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Can Yield Goals Be Predicted?

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ABSTRACT

Predicting required fertilizer N rates before planting a crop embodies the concept of establishing a pre-season yield goal and fertilizing for that expected yield. The study evaluates prediction of yield goals using data from long-term experiments. Winter wheat (*Triticum aestivum* L.) grain yield data from the Magruder plots (Stillwater, OK, 1930–present), Exp. 222 (Stillwater, OK, 1969–present), and Exp. 502 (Lahoma, OK, 1970–present) were used. Annual pre-plant N rates were applied for 87, 45, and 44 yr, respectively. Experiments 222 and 502 used randomized complete block experimental designs. This manuscript applied the theory that average yields over the last 3 to 5 yr can be used to predict the ensuing years' yield, or yield goal. For the Magruder plots, the "NPK" (67–15–29, N–P–K) and Check (0–0–0) Treatments were used. For Exp. 222, Treatments 1 and 4 (0–30–37 and 135–30–37) and in Exp. 502, Treatments 2 and 7 (0–20–55 and 112–20–55) were selected to test this concept. Wheat grain yield averages for the prior 3, 4, and/or 5 yr were not correlated with ensuing season yields in all three long-term experiments. Over sites and years, yield goal estimates were off by up to 3.69 Mg ha^{-1}. Failure of the yield goal concept to predict current-year yields is due to the unpredictable influence of environment. Mid-season prediction of yield potential using active sensors is a viable alternative for improved in-season cereal fertilizer N recommendations.

Core Ideas

- Yield goals are used to determine pre-plant fertilizer N rates.
- Yield goals are used for many agricultural crops.
- Mid-season sensor-based prediction of yield potential is possible.
- Grain yields levels change dramatically every year.
- Optimum fertilizer N rates change every year.

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The yield goal concept has been used for cereal crops, but has not been comprehensively examined using actual yield data from long-term experiments. Before 1957, N rate recommendations were based on soil criteria and crop management. Since 1970, the yield goal approach has been a popular method for determining the N rate for maize (*Zea mays* L.) in the central Great Plains (Fernandez et al., 2009). Dahnke et al. (1988) defined yield goal as the "yield per acre you hope to grow." This was further clarified in noting that what you hope to grow and what you end up with are two different things. Yield goals range from past average yields, to potential yield, to expected yields. Dahnke et al. (1988) further delineated that potential yield was the highest possible yield obtainable with ideal management, soil, and weather. For this paper, what is defined as potential yield would be "maximum yield," since "potential yield" is bound to specific soil and weather conditions that can change. Rehm and Schmitt (1989) noted that with favorable soil moisture at planting it would be wise to aim 10 to 20% higher over the recent average when selecting a grain yield goal. They also suggested that if soil moisture is limiting, use of history and past maximums (used to generate averages) may not be the best method for setting a grain yield goal for the upcoming crop. Use of farm and/or county averages was discouraged for cutting-edge farmers more focused on high farm profitability (Rehm and Schmitt, 1989).

A practical range for a yield goal should be between average to near maximum yield, observed by you or a neighbor under similar conditions (Dahnke et al., 1988). North Dakota State University (NDSU) Extension Service had recommended that the yield goal could be the best achievable yield in the last 4 to 5 yr and that is usually 30 to 33% higher than the average yield. Nonetheless, this has been updated to reflect that NDSU no longer employs yield goals in any of the crops for which they make N fertilizer recommendations (Dave Franzen, North Dakota State University, personal communication, February 2017).

Prior studies from Black and Bauer (1988) understood yield goals as needing to be based on how much water is available to the winter wheat crop from stored soil water to a depth of 1.5 m in the spring plus the anticipated amount of growing

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Abbreviations: MRTN, maximum return to nitrogen; NDSU, North Dakota State University; NDVI, normalized difference vegetation index; NUE, nitrogen use efficiency; RI, response index.

