Evaluation of Nitrogen Uptake Patterns in Spring and Winter Wheat in Western Oregon

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Summary: An understanding of the ground nitrogen (N) uptake pattern for wheat (*Triticum aestivum* L.) is essential to facilitate nitrogen management. The purpose of this study was to determine the nitrogen uptake pattern of spring and winter wheat grown in western Oregon, USA. Data used in this study were obtained from three different trials. For spring wheat rotation trials five spring wheat cultivars were used. Fertilizer N (16-16-16-4) at the rate of 140 kg ha^{-1} was applied at the time of planting. In small plot rotation trials five fertilizer treatments - 0, 50, 100,150 and 200 kg N ha^{-1} - were used. Rotations include winter wheat following clover and winter wheat following oat. The N uptake and dry matter yield of winter wheat were also determined from unfertilized plots of wheat trial. The maximum N uptake for spring wheat and winter wheat were at 1100 and 2000 accumulated growing degree days (GDD), before Feekes 10, respectively. The maximum N uptake rate for spring wheat, 0.038 kg N GDD^{-1}, occurred at 750 GDD and the peak N uptake was observed approximately 35 days after Feekes 2. Nitrogen uptake in winter wheat was significantly affected by rotations.

Introduction

Evaluation of crop nitrogen-uptake pattern in a particular environment is critical for high N fertilizer use efficiency. Maximum efficiency should be expected when plant N availability synchronizes with the stage of crop development that permits rapid N uptake [1, 2]. Nitrogen uptake by plants depends on several factors including nitrogen use efficiency of the plant (yield per unit of N supply), N application rate and timing, availability of N in the soil solution at the root surface, the state and morphology of roots, temperature and other climate-related factors [3, 4].

Nitrogen efficiency illustrates the ability of a plant to take up supplied N however, utilization efficiency shows the capability of plant to utilize N by increasing yield. Muurinena *et al.,* [5] compared nitrogen harvest index (NHI) and nitrogen remobilization efficiency (NRE) among wheat barley and oat and found higher proportion of the assimilated N in the developing grain compare to barley and oat. Hashem *et al.*, [6] studied competition effects on yield, tissue nitrogen, and germination of winter wheat and found that the efficiency of producing biomass per unit of N taken in Italian ryegrass was two times higher than winter wheat.

Nitrogen uptake increases with application of fertilizer N due to increase in biomass [7]. In wheat, nitrogen content per plant is positively correlated with total dry matter [8]. Time of fertilizer N application greatly affects the N uptake efficiency in wheat production systems. In high precipitation regions, spring applied N is superior to fall-applied N [9]. Under dry-land conditions, Johnston and Fowler [10] observed that delaying spring N fertilization prevented early N uptake and growth of winter wheat. Type of fertilizer N also influences the N uptake and total dry matter yield of a wheat crop. Zhanga [11] reported that the total biomass of winter wheat was greater in NH^{4+}-N fertilizer treatments than NO_3–N. One of the primary factors affecting N uptake is the root morphology. Luxova [12] argued that even though the entire root system is involved in uptake, the majority of uptake occurs in the apical zones or axes of branches in young roots.

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Nitrogen uptake closely follows the growth pattern and at a certain developmental stage, N uptake ceases and remobilization of N within the plant starts. Melaj *et al.*, [13] investigated the timing of nitrogen fertilization in wheat and reported that at the ear emergence stage the N accumulation in fertilized plants nearly stopped. Bauer *et al.*, [14] measured N uptake in hard red wheat aerial parts from three-leaf to kernel-stage and found that peak of N uptake in leaves occurred during flag-leaf-extension through the boot stage. Baethgen and Alley [15] observed that the total amount of N found in leaves and stems decreased with time during the spring, while the spike N increased from the earliest stages of development until maturity.

Among environmental factors, temperature is the most important element that affects N uptake in plants by regulating their growth. Many researchers have reported a close relationship between accumulated heat unit (growing degree days) and phenological development in cereals [16]. Because of its precision as in estimator of growth rate, growing degree days (GDD) has been incorporated into N fertilizer management practices and crop development models. Bauer *et al.*, [17] investigated the utility of GDD to estimate spring wheat growth rate and stages and reported that precision of estimating growth rate and stages by GDD was superior to calendar days.

