5-2004

Defining Yield Goals and Management Zones to Minimize Yield and Nitrogen and Phosphorus Fertilizer Recommendation Errors

Jiyul Chang
South Dakota State University, jiyul.Chang@sdstate.edu

David E. Clay
South Dakota State University, david.clay@sdstate.edu

Charles G. Carlson
South Dakota State University, Gregg.Carlson@sdstate.edu

Cheryl L. Reese
South Dakota State University, Cheryl.Reese@sdstate.edu

Sharon A. Clay
South Dakota State University, sharon.clay@sdstate.edu

See next page for additional authors

Authors
Jiyul Chang, David E. Clay, Charles G. Carlson, Cheryl L. Reese, Sharon A. Clay, and Mike M. Ellsbury

SITE-SPECIFIC MANAGEMENT

Defining Yield Goals and Management Zones to Minimize Yield and Nitrogen and Phosphorus Fertilizer Recommendation Errors

Jiyul Chang, David E. Clay,* Charles G. Carlson, Cheryl L. Reese, Sharon A. Clay, and Mike M. Ellsbury

ABSTRACT

Three general approaches (minimize soil nutrient variability, yield, and fertilizer recommendation errors) have been used to assess nutrient management zone boundaries. The objective of this study was to determine the influence of different approaches to define management zones and yield goals on minimizing yield variability and fertilizer recommendation errors. This study used soil nutrient and yield information collected from two east-central South Dakota fields between 1995 and 2000. The crop rotation was corn (*Zea mays* L.) followed by soybean [*Glycine max* (L.) Merr.]. The four management zone delineation approaches tested were to: (i) sample areas impacted by old homesteads separately from the rest of the field; (ii) separate the field into grid cells; (iii) use geographic information systems or cluster analysis of apparent electrical conductivity, elevation, aspect, and connectedness to identify zones; and (iv) use the Order 1 soil survey. South Dakota fertilizer N and P recommendations were used to calculate fertilizer requirements. This study showed that management zones based on a 4-ha grid cell and an Order 1 soil survey had lower within-zone yield variability than the other methods tested. The best approaches for minimizing recommendation errors were nutrient specific. Nitrogen and P recommendations were improved using multiple years of yield monitor data to develop landscape-specific yield goals, sampling old homesteads separately from the rest of the field, and grid cell soil sampling to fine-tune N and P recommendations.

The shapes of management zones are sensitive to the information and classification approach used to derive them. This is a problem because many producers have asked, "which approach is best?" At least three different criteria for assessing management zone boundaries have been used. The first approach used nutrient variability to identify management zones. Directly or indirectly, Franzen et al. (1998), Mueller et al. (2000), Fleming et al. (2000), Mallarino and Wittry (2000), Franzen et al. (2002), and Chang et al. (2003) used this approach to assess management zone boundaries. These studies assume that a *good* sampling scheme minimizes soil nutrient variability within a management zone. Chang et al. (2003) reported that within-zone variability can be reduced by sampling old homesteads or areas impacted by animals separately from the rest of the field and that a 4-ha grid cell sampling was more consistent in reducing within-zone NO_3–N and Olsen-P variability than management zones based on soil attributes. Chang et al. (2003) assessment tool for comparing management zone delineation approaches was an F test ($F = s^2_{\text{field}}/s^2_{\text{pooled}}$).

The second general approach used management zones to minimize yield variability. Experiments that have tested this approach include Bakhsh et al. (2000), Fridgen et al. (2000), Diker et al. (2002), and Kitchen et al. (2002). These studies assume that the best sampling scheme explains the most yield variability. These studies typically calculate variance reductions using the equation, % variance reduction = $100(1 - s^2_{\text{management zone}}/s^2_{\text{field}})$. Fridgen et al. (2000) used a similar approach and reported that management zones based on elevation information could be used to account for 80% of the yield variation.

The third criterion for assessing management zone boundaries is to calculate the impact of the zone boundaries on the fertilizer recommendation error. Experiments that have attempted to solve this problem have determined the impact of landscape position on fertilizer responses (Malzer et al., 1999; Hurley et al., 2002). These experiments may require hundreds of plots and therefore may not be suitable for many production fields. An alternative approach is to use a model to calculate fertilizer recommendations. When using this approach, the recommendations are only as good as the model. It is important to point out that the model may not predict actual fertilizer requirements. Perhaps the most widely used and validated crop nutrient models are the fertilizer recommendation models. These models are based on extensive analysis and testing and were designed to determine long-term fertilizer responses. Many studies that have investigated management zone demarcation have not considered the effect of management zone demarcation on fertilizer recommendation errors. The objective of this study was to determine the influence of different approaches to define management zones and yield goals on minimizing yield variability (Criteria 2) and fertilizer recommendation errors (Criteria 3). A companion study (Chang et al., 2003) evaluated the impact management zone demarcation on explaining soil nutrient variability (Criteria 1).

