Beet Quality Modeling from Remotely Sensed Canopy Data from July to Harvest

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Introduction

Remotely sensed images, either from airborne platforms or from satellites have been used to evaluate agricultural fields for a number of characteristics. Images of bare fields have been used to assist in the development of management zones. Images of mature sugarbeet fields have been used to estimate areas of high and low nitrogen credits for subsequent crops (Moraghan, 1998). Digital satellite imagery is currently available in multispectral form at spatial resolutions of 4 meters. Approval has been given for commercial sale of multispectral data at resolutions finer than 4 meters. Although commercial satellite platforms are currently unavailable at that resolution, it is expected that they will be launched soon. If remote sensing is to be used broadly in a sugarbeet rotation it will be necessary for one or more images to provide sufficient value in the form of useful information to offset the cost of the data and any processing of it for use in a grower GIS or mapping system. Economical use of any of these imaging systems in a sugarbeet rotation may very well include multiple uses of the same data set. It may be that a single image is ultimately used to estimate spatial distribution of beet quality, follow-on nitrogen credit, disease locations, and harvested acres. The work described here involves the modeling of beet root and top quality from two forms of canopy spectral measurements. Differences in the canopy spectra of beets with the disease Beet Necrotic Yellow Vein Virus are also discussed.

Methods

Quality and canopy spectral data were collected from an ongoing experiment involving the effects of nitrogen fertilizer rates and manure applications on sugarbeet yield and quality. That experiment included conventional fertilizer and manure treatments applied in November of 1998. Treatment rates included 0 lb N/ acre, as well as 40, 80, 120, 160, and 200 lbs N / acre. Turkey manure at rates of 2.5 tons/acre (45 lbs total N/acre) and 5.0 tons/acre were also applied. Swine manure at rates of 2500 gal/acre (228 lbs total N/acre) and 5000 gal/acre (455 lbs total N/acre) was also applied for a total of 10 treatments. Each treatment was replicated 4 times (Lamb and Schmitt, 1999). Sugarbeet root yield, and root quality were measured at harvest mid-October 1999. A single set of quality samples was taken at harvest from the center two rows of the six-row plots. The roots were weighed, washed, and analyzed for sugar and quality parameters at the Southern Minnesota Beet Sugar Cooperative Quality laboratory, Renville, MN. Tops were also harvested and analyzed for N uptake.

Spectral Data Collection

Two forms of spectral data from the beet canopy were obtained. Detailed spectral reflectance measurements were made with a FieldSpec FR spectroradiometer. Reflectance data were collected on each of July 27, Aug 10, Aug 27, Sept. 21, and Oct. 5 of 1999. The resulting data set represented wavelength specific canopy reflectance from each plot for that date.

Multi-spectral airborne image data were also obtained for the plot area at several intervals during the same time period. A camera system operated by Airborne Data Systems, Inc.(Wabasso, MN) was used to obtain images. The systems four cameras were fitted with optical interference bandpass filters having center passbands at wavelengths at 490, 570, 660, and 870 nm respectively. The aircraft carrying the camera system was flown over the plot site at two different altitudes to provide effective spatial resolutions of ¼ meter and ½ meter per pixel side. Four blue nylon tarps were placed at locations around the perimeter of the plot area to assist in georegistration of the images. In addition to the corners of the tarps, other features, such as the corners of tilled areas, were used to obtain additional ground control points for registration. A Leica survey quality GPS receiver was used to accurately determine the relative location of each ground control point. Coordinates of the center point of each plot were recorded using the GPS receiver. Images of the plot area obtained from ADS were processed and reviewed using the ERDAS Imagine software. Image data from five overflight dates were subsequently analyzed. Dates of the image acquisition flights included August 4, August 31, September 18, September 21 and October 8.

Each image was georegistered using the known coordinates of the ground control points visible in the images. The plot centers were not inherently visible in the images but the georegistration allowed their locations to be accurately identified by coordinates. These locations were used as the basis for pixel extraction for spectral data from the plots. Each treatment plot was comprised of six 0.56 m (22 inch) rows. The center two rows were ultimately harvested for yield and quality. The center of each plot, as determined by coordinates, was located in the images and a strip of pixels was identified that coincided with the center two rows of the plot. On all but one of the sample days ¼ meter pixel data were used, and the sample area consisted of a block four pixels wide by 17 long. On August 31 the 1/4 meter data was unavailable and a ½ meter resolution block two pixels wide by 9 pixels long was extracted. The ends of the plots were terminated with a tillage strip and these ends were avoided to exclude any edge effects in the images or the beets. The sampled pixel data were averaged for each plot, yielding four spectral band values for that plot.

