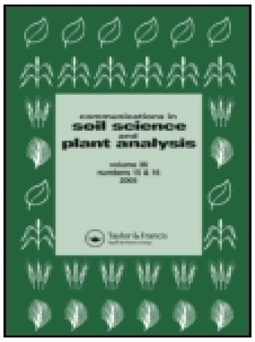

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N Response of No-Till Dryland Winter Triticale Forage

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ABSTRACT
Triticale's forage-yield response to fertilizer nitrogen (N) is impressive on soils testing low in available N. Our objectives were to (1) quantify the forage-yield response of dryland winter triticale to applied N and residual nitrate N and (2) fit the yield data to a regression equation based on both applied N and residual soil nitrates and use the fitted equation to calculate economic optimum N rates for this crop (EONR). Winter triticale was direct seeded no-till into wheat or millet stubble for four site years at the United States Department of Agriculture, Agricultural Research Service (USDA-ARS) Central Great Plains Research Station. In each experiment (1995, 2007, 2009 and 2010) just prior to planting, the soil was sampled for nitrate-N. Replicated field plots were top-dressed with 0, 22, 34, 67, 90, 101 or 135 kg of N fertilizer per ha as urea-N. Yield and total biomass N was then measured in each plot in late spring each year. A relative yield N response equation, fitted to all four years of data, was able to explain 93% of the variability in yield. That equation provided reasonable EONR estimates that matched 87% of the EONRs calculated for individual years.

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Nitrogen; no-till; triticale

Introduction

Triticale (x Triticosecale) production worldwide is estimated at approximately 14 million Mg on 3.9 million ha (Food and Agricultural Organization (FAO) Statistical Yearbook 2007–2008; Mergoum and Gomez-Macpherson 2004). In the USA, nearly 90% of the triticale produced is grown for forage. Dryland producers in the Central Great Plains region (CGPR) primarily grow winter triticale for hay. Winter triticale is well adapted and its forage is palatable and nutritionally competitive with other annual forages grown in the CGPR. Like most cool season grasses triticale on a nitrogen (N) deficient soil responds well to added N fertilizer (Shroyer et al. 1996).

Fertilizer N costs have increased 64% in the last 8 years (United States Department of Agriculture, Economic Research Service (USDA-ERS) July 2013). This fertilizer cost increase coincides with a decrease in crop yields due to drought (Colorado Agricultural statistics 2002–2009). The interplay between expected crop yield and the economic optimal N rate (EONR) is obvious. That leads to the typical producer question "is the optimal N fertilizer rate less in dry years with low yields" and if so how much less? This is further complicated by fluctuations in hay price. Recently because of low yields due to drought, hay prices have been exceptionally good in the past 3 years in CGPR. The increase in hay price of hay then affects how much a farmer can afford additional N and therefore changes the EONR. From a producer's point of view the price of N fertilizer, the value of the hay and the response of the crop to available N all become important in making fertilizer N management decisions for triticale production.

The typical methods used to calculate fertilizer N rate for forage and cereal grains can be found extensively in the literature (Black and Bauer 1988; Dahnke et al. 1988; Hernandez and Mulla 2008;

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Mullen et al. 2003). Most calculations for making N fertilizer recommendations begin with a yield goal (YG) or an assessment of available residual inorganic N (Chang et al. 2004; Kefyalew et al. 2007; Johnson and Raun 2003) A fertilizer N requirement is then calculated to achieve that YG. The logic is that a given unit of yield (in this case Mg of hay) has an associated amount of N "a unit of N" required to achieve the yield in the YG. If soil testing is available, a soil analysis can be incorporated to evaluate residual soil N available at the time of sampling (usually nitrate (NO_3)-N). The soil test might include soil organic matter (SOM) measurement to estimate what will be made available through N mineralization of SOM (N_{min}; Vigil et al. 2002). A fertilizer amount is then recommended to make up for the shortfall of inorganic N and the estimate from N_{min} to match the calculated N requirement (Cabrera, Vigil, and Kissel 1994). Another (although empirical and soil/site specific) approach is to fit N response functions using multiple linear regression to yield data collected from field experiments that have variable N rates applied to a typical soil in the region (Franzen et al. 2010). The response functions are fit either to a calculation of relative yield or to actual yield using a quadratic equation or similar curvilinear model. The fitted grain yield/N rate equation is then used to calculate EONR for that set of data and the fit is specific to the soil, climate and yield range included in the regression fit. Because yield levels are lower in the CGPR then other areas of the country, most of the fertilizer needed can be put on either at planting time or just prior to planting. Farmers in the CGPR currently don't have a simple method of estimating reasonable N rate for triticale hay production. Our objectives are (1) to document dryland winter triticale-hay yield response to applied fertilizer and residual inorganic N collected from four N rate experiments, and (2) use those data to calculate economic optimal N rates (EONR) with changing triticale-hay price and fertilizer N costs both as function of applied N rate and as a function of residual N rate plus applied N rate.