The objective of this study was to determine the N uptake pattern of spring and winter wheat grown in western Oregon.

Results and Discussion

Spring Wheat

Significant interaction between biomass accumulation and sampling date were found ($p < 0.002$) which indicates that the pattern of biomass accumulation of five cultivars varied with date of sampling. The mean values for biomass accumulation, sampling dates and their corresponding accumulated GDD are shown in Table-1 Biomass accumulation followed a sigmoidal response for spring wheat. Maximum biomass yield for all five cultivars was observed at approximately 1432 GDD or Feekes 10.5 (Fig. 1). Biomass accumulation leveled off beyond 1432 GDD. Each of five cultivars accumulated approximately the similar amount of dry matter until 1125 GDD or Feekes 10. A difference in biomass yield among cultivars was observed at 1432 and 1784 GDD, Feekes 10.5 and Feekes 11, respectively (Fig. 1). At 1432 GDD, the difference for biomass yield between Pennawawa and Alpowa was highest among all five cultivars i.e. 2595 kg ha^{-1} (Table-1).

Table-1: Sampling dates and corresponding Feekes growth stages and accumulated growing degree days for spring and winter wheat experimental sites.

Experiment	Sampling Date	Feekes Stage	GDD*
Spring Wheat	April 25	F 2	218
1997	May 13	F 3	466
	May 31	F 6	764
	June 22	F 10	1126
	July 11	F 10.5	1432
	August 1	F 11	1784
Winter Wheat			
1996	March 4	F 4	961
	May 5	F 8	1455
	July 25	F 11	2763
1997			
	February 22	F 4	999
	May 2	F 9	1614
	July 25	F 11	3020

*GDD = Growing Degree Days

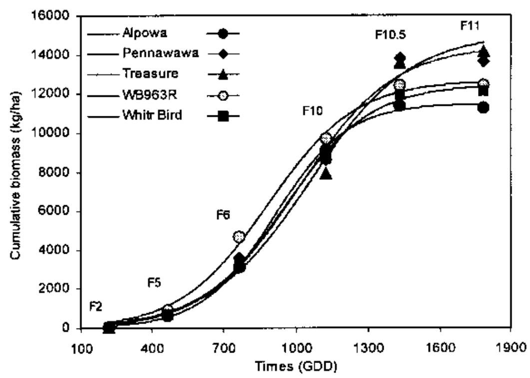

Fig. 1: Comparison of five spring wheat cultivars for biomass accumulation in 1997 growing season.

The interaction effects of cultivar and sampling date for N uptake were not significant ($p > 0.2$) indicating that the pattern of N uptake for all cultivars was same and the magnitude of N uptake of all cultivars was independent of sampling date. Significant differences among cultivars were observed for N uptake ($p < 0.001$). The mean values of N uptake biomass yield and their corresponding GDD with regard to the feeks stages for each cultivar are given in Table-2. The pattern of N uptake and biomass accumulation was described by a sigmoidal equation

Table-2: Accumulative biomass yield and nitrogen uptake of five spring wheat cultivars for 1997 growing season.

Variety	Sampling Time (Growing Degree Days)													
	218		467		763		1125		1433		1784			
	F 2		F 3		F 6		F 10		F 10.5		F 11			
	kg ha^{-1}												Total	Total
	Biomass	N uptake	Biomass	N uptake	Biomass	N uptake	Biomass	N uptake	Biomass	N uptake	Biomass	N uptake	Biomass	N uptake
Alpowa	52	2.5	566	22.5	2512	51	5996	39	2253	-2	-115	4	11264	117
Pennawawa	66	3.2	602	26.8	2905	63	5015	59	5209	3	62	0	13859	155
Treasure	68	3.2	722	24.8	2507	51	4638	67	5625	5	607	1	14167	152
WB963R	80	3.9	829	31.1	3744	70	5076	29	2698	-5	6	5	12433	134
White Bird	58	2.7	639	24.3	2532	46	5453	46	3257	10	183	-1	12122	128

[1]. The coefficient of determination (R^2) for the model ranged from 0.93 to 0.96 indicating a highly significant fit of the model.