Several different indices were tested for a relationship to beet quality. The three indices calculated are defined below. The first index, defined as a Green NDVI uses the mean reflectance between 565 and 575 nm, (Green), and an NIR value calculated as the mean reflectance from 865 to 875 nm. Gitelson et al (1996) showed that a green index calculated this way could be more sensitive to Chlorophyll-a concentration than the well known NDVI, for Chl-a concentrations above 3.6 $\mu g/cm^2$. The conventional NDVI, identical to the Green index described above while substituting the mean red reflectance from 655 to 665 nanometers for the green, was calculated also. A third index, an Amplified Green NDVI,was calculated as the Green NDVI above with the exception that the average green reflectance was multiplied by a factor of 3 in both the numerator and denominator. The reason for testing this index has to do with the magnitude of the differences that occur between the visible and NIR bands. The differences that appear in the reflectance curves from 450 tp 650 nanometers are small in magnitude relative to the differences that occur in the NIR wavelengths. However, the differences appear to be no less real. This index multiplies the green reflectance by an arbitrary factor of 3 to amplify the differences that occur here and allow the visible wavelengths to make a greater contribution to the variability in the overall index.

Simple linear regressions were used to examine the potential of these indices to classify beets for quality from remote data. Recoverable sucrose per ton (RST) is used as the principle measure of beet quality here, and was considered to be the most useful quality indicator to model. The relationship of the three spectral indices to each of the variables comprising RST was examined also. Each of the three indices was calculated from the spectrograph data for each plot for the five dates from July 26 through October 5. The index values for the replicated plots representing a fertility treatment were averaged, as were the beet quality measures for the same treatment. A linear model for each quality variable was then generated from the treatment averages, and the coefficients of determination tabled.

Results

Spectrograph Data The regression results, as measured by the R-squared value are given in Table 1 for the models using the Green NDVI index. Values of the coefficient ranged from a low of 0.708 on August 27 to a high

Table 1. Coefficients of Determination for simple linear regressions between sugar beet quality variables and a Green NDVI index for 10 fertility treatments. Each row represents the regression model result for the spectra collected on that date using a spectroradiometer. Three or four treatment replications were averaged, as were the associated canopy spectra.

Date	Recoverable Sugar Per Ton	Percent Sucrose	PPM Na	PPM K	Amino N	LTM
July 26	**0.7912****	0.7572**	0.1948	0.2066	0.3879	0.1561
August 10	**0.7759****	0.7642**	0.2161	0.2926	0.3340	0.1020

Date	Recoverable Sugar Per Ton	Percent Sucrose	PPM Na	PPM K	Amino N	LTM
August 27	**0.7091****	0.7056**	0.0840	0.4056*	0.3921	0.0812
Sept. 21	**0.7174****	0.7471**	0.1035	0.4843*	0.2717	0.0294
October 5	**0.7632****	0.7656**	0.1466	0.4382*	0.3624	0.0719

* Indicates the model was statistically significant at the 0.05 level.
** Indicates the model was significant at the 0.01 level.

of 0.791 on July 26. All of the other quality measures have weaker correlations, although percent sucrose is quite close to RST in its correlation to canopy spectra. Sodium, Amino N, and overall Loss-to-Molasses appear to have little correlation to the canopy index. The models for potassium are significant at the 0.05 level on the three later sample dates.

The conventional NDVI results are given for the treatment averages in Table 2. The results are quite similar to the Green Index, with the NDVI showing slightly higher correlations to recoverable sugar on all but one of the sample days. Also, the model for Amino N is significant on August 27.

The Amplified Green Index yielded correlations that were nearly the same as those of the Green NDVI. And the conventional NDVI. In this set of models it would appear that the contribution of variation in "greenness" had minimal impact on the ability to relate canopy reflectance to root quality.

Table 2. Coefficients of Determination for simple linear regressions between sugar beet quality variables and the NDVI for 10 fertility treatments. Each row represents the regression model result for the spectra collected on a single day using a spectroradiometer.

Date	Recoverable Sugar Per Ton	Percent Sucrose	PPM Na	PPM K	Amino N	LTM
July 26	**0.8070****	0.7456**	0.3468	0.0497	0.3194	0.2321
August 10	**0.8069****	0.7791**	0.3044	0.1577	0.2964	0.1403
August 27	**0.7857****	0.7536**	0.1487	0.2408	0.4158*	0.1505
Sept. 21	**0.7066****	0.7518**	0.1067	0.4884*	0.2183	0.0155
October 5	**0.7663****	0.7931**	0.1671	0.4534*	0.2670	0.0375

Table 3. Coefficients of Determination for simple linear regressions between sugar beet quality variables and an Amplified Green NDVI for 10 fertility treatments. Each row represents the regression model result for the spectra collected on a single day using a spectroradiometer.