Materials and methods

These experiments were conducted at the USDA-ARS Central Great Plains Research Station located 6.4 km east of Akron, Colorado (40°09′ N, 103°09′ W). The elevation at the site is 1380 m above sea level and the long term (105 year) average annual precipitation is 418 mm. Field operations, precipitation and temperature during the years of the study are summarized in Table 1. The experiments were established on a Weld silt loam soil (fine, smectitic, mesic Aridic, Paleustolls). The soils in a 0–15 cm surface sample ranged in organic matter between 0.9 and 1.2%, and soil pH's ranged from 6.0 to 7.2. Phosphorous levels ranged from marginal to high according to Colorado State University soil test lab results (Brummer and Davis 2014) and no other nutrients or

Table 1. Planting dates, harvest dates, precipitation and temperature during the growing season and expected precipitation based on 105-year weather recorded at the location for N rate triticale experiments.

			Growing season		Preplant	Year 2	Crop in
			Temperature	Precipitation †	Precip ‡	Precip §	Year 1
Crop Year	Planting dates	Harvest dates	°C		mm		
1994–95	9/14/1994	6/6/1995	6.4	439 (231)	99 (35)	526	Wheat
2006–07	9/15/2006	5/25/2007	6.3	224 (198)	155 (54)	355	Wheat
2008–09	10/10/2008	6/30/2009	7.2	311 (255)	35 (12)	494	Proso millet
2009–10	9/15/2009	5/30/2010	6.5	235 (217)	471 (165)	294	Fallow*

† Growing season precipitation is the precipitation received from planting in the fall to harvest the following spring. The values in parenthesis are the expected amounts of precipitation for the growing season based on long term (105 year) precipitation records at the location.

‡ Preplant Precip. is the total precipitation received from approximate physiological maturity of the previous crop to the planting of the triticale in the fall. The values in parenthesis are the expected contributions to soil water storage based on an estimate of 35% for precipitation storage efficiency of soil water stored during the period of non-crop fallow.

§ Year 2 Precip. is the precipitation received the year the crop was harvested. The 105 year average total annual precipitation amount is 418 mm.

* The crop in 2009–2010 was planted into millet stubble that had been summer fallowed for 12.5 months.

micronutrients were found to be yield limiting. The experimental design was a randomized complete block with 4 replications and treatments were a stepwise incremental increase in N rate (0, 34, 67, 101, 135 of applied N per ha). Prior to seeding and fertilization in the fall of 2006, 2008 and 2009, the soil in each replication or block (8 cores at random in each block) were sampled each year to measure residual inorganic N to a depth of 1.2 m. Soil was separated by depth for inorganic N analysis at the 0–15 cm, 15–30, 30–60, 60–90 and 90–120 cm depths. In preliminary work, the best correlations between N response and inorganic N was found by using nitrate N in the top 60 cm whereas nitrate and ammoniacal N found at deeper depths was only poorly correlated to N response. Therefore, data from depths below 60 cm are not used in this analysis. Soil was collected using a 1.5 cm diameter Giddings hydraulic probe (Giddings Machine Co., Windsor Colorado). Eight cores per Block/replication were collected and composited by depth mentioned earlier. Soil was extracted in an 8:1 ratio (extracting solution to soil ratio) with 2 molar potassium Chloride (2 M KCl) and then analyzed on a LACHAT auto-analyzer for nitrate-N (NO_3-N) and ammonium-N (NH_4-N; LACHAT instruments Milwaukee, WI) (Table 2). Individual plots (experimental units) 9.1 m wide and 12.1 m long were fertilized just prior to seeding in 2006, 2007 and 2009. Fertilizer was applied in a preplant broadcast application as dry urea (46-0-0).

