

## SPATIAL VARIABILITY OF PLANT ANALYSIS CALCIUM AND MAGNESIUM LEVELS BEFORE AND AFTER LIMING

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**ABSTRACT:** Plant samples were taken in an 82.5 ft grid at an early and late sampling date in both 1991 and 1992 from a forty acre field in Illinois. Calcium (Ca) and magnesium (Mg) were analyzed on each sample and maps were made showing the levels of each nutrient within the field. Soil pH measurements were also made from each of the same sampling locations following each year of plant sampling. In the fall of 1991, a calcitic lime application was made using soil pH informations from the 1991 soil sampling to determine the boundaries and rate of the application. Calcium and Mg levels in 1991 roughly defined the area of low pH, except for the early sampled Mg levels. However, low Ca and Mg levels did not always indicate low pH levels. High Ca and Mg levels did not always indicate high pH levels. Following liming, plant Ca levels correlated better with soil pH and represented areas of high and low pH better than plant Mg. Other factors which influenced Ca and Mg levels may have been high levels of competitive cations, disease injured plants, and subsoil pH not described by surface pH measurement.

### INTRODUCTION

Spatial studies of plant nutrients have focused on soil sampling and soil test results to define areas of high and low nutrient availability (Burgess et al., 1981; Webster, 1985; Warrick et al., 1986; Miller et al., 1988). Soil testing has long been the preferred method of determining the nutrient status for crops. Soil sampling has several practical advantages over plant analysis including being able to

sample at nearly every time of year. The soil sampler can drive a vehicle across the field when crops do not interfere, thereby increasing the number of samples which could be taken in a day while decreasing sampler fatigue. Plant sample preparation also can require strong acids which most soil testing procedures do not require, making soil testing somewhat safer for technicians.

Critical plant nutrient levels have been established for many crops. While these levels are applicable across wide regions, soil test critical levels and procedures tend to be more localized. Most states and countries have soil testing procedures from which local recommendations are made (Fixen and Grove, 1990). Many regions recognize similar plant analysis critical levels and procedures for extraction and element determination (Jones et al., 1990). Plant analysis bypasses the soil nutrient interactions and looks directly at whether the nutrients are present in sufficient quantities in the plants.

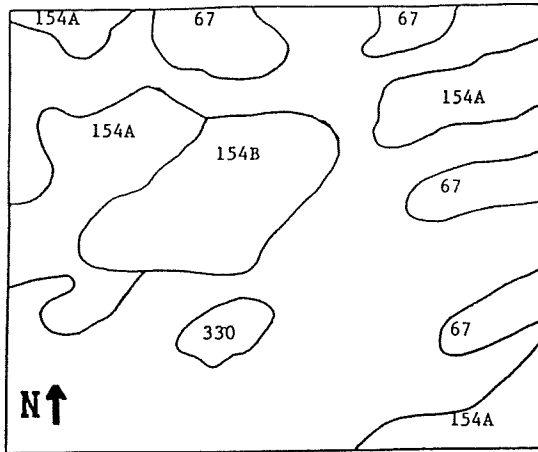
There is a practical problem of sampling several fields during the recommended plant sampling periods in the crop growing season, such as early tassel or five-leaf growth stage of corn. Plant analysis is usually more expensive than soil analysis. However, there might be advantages of plant analysis over soil testing in determining areas in a field which would respond to fertilization. Mostafa and Ulrich (1973) found that sugarbeets may become Ca deficient despite Ca levels in nutrient solution which would normally be described as adequate.

Soil pH measurement and interpretation relies on the direct or indirect effect of soil Ca and Mg levels on base exchange and lime potential (Mehlich, 1943; Schofield and Taylor, 1955; Clark and Hill, 1964). Since agricultural limestone contains considerable amounts of calcium and magnesium carbonates, it suggests that plant Ca and Mg levels may be good predictors of soil pH levels. There may be methods in the future which would improve sample collection techniques and/or utilize less expensive methods of analysis which would make large numbers of plant samples easier and more economical to collect and analyze.

