Integrated approach for site-specific nitrogen management in North Dakota, USA

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Abstract

Nitrogen (N) management is important for farmers in North Dakota to maximize economic return and environmental stewardship. Fall soil sampling for soil nitrate is important to N management. Zone soil sampling is highly recommended over grid soil sampling. Zone development tools include remote imagery, soil electrical and magnetic sensors, multi-year yield maps and topography. Nutrient rate research to support site-specific fertilizer application shows that N rate and yield are not related between fields. Therefore, N rate is not yield-goal based. Zone sampling does not aid in-season N needs. Algorithms are published for use of active-optical (AO) sensors for corn, and work continues in sugarbeet, confection sunflower, and spring wheat. Use of zone soil sampling and the use of active-optical sensors can provide improved site-specific N management.

Key words: Zone sampling; grid sampling; nitrogen; active-optical sensors

Introduction

North Dakota agriculture includes the cultivation of about 6M hectare of nitrogen (N)-requiring crops. The most important of these by area are spring wheat (*Triticum aestivum*, L.), durum wheat (*Triticum turgidum* ssp. Durum), corn (*Zea mays*, L.), and sunflower (*Helianthus annuus*, L.). The foundation of N management in this region is fall soil sampling for residual nitrate. Harvest is usually complete by the end of October, and the soil freezes shortly thereafter. For example, in 2018 at Grand Forks, ND, the bare soil temperature first measured 0°C November 17. (NDAWN, 2018) Residual soil nitrate is trapped in the frozen soil until the spring thaw, which is closely followed by spring planting often while frost can still be found in the soil. In 2018 for example, bare soil temperature at Grand Forks first rose above 0°C April 15. Planting began in the region within 2 weeks.

Starting in 1995, site-specific N application became of interest to farmers and their suppliers as fertilizer applicators capable of varying the rate of fertilizer became available and profitability of crop production became more difficult to attain. Grid soil sampling was first explored, followed by zone soil sampling. Fertilizer recommendations were revised to better serve site-specific field nutrient applications. Today, site-specific nutrient management should also include strategies to account for in-season nutrient requirements. This paper will describe the transition from whole-field nutrient management to site-specific nutrient management in North Dakota, and the integrated approach to nutrient management now recommended to farmers to maximize their profitability and environmental stewardship. This paper may serve to provide an incentive to researchers around the world to utilize some of these ideas to provide improved, practical site-specific nutrient strategies for their farmers to improve the efficiency of nutrient application and profitability of crop production.

Soil sampling

Soil sampling for site-specific nutrient application is not a new concept. The first recommendations to farmers for a site-specific soil sampling strategy was published by Linsley and Bauer (1929) as a guide for site-specific lime application that was labor-saving for the hand-labor used at the time. With the availability of equipment that could more easily apply fertilizers and lime with far less labor, the interest in site-specific application faded for almost 50 years. Interest in within-field nutrient management was again sparked by the development of fertilizer applicators with the ability to apply varying rates of fertilizer within a field, combined with the availability of global positioning satellites (GPS) and the computer capacity to collect GPS data and analyze it by companies and individuals practically and affordably (Franzen and Mulla, 2016).

A series of soil sampling studies were conducted in several states to determine what density of soil sampling would practically and meaningfully result in the determination of fertility patterns in fields that could be better managed through their site-specific nutrient application. The results from Wisconsin (Wollenhaupt et al., 1994), Illinois (Franzen and Peck, 1995) and Nebraska (Gotway et al., 1996) indicated that a sampling density of about 1 sample per 0.4 ha was required to direct meaningful site-specific fertilizer application. In these states, soil sampling is usually directed towards phosphorus (P), potassium (K) and soil pH, with a sampling depth of about 150mm. Each sample that would be sent to a laboratory for analysis would consist of 3-5 soil cores in a composite.

In North Dakota, the sampling depth is most typically 600mm due to the importance of measuring soil nitrate-N for use in N recommendations for small grains, canola (*Brassica napus*), sunflower, corn and other N-requiring crops.

The recommended depth of soil cores for sugar beet (*Beta vulgaris* subsp. *vulgaris*) was 1200mm until recently. The deeper soil samples still required 3-5 cores within a composite. One sample per 0.4 ha would have been impractical for farmers or their consultants from the aspects of time and expense. A field near Valley City, ND was sampled in a 0.1 ha grid. Patterns of nitrate-N, P and other nutrients were mapped. The field was sampled at the same sample density the next year, and patterns mapped in year two were similar to those found in year one (Figure 1). The reason for the similarity in patterns was topography. Water movement and crop growth was influenced by topography (Franzen et al., 1998), and patterns of nitrate and other nutrients were similar between years. The sampling pattern facilitated investigating different sampling patterns on the correlation of nitrate-N values using different soil sample density. The topography-based zone sampling, using a 5-sample composite for each zone was similar in significance or greater than the 0.4 ha grid and greater than grid density of 1 ha, or 2 ha per sample (Table 1). The use of zone sampling greatly reduced the time and expense of soil sampling for meaningful site-specific nutrient application while equaling or exceeding the predictive ability of a 0.4 ha grid. Zone sampling resulted in the practical application of site-specific nutrient application, particularly N, in North Dakota.