MATERIALS AND METHODS

Site Description

This research was conducted in two 65-ha dryland fields located in east-central South Dakota. The field designated as

J. Chang, D.E. Clay, C.G. Carlson, C.L. Reese, and S.A. Clay, Plant Sci. Dep., South Dakota State Univ., Brookings, SD 57007; and M.M. Ellsbury, USDA-ARS, Northern Grain Insect Res. Lab., Brookings, SD 57006. South Dakota Exp. Stn. no. 3346. Research supported by South Dakota Experimental Station, USDA-CSREES, North Carolina Soybean Board, SDNSF EPSCOR (EPS-0091948), and NASA. Received 25 Sept. 2003. *Corresponding author (david_clay@sdstate.edu).

Published in Agron. J. 96:825–831 (2004).

677 S. Segoe Rd., Madison, WI 53711 USA

Abbreviations: EC_a, apparent electrical conductivity; GIS, geographic information systems; MSE, mean square error.

Table 1. Planting and harvest dates, annual precipitation (PPT), growing degree days (GDD), amount of fertilizer applied, crop varieties, and yield goals.

Field/year	Planting completed	Harvesting completed	PPT	GDD	Fertilizer applied N	Fertilizer applied P	Crop variety
			cm	°C	kg ha^{-1}	kg ha^{-1}	
Moody							
1995	21 May	9 Nov.	82	1130	119	26	Pioneer 3733 corn
1996	17 May	5 Oct.	51	1040	0	0	Parker soybean
1997	28 Apr.	27 Oct.	41	1140	154	37	Northrup King 4242 BT corn
1998	7 May	30 Sept.	48	1340	0	0	Kruger 188 soybean
1999	29 Apr.	21 Oct.	52	1160	190	46	Pioneer 36F30 corn
2000	2 May	27 Sept.	57	1180	0	0	Pioneer 92B05 soybean
Brookings							
1995	13 June	19 Oct.			0	0	Parker soybean
1996	20 May	25 Oct.			143	32	Pioneer 3733 corn
1997	25 May	1 Oct.			0	0	Northrup King S14M7 soybean
1998	24 Apr.	1 Nov.			190	46	Pioneer 37R71 corn
1999	23 May	5 Oct.			0	0	Pioneer 91B91 soybean
2000	25 Apr.	6 Oct.			176	55	Pioneer 37M34 corn

	Yield goals Moody	Yield goals Brookings
	Mg ha^{-1}	Mg ha^{-1}
County avg.	8.8	8.8
Field avg.	7.3	8.5
Landscape		
Summit		
Pretile	7.0	8.5
Posttile	7.0	8.5
Backslope		
Pretile	7.8	8.7
Posttile	11.1	11.6
Footslope		
Pretile	7.0	9.0
Posttile	10.7	12.3

Moody was located at 44°10′ N lat and 96°37′ W long, and the field designated as Brookings was located at 44°14′ N lat and 96°39′ W long. Soils at both sites were formed on calcareous glacial till parent materials deposited approximately 10 000 yr ago. The slope at Moody ranged from 0 to 7.2%, and the slope at Brookings ranged from 0 to 10%. Soil series descriptions for these sites were previously reported in Clay et al. (2001a). Dominant soils at Brookings in the summit/shoulder, backslope, and footslope areas were the Barnes (fine-loamy, mixed, superactive, frigid, Calcic Hapludoll), Brookings (fine-silty, superactive, frigid, Cumulic Hapludoll), and McIntosh (fine-silty, frigid Aeric Calciaquoll), respectively. Dominant soils in the summit/shoulder, backslope, and footslope areas in Moody were the Kransburg (fine-silty, superactive, frigid Calcic Hapludoll), Waubay (fine-silty, mixed, superactive, frigid Aquic Hapludoll), and Badger (fine-silty, frigid Aeric Calciaqoll), respectively.

The crop rotation was corn followed by soybean. At Moody, corn was planted in 1995, 1997, and 1999, and at Brookings, corn was planted in 1996, 1998, and 2000. Cultural and climatic information are available in Table 1. Tile lines in both fields were repaired in 1997. Herbicides and fertilizers were applied to minimize or eliminate yield reductions due to weed and nutrient deficiency. Fertilizer rates were decided by the producer following consultation with a crop consultant. Maintenance was conducted on the tiles located in poorly drained areas of the fields between 1996 and 1997.

Database Development

Rainfall and air temperatures were measured at a weather station located near the research sites (Table 1). Growing degree days from May to September were calculated. Corn grain yield was measured with a calibrated yield monitor mounted in a combine equipped with differentially corrected global positioning system (DGPS). The width of the corn harvesting head was 4.6 m (eight rows). Yield information was collected every second as the combine harvested the crop. Yield monitor data were removed from the database if the combine speed was lower than 1.78 m s^{-1} or higher than 3.05 m s^{-1} and if the flow rate exceeded ±3 standard deviations of the average flow rate. To confirm overall yield monitor accuracy, yield monitor data were compared with hand-harvested yields (2.55-m^2 area). Hand-harvested areas were located on four transects. The sampling points on each transect were separated by 30 m.