The purpose of this study is to use plant analysis to determine the plant Ca and Mg concentrations in a field and determine how well the plant Ca and Mg levels reflect soil pH levels.

## MATERIALS AND METHODS

A 40-acre field near Mansfield, IL was sampled each year during 1991 and 1992 for both soil and plant chemical properties in an 82.5 ft. grid. The Mansfield tract was described in detail by Peck (1991). A soil type map is shown in Figure 1.



- 67 Harpster sil, 0-2x slope
- 154A Flanagan sil, 0-2x slope
- 154B Flanagan sil 2-4x slope
- 330 Peotone sil

Figure 1. Mansfield soil type map.

The major soil types are Flanagan silt loam (fine, montmorillinitic, mesic Aquic Argiudolls) Drummer silty clay loam (fine-silty, mixed, mesic Typic Haplaquolls) and Harpster silty clay loam (finesilty, mesic Typic Calciaquolls). The field had last been limed in 1982 (Franzen, 1993).

Five 7-inch deep soil cores were collected from each sampling site with one core in the center of each plot and the other four cores taken from the corners of a 15 foot square surrounding the central core. The five cores were placed in a common bag, dried at 36°C, pulverized, and analyzed for soil pH in a soil paste as described by Eckert (1988). The Mansfield tract was planted to corn in 1991 and to soybeans in 1992.

Two plant samplings were taken each year. The first sampling, described as the early sampling, was taken when the plants were in the five leaf stage. Plants were cut at the soil level, being careful not to contaminate the plants with soil. Approximately ten plants were taken for each sample. The second sampling, described as

the late sampling, was done in corn when most of the field was in the early tassel stage. The leaves below and opposite the ear of ten corn plants were removed with a sharp knife. With soybeans, the late sampling was performed when the plants were in early pod fill and the rows were not yet completely closed together. At this stage, the third leaf from the top of the soybean plant, usually the first fully developed leaf was pulled from 20 plants within each plot for each sample.

After drying in a forced air oven at 80°C, the plant samples were ground to pass a 60-mesh screen, and stored in polyethylene bags. The samples were then digested using a CEM microwave oven. From 0.2 to 0.5 g of plant tissue, depending on the year and crop, were weighed and placed in a microwave bomb. Ten mL concentrated nitric acid was added to the bomb under a hood and allowed to stand for 10 minutes. Five mL concentrated HCl was then added to the bomb which was then capped and torque sealed to manufacturers specifications. The microwave was then programmed to high output for 6 minutes, followed by 12 minutes at low output. The bombs were allowed to cool, and then were uncapped, and the resulting clear solution decanted into nalgene storage bottles. The digest was then diluted and analyzed by inductively couple plasma (ICP) emission spectrometry for Ca and Mg.

Plant Ca concentrations and plant Mg concentrations were entered into the geo-statistical mapping program GS+(Gamma Design Software, Plainwell, MI). The program was used to determine spatial statistics of the data set. Mapping of soil pH, plant Ca, and plant Mg concentrations was done with the program Surfer (Golden Software Co., Golden CO). Since the sample locations were regularly spaced, inverse distance squared estimates of unsampled points were used as an unsampled point estimation tool (Isaaks and Srivastava, 1989; Wollenhaupt, 1994).

In the fall of 1991 following soil sampling and pH analysis, ten acres in the northwest and west central area of the field were limed at the rate of 4 tons/A. The lime used was standard calcitic agricultural limestone from the Fairmount, IL quarry of Vulcan Materials. The Mg content was less than 2%. Before liming, the area of the field to be limed was flagged off. The lime was applied with the cooperation of Shields Soil Service, Inc., Saybrook, IL and their veteran applicator, Lyndon Getty. The lime was applied with a Terragator 1253 with a New Leader box fitted with a Dickey-John belt speed regulator. The lime was applied in three different passes, splitting the middles of each successive application. The first pass applied 2 tons/A. The second pass applied 1 ton/A, and the third pass applied 1 ton/A for a total of 4 tons/A. The researcher rode in the applicator bed with a shovel to make sure that the lime exited the end gate evenly.

