-year corn on fine- and medium-textured soils, especially when early-season growing conditions are cool and wet.

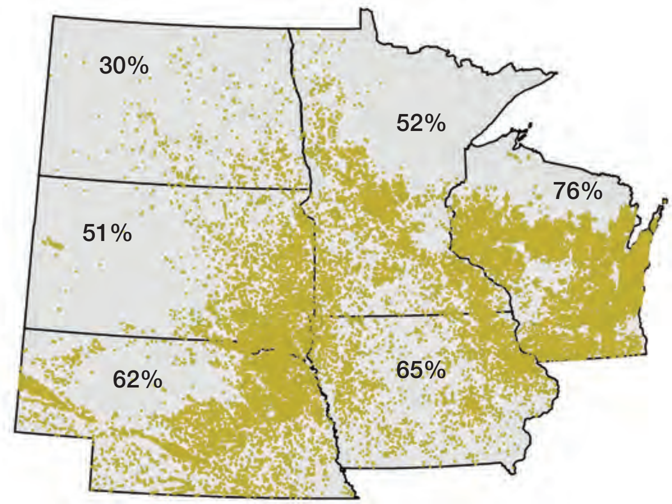

FIGURE 8 Second-year corn following alfalfa during 2009-2012 according to combinations of Cropland Data Layers. Percentages indicate percent of total second-year crop that was corn in each state.

NITROGEN

Alfalfa typically provides N to second-year corn, thereby reducing its fertilizer or manure N requirement compared to continuous corn.

Alfalfa N credit guidelines

Guidelines in Minnesota and several other Midwest states indicate that alfalfa N credits of 75, 50, and 0 lb N/acre should be used for second-year corn following good, fair, and poor alfalfa stands, respectively. When these credits are subtracted from the guideline N rates for continuous corn in Minnesota, guideline N rates for second-year corn range from 0 to 155 lb N/acre (Table 4).

Adoption of second-year corn N rate guidelines

According to survey responses from 273 growers in 2012, only 29% followed Extension N rate guidelines for second-year corn (Yost et al., 2014a). However, adoption ranged from 17-43% among regions and with the presence or absence of manure (Figure 9). Adoption was slightly higher when manure was not applied (33%) than when it was (25%), but most respondents applied manure (79%). Of the respondents who applied manure, 78% applied it to both corn crops following alfalfa. In these cases, the total N rate for second-year corn includes four major N sources in addition to the N supplied from other soil organic matter: a) second-year manure N credit for manure applied to first-year corn, b) second-year alfalfa N credit, c) first-year manure N credit from newly applied manure, and d) fertilizer N. Because alfalfa N credits for second-year corn are estimated to be about one-half of first-year credits, respondents who applied N only as commercial fertilizer did not exceed the guideline rate by more than 100 lb N/acre when alfalfa N credits to second-year corn were not accurately accounted for. However, when manure was applied to one or both corn crops following alfalfa, almost one-third of the respondents exceeded guideline rates by more than 100 lb N/acre and 18% exceeded guideline rates by at least 200 lb N/acre (Figure 10). Therefore, opportunities exist for growers to improve profits from corn by further crediting N from alfalfa and manure.

Validation of N rate guidelines

On-farm research trials were conducted in Iowa between 1989-1991 and in Minnesota between 2011-2012 to determine economic optimum N fertilizer rates for second-year corn following alfalfa and to confirm alfalfa N credits (Yost et al., 2014b). Results from these 28 on-farm trials showed that: a) no N fertilizer was

Table 4 University of Minnesota Extension N rate guidelines for second-year corn following alfalfa.

Soil productivity[a]	Alfalfa stand density	N cost ÷ corn grain price[b]			
		0.05	0.10	0.15	0.20
	--- plants/ft² ---	---------- lb N/acre ----------			
High	4 or more	80	65	55	45
	2 to 3	105	90	80	70
	1 or fewer	155	140	130	120
Medium	4 or more	55	45	35	25
	2 to 3	80	70	60	50
	1 or fewer	130	120	110	100
Low	4 or more	25	15	5	0
	2 to 3	50	40	30	20
	1 or fewer	100	90	80	70

[a] High- and medium-productivity soils should have at least 3% organic matter. Irrigated sandy soils are in the high-productivity category.

