EXPERIENCES WITH SITE-SPECIFIC FARMING IN A DEMONSTRATION PROJECT IN THE SE COASTAL PLAIN

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ABSTRACT

In the SE Coastal Plain, adoption of site-specific farming has lagged behind that in the upper Midwest. While the cause may be both sociological and economical in origin, it was clear that a quantitative awareness of the severity, spatial extent, and persistence of yield variation was needed before adoption could be considered. Consequently, funding was procured for a project in SE North Carolina, titled "Management Practices to Reduce Nonpoint Source Pollution on a Watershed Basis," for a site-specific farming objective titled "To improve and adopt precision farming as a best management practice." The project goals were to show existing variation in crop yield with combine yield monitors, to use computer models to predict yield and relate precision farming to water quality, and to improve and encourage site-specific nitrogen management. For the first goal, commercial yield monitors were placed on farmer combines, and yield maps were acquired during their normal operations. In three years of data collection, more than 4700 ha (11,000 acres) of corn, wheat, and soybean yields were mapped. Data were imported into ARC/Info GIS for summary and statistical analysis. For the second goal, sensitivity analyses of the CERES-Maize crop model were conducted to determine suitability for use in explaining yield variation. For the third goal, yield monitor data points were attributed to county soil survey map units, and for two fields, to fine-scale NRCS mapping units and several proposed management zones. Additionally, a preliminary analysis was conducted of field-scale N balance. This paper presents an overview of the findings in the demonstration project.

Keywords: Yield monitor, yield map, yield distributions, site-specific modeling, nitrogen balance

INTRODUCTION

This report describes findings after four years of a project titled Management Practices to Reduce Nonpoint Source Pollution on a Watershed Basis, which is part of the Agricultural Systems for Environmental Quality (ASEQ) Project. This multi-agency project for cooperative research and demonstration in Duplin County, North Carolina, was funded by USDA-CSREES. The agencies cooperating included Biological and Agricultural Engineering and Cooperative Extension Service, both of North Carolina State University; USDA-NRCS at the state, district, and county levels; USDA-ARS at Florence, SC; US Geological Survey; and several local farmer-cooperators. A description of the overall project and area was given by Stone et al. (1995). Preliminary results from the first year of the site-specific farming objective were reported at this conference in 1998 (Sadler, et al. 1999).

One objective of the ASEQ project was to improve and adopt precision farming as a best management practice. Sub-objectives were: a) to show existing variation in crop yield with combine monitors; b) to use computer models to predict yield and relate precision farming to water quality; and c) to improve and encourage site-specific nitrogen management. Because the sub-objectives were sequential, the rest of this paper will be organized by sub-objective, with materials and methods followed by results within each section.

SUB-OBJECTIVE A:
YIELD MAPPING

Materials and Methods

The yield data were collected from cooperators in Duplin and Sampson Counties, North Carolina, with additional fields in Wayne, Bladen, and Pender Counties proximal to the Duplin or Sampson County borders (Fig. 1). One cooperator operated two John Deere 9500[1] (Deere & Co., Moline, IL) combines with 6-m (20-ft) grain and 8-row corn headers on 76-cm (30-in) spacing. Both had GreenStar yield monitors installed in March 1997. The DGPS units used satellite-based differential correction. They wrote on 1-s intervals to 5-MB data cards, which were read into JDMap V2.1.1 software. Data were collected from this cooperator in 1997 and 1998. The other cooperator operated two Case 2188 combines with 6-m (20-ft) grain and 8-row corn headers on 76-cm (30-in) spacing. One machine previously had an AFS yield monitor without DGPS. On that machine, a DGPS unit (GPS2000, AgLeader Technology, Inc., Ames, IA) was installed by project personnel before wheat harvest in June 1997. This unit used the Ft. Macon Coast Guard beacon for differential correction. The unit wrote on 2-s or 3-s intervals to 1-MB cards, which were read into AgLink Basic V5.2.1 and, later, AgLink Advanced V5.5 (AGRIS Corp., Roswell, GA) software. Data were collected from this cooperator from 1997 through 1999.

[1] Mention of trademarks is for information only. No endorsement implied by USDA-ARS or its cooperators.

Because only one of the two machines was equipped with the yield monitor, and the two machines usually harvested fields together, data from portions of fields were usually acquired.