season precipitation. Combining yield goal, soil test NO_3–N and a simple estimate of nitrogen use efficiency (NUE) can be used to estimate N fertilization requirements. Oklahoma State University Cooperative Extension Service generally recommends that farmers apply 33 kg N ha^{-1} for every 1 Mg of wheat (2 lb N $acre^{-1}$ for every bushel of wheat) they hope to produce, minus the amount of NO_3–N in the surface (0–15 cm) soil profile (Zhang and Raun, 2006). With a yield goal of 2690 kg ha^{-1} (40 bu $acre^{-1}$) and an average grain N content of 2.36 mg kg^{-1}, estimated total N removed would equal 63.6 kg N ha^{-1}. The N use (soil N + fertilizer N) efficiency would be 71% (63.6 kg N ha^{-1} removed/89.6 kg N ha^{-1}, or 80 lb N $acre^{-1}$ for a 40 bu $acre^{-1}$ yield goal). This is far greater than the 33% reported for cereal grain production by Olson and Swallow (1984) and Raun and Johnson (1999). For winter wheat production, even though crop-N-fertilizer needs can be met via fall-applied N, the best time to make final N adjustments is in the spring before the winter wheat surpasses the three-leaf stage (Black and Bauer, 1988).

The historic use of realistic yield goals combined with soil testing have assisted farmers in estimating pre-plant and/or in-season fertilizer N needs. When yield goals are applied, it explicitly places the risk of predicting the environment (good or a bad year) on the producer, but that commonly assures adequate N for above-average growing conditions. University extension (e.g., soil testing), fertilizer dealers, and private consulting organizations have generally used yield goals, due to the lack of improved options.

More recent studies emulated the yield goal concept, but have instead, used mid-season NDVI sensor readings to predict yield potential (Raun et al. (2002, 2005). Unlike the yield goal approach, they used NDVI-estimated-growth from planting to sensing (readings generally collected in late February–March) to reliably establish yield potential in winter wheat. This was in turn used to determine probable N removal and an ensuing mid-season fertilizer N rate. This mid-season fertilizer N rate was expected to deliver that desired level of yield. Implicit in this work was having a reliable estimate of the RI or an in-season estimate of N response, derived from an N-rich strip (Mullen et al., 2003). Furthermore, fundamental to this work was the understanding that estimates of both yield potential and N responsiveness are needed and that they are independent of each other (Raun et al., 2011; Arnall et al., 2013).

Maximum return to N is a procedure for estimating economically optimum N rates. It has been used in the midwestern U.S. Corn Belt and determines maize pre-plant N rates by estimating the yield increase to applied N using current grain and fertilizer prices (Sawyer et al., 2006). This approach provides generalized N rate recommendations over large areas and years. However, it fails to address the issue of year-to-year variability in temperature and rainfall (Shanahan, 2011; Van Es et al., 2006) and does not provide site-year recommendations.

Wide-ranging work by Dhital and Raun (2016), employing 213 site-years of maize data showed that optimum N rates fluctuated from year to year at all locations. They further reported the need to adjust fertilizer N rates by year and location in regions where historically, the same rates are being applied year after year. Although optimal N rates can vary substantially within and between fields, most U.S. maize producers still apply the same rates to entire farms (Scharf et al., 2005). Limiting application rates is the most important factor in reducing environmental impacts; nonetheless, inappropriate methods and poor timing continue to pose the risk of N loss to the environment (Ribaudo et al., 2012). Additionally, the inability to accurately estimate optimum N rates results in overfertilization for some years and fields and underfertilization in others and a lower NUE (Shanahan, 2011). Consequently, there is an urgent need to improve N fertilizer management. The utility of yield goals and/or the lack thereof, remains important because they are still being used. While the estimation of optimum N rates, year to year and field to field remains elusive (Van Es et al., 2006), the promise of mid-season sensor/weather-based methods continues to be promising (Ortiz-Monasterio and Raun, 2007).

Objective

The objective of this work was to evaluate the effectiveness of predicting yield goals, made possible using data from three long-term experiments, all with more than 40 continuous years under winter wheat production.

MATERIALS AND METHODS

Winter wheat grain yield data from the Magruder plots (Stillwater, OK, 1930–present), Exp. 222 (Stillwater, OK, 1969–present), and Exp. 502 (Lahoma, OK, 1970–present) were used to test the hypothesis that yield goals could be used to predict yield for an ensuing year, and that would, in turn, be used to estimate the pre-plant fertilizer N rate. The average yield of the last 3, 4, and 5 yr, plus 20% was used in this work to establish and/or predict the ensuing years' yield, or yield goal. The 20% used could be larger or smaller, but would nonetheless be a fixed value. For all three field experiments N, P, and K were broadcast applied and incorporated in the fall, before planting in all years. Pre-plant fertilizer sources were urea (46–0–0), triple superphosphate (0–20–0), and potassium chloride (0–0–50). Prior to 2004, ammonium nitrate (34–0–0) was used as the N source. Added site details concerning Exp. 222, Exp. 502, and the Magruder plots are reported in Raun et al. (2001) and Girma et al. (2007).

