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Article in Agronomy journal · November 1998

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Winter Wheat Yield Depression from Legume Green Fallow

Merle F. Vigil* and David C. Nielsen

ABSTRACT

Increases in N fertilizer costs have caused some farmers to consider the use of a legume during the fallow phase of a wheat-fallow system as an alternative N source for dryland wheat. Farmers need to know how this system will affect winter wheat (Triticum aestivum L.) production and economic returns. The objectives of this research were (i) to determine the effect of legume green fallow on subsequent winter wheat yields and economic returns and (ii) to determine optimal legume termination dates during the legume phase. Wheat yields following three legumes [Austrian winter pea, Pisum sativum L. subsp. sativum var. arvense (L.) Poir.; spring field pea, P. sativum L.; and black lentil, Lens culinaris Medikus] were compared with wheat yields following fertilized traditional summer fallow. Legume biomass, biomass N, and water use were measured at four termination dates during the green-fallow phase of the rotation. Wheat yields following the annual legume were reduced, compared with traditional summer fallow, by 400 kg ha⁻¹ at the earliest legume termination date and by at least 1050 kg ha⁻¹ at all other dates. Economic analysis indicates that in drier than normal years, that returns are maximized when the legume is not grown during the fallow phase. In 1996, a wet year, returns were maximized when the legume was terminated at the second termination date or after 70% of the potential maximum legume water use. We found that 88% of the variability in winter wheat yield could be explained by legume water use the previous year. In general, the competitiveness of legume green fallow with winter wheat fallow is highly weather-dependent and inconsistent. At current fertilizer costs, legume N (in this system) was too expensive to be considered a reasonable alternative to chemical fertilizer.

Dryland crop production in the central Great Plains of the United States is dominated by winter wheat-summer fallow (Haas et al., 1974). After water, N fertility is probably the most important input to profitable agriculture in the region. For many soils, this system depends on biennial additions of N fertilizer with typical rates between 35 and 70 kg N ha⁻¹ (Westfall et al., 1996). The cost of commercial N fertilizers has increased significantly in recent years, and because nonrenewable fossil fuels are used to manufacture N fertilizer, fertilizer costs are projected to increase over the long term (Douglas, 1980). Informal telephone surveys, conducted by our laboratory, of four northeastern Colorado fertilizer dealers in 1991, 1995, and 1997 indicate N fertilizer costs have increased about 60% since 1991. This has prompted some farmers and researchers to consider alternative cropping systems that include legumes as both a source of N and as forage (Biederbeck et al., 1993; Gardner, 1992; Auld et al., 1982).

Historically, long-term soil-building effects, such as increased soil microbial respiration, improved aggregation, and increased N availability, have been attributed to legumes in rotation with cereal grains (Power, 1990, 1987). Haas et al. (1957) reported alfalfa (Medicago sativa L.) in rotation with winter wheat reduced the loss of soil N, compared with winter wheat-summer fallow. In that early research, tillage (one-way disk and moldboard plows) was used to control weeds. Although continuous cropping and wheat-legume rotations reduced soil C, the reduction was not as severe as with alternate wheat-fallow (Haas et al., 1957).

Annual legumes grown for green manure can release substantial amounts of fixed N (Miller and Hoveland, 1995). The amount of N credited by an annual legume to a succeeding crop ranges between 22 and 213 kg N ha⁻¹ (Bundy et al., 1993). In Idaho, Auld et al. (1982) studied winter field pea and reported between 200 and 400 kg N ha⁻¹ in the pea foliage planted in September and terminated the following June. From Bundy et al.'s work (1993), it appears that the amount of N credited to an annual legume depends on management, annual weather variability, and soil type almost as much as on the species of the legume.

For dryland producers in the western United States, an important consideration regarding growing of legumes is the cost in water use by the legume. In the central Great Plains, where average annual precipitation is between 300 and 560 mm, efficient use of the available precipitation is critical (Peterson et al., 1996).