Project personnel set up and calibrated the monitors using load totals determined with portable truck scales or scale tickets, and trained the operators in monitor operation. During harvest, the operators entered field names, crops, and activated the data collection. On-site project personnel periodically exchanged cards, read them, and transmitted data to the server at USDA-ARS Florence via dial-up networking. In Florence, these data were examined for DGPS problems and operator artifacts, such as erroneous crop codes, field names, turns and trips across the field to unload with the header down, etc. Errant passes were straightened, null passes and turns were deleted, and field names and crop codes were corrected. Data from the two combines for the one cooperator were merged, which required adjacent-pass comparisons to calibrate one of the two combines on some fields. Data from all sources were merged into one comprehensive data set using the AgLink software, then exported to shapefile format for importing into ARC/Info.

For Duplin County, the soil survey (Goldston et al., 1958) was available in digital format. The Duplin County yield data from both cooperators was overlaid in ARC/Info to determine the soil map unit associated with each data point. The resulting ARC/Info table was exported to SAS (SAS, 1990) for summary statistics by soil type. Summary statistics and analyses conducted in SAS include analysis of variance by soil type (for Duplin County data only) and distributions of yield by field, operator, and for the whole data set. The results from this analysis for the 1997 corn yields were presented by Sadler et al. (1999). Project-wide yield distributions are presented here.

Results and Discussion

Total crop area mapped for yield was 4780 ha, with 3.3 million yield data points. The spatial extent and location of all fields mapped, identified by cooperator, is shown in Figure 1. The areas represented by these yield maps collected for each year, crop, and cooperator are shown in Table 1. Corn yields were obtained all three years. In 1998, wheat and soybean data for one cooperator were lost during a computer failure. In 1999, the field data collection was scaled back to only that one cooperator. Note that in 1999, the corn harvest was interrupted by Hurricane Floyd, with heavy rains and flooding. Therefore, the areas harvested before and after the hurricane were retained separately.

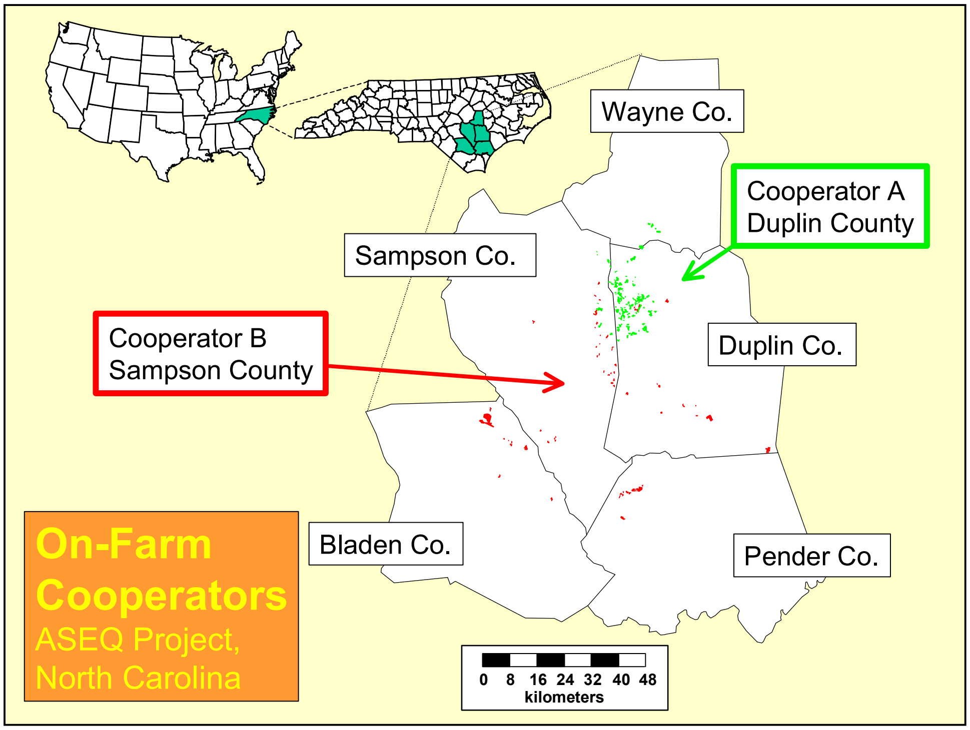

Figure 1. Geographic location of fields mapped in the cooperative ASEQ Project, identified by cooperator.