In the earlier (1994–1995) experiment, similar methods and plot sizes were used with plots fertilized at 0, 22, 44, 67, 90 and 135 kg of fertilizer N per ha as dry urea (46–0–0). The 1994–1995 experiment was part of a long term fertility experiment and so the measured residual inorganic N in the 1994–1995 experiment increases with each increasing N rate (Tables 2 and 3). This was the result of previous fertilization on prior crops at the same N rates used in 1994–1995. In the other years (2006–2007, 2008–2009, and 2009–2010) preplant inorganic was fairly uniform across N rates.

Following fertilization in 1994, 2006 and 2008, the winter triticale cultivar NE422T was direct seeded (in the fall of each year) into standing wheat stubble at a seeding rate of approximately 67 kg ha^{-1} each year (Table 1). Seeding was accomplished each year with a no-till double disc drill, with seed placed at a depth of approximately 5–6 cm in rows spaced 20 cm apart. In 2009, the same cultivar was direct seeded into standing millet stubble. It is important to point out that the crops harvested in summer of 1995 and in 2007 were planted in the fall of 1994 and in the fall of 2006. The fall planting was 8–10 weeks after harvesting wheat the first summer in July of 1994 and 2006. The 2009 crop was planted only 4 weeks after harvesting millet in September of 2008, whereas the 2010 crop was planted after 12.5 months of summer fallow. These differences in planting conditions each year will affect beginning soil water contents and should affect final yield and N response. At seeding, 16.8 of P (kg ha^{-1}) as mono-ammonium Phosphate (11-52-0) was applied with the seed at planting.

In all four site–years forage yield was harvested just as the awns were beginning to emerge from the boot by collecting a 1.1 m swath down through the center of each 12.1-m long plot (Table 1). The fresh weight of the collected forage was measured and a subsample (weighing between 700 g and 1000 g) was collected for measuring forage-moisture, dry weight, and tissue N. Dry weight was determined by taking a fresh weight on the subsamples and then drying the samples at 60°C for a week in a forced air oven and then reweighing the dried samples. After recording dry weights the forage samples were ground, mixed and a subsample was weighed for total carbon (C) and N analysis on a LECO C & N combustion analyzer (LECO CHN-2000, Leco Corp., St Joseph MI). Forage yield on a dry mass basis

Table 2. Average residual NO_3-N in the top 60 cm of the soil profile prior to planting and fertilization each year of the study.

Soil Depth	Year 1995	2007	2009	2010
cm	Kg ha^{-1} soil			
0–15	13.8 (4.15) †	37.3 (12.25)	3.6 (0.43)	17.7 (4.40)
15–30	3.2 (0.42)	10.1 (11.15)	2.4 (0.47)	20.2 (5.09)
30–60	8.0 (2.11)	10.8 (1.59)	3.6 (0.83)	31.8 (8.38)
Total top 60 cm	25.0 (6.19)	58.2 (18.2)	9.7 (1.71)	69.7 (16.91)

†Values in parenthesis are the standard errors of the mean of 4 replications.

Table 3. Forage yield, tissue N, N uptake and preplant nitrate-N (top 60 cm of soil) the years the study was conducted.

1995					2007				
N rate	Preplant NO_3–N	Forage yield†	N uptake	Tissue N	N rate	Preplant NO_3–N	Forage yield	N uptake	Tissue N
Kg ha^{-1}				%		Kg ha^{-1}			%
0	14.7	4431	38.6	0.871	0	58.2	5188	64.8	1.198
22	13.0	5595	42.2	0.755	34	58.2	5420	68.0	1.242
45	25.1	10849	83.9	0.773	67	58.2	6662	84.9	1.268
67	38.6	11943	122.2	1.023	101	58.2	6976	105.9	1.534
90	55.7	14608	187.3	1.282	135	58.2	6381	92.0	1.449
135	107.3	10569	161.6	1.529					
P > F	0.0001	.0010	.0002	.0001		–	0.2854	0.0843	0.0323
2009					2010				
N rate	Preplant NO_3–N	Forage yield	N uptake	Tissue N	N rate	Preplant NO_3–N	Forage yield	N uptake	Tissue N
Kg ha^{-1}				%		Kg ha^{-1}			%
0	9.7	1784	17.6	1.015	0	69.7	5126	60.8	1.186
34	9.7	3074	27.6	0.890	34	69.7	5934	73.1	1.233
67	9.7	4421	39.3	0.894	67	69.7	6670	96.4	1.445
101	9.7	5000	50.2	1.024	101	69.7	6743	104.8	1.554
135	9.7	5139	59.8	1.191	135	69.7	7184	110.5	1.539
P > F	–	.0001	.0002	0085		–	.0001	.0002	.0085

† Forage yield at 12.5% moisture.

was calculated and total N uptake was calculated by multiplying tissue N by forage dry weight. Triticale forage yields were then reported at 12.5% moisture (Table 3). Relative triticale-hay yield was calculated by normalizing each year's hay yield data on the maximum yield measured in a given year.