The Magruder plots were established in 1892, prior to the advent of modern statistics, and were not replicated. This trial has undergone some changes since it was first started in 1892, but where 6 Treatments have continued since 1930 (Girma et al., 2007) and that were used in this paper. Experiments 222 and 502 employed randomized complete block experimental designs with four replications, and both are further described by Raun et al. (2011). For the Magruder plots, the NPK (67–15–29) and Check (0–0–0) Treatments were used to test the yield goal concept. In Exp. 222, Treatments 1 and 4 (0–30–37 and 135–30–37, N–P–K) and in Exp. 502, Treatments 2 and 7 (0–20–55 and 112–20–55, N–P–K) were employed. Weed control followed the Oklahoma Agricultural Experiment Station protocol and different herbicides were used over this extended time period. Soil test data in 2016, for all three sites, coming from surface (0–15 cm) samples taken from each of the six treatments evaluated are reported in Table 1. The soil for Exp. 222 and the Magruder plots are both classified as a Kirkland silt loam: fine, mixed, superactive,

Table 1. Treatments used to test the yield-goal prediction concept, in three long-term experiments (Magruder plots, Exp. 222 and 502), and surface soil test characteristics (0–30 cm), by treatment in 2016.

Experiment	Fertilizer applied			Soil test level		
	N	P†	K	pH	P	K
	kg ha^{-1} yr^{-1}				mg kg^{-1}	
Magruder plots						
Check	0	0	0	5.70	7	123
NPK	67	15	29	4.90	37	190
Exp. 222						
Treatment 1	0	30	37	5.85	51	218
Treatment 4	135	30	37	5.73	26	130
Exp. 502						
Treatment 2	0	20	55	5.95	70	488
Treatment 7	112	20	55	5.49	83	457

† P and K, Mehlich III extractable; pH, 1:1 soil/water.

thermic Udertic Paleustoll. These two trials are located on the Stillwater Agricultural Experiment Station and are 300 m apart. The soil for Exp. 502, is a Grant silt loam: fine-silty, mixed, superactive, thermic, Udic Argiustoll and is 2 km west of Lahoma, OK. The Lahoma Agricultural Experiment Station is 130 km Northwest of Stillwater, OK.

For the Magruder plots and Exp. 222, temperature and rainfall data from 1969 to present were compiled. For Exp. 502, (Lahoma, OK), only climatological data from 1993 to present was available. This included hand tabulated experiment station records (Oklahoma Agricultural Experiment Station), and digitized data from the Oklahoma Mesonet (McPherson et al., 2007; Oklahoma Mesonet, 2017). The Oklahoma Mesonet collaborates with various in-state and international organizations involved in the study of the environment, weather, and climate. At present they manage 121 automated stations in 77 counties, and that covers a surface area of 181,200 km^2.

For each trial, grain yields were averaged over the prior 3, 4, and 5 yr periods, for all treatments delineated, and a linear regression model developed vs. the ensuing years' yield. For example, Treatment 4 in Exp. 222 (135–30–37), the yield was 2.59, 1.71, and 2.02 Mg ha^{-1} in 1969, 1970, and 1971, respectively. The average of these three values, plus 20% would be the "yield goal" which calculated to 2.52 Mg ha^{-1}. This value would constitute the first x value (average of 1969, 1970, and 1971) in the regression equation and where the first y value would be the yield that was observed in 1972, that was 1.59 Mg ha^{-1}. Grain yields for each sequence of 3 yr plus 20% were successively computed and added to the x, y database until years ran out. The last sequence of 3 yr, was 2013, 2014, and 2015 (actual values for Treatment 4 were 0.78, 2.37, and 2.99 Mg ha^{-1}, with an average of 2.46 Mg ha^{-1}), and where the 2016 actual yield was 4.42 Mg ha^{-1}. For Exp. 222, using this approach, a total of 42 values for x and y were included in the regression equation developed (average of the last 3 yr plus 20% versus the ensuing years' yield value). For the 4 and 5 yr averages, 41 and 40, x–y pairs were included. Experiment 502 employed the same 42, 41, and 40 x–y pairs for the 3, 4, and 5 yr averages. Experiment 222, was established 1 yr earlier but had 1 yr (1974) lost due to drought. Similarly, 84, 83, and 82 x–y pairs were used for the Magruder plots (two treatments), corresponding to 3, 4, and 5-yr averages, respectively, for data coming from 1930 to present.

