ESTIMATING GRAIN YIELD USING SPECTRAL REFLECTANCE DATA IN WINTER WHEAT GENOTYPES

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Phil Shields

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Approved by
Rollin G. Sears
Major Professor

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LITERATURE REVIEW

Remote sensing of plant canopies is based on the spectral reflectance of leaves and soil in the visible and near-infrared region of the spectrum as affected by plant growth stage and environment. Reflectance in the visible region is strongly affected by chlorophyll content and is quite low for a crop canopy (Gates et al., 1965). Reflectance in the near-infrared region is affected by internal leaf structure and is much higher. (Bunnik, 1978). Although most remote sensing work has utilized the visible and near-infrared regions of the spectrum, some significant results have been obtained using the microwave region (Ulaby et al., 1984).

Monitoring crop parameters is possible using spectral reflectance data. Ratios and linear combinations of reflectance wavebands have been used to estimate leaf area, plant biomass, water stress, plant height, and growth stage (Mohiuddin and Kanemasu, 1982; Jackson et al.,1983).

Visual evaluation lends itself well to qualitative traits such as plant height, maturity, and disease resistance. Quantitative traits such as yield, however, are much more difficult to evaluate visually with consistent and accurate results (Briggs and Shebesk, 1970; Stuthman and Steidl, 1976). Remote sensing may provide a means by which estimates of yield could be obtained rapidly and accurately without the cost of early generation yield testing.

This review includes an overview on the interactions of light with the canopy; characterization of plant canopies using reflectance indices; defining those plant characteristics that have been estimated using reflectance data and the use of reflectance data to estimate yield.

I. PLANT LIGHT INTERACTION

(A) Single Leaf Reflectance

Remote sensing uses the visible (0.4-0.7 um) and the near infrared (0.7-2.7 um) region of the spectrum in measuring the reflected electromagnetic radiation from the crop canopy. Leaf reflectance is low, about 10%, in the visible part of the spectrum, with a peak at about 0.55 um in the green region. The reflectance in the near-infrared region increases to about 50% over the wavelength range of 0.7-1.3 um, but gradually decreases to a low at about 2.7 um (Knipling, 1970). In the visible region the high absorption of radiation energy is due to leaf pigments, primarily chlorophyll, although carotenoids, xanthophylls and anthocyanins also have an affect (Gates et al., 1965).

The high infrared reflectivity of leaves is caused by their internal cellular structure (Mestre, 1935). The cuticular wax on the leaf is nearly transparent to infrared radiation. Very little of the solar energy incident to a leaf is reflected directly from its outer surface but enters the leaf cells. The radiation is diffused and scattered through the cuticle and epidermis to the mesophyll cells and air cavities in the interior of the leaf. Here the radiation is further scattered as it undergoes multiple reflections and refractions where refractive index differences between air (1.0) and hydrated cellulose walls (1.4) occur. Approximately half of the infrared radiation in the wavelength range of 0.7 um to 1.3 um is scattered upward through the surface of incidence and designated reflected radiation, most of remaining radiation is scattered downward and is designated transmitted radiation. Little or none of the infrared radiation is absorbed internally by the leaf (Knipling, 1970). The most important parameter in determining the level of reflectance is the number of hydrated cell walls to intercellular air space interfaces. A leaf with a relatively compact mesophyll will have a relatively low reflectance compared to a more porous mesophyll. Reflectance is higher for porous mesophylls because light passes more often from hydrated cell walls to air spaces (Gausman, 1974). This characteristic could be used to identify plant species.

(B) Crop Canopy Reflectance

The reflectance properties of a single leaf are similar to those of a plant canopy, but reflectance from a canopy is considerably less than that from a single leaf. This is due to variations in leaf orientation, shadows, and nonfoliage background surfaces. Visible and near-infrared reflectance from a canopy are about 40 and 70%, respectively, of the levels from a single leaf (Knipling, 1970). The smaller reduction in canopy infrared reflectance, compared to visible reflectance, is due to the additional reflectance from lower leaves of infrared light transmitted through the upper leaves (Myers et al., 1966).