ArcView 3.2 (ESRI, Redland, CA), a geographic information systems (GIS) software program, was used to determine the average yield every year for each 0.1-ha area. Yields were converted to relative yields (Ry) across all site years using the equation:

$$Ry = measured/maximum \quad [1]$$

where the maximum value was equal to the highest corn yield during the preceding 6 yr. The maximum value used in Eq. [1] was 15.7 Mg ha^{-1} at both sites. The means and standard deviations of the measured yield values and the standardized yield values for 6 yr were calculated. Yield semivariograms were calculated using GS+ (Gamma Design Software, Plainwell, MI).

Soil samples from the 0- to 15- and 15- to 60-cm soil depths were collected at Moody from a 30- by 30-m slightly offset grid before planting corn in 1995. At Brookings, soil samples were collected from a 60- by 30-m slightly offset grid in 1997. Each sample consisted of 15 individual cores that were collected from within 1 m of the grid center. These samples were analyzed for Olsen P and NO_3–N (Olsen and Sommers, 1982; Maynard and Kalra, 1993). Details on the sampling protocol and laboratory methods are provided in Chang et al. (2003)

and Clay et al. (1997). At sampling sites, elevation and apparent electrical conductivity (EC_a) (Geonics Limited, Mississauga, ON, Canada) were measured (Chang et al., 2003). At each sampling point, EC_a was measured at a single point with an EM-38 at multiple times between 1995 and 1999. A comparison between sampling dates showed that the general patterns were not influenced by sampling date (Clay et al., 2001a). Data included in this classification were obtained in the spring of 1997. The relationship between topography and EC_a as well as the temporal changes in EC_a at these sites are discussed in Clay et al. (2001a).

Identifying Management Zone Boundaries

Details for locating management zone boundary lines are provided in Chang et al. (2003). These methods are summarized below. First, old aerial photographs (1950–1985) along with other evidence were used to separate the field into areas impacted by humans or animals (old homesteads or animal-impacted areas) and nonimpacted areas. Second, the field was split into 16 (4-ha), 9 (7-ha), and 4 (16-ha) square grid cells. Grid cell sampling is an approach where a composite sample is collected from a block with a specified size (Wollenhaupt et al., 1994). The soil sample from each block was analyzed for soil nutrients, and the resulting nutrient concentration represents the average value of the cell. Third, ArcView GIS (ESRI, 1996) was used to define management zones based on EC_a, elevation, aspect, and distance (physically connected or not) information. Forth, Mahalanobis distance and fuzzy *c*-means unsupervised clustering algorithms were used to identify different clusters based on EC_a, elevation, and aspect information (Johnson, 1998; Fridgen, 2000; USDA-ARS, 2000). Fifth, an Order 1 soil survey (1:3960), conducted by USDA-NRCS personnel (Soil Survey Staff, 1993), was used as a basis to separate the field. Each soil type was identified as a different management zone. Examples of the different zone maps are available in Chang et al. (2003).

Assessing Zone Boundaries

A two-step process for assessing zone boundary demarcation was used. In Step 1, the impact of management zones on explaining within-zone yield variability was determined (Criteria 2). In Step 2, the impact of management zone classification on the fertilizer recommendation error was determined (Criteria 3). All calculations are summed over field and years.

Step 1

The within-zone variability (s_p^2) was calculated using the equation:

$$s_p^2 = \sum_{i=1}^{z} (n_i - 1)s_i^2 \Big/ \left(\sum_{i=1}^{z} n_i - z \right) \quad [2]$$

where z was the number of management zones, n_i was the number of samples within zone i, and s_i^2 was the variance within zone i (Steel and Torrie, 1980). The whole-field variance was calculated for each data set using the equation:

$$s_{\text{field}}^2 = \sum_{i=1}^{n} (x_i - \bar{x})^2/(n - 1) \quad [3]$$

where x_i was the parameter value at each sampling point i and $\bar{x}$ was the whole-field mean. An F test (s_{field}^2/s_p^2) at $P < 0.1$ was used to determine significant differences (Steel and Torrie, 1980). Three years of data from each field were included in these calculations. Each zone within a year was treated as a different zone.

Step 2

The mean square errors (MSE) of the different fertilizer recommendations were calculated using the equation:

$$\text{MSE} = \sum_{i=1}^{n} (\text{EFR}_i - \text{MFR}_i)^2/n \quad [4]$$

where n was equal to the total number of comparisons over 3 yr in the two fields (3609), i was each grid soil-sampling point, EFR was the estimated fertilizer recommendation for each management zone (based on mean yield and nutrient content within a zone), and MFR was the predicted fertilizer recommendation (based on measured yield and nutrient concentration at each point within a zone).