Table 1. Summary statistics for yield monitor project by crop, year, and cooperator.

Corn

	Cooperator A			Cooperator B			Total		
	Area		No.	Area		No.	Area		No.
Year	ha	ac	1000s	ha	ac	1000s	ha	ac	1000s
1997	513	1268	408	366	903	142	879	2171	550
1998	796	1967	680	162	400	72	958	2367	752
1999				273	673	125	273	673	125
Pre-Floyd				*157*	*388*	*69*	*157*	*388*	*69*
Post-Floyd				*116*	*286*	*56*	*116*	*286*	*56*
Totals	1310	3235	1088	800	1976	339	2110	5211	1427

Wheat

	Cooperator A			Cooperator B			Total		
	Area		No.	Area		No.	Area		No.
Year	ha	ac	1000s	ha	ac	1000s	ha	ac	1000s
1997	159	393	144	109	269	29	268	662	173
1998	478	1180	419				478	1180	419
1999				266	657	122	266	657	122
Totals	637	1574	563	375	926	151	1012	2499	714

Table 1 Continued.

Soybean

	Cooperator A			Cooperator B			Total		
	Area		**No.**	**Area**		**No.**	**Area**		**No.**
Year	**ha**	**ac**	**1000s**	**ha**	**ac**	**1000s**	**ha**	**ac**	**1000s**
1997	561	1385	470	261	646	115	822	2031	585
1998	546	1348	479				546	1348	479
1999				133	328	54	133	328	54
Totals	1106	2733	949	394	974	169	1501	3706	1118
Totals	3053	7541	2600	1569	3876	659	4622	11417	3258

An example yield map composite for 5 contiguous corn fields in 1997 is shown in Figure 2. This gives a visual impression of the severity and spatial extent of the yield variation encountered in the SE Coastal Plain. Although the 5-field mean yield was 4.5 Mg/ha (approximately the state average for the year), substantial areas of the field were in excess of twice the mean, and substantial areas were less than half the mean. Many of the areas with extreme yields were suitable for grouping into management zones for precision farming.

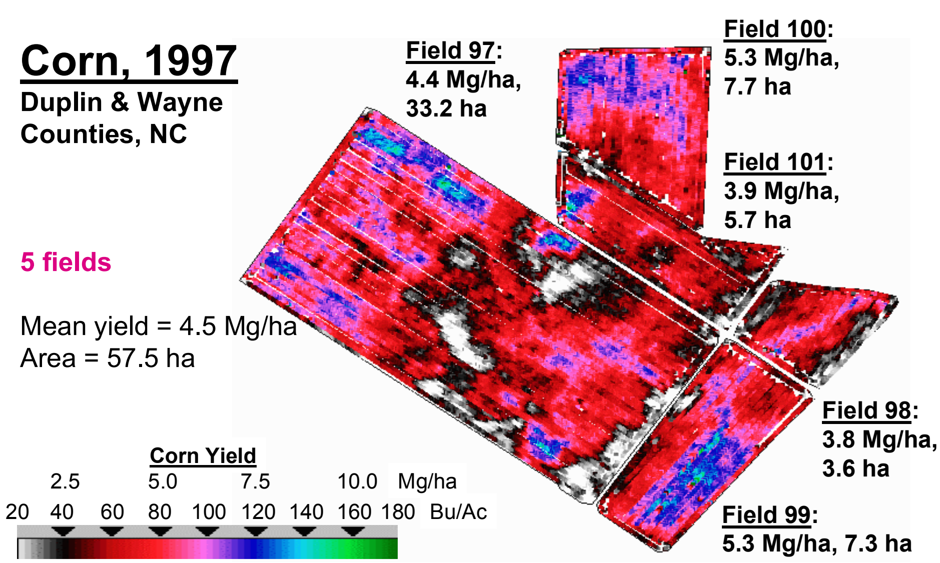

Figure 2. Example of yield maps obtained for corn in 1997 season.

It is clear that there is no efficient mechanism to present the entire yield map dataset, so summaries presented here are in the form of cumulative distribution functions (CDF) of yield for crop and year. Figure 3 shows the CDFs for corn. The first year, 1997, had average yields marginally below those for an average year. The second, 1998, had a severe drought during the growing season and resulted in median yields approximately 2/3 of average. The third year, 1999, showed promise for well-above-average yields until the rains during Hurricane Floyd caused much of the grain to fall below a height that could be harvested. The median yield dropped from 5.8 Mg/ha before the hurricane to 2.0 afterwards, a decrease of 65%.