A final product was to estimate the yield goal error or how far off the 3, 4, and 5-yr yield goal estimates were, from that value actually observed. They were computed by treatment, at each location using the 3, 4, and 5 yr averages. This was reported as an absolute value since some years the yield goal was overestimated and others underestimated. Values for the yield goal error reported in Table 2 were the averages over years.

RESULTS

Over the years included in this analysis, average annual rainfall at Stillwater, OK (Magruder and Exp. 222), and Lahoma, OK (Exp. 502), has ranged from 422 to 1179, and 457 to 1073 mm, respectively (Fig. 1 and 2). Added location details for all three trials are reported in Table 3. Average annual temperatures at these same sites ranged between 14.1 and 21.0°C, and 13.6 to 18.6°C at Stillwater and Lahoma, respectively (Fig. 1 and 2). Temperature and rainfall were both highly variable from 1 yr to the next, and that was expected to influence yield (Fisher, 1925; Wilhelm and Wortmann, 2004). This finding would, in turn, highlight the difficulty in being able to use yield data from 3 to 5 prior years, to predict what might possibly happen in the following year.

For the methods described, it was assumed that there would be interdependence of regression since prior year yield levels were expected to have an influence on ensuing years. Interdependence of regression would not violate this particular assumption because the yield goal concept implies that there should actually be a relationship. Thus the formula to "predict" what that yield will be, embraces the concept that prior 3, 4, or 5 yr yields will influence or impact the ensuing 1 yr. In all cases, and over the time periods evaluated, the prior 3, 4, and/or 5-yr yield average showed no significant relationship with the following year's yield, at all three sites, and for both treatments included at each site (Table 2). The total number of years included in each linear equation, for estimated yield goal using the average of the previous 3, 4, and 5 yr, ranged from 40 to 84 yr (Table 2).

As the number of years used to estimate yield increased, the coefficient of determination (r^2) for the linear relationship between yield goal and the observed yield showed no increase and/or decrease (Table 2). As reported, researchers managing the Magruder plots increased the N rate from 37 to 67 kg N ha^{-1} in 1968 due to increased genetic potential.

Table 2. Linear relationship between the average yield for the previous 3, 4, and 5 yr (yield goal or YG), vs. grain yield for the ensuing 1 yr, Magruder plots, Stillwater, OK, 1930 to 2016 (Treatment 2, 0–0–0, N–P–-K; and Treatment 5, 67–14.6–28.8), Exp. 222, Stillwater, OK, 1969 to 2016 (Treatment 1, 0–29–37 and Treatment 4, 135–29–37); and Exp. 502, Lahoma, OK, 1970 to 2016 (Treatment 2, 0–22–55 and Treatment 7, 112–20–55).

Location†	Treatment, N–P–K	Linear equation	Years to estimate YG	r^2‡	Root MSE	No.	Yield goal error
	kg ha^{-1}						Mg ha^{-1}
Magruder	0–0–0	$y = 0.76+0.24x$	3	0.03	0.456	84	0.46
Magruder	0–0–0	$y = 0.77+0.23x$	4	0.03	0.459	83	0.45
Magruder	0–0–0	$y = 0.821+0.20x$	5	0.02	0.464	82	0.45
Magruder	67–14.6–28.8	$y = 0.90+0.47x$	3	0.16	0.659	84	0.75
Magruder	67–14.6–28.8	$y = 0.89+0.48x$	4	0.14	0.826	83	0.73
Magruder	67–14.6–28.8	$y = 0.86+0.49x$	5	0.13	0.834	82	0.72
Exp. 222	0–29–37	$y = 0.82+0.29x$	3	0.05	0.647	42	0.58
Exp. 222	0–29–37	$y = 0.58+0.46x$	4	0.09	0.637	41	0.52
Exp. 222	0–29–37	$y = 0.71+0.33x$	5	0.06	0.553	40	0.50
Exp. 222	135–29–37	$y = 2.07–0.02x$	3	<0.01	0.899	42	0.93
Exp. 222	135–29–37	$y = 2.05–0.01x$	4	<0.01	0.957	41	0.85
Exp. 222	135–29–37	$y = 2.19–0.09x$	5	<0.01	0.941	40	0.84
Exp. 502	0–20–55	$y = 1.45+0.14x$	3	0.01	0.524	42	0.55
Exp. 502	0–22–55	$y = 1.21+0.26x$	4	0.03	0.526	41	0.55
Exp. 502	0–20–55	$y = 1.13+0.30x$	5	0.03	0.531	40	0.55
Exp. 502	112–20–55	$y = 3.70–0.16x$	3	0.02	1.024	42	1.08
Exp. 502	112–20–55	$y = 2.72+0.10x$	4	0.01	1.042	41	1.03
Exp. 502	112–20–55	$y = 1.78+0.36x$	5	0.04	1.037	40	0.97