The N and P fertilizer recommendation models used in EFR and MFR calculations were

$$\text{N recommendation (kg N ha}^{-1}) = 21.42 \times \text{YG} - \text{STN} - \text{PCC} \quad [5]$$

$$\text{P recommendation (kg P ha}^{-1}) = (0.7 - 0.044 \times \text{STP}) \times \text{YG} \times 7.86 \quad [6]$$

where YG was the yield goal in Mg ha^{-1} at 15.5% moisture, STN was the amount of NO_3–N (mg N kg^{-1}) contained in the surface 60 cm, PCC was the previous crop credit (legume credit, 44.8 kg N ha^{-1}), and STP was the soil test P (mg P kg^{-1}) (Gerwing and Gelderman, 1998). Data used for STN and STP values were collected at Moody in the spring of 1995 and at Brookings in the spring of 1997. These models were used because they are simple to understand, the most widely tested and validated fertilizer recommendation models in South Dakota, and are widely accepted by producers. A considerable amount of uncertainty was associated with selecting yield goals, and therefore the simulation tested three approaches to define yield goals. These approaches were (i) the county average (8.8 Mg ha^{-1} at 15.5% moisture; 140 bu acre^{-1}), (ii) the field average between 1995 and 2000, and (iii) the average yield at specific landscape positions (Table 1).

An F test ($\text{MSE}_{\text{field}}/\text{MSE}_{\text{man. zone}}$) at $P < 0.1$ was used to determine significant differences. The average difference between the predicted and measured fertilizer recommendations (Bias) were calculated using the equation:

$$\text{Bias} = \sum_{i=1}^{n} (\text{EFR}_i - \text{MFR}_i)/n$$

A negative value indicates that, on average, the predicted recommendation underestimated the recommendations in kilograms per hectare.

RESULTS AND DISCUSSION

Criteria 1: Minimizing Nutrient Variability

In a companion paper, Chang et al. (2003) discussed the impact of different classification approaches to define management zones on Olsen P and nitrate N sampling errors. Findings from this study showed that Olsen P and nitrate N sampling error could be minimized by sampling old homesteads separately from the rest of the field combined with 4-ha grid cell sampling.

Criteria 2: Minimizing Yield Variability

Spatial and Yield Variability

Corn yield contained spatial structure at all sites (Table 2). The highest nugget/sill ratio was observed at

Table 2. Statistical summary of whole field and old homestead locations and semivariogram of whole field for yield over the 6 yr.

	Moody			Brookings		
	1995	1997	1999	1996	1998	2000
	Mg ha^{-1}					
Whole field						
Mean	5.77	6.51	9.48	6.17	10.50	8.89
Median	6.04	6.69	9.66	6.38	10.55	9.08
Variance	1.80	1.07	1.65	2.35	1.70	1.52
Skewness	−0.72	−0.68	−0.47	−0.65	−0.49	−0.36
Kurtosis	3.08	3.44	2.97	2.99	3.37	2.69
Homestead						
Mean	6.57	6.71	7.64	8.32	10.95	10.04
Variance	0.52	0.83	1.08	0.97	1.90	0.97
	Semivariogram					
Nugget	186	199	106	120	151	133
Sill	514	398	440	761	481	675
Range, m	177	913	87.0	140	140	854
Model	exp.†	exp.	exp.	exp.	exp.	lin.‡
Nugget/sill	0.36	0.50	0.24	0.16	0.31	0.20

† Exp., exponential.
‡ Lin., linear.

Moody in 1995, and the lowest ratio was observed at Brookings in 1996. Average corn yields between 1995 and 1997 were lower than yields between 1998 and 2000. Low yields 1995 and 1998 were attributed to a heavy snowfall; a cold, wet spring; and a clogged tile. Generally, corn yields increased every year from 1995 to 2000.

Histograms of corn yields harvested from summit/shoulder, backslope, and footslope areas over the 3 yr showed that landscape position impacted probability distributions. At Moody, one peak was observed at approximately 0.5 (7.03 Mg ha^{-1}) in summit/shoulder areas (Fig. 1) while in backslope [0.55 (7.23 Mg ha^{-1}) and 0.7 (10.0 Mg ha^{-1})] and footslope [0.4 (5.35 Mg ha^{-1}) and 0.8 (10.7 Mg ha^{-1})] areas, two peaks were observed. Histograms such as these are useful in developing landscape-specific yield goals.

Similar results were observed at Brookings (data not shown). In summit/shoulder areas, one peak was observed at about 0.5 (8.45 Mg ha^{-1}). In backslope areas, two peaks were observed. One peak was at 0.5 (7.55 Mg ha^{-1}) while the other peak was at 0.6 (11.63 Mg ha^{-1}). In footslope areas, two peaks were also observed. One peak was at 0.4 (6.29 Mg ha^{-1}) while the other peak was at 0.7 (12.26 Mg ha^{-1}). In both fields, landscape-induced differences in the histograms were attributed to either too much or too little plant available water. The low yields in both fields in the footslope and backslope positions were associated with years before tile maintenance. Related work showed that low yields in summit/shoulder areas resulted from water stress (Clay et al., 2001b).