Mapping of 1991 and 1992 low and high Ca and Mg levels were compared to soil pH mapping by overlaying maps and comparing areas of relatively high and low values with the corresponding soil pH map. Correlations and fit into soil test categories were compared.

### RESULTS AND DISCUSSION

In 1991 there was a significant positive correlation between soil pH and 5 leaf Ca, soil pH and ear leaf Ca and soil pH and ear leaf Mg (Table 1). The 1991 Mansfield soil pH map is shown in Figure 2. The heavy dashed line in Figure 2 outlines the area which received a lime application in the fall of 1991 following sampling.

The 1991 Mansfield 5 leaf Ca concentration map is shown in Figure 3. The 1991 Mansfield ear leaf Ca concentration map is shown in Figure 4. The Mansfield 5 leaf 1991 Mg concentration map is shown in Figure 5, and the Mansfield ear leaf 1991 Mg concentration map in Figure 6. The area in the east central region of the field is a low, very poorly drained area of the field with no tile outlet. In years of normal or wetter rainfall, crops become flooded and die in that area. Crops growing in that area during the study were often damaged with standing water, and the low Ca and Mg levels in this area were the result of poor crop growth because of the excess water and not low pH, as shown in Figure 2.

Calcium and Mg levels at both the early and late sampling dates were subjected to geostatistical analysis to determine spatial statistics of the samplings. A summary of general statistics is shown in Table 2 and geostatistics are displayed in Table 3. All of the samplings have highly correlated variogram models which indicates that all samplings were spatially variable.

The maps made with plant analysis data from the 1991 Ca and Mg concentration maps show similar boundaries between lower and higher Ca and Mg levels. The 1991 early and late sampled Mg maps show very similar boundaries. The low Mg levels in the northwest correspond closely to the low pH area to which lime was applied. However, the low Mg levels in the east in the early and late sampled maps are mostly in areas of high pH. The eastern area is also in the region of high seasonal soil water, plant disease, and also in an area of relatively high potassium (K) levels (Franzen and Peck, 1993).

The early season 1991 plant Ca concentration map shows low Ca in the northwest in the general area of low pH. There is also an area of low pH and low

**Table 1. Correlation (r) between soil pH and plant Ca-Mg levels.**

Comparison	1991	1992
Soil pH and early Ca	0.382	0.509
Soil pH and late Ca	0.291	NS
Soil pH and early Mg	NS	NS
Soil pH and late Mg	0.383	0.223
Early Ca and late Ca	0.349	0.232
Early Mg and late Mg	0.610	0.295

NS denotes that the correlation is not significant at  $P < 0.01$  level.

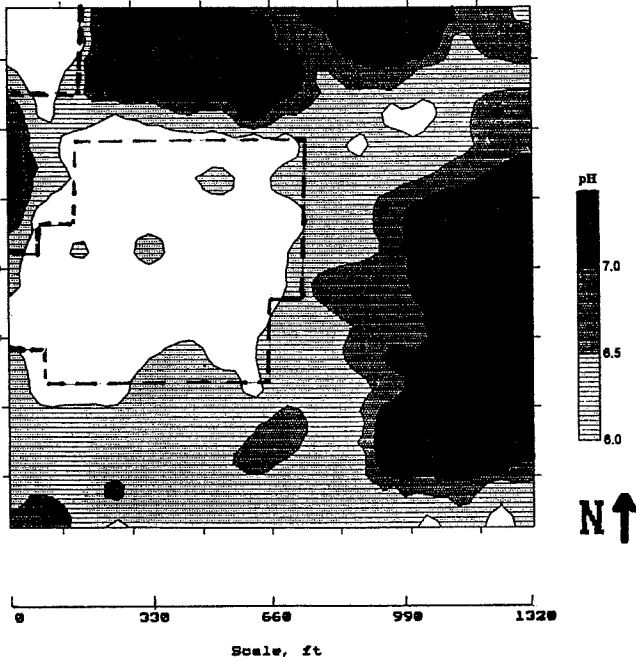


Figure 2. Mansfield pH 1991.

