THE EFFECT OF LEGUMES IN A GREEN FALLOW ROTATION ON WINTER WHEAT YIELDS

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ABSTRACT

With the exception of water, nitrogen (N) nutrition is considered the most important limiting input to profitable winter wheat production in the central Great Plains. Increases in N fertilizer costs have caused some farmers to consider alternative cropping systems that include legumes as a source of N. Farmers need to know how these alternative systems impact winter-wheat yields and their pocket book. The objectives of this research are to: (i) measure legume biomass production, water use and N dynamics in a green fallow-rotation with winter wheat, and (ii) determine the effect of legume-green fallow on subsequent-winter-wheat yields. Three species of annual legume were evaluated for biomass production and biomass N at four legume termination dates, as were winter wheat yields following these legumes in a dryland-wheat-green-fallow rotation. Austrian-winter peas produced the most biomass and contained up to 116 lbs of N per acre in the above-ground biomass. Winter wheat yields were reduced by at least 2 bu/acre at the earliest legume termination date and by at least 12 or more bu/acre at all other dates.

INTRODUCTION

Dryland-crop production in the Central Great Plains is dominated by winter wheat-summer fallow (Haas et al. 1974). For many soils, this system depends on bi-annual additions of N fertilizer (typical rates are between 30 and 60 lbs of N per acre). In fact, after water, N fertility is probably the most important input to profitable agriculture in the central Great Plains. The cost of commercial N fertilizers have 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). This has prompted some farmers and researchers to consider alternative cropping systems that include legumes as a source of N and as a 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; Power, 1987). Haas et al. (1957) reported legumes in rotation with winter wheat reduced the loss of soil N as compared to other rotations which do not include a legume. In that early research, tillage (with one-way disk and moldboard plows) was used to control weeds. While soil-organic carbon levels decreased with winter wheat-legume rotations, the decrease was less than that measured for winter wheat-summer fallow.

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 range between -20 and 190 lbs per acre (Bundy, 1993). In Idaho, Auld et al. (1982) studied winter-field peas and reported between 190 and 356 lbs of N in pea foliage planted in September and terminated the following June. From Bundy's work 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 the species of legume.

For dryland farmers in the west, whether the amount of legume N fixed is 30 lbs or 300 is not nearly as important as the cost in water use by the legume. In the Central Great Plains where average annual precipitation is between 12 and 22 inches, efficient use of available precipitation is critical. For the production of dryland winter wheat, about 7 inches of total water are needed before any yield will be harvested. That 7 inches can come from stored soil water or precipitation. After the first 7 inches of water, any additional water (whether it be stored or fall as rain) produces about 6.5 bushels of grain per inch of water (Nielsen, 1995). From water production functions developed at Akron, we can deduce a rough dollar value for in-season precipitation of about $25 per inch. Biederbeck and Bouman (1994) estimated the water use efficiency of several annual-legume species to be between 254 and 660 lbs per inch (11-29 kg ha^{-1} mm^{-1}). If one assumes 3 % N in green legume tissue, we would have 7.6 to 20 lbs of N in above-ground forage per inch of water use. Of course, not all of this N is fixed N. Much of it is recycled residual N taken up by the legume from the soil. On the other hand, one should also consider the below ground portion of fixed legume N that is contributed to the system but not measured in above ground biomass. This would include the amount sloughed off in legume/rhizobium nodules and through the constant seasonal turnover of live and dead legume roots. In any case, at current fertilizer N costs of $0.19 per lb (anhydrous ammonia at $300/ ton) and with an intrinsic value of stored or precipitation water of $25 per inch, legume N could be very expensive. The objectives of this research are to: (i) measure legume biomass production, water use, and N dynamics in a green fallow-rotation with winter wheat, and (ii) determine the effect legume-green fallow has on subsequent-winter-wheat yields.

MATERIALS AND METHODS

Austrian winter peas, spring-field pea (cv. Trapper) and Indianhead lentils were planted on April 1, 1994 in a Weld silt loam at the Central Great Plains Research Station, Akron, CO. A fertilized summer fallow plot was also maintained in the experiment to compare wheat yields after traditional summer fallow with those following legumes. For each legume, four sequential termination dates were used to estimate total legume biomass yield, above ground biomass N and water use over time. In 1995, a second site was established with the same legume species. These were planted April 6, 1995 on soil also mapped as a Weld silt loam.

The experimental design was a randomized strip-plot with four replications. The main plots consist of legume species: Austrian winter peas, spring field pea (cv. Trapper), Indianhead lentils and a no-legume-summer-fallow plot fertilized at four N rates 0, 30, 60, and 90 lb N/ac. Within each main-plot four sub strip-plots were maintained which consisted of four legume growth termination dates spaced two weeks apart. In 1994, legume termination began on May 31 and termination was performed using sweeps. In 1995 a wet spring shifted the first termination date to June 28. A burn-down herbicide (glyphosate) was used just prior to planting to kill weeds. In 1995, legumes were terminated in two replications by spraying herbicide (glyphosate or paraquat) and in the other two replications legumes by undercutting with sweeps. Soil water was measured using neutron probes and time-domain reflectometry at legume planting in April, at each growth termination event, at wheat planting and at wheat harvest to determine water used. Total above ground N and total legume biomass was determined at each termination date. Soil inorganic N was measured in each plot at each termination date in the top 2 feet of soil and at wheat planting time. The following fall, wheat was planted and harvested using standard BMP's for dryland winter wheat-fallow.