Precipitation received each year was measured daily at a weather station located within 1000 m of the plots (Table 1). Estimates of precipitation stored in the soil was based on previous work that found that during the warm summer months of July through mid-September about 35% of the precipitation received gets stored in the soil for use by the next crop (Nielsen and Vigil 2010).

Response functions (simple quadratic regression equations) were fitted to individual years as a function of N available to the crop (applied fertilizer N plus nitrate-N found in the top 60 cm of the soil profile) hereafter referred to as "total N available". Response functions for both forage yield (kg ha^{-1}) and relative forage yield were fitted to the total N available data as follows:

$$\text{Triticale Hay Yield} = \beta_o + \beta_1 \text{Nrpres} + \beta_2 * (\text{Nrpres})^2, \tag{1}$$

$$\text{Relative Yield} = \beta_o + \beta_1 \text{Nrpres} + \beta_2 * (\text{Nrpres})^2, \tag{2}$$

where "Triticale Hay Yield" is forage dry matter yield at 12.5% moisture in kg ha^{-1}, Nrpres is the kg of N applied as fertilizer per ha plus the residual nitrate-N in the top 60 cm of soil, and "Relative Yield" is triticale-hay yield normalized to a number between 0 and 100.

Relative yield (sometimes referred to as normalized yield) was calculated by dividing the mean yield of four replications at a given N rate by the maximum mean yield found that year (for any given N rate) and then multiplying all values by 100. For example, in 1995 the maximum mean yield of 14,608 kg ha^{-1} was used as the maximum yield that year (Table 3). Therefor the relative yield at the 0 N rate in 1995 would be:

$$\text{Relative yield} = 4431/14608 \times 100 \text{ or } 30.33\%.$$

This normalizing procedure allows all data for the various years to be pulled into a single relationship (Figure 1b). Response functions were also fitted to total N available (nitrate-N, plus ammoniacal N, plus fertilizer applied). The fitted equations that included extracted ammonia were of poorer quality with respect to coefficient of determination (R^2) and root mean square error (RMSE) values and so are not included here. The Weld soils have 2:1 smectite/montmorillonitic clays and much of the ammoniacal N extracted with KCl may be associated with the 2:1 interlayer of these clays and therefore less available for plant uptake than the nitrate found in these soils. A combined response function was also fitted to all 4 years of the normalized data. Here we hoped that the "Wisdom of crowds" idea would prevail. That is that 4 years of data is probably a better approximation of the N response than any single site-year (Surowiecki 2004). We then inserted the economics of fertilizer costs at $01.3–01.8 kg of N and inserted prices of hay at $60–$120 ton. A production cost estimate of $250 per ha for no-till winter triticale-hay was then used to develop Eq [3]. Equation 3 was then optimized for different yield scenarios and costs of N to calculate economic optimum N rates (EONR);

$$\text{Net returns} = \left\{\beta_o + \beta_1 \text{Nrpres} + \beta_2 (\text{Nrpres})^2\right\} * \text{maxyd} * \text{Price} - \$1.3\text{Nrpres} - \$250, \tag{3}$$

where

net returns is in $ per ha and $\{\beta_o + \beta_1\text{Nrpres} + \beta_2(\text{Nrpres})^2\}$ is the fitted response function,

β_o is the y intercept of the N response function,

β_1 is the linear slope of the response function,

β_2 is the quadratic slope of the response function,

maxyieldis the triticale-hay yield range you are concerned with,

priceis the hay price in $ per Mg ($60–$120),

$1.3 is the price of fertilizer N in $ per kg of N ($1.3–$1.8) here we assumed the value of the residual inorganic as equal to that of the applied fertilizer,

$250 is the production costs for winter triticale hay in $ per hectare.

