Winter Wheat Nitrogen Use Efficiency in Grain and Forage Production Systems

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ABSTRACT

Nitrogen use efficiency (NUE) is known to be less than fifty percent in winter wheat production systems. This study was conducted to determine potential differences in NUE when winter wheat (*Triticum aestivum* L.) is grown strictly for forage or grain. The effects of different nitrogen rates on plant N concentrations at different growth stages and on grain at harvest were investigated in two existing long-term winter wheat experiments near Stillwater, (experiment 222) and Lahoma (experiment 502), Oklahoma. Grain and forage yields for the 1996 harvest were low, due to a dry fall and winter. Harvest data for the 1997 crop year is not yet available, but the potential for high yields exists. Nitrogen content decreased as the plants aged over the season. Nitrogen use efficiencies were much greater for the forage-only systems at both sites when compared to grain-only. The two forage harvests employed here (March and May) were both prior to flowering, and prior to the time when gaseous plant N losses are greatest (flowering to maturity). By harvesting the plant for forage before grain fill, potential gaseous plant N losses were avoided, thus increasing NUE. At both locations, grain-only production systems had estimated NUE's less than 50 percent. With forage-only production systems, NUE's were much greater, exceeding 80% at Lahoma.

INTRODUCTION

Nitrogen use efficiency (NUE) is an important topic when discussing fertilizer applications and plant growth. Nitrogen use efficiency is defined as production per unit of N available in the soil. This is represented by the amount of grain or forage produced divided by the amount of N supplied to the plant by the soil. The two components of NUE are efficiency of uptake and efficiency of N utilization to produce grain or forage (Moll et al., 1982). Nitrogen use efficiency depends on the nitrification rate of the soil, the form of N applied and the growth stage of the plant. Farmers must apply N at the ideal time and use the fertilization method which will optimize efficiency. Environmentally, it is important to know how much fertilizer is used by the plant and how much is lost. Scientifically, it is important to understand the plant processes and storage methods for N and other nutrients.

In the south-central United States, producers often use winter wheat (*Triticum aestivum* L.) as a forage crop for cattle, as well as grain. Research indicates that forage production systems are more efficient users of N than grain production systems. Many research sources are available when discussing NUE in either forage or grain production systems, but there is little information comparing forage-only versus grain-only production systems for the same crop.

Nitrogen is essential for plant growth and is known to be present in proteins, nucleic acids and chlorophyll. Nitrogen is the nutrient most susceptible to loss and recovery of N is usually less than half of that applied (Boswell et al., 1985). Whitehead (1995) found that N concentration tends to decrease as plants age, mostly due to the increase in cell wall material and decrease in cytoplasm. Similar studies by Harper et al. (1987) noted decreased N concentrations in winter wheat with time during the growing season.

Nitrogen is assimilated by plant roots mostly as ammonium and nitrate. Adequate N nutrition is required for full development of tillers and leaves and also enables the plant to operate at peak photosynthetic capacity. Nitrogen use efficiency varies with the growth stage of the plant (Wuest and Cassman, 1992) Gaseous plant N loss has been found to be significant from flowering to physiological maturity (Harper et al., 1987). Recent work has found that the total N content of the grain and straw components is not equal to total N content of plants at flowering. Fertilizer use efficiency, as reflected in grain yield of winter wheat, has also been shown to change with time and rate of application (Ellen and Spiertz, 1980). Increased N rates have resulted in increased N concentrations in leaves of tall fescue and switchgrass (Staley et al., 1991). Grain yield and N content of cereal grain crops increase significantly with applied N (Simonis, 1987).

Much of the loss of N fertilizer efficiency is due to the loss of N to the atmosphere at senescence (Harper et al., 1987). At flowering, N is translocated to the grain and movement at this stage of development causes gaseous N losses to increase and efficiency to decrease (Harper et al., 1987).

Research has indicated that NUE decreases at grain fill in cereals, mostly due to gaseous N loss (Bruno et al., 1987). In the south-central United States, winter wheat is often produced for grain and forage. Little research exists that compares NUE of forage and grain production in a crop, like winter wheat, that can be used for both. The objective of this experiment is to document potential differences in NUE when winter wheat is grown strictly for forage or for grain.

MATERIALS AND METHODS

Experimental sites were selected as sub-plots in two existing long term winter wheat experiments near Stillwater (experiment 222) and Lahoma (experiment 502), Oklahoma where N rates have been applied annually since 1969 and 1970, respectively. Initial soil test characteristics and soil classification are reported in Table 1. Nitrogen rates at Stillwater were 0, 44, 90, and 134 kg N /ha. Nitrogen rates at Lahoma were 0, 22, 45, 67, 90, and 112 kg N /ha. Ammonium nitrate was the N source applied broadcast and incorporated preplant at both sites. In 1995-96 forage sub-plots (1.83 x 1.14 m) were hand harvested at Feekes growth stages six (mid-March) and ten (May) (Large, 1954). Grain yield sub-plots, adjacent to forage sub-plots, were harvested with a combine from a 2.0 x 1.83 m area. In 1996-97 sub-plot sizes were 1.33 x 2.13 m with the outside 2 rows and 25 cm removed from each end of the plot to negate border effects, giving an actual harvest area of 0.95 x 1.52 m. Forage harvests were taken by hand at Feekes growth stages 4, 7, and 10. Grain was harvested by combine from an area 2.0 x 1.83 m from a paired plot next to the forage area. Forage and grain samples were dried and ground to pass a 140 mesh sieve (100 um) and analyzed for total N content using a Carlo-Erba NA 1500 automated dry combustion analyzer (Schepers et al., 1989).

