The Magruder Plots: 120 years of Continuous Winter Wheat Research

By Brian Arnall

Over the decades several articles, journal publications, and many insights have been derived from this un-replicated fertility study consisting of six simple treatments.

In the summer of 1892 A.C. Magruder, the first professor of agriculture at the newly created Oklahoma Agricultural and Mechanical College, plowed under one acre of Tall Grass Prairie with an interest in producing continuous wheat without the addition of any fertilizer material. This acre would be used to demonstrate the need for fertility management. Over the next 120 years, treatments would be added and adapted. In 1898 a manure treatment was added, commercial fertilizer treatments were added in 1930, and N rates increased in 1967 to reflect higher yield potentials. Eventually the top 16 in. of soil from six treatments (**Table 1**) were moved to a new location in 1947.

Table 1. List of the six treatments in the Magruder Plots, established in Stillwater, OK in 1892.

Treatment	Description
Manure	1891 to 1967 – applied at a rate of 120 lb N/A every four years; 1968 to present applied at a rate of 240 lb N/A every four years
Check	No soil amendments added
P	1930 to 1967 – P applied as ordinary superphosphate at a rate of 30 lb P_2O_5/A; 1968 to present – applied as triple superphosphate
NP	1930 to 1945 – N applied as sodium nitrate at a rate of 33 lb N/A; 1946 to 1967 – N applied as ammonium nitrate at a rate of 33 lb N/A; 1968 to present – N applied a rate of 60 lb N/A; P application same as P only treatment
NPK	N and P applied same as NP treatment; 1930 to present – K applied as potassium chloride at a rate of 30 lb K_2O/A
NPKL	N, P and K applied the same as NPK treatment; lime applied when soil pH < 5.5

In a previous *Better Crops* article Mullen et al. (2001) described the onset of macronutrient deficiencies over the life span of the Magruder plots. When commercial fertilizer (P, NP, NPK, and NPKL) was first added in 1931 the crop immediately responded to P as is shown in **Figure 1**. A response to N fertilizer was not evident until the 1960s, it was also at this time that the impact of P was diminished. This occurred because at the outset P was the most limiting nutrient, but with time (by the 1960s) N became more limiting. It was not until the 1980s that soil reserves of K were depleted to the point that a response to K fertilizer was observed. The article by Mullen et al. documents the decline in soil test P and K.

One might wonder why there was no N response for so many decades. This can be explained by the original soil conditions. The virgin prairie soils of the Great Plains were rich in organic matter, and thus had high levels of organic N.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; L = lime.

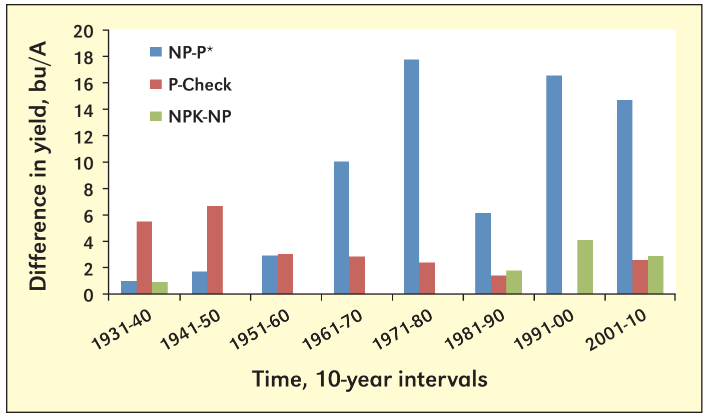


Figure 1. Difference among selected treatments of the Magruder Plots, 1930 to 2010.

*NP-P – difference in winter wheat yield between NP and P only treatments; P-Check – difference in winter wheat yield between P only and check treatments; NPK-NP – difference in winter wheat yield between NPK and NP treatments.