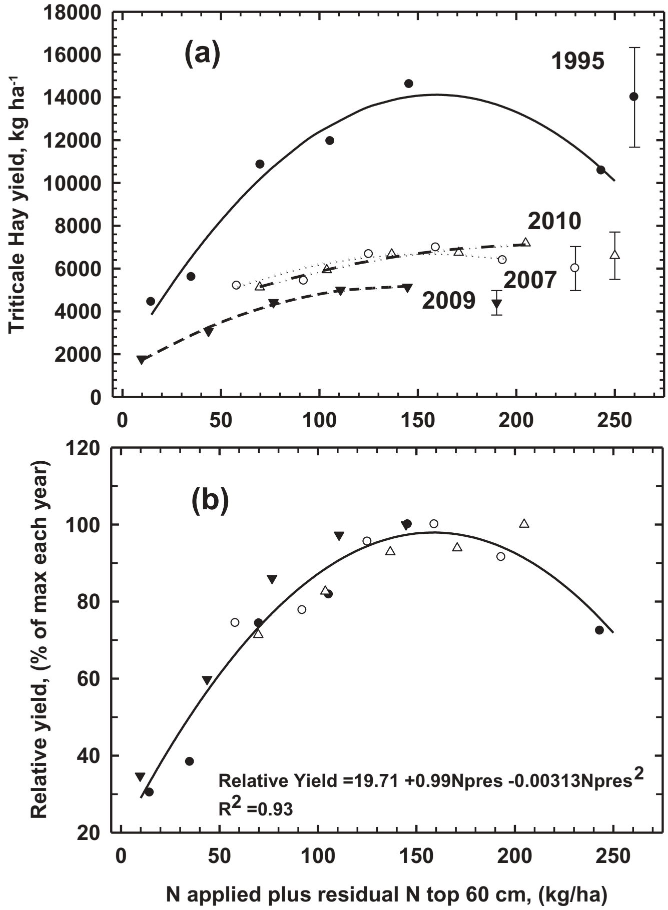

Figure 1. Triticale hay yields as a function of total N available (N applied as fertilizer, plus NO_3-N in the top 60 cm of soil): (a) Triticale hay yields for each year the study was conducted versus total available N; the symbols are the mean of four replications and the line is the fitted regression equations presented in the top half of Table 4. The error bar is the largest standard error of any N rate for each year; (b) all four years of data normalized, relative to the maximum yield measured each year, the symbols are the normalized means of four replications and the line is the fitted regression equation of relative yield on total available N.

The optimization is done by standard methods as described in Vigil et al. (1993). Briefly, the first derivative with respect to Nrpres is calculated for Eq.(3); the first derivative is set equal to zero, and the equation is solved to find the N amount that maximizes net returns for any given price of hay and cost of N. This can be calculated for several yield ranges for dry years, average years and high yielding wet years. No mean separation was performed on the data set whereas, regression analysis (SAS Institute 2009) was used to evaluate overall treatment effects. Analysis of variance (PROC ANOVA) was performed to evaluate significance of treatment effects.

Results and discussion

Triticale yield response to applied N varied from year to year and was greatly influenced by precipitation received during the growing season and previous cropping history (Table 1 and Figure 1a). In semi-arid climates (like at Akron Colorado), crop yield is highly dependent on the amount of precipitation received during the growing season, but can also be influenced by the amount of water stored in the profile at planting. It is highly likely that the hay crop harvested in 2009, which has the lowest yields compared to the other three years, also had the lowest starting soil water contents (Tables 1 and 3). From our other work (Nielsen and Vigil 2010) we estimate that as much as 35% of the precipitation that fell prior to planting the triticale each year would be stored in the soil profile and contribute to the productivity of the hay produced that next year (Table 1). The millet that preceded the 2009 hay crop most likely used all precipitation received in year 1 (2008) until it was harvested in late August of 2008. So the contribution from stored precipitation only comes from the 6 weeks following millet harvest. We estimate the amount would have been less than 20 mm (Table 1). The 2009 hay crop was planted less than 6 weeks after millet harvest in 2008 was likely short on starting soil water contents (Tables 1 and 3). On the other hand, the 2010 crop, which had 12.5 months of summer fallow before planting, more than likely had the highest starting soil water content. That additional moisture may have influenced the good yields measured that year and may partially explain the almost linear response to total N available in 2010 (Figure 1a and Table 3). In 1995, with 439 mm of growing season precipitation (nearly twice the amount normally expected) a maximum yield of 14,608 kg ha^{-1} was measured at a total N availability of 146 kg of N (Table 3). The large hay yields measured in 1995 were more than double the hay yields measured in the other years (Table 3). The large forage yields measured in 1995 can be attributed to high amounts of precipitation received that year.