Date	Recoverable Sugar Per Ton	Percent Sucrose	PPM Na	PPM K	Amino N	LTM
July 26	**0.7922****	0.7570**	0.1914	0.2033	0.3924	0.1594
August 10	**0.7775****	0.7645**	0.2059	0.2937	0.3433	0.1049
August 27	**0.7006****	0.6954**	0.0792	0.4047*	0.4002*	0.0838
Sept. 21	**0.7131****	0.7426**	0.0979	0.4847*	0.2789	0.0309
October 5	**0.7618****	0.7620**	0.1428	0.4355*	0.3715	0.0755

The data for the models presented in tables 1-3 were organized by treatment. The quality data from the three or four plots for each fertility treatment were averaged, as were the spectra for those plots. This was done under the assumption that similarity in fertility treatment would produce similar results in canopy and quality. There was considerable variation in quality values and canopy values within some of the treatments. In consideration of that variability, the quality and spectral data were resorted by value of RST from lowest to highest recoverable sugar, independent of the treatment producing that RST. Figure 1 represents the value of RST plotted against the ranking of that experimental plot. These 35 observations were then grouped into seven classes, each represented by five plots, and the quality and spectral values for the plots in each category were averaged. The result was a data set that was used to examine relationships between beet quality variables and canopy spectra that does not consider the treatment that produced that quality. This is more representative of the classification procedure that might ultimately be used to map beet quality, as the total fertility at most points in the field will not be known and it would be desirable to be able to link canopy parameters to root quality irrespective of the fertility.

Figure 1. Treatment plots ordered by increasing RST. Data were subsequently clustered in groups of five plots in ascending order. Spectral data for these plot groups were averaged, as were the quality variables.

Table 4 represents results for regressions using the Green NDVI for each of the quality variables. In general this method of organizing the quality and canopy data produced higher correlations. The model for August 10 yields a value of R-squared of 0.8846, indicating a relatively strong correlation between the canopy reflectance on that date and the recoverable sugar obtained at harvest two months later. It is also notable that the correlation appears weaker on both the July date (0.463) and the October sample date (0.524). The models are not statistically significant on either of these dates. The three dates in August and September on which reflectance was measured all

yielded correlations above 0.8 for RST. Correlations for percent sucrose closely parallel those obtained for RST. Correlations for Sodium were much higher using this approach than were obtained when looking at treatment averages. The models from the end of July to the end of August were significant at the 0.05 level. Amino N also has higher correlations in this analysis although the model was only statistically significant on the August 10 sample event. Potassium still shows no useful correlation. The Loss-to-Molasses has somewhat higher correlation as it benefits by formula from higher correlations for sodium and amino N.

Table 4. Coefficients of determination (R^2) for a Green NDVI index regressed on sugarbeet quality variables. Spectral data acquired with a handheld spectroradiometer. The plot data and spectra were sorted by ascending RST and averaged in groups of five, rather than by treatment average.

Date	Recoverable Sugar Per Ton	Percent Sucrose	PPM Na	PPM K	Amino N	LTM
July 26	**0.4608**	0.4605	0.6404*	0.0817	0.0155	0.3089
August 10	**0.8850****	0.8618**	0.6496*	0.0431	0.6108*	0.7893**
August 27	**0.8682****	0.8650**	0.5973*	0.0018	0.5652	0.5443

Date	Recoverable Sugar Per Ton	Percent Sucrose	PPM Na	PPM K	Amino N	LTM
Sept. 21	**0.8151****	0.8194**	0.5579	0.0218	0.5307	0.4425
October 5	**0.5228**	0.5265	0.2389	0.0505	0.5627	0.2779

Table 5. Coefficients of determination (R^2) for the conventional NDVI index regressed on sugarbeet quality variables. Spectral data acquired with a handheld spectroradiometer. The plot data and spectra were sorted by ascending RST and averaged in groups of five, rather than by treatment average.

Date	Recoverable Sugar Per Ton	Percent Sucrose	PPM Na	PPM K	Amino N	LTM
July 26	**0.1729**	0.1632	0.3703	0.3243	0.0029	0.2545
August 10	**0.8439****	0.8127**	0.6788*	0.1407	0.5033	0.8688**
August 27	**0.8682****	0.8497**	0.6440*	0.0579	0.4836	0.7242*
Sept. 21	**0.8525****	0.8490**	0.5610	0.0018	0.5832*	0.5405
October 5	**0.4780**	0.4795	0.1743	0.0273	0.5528	0.2700

The results for the NDVI index are give in Table 5. The RST and percent sugar values are similar to those obtained with the GreenNDVI index. On four of the sample days the NDVI has lower values of the coefficients while on the September 21 event it exceeds the performance of the Green index. Magnitudes of the correlations between the NDVI and the variables making up LTM are similar to those obtained with the Green index.