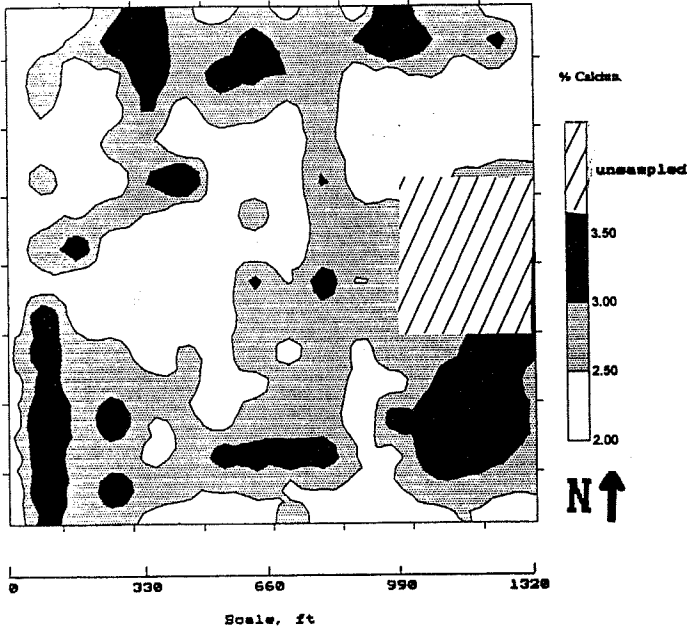


Figure 3. Mansfield 1991 5 leaf corn % Ca.

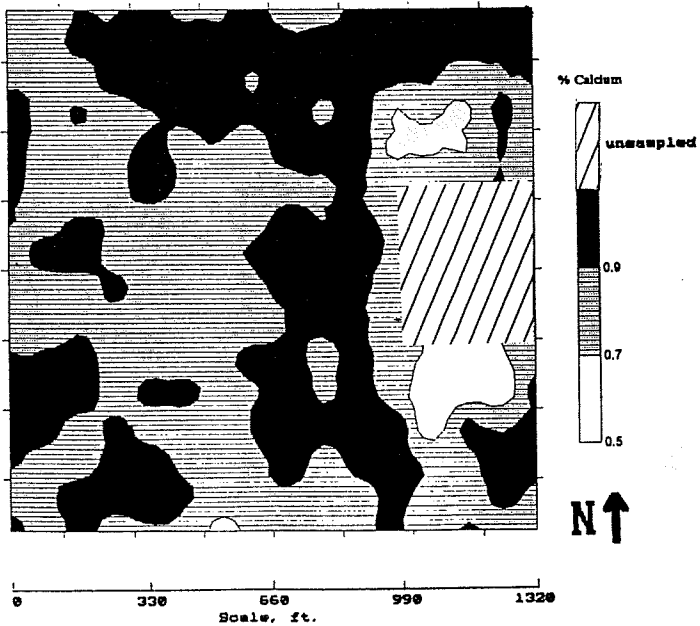


Figure 4. Mansfield 1991 ear leaf corn % Ca.