Nielsen and Halvorson (1991) developed a simple linear equation of winter wheat grain yield as a function of evapotranspiration (ET). That equation, further refined by Nielsen (1995), is

\[
\text{Grain Yield} = 17.23(\text{ET}) - 2956 \quad [1]
\]

where grain yield is in kg ha⁻¹ and ET is in mm. The relationship was developed using 2 yr of wheat yield and water-use data from a field plot study where typical semidwarf winter wheat cultivars were grown. If the equation is set equal to zero, one can solve for the amount of ET required to grow the crop without producing any grain yield (about 172 mm). In other words, if only 172 mm of stored soil water plus precipitation were available in the central Great Plains during the wheat growing season, farmers in the region would have no grain to harvest. After the first 172 mm, any additional water (either stored soil water or precipitation) produces about 17.23 kg grain ha⁻¹ mm⁻¹ of water use. Using Eq. [1] and assuming a value of wheat grain of $0.147 \text{ kg}^{-1}$, we can deduce a rough dollar value (as grain for market) for growing-season water use on one hectare of land to be about $2.5 \text{ mm}^{-1}$. This type of

Abbreviations: ET, evapotranspiration; ET₉₀₀, evapotranspiration normalized on the maximum evapotranspiration measured for that year; LGY, legume yield; LG₉₀₀, value of legume hay; RMSE, root mean square error; TDR, time domain reflectometry; TGR, total gross returns; WHTY, wheat yield; WHT₉₀₀, value of wheat grain.
time. Soil excavated in the access tube installation was used for tillage and planting operations. Probe access tubes (with 30-cm-long removable tops, removed was 4.8 m in length by 9.1 m wide.

Four legume termination dates (for legume plots) or fertilizer application rates of fertilizer N: 0, 34, 68, or 102 kg N ha⁻¹. No fertilizer application prior to legume termination.

The site had previously been in a dryland winter wheat-corn rotation (Rhizobium leguminosarum) into main-plots. The legumes were planted in spring, approximately 1730 000 seeds ha⁻¹ (about 35 kg ha⁻¹) for each species. The legumes were planted in rows spaced 20 cm apart, with pea species at approximately 740 000 seeds ha⁻¹ (about 95 kg ha⁻¹) and lentil at approximately 728 000 seeds ha⁻¹ (about 60 kg ha⁻¹) for each species.

Legume sample using an automated C and N analyzer was measured in each individual weed and legume sample using an automated C and N analyzer. Each sample was ground to 60°C and dry weights were recorded. Samples were dried in a forced-air oven at 60°C and dry weights were recorded. Samples were dried in a forced-air oven at 60°C and dry weights were recorded. Samples were dried in a forced-air oven at 60°C and dry weights were recorded. Samples were dried in a forced-air oven at 60°C and dry weights were recorded.

The experiment was arranged in a randomized split-block design with four replications (Little and Hills, 1978). A replicate consisted of a 3-m-wide by 6-m-long plot with a 2-m-wide by 6-m-long control plot. The control plot represented the traditional winter wheat-summer fallow rotation common to dryland grain production in our region. On 1 Apr. 1994, Aussie 452 (26 kg ha⁻¹) and Lockney, TX) into main-plots. The legumes were planted in June, 12 July, 27 July, and 4 August. Prior to legume termination, the aboveground plant biomass (both weeds and legumes) in three random 1-m² areas in each plot was collected, which delayed development, so termination dates were 28 May, 10 June, 17 June, and 24 June. In 1995, early spring temperatures were cooler than in 1994 (Table 1), and legume termination dates were 31 May, 13 June, 28 June, and 8 July. In 1996, legume termination dates were 30 May, 7 June, 20 June, and 4 July.