The N uptake of all cultivars was rapid at early growth stage of the crop until the crop accumulated 1000 GDD. After accumulation of 1000 GDD, N uptake became slow and virtually there was no N uptake from 1120 to 1784 accumulated GDD, Feekes 10 to Feekes 11, respectively, for all cultivars (Fig. 2). Rapid N uptake at early growth stages was associated with increase in biomass since it is well known that in wheat N uptake and dry matter accumulation is positively correlated [18]. Maximum N uptake for all cultivars except WB963R was observed at approximately 1100 GDD, before Feekes 10. For WB963R, maximum N uptake was obtained at approximately 900 GDD (Fig. 2). Similar results were reported by Bauer *et al.*, [17] when spring wheat peak N uptake occurred during flag-leaf extension (Feekes 10) to boot stage (Feekes 10.1). At Feekes 10, greatest N uptake was observed for Pennawawa and Treasure, 152 and 146 kg N ha^{-1}, respectively. The lowest plant N uptake at Feekes 10 was observed for Aplowa and White Bird, 115 and 119 kg N ha^{-1}, respectively (Table-2). Overall, Penn wawa had the highest and Alpowa had the lowest N uptake throughout the growing season.

Average N uptake (kg/ha/GDD) of all five cultivars is shown in Fig. 3. Plant N uptake was very high from 218 GDD (first sampling date) to 750 GDD. The maximum N uptake rate, 0.038 kg N GDD^{-1}, occurred at 750 GDD (Fig. 3). After accumulating 750 GDD, the rate of plant N uptake declined and the crop almost stopped taking N at 1100 GDD. The window of N uptake on a calendar day basis was about 50 days, starting April 25 and ending June 15. However, the peak N uptake was observed at May 30, approximately 35 days after Feekes 2.

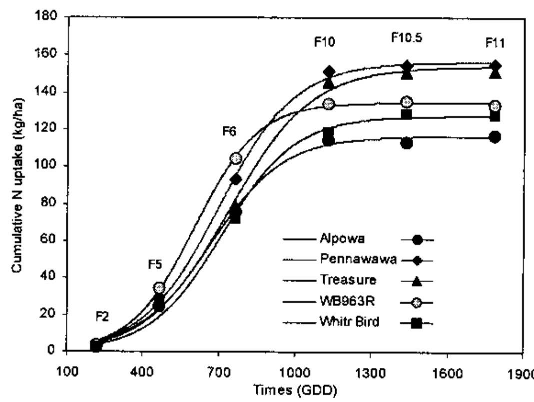

Fig. 2: Comparison of five spring wheat cultivars for nitrogen uptake in 1997 growing season.

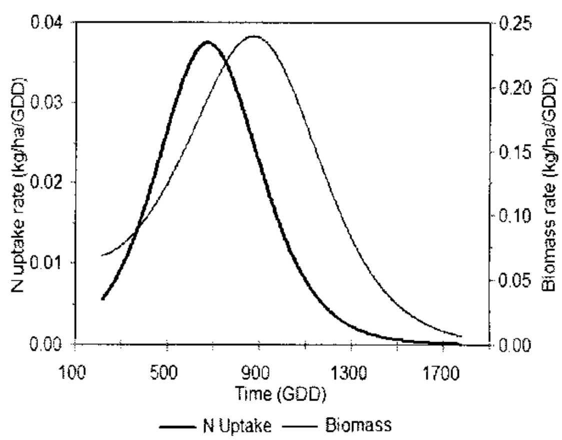

Fig. 3: Average nitrogen uptake and biomass accumulation rates of spring wheat in 1997 growing season.

Winter Wheat

A similar pattern for N uptake in winter wheat was observed for both 1996 and 1997 growing years.

