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SITE SPECIFIC MANAGEMENT VERSUS WHOLE FIELD MANAGEMENT OF SOIL FERTILITY ASPECTS IN ALFALFA

presented by

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has been accepted towards fulfillment of the requirements for

Masters degree in Crop and Soil Science

Major professor

Date February 1, 2002

SITE SPECIFIC MANAGEMENT VERSUS WHOLE FIELD MANAGEMENT OF SOIL FERTILITY ASPECTS IN ALFALFA

By

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A THESIS

Submitted to
Michigan State University
In partial fulfillment of the requirements
For the degree of

MASTER OF SCIENCE

Department of Crop and Soil Science

2002

ABSTRACT

SITE-SPECIFIC MANAGEMENT VERSUS WHOLE-FIELD MANAGEMENT OF SOIL FERTILITY ASPECTS IN ALFALFA

By

Dennis R. Pennington

As agriculture evolves and changes, new ways are sought out to become more efficient through decreased inputs and increased outputs. Site-specific management (SSM) is an opportunity that needs to be researched to determine its role in agriculture. Technology is changing at a rapid pace. Research needs to be conducted to evaluate this new technology in order to make the changes necessary to continue improvement.

Evaluation of yield, ADF, NDF and CP using SSM of soil fertilizer inputs was conducted for alfalfa production under Michigan growing conditions. Lime, phosphorus and potassium were applied under two different management regimes: 1) recommendations for SSM were made based on soil samples collected within each plot, 2) recommendations for WFM were made based on the average of grid point samples collected on a 61 meter grid from the whole field. The small plots were 6.1 x 15.24 meters and located in areas of the field that were the most deficient in pH, phosphorus and potassium. Four locations were selected throughout west central Michigan.

In addition to production factors, an economic indicator was calculated to give farm managers and decision makers a means to compare SSM and WFM. Net return to fixed resources (NRFR) was determined for each treatment. The cost of sampling and variable rate application was not included. This allows farm managers to customize the equation to their own farm. The results in this study indicate that there is no advantage from SSM over WFM. In fact WFM produced the highest NRFR.

ACKNOWLEDGMENTS

The author wishes to thank Dr. Richard Leep for his expertise and guidance throughout my program. The effort put forth by James DeYoung, Tim Boring and Tim Dietz was critical to the success of this research. A special thank you to my committee, Dr. Roy Black, Department of Agricultural Economics and Dr. Darryl Warncke, Department of Crop and Soil Sciences. Dr. Sasha Kravchenko, Department of Crop and Soil Sciences provided statistical support and help.

A special thank you goes to my wife, kids and family for their support and encouragement. I could not have completed this without them. I love you with all my heart.

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INTRODUCTION

In the world of advancing technology, new opportunities to collect and manage information are abundant. Everyone in the agriculture industry is faced with making decisions each day that will affect the profitability of their business. In order to make sound decisions they must have good information.

Site-specific management (SSM) in agriculture is the application of technologies and principles used to manage spatial and temporal variability associated with all aspects of agricultural production for the purpose of improving crop performance and environmental quality (Pierce and Nowak, 1999). Conditions in the field can be characterized and subsequently managed using this approach.

SSM utilizes variable rate application (VRT) equipment to apply different rates of fertilizer based on soil test levels of each nutrient. Areas of the field that are high in a nutrient receive less fertilizer than areas that are lower. According to Sawyer (1994), there are five critical components that are directly related to the success of SSM. If just one principle is not met, SSM will not likely produce greater yields and economic returns. The five critical components are:

(i) within field variation exists-of important factors that affect crop yield;
(ii) variation does influence crop yield;
(iii) variation can be identified, measured and delineated (mapped);
(iv) precise crop response models are available to determine appropriate variable input rates; and
(v) data processing procedures and application equipment are available that can effectively manage and variably apply crop production inputs.

Field research indicates that positive economic return to VRT application does not always occur. There are complicating factors that limit its effectiveness. They are:

(i) the cost of implementation (sampling, mapping, equipment, personnel);

(ii) lack of expected increase in crop yield (little actual variation, incorrect assessment of variation or low accuracy mapping, and low precision crop-input response function or incorrect interpretation of expected crop response); and

(iii) lack of input savings.

As a result, no definitive answer exists as to whether VRT should be used in every field or if it is the best crop input management practice for all farmers (Sawyer, 1994).

There has been a significant amount of work published to evaluate the potential for SSM in corn and soybean production. The results have been somewhat variable, finding that it pays in some fields and not in others. Generally, the more variability there is in a field, the greater the chance that SSM can provide additional profit to the farmer.

Studies conducted to evaluate the feasibility of SSM in alfalfa are nonexistent. Alfalfa is the third largest crop in Michigan, with over 1,200,000 acres harvested in 2000. The average yield was 2.51 tons per acre. The majority of alfalfa harvested in Michigan is fed to dairy cows. Forage quality is of utmost importance in maximizing milk yield per cow. The goal is to maximize yield and quality, which results in the greatest return in milk production. The need for high yielding, high quality alfalfa stands in Michigan supports the purpose for studying the effects of VRT on alfalfa production.

Objectives

1. To determine if spatial and temporal variation in typical Michigan alfalfa fields warrant SSM.
2. To determine yield differences in alfalfa between SSM and WFM.
3. To evaluate forage quality variations between SSM and WFM.
4. To test the net return to fixed resources from SSM and WFM.

Statement of Hypotheses

The following 3 null hypotheses have been determined:

1. H_{O1}: SSM has no effect on alfalfa yield compared with WFM.
2. H_{O2}: SSM has no effect on alfalfa forage quality parameters (CP, NDF & ADF) compared with WFM.
3. H_{O3}: SSM has no effect on net return to fixed resources compared with WFM.

LITERATURE REVIEW

LITERATURE REVIEW

Background

The earliest effort in what is now called site-specific management (SSM) was the International Minerals and Chemicals (IMC) program. This program was started in the mid-1960's in effort to treat subsets of fields with individualized amounts and types of fertilizer based on soil test and yield goal. This program was terminated after 5 years because of poor economics (Runge, 1999).

Over the past two decades, SSM has been described in many ways, including farming by the foot (Reichenberger and Russenogle, 1989), farming by soil (Carr et al., 1991), variable rate technology (VRT) (Sawyer, 1994), precision agriculture (Stafford, 1996) and site-specific management (Pierce and Sadler, 1997). Although there are some variations in the terminology, there resides a common theme of managing crop production on a smaller scale than the conventional whole-field method. Traditionally, farm fields have been managed as homogenous units and are fertilized with a single and uniform blend of fertilizer (Wollenhaupt, Wolkowski and Clayton, 1994).

Soil sampling to determine the central tendency of the field is the basis of conventional crop nutrient management (Wollenhaupt, Wolkowski and Clayton, 1994). However, soil fertility can be extremely variable across each field. The conventional method of soil sampling can cause over or under application of nutrients in some or all parts of a field.

Scope of SSM

SSM encompasses a broad array of topics, including variability of the soil resource base, weather, plant genetics, crop diversity, machinery performance, and most physical, chemical and biological inputs used in the production of a crop (Pierce, 1999). SSM utilizes global positioning systems (GPS) and geographic information systems (GIS) and computers to collect store and manage data. GPS is used to determine the exact position (latitude, longitude, altitude). GIS allows for the organization and manipulation of the data for use in making management decisions, like in grid soil sampling and fertilizer application. Variable rate technology (VRT) is the equipment used to apply nutrients at different rates based on soil test data collected.

In Michigan where a typical crop rotation includes corn, soybeans and wheat, alfalfa is a crop that requires a different soil fertility regime. Alfalfa is more productive on higher pH soil and the K requirement is much greater than most other crops grown in Michigan. These are the two most important fertility factors in alfalfa production and are likely to be the most responsive to SSM. Information in the literature suggests that alfalfa yields are related to soil pH and K fertilization, supporting Sawyer's (1994) first critical component that variable factors in the field do influence yield.

Crop Response to pH

McLean and Browns (1984) found that alfalfa was strongly affected by a pH range of 5-6. Mahler (1983) studied the effects of pH on alfalfa growth and establishment using Mission silt loam soil in a greenhouse study. Alfalfa was planted into pots of soil with varying pH levels. Aluminum sulfate and finely ground calcium carbonate was used to adjust pH within each pot to 8 different levels (4.8, 5.1, 5.6, 6.2, 6.4, 6.9, 7.0 and 7.4). Yield (biomass) was strongly correlated ($r^2 = 0.981$) with soil pH. Petit et al. (1992) found that concentrations of crude protein, acid detergent fiber, acid detergent lignin, stem length, leaf area and the number of stems increased in parallel with soil pH.

Crop Response to K (Potassium)

Cahn et al (1994) reported that PO_4-P and K show promise as variables for site-specific crop management because they are spatially correlated over longer distances. PO_4-P and K are also less mobile in the soil, as compared to NO_3-N, which means there is less temporal variance. With NO_3-N, applications need to be made soon after sampling because leaching may reduce levels of N in the soil (higher temporal variation). This is important because if K levels in the soil were highly fluid throughout a given year, it would add another dimension of difficulty in accurately assessing the variability in field and then attempting to relate that variability with yield. It is assumed that K levels do not change significantly over time, as does NO_3-N.

Alfalfa requires large amounts of K as compared to other crops. Alfalfa yielding 5 tons per acre will remove as much as 109 kg ha^{-1} of K_2O, while 130 bushel corn and 45 bushel soybeans remove 16 and 28.6 kg ha^{-1} respectively (Christenson, D.R., Warncke, D.D. and Vitosh, M.L. 1992). K plays a role in cation transport across membranes, is involved in water economy/uptake, enzyme activation and stand persistence (Barbarick, 1985). A study conducted by Collins and Duke, (1981) showed that when K is applied at extremely high rates (673 kg ha^{-1} $year^{-1}$) nodule mass and resulting N_2 fixation increased.