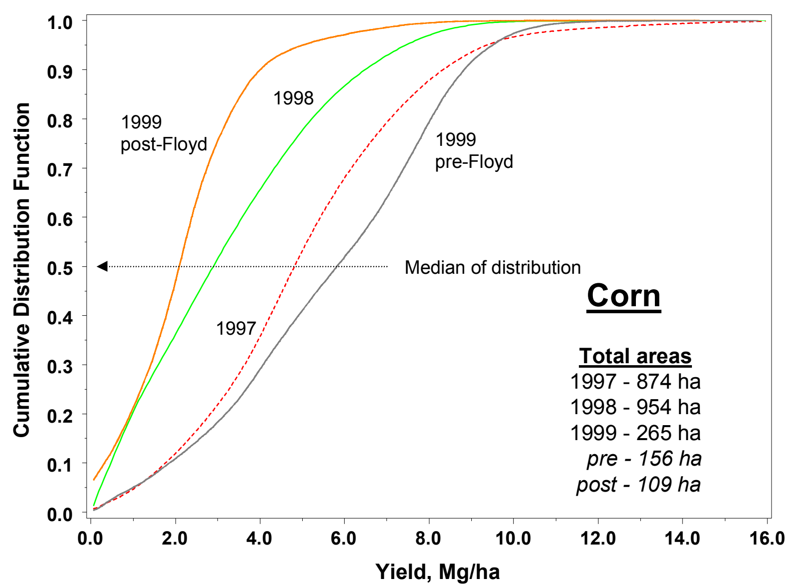

Figure 3. Cumulative distribution function for corn yield during the three years of the study. The 1999 data were segregated into that harvested before and that harvested after Hurricane Floyd. Totals differ slightly from those in Table 1 because some fields were not included in this analysis.

Wheat yields generally decreased during the three years, with medians in 1997 of 3.0 Mg/ha decreasing to 2.2 and 1.8 Mg/ha in the latter two years (Figure 4). Median soybean yields were not high in any year, the maximum for both 1997 and 1998 being about equal at 1.7 Mg/ha (Figure 5). The variance in 1997 was more than in 1998, but that was a result of the second cooperator's data being included in 1997 and not in 1998. The CDFs for the first cooperator in 1997 and 1998 were virtually identical. The increase in variance when the second cooperator's data were included in 1997 was caused by both an increased spatial extent and the fact that some of the area for that cooperator was custom-harvested by the cooperator for several different farm operators, where all area for the first cooperator was his own operation. We expect probable differences in fertility, cultivar, population, tillage, and pest control to have caused the variance shown in Figure 5.

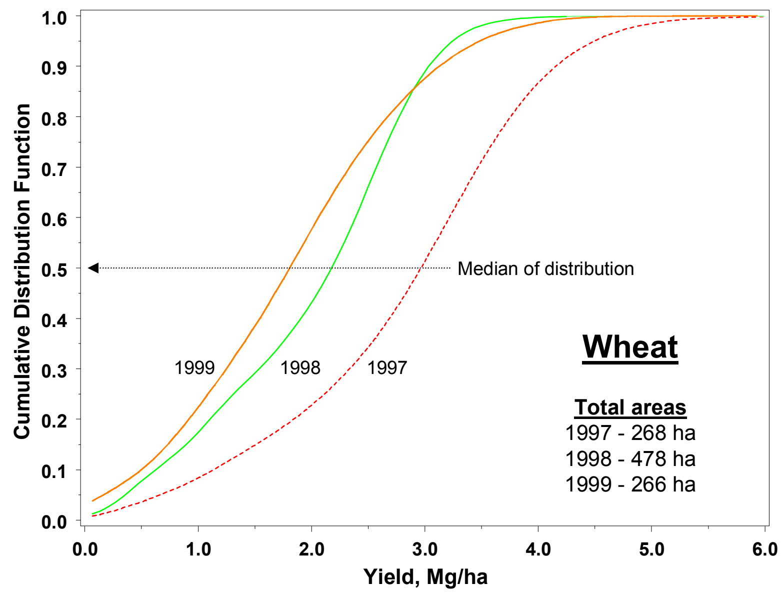

Figure 4. Cumulative distribution function for wheat yield during the three years of the study.

