Synchrony and Contribution of Legume Nitrogen for Grain Production Under Different Tillage Systems

Final Report for LNC89-025

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Region: North Central
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Project Coordinator:

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Project Information

Summary:

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The benefits of crop rotations on agricultural productivity have long been known and are an important component of sustainable agriculture. Legumes in rotation can provide significant quantities of N to succeeding non-leguminous grain crops. Research was initiated on a Reading silt loam at 2 sites to determine the contribution and synchrony of legume N from soybeans, hairy vetch, and red clover for grain sorghum, and from hairy vetch, sweet clover and alfalfa for winter wheat, under conventional and no-tillage residue management. Nitrogen rates of 0, 60, and 120 kg N ha^{-1} were applied to sorghum following legumes. Nitrogen rates of 0, 30, and 60 kg N ha^{-1} were applied to wheat in 1991, and 0, 50, and 100 kg N ha^{-1} to wheat in 1992 following legumes. The rotational benefit gained from legumes in these rotation were highest following hairy vetch (wheat and sorghum) and red clover (sorghum) and sweet clover (wheat). Residual rotational benefit was also greatest from hairy vetch. At site 1 in 1991 sorghum yields were highest following continuous sorghum. Due to the advanced maturity of sorghum following hairy vetch and red clover in 1991, more of the grain filling period of sorghum following these crops was subjected to drought conditions which reduced yields. Sorghum yields were highest following hairy vetch and red clover at site 2 in 1992. Wheat yields in 1991 following hairy vetch were lower than following the other previous crops because the high N availability following hairy vetch contributed to extensive powdery mildew infection the reduced grain yield. Tillage did not significantly influence grain yield. Nitrogen uptake patterns were similar for both tillage systems and both years. Generally, N uptake increased with N rates. At the beginning of the growing season, soil nitrate levels were highest following hairy vetch, sweet clover and red clover in both years. Increased soil nitrate levels during much of the maximum sorghum N uptake period in 1992 suggested that N synchrony was better

than in 1991 when soil NO3--N decreased after the initial sampling. The reverse was true for winter wheat.

The critical component of these rotations is legume establishment. Under the proper growing conditions, hairy vetch, sweet clover and red clover have the ability to fix large quantities of N and supply most or all the N a wheat or sorghum crop requires. In order to maximize the efficiency of the rotation, synchronization of N mineralization with wheat and sorghum N uptake is important but will vary between years.

Project Objectives:

1. Quantify nitrogen (N) mineralization from forage and grain legumes and subsequent N availability to non-legume grain crops.

2. Evaluate the influence of tillage on the quantity of N mineralization and availability to grain sorghum and winter wheat.

3. Describe and quantify the synchrony of soil and legume N mineralization and N uptake by non-legume grain crops.

4. Evaluate the potential use and N balance of mono- and poly-culture production of perennial grain crops.

Research

Research results and discussion:

Sorghum Grain Yield

Precipitation during grain fill was lower than normal and influenced the grain sorghum response to previous crop in 1991. Yields for continuous sorghum and sorghum following soybeans were significantly greater than sorghum following hairy vetch and red clover (Table 1). Sorghum following hairy vetch and red clover had greater vegetative growth and matured earlier because of higher N availability (Fig. 1) compared to continuous sorghum. Because of the advanced maturity of sorghum following hairy vetch and red clover, more of the grain filling period was subjected to drought. Continuous sorghum grain yields were higher, because it was still in the drought-tolerant vegetative stage during part of the low rainfall period. Although 1991 was dry during grain fill, tillage did not significantly influence grain yield (Table 1).

Nitrogen did not significantly increase sorghum grain yields in 1991 (Table 1). Also, there was no significant crop x N interaction. An expected result would be a response to N for continuous sorghum and sorghum following soybeans and little or no response to N for sorghum following hairy vetch and red clover. However, continuous sorghum and sorghum following soybeans did not respond to N because of poor growing conditions in 1991.