Control weeds (four operations). This plot represented the traditional winter wheat-summer fallow rotation common to dryland grain production in our region. On 1 Apr. 1994, Aussie 452 (26 kg ha⁻¹) and Lockney, TX) into main-plots. The legumes were planted in June, 12 July, 27 July, and 4 August. Prior to legume termination, the aboveground plant biomass (both weeds and legumes) in three random 1-m² areas in each plot was collected, which delayed development, so termination dates were 28 May, 10 June, 17 June, and 24 June. In 1995, early spring temperatures were cooler than in 1994 (Table 1), and legume termination dates were 31 May, 13 June, 28 June, and 8 July. In 1996, legume termination dates were 30 May, 7 June, 20 June, and 4 July.

C. to allow for monitoring of possible changes in soil N and C dynamics that might result from the various rotations. Use of company or trade names is for the benefit of the reader and does not imply endorsement by the USDA-ARS of the products named nor criticism of similar ones not mentioned.
Using Eq. [2], the TGR for the winter wheat-legume-fallow nongreen portion of the fallow period (Vigil et al., 1997).

\[ \text{TGR} = \left( \text{LGY} \times \text{LP}_\text{p} \right) + \left( \text{WHT}_\text{Y} \times \text{WHT}_\text{p} \right) \]

where LGY is legume yield in kg ha\(^{-1}\); WHT\(\text{Y}\) is wheat yield in kg ha\(^{-1}\); LP\(\text{p}\) is the selected value of legume hay, $0.083 kg\text{ha}\(^{-1}\); WHT\(\text{p}\) is planting costs, $50 ha\(^{-1}\); and tillage costs, $15 ha\(^{-1}\); are for sweep-plow tillage during the fallow. These data, combined with daily precipitation records, were used to estimate evapotranspiration (ET) in each plot. Soil-water-content measurements were taken to a depth of 180 cm prior to legume planting, at each legume termination, and prior to wheat planting, monthly during the wheat grow-1.5 m wide and 7.6 m long in the middle of each sub-strip, and 107') was planted at 2,500,000 seed ha\(^{-1}\) (about 67 kg ha\(^{-1}\)). On 26 Sept. 1994 and 27 Sept. 1995, winter wheat ('Tam 1.5 m wide and 7.6 m long in the middle of each sub-strip, and 107') was planted at 2,500,000 seed ha\(^{-1}\) (about 67 kg ha\(^{-1}\)).

In both years, growing these legumes to increase N fertility was not cost effective. Nitrogen fertilizer costs of producing 4281 kg ha\(^{-1}\) of wheat grain valued at $629. In essence, 420 mm of water was taken up from the soil. In any case, the accumulated \(\text{ET} = 107\text{mm} + 385\text{mm} = 492\text{mm}\) is the selected value of legume hay, $0.083 kg\text{ha}\(^{-1}\); WHT\(\text{Y}\) is wheat yield in kg ha\(^{-1}\); LP\(\text{p}\) is planting costs, $50 ha\(^{-1}\); and tillage costs, $15 ha\(^{-1}\); are for sweep-plow tillage during the fallow. These data, combined with daily precipitation records, were used to estimate evapotranspiration (ET) in each plot. Soil-water-content measurements were taken to a depth of 180 cm prior to legume planting, at each legume termination, and prior to wheat planting, monthly during the wheat growing season.
Above ground biomass N

Water use (ET)

Fig. 1. Legume biomass yield, water use and total aboveground biomass N at four harvest dates in 1994 and 1995. A, Austrian winter pea; F, spring field pea; L, Indianhead black lentil. Error bars show the largest standard errors of the mean of four replicates for all three species.

55 mm of water, whereas only 20 mm of ET was lost from the summer fallow plots during the same legume growth period (Table 3). The 34 to 55 mm of ET used by the legumes terminated 31 May 1994 was statistically the same as the 52 mm of ET measured on 8 July 1994 in traditional summer fallow (Table 3). In other words, approximately one month of legume growth used as much water as three months of traditional summer fallow in 1994. Precipitation and stored soil water that would have been used by the subsequent wheat crop was used to grow legumes. For comparison, measured ET from the traditional summer fallow plots for the period between planting of the legumes in April until the last termination date on 4 Aug. 1995 was 267 mm. This 267 mm of ET was about the same as the water used by the three legumes measured at the first termination date on 28 June 1995 (Table 3). In 1995, 73% of the variability in wheat yield ($R^2 = 0.73$) could be

Table 2. Winter wheat yields in 1995 and 1996 following three legumes in a green-fallow rotation, and the legume's water use (ET) the previous year as affected by termination date.