Alfalfa yield response to K fertilizer has generally been variable. Barbarick (1985) found a yield response to K applications up to 750 kg K ha^{-1}. However, yield increases were not enough to offset the cost of additional fertilizer. Initial soil test levels were 335 and 308 mg kg^{-1} for depths of 0-15 and 15-30 cm respectively. At this level, additional K fertilizer would not be recommended in Michigan. Gossen et al. (1994) found that K fertility had minimal effect on plant survival and yield of alfalfa. Havlin et al. (1984) studied the effects of fertilization and soil maintenance of K. Initial soil K levels were determined in a Keith clay loam and a Ravola loam. Although the Ravola soil had a much lower K level (126 mg kg^{-1}) compared to the Keith soil (555 mg kg^{-1}), the Ravola soil required less K supplementation to maintain the high levels. It was determined that maintenance of soil levels of K was not a profitable management practice and that both soils were able to supply adequate K without affecting yield over the six year period. The Ravola soil had higher illite content than the Keith soil, which might explain the observed K-buffering capacity.

SSM Impact on Forage Quality

Forage quality is defined as the sum total of the plant constituents that influence an animal's use of the feed. Along with its quality, the overall potential feeding value of a forage is influenced by the form in which it is fed (e.g., particle size), the palatability of the forage, and by the quality of other feeds in the ration (associative feed effects) (Cherney and Hall, 1997). The typical indices of forage quality include crude protein (CP), neutral detergent fiber (NDF) and acid detergent fiber (ADF). These parameters are often used to compare forages and balance feeding rations.

Forage quality of alfalfa is influenced by a number of factors including cultivar, maturity, harvest and storage method, environment (climate) and soil fertility. Although it is necessary to balance soil fertility to avoid mineral imbalances in ruminants, soil fertility affects forage yield much more than it does quality. Low soil fertility, as well as very high fertility, has resulted in reduced forage quality. One of the goals of SSM is to reduce the incidence of very low and very high fertility levels in the field and as such may contribute to more uniform and overall increased forage quality.

Previous work in forage quality that has tested the relationship between soil fertility and forage quality factors has been conducted on a WF basis. Given the fact that soil is highly variable, it is possible that assessing and managing the variability on a precise scale could reveal a relationship between soil and forage quality factors not previously detected. Conducting this research provides an opportunity to test these relationships.

Accuracy in Mapping

Sawyer's (1994) third critical component in the success of SSM is that variation in the field can be properly identified and mapped. The methods used to assess field variation can greatly affect how accurately the variation is identified. Increasing the intensity of soil sampling in a field improves the accuracy in identifying the variation. As sampling cost becomes limiting, the benefits of improved accuracy needs to be weighed against the cost.

It is critical to make sure that sampling and mapping accurately describe the field because it is this information that is used to determine how much fertilizer to apply. If the maps don't accurately define a field, over or under application of nutrients will occur. The whole goal behind SSM is to minimize this, which emphasizes the importance of accurately describing the variability within a field. Statistical methods have been identified and developed to help ensure the accuracy of these maps. These methods are referred to as geostatistics and will be discussed later.

Soil Sampling Units

There are different philosophies on how to develop soil-sampling schemes and subsequently map the variability within a field. One proposed soil sampling scheme involving soil type or map unit (Figure 1) is where samples are randomly collected throughout a predefined area and composited for that area. This method utilizes soil survey maps and aerial and satellite imagery to delineate a soil type or map unit. Another soil sampling scheme called grid point sampling (Figure 2) is where 8 cores are taken systematically from a 10-foot radius around a specific point. Grid cell sampling (Figure 3) involves breaking the field up into "sub-fields" where several core samples (at least 5) are taken systematically throughout the sub-field and composited. Wollenhaupt and Wolkowski (1993) and Franzen and Peck (1993) found that grid point sampling proved to be more accurate in estimating the actual variability in fields as compared to other methods.

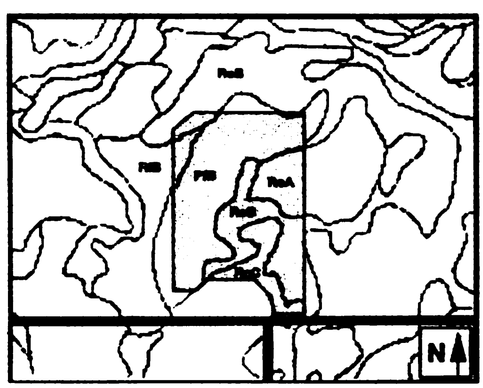


Figure 1. Soil type or map units taken from the USDA-SCS soil survey map (Wollenhaupt et al., 1994).

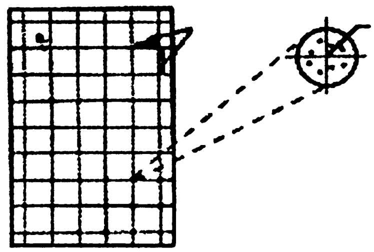


Figure 2. Grid point sampling technique (Wollenhaupt et al., 1994).

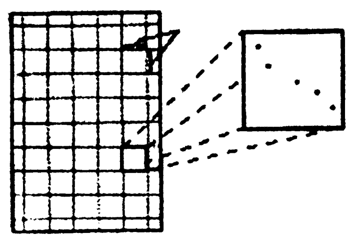


Figure 3. Grid cell sampling technique (Wollenhaupt et al., 1994).

Franzen and Peck (1993) also found that soil pH, P, and K patterns are not always related to soil types, discounting potential accuracy of the soil type or map unit method. Holzhey et al., (1993) reported that large soil test variations could occur within soil map units. This supports Franzen and Peck (1993) and Wollenhaupt and Wolkowski (1993), who also determined that grid point sampling is superior to soil type and grid cell sampling.

Grid size

The accuracy of VRT management maps depends on the frequency and pattern of soil sampling (Wollenhaupt, Wolkowski and Clayton, 1994). Wibawa et al. (1993) found that sampling on a 15.2-meter (50-foot) grid can effectively evaluate soil fertility variability within a field. However, Wibawa et al (1993) also reported that the conventional method of whole-field fertilization was more profitable than grid sampling on a 15.2-meter grid even though the 15.2-meter grid resulted in higher yields than the conventional method of whole-field fertilization. The costs associated with collection, lab analysis and application were greater than the return from the increased yield.

Pozdnyakova and Zhang (1999) sampled on a 200 by 200 meter (656 foot) grid to determine soil salinity. Mulla et al. (1992) grid sampled on a 15.2 by 122 meter (50 by 400 foot) grid to compare yield and quality of winter wheat under uniform and SSM management. Mulla and Hammond (1992) compared grid sizes of 30.5, 61 and 122-meter (100, 200 and 400 feet) square and concluded that 61-meter was adequate for developing soil test maps.

<u>Geostatistics</u>

Two commonly used forms of geostatistics are variography and kriging. Variography uses semivariograms to characterize and model the spatial variance of data, whereas kriging uses the modeled variance to estimate the values between samples. Proper estimation of the semivariogram is essential for characterizing the spatial patterns of soil nutrients. The semivariogram is based on the assumption that the data are stationary (Cahn et al. 1994).

A semivariogram illustrates the relationship between the sample variance and the distance between sample points (also known as the lag). For example, core samples are taken at 0, 2, 5, 10, 15, 25 feet from a grid point (this is also called cluster sampling). The sample variance for a nutrient, like K is plotted against the distance between the samples as in Figure 4, Cahn et al. (1994). The range is the lag distance where the semivariance increases. It also represents the distance between sample points. As the distance between grid sample points increases, eventually a point is reached where the semivariance does not increase any more with distance between points. This point is called the sill. What this means is that if one samples at distances in the sill range, one will not likely be able to identify the variation in the soil.

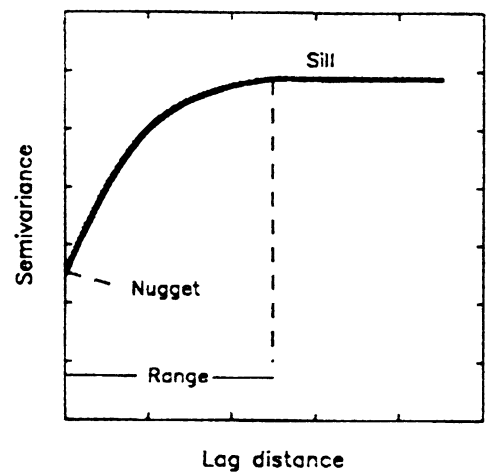


Figure 4. Semivariogram, showing the range, nugget and sill (Cahn, 1994).

one would rather want to collect samples on a grid that is spaced at distances that fall within the range of the semivariogram. The nugget represents the residual variance that is not removed by sampling closer together (Cahn, 1994).

The semivariogram not only helps to characterize the variance and distance, it also provides some insight on the size grids that should be used to properly determine the variation in a particular field.

One critical point to consider when using a semivariogram to estimate the variance of soil nutrients in a field, is that the residuals should be normally distributed and stationary (not temporally variable) (Webster, 1985). If the data is not normally distributed, there are some things one can do to correct for this problem. Han et al. (1993)

suggested the following approach for mapping in order to achieve maximum accuracy in mapping soil properties (like pH, P, K) where there is large-scale variation:

(i) detrend the data by median polishing,
(ii) model the variance-distance relationship of the residual data,
(iii) develop kriged estimates of the residual values at unsampled locations from the modeled variance and
(iv) add these estimated values back to the trend.

Cahn et al. (1994) added that removing outlying data may also aid in modeling the variance-distance relationship. Understanding how these statistics work can be very difficult, but essential in creating nutrient recommendation maps that are accurate. Remember, if one is not any more accurate in measuring the variability in a soil, one may as well revert back to the conventional method of managing the field as a whole.

Geostatistics were not used in this research. In the materials and methods, one will see that small plots in a randomized complete block design were used to evaluate SSM. It does not make sense to map the variability in a 93 m^2 area. However, it is very important to understand the statistical methods used on a whole field basis. In a real farm situation, one would not be dealing with small plots, but rather the whole field.

VRT

Variable rate technology (VRT) is the enabling technology for site-specific management of crop production. If one cannot apply fertilizer nutrients at variable levels across a field, evaluating soil nutrient levels on a site-specific basis would be useless.

