Cropping system nitrogen use efficiency after 10 years of no-tillage

Rachel Unger (rachel.unger@wsu.edu) WSU and Dave Huggins USDA-ARS

Nitrogen use efficiency (NUE) calculated from a single growing season is often 40% or lower and likely underestimates cropping system NUE, as it does not include nitrogen still cycling within the soil. Therefore, evaluating NUE over multiple growing seasons, rather than a single growing season, may provide an improved assessment of NUE. Cropping system NUE may also vary spatially across heterogeneous landscapes and soils due to differences in crop performance and pathways of nitrogen loss or internal nitrogen storage within the soil.

IMPACT

A study of the effect of conversion from conventional tillage to no-tillage showed that soil profile nitrogen increased by 35 pounds per acre annually. Cropping system nitrogen use efficiency (NUE) was about two times greater than what is typical of a single crop. This occurred as applied fertilizer nitrogen promoted increases in soil organic matter as well as crop yield. Quantifying NUE based on cropping system evaluations is an improved approach over single-year assessments; however, long time periods are required, and errors associated with the measurements make accurate quantification problematic.

A long-term, field-scale cropping systems study under continuous no-tillage was established on a 92 acre field at the Washington State University Cook Agronomy Farm (CAF) near Pullman, WA, in 1998. Previously, the field was managed under conventional tillage. Georeferenced sampling locations were determined at the onset of the study to allow for grain, biomass, and soil samples to be collected from the same locations over the course of the study (Figure 1). Spring wheat (SW) was planted in 1999, spring barley (SB) in 2000, and then different three-year crop rotations of spring wheat, winter wheat (WW), and alternative crops (spring or winter plantings of barley (B), canola (C), or pea (P)). The 92 acre field was divided into three smaller fields (fields A, B, and C), and each part of all crop rotations was represented every year.

We took soil samples before the conversion from conventional tillage to no-tillage in the fall of 1998 (Figure 1). No differences in overall soil nitrogen were found among the three small fields in 1998, and soil nitrogen averaged 4,700 pounds per acre for the 0- to 1-foot soil depth and 8,450 pounds per acre for the 1- to 5-foot depth (Table 1). Different soil series had dissimilar amounts of soil profile nitrogen, with Caldwell silt loams having the most soil nitrogen and Staley silt loams the least amount for the 0- to 1-foot and 1- to 5-foot depths (Table 1).

After ten years (2008), soil samples were collected from the same georeferenced locations. Overall, soil nitrogen concentration had increased from 13.1% (1998) to 16.4% (2008) for the 0- to 1-foot depth and from 4.2% (1998) to 4.5% (2008) for the 1- to

Soil series	Taxonomic classification	Sampling locations	Soil N 1998 (0–1 feet)	Soil N 2008 (0–1 feet)	Soil N 1998 (1–5 feet)	Soil N 2008 (1–5 feet)	Soil N 1998 (0–5 feet)	Soil N 2008 (0–5 feet)
	Field survey		pounds per acre	pounds per acre	pounds per acre	pounds per acre	pounds per acre	pounds per acre
Staley	Fine-silty, mixed, superactive, mesic Calcic Haploxerolls	15	4,265	4,443	6,754	7,628	11,019	12,071
Naff	Fine-silty, mixed, superactive, mesic Typic Argixerolls	23	4,327	4,711	7,610	8,369	11,938	13,080
Palouse	Fine-silty, mixed, superactive, mesic Pachic Ultic Haploxerolls	90	4,693	5,175	8,628	9,011	13,321	14,186
Thatuna	Fine-silty, mixed, superactive, mesic Oxyaquic Argixerolls	42	5,023	5,255	8,984	9,689	13,999	14,953
Latah	Fine, mixed, superactive, mesic Xeric Argialbolls	11	4,800	5,228	8,744	9,993	13,544	15,221
Caldwell	Fine-silty, mixed, superactive, mesic Cumulic Haploxerolls	2	5,335	5,817	10,126	10,376	15,462	16,193
All		183	4,741	5,105	8,474	9,178	13,215	14,283

Table 1. *Total soil nitrogen (N) (pounds per acre) based on soil series taxonomic classification at three sampling depths (0 to 1 foot, 1 to 5 feet, and 0 to 5 feet) for the 92 acre Washington State University Cook Agronomy farm.*

	Mass balance	NUE	Nitrogen balance
Crop sequence†	0–1 feet (pounds per acre)	0–1 feet (%)	index (%)
SW-WW-SB	-239	82	54
SW-WW-SC	-382	72	50
SW-WW-SP	-184	88	52
SW-WW-WB	-471	65	47
SW-WW-WC	-257	81	50
SW-WW-WP	-190	85	50

†SW = spring wheat; WW = winter wheat; SB = spring barley; SC = spring canola; SP = spring pea; WB = winter barley; WC = winter canola; WP = winter pea.

Table 2. *Total soil nitrogen (N) mass balance (pounds per acre) and nitrogen use efficiency (NUE) (%) by crop rotation based on the 0- to 1-foot sampling depth and the N balance index (%) for the 92 acre Washington State University Cook Agronomy farm.*

5-foot depth. Low soil nitrogen concentration in the 1- to 5-foot depth may be a source of error in overall soil profile nitrogen calculations, as soil nitrogen concentrations are combined with soil bulk densities to determine soil nitrogen (lbs/acre). Errors generated from low nitrogen concentrations may be an inherent limitation to the study.