Continuous sorghum had the highest yields under both tillage systems, while sorghum following red clover had the lowest yields with no N applied. At N rates of 60 and 120 kg N ha^{-1}, yields for continuous sorghum and sorghum following soybeans were generally greater than yields of sorghum following hairy vetch and red clover under both tillage systems. Between tillage systems at 120 kg N ha^{-1}, yields of sorghum following red clover were significantly greater for NT than for CT.

Growing conditions in 1992 were ideal in that growing season temperatures were below normal and growing season rainfall was above normal due to an unusually wet July. The favorable growing conditions are reflected in the grain sorghum yields which were 2 to 3 times higher than those in 1991 depending on previous crop and N rate. Although tillage did not statistically influence grain yield, sorghum grown under the NT system averaged across previous crop and N rate yielded 0.6 Mg ha^{-1} more than sorghum grown under the CT system (Table 2).

Sorghum following hairy vetch and red clover had higher yields than sorghum following soybeans and significantly higher yields than continuous sorghum when no N was applied in 1992 (Table 2). The higher yields of sorghum following hairy vetch and red clover were expected due to the favorable growing conditions in 1992 and are a result of the N contributions and rotational effects of the legumes. Sorghum following soybeans and continuous sorghum showed the largest increases in yields with applied N (Table 2). Continuous sorghum showed the greatest response to N with yields significantly higher at each increasing N rate.

The response to N by continuous sorghum and sorghum following soybeans was expected due to the favorable growing conditions in 1992.

Since not all of the N fixed by legumes is available to the following crop, sorghum was planted again at site 1 in 1992 to determine the residual N contribution of the legumes planted in 1990. Previous crop and N rate each significantly influenced grain sorghum yields (Table 3). Sorghum yields following hairy vetch were significantly greater than yields of sorghum following all other previous crops with no N applied (Table 3). Yields for continuous sorghum and sorghum following red clover and soybeans were significantly higher at 60 kg N ha^{-1}, while sorghum following hairy vetch did not show a significant yield increase. Even at 60 kg N ha^{-1}, the yields for continuous sorghum and sorghum following soybeans were lower than yields for sorghum following hairy vetch with no N applied. These yield results show that the residual N contribution from hairy vetch was substantial. The N contribution of hairy vetch was likely due to the excellent biomass production of hairy vetch in 1990 and dry conditions in 1991 which decreased mineralization.

Sorghum N Uptake

N uptake was similar from 22 to 43 days after planting (DAP) (Figure 2). The period between 32 and 43 DAP showed sharp increases in N uptake with sorghum following hairy vetch and red clover significantly greater than continuous sorghum. The rapid increase in N uptake is due to the sorghum plant entering the period of rapid dry matter accumulation or "grand period of growth". Although some differences in N uptake were observed at 55 DAP, none of these differences were statistically significant. Also, uptake of N was greater for sorghum following hairy vetch than all other crops. Nitrogen uptake had decreased at 124 DAP probably due to N volatilization losses from the sorghum plants.

Due to cool wet conditions after planting, emergence was delayed in 1992. As a result, the first plant samples were not taken until 41 DAP. Sharp increases in plant uptake of N between 41 and 64 DAP were observed (Figure 3). Nitrogen uptake was significantly greater under the CT system than under the NT system. Nitrogen uptake for sorghum following hairy vetch was significantly greater than continuous sorghum and sorghum following soybeans. Sharp increases in N uptake were again observed at 144 DAP. Nitrogen uptake for sorghum following red clover and hairy vetch was significantly greater than continuous sorghum.

Soil Nitrates (Sorghum)

At the beginning of the 1991 growing season, soil NO_3^--N concentrations to 30 cm were highest following hairy vetch and red clover under both tillage systems (Figure 1). Higher NO_3^--N concentrations at the beginning of the growing season following hairy vetch and red clover were expected due to their N contributions as legumes and subsequent N availability to the succeeding sorghum crop. As the growing season progressed, NO3--N concentrations following all previous crops declined due to plant uptake (Figure 1). During this period of rapid N uptake by the sorghum crop, NO3--N concentrations were highest following hairy vetch and red clover. At the last sampling date, NO3--N concentrations increased due to lower uptake by sorghum (Figure 1). Again, NO3--N concentrations were highest following hairy vetch and red clover.