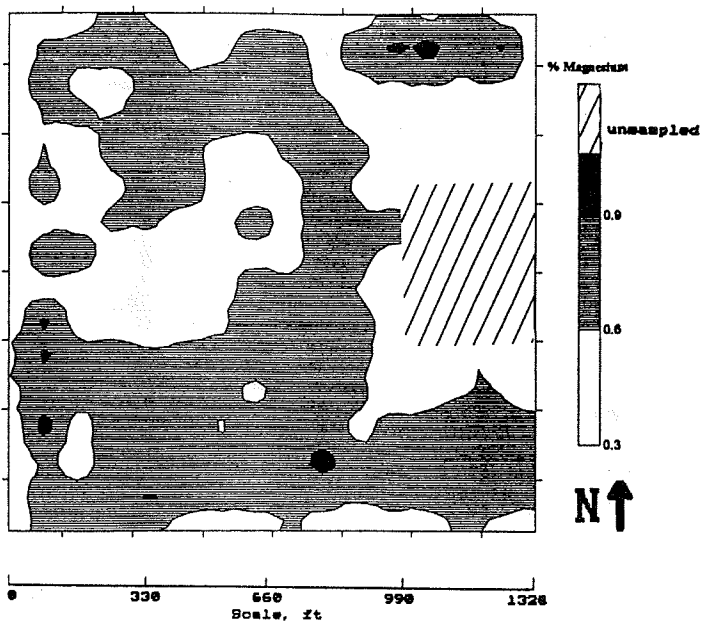


Figure 5. Mansfield 1991 5 leaf corn % Mg.

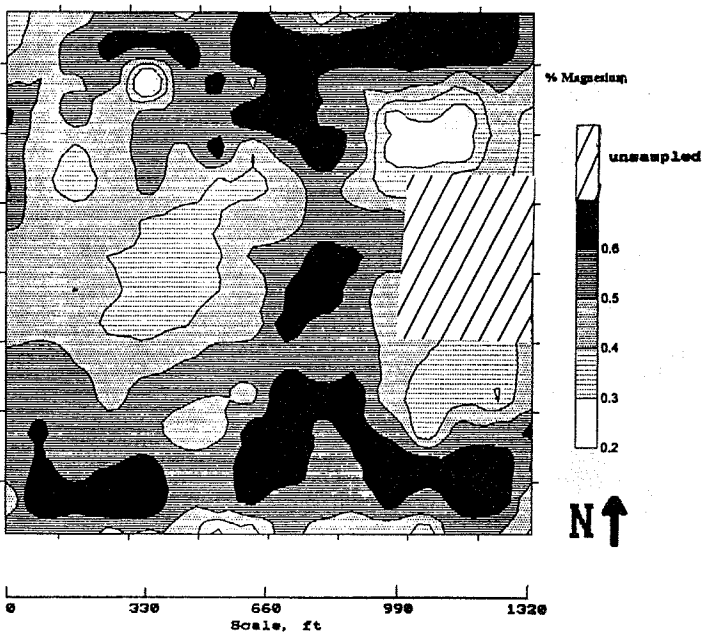


Figure 6. Mansfield 1991 ear leaf corn % Mg.



**Table 2. Summary of statistics.**

Sampling date	n	Mean	Standard Deviation	Skewness	Kurtosis	Transformation
1991 early Mg	232	0.60	0.16	0.108	2.487	None
1991 late Mg	236	0.51	0.12	-0.073	3.387	None
1992 early Mg	256	0.69	0.10	0.124	2.457	None
1992 late Mg	256	0.35	0.07	-0.563	3.577	None
1991 early Ca	232	0.92	0.19	0.010	2.809	Logrithmic
1991 late Ca	236	0.89	0.11	-0.283	4.606	None
1992 early Ca	255	0.77	0.10	0.102	2.819	Logrithmic
1992 late Ca	256	1.08	0.20	-0.151	3.222	None

**Table 3. Summary of spatial statistics.**

	Variogram model	r <sup>2</sup> of variogram model	Nugget	Sill	Range ft.	Nugget as % of sill
1991						
early Mg	Linear	0.818	0.0197	0.0279*	1320	70.6
late Mg	Exponential	0.972	0.0023	0.0147	156	15.6
early Ca	Exponential	0.835	0.0239	0.0393	362	60.8
late Ca	Linear	0.648	0.0089	0.0130*	1320	68.5
1992						
early Mg	Spherical	0.947	0.0045	0.0104	548	43.3
late Mg	Exponential	0.957	0.0006	0.00535	290	11.0
early Ca	Spherical	0.928	0.0042	0.0108	510	38.9
late Ca	Spherical	0.765	0.0127	0.0409	350	31.1