Nitrogen uptake was significantly affected by rotations. Wheat following clover had greater N uptake at all sampling dates for 56 and 112 kg ha^{-1} N, over two years period as compared to wheat following oat (Figs. 4a-4b). Nitrogen uptake of wheat following clover receiving 100 kg ha^{-1} was very rapid at early growth stages compared to wheat following oat (Fig. 4). In wheat following clover, maximum N uptake, 140 kg N ha^{-1}, was observed at approximately 1400 GDD, prior to Feekes 9 growth stage during 1996. There was no N uptake after 1350 GDD until maturity. In wheat following oat, the crop continued N uptake after Feekes 9 growth stage in both years. In 1996, maximum N uptake, 105 kg N ha^{-1}, was observed at approximately 1750 accumulated GDD, while in the 1997 growing season, the peak N uptake of 100 kg N ha^{-1} for wheat following oats was at 2180 GDD (Fig 4).

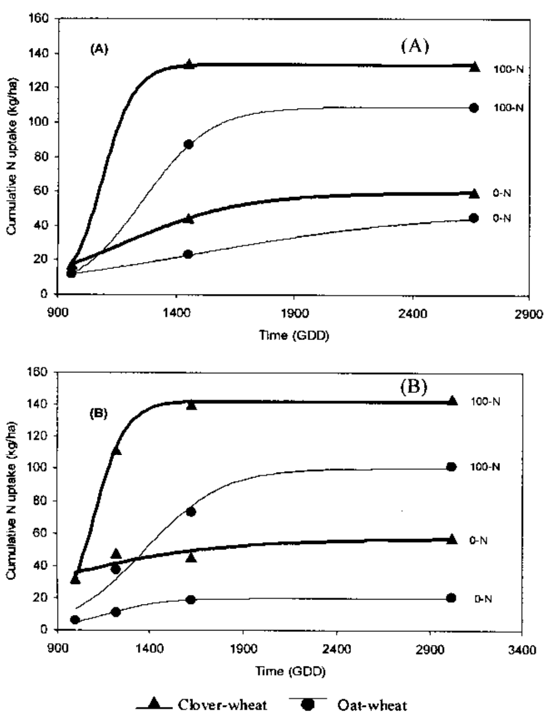

Fig. 4: Nitrogen uptake rate in winter wheat receiving as influenced by different rotations and fertilizer N rates (A) 1996 and (B) 1997 at Hyslop Farm.

The first order derivative sigmoidal curve describing N uptake rate clearly shows the significant differences for rate and time of maximum uptake between rotations where 100 kg ha^{-1} N fertilizer was applied (Fig. 5). The wheat following clover had significantly higher N uptake rates in both growing years compared to wheat following oat. The maximum N uptake rate of both rotations dropped in the1997 growing year because of the high average rain in that year. As shown in (Fig 5), in wheat following clover, maximum rates of N uptake of 0.5 and 0.4 kg N GDD^{-1} were observed in 1996 and 1997 growing seasons, respectively, at approximately 1100 GDD. After accumulation of 1100 GDD, the rate of plant N uptake declined sharply and crop almost stopped taking N at 1400 accumulated GDD. The maximum rate of N uptake of 0.2 and 0.1 kg N GDD^{-1} for wheat following oats was observed in 1996 and 1997 growing seasons, respectively, at approximately 1300 GDD. The rate of N uptake decreased after accumulated 1300 GDD and ceased at 2000 accumulated GDD. It is also obvious from Fig. 4 that both rotations attained maximum uptake rate at about the same accumulated GDD in both growing years.