Continued research in the region, amounting to over 50 site-years of whole-field data with experimental base grid sampling of 0.1 ha to 0.2 ha densities, showed that zone sampling was appropriate from eastern Montana through western Minnesota. Tools to develop effective zones were aerial and satellite imagery, soil electrical conductivity sensing, soil magnetic conductance sensing, topography (not elevation, but landscape structure), and multi-year yield maps (with each year standardized for relative yield) (Franzen et al., 2011). It was important that at least two tools were utilized to produce the nutrient management zones. Tools that researchers have used to delineate zones include aerial imagery, satellite imagery, soil EC sensor data, soil EM sensor data, multi-year yield maps, farmer experiences and observations, and topography (Hornung, 2006; Franzen et al., 2011). In a given year, use of only one tool has a chance of not representing nutrient patterns, while two tools have a much greater ability to represent patterns even if the other tool is not as useful.

Table 1. Regression coefficients (r^2) for comparison of zone-based and less dense grid estimates with the 0.1 ha sampling grid, Valley City, ND.

	r^2 for estimates with 0.1 ha grid values			
Year	Topography	0.4 ha	1 ha	2 ha
1994	0.29**†	0.18	0.07	0.07
1995	0.38**	0.50**	0.21*	0.21*
1996	0.49**	0.34**	0.41**	0.01

†* indicates significance of regression coefficient at $P<0.05$. ** indicates significance of regression coefficient at $P<0.01$.
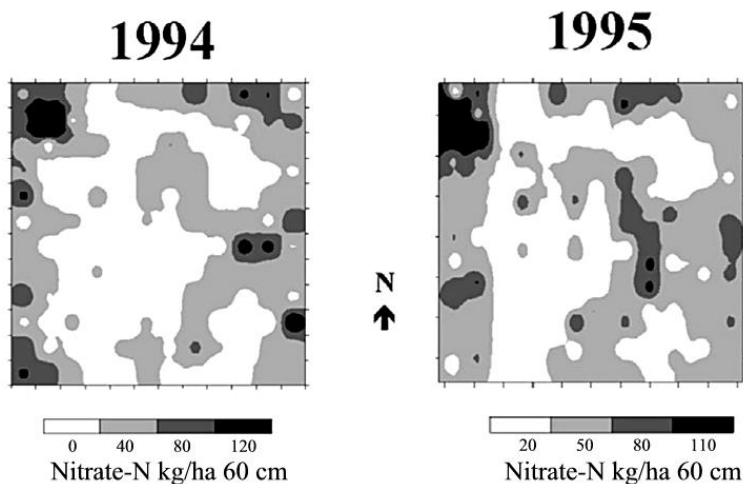
Figure 1. Residual soil nitrate-N mapping of a square 12.5 ha field near Valley City, ND in 1994 (after spring wheat) and in 1995 (after sunflower), sampled in a 0.1 ha grid. The patterns indicate stability of relative residual nitrate values between years.

A zone sampling approach for crop nutrients has also been explored by other researchers in the USA. Mallorino & Wittry (2004) found that zone sampling in Iowa was superior to grid sampling for soil pH, organic matter and potassium. Grid sampling was superior to zone sampling for phosphorus. Khosla et al. (2002) showed that zone-based N management improves N management in Colorado.

Adoption of zone sampling is high among North Dakota farmers and their consultants. In 2016, use of variable-rate N application using zone sampling was used on nearly 54% of sugar beet acres, with profitability of its use was about $120 ha^{-1} yr^{-1} averaged over 10 years (American Crystal Sugar Co., Moorhead, MN, personal communication).

North Dakota N recommendations and recommendations for other plant nutrients of interest were formally yield-based. Yield-based recommendations tended to be embraced by farmers utilizing site-specific nutrient application because it was easy to link productivity to a nutrient rate. However, N rate trials on spring wheat (Franzen, 2018), corn (Franzen, 2017), and sunflower (Schultz et al., 2018) showed that N rate and yield between fields were not related. Raun et al. (2011) first recognized the lack of yield and N relationship between fields, and several US Corn Belt states do not recognize yield as a factor in their economic production function N rate models (Sawyer, 2018). The lack of yield-goal based N recommendations places greater emphasis on attention to other tests, such as soil nitrate-N sampling and analysis. From this type of test, regional soil rate responses (as detailed in the literature) produce N fertilizer recommendations such as N-calculators (Sawyer and Nafziger, 2005; Franzen, 2009; Franzen, 2015; Franzen, 2016; Sawyer, 2018). According to the largest soil testing laboratory in the region, 40% of samples received from North Dakota are intended to direct site-specific nutrient application, with zone samples by far the largest proportion of site-specific nutrient soil samples (Agvise, 2018).

The regression analysis of zone sampling with the experimental 0.1 ha base grid values used as a standard for comparison of less dense grids (i.e. 1 sample ha^{-1}) for soil nitrate-N suggests that soil analysis only represents 50% of soil nitrate-N variability (Franzen et al., 1998). Active-optical (AO) sensors are able to recognize small-scale variability in N availability and were developed as a soil fertility management tool to serve that purpose (Raun et al., 2002).