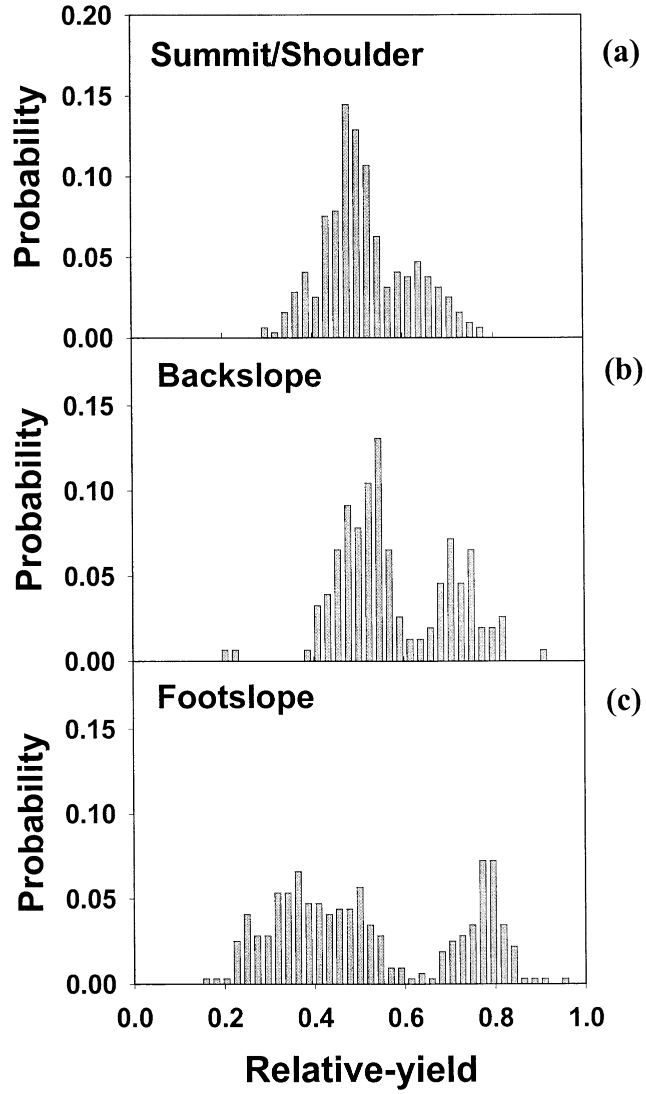

Fig. 1. Histogram of 3 yr (1995, 1997, and 1999) of standardized corn yields (measured yield/15.7 Mg ha^{-1}) at selected landscapes in Moody. The landscape positions are the (a) summit/shoulder, (b) backslope, and (c) footslope.

Management Zone Impact on Minimizing Yield Variability

Relative to the whole-field variance, splitting the field into two zones, old homestead and the rest of the field, did not reduce the corn yield pooled variance (Table 3). However, separating into grid cells, soil type, or using GIS or cluster analysis of soil attribute information reduced within-zone yield variability (s_p^2). For all the methods tested, 4-ha grid cell and using the Order 1 soil survey to identify soil zones had the lowest pooled variances. These results indicate that defining zones based on the soil survey had a larger impact on reducing within-zone yield variability than defining zones based on homestead location. These results were different than those reported for Criteria 1 (Chang et al., 2003). Differences between Criteria 1 and 2 were attributed to two factors. First, Olsen P concentrations were impacted by activities that occurred around old homesteads 30 to 50 yr ago. Second, yields in the areas with the highest P concentrations (summit/shoulder areas) were limited by water stress. In other words, areas with the highest P concentrations had the lowest yields.

Criteria 3: Fertilizer Recommendation Errors

Fertilizer Recommendations

Fertilizer recommendation models for South Dakota require both yield and soil test information (Gerwing

Table 3. The influence of different approaches on explaining corn yield variability. Data from both Moody and Brookings collected between 1995 and 2000 were included in these calculations.