The results of evaluation of the Amplified Green NDVI are given in Table 6. The index is calculated from the same base data as the Green NDVI but the green reflectance is multiplied by a factor of three. The correlations to RST and percent sugar appear to be higher, although only marginally so. Otherwise they are very similar in magnitude to those correlations obtained with the Green NDVI.

Airborne Image Data Data from bands 2,3, and 4 (Green, Red, and NIR) of the airborne images of the plot areas were used to calculate a Green NDVI index and the conventional NDVI for each plot. The amplified Green NDVI calculated with the spectroradiometer data was not appropriate for use with the airborne image data. Unlike the reflectance curves from the spectrograph, the camera gain settings determined the general magnitude of the visible band measurements. In some cases, these values were at the same level as the NIR band measurement and there was no advantage to amplifying the green band in the calculation of the indices.

The spectral index data and the quality data were first organized by fertility treatment and the average treatment index values were regressed on the average fertility treatment quality values. Linear regressions for a Green NDVI and Recoverable Sugar ranged from a high of 0.820 on August 31 to a low of 0.737 on October 8 (Table 7). The correlations appeared to be highest in August and then decline through September towards harvest in October. Models linking percent sucrose and the index closely paralleled the RST models in degree of correlation. Models for PPM sodium and potassium showed little correlation to the canopy spectral index.
The amino N models appear to have some correlation, with R-squared values highest on August 31 at 0.435 when the model is statistically significant. Correlation in the models of LTM was very weak.

Table 6. Coefficients of determination (R^2) for an Amplified Green NDVI index regressed on sugarbeet quality variables. Spectral data acquired with a handheld spectroradiometer. The plot data and spectra were sorted by ascending RST and averaged in groups of five, rather than by treatment average.

Date	Recoverable Sugar Per Ton	Percent Sucrose	PPM Na	PPM K	Amino N	LTM
July 26	**0.4721**	0.4715	0.6494*	0.0834	0.0176	0.3184
August 10	**0.8897****	0.8670**	0.6613*	0.0420	0.5996*	0.7857**

Date	Recoverable Sugar Per Ton	Percent Sucrose	PPM Na	PPM K	Amino N	LTM
August 27	**0.8704****	0.8676**	0.6101*	0.0028	.05621	0.5403
Sept. 21	**0.8154****	0.8201**	0.5702*	0.0250	0.5274	0.4392
October 5	**0.5234**	0.5273	0.2439	0.0554	0.5638	0.2756

Table 7. Coefficients of determination for regression models between a Green NDVI and sugar beet quality variables. Indices are calculated from four-band airborne digital images of the plot area. Data were grouped by treatment, and averaged over three or four repetitions.

Date	Recoverable Sugar Per Ton	Percent Sucrose	PPM Na	PPM K	Amino N	LTM
August 4	**0.7710****	0.7238**	0.2596	0.074	0.3081	0.1866
August 31	**0.8201****	0.7926**	0.0836	0.2570	0.4345*	0.1388
Sept. 18	**0.7681****	0.7557**	0.1448	0.2768	0.3475	0.0954
Sept. 21	**0.7449****	0.7193**	0.1285	0.2560	0.3954	0.1222
October 8	**0.7369****	0.7202**	0.0707	0.3038	0.3974	0.0982

Table 8 contains the correlation values for the NDVI calculated from the airborne images. Performance of this index is mixed. On the first and last sample days it had a slightly higher correlation than the Green NDVI, while on the late August and September dates it underperformed the Green index. Correlations for percent sugar are very similar to those obtained for RST. Again, there is relatively little predictability in the contaminant variables of PPM sodium and potassium, although the potassium models are significant on the two dates in September. Amino N has similar predicability as was obtained with the Green index for the same quality data. LTM shows little to no variation that can be predicted by the spectral index NDVI.

Table 8. Coefficients of determination for regression models between the NDVI and sugar beet quality variables. Indices are calculated from four-band airborne digital images of the plot area. Data were grouped by treatment, and averaged over three or four repetitions.