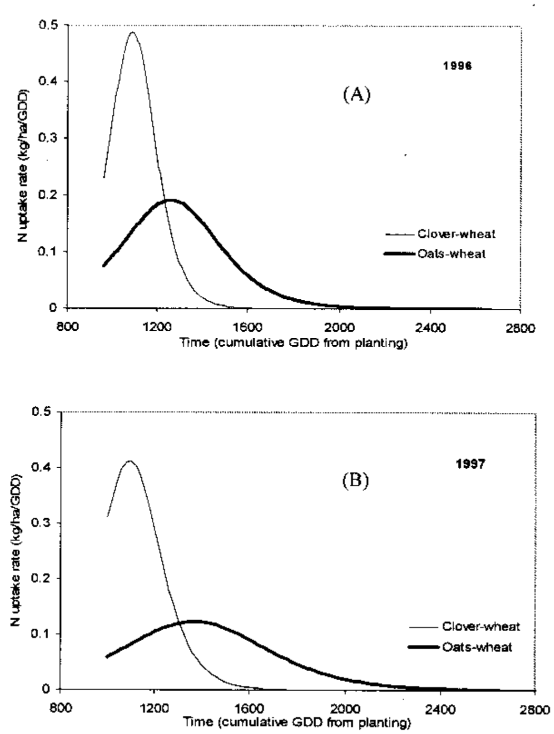

Fig. 5: Nitrogen uptake rate in winter wheat receiving 100 kg N Ha^{-1} as influenced by different rotations in (A) 1996 (B) 1997 at Hyslop Farm.

Table-3: Biomass yield, nitrogen uptake, and carbon to nitrogen ration of winter wheat of small plot research experiment for 1996 and 1997 growing seasons.

Fertilizer N kg ha^{-1}	Previous crop											
	Oat-wheat						Clover-wheat					
	Biomass		N uptake		C:N ratio		Biomass		N uptake		C:N ratio	
	1996	1997	1996	1997	1996	1997	1996	1997	1996	1997	1996	1997
	---- kg ha^{-1} ----						---- kg ha^{-1} ----					
0	5660	2965	44	20	171	181	7140	9420	59	57	175	274
50	9292	10047	64	54	201	336	15951	16726	120	94	194	282
100	15836	17245	109	101	209	284	15979	20814	133	143	160	189
150	16734	18620	131	140	152	262	17603	21776	135	168	165	153
200	19741	19525	156	174	125	139	21976	21479	215	225	103	104
PLSD (0.05)	4506	3151	38.4	25.5	24.4	64	4506	3151	38.4	25.5	24.4	64
CV (%)	21	13	22	14	10	19	21	13	22	14	10	19

The effect of added fertilizer N, 0, 50, 100, 150 and 200 kg N ha^{-1} on N uptake and biomass yield of winter wheat was also examined in this study. The mean values of each variable are given in Table-3. The N uptake by winter wheat was significantly influenced by rotations and added fertilizer ($p < 0.01$). In 1996, the interaction effects of rotation and N fertilizer treatments for N uptake were not significant ($p > 0.2$); however in 1997, significant interaction was observed between rotation and N fertilizer treatments. In 1997, the influence of previous crop on N uptake was greater relative to 1996 especially for wheat following clover where N uptake increased in 1997 compare to wheat following oats. This indicates that N was more readily available following clover over time. Nitrogen uptake was significantly higher following clover than following oats at each level of applied N fertilizer. Overall, in both rotations, N uptake increased almost linearly with added fertilizer N.

No significant interaction between rotation and fertilizer N treatments was found for biomass yield. In 1996, the rotation effect was not significant, but in 1997 the difference between the two rotations for biomass yield was significant ($p < 0.04$) perhaps indicating that with time the difference between the two rotation is becoming more obvious. A significant increase in biomass yield was observed at the first increment of N fertilizer for both rotations over years (Table 3). In 1996, increasing N fertilizer from 100 to 150 kg N ha^{-1} did not increase the biomass yield in either rotation. In 1997, biomass yield of wheat following clover was significantly higher than wheat following oats. In wheat following clover, increasing N fertilizer from 100 to 200 kg ha^{-1} did not significantly increased biomass yield (Table 3). The biomass 1997 yield of wheat following clover with no fertilizer N was 6500 kg ha^{-1} higher than the biomass yield of wheat following oats.

Nitrogen uptake and biomass yielded in the 1996 unfertilized Stephens plots showed the same pattern as it was observed in the Hypslop farm rotation experiment (data not shown). At early growth stages, Feekes 3 to Feekes 5, N uptake was rapid. Maximum N uptake was achieved at Feekes 8 (May 8). There was no N uptake from Feekes 8 to maturity. Biomass yield increased linearly from Feekes 3 to Feekes 8. Highest increase in biomass yield was observed at Feekes 8 to Feekes 10.1. Maximum biomass yield was obtained at Feekes 10.1 and beyond that biomass accumulation leveled off.