The reflectance of a crop canopy is largely related to the amount of vegetation present. The red and near-infrared reflectance values are affected by the changing amounts of green leaf biomass as the crop develops. The red reflectance decreases rapidly as chlorophyll absorption increases due to increased green leaf biomass. As the growing season progresses and senescence begins, red reflectance begins to increase as the chlorophyll level in the plant canopy declines through chlorophyll breakdown and leaf loss. Red reflectance reaches a minimum relatively early in the growing season because additional green biomass in the canopy does not reflect additional red light (Tucker 1977). The infrared radiance increases with green leaf biomass. The increase is gradual and peaks later in the season than red reflectance. It then gradually falls off as the crop senesces.

(C) Soil Background Effects

As the incoming irradiance interacts with the crop canopy it will also interact with the soil. The amount of interaction with soil will decrease as green leaf biomass increases until the asymptotic spectral radiance is reached (Tucker, 1977a). After the asymptotic spectral radiance has been reached further increases in biomass will cause minor effects on the canopy spectra. At this point the canopy is of sufficient density to prevent the penetration of incident irradiance to lower levels of the canopy (Tucker and Miller, 1977). In the visible region, asymptotic spectral radiance is reached with two layers of leaves; the near-infrared region requires 6 to 8 layers (Weigand et al., 1971).

When bare soil is exposed it will have an affect on the overall canopy reflectance. Soil reflectance is strongly influenced by soil moisture. A dry soil surface is more reflective than a wet soil surface. The near-infrared band is the most sensitive to soil moisture (Kanemasu, 1974).

II. VEGETATIVE INDICES USED TO PREDICT CROP PARAMETERS

Ratios or linear combinations of spectral reflectance measured by a radiometer are used to predict many crop parameters. Many of the formulas use only the MSS5 band (red region) and the MSS7 band (near-infrared region).

(A) Near-IR/Red Ratio

The simplest formula involves a ratio of two bands. The data from one band should decrease, and data from the other band should increase, with increasing green vegetation

(Jackson et al., 1980). The red region (0.63-0.69 um) exhibits a nonlinear inverse relationship between spectral radiance and green biomass. The near-infrared region (0.75-0.80 um) exhibits a nonlinear direct relationship (Tucker, 1979). These two bands are used in the ratio MSS7/MSS5 or near-IR/red ratio.

Jackson et al. (1983) conducted an extensive study comparing various ratios and linear combinations of bands, and their relative ability to discriminate vegetative growth and plant stress of wheat. The near-IR/red ratio was found to be only slightly influenced by changes in soil reflectance caused by soil water content changes. They concluded that the ratio is a sensitive indicator of vegetation when vegetative cover is greater than 50%.

(B) Normalized Difference

The normalized difference (ND) is calculated using the formula (MSS7-MSS5)/(MSS7+MSS5). Early season rains affected the ND more than the near-IR/red ratio, indicating that ND is more sensitive to the soil background (Jackson et al., 1983). The ND values increased above values for bare soil before 15% green cover was achieved, indicating that ND is sensitive to vegetation early in the year. A stress period occurred during the jointing period with both the ratio and ND detecting it but the ND to a lesser degree. These data indicate that ND is a poor discriminator of stress at high values of green cover. A similar index used when vegetation density is low and ND may become negative is termed Transformed ND (TND). $TND= (ND+0.5)^{.5}$ (Jackson et al., 1980).

(C) Perpendicular Vegetation Index

The perpendicular vegetation index (PVI) of Richardson and Wiegand (1977) uses algebraic relations in two dimensions. It requires the use of a soil line developed from a plot of data from a bare field of MSS7 versus MSS5. They indicate that the soil line may be constant for various soils and wet and dry soils would fall on the same line, eliminating differences in reflectance caused by changes in soil moisture. The PVI is the perpendicular distance from the soil line to the data point.