\*Sill value in the linear model was taken at the maximum possible range between sample locations. The range was the maximum range determined.

plant Ca content in the northeast. Areas of high pH correspond with areas of high relative plant Ca content in the early and late sampling maps. The late sampled Ca mapping does not show the low area of Ca in the northwest as the early sampling shows. It is possible that Ca deeper in the profile than the sampled 7 inches contributed to higher Ca nutrition of the plants at the later sampling date. Relatively low Ca levels were only displayed in the northeast part of the field where high soil K levels were present, and in the southeast, where crop growth was impaired by

high soil water levels. Moderate levels of Ca were in the northwest part of the field but extended south of the low pH area into areas of acceptable pH.

Table 4 shows the ability of the Ca and Mg concentration mapping to represent the areas in the 1991 pH map which required liming. Plant Ca levels represented soil pH levels better at both sampling dates than plant Mg levels.

In the fall of 1991, ten acres in the west and northwest areas of the Mansfield tract were limed according to the the 1991 Mansfield pH map in Figure 2 and by the method described previously. The Mansfield 1992 pH map is shown in Figure 7. Soil pH in 1992 was correlated to whole soybean plant Ca at the early sampling, but not in the later sampling. The explanation may be because at the later sampled date, plants were rooting into soils not described by the surface pH. Lindsley and Bauer (1929) described a soil grid sampling technique which included deep soil samples as part of the sampling pattern. Deep sampling for pH is not currently recommended in Illinois.

The 1992 soil pH was not as strongly related to the ear leaf Mg concentration as in 1991, although the relationship was still significant. There was no significant relationship between pH and 5 leaf Mg in 1992. The early sampled Ca was correlated with late sampled Ca in both 1991 and 1992. The early sampling of Mg was also correlated with late sampled Mg in both 1991 and 1992.

In 1992, following the lime application, the Ca variability within the field was reduced from 1991 levels as shown from the lower standard deviation between the two years. The 1992 early sampled soybean plant Ca map in Figure 8 shows only a small area in the limed west central region where the Ca concentration was relatively low. The pH of this area may not have reached fall 1992 levels at the early summer of 1991 sampling date. The relatively low Ca concentrations in the north east, where both low pH and high soil K levels were found persisted into this sampling because the area was not limed. Low concentrations of Ca were present in the east central area where crop growth was adversely affected by water.

In the later sampled Ca concentration map in Figure 9, three locally low concentrations are within or near the liming boundaries, however, the relatively large area of low plant Ca in the limed area is no longer visible, probably due to the greater liming effect on pH as the season progressed. It also shows relatively low Ca levels in the northeast. Two additional areas with low Ca concentration are shown in the southwest and eastern portions of the map. These two areas had been

**Table 4. Percent of plant sample values which correctly estimated relative soil pH levels.**

	1991		1992	
	Ca	Mg	Ca	Mg
Early sampling	61.2	44.0	61.3	39.8
Late sampling	60.8	55.6	52.3	33.2