VRT is being considered by farmers and the fertilizer industry because factors that affect crop yield are not always uniform within fields and therefore, do not allow optimum efficiency or profitability from uniform application. VRT has the potential to improve input efficiency, field profitability, and environmental stewardship (Sawyer, 1994).

Economic Indicators

Swinton et al. (2000) studied the effect of site specific management compared to whole field management on a 2-year corn/soybean rotation. Two fields were soil sampled on a 61 m grid. Sub-plots were established within each field. Each sub-plot was assigned to one of two treatments: site-specific management (SSM) or whole field management (WFM). Nutrient recommendations were made and fertilizer was applied based on soil test and yield goal. For the WFM treatment, the recommended application was determined by the average of the soil sample results for the whole field. Recommendations for the SSM treatment were determined based on soil samples taken within each subplot. Although the SSM treatments resulted in higher yields, the difference was not statistically significant at $Pr>t = 0.05$. The cost of SSM was significantly higher than WFM, which drew the authors to the conclusion that SSM in a corn/soybean rotation was not an economically feasible management practice.

In another study conducted by Shearer et al. (2000), a similar approach of comparing the management styles of SSM versus WFM during a single year within a corn field in Kentucky. Soil fertility recommendations were made using whole field data and models including soil test, topography, yield history, etc. This study found a \$6.37 ha^{-1} return on SSM, but this was not enough to compensate for the additional costs associated with SSM.

MATERIALS AND METHODS

MATERIALS AND METHODS

Four commercial fields of alfalfa were identified and labeled as follows: KBS (Kellogg Biological Station in Kalamazoo county near Hickory Corners, MI), ION (in Ionia county near Belding, MI) and OSC1 (in Osceola county near Leroy, MI) (Figure 5). A second field was added in Osceola County in 2001 named OSC2. The fields are 21, 9.8, 13.9 and 13 hectares respectively. The predominant soil types were Oshtemo sandy loam, Menominee loamy sand, Kawkawlin loam and Nester loam at KBS, ION, OSC1 and OSC2 respectively.

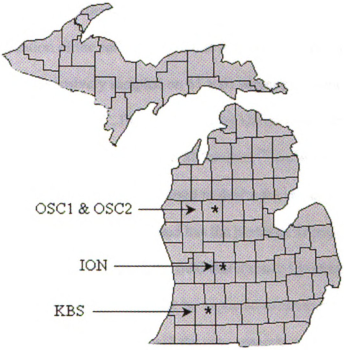


Figure 5. Map of Michigan showing the location of each trial.

This research effort was included as part of a larger project designed to characterize the variation in typical Michigan alfalfa fields, test different methods of quantifying yield and determine the potential impact of SSM in alfalfa production. It was the intent of the larger project to conduct the research in a manner consistent with how farmers might manage their own fields. A yield monitor was used to collect yield data, fields were also grid sampled for yield and soil nutrients on a 61-m grid and applications of nutrients were made using commercial VRT applicators. Getting precise, accurate data and the ability to control some of the variables that are inherent in this type of research project are challenging. It was decided that small plots would be useful in verifying the results of the larger project that was managed much the same as a farmer would manage their fields. Randomization and replication in small plots provide the avenue for more statistically sound data. For this thesis, the small plots, as described below, will be the basis for data collection and analysis.

Initial characterization of the soil fertility status for each field was surveyed in 1999, when each field was intensively sampled on 61 x 61 meter grid sampling scheme. Samples were tested for OM, pH, CEC, Bray I-P and K by Harris Soil Testing Labs (Lincoln, Nebraska). Soil data was imported into SSToolbox™ software. Surface maps were generated for pH, P and K. This data was used to determine small plot location within each field that was low in pH, P and K and has the potential to respond to application of nutrients. Selecting an area in the field that already has enough soil reserves to sustain normal crop growth would not be expected to show any yield response to SSM. Sawyer (1994) asks the questions, "will the crop respond positively to the input, and if so, how large will the response be and what rate optimizes the crop response?" As shown in Figure 6, (Sawyer, 1994) potential yield increase from SSM is dependent upon how much of the field falls under zone A or B. If there are enough nutrients available in the soil (zone C), there will not likely be an increase in yield due to SSM application.

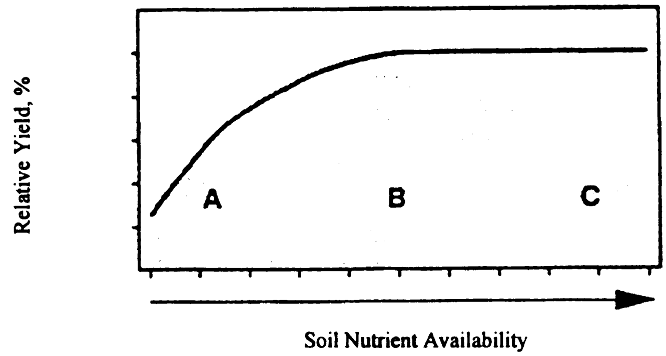


Figure 6. Generalized crop yield response curve indicating relative yield and expected positive response to an applied nutrient (A = highly likely, B = marginal and, C = highly unlikely).

Since each nutrient varied differently within each field, we attempted to identify areas that fit zone A for as many nutrients as possible. The area in each field also needed to be accessible without disturbing too much of the rest of the field. Uniform topography was also a goal in determining the area used for the small plots. Each small plot was 6.1 x 15.24 meters and laid out as describe in Figure 7 and Figure 8. These small plots were the basis for the research.

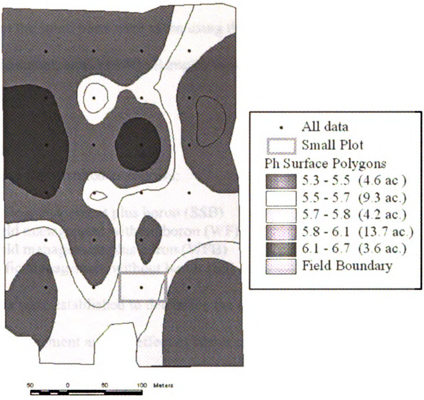


Figure 7. Small plot area overlay on soil pH at KBS location. Areas for small plots were located where they were easily accessible and in areas will sub-optimal nutrient status for alfalfa.

101	102	103	104
201	202	203	204
301	302	303	304
401	402	403	404

Figure 8. Small plot layout at each location within the whole field. The first number represents the replication, the second and third number represent the plot number.

Soil samples from the small plots were taken using the grid cell method as described in Figure 3 by Wollenhaupt, et al. (1994). Samples were sent to Harris Labs to be analyzed as described above.

Treatments

Four treatments were created as follows:

1. Site specific management plus boron (SSB)
2. Whole field management without boron (WF)
3. Whole field management plus boron (WFB)
4. Site specific management without boron (SS)

The treatments were established to determine the effect of site-specific management and whole field management and the effect of boron application. The only difference between the SS and WF plots are the method in which fertilizer recommendations are made. In the SS plots, fertilizer recommendations were made based on the soil test results form the grid cell samples pulled from the small plots. In the WF plots, the soil data was averaged for grid point samples collected on the 61-meter grid from the whole field. In essence, taking the average of the grid points would be comparable to determining the central tendency of the field as would be done using conventional methods for testing soils and determining fertilizer requirements. As a result, the WF plots received the same amount of fertilizer, regardless of the grid cell sampling results. The SS plots received varying amounts of fertilizer depending on the grid cell sampling results. A common yield goal of 11.2 Mg Ha^{-1} was used in determining the amount of fertilizer needed in both management schemes across all locations. Fertilizer was applied to each plot using a 10 foot wide Gandy drop spreader.

Experimental Design

A randomized complete block design was used. Treatments were replicated 4 times at all four locations. Each replication at each location was separately randomized using proc plan in SAS.

Data Collection

In 2000, a 0.6 m^2 area was harvested by hand from each small plot. Alfalfa was clipped to a height of 5 cm. The fresh material was then weighed, dried in an oven at 65°C and weighed again. Percent moisture was determined and dry matter yield calculated for each plot.

In 2001, a Carter forage harvester was used to harvest a 1.2 by 14.3 meter strip down the middle of each plot. Total fresh weight was recorded. A sub-sample was taken from each plot, weighed and dried as described above and weighed again. Percent moisture and dry matter yield was calculated.

The harvested alfalfa in both years was kept and used for forage nutritive evaluation. Dried samples were ground to pass through a 2 mm sieve using a Udy plant tissue grinder. Samples were consequently analyzed for crude protein (CP), neutral detergent fiber (NDF) and acid detergent fiber (ADF) using a 6500 Foss NIRS.

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

Variation Within the Field

Sawyer's (1994) first critical component is that there must be variation within a field in order for SSM to be useful and economically viable in production agriculture. At the KBS location, soil pH ranged from 5.9 to 6.8, P levels range from 82 ppm to 126 ppm, and K levels range from 68 ppm to 120 ppm. (Table 1.) Since alfalfa is highly responsive to both soil pH and K, one would expect to see a positive yield response in the plots testing low for these nutrients.

Table 1. Soil test data by location, spring 2000.

		pH	CEC	P[†]	K[†]
KBS	min	5.9	5.0	82	68
	max	6.8	8.4	126	120
	mean	6.4	6.6	102	92
ION	min	6.3	5.4	22	127
	max	6.7	9.1	36	210
	mean	6.6	6.4	29	157
OSC1	min	6.4	7.7	17	55
	max	7.1	12.8	36	156
	mean	6.9	10.1	24	91
OSC2	min	7.1	9.8	10	76
	max	7.5	17.3	26	184
	mean	7.3	11.3	15	99

[†] ppm

Yield Relationship with Variation

The second criterion identified by Sawyer (1994) was that this variation is related to and influences crop yield. Procedure reg in SAS™ was used to determine the relationship between soil pH, soil P, and soil K with yield. Yield regressions were also conducted for lime, P and K fertilizer application rates. Table 2 lists the regression output.

Table 2. Yield ANOVA of soil pH, soil P, soil K, lime application, P application and K application over all sites and both years and by year.