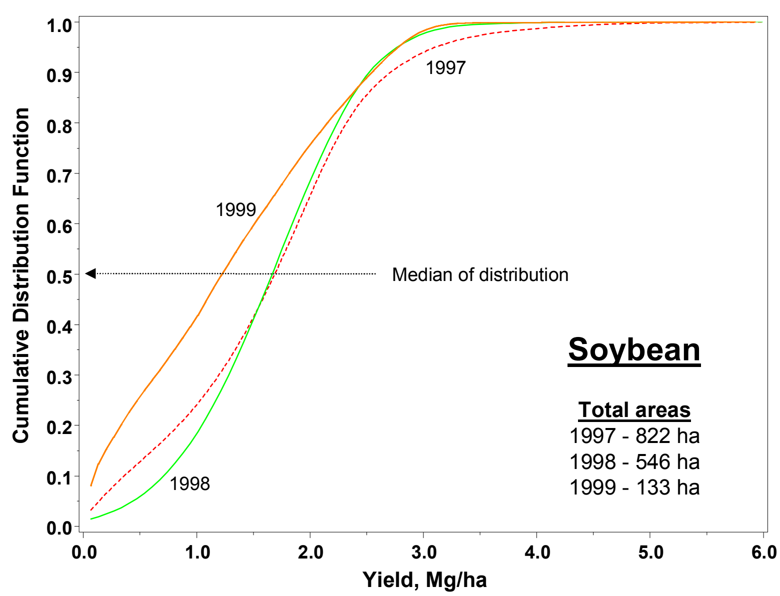

Figure 5. Cumulative distribution function for soybean yield during the three years of the study.

SUB-OBJECTIVE B:
MODELING

The modeling of crop growth and yield in this project met with, at best, mixed results. It had been hoped that the authors prior work in developing soil profile descriptions for the CERES-maize model in the DSSAT suite would provide sufficient foundation for some success. However, continued difficulties in sensitivity analyses (Sadler et al., 1998), despite increasingly site-specific parameterization (Sadler, et al., 1999), produced results that were not encouraging (Sadler et al., 2000). Reasons for the difficulties appear to be linked to the extremely sandy soils in the region, which exacerbate the sensitivity of the real system to water shortages and for which the sensitivity of the model did not appear suitable (Sadler, et al., 2000). Changes to the model that could improve its performance under these conditions included additional routines for partitioning rainfall into runoff and infiltration, and for decoupling crop temperature from air temperature under conditions of water stress (Sadler et al., 2000).

SUB-OBJECTIVE C:
SITE-SPECIFIC NITROGEN FERTILIZER RECOMMENDATIONS

Materials and Methods

The difficulties in achieving success in site-specific modeling hindered the development of recommendations. To make progress as we could, we worked in two areas. The first was developing methods to create management zones, with approximately equal within-zone yields, suitable for precision farming in the SE Coastal Plain. The results from this approach are presented by Gerwig et al. (2000, this proceedings). The second approach was to analyze empirical data to show the probable risk of N leaching in the mapped areas.

Such risk can be inferred from the amount of fertilizer N that is not removed from the field in grain. Spatial extent and severity of variation in residual fertilizer N was calculated from assumptions of average application and average grain N content. Additional assumptions regarding fertilizer N recovery efficiency and crop residue N content allow a second evaluation of the amount remaining in the soil and in the crop residue.

For this paper, these calculations were done, not on the spatial data, but on the frequency distributions of the corn grain yield. Simplifying assumptions for average area each point represents were made on a field-average basis. The resulting CDF represents the proportion of the area for which a given amount of N is removed from the soil. Repeating the CDF for the function of (applied-N minus removed-N) represents the proportion of the area for which a given amount of N is left in the field. Some of these values are, of course, negative, which occurs when the yield exceeds the target yield, and means that N is being mined from that area.

Figure 6 shows a graphical representation of the steps involved. The vertical axis is the amount of N per unit area in the forms of application, grain removal, residue content, and that remaining in (or lost from) the field, all as a function of yield. The sample case shown is corn in 1997, for which the total area was 874 ha, distributed as shown across the yield axis. For this analysis, the amount of N applied was set to 160.5 kg/ha, which was the amount used in NCSU extension's 1999 Sampson County yield trials, and which corresponds to a target yield of approximately 7.5 Mg/ha (120 Bu/Ac). While this value should vary according to soil (Hodges et al., 2000), for these rough calculations, it was not considered a variable. The amount of N removed in grain was set at 1.5% of yield, corresponding to 10.9% crude protein and the N fraction of protein of 16%. This is slightly below the 1.6% listed for grain N content by Zublena (1991). Subtracting the grain removal from the application gives the amount of N left in or lost from the field.