Date	Recoverable Sugar Per Ton	Percent Sucrose	PPM Na	PPM K	Amino N	LTM
August 4	**0.7932****	0.7509**	0.1553	0.1781	0.4164*	0.1815
August 31	**0.7848****	0.7441**	0.0797	0.1890	0.4434*	0.1730
Sept. 18	**0.7139****	0.7232**	0.0901	0.4202*	0.3389	0.0537
Sept. 21	**0.7051****	0.7105**	0.0808	0.4148*	0.3545	0.0591
October 8	**0.7466****	0.7477**	0.0791	0.3731	0.3563	0.0669

The data were then regrouped by ascending value of RST at harvest, as was done earlier for the spectrograph data. Regression models were generated for treatments consisting of 5 plots with similar values of RST. The results for the Green NDVI index are given in table 9. The peak value of the coefficient of determination occurs on August 31 and is considerably higher at 0.865 than was found for the same index when grouping the data by fertility treatment. However, the correlations for the early and late data collection dates of August 4 and October 8 are considerably lower than when the data were grouped by treatment. Also, now the models for PPM sodium show a relatively high correlation with R-squared values that are highest on August 4 at 0.7798 and then decline to 0.453 by the 8th of October. Potassium continues to be unpredictable by spectral index. The amino N variable has little correlation to canopy parameters at the start of the experiment and increases in correlation to a high of 0.678 on September 21. The higher predictability of sodium and and amino N produce higher values of R^2 in the LTM variable, which now is statistically significant on the two sample dates in September.

Table 9. Coefficients of determination for regression models between a Green NDVI and sugar beet quality variables. Indices are calculated from four-band airborne digital images of the plot area. Data were grouped into 7 groups of five plots, each with similar values or RST.

Date	Recoverable Sugar Per Ton	Percent Sucrose	PPM Na	PPM K	Amino N	LTM
August 4	**0.6321****	0.6229*	0.7798**	0.0965	0.0965	0.4962
August 31	**0.8649****	0.8668**	0.6905*	0.0060	0.4625	0.5023
Sept. 18	**0.7896****	0.7743**	0.5673	0.0005	0.6706*	0.6407*
Sept. 21	**0.7870****	0.7687**	0.5614	0.0049	0.6779*	0.6775*
October 8	**0.6871***	0.6863*	0.4530	0.0106	0.5242	0.4292

The last of the beet quality analyses looks at the conventional NDVI index when the data are grouped by similar values of RST (Table 10). This index produces the highest correlation to RST of the experiment on August 31 at 0.9168. It is notable that the correlation declines to 0.585 by October 8. Models for PPM sodium also peak on the August 31 event and then decline towards harvest. The October 8 value is 0.287 while on August 31 a correlation of 0.785 was obtained. The predictability of amino N, on the other hand appears to increase as the season progresses with the highest correlation coming on October 8 at a value of 0.723. Potassium appears again to be unrelated to canopy spectra. The Loss-to-Molasses combines the decreasing predictability of sodium and the increasing correlation of amino N to yield correlations that are strongest on the earliest sample event on August 4 with a value of 0.6598.

Table 10. Coefficients of determination for regression models between the NDVI and sugar beet quality variables. Indices are calculated from four-band airborne digital images of the plot area. Data were grouped into 7 groups of five plots, each with similar values or RST.

Date	Recoverable Sugar Per Ton	Percent Sucrose	PPM Na	PPM K	Amino N	LTM
August 4	**0.8909****	0.8774**	0.7127*	0.0328	0.4431	0.6802*
August 31	**0.9171****	0.9063**	0.7863**	0.0078	0.4723	0.6615*
Sept. 18	**0.7696****	0.7631*	0.4449	0.0059	0.6764*	0.5114
Sept. 21	**0.7763****	0.7693**	0.4489	0.0037	0.6721*	0.5217
October 8	**0.5856***	0.5712*	0.2869	0.0000	0.7225*	0.5133

Discussion

The spectrograph data and results tend to verify those obtained from the digital image data. Models from both data sets suggest that the greatest correlation to any of the three indices tested comes in August. Both data sets, using the beet quality data grouped by similar value of RST, indicate an early peak in the correlations to recoverable sugar and PPM sodium which then declines towards harvest. These trends are clear in Figures 2 and 3. Similarly, the ability to predict amino N from canopy spectra seems to *increase* from early August through the period in which these data were collected (Figure 4). Correlations for the variable PPM potassium do appear to vary somewhat with fertility treatment (Tables 1-3). The quality of these correlations appears to increase from early August to harvest *when the data are grouped by treatment*, although the correlation is never very high. This variable is singularly unpredictable when the data are grouped by similar values of RST. This suggests that potassium is related to the fertility treatment, and the average spectral properties of that treatment, but not necessarily linked to canopy spectral characteristics that are associated with high or low recoverable sugar. Loss-to-Molasses is a linear combination of the three contaminant variables, and with at least two of those variables taking opposite directions with time, the LTM models never produced higher correlations than the component variables.