	Pr > F		
	Overall	2000	2001
pH	0.8028	0.8807	0.5510
P	0.2311	0.7303	0.6150
K	0.0035	0.0001	0.1697
Lime	0.1760	0.7612	0.8338
P fert.†	0.0189	0.9899	0.5828
K fert.†	0.1025	0.0001	0.7291

† See Tables 1-4 in Appendix A for amounts and type of fertilizer applied.

Soil pH and P show no relationship with yield. However, a strong relationship did exist with soil K and yield overall and in the 2000 year. Note that 2001 yield data was not significantly related with K. Lime applications were not related to yield either. P applications were overall, but not within either year. K applications were significant overall and in 2000, but not in 2001. This could be due to the fact that soil levels in deficient plots have been brought up to maintenance levels. This is substantiated by the fact that soil K was not related to yield in 2001.

Sawyer's (1994) third criteria are that the variation of yield impacting variables can be correctly identified, measured and delineated. This is addressed via the research plot design. Testing this would involve some form of evaluation of the accuracy in which soil variables are identified and mapped. On a whole field basis this could be done using geostatistics (see Cahn, 1994). In this research, the small plot design eliminates the chance for error in mapping soil variables. Ten core samples were taken and composited for each small plot. With respect to the size and scale of SSM, there would not be enough variation within each plot to be of significance in this research.

The fourth criterion identified by Sawyer (1994) is that precise crop response models are available to determine the appropriate variable input rates. Fertilizer recommendations from Michigan State University (E-550A) (Christenson et al., 1992) were used in determining the correct amount of fertilizer to apply to each plot. Certainly there is a high degree of variability between the crop acreage represented by these recommendations. These recommendations are somewhat liberal. One of the fears of the farmer is that in a good year, he did not put enough fertilizer on, so these recommendations are somewhat inflated. It would make sense that more precise recommendations that are more specific to soil types and management styles would be an improvement in making soil fertility recommendations and make SSM more robust. The concept of SSM is to manage on a smaller scale. In order to do that, one needs to be able to develop response models that are on a similar scale.

Tests for Normality

Yield and forage quality data was first tested for normality and skewness using procedure univariate in SAS™. Outliers that were beyond the third interquartile region were omitted for succeeding analyses. It was also found that the 2001 yield data was not normally distributed using the Wilk-Shapiro test. In order to continue with data analysis, the 2001 yield data residuals were tested and found to be normally distributed. This allows regression and other comparisons to be conducted. Forage quality data was found to be normally distributed.

Yield

Yield data was not statistically significant in any of the locations for either year. The first alternative hypothesis set in the introduction stated: H_{O1}: SSM has no effect on alfalfa yield compared with WFM. This hypothesis is in fact true as described by the data in Table 3.

Table 3. Yield and forage quality data by treatment over all locations and years.

		Yield†‡	% ADF‡	% NDF‡	% CP‡
Treat 1	Mean	**9.49**	**28.9**	**38.9**	**21.4**
	Std Dev	1.55	4.7	6.3	2.8
Treat 2	Mean	**9.42**	**28.5**	**38.6**	**21.4**
	Std Dev	1.78	5.0	6.4	2.6
Treat 3	Mean	**9.49**	**28.8**	**38.8**	**21.4**
	Std Dev	1.50	5.0	6.5	2.6
Treat 4	Mean	**9.46**	**28.8**	**38.9**	**21.3**
	Std Dev	1.55	5.2	7.1	2.8

† Mg Ha^{-1}
‡ NS at 0.05

Table 4. Treatment means and standard deviation for soil test variables and nutrient application rates across all locations and both years.

		pH	P	K	Lime†	P Rate‡	K Rate‡	B Rate‡
Treat 1	Mean	**6.7**	**48**	**101**	**0.09**	**68**	**215**	**1.3**
	Std Dev	0.4	39	49	0.30	56	135	0.3
Treat 2	Mean	**6.6**	**47**	**104**	**0.00**	**47**	**146**	**0.0**
	Std Dev	0.5	35	62	0	51	80	0
Treat 3	Mean	**6.6**	**46**	**106**	**0.01**	**47**	**146**	**1.3**
	Std Dev	0.4	36	53	0.11	51	80	0.3
Treat 4	Mean	**6.6**	**50**	**108**	**0.10**	**63**	**209**	**0.0**
	Std Dev	0.4	38	52	0.32	53	140	0.2

† Mg Ha^{-1} actual P and K.

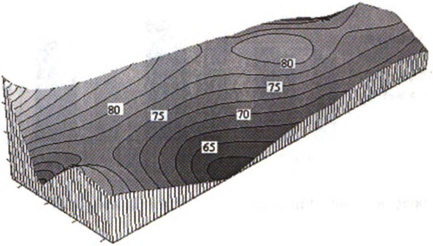
† Kg Ha^{-1} actual B.

There are a number of reasons why there was no yield difference. First, despite the range in values for soil pH, P and K, the recommended fertilizer application rates did not vary greatly. Table 4 shows the mean values for soil pH, P and K as well as application rates for lime, P, K, and B for each treatment across all locations. Each location was sampled in the spring of 2000 and 2001. The overall treatment average for soil pH varied only by 0.1, P levels varied by 4 ppm and K levels varied by 7 ppm.

Each location had more variation between the treatments than the average of all locations. Figure 9 depicts the variation in soil K at the KBS location in 2000 and 2001. Initially, the range in K levels was 68 to 120 ppm in 2000 and 64 to 81 ppm in 2001. One of the goals of SSM is to reduce the variation in a field by reducing fertilizer applications in areas that test high and applying more fertilizer in the areas that test low.

When one looks at the overall variation in soil test values and the resulting application rates, the variation may be too small to preclude seeing any significant response in yield. In order to expect differences in yield, the treatments should vary significantly. Even though it was attempted to locate the plots in deficient areas of the field, the lack of overall variation confounded the experiment. Perhaps one could conclude that WFM has been an effective management strategy.

2000 Potassium KBS



2001 Potassium KBS

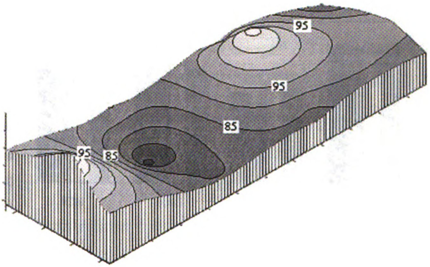


Figure 9. Soil test levels of small plots in 2000 and 2001. Note that the high and low spots in the field are less pronounced in 2001.

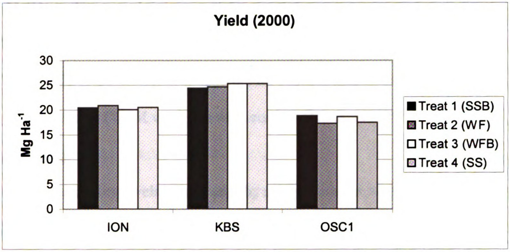


Figure 10. Total annual yield for each treatment by location (2000).

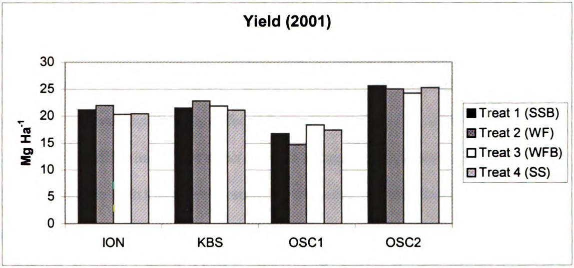


Figure 11. Total annual yield for each treatment by location (2001).

In combining data across both years and all locations, there is no significant difference in yield. This trend holds true if the research is analyzed by year and location (see Figures 10-11). The highest yielding treatment is not consistent between locations or between years. At the KBS location in 2000, Treatment 3 resulted in the highest yield of

25.36 Mg Ha^{-1}. The same location in 2001, resulted in Treatment 2 yielding the highest at 22.8 Mg Ha^{-1}. In 2001, the highest yielding treatments were 2, 2, 3 and 1 at ION, KBS, OSC1 and OSC2 respectively. It is apparent that factors other than the fertility management scheme (WFM vs. SSM) were contributing to yield differences.

Forage Quality

The targeted quality levels sought after by a farm manager are CP=20%, ADF=30%, and NDF=40%. In order to maximize milk yield, one needs to balance the right amount of fiber in the diet with protein and other mineral nutrients. Diets are the easiest and most cost effective to balance under the above-prescribed conditions. The maturity of alfalfa at the time of harvest has a more profound affect on these forage quality factors than soil fertility levels. Our objective in this research was to try to harvest in a timely manner that is consistent with what a farm manager would do. The CP, ADF and NDF samples analyzed here were not significantly different between treatments (Table 3), indicating that SSM of soil fertility had no net effect on these forage quality parameters.

Another problem with this type of research is the number of uncontrollable variables. Temperature, rainfall, pest invasion and soil physical properties can interact in such a manner that it would be difficult at best for this type of experimental design to pick out differences between treatments. If these tests could be conducted in the greenhouse where one has control over these environmental variables, there would be a greater chance of seeing a difference.

Economics

As a farm manager, it is important to look at all aspects of a situation before making decisions. With SSM, economics are a very important aspect of the decision making process. It would be senseless to invest money in grid sampling and variable rate application if it did not return a profit or at least break even. Calculating the economics of SSM is very difficult and can be tedious depending on how in-depth one would want to delve. Another complicating factor is that the cost associated with collecting soil samples and applying fertilizer at variable rates is highly variable. Each farmer would have to contact their local consultant to find out how they charge for their services.

It is not the intention of this paper to get into the depths of economic analysis. However it is valuable to apply some level of economics so farm managers might make their own decisions about SSM. To keep things simple, I have suggested some guidelines set forth in Swinton et al. (2000) to calculate Net Return to Fixed Resources (NRFR). The formula for NRFR is as follows:

$$\mathbf{NRFR=Yield*Price - Lime*P1*A - P*P2 - K*P3 - B*P4}$$

Where P1 is the price of lime, A is the annualized fraction of lime, P2 is the price of 0-46-0, P3 is the price of 0-0-60 and P4 is the price of B. This formula accounts for yield and price received for the alfalfa minus the cost of nutrients that were applied to each treatment. This does not figure in the cost of soil sampling or the variable rate application of fertilizer. It is suggested that each farm manager contact their local supplier to find out how much it will cost them for sampling and application. These costs would need to be included in order to compare SSM and WFM.