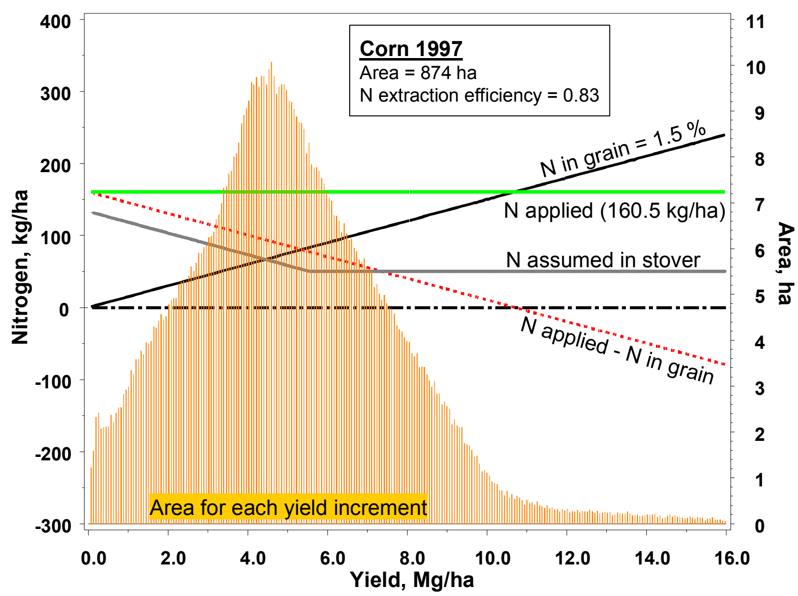

Figure 6. Per-unit-area nitrogen values as a function of grain yield, and areal distribution of grain yield. Total area differs slightly from Table 1 because a limited number of fields were not included in this analysis.

While the seasonal N balance thus obtained is useful for several purposes, a substantial amount of N is taken up by the plant and returned to the soil via decomposition of crop residues. That amount not taken up by the crop is subject to within-season or short-term loss from the soil, but that in residue is not subject to loss until decomposition, which occurs over a longer period. Therefore, it would be useful to estimate the amount taken up and not translocated to grain. For moderately low-yield conditions (similar to those encountered in these data), simulations suggested that N taken up was reasonably constant at about 83% of applied N. Therefore, (N in residue) = (N applied) * 0.83 - (N in grain). This approach suffers under two conditions. For extremely low-yield areas, the plant uptake would trend back toward zero because of low plant growth, but this detail was not examined in this analysis.

Further, this approach would obviously not work for high-yield conditions, where presumably higher residue amounts would occur, with some minimum N content. Although this was a gross simplification, we set 50 kg/ha as a minimum N content of residue, which is consistent with data collected at Florence under high-yield conditions (Camberato, 2000, personal communication). For each curve, the value at a given yield was multiplied by the area corresponding to that yield. Summations for the entire dataset provided the N balances for the entire 874 ha.

Results and Discussion

For the 1997 corn data, the peak area distribution was about 10 ha with 4.8 ± 0.03 Mg/ha yield, with approximately 900 kg N not removed in grain (Figure 7). The average N remaining in the field for that 10 ha was then approximately 90 kg/ha of the 160.5 kg/ha applied. When this calculation was repeated for each yield increment and summed, the 140 Mg of N applied resulted in 67 Mg removed in grain and 74 Mg left in the field. The 1-Mg discrepancy comes from both rounding and the mining of a small amount of N in the high-yield areas. While the inclination is to report this on a per-unit-area basis, doing so misrepresents the fact that these activities occur specifically on different areas, and we have left them stated on an area-wide basis.