For all years, as applied N rate increased, the hay yields, total tissue N and N uptake increased (Table 3). In 1995 and in 2007 the maximum yield was measured at 90 and 101 kg of N applied N, just short of the highest N rate applied those years (Table 3). In 2009 and 2010 maximum yield was measured at the highest N rate applied.

Regression equations fitted to the hay yield data as a function of total available N explained more than 82% of the variability in forage yield (Table 4). This held true for the individual years fitted to relative yield as well. On a yearly basis, the regression equations varied in the magnitude of their fitted parameters (Table 4). This is especially true in comparing the equations fit to the 1995 data with the other three years (Table 4).

In an effort to pull all of the data into one relationship we combined all four years into one data set and then regressed forage yield and relative yield on both total available N and just applied N rate (Table 5). Even though yields varied from year to year, the relative yield response to available N was similar irrespective of year (Figure 1b). A useful result is the relative values of the coefficients of determination (R^2 values) for each of the fitted models (Table 5). The regression fit on all four years of data for forage yield produced an R^2 of only 0.26, whereas the relative equation explains as much as 93% of the variability in all four years of relative yield data (Table 5). This best fit relative yield equation emphasizes the value of the pre-plant nitrate N in the top 60 cm of soil. Compare the relative

Table 4. Quadratic regression equations of forage yield and relative yield as a function of applied N (kg ha^{-1}) and residual nitrate N found pre-plant and pre-fertilization in the top 60 cm of soil for individual years.

		Independent variables					
Year	Dependent Variable	Intercept	Nrpres ‡	(Nrpres)^2	R^2	RMSE §	F
1995	Forage yield †	1650.082	156.505	−0.49093	0.9662	924.753	42.82***
2007	Forage yield	2466.347	52.42286	−0.16209	0.8244	464.0618	4.70
2009	Forage yield	1194.533	55.50619	−0.19358	0.9939	157.887	162.97***
2010	Forage yield	2868.928	38.80204	−0.08816	0.9778	170.751	43.96**
1995	Relative Yield	11.29687	1.07137	−0.00336	0.9662	6.32729	42.87**
2007	Relative Yield	35.37033	0.75113	−0.00232	0.8243	6.6536	4.69
2009	Relative Yield	23.24387	1.0804	−0.00377	0.9939	3.07734	162.46***
2010	Relative Yield	39.93109	0.54017	−0.00123	0.9776	2.385	43.66**

†Forage yield at 12.5% moisture in kg ha^{-1}. Relative yield is on a 0–100% scale where maximum yield in a given year is set to 100 and all other values are normalized to that value.

‡Nrpres is the N applied (kg ha^{-1}) plus the residual nitrate N found in the top 60 cm of the soil profile pre-plant and pre-fertilization.

§RMSE is the root mean square error. Regression equation F values followed by *** are significant at the 0.01 level of probability and those followed by ** are significant at the 0.05 level of probability.

Table 5. Quadratic regression equations of forage yield and relative yield as a function of applied N (kg ha^{-1}) and residual NO_3-N found pre-plant and pre-fertilization in the top 60 cm of soil, fitted to all four years of data as one data set.

Dependent Variable	Independent variables					
Applied N plus Residual N						
	Intercept	Nrpres ‡	$(Nrpres)^2$	R^2	RMSE §	F
Relative Yield †	19.40054	0.98994	−0.00312	0.9305	6.05765	120.59 ***
Forage yield †	2963.576	49.295	−0.10934	0.2631	2742.865	3.21*
Applied N Only						
	Intercept	N rate	$(N\ rate)^2$	R^2	RMSE	F
Relative Yield	48.47234	0.83904	−0.00378	0.6353	13.88044	15.68***
Forage yield	3881.612	91.1983	−0.49257	0.2529	2761.791	3.05*

†Forage yield at 12.5% moisture in kg ha^{-1}. Relative yield is on a 0–100% scale where maximum yield in a given year is set to 100 and all other values are normalized to that value.
‡Nrpres is the N applied (kg ha^{-1}) plus the residual NO_3–N found in the top 60 cm of the soil profile pre-plant and pre-fertilization. "N rate" is the N applied as chemical fertilizer in kg ha^{-1}.
§ RMSE is the root mean square error of the regression. Regression equation F values followed by *** are significant at the 0.01 level of probability, those followed by ** are significant at the 0.05 level of probability, and those followed by * are significant at the 0.10 level of probability.

yield equation fit on applied N only (Table 5). That equation only explains 63% of the variability in the relative yield data versus 93% when nitrate in the top 60 cm is included in the fitted equation.