RESULTS

Analysis of variance and associated means for total forage yield and N uptake, and grain yield and grain N uptake are reported in Tables 2 and 3 for Stillwater and

Lahoma, respectively. A significant grain yield and grain N uptake response to N fertilization was found for the grain production system at both sites. Similarly, forage, and forage N uptake responded to applied N at both sites, for the forage-only production system. It was interesting to note that the dry matter production levels were nearly double for forage-only when compared to the grain production system at both sites. Although less pronounced, forage N uptake or removal was nearly double in the forage-only system when compared to grain-only at both locations (Tables 2 and 3).

As a result of increased dry matter production and N removal, N use efficiencies were much greater for the forage-only systems at both sites when compared to grain-only (Tables 4 and 5). Gaseous plant N losses are known to be greatest between flowering and maturity. The two forage harvests employed here (March and May) were both prior to flowering. Regrowth including secondary tillers, following the first March harvest did produce plants with heads by May, however, flowering was not achieved. Only limited growth was observed in the forage-only plots following the May harvest. By harvesting the plant for forage before grain fill, potential losses were avoided, thus increasing NUE. At both locations, grain-only production systems had estimated NUE's less than 50 percent. With forage-only production systems, NUE's were much greater, exceeding 80% at Lahoma.

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Table 1. Soil chemical characteristics and classification at Stillwater and Lahoma, OK.

Location	pH[a]	NH_4-N	NO_3-N	P[b]	K[b]	Total N[c]	Organic C[c]
		--------------mg kg^{-1}	---------------			------mg g^{-1}-----	
Stillwater	5.7	4.64	2.3	33	159	.09	1.06
Classification: Kirkland siltloam (fine-mixed, thermic Udertic Paleustoll)							
Lahoma	5.6	5.6	4.0	77	467	.09	1.1
Classification: Grant siltloam (fine-silty, mixed, thermic Udic Argiustoll)							

[a]pH: 1:1 soil:water, [b]P and K: Meilich III, [c]Organic C and total N: dry combustion

Table 2. Analysis of variance and means for total forage yield (sum of harvests in March and May) and N uptake, Stillwater, OK, 1996

		-----------Forage----------		-----------Grain-----------	
		Yield	N uptake	Yield	N uptake
Source of variation	df	--------------------------mean squares		--------------------------	
Replication	3	0.690	164	0.037	38
N rate	3	1.956*	1995*	0.329*	628*
Residual error	9	0.612	396	0.059	108
SED		0.553	14.0	0.171	7.3
N rate, kg ha^{-1}		Mg ha^{-1}	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}
0		2.719	49.58	1.007	28.95
44		2.841	59.01	1.274	35.61
90		3.553	83.12	1.382	48.49
134		4.228	98.52	1.701	56.79

* Significant at the 0.05 probability level.

Table 3. Analysis of variance and means for total forage yield (sum of harvests in March and May) and N uptake, Lahoma, OK, 1996

		------------Forage-----------		-----------Grain------------	
		Yield	N uptake	Yield	N uptake
Source of variation	df	--------------------------mean squares		--------------------------	
Replication	3	1.300	1394	0.912*	633*
N rate	5	3.197*	4844*	0.695*	1094*
Residual error	13	0.520	568	0.184	128
SED		0.509	16.8	0.303	8.0
N rate, kg ha^{-1}		Mg ha^{-1}	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}
0		2.89	57.98	1.40	33.22
22		3.61	75.90	2.17	52.65
45		3.49	87.32	2.18	57.87
67		4.29	113.32	2.19	62.09
90		5.24	149.90	2.55	74.37
112		4.91	133.93	2.53	80.07

Table 4. Analysis of variance for N use efficiency over system of production (grain only versus forage only) Lahoma, OK, 1996.

Source of Variation	df	Mean Squares
Replication	3	3383
N Rate	4	351
Rep x N Rate	12	1286
System	1	21484**
N Rate x System	4	461
Residual Error	15	194

N Rate	Forage	Grain
22	80	44
45	95	36
67	80	31
90	102	37
112	68	34
SED	9.8	

Table 5. Analysis of variance for N use efficiency over system of production (grain only versus forage only) Stillwater, OK, 1996.

Source of Variation	df	Mean Squares
Replication	3	192
N Rate	2	332
Rep x N Rate	6	369
System	1	938*
N Rate x System	2	59
Residual Error	9	192

N Rate	Forage	Grain
45	21	15
90	37	22
134	36	21
SED	9.7	