Theoretically PVI values should not be influenced by changes in soil reflectance due to changes in soil moisture. The data from Jackson et al. (1983) indicated that changes in soil moisture can have a considerable affect under partial cover. The reason being that plants transmit most of the near-IR radiation and absorb much of the red, resulting in the near-IR seeing more soil and is influenced more by changes in soil reflectance. They concluded that the PVI, in comparison to the other formulas, to be moderately sensitive to vegetation and not a good detector of stress.

(D) Tasseled Cap Transformation

The tasseled cap transformation of Kauth and Thomas (1976) uses four linear equations obtained by principal component analysis. One of the equations, greenness, is used in vegetation estimates. The equation uses values obtained from all four MSS bands. Theoretically greenness is not influenced by the soil background. Jackson et al. (1983) found that changes in soil moisture did have some affect on the greenness value, the reason being the same as that for PVI. Greenness appears to be a good indicator of the amount of vegetation present.

III. CROP PARAMETERS PREDICTED BY REFLECTANCE DATA

(A) Leaf Area Index

Leaf area index (LAI) is an important plant canopy parameter but direct measurements are difficult and tedious to obtain. Considerable work has been done to determine if spectral reflectance data can be used to estimate LAI. Numerous variables have been used to determine the stability of these estimates.

Hatfield et al. (1985) conducted an experiment to determine the stability of LAI estimates from spectral measurements over various planting dates of wheat. The experiment included five planting dates over two years. The coefficient of determination (R^2) values for the linear model between LAI and greenness and near-IR/red ratio for the combined planting dates were 0.73 and 0.85 respectively, first years data only. A relationship was not found between greenness and LAI on irrigation treatments within a planting date. However, the near-IR/red ratio was quite stable over the irrigation treatments. This suggests that the ratio is a reliable indicator of LAI. The relationship between the near-IR/red ratio and LAI developed the first year was used to predict LAI the second year, R^2=0.87. The relationship suggests that a general equation could be used to predict leaf area.

A similar experiment by Asrar et al. (1985) assessed the affects of different cultural practices on LAI estimates of wheat obtained from spectral reflectance data. The treatments were five planting dates and three irrigation levels. A good agreement was found between measured and estimated LAI up to an LAI of 6.0 (booting) for all treatments.

(B) Plant Biomass

Total dry matter production measurements are used in estimating grain yield production and as an aid in residue management decisions. Field sampling is the most direct method but is destructive and time consuming. Numerous experiments have been conducted to determine the effectiveness of remote sensing in estimating dry matter accumulation.

An experiment by Aase and Siddoway (1981a) included six stand densities of a hard red spring wheat. Results indicated that ND was related to leaf biomass ($R^2=0.87$). ND was also related to total dry matter at harvest. Correlations were highest when the wheat was just past tillering until the watery ripe stage (Feekes 5-10.5.4). As senescence began, the relationship deteriorated rapidly. An earlier experiment (Aase and Siddoway, 1981) indicated a good relationship between seasonal dry-matter accumulation and reflectance values through the end of tillering. As stems became more dominant in total biomass the relationship declined. Similar results were observed by Tucker et al. (1981). Biomass estimates also appeared to be possible in other crops as well, such as corn and soybeans (Tucker et al., 1979a) and Alicia Grass (Richardson et al., 1983).

(C) Plant Stress

Indications of crop stress may be detected by measurements of biomass production, LAI, and ground cover. The reduction in leaf area and vegetative ground cover can be detected by spectral measurements. Kanemasu (1974), in an experiment on seasonal canopy reflectance patterns, observed that the reflectance ratio of yellowed soybeans decreased to less than one, concluding the the reflectance ratio could be used as an indicator of physiological stress. Tucker et al. (1980) found a significant relationship between spectral data and estimated drought stress in alfalfa. However, spectral measurements are unable to detect water stress until after growth is retarded (Jackson et al., 1983).