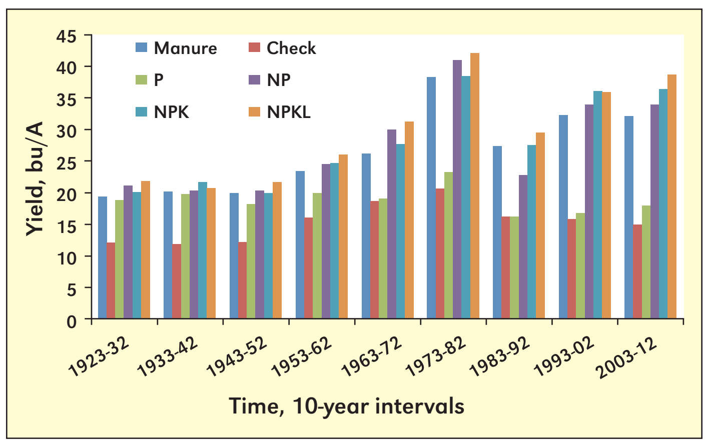
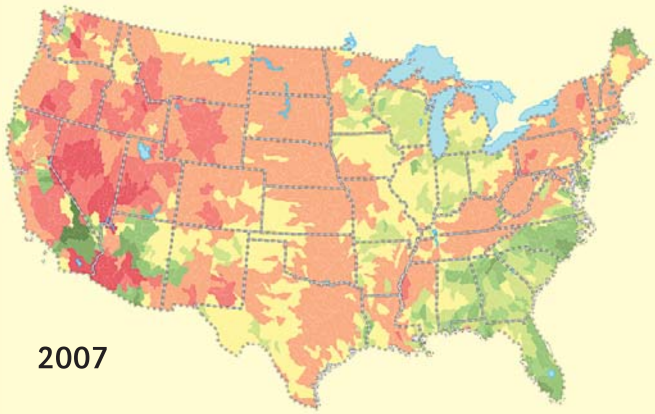
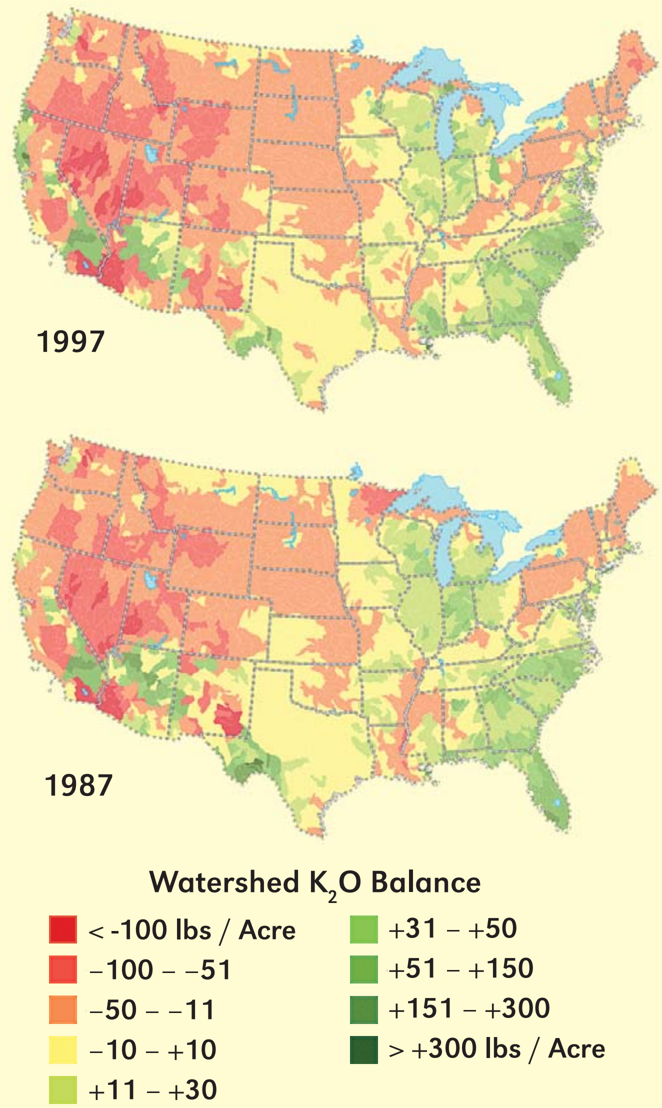


Figure 2. Ten-year average yields from the Magruder Plot treatments, Stillwater OK, 1923-2012. Data from 1893 to 1922 were not included as inorganic fertilizer was not applied during this time frame.