† Nitrogen rate in the Magruder plots was 37 kg N ha^{-1} each year from 1930 to 1967. This was increased to 67 kg N ha^{-1}yr^{-1} in 1968 due to increased genetic yield potential. From 1930 to present P has been applied at 14.6 kg P ha^{-1} yr^{-1}, and K at 28.8 kg K ha^{-1} yr^{-1} using triple superphosphate (TSP, 20%P) and potassium chloride (KCl, 52%K), respectively. Urea (45–0–0) has been used as the N source at all locations since 2004. Prior to 2004, ammonium nitrate (33.5–0–0) was used as the N source. Yield goal error, in Mg ha^{-1} calculated as the average of absolute value differences (yield goal predicted minus the observed yield), over the number of years included at each site).

‡ r^2, coefficient of determination, simple linear regression; No., number of observations (years) used.

Table 3. Long-term experiment included in the analysis, year established, annual average rainfall, range in annual rainfall, and mean annual temperature, Exp. 222 and Magruder, 277 m above sea level, Exp. 502, 389 m above sea level.

Experiment	Longitude, Latitude	Year established	Tillage	No. of replications	Annual avg. rainfall	Range	Mean annual temperature
					mm		°C
Magruder†	36.119681, –97.088745	1892	CT‡	1	835	422–1179	16.8 (14.1– 20.9)
Exp. 222	36.122056, –97.091259	1969	CT, NTΔ	4	835	422–1179	16.8 (14.1– 20.9)
Exp. 502§	36.388267, –98.108654	1970	CT, NTΔ	4	765	457–1073	15.3 (13.6–18.6)

† The Magruder plots, are 300 m from Exp. 222, and use the same weather records available, since 1969.

‡ CT, conventional tillage; NT, no tillage; NTΔ, no tillage, 2011 to present.

§ Experiment 502 weather data encumbered 1993 to 2016.

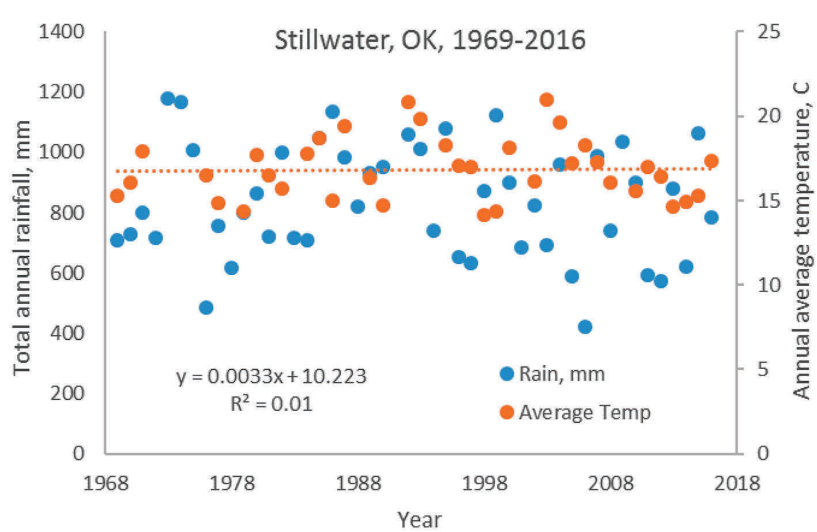

Fig. 1. Total annual rainfall (mm) and average annual temperature (°C), from 1969 to 2016, Stillwater, OK.