[b] Ratio is calculated as N fertilizer cost ($/lb N) ÷ corn grain price ($/bu). For example, for urea that costs $460 per ton, the N cost is $0.50 per pound. If grain is worth $5.00 per bushel, then the fertilizer N cost ÷ corn grain price ratio is $0.50 ÷ $5.00 = 0.10.

needed to maximize grain yield on 14 fields, b) the optimum N rate was less than 80 lb N/acre on 5 fields, c) the optimum N rate was less than 120 lb N/acre on 6 fields, and d) the remaining 3 fields needed 175 lb N/acre (Figure 11). What was most striking about these results was that **N fertilizer did not increase yield on one-half of the fields.** As was the case with first-year corn, alfalfa stand density did not relate well to the size of the alfalfa N credit to second-year corn. The PSNT also had low accuracy in second-year corn, as only 57% of 53 trials in Minnesota and the literature were correctly predicted as being responsive or nonresponsive to fertilizer N (Walker et al., 2014).

Potential field-specific N rate guidelines

In order to identify when second-year corn following alfalfa requires N fertilizer and how much N is needed on responsive fields, the same approach as for first-year corn is being used with 200 trials of second-year corn and is expected to be completed in 2015. These ongoing efforts should be able to identify when corn following alfalfa will need N fertilizer and what N rates to apply.

PHOSPHORUS AND POTASSIUM

Management of P and K for second-year corn following alfalfa can be according to guidelines for corn following corn.

MANURE

If manure was applied to first-year corn, be sure to subtract second-year manure N credits to further reduce the amount of N applied for second-year corn as fertilizer or manure. If the second-year alfalfa N credit (up to 75 lb N/acre) plus the second-year manure N credit from first-year corn do not meet the economically optimum N rate for second-year corn, use properly credited manure N or fertilizer N to bring the total N rate up to the Extension guideline rate.

INSECTS, WEEDS, AND DISEASES

Insect, weed, or disease management in second-year corn following alfalfa can be according to guidelines for corn following corn.

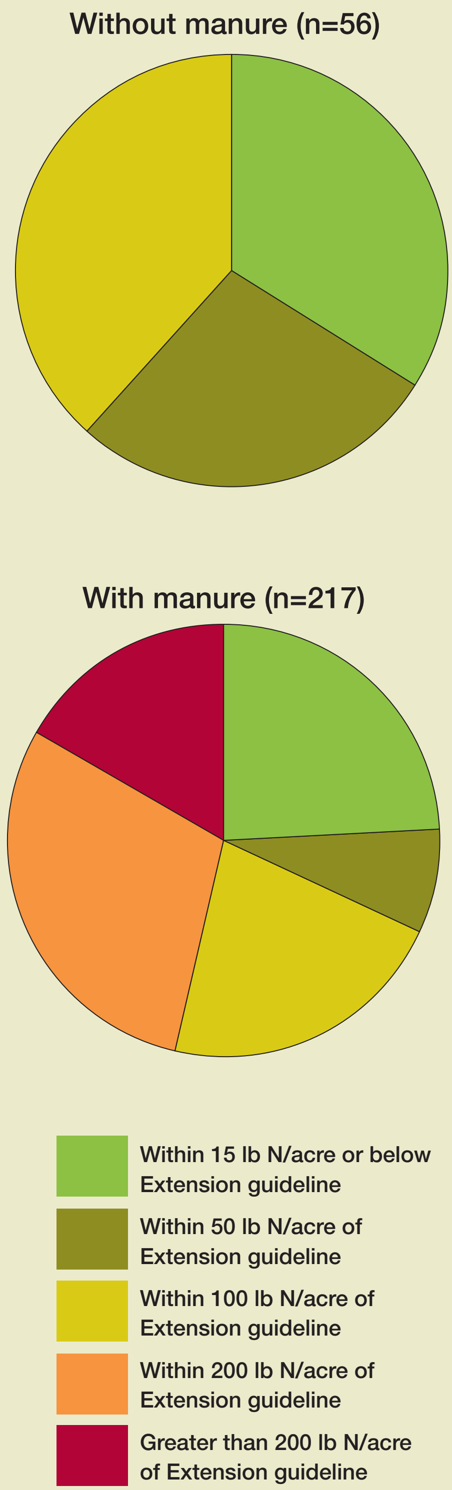

FIGURE 10 Reported rates of N application by survey respondents who use fertilizer only or fertilizer plus manure for second-year corn following alfalfa.