(D) Plant Height, Crop Cover, and Growth Stage

Results from several experiments indicate that spectral reflectance data can estimate plant height, crop cover, and growth stage. Bauer et al. (1977) reported a high correlation between spectral measurements and winter wheat height and percent cover. Similar results have also been reported in soybeans and corn (Tucker et al., 1979a). Tucker et al. (1979) were able to define five distinct stages of crop development for corn and soybeans based on spectral measurements.

(E) Grain Yield

Grain yield could perhaps be the most beneficial of all crop parameters estimated by spectral reflectance data. Spectral reflectance has the potential to predict crop production on a large scale basis such as the Great Plains. It may also find a use as a tool to aid plant breeders in predicting yield from small plots. Research relating spectral reflectance data to grain yield has recently been undertaken and much is still unknown. Conditions which adversely affect plant growth and development reduce the amount of photosynthetically active biomass. Photosynthetically active biomass is basic to primary production and can be monitored throughout the growing season. It then seems logical that inferences could be made regarding grain yield from monitoring this variable (Tucker et al., 1980).

An experiment by Tucker et al. (1980a) related spectral reflectance data to grain yield variation. The experiment included 20 plots of a single winter wheat cultivar. Spectral reflectance readings were obtained on 21 days throughout the season. The R^2 values of spectral reflectance to grain yield generally increased until reaching a high of 0.69 on sampling date 13 (Feekes 10.1) for near-IR/red ratio. As senescence progressed the correlation decreased. A 40-day time frame existed when spectral data was highly correlated with grain yield, but the regression equation coefficients varied. An integration of spectral data in terms of Julian date was also evaluated. A 40 day period corresponding to maximum green leaf biomass gave the highest R^2 value of 0.66 for ND. This is probably a measure of the duration and magnitude of green leaf area index.

Aase and Siddoway (1981a) used six seeding rates of a spring wheat in evaluating spectral reflectance as an estimator of grain yield. The study indicated that spectral reflectance data were able to estimate yield from just past tillering until watery ripe stage (Feekes 5-10.5.4). The highest R^2 values existed at stage 10.5.4 (R^2=0.98 for ND).

In this study a strong relationship was found between total dry matter and grain yield over a wide range of conditions. This would account for the ability of spectral data to estimate grain yield. A similar experiment which included data from Aase and Siddoway (1981) combined three years of data (Aase et al., 1984). The data set included two spring wheats and one winter wheat. The analysis used reflectance data from nearly the same growth stage for each year (quarter heading to flowering complete, Feekes 10.2-10.5.4). The combined analysis of spectral reflectance to grain yield was R^2=0.84 for near-IR/red ratio.

A method based on the spectral reflectance trend over a critical period rather than single-date observations was utilized by Pinter et al. (1981) to estimate yield of two wheat and one barley cultivar. When ND values were high during grain filling, higher yields were observed. Low ND values during this same period corresponded to low yields. They theorized that the longer periods at high levels represent a greater amount of photosynthetically active tissue present for a longer duration, allowing for more input into grain. The integration of ND with time takes into account both the magnitude of the ND value and its persistence during grain filling. An accumulated index was developed by summing smoothed daily ND values minus a baseline from heading (Feekes 10.5) until senescence, the baseline being equivalent to ND for a dense, totally senescent canopy. This baseline minimizes the contribution of non-photosynthesizing canopy and soil background, it also provides a method for determining date of canopy senescence. The accumulated index was exponentially related to grain yield (R^2=0.88). The performance of the model was optimum when started at a specific growth stage. A ±2 day error in heading date for a high yielding plot resulted in a yield predictive error of ±100 g/m^2.

Previous experiments discussed on predicting yield contained one or only a few genotypes. Hatfield (1981) evaluated the use of TND in yield estimates across a wide range of genotypes. Fifty spring and 32 winter wheats were evaluated. Little variation in spectral reflectance data between genotypes was present before heading and variability was largest before maturity. Genotypes were placed in yield groups of 1000 kg/ha increments. When yield groups 3000-4000 kg/ha and 5000-6000 kg/ha were compared, no differences in spectral behavior were found. Differences in TND values were found only when comparing the highest yielding genotype to the lowest yielding genotype, with differences being detected during grain filling. Very little variation was seen in TND values between plots when all plots had 100 percent ground cover during grain filling. This resulted in only small differences in reflectance values between plots. Because of the 100 percent cover, differences in head size could not be detected. In summary he suggested that spectral data alone could not predict wheat yields.