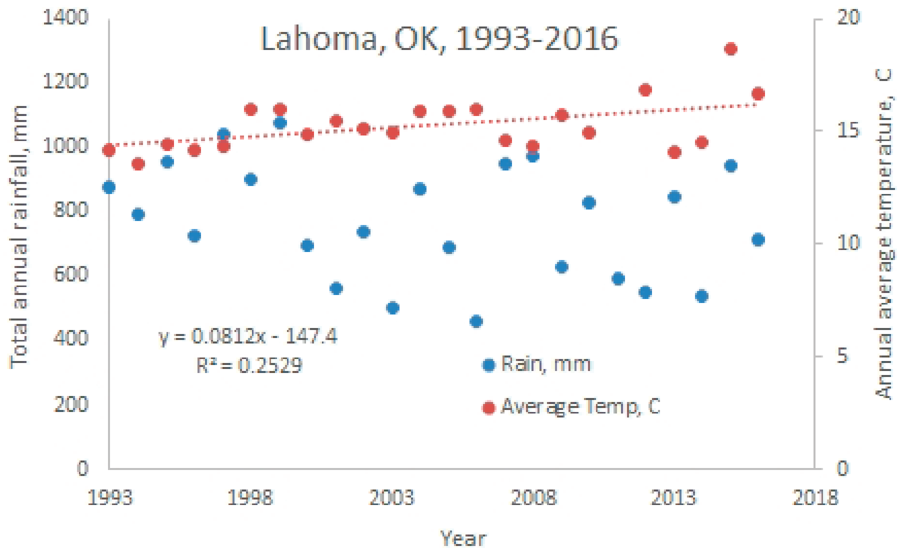

Fig. 2. Total annual rainfall (mm) and average annual temperature (°C), from 1970 to 2016, Lahoma, OK.

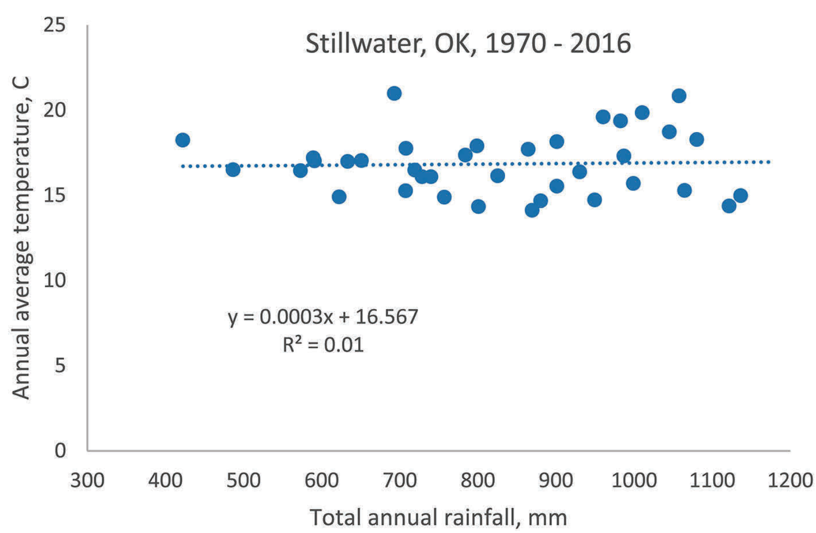

Fig. 3. Relationship between average annual temperature (°C) and total annual rainfall (mm), from 1969 to 2016, Stillwater, OK.

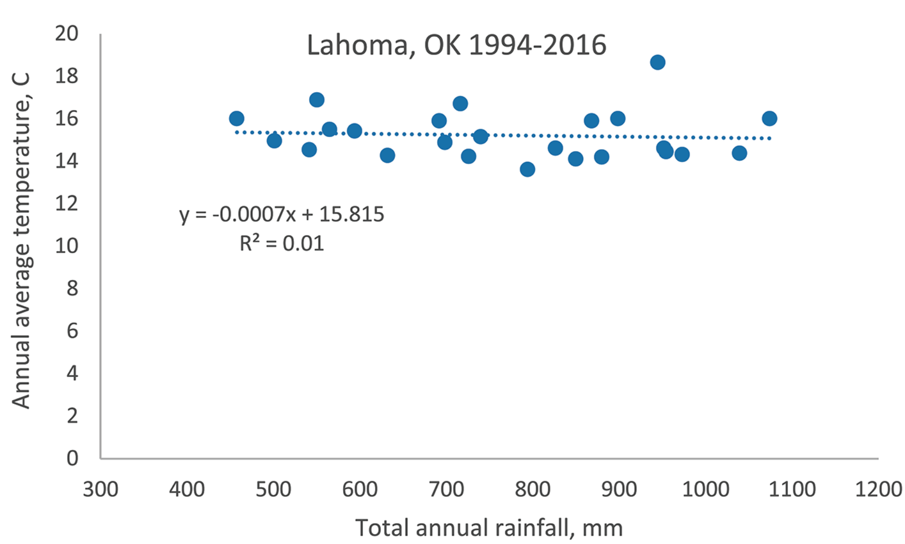

Fig. 4. Relationship between average annual temperature (°C) and total annual rainfall (mm), from 1970 to 2016, Lahoma, OK.