Soil profile nitrogen at 0 to 5 feet increased by approximately 35 pounds per acre per year following the conversion from conventional tillage to continuous no-tillage. The increase in soil profile nitrogen can be attributed to increases in soil organic matter following the conversion to no-tillage. While soil nitrogen increased on average for the entire field, there was considerable variability within the field, where soil nitrogen either increased or decreased from 1998 through 2008 (Figures 1 and 2). Although the crop rotations had been in place for eight years, no statistical differences in soil nitrogen among the different rotations were detected.

Nitrogen mass balance (Equation 1) and NUE (Equation 2) were calculated for each cropping systems based on 0- to 1-foot and 0- to 5-foot soil depths as follows:

$$\textit{N mass balance} = \textit{Soil N in } 2008 - (\textit{Initial soil N } (1998) + \textit{Total applied fertilizer N } (1998-2008) - \textit{Total harvested grain N } (1998-2008)) \quad [1]$$

$$\textit{Cropping system NUE (\%)} = \left(\frac{\textit{Total harvested grain N} + (\textit{Soil N 2008} - \textit{Soil N 1998})}{\textit{Total applied fertilizer N}}\right) \times 100 \quad [2]$$

All rotations gained soil nitrogen throughout the top foot of the soil profile; however, all had a negative mass balance (Table 2), indicating losses of nitrogen from the system (not directly measured). Nitrogen concentrations in the subsoil were low, which could result in analytical and mass balance calculation errors. This is why the focus of this study is on the top foot of the soil profile. Not all nitrogen inputs (e.g., N_2 fixation, atmospheric deposition) and outputs (e.g., leaching, denitrification) were directly measured in this study.

Overall, the cropping system NUE calculated from this multiyear study ranged from 65% to 88% and was over two times greater than that typically reported for a single growing season (20% to 40%) (Table 2). In addition, we did not have any significant differences in NUE or nitrogen balance index (Equation 3) due to crop rotation (Table 2), and all rotations at the CAF appear to be efficient users of available soil nitrogen.

$$\textit{N balance index (\%)} = \left(\frac{\textit{Total harvested grain N}}{\textit{Total applied fertilizer N}}\right) \times 100 \quad [3]$$

As the research continues, our understanding of no-tillage cropping systems and nitrogen pathway effects on NUE will improve, leading to more informed cropping system recommendations for managing nitrogen more efficiently throughout the high precipitation zone within the REACCH region.

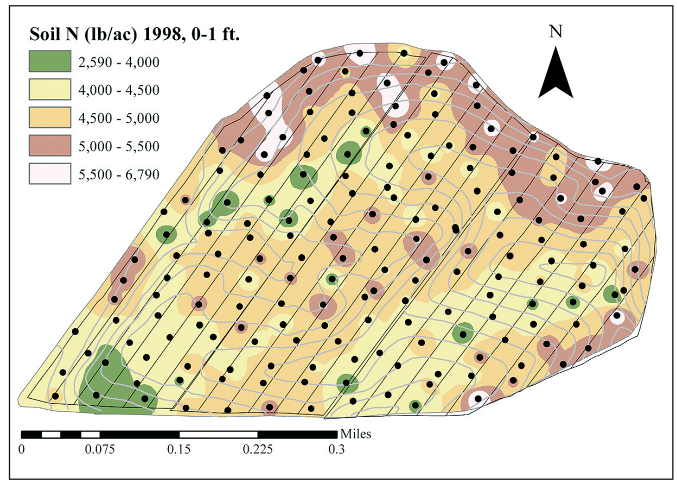

Figure 1. *Total soil nitrogen (pounds per acre) for the 0- to 1-foot sampling depth in 1998 at the Cook Agronomy Farm. Georeferenced sampling locations are marked as black points, and gray lines are contour intervals (9.8 feet). Field strips where different crop rotations were established are bounded by black lines.*

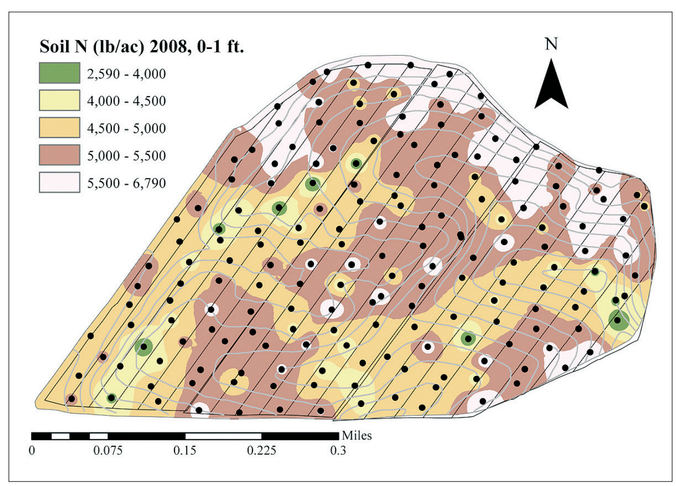

Figure 2. *Total soil nitrogen (pounds per acre) at the 0- to 1-foot sampling depth in 2008 on the Cook Agronomy Farm. Georeferenced sampling locations are marked as black points, and gray lines are contour intervals (9.8 feet). Field strips where different crop rotations were established are bounded by black lines.*