RESULTS

The summer of 1994 was the driest summer in 87 years of recorded weather (4.8 inches received May through August). In 1994 at Akron, CO, the total precipitation received between January and the end of June was 4.1 inches. In 1995, 15.1 inches was received for the same 6 months. Heat unit accumulation was different for both years as well, particularly in the early spring. In 1994, 1004 heat units were accumulated between May 1 and June 30. Whereas in 1995, only 459 were accumulated for the same 2 month period. Because of the greater early-heat-unit accumulation in 1994, biomass yields on June 28, 1994 were slightly greater than on June 28, 1995 (Fig. 1). After June, the lack of seasonal precipitation in 1994 caused most of the legumes to desiccate and die by July 8, 1994. However in 1995, because of cooler and wetter conditions, natural desiccation didn't begin until the end of July. Biomass measured in early July, 1995 was nearly double that measured in 1994 (compare Austrian winter peas at 2400 lbs/acre on July 12, 1995 with only 1300 lb/acre on July 8, 1994 (Fig. 1)).

In both 1994, and 1995 we measured more above-ground biomass with Austrian-winter peas than with the other legumes (Fig. 1). We measured as much as 116 lb of N in the above ground portion of this legume on July 27, 1995 (Fig. 1). From the biomass data, precipitation data, and soil water depletion data we calculated water-use efficiency for above-ground biomass and above-ground-biomass N. For the Austrian-winter peas we calculated a water-use efficiency of 335 lbs of dry matter per inch of water used on June 13, 1994. The 335 lbs of biomass, contained 11.6 lb of N. In other words, 11.6 lbs of N was fixed or taken up by the legume for each inch of water use.

With the cost of N at $0.19 per lb, an inch of water produced only $2.20 worth of legume N. Using our water production functions the same inch of water could have produced 6.5 bushels of wheat. With $4.00 wheat that would be a gross income of $26 dollars. If we subtract the $2.20 for N fixed we would still be short $23.80 in potential wheat yield. Because 1994 was the driest summer on record at the Central Great Plains Research Station one might expect less soil-water storage in green fallow reducing wheat yields more drastically than in a normal year. In 1994 and 1995 growing the legumes we studied to increase N fertility is not cost effective. Nitrogen-fertilizer costs would have to increase more than 10 fold before legume N would become competitive.

Soil-water depletion by legumes terminated on June 13, 1994 reduced wheat yields in 1995 12-15 bushels (Fig. 2). If we assume a market price of $80.0 per ton, the value of the harvestable-legume forage grown on those plots (which averaged 16-17 % protein) was $45. The $45 worth of forage is less than the value of the wheat-yield loss of 15 bushel ($60). In 1995, we produced 1.6 tons of harvestable forage ($128 worth of forage). This required the additional consumptive use (beyond that used in summer fallow) of 5 inches of precipitation and stored soil-water. Using a water use production function for dryland wheat (Nielsen 1995), that 5 inches of water use, potentially translates into 33 bushels of wheat with a value of $130. For most farmers in our region a 33 bushel reduction in wheat yield can not be offset by 2 tons of legume forage. We know that this legume forage is high in protein. However, will dairy farmers and equine producers pay a premium for pea forage as they have for alfalfa? Practical questions of who will buy the forage, the degree of animal palatability and the amount of animal weight gains to expect from such forage must be answered before many farmers will be interested.

With only a single legume crop grown at each site, no significant increases in total or inorganic N have been observed with legume fallow as compared to traditional summer fallow (soil data not presented).

SUMMARY

Our one year of wheat-yield production after green-fallow legumes, followed the driest summer on record at Akron, CO. Because of the unusual weather in 1994, long-term conclusions regarding this system are suspect at this point. However, at current costs for commercial-fertilizer N, legume N is too expensive to be considered a viable alternative. Of the legume species studied, Austrian winter peas were the most productive and contained more total-above-ground N (116 lbs N) than the other species. Wheat yields in 1995 were reduced by at least 2 bushels by all legumes grown, if the legumes were terminated as early as May 31, 1994. For termination dates later than June 13, 1994 wheat yields were reduced 12 or more bushels per acre. An analysis of changes in soil organic matter, total soil N and soil inorganic N between green fallow plots and traditional summer fallow plots were not significantly different after one year of green fallow at either site.