Lime is the only nutrient that is annualized over time. The annualization of the other nutrients is built into the fertilizer recommendations. The assumptions used are that fields are soil sampled every three years and the build up of soil levels is spread evenly over those three years. Because of the nature of the recommendations, annualizing P and K in the above equation is not necessary.

Lime costs were annualized over a 5-year period (A=0.2 per year). The prices used in the calculations are as follows: alfalfa (\$110.25 Mg^{-1}), lime (\$18.19 Mg^{-1}), P (\$0.2026 Kg^{-1} actual P), K (\$0.1586 Kg^{-1} actual K), and B (\$5.86 Kg^{-1} actual B). Over both years combined, there is not a significant difference in NRFR. When sorted by year, there was a significant difference in NRFR for 12001. Treatment 3 (WFB) generated an additional \$7.55 over treatment 1 (SSB). Treatment 2 (WF) was higher than Treatment 4 (SS) by \$10.76. (Table 5)

Table 5. Treatment means for NRFR for 2000, 2001 and both years combined.

	Overall†	2000†	2001‡
Treat 1	\$ 94.96	\$ 113.31	\$ 81.13 B
Treat 2	\$ 100.86	\$ 118.32	\$ 90.18 A
Treat 3	\$ 99.68	\$ 116.31	\$ 88.68 A
Treat 4	\$ 94.43	\$ 117.52	\$ 79.42 B

† NS

‡ α=0.05

This result is important because the WF treatments actually generated greater NRFR than SS treatments. There are additional sampling and application costs for SSM that is not figured into this equation. Once these items are figured in, it will look even more favorable for conventional WFM. It should be noted that fertilizer inputs were higher for treatments 1 and 4 (SSB and SS respectively). This research would have to be continued beyond 2 years to determine if this is the case and what the overall affect of SSM would have on NRFR.

Farmers would be more interested in seeing the results for the entire field, rather than just small plots. To address this statement, yield and soil data and application rates of fertilizer were used to calculate the NRFR at the OSC1 location in 2000 on a SSM and WFM basis using the formula for NRFR as described above. From Figure 12, one could conclude that both management schemes were very similar in identifying the range in NRFR. This is consistent with the results found in the small plots. Using the maps from Figure 12, the total income from the SSM NRFR was $4375 while total income from the WFM NRFR was $4150. Total NRFR is based on one-year yield of the field. One could suggest that over the life of the stand that SSM NRFR might be more profitable at this location as increased soil sampling costs would be prorated over the life of the stand.

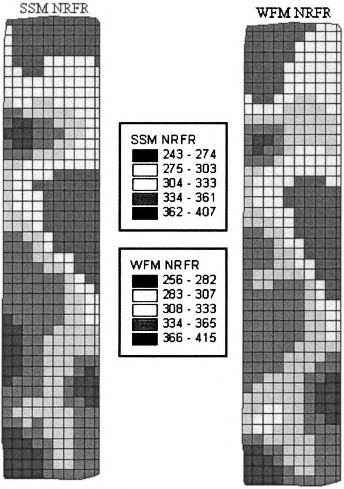


Figure 12. NRFR for the entire field at OSC1. NRFR for SSM was calculated using the actual amount of fertilizer applied. NRFR for WFM was calculated using mean values for pH, P and K as if they were applied uniformly across the entire field.

CONCLUSIONS

CONCLUSIONS

SSM compared with WFM of alfalfa had no significant impact on yield. Likewise, there was a lack of response in forage quality (ADF, NDF, CP) parameters as well. When economic factors are applied, it becomes clear that WFM resulted in more profits than SSM. The SSM plots received higher fertilizer inputs compared with WFM. This suggests that either the alfalfa crop is not responsive to fertilizer inputs at the current soil levels or the basis for making fertilizer recommendations need to be adjusted. Application of additional fertilizer should only be made if crop yield or quality is increased. Otherwise it is not economically feasible to apply fertilizer at the higher rate.

It is important to note though that this study was conducted over a 2-year time frame. The long term affects and profitability of SSM cannot be estimated by the data collected here. There could be benefits from SSM that have yet to be identified. One certain benefit is environmental protection through improved accuracy of nutrient applications.

This study attempted to evaluate the potential for SSM in alfalfa production. Sawyer (1994) pointed out that several criteria must be met in order for SSM to work in agricultural production. First, there must be inherent variations of factors that affect crop production. There was variation in soil pH, P and K as demonstrated by Table 1. Second, these factors must influence crop yield. Regressions of soil pH, P and K indicate that only soil K was related to yield (Table 2). With K as the only factor related to crop yield, it is questionable whether one would see a response from SSM. The third criterion is that crop response models must exist that determines the economically important rates that need to be applied to crops. Fertilizer recommendations from Michigan State

University are based on a wide array of management schemes. Typically growers tend to err on the side of over-application of nutrients to ensure that fertility is not a yield-limiting factor. The recommendations are already generous in the amount of fertilizer recommended. The results of this study help to prove that growers may be applying more fertilizer than needed. Also, different growers have different goals. Some fields are intensively cropped and managed while others are not. If the model could be tailored to meet more specific criteria, such as soil type or field history, there would be a greater potential for SSM to be a useful and economical management alternative.

NRFR was higher for WFM plots because the amounts of fertilizer inputs were higher on the SSM plots. It is possible that these plots are in the building phase of soil fertility. If this were the case, then one would not expect to see the benefits of SSM within a 2-year time frame. A longer-term study might be more accurate in predicting the profitability of SSM.

Future Approaches to SSM

This research identified areas of low fertility within the alfalfa fields to conduct the research using replicated small plots. Results of an economic analysis found WFM treatments produced higher NRFR as a result of increased fertilizer application rates to SSM treatments. This model correctly identified the areas of lower fertility, resulting in higher rates of fertilizer application to the SSM treatments. If the treatments were located in areas higher in soil fertility, the application of fertilizer to SSM treatment would have been lower than the WFM treatments. In this case, it is likely that NRFR would have been greater on SSM treatments.

Replicated treatments were used to evaluate SSM vs. WFM. The goal of SSM is to manage smaller units within a field rather than the whole field collectively. However, the smaller units need to be large enough to make it practical and economical from the grower's perspective. The plot size used in this experiment was small enough for all four replications of each treatment fit into one "smaller unit" of the field. It is not likely that amount of variation in the "smaller unit" is as great as the entire field. Rather than locating all of the small plots in a block together, spreading them around the field randomly could help to identify and quantify the effects of SSM of the field more accurately.

To help identify field variability, it might be useful to collect other data besides soil fertility factors. For example, texture or bulk density could help to explain the some of the results and give insight to aid in the design and layout of research plots.

Yields were variable across locations and years. Fertilizer recommendations were based on an 11.2 Mg Ha^{-1} yield goal. Adjusting this yield goal for each location would be useful in applying the correct amount of fertilizer. Farm records could be used to adjust the yield potential from site to site.

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REFERENCES

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APPENDIX

Table A1. KBS Treatments soil test values and fertilizer recommendations.

		Spring 2000								Spring 2001							
		Soil Test Level				Fertilizer Application Rate				Soil Test Level				Fertilizer Application Rate			
Plot	Treatment	pH	CEC	P$^{\pm}$	K$^{\pm}$	Lime†	P†	K‡‡	B†	pH	CEC	P$^{\pm}$	K$^{\pm}$	Lime†	P‡	K‡‡	B†
101	SS	6.2	7.7	102	68	0.0	0	179	0.0	6.8	5.9	101	81	0	0	336	0.0
102	WFB	6.7	6.7	101	98	0.0	0	168	1.7	6.5	5.2	95	64	0	0	202	1.1
103	WF	6	7.9	99	78	0.0	0	168	0.0	6.4	10.8	88	69	0	0	202	0.0
104	SSB	6.2	7.7	82	80	0.5	0	252	1.7	6.5	4.8	77	78	0	0	336	1.1
201	WF	5.9	7.6	97	106	0.0	0	168	0.0	5.8	6.4	88	84	0	0	202	0.0
202	SSB	6	6.8	97	90	0.5	0	168	1.7	6.2	6.6	109	99	0	0	336	1.1
203	SS	6.6	5.3	99	92	0.5	0	134	0.0	6.3	6.3	90	68	0	0	336	0.0
204	WFB	6.2	6.9	102	99	0.0	0	168	1.7	6.4	6.3	96	77	0	0	202	1.1
301	WFB	6.5	5	113	88	0.0	0	168	1.7	6.3	6.1	124	66	0	0	202	1.1
302	SS	6.2	7	126	80	0.0	0	196	0.0	6.2	6.4	112	78	0	0	336	0.0
303	SSB	6.5	5.9	95	86	0.0	0	179	1.7	6.6	5.2	118	80	0	0	336	1.1
304	WF	6.6	5.8	110	93	0.0	0	168	0.0	6.6	5.7	90	71	0	0	202	0.0
401	SS	6.8	6.4	101	113	0.5	0	179	0.0	6.8	5.3	109	71	0	0	336	0.0
402	SSB	6.4	8.4	83	120	0.0	0	168	1.7	6.7	5.4	118	82	0	0	336	1.1
403	WF	6.8	5.5	104	99	0.0	0	168	0.0	6.6	5.6	82	82	0	0	202	0.0
404	WFB	6.5	5.5	113	83	0.0	0	168	1.7	6.6	5.9	76	83	0	0	202	1.1

$^{\pm}$ppm, †kg ha^{-1}, ‡kg ha^{-1} actual phosphorus, ‡‡kg ha^{-1} actual potassium.

Table A2. ION Treatments and fertilizer recommendations.