In 1992, soil NO3--N levels to 30 cm were highest following red clover and hairy vetch under both tillage systems at the first sampling date (Figure 4). At the next two sampling dates, soil NO3--N concentrations following all previous crops increased due to mineralization exceeding plant uptake. Nitrate concentrations were significantly greater following red clover than all previous crops and lowest following sorghum. The fourth sampling date showed sharp decreases in nitrate levels following all previous crops due to uptake exceeding mineralization (Figure 4). Nitrate levels continued to decrease at the last sampling date due to low mineralization.

Wheat Grain Yield

Wheat yields following hairy vetch were significantly less than following other legumes or following wheat in 1991 (Table 4). Residual soil nitrate concentration was greater following hairy vetch than with the other previous crops (Figure 5). The additional N availability following hairy vetch contributed to enhanced biomass production and contributed to infection by powdery mildew that reduced wheat yield. Also, increasing N rate decreased wheat yield, especially following hairy vetch, again due to powdery mildew. Continuous wheat yield under NT was less than under CT and was likely due to alleopathic effects of the wheat residue. In general, tillage had little ifluence on wheat grain yield.

Due to drought conditions we could only establish hairy vetch in the fall 1991 (site 2). To establish different previous crop N levels, the duration of hairy vetch growth was varied from 59 to 150 days. In general, increasing days of hairy vetch growth increased wheat grain yield in 1992 (Table 5). Increasing N rate had no affect on wheat following hairy vetch, but did increase grain yield in continuous wheat. Also, tillage had little influence on wheat grain yield.

To evaluate additional N availability from the previous legumes in the 1990 site, wheat was planted again in fall 1991. Wheat grain yield was not influenced by previous legume crops, N rate, or tillage treatment (Table 6).

Cumulative N Uptake in Wheat

Cumulative N uptake by wheat in 1991 was greater following hairy vetch and Sweet clover than alfalfa or wheat (Figure 6). Nitrogen availability following hairy vetch was slighlt greater than sweet clover under NT, but was similar under CT. In contrast, CT appeared to enhance N availability in alfalfa compared to wheat as previous crops. In 1992, CT generally increased N availability to wheat compared to NT (Figure 7). Increasing the duration of hairy vetch growth significantly increased N availability to wheat as measured by cumulative N uptake.

Soil Nitrates (Wheat)

Soil NO3-N concentration at the beginning of the 1991 wheat growing season increased in the order of hairy vetch > sweet clover > wheat > alfalfa (Figure 5). Increasing N uptake (Figure 6) with increasing wheat growth decreased soil NO3-N concentration with all previous crops treatments. In general, soil NO3-N concentration with hairy vetch and sweet clover were greater than with alfalfa and continuous wheat and indicates greater or additional potential N mineralization after the maximum N uptake period in wheat. Compared to NT, CT generally increased initial soil NO3-N concentration. Higher soil NO3-N concentration also was observed with alfalfa than with wheat under CT compared, where the reverse was true under NT (Figure 5). Similar soil NO3-N concentrations were observed between CT and NT later in the growing season after wheat had accumulated much of its' N.

Hairy vetch increased soil NO3-N concentration at the beginning of 1992 compared to wheat as the previous crop (Figure 8). As the growing season progressed, soil NO3-N concentration decreased with increasing N uptake (Figure 7), then increased greatly after 120 days of growth. The substantial increase in soil NO3-N is likely due to N mineralization. In contrast to 1991, soil NO3-N concentration was greater under CT than NT.

N Synchrony - Sorghum

Results from 1991 show that N mineralization was not in synchrony with sorghum uptake. Nitrate concentrations were high at the beginning of the growing season but decreased rapidly as the sorghum plants began their period of rapid growth and N uptake. Ideally, NO3--N concentrations would be low at the start of the growing season and increase due to mineralization and peak at maximum N uptake by sorghum. As illustrated (Figure 1), soil NO3--N levels only increased at the last sampling date due to mineralization exceeding uptake.