Before cultivation the reddish prairie soils of the Magruder Plots contained about 4% organic matter and over 8,000 lb N/A (Boman et al., 1996). This massive soil reservoir supplied enough N through mineralization to meet crop needs until the 1960s, when response to N was first observed.

Figure 2 documents the 10-year average yields for the six treatments shown in **Table 1**. In this figure it is evident why the researchers felt the need to increase N rate in the late 1960s as the 10-year average maximum yields increased from 20 to 30+ bu/A. Boman et al. (1996) attributed the yield jump in this time frame to the increased yield potential of the improved





Nutrient Balance and NuGIS

NuGIS (Nutrient Geographic Information System) is a web-based tool developed by scientists at the International Plant Nutrition Institute (IPNI) that is designed to assess nutrient balance and nutrient use efficiency on large scale, ongoing basis. NuGIS makes available both numeric and map-based information on nutrient balance and removal to use ratios for N, P and K for ag census years (every 5 years) going back to 1987. Information is available for the U.S. on the county, watershed and hydrologic unit levels. NuGIS maps show many interesting regional trends, including chronic K deficits in many areas of the Great Plains. Although soil K levels are generally high in the Great Plains, the reserves are not endless. NuGIS serves as a beacon, warning against over exploitation of our soil fertility resources. The treatment information provided in the Magruder article supports the need for tools such as NuGIS by showing how long-term production can ultimately lead to soil fertility depletion and reduced productivity.

For more on NuGIS go to http://www.ipni.net/nugis

varieties of the time. This figure also shows the increase in yield due to N, K and the application of lime.

An interesting aspect of the Magruder plots is the ability to evaluate nutrient mass balance (for more on nutrient balance see accompanying note on NuGIS). **Figure 3** documents the removal of N, P, K, Ca and Mg. **Table 2** lists the amounts of N, P, K, Ca and Mg both; added as manure and commercial fertilizer and removed by the grain from the manure, check and NPKL treatments. From these values N use efficiency can be calculated (grain N removed from fertilized plot – grain N removed from check plot / total N added) resulting in a 45% NUE. It should be noted that if the Magruder plot N rate was based on a yield goal recommendation (5-year average plus 20%) the application rate would be 100 lb/A, not 60.

Table 2. Amounts (lb/A) of N, P, K, Ca, and Mg added to the Manure treatment since 1899, and NPK treatment since 1929, and the amounts of N, P, K, Ca, and Mg removed by the Manure, Check and NPKL treatments since 1929.

Nutrient	Manure (1899)	NPK (1929)	Manure removed	Check removed	NPKL removed
N	4,920	3,888	3,412	1,980	3,723
P	1,877	1,073	496	288	541
K	4,254	2,017	653	379	712
Ca	11,562	.	364	211	397
Mg	2,165	.	182	106	199

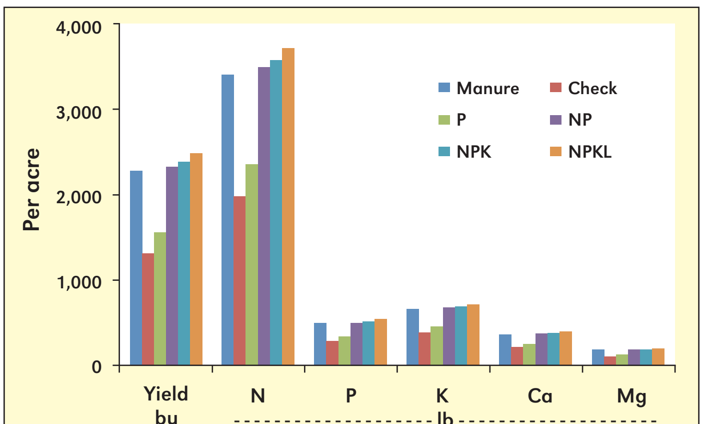


Figure 3. Total yield (bu/A) and total nutrients (lb/A) removed from each treatment from 1930 to 2012.