		Spring 2000								Spring 2001							
		Soil Test Level				Fertilizer Application Rate				Soil Test Level				Fertilizer Application Rate			
Plot	Treatment	pH	CEC	P±	K±	Lime†	P‡	K‡‡	B†	pH	CEC	P±	K±	Lime†	P‡	K‡‡	B†
101	SS	6.3	7.4	33	161	0.0	40	43	0.0	5.9	7	39	96	0.0	0	0	0.0
102	WFB	6.4	9.1	35	206	0.5	37	0	0.0	6.3	5.6	39	68	0.0	89	0	0.0
103	WF	6.6	7.3	31	210	0.0	40	43	1.7	6.3	5.8	32	77	0.0	0	0	1.1
104	SSB	6.6	7.3	34	164	0.0	36	43	1.7	6.4	5.5	34	87	0.0	89	0	1.1
201	WF	6.7	5.7	27	128	0.0	40	43	1.7	6.2	6.5	26	89	0.0	0	0	1.1
202	SSB	6.7	6.3	29	150	0.0	43	45	1.7	6.2	6	25	69	0.0	89	0	1.1
203	SS	6.7	5.7	32	138	0.0	40	43	0.0	6.3	5.5	30	72	0.0	0	0	0.0
204	WFB	6.7	6	36	127	0.0	36	52	0.0	6.3	5.3	33	71	0.0	89	0	0.0
301	WFB	6.7	6	30	134	0.0	38	52	1.7	6.3	6.1	26	102	0.0	89	0	1.1
302	SS	6.7	5.7	29	156	0.0	40	43	0.0	6.2	5.9	27	88	0.0	0	0	0.0
303	SSB	6.7	6.6	27	173	0.0	43	0	0.0	6.3	5.8	28	76	0.0	89	0	0.0
304	WF	6.7	5.7	29	156	0.0	40	43	1.7	6.4	5.4	31	64	0.0	0	0	1.1
401	SS	6.6	5.8	22	155	0.0	40	43	0.0	6.2	5.9	20	96	0.0	0	0	0.0
402	SSB	6.5	5.4	23	148	0.0	45	45	0.0	6.2	4.9	28	72	0.0	89	0	0.0
403	WF	6.5	5.4	24	155	0.0	43	0	1.7	6.3	5.8	30	82	0.0	89	0	1.1
404	WFB	6.6	5.8	32	167	0.0	40	43	1.7	6.4	5.5	28	87	0.0	0	0	1.1

± ppm, † $kg\ ha^{-1}$, ‡ $kg\ ha^{-1}$ actual phosphorus, ‡‡ $kg\ ha^{-1}$ actual potassium.

Table A3. OSC1 Treatments and fertilizer recommendations.

		Spring 2000								Spring 2001							
		Soil Test Level				Fertilizer Application Rate				Soil Test Level				Fertilizer Application Rate			
Plot	Treatment	pH	CEC	P±	K±	Lime†	P‡	K‡‡	B†	pH	CEC	P±	K±	Lime†	P‡	K‡‡	B†
101	SS	6.6	12.8	18	122	0	56	196	1.7	6.5	7.9	14	77	0	117	202	1.1
102	WFB	7.1	12.3	17	83	0	78	235	1.7	7.1	9.3	15	56	0	145	336	1.1
103	WF	7.1	9.1	24	55	0	56	196	0.0	7.1	7.3	23	52	0	117	202	0.0
104	SSB	6.6	7.7	27	59	0	45	308	0.0	6.7	5.1	26	75	0	89	336	0.0
201	WF	6.7	8.6	17	62	0	84	291	1.7	6.9	7.4	17	69	0	89	336	1.1
202	SSB	6.8	9.5	21	60	0	56	196	0.0	6.9	6.9	17	41	0	117	202	0.0
203	SS	6.8	8.2	25	57	0	56	291	0.0	6.7	6.7	21	64	0	145	336	0.0
204	WFB	6.4	9.9	33	62	0	56	196	1.7	6.5	5.2	29	50	0	117	202	1.1
301	WFB	7.1	9.7	30	114	0	56	196	0.0	7	8.5	31	108	0	117	202	0.0
302	SS	7	10	22	97	0	67	213	1.7	7.1	8.5	21	77	0	117	336	1.1
303	SSB	7.1	12	23	122	0	56	196	1.7	7	8.7	16	90	0	117	202	1.1
304	WF	7	12.7	17	156	0	90	101	0.0	7	9.9	15	106	0	145	336	0.0
401	SS	6.8	9	30	115	0	34	157	0.0	6.8	7	24	83	0	117	336	0.0
402	SSB	6.9	8.7	36	98	0	56	196	0.0	6.8	5.9	33	60	0	117	202	0.0
403	WF	7.1	9.9	31	102	0	34	179	1.7	7	8.3	26	85	0	145	336	1.1
404	WFB	7.1	10.9	22	109	0	56	196	1.7	7	8.8	19	73	0	117	202	1.1

± ppm, † $kg\ ha^{-1}$, ‡ $kg\ ha^{-1}$ actual phosphorus, ‡‡ $kg\ ha^{-1}$ actual potassium.

Table A4. OSC2 Treatments and fertilizer recommendations.

		Spring 2001							
		Soil Test Level				Fertilizer Application Rate			
Plot	Treatment	pH	CEC	$P^{\pm}$	$K^{\pm}$	$Lime^{\dagger}$	$P^{\ddagger}$	$K^{\ddagger\ddagger}$	$B^{\dagger}$
101	SS	NA	NA	26	291	0	89	336	0.0
102	WFB	NA	NA	12	313	0	145	336	1.1
103	WF	NA	NA	10	378	0	117	202	0.0
104	SSB	NA	NA	14	316	0	117	202	1.1
201	WF	7.3	13	12	107	0	117	202	0.0
202	SSB	7.3	10.6	10	88	0	145	336	0.0
203	SS	7.3	11.5	14	108	0	117	202	1.1
204	WFB	7.2	10.7	11	93	0	145	336	1.1
301	WFB	7.3	10.3	13	93	0	117	202	1.1
302	SS	7.3	9.8	12	86	0	145	336	1.1
303	SSB	7.5	17.3	23	184	0	117	336	0.0
304	WF	7.3	11.2	15	95	0	117	202	0.0
401	SS	7.4	11	13	76	0	117	202	0.0
402	SSB	7.3	11.5	19	87	0	145	336	0.0
403	WF	7.4	9.5	16	71	0	117	202	1.1
404	WFB	7.3	9.9	17	78	0	145	336	1.1

$^{\pm}$ ppm, † kg ha^{-1}, ‡ kg ha^{-1} actual phosphorus, ‡‡ kg ha^{-1} actual potassium.

Table A5. Yield† data, KBS.

		2000					2001				
Plot	Treatment	Cut 1	Cut 2	Cut 3	Cut 4	**Total**	Cut 1	Cut 2	Cut 3	Cut 4	**Total**
101	SS	2.66	2.73	3.14	3.26	**11.79**	2.49	2.03	2.13	2.22	**8.86**
102	WFB	2.52	2.94	2.40	3.26	**11.12**	3.74	2.24	1.59	2.24	**9.82**
103	WF	2.25	2.90	2.23	3.26	**10.64**	3.39	2.48	2.09	2.22	**10.17**
104	SSB	2.62	3.11	2.51	3.26	**11.50**	3.44	3.07	2.44	2.27	**11.23**
201	WF	2.67	2.81	2.09	3.26	**10.84**	4.78	2.61	1.85	2.12	**11.35**
202	SSB	2.16	2.89	2.67	3.26	**10.98**	3.99	2.55	2.18	2.07	**10.79**
203	SS	2.42	3.19	2.94	3.26	**11.81**	2.32	2.52	2.12	2.22	**9.18**
204	WFB	2.71	3.06	2.67	3.26	**11.70**	2.72	2.87	2.16	2.27	**10.02**
301	WFB	2.53	2.57	2.64	3.26	**11.00**	2.33	2.14	1.77	1.82	**8.07**
302	SS	2.36	2.63	2.47	3.26	**10.73**	3.28	2.75	2.03	2.14	**10.21**
303	SSB	2.83	2.25	2.72	3.26	**11.06**	2.70	2.46	2.00	2.07	**9.23**
304	WF	2.43	2.59	2.83	3.26	**11.12**	4.03	2.91	2.07	2.37	**11.38**
401	SS	3.39	2.85	3.94	3.26	**13.44**	3.32	2.10	1.46	2.51	**9.39**
402	SSB	2.43	3.10	2.84	3.26	**11.62**	2.87	2.39	1.87	2.64	**9.77**
403	WF	2.54	2.79	3.04	3.26	**11.63**	3.94	2.39	1.68	2.56	**10.58**
404	WFB	2.96	2.38	2.89	3.26	**11.49**	3.98	3.29	1.84	2.39	**11.50**

† Mg Ha^{-1}

Table A6. Yield† data, ION.

		2000				2001				
Plot	Treatment	Cut 1	Cut 2	Cut 3	**Total**	Cut 1	Cut 2	Cut 3	Cut 4	**Total**
101	SS	3.07	3.44	3.60	**10.10**	5.65	1.68	0.86	2.40	**10.59**
102	WFB	2.60	3.49	3.16	**9.25**	4.71	1.64	1.10	2.10	**9.54**
103	WF	3.20	3.45	3.41	**10.06**	4.92	1.68	0.98	2.26	**9.84**
104	SSB	3.40	2.67	3.74	**9.81**	4.27	1.54	1.15	2.30	**9.26**
201	WF	2.39	4.16	2.61	**9.16**	4.92	1.93	0.81	2.07	**9.73**
202	SSB	3.05	2.98	3.26	**9.29**	4.78	1.48	1.06	2.11	**9.43**
203	SS	2.75	3.71	2.87	**9.32**	5.07	1.78	0.82	1.65	**9.32**
204	WFB	3.07	3.17	3.14	**9.38**	4.35	1.72	1.04	1.97	**9.08**
301	WFB	2.77	3.87	3.13	**9.76**	4.35	1.65	0.93	2.43	**9.35**
302	SS	3.54	3.50	2.00	**9.04**	4.71	1.59	0.93	2.90	**10.14**
303	SSB	3.14	3.64	1.54	**8.32**	5.00	1.87	0.84	2.09	**9.79**
304	WF	2.23	4.66	2.11	**9.01**	4.20	1.38	0.97	1.87	**8.42**
401	SS	2.86	4.15	1.88	**8.88**	4.49	2.00	0.74	1.92	**9.15**
402	SSB	3.07	4.38	2.34	**9.80**	4.27	1.56	0.81	1.36	**8.01**
403	WF	2.86	2.62	2.19	**7.67**	4.92	1.59	0.91	2.35	**9.77**
404	WFB	2.14	3.32	2.19	**7.64**	3.91	1.38	0.99	2.02	**8.30**

† $Mg\ Ha^{-1}$

Table A7. Yield† data, OSC1.