Despite this change, no relationship was found between yield goal determined using either 3, 4, or 5 prior years, and the ensuing years' yield, for the 1930 to 1967 and 1968 to 2017 time periods (not included in Table 2). At both locations (Magruder plots and Exp. 222 at Stillwater, and Exp. 502 at Lahoma), there was no relationship between total rainfall, and average annual temperature (Fig. 3 and 4). It is understood that specific months/periods when rainfall and/or high temperatures are encountered, would be more likely to influence yield. For this work, finding no relationship indicated that the annual average temperature was not influenced by total rainfall. Understanding this supports the concept that a 3-to-5-yr yield average that was high, would not likely be an indicator of yield and/or yield potential in an ensuing year. This observation was consistent with parallel work by this group showing that cereal grain yield potential and the response to fertilizer N are independent (Raun et al., 2011). Both papers also highlight dramatic climate differences from year to year, and that impact grain yield.

The computed yield goal errors reported as the averages for all years at each site, ranged from 0.46 to 1.08 Mg ha^{-1} (6.8 to 16.1 bu acre^{-1}, Table 2). Actual by-year yield goal errors (not averaged over years) ranged from 0.01 to 3.67 Mg ha^{-1} (0 to 55 bu acre^{-1}). This analysis further reveals the magnitude of the expected errors that will be encountered when using a conventional yield goal approach.

DISCUSSION

Over much of the maize-producing landscape in the United States, recent work has documented that optimum fertilizer N rates are highly variable and fluctuate from 1 yr to the next, at the same site (Dhital and Raun, 2016). Work by Huang et al. (2016) further noted temporal variation in atmospheric N deposition, as an important N source in agro-ecosystems, and that has increased in China. The influence of the environment (rainfall and temperature) on fluctuating yields, soil N mineralization and ultimately N demand have been common observations coming from this work and that of others (Scharf et al., 2006; Vanotti and Bundy, 1994).

Finding that yield goals cannot be predicted is of value considering the number of regions where this concept has been applied, over many years, and for a range of cereal crops. Some of the U.S. Cooperative Extension Services where yield goals have been used include Illinois (Olson, 2000), Iowa (Miller, 1986), Kansas (Black and Bauer, 1988), Minnesota (Rehm and Schmitt, 1989), Missouri (Scharf and Lory, 2006), Nebraska (Shapiro, 2008), North Dakota (Dahnke et al., 1988), and Oklahoma (Raun et al., 2001). This was by no means an endorsement, as many states like North Dakota have publicly distanced themselves from the use of this concept (Franzen, 2016). The question being asked in this work was simply whether or not it was possible. These results from three comprehensive winter wheat experiments and that included a wide range of environments suggest that using yield goals would not be an appropriate strategy for determining preplant fertilizer N rates.

Furthermore, these findings elucidate the importance of using better methods to predict yield potential (replacement for yield goals), and that is possible using mid-season active sensor data (Raun et al., 2001; Teal et al., 2006; Girma et al., 2006). This nondestructive methodology using active sensors, that can be used day or night, is commercially available and has delivered increased profits for wheat and maize producers (Scharf et al., 2011). Added studies have used algorithms that employ mid-season sensor readings for predicting yield potential and via well-defined algorithms have resulted in refined fertilizer N rates (Bushong et al., 2016; Singh et al., 2011; Solie et al., 2012; Crain et al., 2012). This methodology has also resulted in more accurate prediction of agronomic optimum N rates compared to yield goal/soil test based methods.

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Conflict of Interest

The mention of any trademarked products or equipment utilized in this experiment was for research purposes only and does not act as an endorsement by Oklahoma State University. The authors and Oklahoma State University have no direct financial relation with any of the named manufacturers, thus the authors declare there is no conflict of interest regarding the publication of this manuscript.

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