<table>
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<td>kg ha-1</td>
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<td></td>
<td>31 May</td>
<td>2950</td>
<td>166</td>
<td>54</td>
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<td>13 June</td>
<td>2250</td>
<td>156</td>
<td>72</td>
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<td></td>
<td>28 June</td>
<td>2360</td>
<td>167</td>
<td>129</td>
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<td></td>
<td>8 July</td>
<td>1800</td>
<td>68</td>
<td>151</td>
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<td></td>
<td>LSD (0.05)</td>
<td>403</td>
<td>35</td>
<td>516</td>
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<td></td>
<td>1996</td>
<td></td>
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<tr>
<td></td>
<td>28 June</td>
<td>4450</td>
<td>374</td>
<td>282</td>
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<td></td>
<td>12 July</td>
<td>4090</td>
<td>406</td>
<td>321</td>
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<td></td>
<td>27 July</td>
<td>2470</td>
<td>290</td>
<td>413</td>
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<td></td>
<td>4 Aug.</td>
<td>2050</td>
<td>226</td>
<td>403</td>
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<td>LSD (0.05)</td>
<td>763</td>
<td>92</td>
<td>605</td>
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Values in parenthesis are the standard error of the mean.
VIGIL & NIELSEN: WHEAT YIELD DEPRESSION

Fig. 2. Wheat yields as affected by previous legume biomass production (Austrian winter pea and spring field pea data only).

explained by the previous year's legume growth using the fitted regression equation
\[ \text{wheat yield} = 3225 - 0.74(\text{legume yield}) \]
where wheat yield is in kg ha\(^{-1}\) and legume yield is the previous year's legume yield in kg ha\(^{-1}\) (Fig. 2). The root mean square error (RMSE) was 227.7, and the F-value of regression was 16.4 (P < 0.007). In 1996, 99% of the variability in wheat yield (R\(^2\) = 0.99) could be explained by the following regression equation:
\[ \text{wheat yield} = 3717 + 0.79(\text{legume yield}) - 0.0002(\text{legume yield})^2 \]
where wheat and legume yield are as described above. The RMSE and F-value of regression were 131.7 and 185 (P < 0.0001), respectively.

A look at the data Fig. 1 suggests that legume biomass yields leveled off between the third and last termination dates. Between the third and last termination dates, however, the continued legume water use reduces subsequent wheat yield (Table 2). For these reasons, legume ET the previous year is probably more highly related to the subsequent wheat yield than legume biomass production. Therefore, we normalized and then combined the data of both years and found that 88% of the variability in wheat grain yield could be explained by legume ET from the previous year:
\[ WHT = 1.03 - 0.26(\text{ET}) - 0.29(\text{ET,o,m}) \]
where WHT is the normalized wheat yield and ET is the normalized legume ET of the previous year. The R\(^2\) was 0.88, the RMSE was 0.0756, and the F-value of regression was 73.9 (P < 0.0001) for Eq. [5] (Fig. 3).

Others have reported similar findings with respect to yield depression after green manure crops. In a review article, Power (1990) reported that research conducted before 1960 showed that green manure crops often reduced yields of the following crop. At two locations in Montana, lower yields were measured following green-manure legumes than following summer fallow (Army and Hide, 1959). In more recent research, Zentner et al. (1996) reported less wheat yield after black lentil green fallow than after traditional summer fallow. Gardner (1992) reported data indicating that when and how the legume is terminated during the fallow period will effect soil water storage and the yield potential for the subsequent crop.