		2000				2001				
Plot	Treatment	Cut 1	Cut 2	Cut 3	**Total**	Cut 1	Cut 2	Cut 3	Cut 4	**Total**
101	SS	2.97	3.79	2.82	**9.59**	3.48	3.33	0.92	1.25	**8.97**
102	WFB	2.97	2.77	2.19	**7.93**	3.04	2.55	1.04	NA	**6.63**
103	WF	2.97	2.67	1.84	**7.48**	2.75	1.64	0.71	1.03	**6.12**
104	SSB	2.97	1.97	2.06	**7.00**	2.17		0.89	1.01	**6.30**
201	WF	2.97	3.47	2.62	**9.07**	2.97		0.79	1.47	**8.26**
202	SSB	2.97	3.38	2.36	**8.71**	2.03		1.04	NA	**6.12**
203	SS	2.97	2.02	2.15	**7.15**	3.11	2.52	0.89	0.97	**7.49**
204	WFB	2.97	2.86	2.45	**8.28**	3.26	2.40	0.69	1.03	**7.39**
301	WFB	2.97	2.94	2.73	**8.64**	2.32	2.20	0.84	1.22	**6.58**
302	SS	2.97	3.59	3.34	**9.91**	2.32	2.40	0.95	1.32	**6.98**
303	SSB	2.97	4.04	2.10	**9.10**	2.03	2.96	0.79	1.15	**6.93**
304	WF	2.97	3.15	2.67	**8.79**	3.19	2.61	1.04	1.71	**8.54**
401	SS	2.97	3.52	2.68	**9.17**	1.96	2.90	1.02	1.44	**7.31**
402	SSB	2.97	3.53	2.62	**9.13**	1.96	2.40	0.99	1.61	**6.95**
403	WF	2.97	3.24	2.48	**8.69**	3.04	2.24	0.94	1.25	**7.46**
404	WFB	2.97	2.50	2.63	**8.10**	3.62	3.15	1.08	1.64	**9.50**

† $Mg\ Ha^{-1}$

Table A8. Yield† data, OSC2.

		2001				
Plot	Treatment	Cut 1	Cut 2	Cut 3	Cut 4	**Total**
101	SS	4.40	3.90	1.00	2.77	**12.07**
102	WFB	4.08	3.63	0.69	2.65	**11.05**
103	WF	3.95	2.60	0.63	1.91	**9.09**
104	SSB	4.10	2.91	1.03	2.23	**10.27**
201	WF	5.02	4.50	1.08	1.99	**12.60**
202	SSB	4.03	4.08	1.16	2.14	**11.41**
203	SS	4.45	2.90	0.99	2.20	**10.53**
204	WFB	5.54	3.36	1.08	2.76	**12.74**
301	WFB	4.93	4.13	1.23	2.54	**12.83**
302	SS	3.18	3.61	1.43	2.56	**10.78**
303	SSB	4.01	3.41	1.08	1.57	**10.08**
304	WF	4.57	3.79	1.08	2.66	**12.11**
401	SS	3.81	3.17	1.13	2.77	**10.89**
402	SSB	3.73	3.75	1.28	2.74	**11.50**
403	WF	3.51	2.64	1.04	2.51	**9.70**
404	WFB	4.06	3.19	1.33	2.54	**11.12**

† $Mg\ Ha^{-1}$

Table A9. Quality data, KBS, 2000.

		Cut 1			Cut 2			Cut 3		
Plot	Treatment	% ADF	% NDF	% CP	% ADF	% NDF	% CP	% ADF	% NDF	% CP
101	SS	25.50	33.73	25.41	30.66	39.68	23.65	33.888	48.461	21.72
102	WFB	26.08	35.51	26.66	31.14	40.29	23.55	35.412	45.298	22.13
103	WF	26.77	36.86	25.36	30.67	39.44	22.99	35.479	46.5	22.42
104	SSB	26.69	36.33	25.98	29.00	37.70	23.75	37.631	49.803	21.85
201	WF	25.81	35.99	24.91	31.75	39.34	23.02	35.025	47.549	22.58
202	SSB	26.15	35.99	25.42	29.59	39.04	23.43	37.81	47.763	21.83
203	SS	25.27	33.49	25.84	29.71	38.35	25.41	37.202	49.302	20.74
204	WFB	25.79	34.33	25.54	31.18	41.35	22.25	36.38	48.319	21.96
301	WFB	26.75	35.87	25.63	30.83	41.37	23.42	35.768	46.546	21.86
302	SS	27.82	37.99	25.01	29.88	39.13	25.16	34.661	44.28	22.97
303	SSB	28.05	37.26	25.05	32.03	41.16	23.57	33.361	46.311	22.82
304	WF	25.20	33.60	25.57	31.07	41.33	23.69	33.808	45.046	22.52
401	SS	28.35	37.69	24.76	33.32	44.00	21.27	35.566	46.732	20.95
402	SSB	27.37	37.36	24.85	30.01	36.58	25.74	36.44	47.622	21.19
403	WF	27.48	36.57	25.31	29.63	39.17	22.31	35.432	46.137	21.6
404	WFB	28.00	36.86	25.44	31.42	41.35	22.73	33.864	44.855	21.62

Table A10. Quality data, KBS, 2001.

		Cut 1			Cut 2			Cut 3			Cut 4		
Plot	Treatment	% ADF	% NDF	% CP	% ADF	% NDF	% CP	% ADF	% NDF	% CP	% ADF	% NDF	% CP
101	SS	20.63	26.55	24.51	25.75	38.66	19.51	NA	NA	NA	NA	NA	NA
102	WFB	25.84	35.50	21.54	25.52	39.10	19.62	26.28	37.55	18.84	NA	NA	NA
103	WF	28.30	38.53	19.63	25.01	39.00	19.51	27.76	40.38	17.54	NA	NA	NA
104	SSB	23.13	32.55	21.97	25.06	38.34	19.73	27.00	39.60	18.12	NA	NA	NA
201	WF	28.10	37.91	20.29	26.89	40.62	19.32	27.02	37.91	18.20	26.08	40.22	19.46
202	SSB	24.06	35.95	21.54	27.14	41.29	18.30	27.40	41.11	18.04	25.86	40.51	19.44
203	SS	26.92	37.07	20.93	24.81	38.30	20.27	27.29	38.88	17.68	NA	NA	NA
204	WFB	23.59	32.45	22.98	24.66	37.78	19.95	30.74	43.15	15.81	22.86	33.98	21.54
301	WFB	23.40	32.27	22.87	27.02	41.04	18.75	30.60	43.62	16.88	22.82	35.30	21.92
302	SS	26.66	36.31	20.45	22.61	35.45	20.93	29.28	40.09	17.42	25.39	38.85	19.82
303	SSB	24.69	34.24	21.66	27.97	41.95	18.24	29.25	40.23	16.96	NA	NA	NA
304	WF	24.78	33.91	22.06	28.92	42.99	18.34	26.70	38.99	18.59	NA	NA	NA
401	SS	24.16	33.46	22.05	29.14	43.38	18.31	30.35	41.71	17.49	23.34	36.78	20.36
402	SSB	25.08	34.90	22.14	27.09	40.06	19.18	28.98	41.20	16.80	25.00	37.03	21.33
403	WF	27.57	37.43	20.17	26.66	39.72	19.33	29.01	40.63	17.43	24.79	36.61	21.38
404	WFB	25.92	35.64	21.16	30.72	45.76	17.31	27.25	37.93	19.06	NA	NA	NA

Table A11. Quality data, ION, 2000.

		Cut 1			Cut 2			Cut 3		
Plot	Treatment	% ADF	% NDF	% CP	% ADF	% NDF	% CP	% ADF	% NDF	% CP
101	SS	29.36	40.61	22.54	34.66	44.81	22.03	32.925	42.6	23.42
102	WFB	27.99	38.40	24.85	37.55	48.52	22.12	33.474	44.436	22.86
103	WF	29.11	40.62	23.70	35.78	46.16	22.68	32.816	43.068	22.07
104	SSB	28.85	40.68	24.58	33.77	44.37	22.60	32.109	42.278	21.9
201	WF	27.16	38.95	23.01	35.46	46.48	21.13	32.151	42.761	24.95
202	SSB	29.43	39.13	22.73	34.25	45.23	22.60	31.849	42.574	23.89
203	SS	29.25	39.59	23.72	34.98	44.81	21.89	34.35	45.098	22.05
204	WFB	28.16	38.75	24.15	33.95	44.70	23.05	32.521	42.994	22.75
301	WFB	28.77	39.55	22.42	37.39	51.26	19.83	30.922	45.957	23.34
302	SS	30.30	40.95	22.69	36.22	46.41	21.09	33.269	45.894	24.04
303	SSB	28.40	38.27	21.59	39.75	57.80	18.39	31.682	44.396	24.35
304	WF	28.92	40.90	23.18	39.97	53.20	19.08	32.717	44.574	24.81
401	SS	29.47	39.60	21.54	36.04	46.39	21.44	32.717	43.01	23.77
402	SSB	30.53	42.20	20.93	35.39	45.30	21.38	33.759	44.621	21.54
403	WF	31.13	41.74	20.89	39.37	49.71	20.28	32.97	43.855	22.38
404	WFB	28.46	39.07	21.80	39.11	50.29	20.43	33.51	44.344	23.09

Table A12. Quality data, ION, 2001.