The results suggest that airborne images, and potentially, four band satellite images may be useful for modeling sugarbeet quality variables. The results also have impact on the most appropriate dates for collection of those images. From the standpoint of direct estimation of RST alone it would appear that a date in mid August would have the greatest potential to accurately map recoverable sugar per ton at harvest.

Figure 2. Trend in model correlation for Recoverable Sugar Per Ton for both the spectrograph and airborne image generated Green NDVI and conventional NDVI indices.

Figure 3. Trend in model correlation for ppm sodium for both spectrograph and airborne image generated versions of the GreenNDVI and conventional NDVI.

Figure 4. Trend in model correlation for amino N for both spectrograph and airborne image versions of the GreenNDVI and conventional NDVI.

Beet Top N Models

Linear models were also generated using the canopy spectral indices and a measure of the nitrogen uptake in the beet tops. Percent total N in the tops was multiplied by the dry matter yield in lbs per acre to obtain N uptake. As with the beet root quality the four plots representing a fertility treatment and their associated spectra were averaged. Table 11 gives the model coefficients of determination for the Green NDVI and the NDVI using the spectrograph data for canopy reflectance. The Green Index consistently yields slightly higher correlations than the conventional NDVI. Values for the Geen Index range from a low of .762 on August 10 to a high of 0.881 just prior to harvest.

When the same plot data re reorganized into groups by similar value of N uptake the correlations are not substantially different (Table 11). The models account for 75 to 88 percent of the variability in N uptake in these averaged plots. Again, the Green NDVI Index is slightly but consistently better at relating canopy spectra to nitrogen content.

Table 11. Correlations (R^2) for models from spectrograph data relating two indices to beet top N uptake. The data were first grouped by fertility treatment and averaged over 4 replications, as were the plot spectra. They were then regrouped by similar N uptake. All of the models were significant at the 0.01 level except the NDVI on August 10 by N uptake, which was significant at the 0.05 level.

Date	Green Index (Grouped by treatment)	NDVI Index (Grouped by treatment)	Green Index (Grouped by N Uptake)	NDVI Index (Grouped by N Uptake)
July 26	0.787	0.664	0.879	0.686
August 10	0.762	0.684	0.751	0.582
August 27	0.803	0.789	0.798	0.698
Sept. 21	0.778	0.716	0.830	0.750
October 5	0.881	0.811	0.876	0.773

A similar set of models was generated from the airborne image data extracted from the plots. The R-squared values for these regressions are given in table 12. Magnitudes of the correlations are similar to those obtained with the spectrograph data. Peak correlations for the Green Index occur on August 31 and October 8, although the variation with time is not large. There does not appear to be a marked difference in the quality of models when grouped by similar value of N uptake as compared to grouping plots by fertility treatment. However the Green Index in every model had a higher value of the coefficient of determination (R^2) than the NDVI.

Table 12. Correlations (R^2) for models relating airborne image data and two spectral indices to beet top N uptake. The data were first grouped by fertility treatment and averaged over 4 replications, as were the plot spectra. They were then regrouped by similar N uptake. All of the models were significant at the 0.01.

Date	Green Index by Treatment	NDVI Index by Treatment	Green Index by similar N uptake	NDVI Index by similar N uptake
August 4	0.779	0.768	0.698	0.868
August 31	0.901	0.843	0.919	0.834
September 18	0.832	0.800	0.852	0.769
September 21	0.814	0.797	0.852	0.763
October 8	0.906	0.897	0.913	0.861