		Old homestead			
		Sampled separately		Not sampled separately	
Sampling methods	Management zones per field	Pooled variance†	F test	Pooled variance	F test
Grid cell					
4-ha grid cell	16	0.682	1.26†	0.676	1.27†
7-ha grid cell	9	0.726	1.18†	0.721	1.19†
16-ha grid cell	4	0.772	1.11‡	0.777	1.10‡
GIS					
EC_a–elev.§	19	0.704	1.22†	0.702	1.22†
EC_a–aspect	34	0.753	1.14†	0.760	1.13†
EC_a–distance	28	0.731	1.17†	0.736	1.16†
Cluster					
EC_a–elev.	7	0.744	1.15†	0.749	1.14†
EC_a–aspect	4	0.801	1.07	0.811	1.05
EC_a–elev.–aspect	9	0.831	1.03	0.847	1.01
Soil survey	25	0.633	1.35†	0.635	1.35†
Whole field		0.839		0.856	

† Pooled variance values are significantly different with whole field at $P = 0.05$. The degrees of freedom of the numerator and denominator were 1200 and $1200 - n$, respectively.
‡ Pooled variance values are significantly different with whole field at $P = 0.1$. The degrees of freedom of the numerator and denominator were 1200 and $1200 - n$, respectively.
§ EC_a, apparent electrical conductivity; elev., elevation.

and Gelderman, 1998). The yield goals can be based on many different databases (county, field, or landscape specific). Some agronomists recommend using county averages for yield goals while others prefer using the highest yield measured over the past couple of years (Taylor, 1998). Hanway and Sander (1997) recommended that the yield goal should be flexible; if climatic conditions exist that enhance yields, then the yield goal should be increased, and if climatic conditions exist that are detrimental to yield, then the yield goal should be reduced. Taylor (1998) used a slightly different approach to define the yield goal and suggested that yield monitor data from previous years combined with a uniform yield goal could be used to improve yield goal predictions. Irrespective of the approach used to select the yield goal, most agronomists agree that the selection of the yield goal is one of the most important decisions that a producer can make. Based on the importance in selecting a yield goal, the simulation used three different approaches to define the yield goals.

The predicted fertilizer recommendations were influenced by the yield goal. Fertilizer recommendations were lowest for the pre-tile drainage landscape specific yield goals and highest for the post-tile drainage landscape specific yield goals (Table 4).

Relative to the whole-field sampling, sampling the old homesteads separately from the whole field or identifying the management zones based on the Order 1 soil survey increased P recommendation (Table 4). Differences in the P recommendations between the Order 1 and the 4-ha grid cell sampling were attributed to areas having high P (old homesteads). For example, at Moody, the homestead area was located on Vienna (Calcic Haplodoll) and Kranzburg (Calcic Hapludoll) soils. These soils occupied 42% (27 ha) of the field. By separating the 27 ha into two zones, with and without the old homestead, P recommendation for the area not containing the old homestead was increased 173 kg P, when the field average yield goal was used.

Sampling the old homestead separately from the rest of the field had a minimal impact on the N recommendation. The highest N recommendation was associated with the landscape-specific recommendation after tile maintenance. Nitrogen recommendations for the grid cell sampling were higher than those observed for the Order 1 soil survey or the whole-field approaches.

Table 4. The influence of six approaches for identifying management zones and three approaches for determining yield goals on P and N fertilizer recommendations. The fertilizer recommendations were summation of the two fields. The three approaches for determining yield goals were the county average (8.8 Mg ha^{-1}), field average (7.3 and 8.5 Mg ha^{-1} for Moody and Brookings, respectively), and landscape specific.

					Landscape specific			
	County average		3-yr average		Pretile drainage		Posttile drainage	
Sampling methods	P	N	P	N	P	N	P	N
	kg two fields^{-1}							
Old homestead								
Sampled separately								
4-ha grid cell	995	10 010	761	8 360	678	5 310	947	12 170
Soil survey	748	9 210	620	7 320	582	4 980	814	12 130
Whole field	720	8 810	592	6 530	566	4 660	797	11 420
Not sampled separately								
4-ha grid cell	898	9 990	756	8 340	674	5 310	943	12 140
Soil survey	542	9 280	447	7 310	416	4 970	604	12 130
Whole field	516	8 880	424	6 430	405	4 560	570	11 490

Table 5. The influence of six sampling approaches and three approaches to define yield goals on the fertilizer recommendation mean square error (MSE) and fertilizer recommendation bias. The three approaches for determining yield goals were the county average, field average, and landscape specific.

	Yield goal approach											
	County average				3-yr average				Landscape specific			
Sampling technique	P	P	N	N	P	P	N	N	P	P	N	N
	MSE	Bias	MSE	Bias	MSE	Bias	MSE	Bias	MSE	Bias	MSE	Bias
Old homestead												
Sampled separately												
4-ha grid cell	64.0	−2.06	1980	12.53	64.0	−0.35	1830	−12.36	59.0	−3.90	1050	−2.06
Soil survey	74.0	−5.11	1960	1.04	76.0	−6.99	2290	−27.11	71.0	−6.36	1330	−7.72
Whole field	75.0	−5.39	1910	0.36	78.0	−7.27	2480	−33.06	73.0	−6.52	1340	−10.36
Not sampled separately												
4-ha grid cell	65.0	−2.26	2070	13.37	65.0	−4.52	1870	−12.66	61.0	−4.10	1100	−2.64
Soil survey	87.0	−7.77	2000	2.01	91.0	−9.25	2330	−28.81	86.0	−8.73	1370	−8.76
Whole field	84.0	−8.00	1940	−1.34	90.0	−9.42	2580	−36.58	85.0	−8.85	1250	−11.78

Fertilizer Recommendation Error

The 4-ha grid cell sampling had lower P fertilizer MSE and bias than the other techniques tested (Table 5). A large MSE and small bias indicates that there are large differences between measured and predicted values and that, on average, these differences sum to a small value. Sampling by Order 1 soil series did not significantly reduce N or P MSE values; however, relative to the whole-field sampling, it had slightly smaller bias. Sampling the old homesteads separately from the rest of the field reduced P recommendation MSE and bias values and had a minimal impact on N MSE and bias values.