We measured higher wheat yields both years in plots that were traditionally summer fallowed and fertilized with only 34 kg of commercial N ha\(^{-1}\) than in any of the legume plots (Table 4). Soil-water depletion by legumes terminated on the first termination date in 1994 and 1995 resulted in subsequent wheat yields in 1995 and 1996 that were 500 to 800 kg ha\(^{-1}\) less than wheat yields fertilized with 34 kg of N ha\(^{-1}\) in traditional summer fallow. In 1995, we measured wheat grain yields that were 700 kg ha\(^{-1}\) greater when following nonfertilized traditional summer fallow than when following legumes terminated as early as 13 June (Table 4). In 1996, fertilizer application increased wheat grain yield by as much as 1200 kg ha\(^{-1}\) (Table 4). Grain yield response to fertilizer application in traditional summer fallow was not significant in 1995. In October 1994, preplant soil NO\(_3^-\) levels were marginal to adequate in the top 60 cm of soil after green fallow and traditional summer fallow (Table 5), yet dry conditions are thought to be the reason for a lack of a statistically significant winter wheat response to fertilizer application.
Table yields differ among species, water use was similar (Fig. 4 vs. 9). While legume biomass of previous legume species did not matter. In this experiment, all legume species depressed subsequent wheat yields, but the type of legume green fallow plots (Table 5). Less available inorganic N in the surface soil prior to planting the 1996 winter wheat yields after green fallow. Denitrification allowed to grow and use the mineralized N), greater amounts of mineralized N accumulated than in the legume green fallow plots (Table 5). And the rainfall also may have caused some movement of soil nitrate below the top 60 cm of soil (Table 5). And the wet conditions also enhanced biomass production and N uptake. Greater denitrification. All of the above-mentioned processes could partially explain the low NO_3 levels measured just prior to wheat planting in 1995 (Table 5). In the treatment NH_4-N, NO_3-N, NPh-N, NOy-N...
Normalized legume ET

Fig. 4. Normalized legume yields as a function of legume water use (Austrian winter pea and spring field pea data only).

From the economic analysis, we determined that for a year combination similar to 1994-1995 (green fallow followed by winter wheat), a legume should not be grown at all. Maximum returns would be achieved by growing only winter wheat in the sequence (Fig. 5). In years similar to the 1995-1996 combination, maximum economic returns would be achieved by allowing the legume to grow to approximately 70% of its maximum total seasonal water use (Fig. 5). During the 1995 year, that would correspond to about the first week of July (very close to our second legume termination date, 12 July).

SUMMARY

Compared with traditional fallow, green fallow reduces subsequent winter wheat yields. Eighty-eight percent of the variability in wheat grain yield reduction (calculated as a percentage of the maximum achieved in a given year) could be described by a quadratic equation based on the previous year's legume ET. Legume water use during the summer fallow phase reduces subsequent winter wheat yields by as much 15.2 kg ha$^{-1}$ per millimeter of legume ET. This correlates well with water-use production functions that have been developed for winter wheat in our region, where the slope of the linear relationship between water use and grain production is 17.2 kg ha$^{-1}$ per millimeter of water use (Nielsen, 1995). The economically optimum legume termination date is highly weather-dependent. In a wet year (1995), the optimum termination date was after the legume had used 70% of its maximum water use that season, which occurred about 12 July. Since weather patterns in the central Great Plains are quite variable, the economically optimum termination date will oscillate from year to year based on accumulated heat units and precipitation. In a dry year (1994), the economically optimum situation is to not grow a legume at all. It is interesting that in 1994 (a drier and warmer year than in 1995) the legume had used 70% of its maximum water use by 13 June (one month earlier than in 1995). In wet years, the combination of the legume for hay and wheat grain for market is more economically favorable than traditional wheat fallow. At current costs for fertilizer N, legume N (as used in this system) is too expensive to be considered a reasonable alternative to chemical fertilizer.

ACKNOWLEDGMENTS

The authors wish to recognize technicians Cindy Johnson, Linda Hardesty, Karen Couch, Albert Figueroa, and Carolyn Brandon for their help with these plots.