Experimental

Data were obtained from three different trials. Information about each trial follows: Sampling dates, Feekes growth stage, and accumulated growing degree days (GDD) and all of these trials are shown in Table-1.

Spring Wheat Rotation Experiment

Nitrogen uptake and dry matter production in spring wheat were measured in an on-going rotation study in 1997. The experiment was conducted at the USDA-ARS Sustainable Grass Seed Production Research Project Coon Farm site located in Linn county, Oregon. The five spring wheat cultivars used in this study were: Alpowa (soft white; SW), Pennawawa (SW), Treasure (SW), WB936R (hard red; HR), and Whitebird (SW). The experimental design used was a randomized complete block with four replications. Two 10-rows wide strips of each cultivar were planted in each of four replicated blocks. Fertilizer N (16-16-16-4) at the rate of 140 kg ha^{-1} was shanked into the soil at the time of planting in 1996. An additional 194 kg ha^{-1} of fertilizer (46-0-0-0) was broadcast on Aril 27, 1997. Aboveground plant samples were taken randomly selected 1 m of row approximately every 250 growing degree days starting from Feekes GS 1 and continuing until maturity. Total N content was determined by combustion analysis. Nitrogen uptake in kg N ha^{-1} was calculated as product of total N content (%) in plant tissue times the biomass in kg ha^{-1} divided by 100.

Small Plot Research Station Trials for Winter Wheat

Nitrogen uptake and biomass data for winter wheat were obtained from fertility trials established during the 1993-94 growing season at the Hyslop Experimental Farm of the Department of Crop and Soil Science, Oregon State University, Corvallis, Oregon. The experiment was arranged as a split plot design with four replications having rotation as main plot and fertilizer treatments as sub-plots. Rotation strip size is 12 m × 45m, while sub plot fertilizer treatment size is 12 m × 9m. Five fertilizer treatments - 0, 50, 100,150 and 200 kg N ha^{-1} - are used. Rotations include winter wheat following clover and winter wheat following oat. Plant tissue samples were collected at three different growth stages in 1996 and 1997 and used for dry matter yield and nitrogen uptake determination. Data used in this study were obtained from two N rate treatments; 0 and 100 kg N ha^{-1}. Plant samples were collected at Feekes 5 (spring fertilization), at Feekes 9 (flag leaf), and at Feekes 11 (maturity). At Feekes 5 and Feekes 9, plant samples were taken from one m of row. At maturity, four plant samples of 1.5 meter of row were cut from drill strips in each plot. Heads were cut, threshed and weighed. Grain and straw were analyzed separately for their nitrogen content by combustion analysis. Plant N uptake (kg N ha^{-1}) was calculated by multiplying the N concentration in the tissue by dry matter production (kg DM ha^{-1}).

N Uptake from Unfertilized Plot

In 1996, N uptake and dry matter yield of winter wheat were determined from unfertilized plots of Stephens wheat in a trial at Hyslop Experimental Farm of the Department of Crop and Soil Science, Oregon State University, Corvallis, Oregon. Three 30 cm rows of above-ground plant tissue were randomly cut at approximately 15 days intervals starting a Feekes 5 and continuing until maturity. All three plant samples were mixed and total N content was determined by combustion analysis. Nitrogen uptake (kg ha^{-1}) was calculated as product of total N content (%) in plant tissue times the biomass kg ha^{-1} divided by 100.

Statistical Analysis

In the spring wheat trial, sampling date was treated as main plot and cultivars as subplots. In the Hyslop Farm rotation trial, treatment variables included rotation as main plot and fertilizer N treatments as subplot. No statistical analysis was used for the unfertilized wheat trial.