Because 93% of the variability in relative yield could be explained by the relative yield equation regressed on total N available, we felt confident in using this equation to calculate EONR for various values of hay price and N cost. Also, because this equation is a relative fit we could easily manipulate the equation to generate EONR for a range of expected hay yields for dry years, average years, and wet years.

Calculated EONR values at a fixed N cost of $1.32 per kg of fertilizer N, for various hay prices and yield ranges are presented in Table 6. The EONR values in Table 6 help to illustrate the usefulness of the relative yield equation for calculating EONR for a range of hay prices and expected yields. This is the practical part of this work for aiding producers in making N fertilizer decisions for triticale as a hay crop. Hay profitability will vary from year to depending on expected supply demand and price and cost variation from year to year. Hay yields will also vary based on differences in precipitation received from year to year. Because weather and prices are quite variable among years, the approach used here represented by the data generated in Table 6 gives a producer a flexible tool to use as a guide from year to year for making N fertilizer management decisions.

We also used each of the fitted equations on forage hay yield fitted each year given in the top half of Table 4 to calculate EONR for two hay prices and at two N costs. Presumably the fitted equations for the individual years should be more accurate for calculating EONR for the given yield range

Table 6. Economically optimum fertilizer N rate (EONR) calculated using Eq. (3). Rounded to the nearest 10 kg. These EONR assume zero residual nitrate-N in the top 60 cm of soil. That is hardly ever the case. The actual amounts of N recommended using this table should be adjusted based on NO_3-N measured in the soil. These data were calculated using a fertilizer cost of $1.32/kg N using Eq. (3).

	Yield range	$60/Mg	$80/Mg	$100/Mg	$120/Mg
Climate	Mg/ha	EONR, kg/ha			
Dry years	1.5	0	0	30	50
	2.0	0	40	60	80
	4.0	80	100	110	120
Average years	5.0	100	110	120	130
	6.0	110	120	130	130
	7.0	120	130	130	140
Wet years	8.0	120	130	140	140
	10.0	130	140	140	140
	12.0	130	140	140	150

Table 7. Comparison of economic optimum N rates (EONR) calculated from the fitted regression equations in Table 4 fit to each year's forage-yield data versus EONR calculated from the best relative yield equation presented in Table 5 with an R^2 = 0.9305. The yield ranges represent the maximum forage yields achieved in 1995, 2007, 2009, and 2010. The comparisons are made at two N costs ($1.32/kg N and $1.65/kg N) and two hay prices of $100 and $140 per Mg.

		Yield range	N cost $1.32/kg		Ncost $1.65/kg	
			Hay price		Hay price	
			$100/Mg	$140/Mg	$100/Mg	$140/Mg
		Kg ha^{-1}				
Year	R^2		EONR (kg ha^{-1})			
1995	0.96	14600	147	151	144	149
2007	0.82	7000	125	135	116	129
2009	0.99	5100	111	120	104	115
2010	0.98	7200	152	172	135	159
Relative yield equation in Table 5 R^2 = 0.9305		14600	146	150	143	147
		7000	132	140	125	135
		5100	122	132	113	126
		7200	133	140	126	135

measured in each individual year. If true, how accurate would EONR calculated from the overall relative yield equation (presented as the first equation in Table 5) be compared to EONR calculated from equations fit on the individual years (equations presented in the top half of Table 4)? That comparison is presented in Table 7.

We were surprised at how closely EONR calculated using the relative yield equation (fit to all of four years of data) matched the EONR calculated from the equations fit to a single year of forage-yield data (Table 7). The 1995, 2007 and 2009 estimates are nearly the same. The 2010 year matches the overall relative yield equation less well. The EONR miss-match with 2010 is at high hay prices and low N costs. Compare the EONR estimate of 172 kg of N for a hay price of $140/Mg calculated using the equation for 2010 versus the EONR of 140 calculated from the relative yield equation at the same hay price. If we assume that for 2010, the equation fit to that actual year is a better equation for estimating EONR in 2010 year, how bad is the 32 kg N ha^{-1} miss using the relative yield equation? Also how good are the matches for 1995, 2007 and 2009? To attempt to answer these questions, we back calculated the expected net returns using Eq. (3) for each EONR estimates given in Table 7. To accomplish this calculation we first assume that the best EONR estimate for a given year and for the yield range measured that year would be calculated from the regression equation fitted to that years data (the equations in Table 4). The EONR estimated from the relative yield equation is expected to deviate from the EONR calculated using the fitted equation for a specific year. In this back calculation each estimated EONR value in Table 7 is substituted for Nrpres in the fitted response functions in Eq. (3). We then calculated the difference in expected net returns using the following relationship:

Difference in net returns = Eq. (3) using the individual year (1995, 2007, 2009, or 2010) response function with that years estimated EONR as the substitute value for Nrpres

Eq.(3) using the same response function but with the relative yield equation estimates for EONR for that same years yield range as the substitute value for Nrpres.