Nitrogen synchrony in 1992 was considerably better than in 1991. Soil NO3--N levels increased two sampling dates after the initial sampling date (Figure 4). Also at this time, sorghum N uptake was rapid which indicates mineralization of N was considerable because it was exceeding plant uptake during this period of rapid uptake. This shows that N mineralization was in synchrony with sorghum plant uptake. After this period, NO3--N levels dropped considerably due to plant uptake.

N Synchrony - Wheat

Nitrogen synchrony in 1991 was considerably better than in 1992. Soil NO3--N levels in 1992 increased after the initial two sampling dates (Figure 8), indicating addtional mineralization after most of the N was taken up by the wheat. The decrease in soil NO3-N concentration as the 1991 growing season progressed indicates that N mineralization was better synchronized with N uptake in 1992 compared to 1991. This shows that N mineralization was in synchrony with N uptake. After this period, NO3--N levels dropped considerably due to plant uptake.

Research conclusions:

Specific practical applications cannot be provided from rotation studies conducted over only two years. The objectives could only be addressed from a minimum of four to six years.

Economic Analysis

The results of these studies showed that sufficient plant available N was mineralized following hairy vetch and red or sweet clover to meet the N requirements of wheat and grain sorghum. With average fertilizer N rates of 80 and 100 kg N ha^{-1} for wheat and sorghum, respectively, \$35 to \$45 ha^{-1} in reduced N costs are realized (\$0.44 kg^{-1} N). The costs of established hairy vetch and clover are greater than the fertilizer N costs, however, the added-value of feeding the legume forage to livestock would offset these costs.

Farmer Adoption

Four farmers participated in the on-farm component in the studies. These farmers still plant legumes in rotation with wheat and sorghum, although the legumes are grown for at least three years to offset establishment costs. No specific recommendations can be forwarded because of the short time period the treatments were evaluated.

Producer Involvement

Field Days (August 12, 1991 - Konza Prairie Open House): 24

Participation Summary

Educational & Outreach Activities

PARTICIPATION SUMMARY:

Education/outreach description:

Nienke, S.R., J.L. Havlin, and C.W. Rice. 1991. Synchrony and Contribution of Legume Nitrogen for Grain Sorghum Under Different Tillage Systems. p.296. Agron. Abst. Madison, WI.

Nienke, S.R., G.T. Wheatley, J.L. Havlin, and C.W. Rice. 1992. Synchrony and Contribution of Legume Nitrogen for Grain Sorghum Under Different tillage Systems. p.287. Agron. Abst. Madison, WI.

Wheatley, G.T., Nienke, S.R., J.L. Havlin, and C.W. Rice. 1992. Synchrony and Contribution of Legume Nitrogen for Winter Wheat Under Different tillage Systems. p.296. Agron. Abst. Madison, WI.

Wheatley, G.T. S.R. Nienke, J.L. Havlin, C.W. Rice, and R.E. Brown. 1992. Synchrony and Contribution of Legume Nitrogen for Winter Wheat under Different Tillage Systems. p. 16-17. In R.E. Lamond (ed.) Kansas Fertilizer Research 1991. Kansas Agric. Exp. Stn. Report of Progress 647.

Nienke, S.R., G.T. Wheatley, J.L. Havlin, and C.W. Rice. 1993. Synchrony and Contribution of Legume Nitrogen for Grain Sorghum under Different Tillage Systems. p.118-120. In R.E. Lamond (ed.) Kansas Fertilizer Research 1992. Kansas Agric. Exp. Stn. Report of Progress 670.

Wheatley, G.T. S.R. Nienke, J.L. Havlin, and C.W. Rice. 1993. Synchrony and Contribution of Legume Nitrogen for Winter Wheat under Different Tillage Systems. p. 17-20 In R.E. Lamond (ed.) Kansas Fertilizer Research 1992. Kansas Agric. Exp. Stn. Report of Progress 670.

Project Outcomes

Recommendations:

Areas needing additional study

Thorough evaluation of the stated project objectives requires additional years of production the two-year rotations.

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