The criteria to select a yield goal influenced N recommendation MSE and bias values. If the county average was used, then management zone demarcation did not improve N recommendations. If the 3-yr corn average was used, then the 4-ha grid cell sampling improved N recommendations. However, relative to comparative treatments, the highest negative bias was associated with the 3-yr average. The lowest N recommendation MSE was observed for the landscape-specific yield goals. In this treatment, the lowest N bias was associated with the 4-ha grid cell sampling.

CONCLUSIONS

Results from this study show that both soil nutrient variability and yield variability must be considered in developing management zones. Chang et al. (2003) reported that one of the most important factors for reducing nutrient variability was to sample the old homestead separately from the rest of the field (Criteria 1). However, sampling old homesteads separately from the rest of the field did not reduce within-zone yield variability (Criteria 2). The management zone approach that was most successful at minimizing yield variability was the 4-ha grid cell and the Order 1 soil survey. These results showed that it is possible to arrive at different answers for different questions. When both nutrient and yield variability are considered, the probability of selecting an appropriate approach to define zones may be improved.

The simulation using the South Dakota N and P recommendation models showed that selecting an appropriate yield goal is one of the most important decisions a producer can make. The landscape-specific yield goals generally had less error and bias than recommendations based on county averages or field averages (Table 5). Phosphorus and N recommendations could be further improved by sampling old homesteads separately from the rest of the field and grid cell soil sampling. Results from this study show that: (i) multiple years of yield monitor data can be used to select yield goals; (ii) if only N is considered in developing management zones, then P recommendations may not be optimized and vice versa; (iii) sampling the old homestead separately from the rest of the field improved P recommendations and had a small impact on N recommendations; and (iv) P recommendations were less impacted by landscape-specific yield goals than N recommendations.

REFERENCES

Bakhsh, A., T.S. Colvin, D.B. Jayns, R.S. Kanwar, and U.S. Tim. 2000. Spatio-temporal analysis of yield variability for a corn–soybean field in Iowa. Trans. ASAE 43:31–38.

Chang, J., D.E. Clay, C.G. Carlson, S.A. Clay, D.D. Malo, R. Berg, J. Kleinjan, and W. Weibold. 2003. Different techniques to identify management zones impact nitrogen and phosphorus sampling variability. Agron. J. 95:1550–1559.

Clay, D.E., C.G. Carlson, K. Brix-Davis, J. Oolman, and B. Berg. 1997. Soil sampling strategies for estimating residual nitrogen. J. Prod. Agric. 10:446–452.

Clay, D.E., J. Chang, D.D. Malo, C.G. Carlson, C.L. Reese, S.A. Clay, M. Ellsbury, and B. Berg. 2001a. Factors influencing spatial variability of soil apparent electrical conductivity. Commun. Soil Sci. Plant Anal. 32:2993–3008.

Clay, D.E., S.A. Clay, Z. Liu, and C.L. Reese. 2001b. Spatial variability of C-13 isotopic discrimination in corn (*Zea mays*). Commun. Soil Sci. Plant Anal. 32:1813–1827.

Diker, K., G.W. Buchleiter, H.J. Farahani, D.F. Heermann, and M.K. Brodahl. 2002. Frequency analysis of yield for delineating management zones. *In* P.C. Pierre (ed.) Precision agriculture [CD-ROM]. Proc. Int. Conf., 6th, Minneapolis, MN. 14–17 July 2002. ASA, CSSA, and SSSA, Madison, WI.

ESRI. 1996. Using ArcView. ESRI, Redland, CA.

Fleming, K.L., D.G. Westfall, and W.C. Bausch. 2000. Evaluating management zone technology and grid soil sampling for variable rate nitrogen application. *In* P.C. Robert et al. (ed.) Precision agriculture [CD-ROM]. Proc. Int. Conf., 5th, Minneapolis, MN. 16–19 July 2000. ASA, CSSA, and SSSA, Madison, WI.

Franzen, D.W., L.J. Cihacek, V.L. Hofman, and L.J. Swenson. 1998. Topography-based sampling compared with grid sampling in the northern Great Plains. J. Prod. Agric. 11:364–370.

Franzen, D.W., D.H. Hopkins, M.D. Sweeney, M.K. Ulmer, and A.D. Halvorson. 2002. Evaluation of soil survey scale for zone development of site-specific nitrogen management. Agron. J. 94:381–389.