		Cut 1			Cut 2			Cut 3			Cut 4		
Plot	Treatment	% ADF	% NDF	% CP	% ADF	% NDF	% CP	% ADF	% NDF	% CP	% ADF	% NDF	% CP
101	SS	32.89	42.66	18.04	34.99	51.82	12.76	NA	NA	NA	21.58	27.82	24.40
102	WFB	30.35	40.71	17.93	33.96	49.25	13.76	NA	NA	NA	21.00	26.64	23.85
103	WF	28.37	36.98	18.64	28.37	42.08	17.53	32.38	44.31	19.10	21.86	27.81	23.45
104	SSB	29.29	38.74	18.96	28.85	41.38	18.32	31.72	43.50	18.36	24.57	29.75	22.49
201	WF	29.74	38.88	18.58	33.77	48.12	18.07	31.19	43.12	17.85	22.44	27.74	22.38
202	SSB	31.34	39.83	17.24	31.82	47.39	15.37	34.00	46.64	17.64	22.76	29.27	22.86
203	SS	30.26	39.71	18.30	29.59	44.12	16.79	32.38	43.93	18.53	21.18	27.58	23.42
204	WFB	31.11	42.83	16.49	31.38	43.93	17.63	NA	NA	NA	22.49	28.02	23.13
301	WFB	29.22	39.16	18.01	31.69	44.68	17.23	32.39	44.73	18.90	24.15	30.14	22.22
302	SS	31.87	42.33	16.22	29.15	44.17	15.89	32.04	43.57	18.94	24.64	30.86	21.83
303	SSB	28.01	36.60	18.20	31.30	45.40	16.66	33.91	46.69	18.57	21.70	26.95	23.03
304	WF	29.97	40.06	17.66	31.70	45.59	16.64	32.58	44.25	18.76	21.27	26.91	23.10
401	SS	27.82	37.27	19.18	32.11	44.61	17.85	NA	NA	NA	20.71	26.35	23.42
402	SSB	29.20	38.34	18.72	30.24	45.42	16.27	33.62	45.80	18.12	20.26	26.11	24.99
403	WF	30.02	38.52	18.23	30.59	44.31	16.73	31.28	43.33	19.59	21.32	27.70	25.44
404	WFB	28.09	37.11	18.29	NA	NA	NA	NA	NA	NA	20.63	26.55	24.51

NA=Not available. Samples in storage molded.

Table A13. Quality data, OSC1, 2000.

		Cut 1			Cut 2			Cut 3		
Plot	Treatment	% ADF	% NDF	% CP	% ADF	% NDF	% CP	% ADF	% NDF	% CP
101	SS	31.43	41.44	21.66	34.37	46.14	20.89	33.52	44.65	22.86
102	WFB	29.37	38.43	22.61	33.84	45.10	23.14	31.88	43.69	24.39
103	WF	32.64	40.33	21.02	34.96	46.25	22.07	32.55	44.40	24.15
104	SSB	33.75	44.96	20.46	37.89	50.50	21.06	34.06	44.99	22.84
201	WF	29.39	39.44	22.19	33.29	45.46	23.24	34.01	45.91	22.69
202	SSB	32.10	42.68	21.18	35.59	47.44	22.43	33.18	45.70	22.67
203	SS	35.98	50.20	18.32	37.31	50.13	20.46	32.16	44.26	23.54
204	WFB	34.21	43.31	21.53	36.01	47.62	21.29	32.89	44.25	23.30
301	WFB	31.75	42.17	21.37	34.79	45.00	20.99	35.45	47.93	22.59
302	SS	32.08	40.29	23.01	34.21	44.57	22.78	34.16	45.85	23.36
303	SSB	31.19	40.55	21.88	34.46	44.64	23.08	32.02	44.02	25.06
304	WF	32.18	42.00	22.27	34.95	45.55	21.27	34.99	48.41	22.29
401	SS	32.22	40.77	21.38	32.39	42.36	21.72	32.63	43.21	23.68
402	SSB	31.78	41.78	20.83	34.70	46.05	22.92	31.65	41.77	23.10
403	WF	37.66	46.57	20.63	33.68	43.36	23.11	29.08	38.86	24.08
404	WFB	32.50	41.68	22.08	35.40	45.71	21.70	33.90	44.57	23.16

Table A14. Quality data, OSC1, 2001.

		Cut 1			Cut 2			Cut 3			Cut 4		
Plot	Treatment	% ADF	% NDF	% CP	% ADF	% NDF	% CP	% ADF	% NDF	% CP	% ADF	% NDF	% CP
101	SS	NA	NA	NA	23.51	34.29	20.30	NA	NA	NA	19.81	26.71	25.78
102	WFB	NA	NA	NA	24.07	34.90	19.79	NA	NA	NA	18.86	25.05	25.74
103	WF	NA	NA	NA	21.61	33.03	20.89	NA	NA	NA	18.81	27.92	24.63
104	SSB	NA	NA	NA	24.55	36.37	19.36	NA	NA	NA	20.36	28.44	24.48
201	WF	NA	NA	NA	22.10	32.26	19.54	NA	NA	NA	19.56	26.01	24.91
202	SSB	NA	NA	NA	23.64	35.35	19.52	NA	NA	NA	21.54	27.57	25.81
203	SS	NA	NA	NA	22.61	33.51	20.24	NA	NA	NA	18.54	26.85	24.85
204	WFB	NA	NA	NA	23.69	34.87	19.58	NA	NA	NA	20.63	30.15	23.54
301	WFB	NA	NA	NA	19.96	31.80	20.15	NA	NA	NA	16.83	25.72	25.47
302	SS	NA	NA	NA	23.46	36.76	19.84	NA	NA	NA	18.15	25.09	25.57
303	SSB	NA	NA	NA	NA	NA	NA	NA	NA	NA	18.68	25.16	24.37
304	WF	NA	NA	NA	20.65	31.29	20.56	NA	NA	NA	20.63	26.44	24.59
401	SS	NA	NA	NA	22.61	35.25	20.33	NA	NA	NA	18.49	25.72	25.32
402	SSB	NA	NA	NA	22.52	36.00	20.47	NA	NA	NA	20.18	26.93	24.75
403	WF	NA	NA	NA	22.89	33.47	20.50	NA	NA	NA	18.43	25.86	25.12
404	WFB	NA	NA	NA	NA	NA	NA	NA	NA	NA	19.43	27.18	24.65

NA=Not available. Samples in storage molded.

Table A15. Quality data, OSC2, 2001.

		Cut 1			Cut 2			Cut 3			Cut 4		
Plot	Treatment	% ADF	% NDF	% CP	% ADF	% NDF	% CP	% ADF	% NDF	% CP	% ADF	% NDF	% CP
101	SS	31.15	37.47	17.30	27.95	34.32	18.91	NA	NA	NA	22.62	28.09	24.94
102	WFB	28.87	35.38	18.23	28.72	35.78	19.12	NA	NA	NA	24.12	28.66	24.40
103	WF	25.95	31.71	19.36	26.61	33.33	19.81	NA	NA	NA	20.16	26.94	25.21
104	SSB	26.96	32.99	18.29	26.37	32.10	20.34	NA	NA	NA	20.47	26.88	25.03
201	WF	28.88	35.44	18.15	28.44	34.73	19.80	NA	NA	NA	20.78	26.99	24.94
202	SSB	27.99	33.26	18.47	28.23	34.96	19.57	NA	NA	NA	21.61	27.44	25.78
203	SS	28.29	34.90	18.05	29.26	34.62	19.52	NA	NA	NA	20.55	27.03	25.44
204	WFB	28.41	34.37	17.41	29.42	36.20	18.87	NA	NA	NA	18.73	24.31	26.57
301	WFB	29.67	35.55	17.34	29.36	38.20	18.75	NA	NA	NA	23.18	29.16	24.54
302	SS	28.61	37.56	18.99	26.43	33.56	19.75	NA	NA	NA	20.72	27.03	26.05
303	SSB	26.00	33.34	20.12	28.27	35.17	19.15	NA	NA	NA	20.05	26.54	25.65
304	WF	27.12	33.61	19.13	26.15	33.08	19.59	NA	NA	NA	20.61	26.12	25.52
401	SS	NA	NA	NA	26.13	31.72	20.58	NA	NA	NA	21.89	27.32	24.96
402	SSB	27.18	34.57	19.43	29.33	32.38	18.40	NA	NA	NA	21.72	27.36	25.34
403	WF	29.49	36.02	18.52	27.06	32.85	19.62	NA	NA	NA	20.40	26.53	25.59
404	WFB	30.24	36.62	17.75	31.86	34.36	17.84	NA	NA	NA	19.91	25.83	25.82

NA=Not available. Samples in storage molded.

Table A16. Monthly average high and low temperatures and actual precipitation by location and year.

		2000			2001		
		Precip. (in)	Avg. Low (°F)	Avg. High (°F)	Precip. (in)	Avg. Low (°F)	Avg. High (°F)
ION							
	May	6.56	45.6	66.7	5.29	47.5	69.2
	June	3.82	54.1	75.0	2.80	53.3	76.3
	July	3.60	55.4	77.6	1.11	55.6	82.2
	August	2.26	56.2	79.0	5.55	58	81.6
	September	4.68	47.9	70.0	4.00	47	69.1
	October	1.31	41.4	64.0	5.85	39.[illegible]	58.4
	Total	22.23		Total	24.60		
KBS							
	May	9.14	50.9	75.0	7.67	50.6	75.6
	June	4.01	57.1	80.4	4.56	56.9	80.4
	July	4.84	58.0	82.6	2.01	58.9	87.4
	August	4.63	59.5	82.8	5.82	62.9	85.3
	September	5.26	52.0	75.3	4.93	50.8	72.8
	October	2.66	45.3	68.3	7.71	43.6	62.4
	Total	30.54		Total	32.70		
OSC							
	May	5.74	46.1	69.7	6.55	46.8	69.8
	June	3.56	53.4	76.0	2.68	52.8	78.1
	July	3.58	54.9	78.7	1.35	56.1	83.7
	August	3.20	55.1	79.8	5.32	57.6	82.7
	September	3.72	46.8	70.5	3.75	46.5	69.6
	October	2.33	38.1	63.9	7.86	37.7	60.2
	Total	22.13		Total	27.51		