Development of active-optical sensor algorithms for in-season N fertilization
In a series of N-rate experiments in corn, the AO sensors at growth stage V5 and V10 were used to relate the red NDVI (RNDVI) and red edge NDVI (RENDVI) (when possible with the instrument) to yield (Sharma et al., 2015). The AO sensors used were the GreenSeeker® (Trimble, Inc., Sunnyvale, California, USA), and the Holland Scientific® Crop Circle A470 (Holland Scientific, Lincoln, NE, USA) sensor. The GreenSeeker (GS) only had a RNDVI light source/detector, while the Crop Circle (CC) generated RNDVI and RENDVI data. The results indicated a strong relationship between yield and both RNDVI and RENDVI at V5, but only RENDVI at V10.

The results of the study were further condensed and incorporated into a series of algorithms for use by farmers for site-specific on-the-go N application (Franzen et al., 2014). These algorithms would enable the farmer to apply a base preplant N rate across the field of about 50-75% of total recommended seasonal N indicated by zone sampling and the N recommendation. At about V5 (Ransom, 2013), the sensor would be used to deliver any remaining N to the field in a small-scale site-specific manner on-the-go using the algorithm developed for their region and soil. The algorithms also contain a minimum value for sensor readings whereby the likely cause of deficiency is something other than N. Readings below the minimum are probably the result of a poor plant stand, high salts or another non-N factor. This prevents the grower from wasting fertilizer N on a field area where the N will not be helpful for yield improvement. The standard against which the algorithm rate is based comes from an N-non-limiting area established at the time of preplant N application. The readings from the N non-limiting area would represent the greatest yield possible with any rate of N applied. The difference in yield prediction between the N non-limiting area and any other area of the field would be used by the algorithm to calculate the N required to approach the higher yield. A similar concept is also used by others in the USA to direct in-season N application (Franzen et al., 2016a). The regression equations from these studies that relate AO sensor readings to crop yield identify an additional 25% of field variability. The combination of zone soil sampling with the use of an AO sensor would identify about 75% of total N variability within fields.

Algorithm development for spring wheat, sugar beet and sunflower is currently on-going. The algorithms for spring wheat will include early-season N algorithms for yield increase, and anthesis-timing algorithms for protein enhancement N applications. The sugar beet algorithms will be needed for a series of harvest dates based on growing degree days, since sugar beet continues to develop and increase in tonne yield and sucrose concentration from the beginning of sugar beet harvest in the region until the end; about a 6 week period. The algorithm will therefore have to be growing degree day by yield by N rate, or a 3-dimensional model (Bu et al., 2017).

Sunflower algorithms for confection sunflower are likely, though not yet developed, since there is a strong relationship between confection sunflower RNDVI, RENDVI and yield at V6 (Schultz et al., 2019). Oil-seed sunflower yield was

not related to AO sensor readings (Franzen et al., 2019); however, they are related to crop height, which was determined using an acoustic height sensor (Sharma et al., 2015). Corn yield is also related to crop height, but the RNDVI and RENDVI relationships with corn yield were strong enough that crop height was not included in corn AO sensor algorithms. The algorithms developed for corn may be modified by farmers. To do so, they need to turn off the in-season N application in a pass through the field, but continue to collect NDVI readings. At harvest, the relationship between the NDVI readings and yield will result in a new relationship equation. This can be combined with a weighted equation based on the number of sites used to develop the algorithm, and a new algorithm is produced which, over time, will become the farmer's farm algorithm. Since there will be year to year variation in growing season moisture and temperature conditions, it would probably take multiple years to produce an algorithm that would provide farmer confidence.

Currently, few farmers are using AO sensors for variable-rate in-season N application. Feedback from farmers indicates that they do not trust the technology to automatically apply different N rates to their fields. However, an increasing number of farmers use the N non-limiting concept to help them determine whether or not they require in-season supplemental N applications. An N non-limiting area will also serve to indicate a S deficiency in corn, based on a recent study (Franzen et al., 2016b). When N limits yield, S deficiency is not as severe. When N is non-limiting, S deficiency intensifies.

Conclusions

The goal of a site-specific nutrient management Extension education program should be to move the farmer to a more integrated site-specific approach, with early crop health and in-season adaptable nutrient management due to early-season rainfall. In N research on high clay soils, those with clay content greater than 350 g kg^{-1} soil dry matter, excessive early-season rainfall can result in denitrification with losses in excess of 100 kg ha^{-1}. In addition, coarse textured soils are susceptible to high N leaching losses. Therefore, in these soils, preplant N application alone may result in N loss and lower yield in wet years. By using zone soil sampling as a basis for about half the required N applied as a preplant rate, followed by AO guided in-season N application, the efficiency of the total N applied increases, and small-scale in-season N variability is addressed. By using a zone sampling strategy for soil nitrate-N, farmers are able to address about 50% of the N variability within their fields. If farmers additionally utilize AO sensors to direct in-season N management a total of 75% of field N variability would be addressed according to this research.

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