The expected differences in net returns using this approach are given in Table 8. In this back calculation we are using the individual year's fitted response function from Table 4 for calculating Net returns. However, in each calculation we are either using the EONR estimate from the relative yield equation fit to all four years, or the EONR estimates from each year's individual fitted equation. The expected losses in net returns using the two different estimates of EONR are negligible most of the time (87% of the values are different by less than $4.25 per ha). The biggest difference was with the year 2010 at $13.54 per ha with a hay price of $140/Mg at N cost of $1.32/kg of N fertilizer. The calculations in Table 8 suggest that for the most

Table 8. The calculated difference in expected Net returns in using the relative yield equation to calculate EONR versus the EONR calculated from equations fit to individual years. This table was generated from the EONR values presented in Table7.

	Hay price	N cost $/Kg	
Year	$/Mg	$1.32	$1.65
1995	$100	$0.00	$0.10
	$140	$0.10	$0.20
2007	$100	$0.90	$1.60
	$140	$0.50	$1.00
2009	$100	$2.40	$1.90
	$140	$4.20	$3.90
2010	$100	$3.56	$0.81
	$140	$13.54	$8.11

part the relative yield equation is as good of an estimate of EONR as any individual fit on a single year.

It is interesting to ponder why yields in 2007 and 2010 which are similar in magnitude (7000–7200 kg ha^{-1}) are different in the EONR estimates for a given yield maximum. The regression equations fit in 2007 and 1995 decline at high N availability. This occurs because the actual measured yields decline in 1995 and 2007 at the highest N availability (Figure 1a). In 2010 the regression response is almost linear although the quadratic fit was statistically significant at the 0.05% level (Table 4). Overall, the yield data are quite similar between 2007 and 2010 except at the highest N rate were the yield is still increasing in 2010 but declines in 2007. We attempted to look at rainfall received by month and at temperatures for the two years. That analysis did not explain the differences in the two years, and similar precipitation during the growing season (Table 1) occurred both years (with a slight advantage of 35 mm more precipitation in 2010 than in 2007). In 2010 the real advantage may have come from greater soil water storage discussed earlier (Table 1). The above reasons may partially explain the slightly higher yields in 2010 versus 2007 making the crop more responsive to N in 2010 than in 2007. In any case, because the fit on 4 years of data works as well for most of the data and because it is based on more than a single year of data, that equation is more likely a better tool for estimating yields over a range of years.

Conclusions

Four years of triticale yield response to N availability was measured. The response was greatly influenced by precipitation received each year. Using relative yield as a strategy to pull diverse yield responses to N into a single relationship was a reasonable way to summarize the four site-years of data. The relative yield equation was useful for predicting EONR for a range of triticale hay prices and N costs and for variable yield expected from a variable climate. The equations fit to individual years predicted EONR that ranged from 104 to 172 kg of N ha^{-1}. The relative yield equation was able to capture much of that variability matching EONR estimates for three of the four years exceptionally well. The relative yield equation predicted EONR rates of 0 when hay prices and yields were low, and adjusted with higher EONR values as the hay price and yield increased. The generated EONR values (Tables 6 and 7) are helpful in interpreting the general economic relationships with respect to dryland triticale-hay yield and N rate/residual N. The tables are not a substitute for soil testing from a reputable soil test lab. The tables do represent a calculated estimate of N fertility needs for this crop planted in dryland-silt loam soils in the CGPR. The analysis indicates that the economically optimum N rate decreases (as might be expected) when yield potential is low, when hay prices are low, and when N fertilizer costs are high (compare data in Tables 6 and 7 for the same hay price and yield level).

Conflict of Interest

All mention of trade names is for the benefit of the reader and does not imply endorsement or criticism by USDA-ARS of the products mentioned or of similar products not mentioned.

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