Spectral reflectance data have also been shown to be related to yield in rice (Patel et al., 1985). Using 12 fertilizer treatments of a single genotype grain yield was correlated with near-IR/red ratio (r=0.72). However, spectral data was not related to yield when six cultivars were compared.

A different approach to predicting yield was developed by Idso et al. (1980). The technique involved monitoring the senescence rate. They proposed that the assessment of senescence rates could correlate with grain yield. The slope of the curve drawn through data points of TND versus days after planting was used to characterize the senescence rate. A R^2 of 0.61 existed for senescence slope and grain yield.

IV. CONDITIONS AFFECTING REFLECTANCE DATA

A considerable amount of research effort has been conducted developing relationships between reflectance properties of crop canopies and agronomic parameters. Environmental conditions other than a cloud free atmosphere are for the most part ignored by many when obtaining reflectance data. Windy conditions have been shown to cause up to a 60% difference in extreme values in the red region and 40% in the far-red region (Lord et al.,1985). Dew can cause a 20-30% reduction in the near-IR/red ratio, possibly masking actual reflectance differences present (Pinter, 1986). Plant architecture will also affect the amount of reflectance from the canopy. Near-IR/red ratios for a planophile canopy are considerably lower than for a erectophile canopy of wheat with similar biomass values. In general radiation reflected from a planophile canopy is considerably greater than from a erectophile canopy (Jackson, 1986).

V. SUMMARY

Remote sensing involves the use of radiation reflected from the crop canopy to estimate crop parameters. The two spectral regions used most often are the visible and near-infrared regions, the visible being most sensitive to chlorophyll content and near-infrared internal cellular structure. Reflectance in the visible region decreases as the crop develops while reflectance in the near-infrared region increases. Ratios and linear combinations of the bands in these regions have been used to estimate leaf area index, plant biomass, stress, plant height, and, with some success, grain yield.

Near-infrared/red ratio and normalized difference have been used most often in crop estimates. Normalized difference is more sensitive to vegetation than near-infrared/red ratio when vegetation cover is less than 50%.

Normalized difference is used most often in estimates, especially for grain yield.

Most studies indicate that grain yield can be estimated by use of spectral reflectance data; however these studies used one or a few genotypes. Further research needs to be conducted to determine the feasibility of estimates across a range of genotypes and stability over years.

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ABSTRACT

Selection in the early generation stages of a breeding program is visual for both qualitative and quantitative traits. Remote sensing may provide a method by which early generation material could be rapidly and accurately screened for yield without the expense of yield testing. The experiment included sister lines from five different families and 14 released or advanced generation experimental lines, totaling 52 genotypes of winter wheat (Triticum aestivum L.). The experiment consisted of two replications in a randomized complete block augmented design planted at Manhattan and Hutchinson, KS and a short-row single replication augmented design planted at Manhattan in 1985. Canopy spectral reflectance was measured nine times throughout the growing season at Manhattan and twice at Hutchinson. Data were analyzed in two ways: (1) by family, in which sister lines within each family were averaged to obtain one value and (2) by entry, in which all genotypes were considered separately. A model containing spectral data, plant height, and heading date was significantly related to grain yield (R^2=0.81 at Manhattan and R^2=0.67 at Hutchinson) when analyzed by family. Analyzed by entry, values were lower but significant (R^2=0.53 and 0.52 for Manhattan and Hutchinson, respectively). The model was as efficient as visual selection for selecting high yielding

genotypes. Spectral reflectance may represent an additional tool that can assist plant breeders in visual observation and selection. Since measurements are taken prior to visual selection for yield, the breeder can utilize the data to complement his own choices.