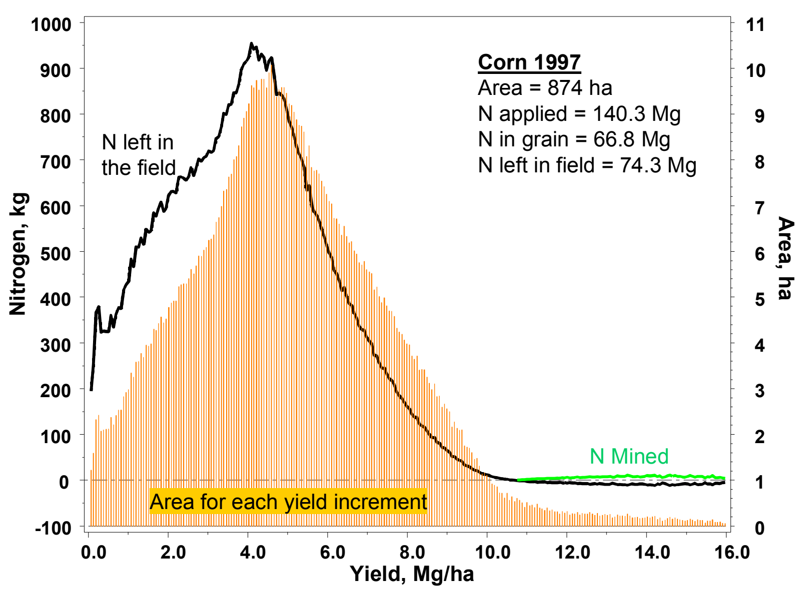

Figure 7. Field N balance as a function of grain yield, and summations for the entire area. Total area differs slightly from Table 1 because a limited number of fields were not included in this analysis.

The curve (Figure 8) labeled "N in soil" represents N that is in neither grain nor crop residue. Although labeled as in soil, it could have been lost through leaching or volatilization during the season and not be present at harvest. Where this curve becomes negative, more N was taken up during the season than was applied, meaning that the plant mined some N from the soil. For the assumptions used here, this occurred wherever yield exceeded 7.3 Mg/ha. The summation over yield resulted in a seasonal balance of 67 Mg in grain, 60 Mg in crop residue, 17 Mg left in the soil in low-yield areas, and 4 Mg mined from high-yield areas.

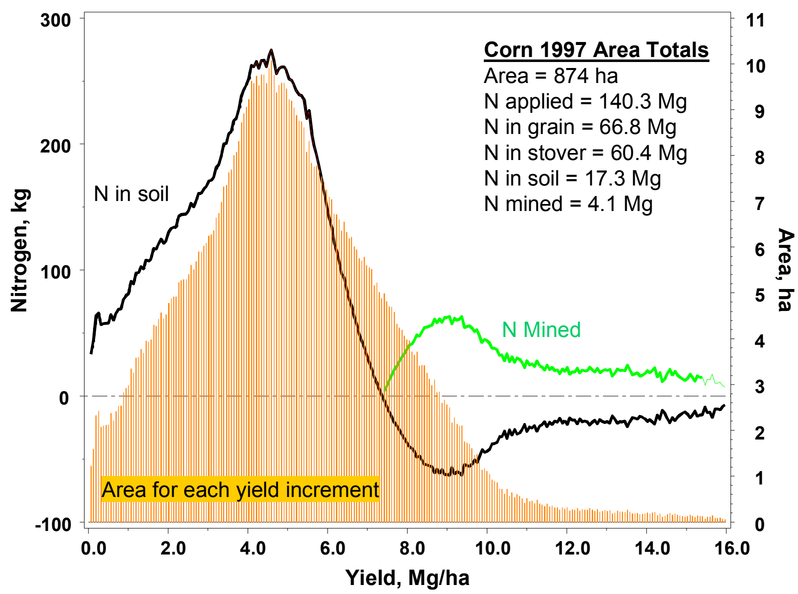

Figure 8. Rough approximation of N remaining in or removed from the soil as a function of grain yield, and summations for the entire area. Total area differs slightly from Table 1 because a limited number of fields were not included in this analysis.

One must remember that these particular calculations are extremely approximative, and are shown here to illustrate the possible consequences of uniform N management on extremely variable soils. Certainly the N uptake, grain N concentration, residue N concentration, and residue amount all vary in space beyond that variation solely attributable to yield. The N application rate may actually be higher than that used in these calculations, with 180 kg/ha commonly used for fields with better soils as the predominant type. Clearly, the value chosen for N content of residue would require serious study before conducting any similar analysis for data with significantly more high-yielding areas. However, despite the cautionary approach one must use in interpretation, the preliminary calculations shown here strongly suggest that significant environmental benefits could accrue to site-specific N management.

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