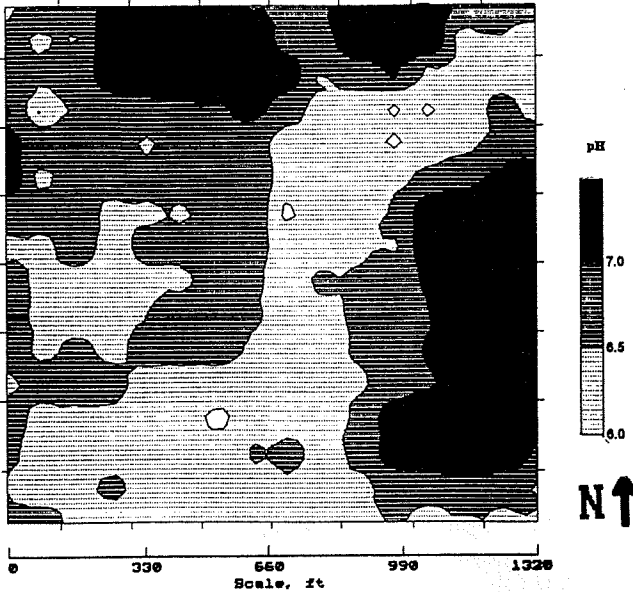


Figure 7. Mansfield pH 1992.

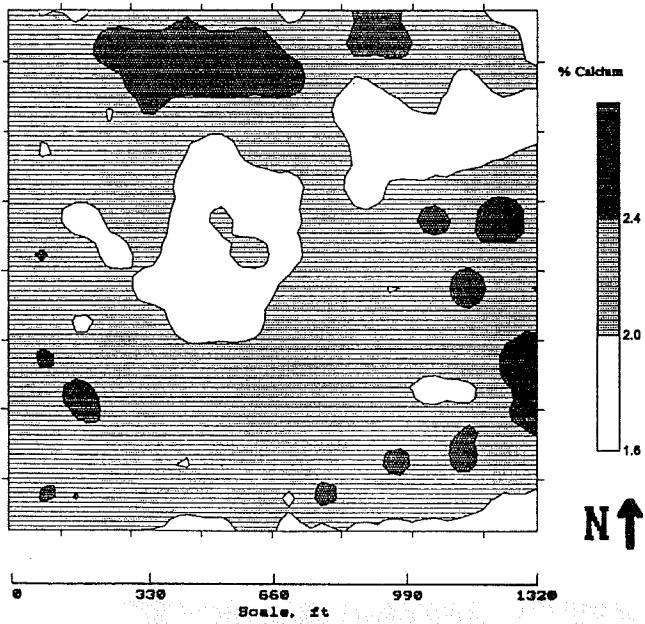


Figure 8. Mansfield 1992 5 leaf soybeans, % Ca.

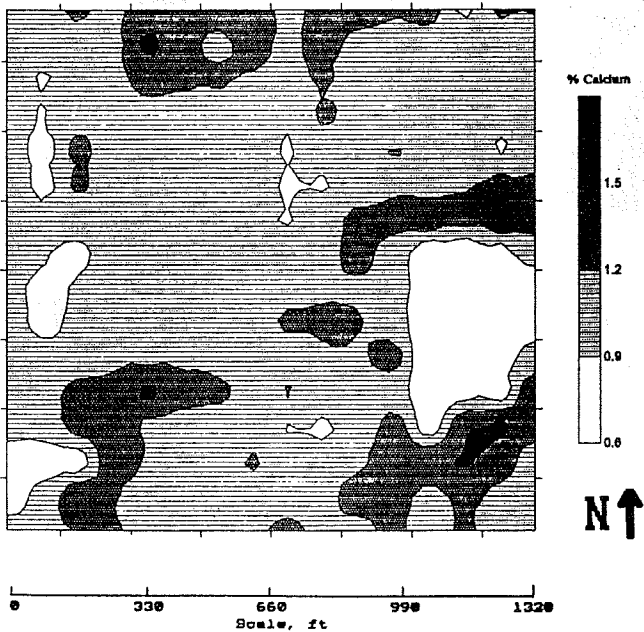


Figure 9. Mansfield 1992 soybeans, third leaf from the top, % Ca.