INTRODUCTION

As wheat is systematically improved it becomes increasingly difficult to identify new and improved genotypes. To find these genotypes requires larger populations, increased land and considerably more time and effort. Promising genotypes are identified in early generations by visual selection. Visual selection can be used to select for qualitative traits such as plant height, maturity, and disease resistance. However, quantitative traits such as yield are much more difficult to evaluate visually with consistent and accurate results, especially under stress conditions (Briggs and Shebesk, 1970; Stuthman and Steidl, 1976).

Remote sensing may provide a means by which estimates of yield could be obtained rapidly and accurately without the cost of early generation yield testing. Remote sensing is the measurement of spectral reflectance from the crop canopy in the near-infrared and visible regions of the light spectrum. As green leaf biomass increases during crop development, red radiance decreases due to increased chlorophyll absorption (Gates et al., 1965) and infrared radiance increases due to an increased number of hydrated cell walls to air space interfaces (Mestre, 1935).

Spectral reflectance measurements have been shown to be related to leaf area index (LAI) across planting dates

(Hatfield et al., 1985) and irrigation levels of wheat (Asrar et al., 1985), sorghum, and soybean (Kanemasu, 1974). Aase and Siddoway (1981) found that spectral data could predict total dry matter accumulation in wheat. Using data from 24 separate studies their results showed that a strong relationship existed between total dry matter and grain yield over a wide range of environments, cultivars, and time (R^2=0.95). This suggests that it may be possible to predict grain yield in wheat using spectral reflectance data.

Using spectral reflectance data Tucker et al. (1980) was able to explain 64 percent of the variation in grain yield between plots of a single variety of wheat. A 40 day time frame existed when spectral data were correlated to grain yield with the highest correlations occurring at heading. Aase et al. (1984) combined three years of data for two spring wheats and one winter wheat. A significant relationship was found between spectral reflectance data and grain yield (R^2=0.84). Pinter et al. (1981) used a method based on the spectral reflectance trend over a critical period, grain filling, rather than single-date observations. The integration of spectral data over time measures the duration and amount of photosynthetically active tissue present. For two wheats and one barley variety, grain yield was predicted with R^2=0.88.

Hatfield (1981) evaluated the use of spectral data in estimating yield across a range of wheat genotypes. Very little variation in spectral data was observed between genotypes prior to heading. When genotypes were grouped according to yield no differences in spectral reflectance were observed between the 3000-4000 kg/ha and 5000-6000 kg/ha groups. Differences were found only when specific comparisons were made among the highest and lowest yielding genotypes. He concluded that spectral data alone could not predict wheat yields.

Most previous studies contained only one or a few genotypes and results were directed towards the potential use of LANDSAT in predicting global crop production. Our objective was to use many genotypes, some of them related as is typically seen in a wheat breeding program and determine 1) if a relationship exists between spectral reflectance data and grain yield across many genotypes and 2) can spectral data detect yield differences between similar genotypes.

MATERIALS AND METHODS

The experiment was conducted at the Ashland Experiment Station south of Manhattan, KS on a Reading silt loam soil (fine, mixed, mesic, typic Argindolls) and the Hutchinson Experiment Station south of Hutchinson, KS on a Clark-Ost complex loam soil (Clark: fine-loamy, mixed, thermic, typic Calciustolls; Ost: fine-loamy, mixed, thermic, typic Argiustolls). Plots of winter wheat (Triticum aestivum L.), 4.6 m long, containing 3 rows 17.6 cm apart were planted Oct. 17 and Oct. 23, 1985 at Manhattan and Hutchinson, respectively, at a rate of 72 kg/ha. Plots were later trimmed to a final length of 3 meters at harvest. Before seeding, fertilizer was applied at a rate of 114 kg N/ha and 40 kg P/ha. The herbicide Glean was applied at a rate of 23.4 g/ha during the winter to prevent the emergence of any broadleaf weeds. On April 8, 1986, plots at Hutchinson were topdressed with 61.4 kg N/ha at growth stage Feekes 7. The fungicide Tilt was applied to plots at Manhattan May 19, 1986, growth stage Feekes 10.5.3-11.1. Plots were harvested June 16 and June 25, 1986 at Hutchinson and Manhattan, respectively.