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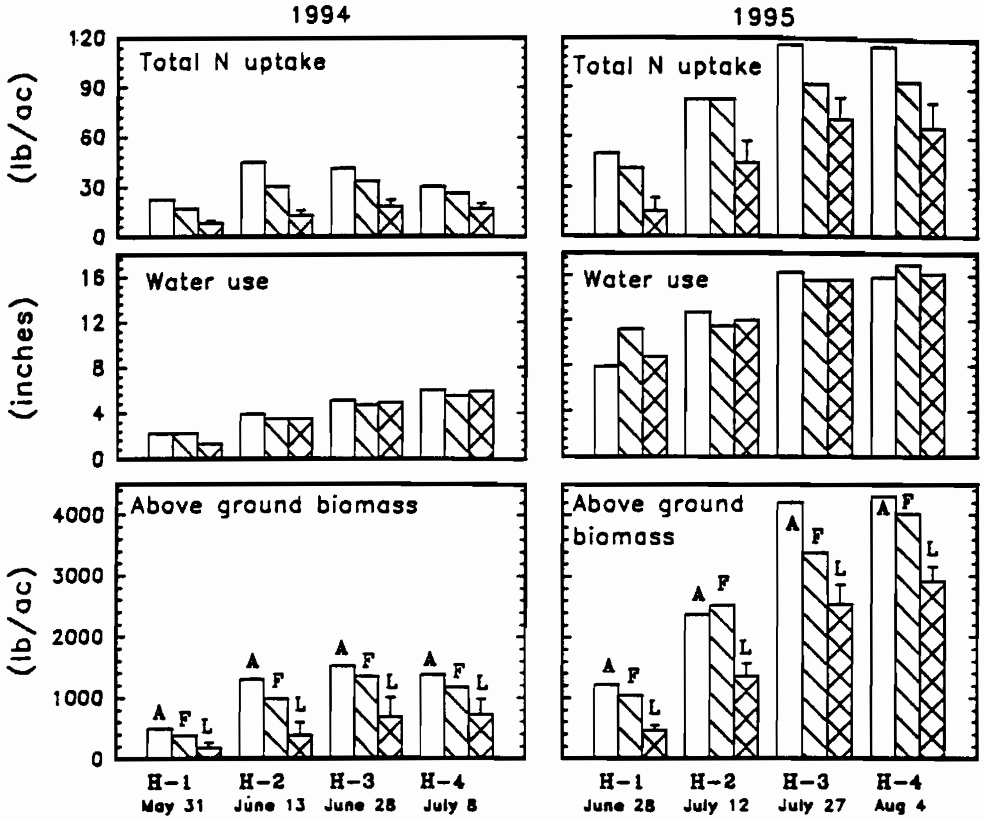

Fig. 1. Legume biomass yield, water use and biomass N at four harvest dates in 1994 and 1995. A= Austrian winter peas, F= Spring-field pea (cv Trapper) and L=Indian head lentils. The error bars are the largest standard errors of the mean of 4 replications for all three species.

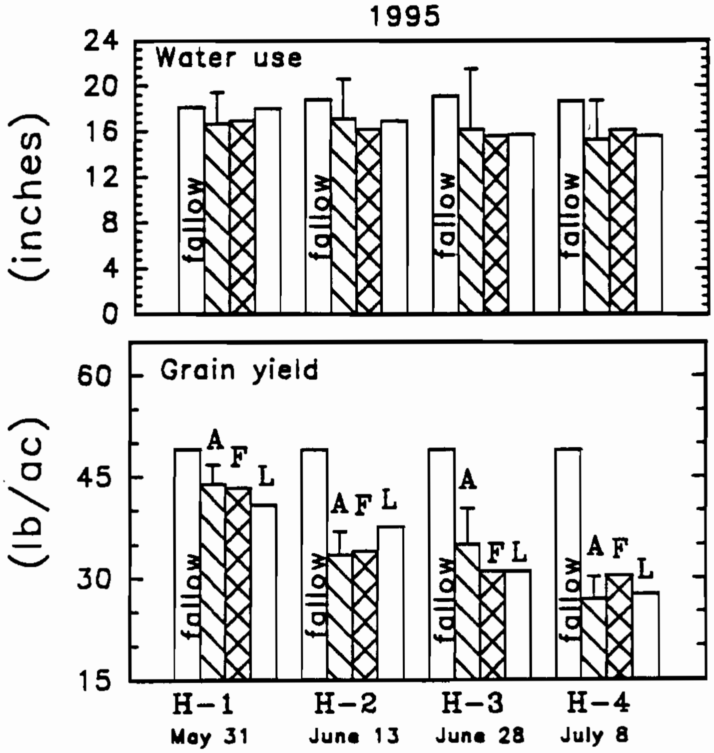

Fig. 2. Wheat yields and wheat-water use in 1995, as affected by legume termination date, legume species and traditional summer fallow. A= Austrian winter peas, F= Spring-field pea (cv Trapper) and L=Indian head lentils. The error bars are the largest standard errors of the mean of 4 replications for all three species.