A logistic model was used to describe biomass accumulation and N uptake as a function of time. The model used for fitting the plant growth and nitrogen uptake is given in eq. 1. The parameters of the model describing dry matter accumulation and accumulative N uptake were estimated by using Statgraphic DOS ver. 2.0.

$$N_t = \frac{K}{1 + \left[\frac{(K - N_0)}{N_0}\right] \exp - rt} \quad (1)$$

where:

N_t = Biomass accumulation or N uptake at time t
K = Maximum Biomass accumulation or N uptake
N_0 = Initial or minimum biomass accumulation or N uptake
r = Rate of increase (slope factor) in biomass accumulation or N uptake
t = Time (growing degree days)
exp = Base of natural log, 2.71828

The first derivative of equation [1] was taken to determine a rate function dN/dt eq. 2. The time of maximum biomass accumulation and maximum N uptake were estimated by plotting dN/dt.

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right) \quad (3)$$

Growing degree days were calculated from daily maximum and minimum temperatures by eq. 3:

$$GDD = [(T_{max} + T_{min})/2] - T_b \quad (3)$$

where,

T_{max} = Daily maximum temperature (°C)
T_{min} = Daily maximum temperature (°C)
T_b = Based temperature with 0 °C

Conclusion

$\frac{dN}{dt}$ = The amount of N taken up by spring wheat was among cultivars; however, the pattern of plant

N uptake was same for all five spring cultivars. Maximum N uptake for all five cultivars was observed at approximately 1100 accumulated growing GDD, before Feekes 10.

The maximum N uptake rate, 0.038 kg N GDD^{-1}, occurred at 750 GDD. On calendar day bases, the range of N uptake was about 50 days, starting from April 25 and ending at June 15. The peak N uptake was observed at May 30, around 35 days after Feekes 2.

Nitrogen uptake in winter wheat was significantly affected by rotations. Wheat following clover had greater N uptake at all sampling dates for both levels of N over two years as compare to wheat following oat. Significant differences for rate and time of maximum uptake between rotations were also observed. The maximum rate of N uptake for wheat following clover was observed at about 1300 accumulated GDD, while the maximum rate of N uptake for wheat following oats was at 2000 GDD.

References

1. K. M. Camara, W. A. Payneb, and P. E. Rasmussenc, *Agronomy Journal,* **95**, 828 (2003).
2. R. A. Olson, and L. T. Kurtz, *Agron. Monogr.* **22**. ASA, CSSA, and SSSA, Madison, WI. (1982)
3. J. L. Rafael, L. López-Bellidob, B, Jorge, and J. L. Francisco, *Agronomy Journal,* **99**, 59 (2007)
4. A. Tala, U. Yermiyahub, J. Berauda, and M. Keinana, *Journal of Environmental Quality*, **33**, 1855 (2004).
5. S. Muurinena, J. Kleemolab, and P. Peltonen-Sainioa, *Agronomy Journal,* **99**, 441 (2007)
6. A. Hashem, S. Radosevich, and R. Dick, *Weed Technology*, 0890-037X. **14**, 718 (2000)
7. K. D. Subedi, B. L. Ma, and A. G. Xue, *Crop Science*, **47**, 36 (2007)
8. S. R. Takahashia, B. Muhuddin, and G. Sharon, *Agronomy Journal,* **99**, 1151 (2007)
9. E. C. Doll, *Agronomy Journal,* **54,** 471 (1962).
10. A. M. Johnston, and D. B. Fowler, *Agronomy Journal*, **83**, 722 (1991).
11. F. Zhanga, S. Kanga, A.Renduo, and L. Fusheng, *Soil Science Society of America Journal,* **68**, 1890 (2004).
12. M. Luxova, *Plant and Soil*, **111**, 187 (1988).
13. A. M. Melaj, H. E. Echeverríab, S. C. Lópeza, and N. O. Bárbaroa, *Agronomy Journal,* **9**, 1525 (2003)
14. A. Bauer, A. B. Frank, and A. L. Black, *Agronomy Journal,* **79**, 852 (1987).
15. W. E. Baethgen, and M. M. Alley, *Agronomy Journal,* **81**, 116 (1989).
16. D.R. Buxton, and G. C. Marten, *Crop Science,* **29**, 429 (1989).
17. A. Bauer, A. B. Frank, and A. L. Black, *Agronomy Journal,* **76**, 829 (1984).
18. R. B. Austin, M. A. Ford, J. A. Edrich, and R.D. Blackwell, *Journal of Agricultural Sciences,* **88**, 159 (1977).