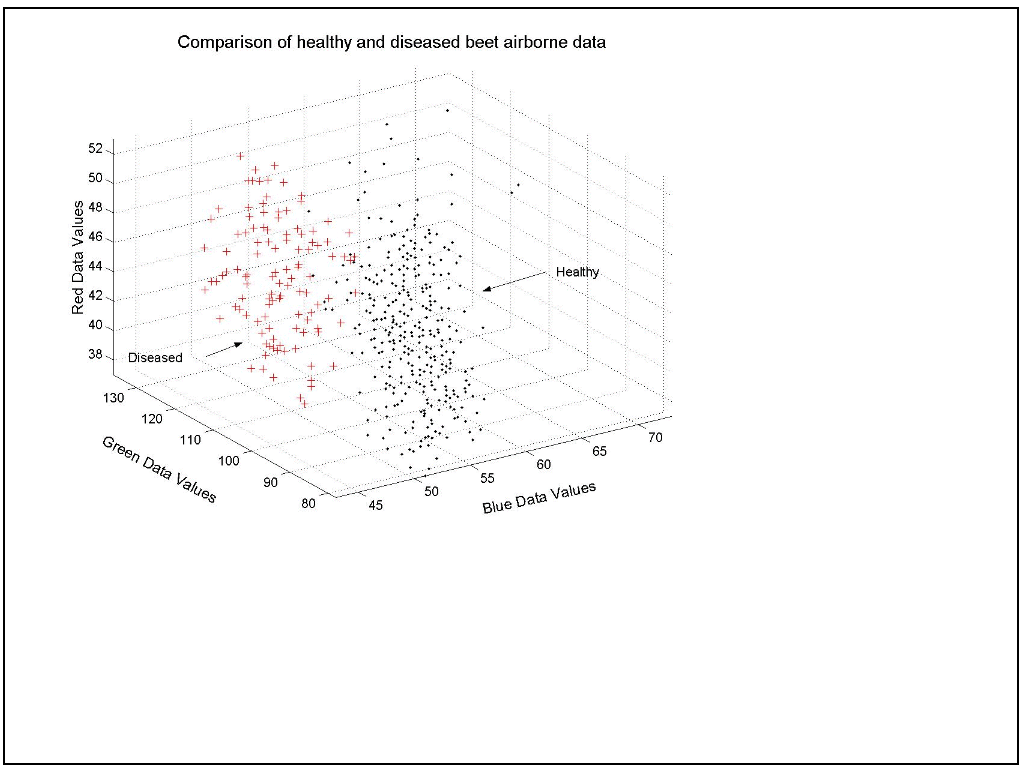
The quality of the models for canopy N uptake is plotted for the time period over which the canopy spectra were collected in figures 5 and 6. It can be seen that there is not a clear or dominant trend over the time period from the beginning of August through harvest in October. Although there appears to be somewhat of a trend for the model quality to increase towards harvest in Figure5, the magnitudes of the changes are small. No trend is apparent in Figure 6 which represents the airborne image data set. This suggests that the time period for a single image used to predict beet quality as well as top-N credit could be selected in late August with reasonable ability to predict both root and top quality variables.

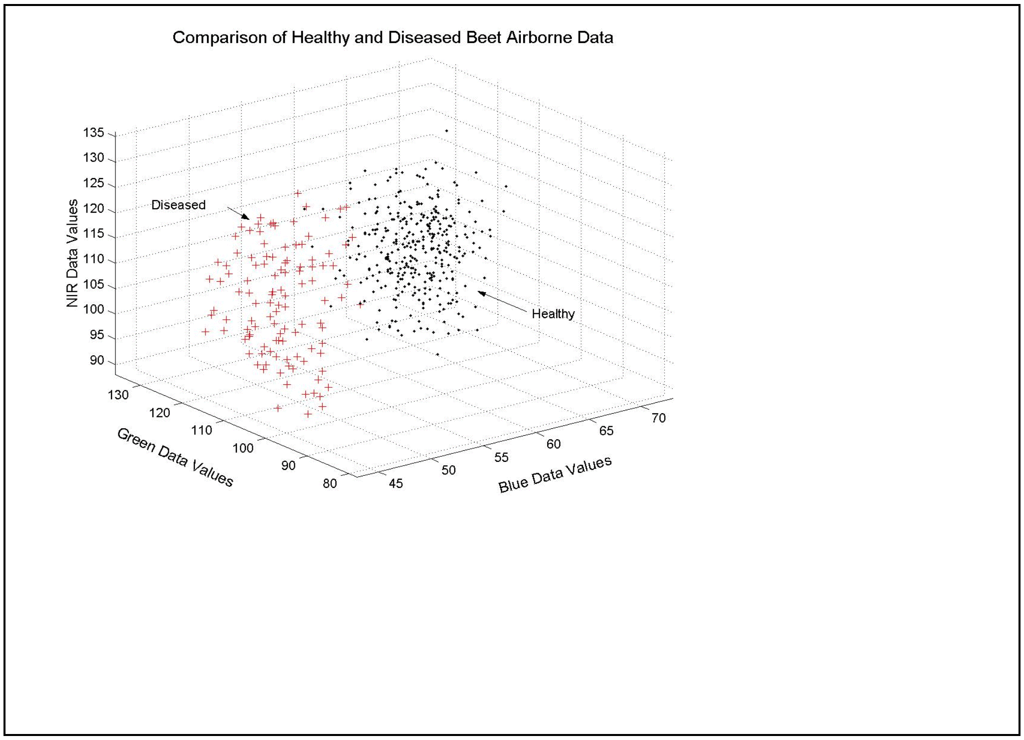
Figure 5. Coefficients of determination over time for models that relate canopy N uptake to two spectral indices. Data are from a spectrograph and were organized first by treatment average and then by the average of a group of plots with similar N uptake.