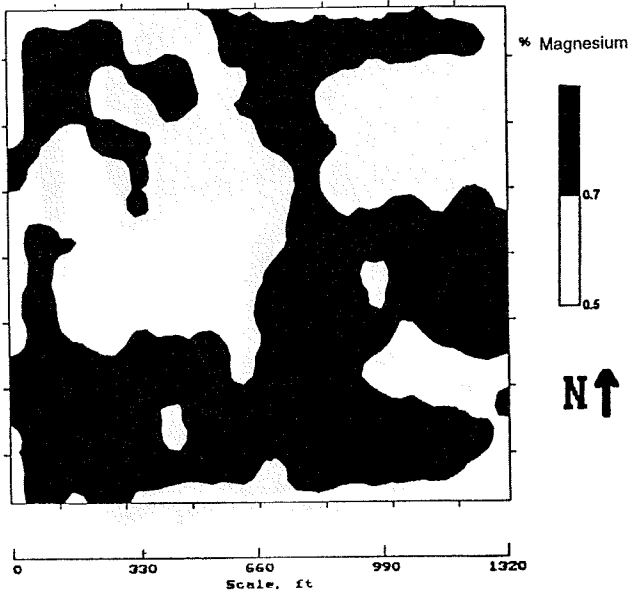


Figure 10. Mansfield 1992 5 leaf soybeans, % Mg.

recently flooded just prior to the sampling by very heavy rains. The areas eventually flooded out and the soybeans died by harvest time.

The 1992 soybean early sampled plant Mg concentrations in Figure 10 show variability and boundaries similar to those in 1991. The lime used to correct pH was calcitic, with Mg contents less than 2% (Vulcan Materials, Fairbury, IL, personal communication). Although the lime application decreased the variability of plant Ca levels, it did not reduce variability in plant Mg levels. In the later sampled soybean Mg concentration maps in Figure 11, besides the relatively low areas in the east and southwest where water damage affected the concentrations, there are relatively low areas in the west, central, and the northeast feed lot regions. These boundaries are much the same as the 1991 maps. The Mg levels in 1992 correctly estimated relative soil pH levels only 39.8% and 33.2% of the time at the early and later sampling period, respectively. The plant Mg levels did not reflect the pH increases of the 1992 soil pH mapping.

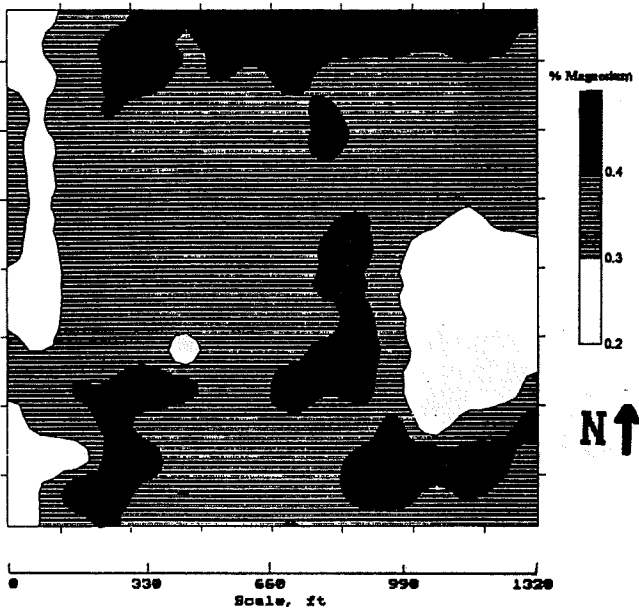


Figure 11. Mansfield 1992 soybeans, third leaf from the top, % Mg.

The plant analysis shows that in some cases the soil pH level features agree with the relative plant analysis levels for Ca and Mg. Lime application could be based on the Ca and Mg mapping boundaries of the plant analysis in certain cases where the history of the field and general pH levels within the field were known. The Ca and Mg levels did not always vary together. Liming with a calcitic ag-lime separated mapping features of Ca and Mg so that Mg was no longer as good an indicator of soil pH levels.

Field conditions beyond the plant analysis must be known to base a liming application on plant analysis Ca or Mg. The soil K levels, general plant health and degree of maturity variation of the crop needs to be considered before lime is applied. Plant analysis mapping only describes relative levels of fertility. Some soil testing would still be required to determine levels of lime needed and to define the boundaries of the application area.

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