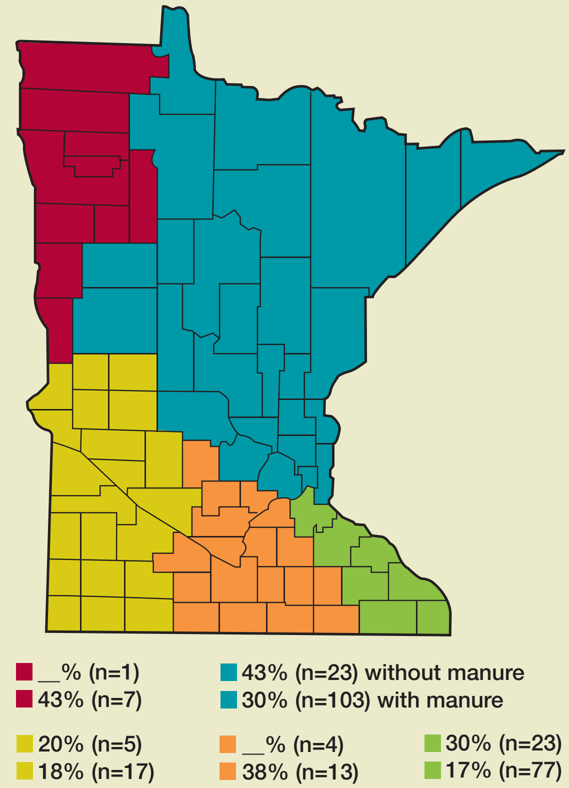

FIGURE 9 Percent adoption (number of respondents) of current N guidelines for second-year corn following alfalfa in Minnesota by region when manure was not (top value in each pair) or was (bottom value) applied. Data are not shown for regions with less than five responses.

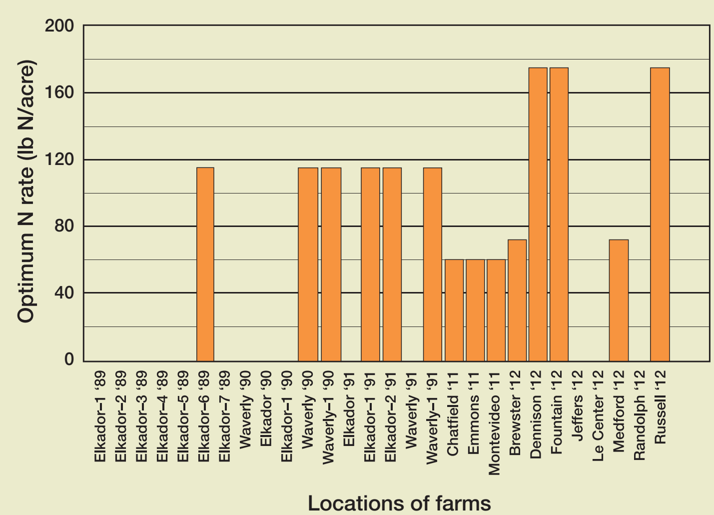

FIGURE 11 Economically optimum N rates at the N fertilizer cost ($/lb) ÷ corn grain price ($/bu) ratio of 0.10 for 28 on-farm trials conducted in Iowa during 1989–1991 and in Minnesota during 2011–2012.

RESOURCES FOR ADDITIONAL INFORMATION

University of Minnesota Extension fertilizer recommendations for agronomic crops in Minnesota: **http://www.extension.umn.edu/agriculture/nutrient-management/nutrient-lime-guidelines/**

University of Minnesota Extension calculator for alfalfa nutrient needs: **http://www.extension.umn.edu/agriculture/nutrient-management/crop-calculators/**

Regional corn N rate calculator: **http://extension.agron.iastate.edu/soilfertility/nrate.aspx**

University of Minnesota Extension manure N credit guidelines: **http://www.extension.umn.edu/agriculture/manure-management-and-air-quality/manure-application/manure-management-in-minnesota/**

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