Disease Identification

The identification of potentially diseased areas of a beet field is of interest for several reasons. Having knowledge of the location of soil borne diseases may be of interest in its own right as an additional layer of a Geographic Information System developed for a sugarbeet rotation. Since disease also affects the spectral characteristics of the plant, classifying images for sugar or N uptake from canopy may be confounded by the presence of disease in some areas of the field. The fertility experiment used for modeling beet quality also provided an opportunity to examine spectral limits of a diseased canopy in an airborne image. The field in which the fertility plots were located also included areas affected by Beet Necrotic Yellow Vein Virus. Since both areas were visible in the same image it was possible to study spectral band values of diseased beets while the fertility plots represented the variation that would be expected in healthy beets under a wide range of fertility. Areas of BNYVV were visually identified in the image and pixel subsets of these areas were extracted for their numerical values. Similarly, values from about half of the pixels in the fertility plot areas were extracted for comparison. The two groups of spectral values were compared by graphing three of the four spectral bands at a time on 3-D scatter graphs. Two of these graphs are shown in figures 7 and 8. The appearance of distinct “clouds” of points in those graphs indicates that there is a plane in the 3-D color space that would effectively separate the two types of canopy into diseased, and healthy in this image. Characteristics of the lens system used in this imaging system prevent us from classifying this image for disease. However it should be possible in a corrected image to isolate areas affected by this disease and eliminate them from the classification procedure used to quantify beet qualities.

Figure 6. Coefficients of determination over time for models that relate canopy N uptake to two spectral indices. Data are from airborne images and were organized first by treatment average and then by the average of a group of plots with similar N uptake.




Comparison of Healthy and Diseased Beet Airborne Data
NIR Data Values
Green Data Values
Blue Data Values
Diseased
Healthy
135
130
125
120
115
110
105
100
95
90
130
120
110
100
90
80
45
50
55
60
65
70

Summary

The models developed in this work indicate that in healthy beets with a reasonably uniform stand there is a strong correlation between canopy characteristics and beet quality as measured by Recoverable Sucrose per Ton. Canopy spectral properties were measured both with a radiometer as reflectance, and as radiance from digital numbers in an airborne image. Data from this experiment indicate that the strongest correlation to beet quality will be obtained if the images are acquired in mid August. Either a Green Index or the NDVI may be potentially used as the index to be related to RST. The nitrogen stored in the beet tops was also strongly correlated to the canopy characteristics. It appears that the Green Index, calculated as the NDVI with the substitution of the green band for the red, has a stronger correlation to N uptake in the beet tops. The date of image acquisition was less important in the models of top N uptake than in the models of root quality.

If the date of August 31 was used from this study, the equation for classifying RST from a Green Index in the airborne image of this field would be:

RST = 368 - 1.92 x (Green Index Value of a pixel) in lbs/ton.

Similarly the N uptake credit could be calculated from its model on that date as:

N uptake = 55 + 3.01 x (Green Index Value of a pixel) in lbs/ acre

These models would apply to the field from which the plot areas of the model were drawn. The models might also be used in fields nearby, imaged at the same time that have the same variety of beets. In the case of satellite images where a relatively large area is imaged in a single exposure the model might be applied to a large number of fields. The process of applying these models to a multi-spectral image of the field is not difficult. However the quality of the map that results will be influenced by a number of factors. These include the spatial resolution of the imaging system and the presence of anomalies in the field, such as diseased areas, weedy areas, or pockets of reduced stand. If these anomalous areas can be identified and removed from the classification process the resulting map of beet qualities will be more accurate. Developing a protocol for managing these problem areas and mapping beet characteristics in a larger region is the next logical step in making fuller use of remote sensing as a part of a site-specific management system in a sugarbeet rotation.

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References

Lamb, J.A., and M.A. Schmitt. 2000. Management of turkey and swine manure derived nitrogen n a sugar beet cropping system. In: 1999 Sugarbeet research and extension reports. Vol 30: 132-135. NDSU

Extension Service.

Moraghan, J. T. 1998. Sugarbeet canopy type and accumulation of plant nitrogen as delineated by aerial photography and global positioning systems. *Comun. Soil Sci. Plant Anal.* 29(19&20):2953-2959