Fridgen, J.J. 2000. Development and evaluation of unsupervised clustering software for sub-field delineation of agricultural fields. M.S. thesis. Univ. of Missouri, Columbia.

Fridgen, J.J., N.R. Kitchen, and K.A. Sudduth. 2000. Variability of soil and landscape attributes within sub-field management zones. *In* P.C. Robert et al. (ed.) Precision agriculture [CD-ROM]. Proc. Int. Conf., 5th, Minneapolis, MN. 16–19 July 2000. ASA, CSSA, and SSSA, Madison, WI.

Gerwing, J., and R. Gelderman. 1998. Fertilizer recommendations guide (EC 750) [Online]. Available at http://plantsci.sdstate.edu/woodardh/soiltest/ (verified 11 Feb. 2004). Coop. Ext. Serv., South Dakota State Univ., Brookings.

Hanway, D.G., and D.H. Sander. 1997. Setting your corn yield goal is important [Online]. NebGuide G79–481-A. Available at http://www.ianr.unl.edu/pubs/fieldcrops/g481.htm (accessed May 2003; verified 10 Feb. 2004). Coop. Ext., Inst. of Agric. and Nat. Resour., Univ. of Nebraska, Lincoln.

Hurley, T.M., G.L. Malzer, and B. Killian. 2002. A test of within field variation for corn responses to nitrogen in central Minnesota. *In* P.C. Robert et al. (ed.) Precision agriculture [CD-ROM]. Proc. Int. Conf., 6th, Minneapolis, MN. 14–17 July 2002. ASA, CSSA, and SSSA, Madison, WI.

Johnson, D. 1998. Applied multivariate methods for data analysis. Duxbury Press, Thomson Publ., Pacific Grove, CA.

Kitchen, N.R., K.A. Sudduth, S.T. Drummond, J.J. Fridgen, W.J. Wiebold, and C.W. Fraisse. 2002. Procedures for evaluating unsupervised classification to derive management zones. *In* P.C. Robert et al. (ed.) Precision agriculture [CD-ROM]. Proc. Int. Conf., 6th, Minneapolis, MN. 14–17 July 2002. ASA, CSSA, and SSSA, Madison, WI.

Mallarino, A.P., and D.J. Wittry. 2000. Identifying cost effective soil sampling schemes for variable-rate fertilization and liming. *In* P.C. Robert et al. (ed.) Precision agriculture [CD-ROM]. Proc. Int. Conf., 5th, Minneapolis, MN. 16–19 July 2000. ASA, CSSA, and SSSA, Madison, WI.

Malzer, G.l., D.J. Mulla, and T.S. Murrell. 1999. Getting specific with site-specific nutrient management. SSMG 23. *In* D. Clay et al. (ed.) Site specific management guidelines [Online]. Available at http://www.ppi-far.org/ssmg (accessed 22 Sept. 2003; verified 10 Feb. 2004). Potash and Phosphate Inst., Norcross, GA.

Maynard, D.G., and Y.P. Kalra. 1993. Nitrate and exchangeable ammonium nitrogen. p. 25–38. *In* M.R. Carter (ed.) Soil sampling and methods of analysis. Lewis Publ., Boca Raton, FL.

Mueller, T.G., K.L. Wells, G.W. Thomas, R.I. Barnshisel, W.J. Hartsock, S.A. Shearer, and A. Kumar. 2000. Soil fertility map quality: Case study in Kentucky. *In* P.C. Robert et al. (ed.) Precision agriculture [CD-ROM]. Proc. Int. Conf., 5th, Minneapolis, MN. 16–19 July 2000. ASA, CSSA, and SSSA, Madison, WI.

Olsen, S.R., and L.E. Sommers. 1982. Phosphorus. p. 403–430. *In* A. Klute (ed.) Methods of soil analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Soil Survey Staff. 1993. USDA handbook 18. Soil survey manual. NRCS, Washington, DC.

Steel, R.G.D., and J.H. Torrie. 1980. Principles and procedures of statistics. 2nd ed. McGraw-Hill, New York.

Taylor, R.W. 1998. Realistic yield goals for crops considerations and suggestions [Online]. Agron. Fact Ser. AF-03. Available at http://ag.udel.edu/extension/information/af/af-03.htm (verified 11 Feb. 2004). Delaware Coop. Ext., Univ. of Delaware, Newark.

USDA-ARS. 2000. Management Zone Analyst 1.0 [Online]. Available at http://www.fse.missouri.edu/mpac/whatsnew.htm (verified 11 Feb. 2004). Missouri Precision Agric. Cent., Univ. of Missouri, Columbia.

Wollenhaupt, N.C., R.P. Wolkowski, and M.K. Clayton. 1994. Mapping soil test phosphorus and potassium for variable-rate fertilizer applications. J. Prod. Agric. 7:441–448.