Another important observation from the Magruder Plots is the impact of crop production and fertilization on soil pH. **Figure 4** demonstrates the effect of crop removal (i.e., removal of base cations) and N fertilization on soil pH. The check plot, which has a total removal equal to half that of the fertilized plots has seen little change in soil pH, the NPK plots have documented a decline, and the manure plot soil pH has increased. It is interesting to note that the soil pH of all treatments remained relatively stable until yields increased and N application increased. For this reason data prior to 1975 is not shown.

The Magruder plots are one of the few historic and on-going soil fertility experiments in the world. The data collected from 120 years of monoculture winter wheat will surely continue to contribute to the advance of wheat production science in the years to come. BC

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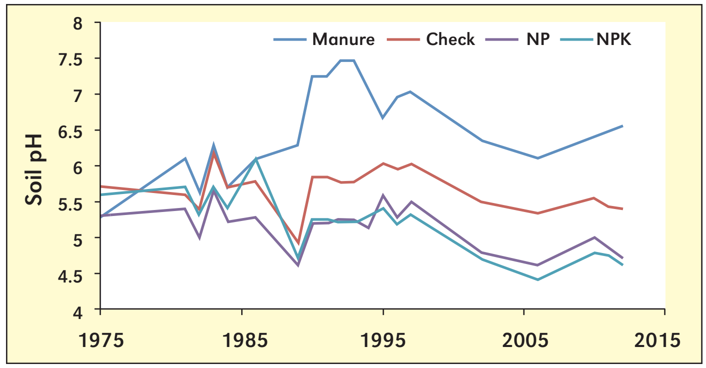

Figure 4. Soil pH trend in the Manure, Check, NP, and NPK plots from 1975 to 2012. Soil test results prior to 1975 show consistency of soil pH values.

References

Boman, R.K., S.L. Taylor, W.R. Raun, G.V. Johnson, D.J. Bernardo, and L.L. Songleton. 1996. Dept. of Agronomy, Oklahoma State Univ.

Mullen, R.W., K.W. Freeman, G.V. Johnson, and W.R. Raun. 2001. Better Crops with Plant Food, 85 4:6-8.

Conversion Factors for U.S. System and Metric

Because of the diverse readership of *Better Crops with Plant Food*, units of measure are given in U.S. system standards in some articles and in metric units in others…depending on the method commonly used in the region where the information originates. For example, an article reporting on corn yields in Illinois would use units of pounds per acre (lb/A) for fertilizer rates and bushels (bu) for yields; an article on rice production in Southeast Asia would use kilograms (kg), hectares (ha), and other metric units.

Several factors are available to quickly convert units from either system to units more familiar to individual readers. Following are some examples which will be useful in relation to various articles in this issue of *Better Crops with Plant Food*.

To convert Col. 1 into Col. 2, multiply by:	Column 1	Column 2	To convert Col. 2 into Col. 1, multiply by:
	Length		
0.621	kilometer, km	mile, mi	1.609
1.094	meter, m	yard, yd	0.914
0.394	centimeter, cm	inch, in.	2.54
	Area		
2.471	hectare, ha	acre, A	0.405
	Volume		
1.057	liter, L	quart (liquid), qt	0.946
	Mass		
1.102	tonne[1] (metric, 1,000 kg)	short ton (U.S. 2,000 lb)	0.9072
0.035	gram, g	ounce	28.35
	Yield or Rate		
0.446	tonne/ha	ton/A	2.242
0.891	kg/ha	lb/A	1.12
0.0159	kg/ha	bu/A, corn (grain)	62.7
0.0149	kg/ha	bu/A, wheat or soybeans	67.2

[1]The spelling as "tonne" indicates metric ton (1,000 kg). Spelling as "ton" indicates the U.S. short ton (2,000 lb). When used as a unit of measure, tonne or ton may be abbreviated, as in 9 t/ha. A metric expression assumes t=tonne; a U.S. expression assumes t=ton.