The experiment consisted of two replications of 60 plots at each location. The experimental design was a randomized complete block augmented design. Each replication consisted of four blocks of 15 plots per block.

Two plots in each block were checks, 'Arkan' and 'KS831374'. The experiment contained 52 genotypes: 14 released cultivars or advanced experimental lines and sets of sister lines from 5 different families (Table 1). The five families represented different plant architecture, differing in leaf angle, plant height, tillering and head size.

A short-row non-replicated test was included at Manhattan. Plots were 1 m long, containing 3 rows 17.6 cm apart. The test included the same genotypes as the replicated test and consisted of five blocks with 15 plots per block. Four plots in each block were checks (Arkan, KS831374, 'Victory', and 'TAM 107'). Seeding, fertilizer, herbicide, and fungicide rates were identical to rates for the replicated test at Manhattan.

Canopy spectral reflectance measurements were made with a 15^{o} field-of-view Exotech radiometer, Model 100A, which has four multispectral (MSS) bands, MSS 4, 0.5-0.6 um; MSS5, 0.6-0.7 um; MSS 6, 0.7-0.8 um; and MSS7, 0.8-1.1 um. The radiometer was held at a height of 2.3 meters above the surface of the soil using a hand-held boom while measurements were taken. Three measurements within each plot were made with a Omnidata Polycorder used to record the data. Spectral reflectance measurements were obtained nine times throughout the growing season at Manhattan, beginning at second node formation (Feekes 7) and ending at maturity (Feekes 11.2) (Table 2). Measurements were taken seven times for the short-row test. Measurements were taken twice at Hutchinson, once at heading to beginning flowering (Feekes 10.1-10.5.1) and again at kernel milky ripe (Feekes 11.1-11.2). Standard reflectance was measured using a barium sulfate panel every 30 plots. Normalized difference vegetative index (ND) was used to relate spectral reflectance data with grain yield. Prior to harvest 0.5 m of the middle row was cut at the soil line. Total biomass, number of spikes, spikelets/spike, and kernel weight were measured. Additional data collected from each plot included heading date, height, disease ratings and grain yield.

$$\mathrm{ND} = (\mathrm{MSS7} - \mathrm{MSS5})/(\mathrm{MSS7} + \mathrm{MSS5})$$

All data collected from the plots were adjusted before analysis. The plots within each block were compared to the checks within that same block. Differences in check plots across blocks were assumed to be environmentally caused and to affect all plots to the same extent within a block. An adjusted value for each plot was obtained using the equation:

$$\underset{\text{value}}{\text{adj}} = \underset{\text{value}}{\text{plot}} - (\text{check(block) mean} - \text{overall check mean})$$

The overall check mean of the entire experiment was subtracted from the average of the checks within a block. This represents the environmental effect on the block. This value was then subtracted from each plot within that same block to obtain adjusted values. Adjusted values were then used in the analysis.

Data from the experiment were analyzed by entry and by family. When analyzed by entry each genotype was considered separately for a total of 52. When analyzed by family the sister lines within each of the five families were averaged to obtain one value. Each of the 14 released or advanced experimental lines was considered as a separate family, for a total of 19 families.

A multiple regression model containing ND values from the nine days, along with heading date and plant height was used to determine if reflectance data from multiple days or additional variables could provide a method of predicting yield. A stepwise procedure was used to determine the best model. The procedure began with the most significant variable, and each step added a variable to the model if significant at the 0.15 level and removed a variable if not significant at the 0.05 level the step after entering the model (SAS). The best fit model was the model with all variables significant at the 0.01 level.

RESULTS AND DISCUSSION

A combined analysis of variance for yield for the replicated test across both locations indicated that genotypes and environment were significant sources of variation, but genotype X environment was not significant (Table 4). The mean square error for yield of the short-row test was much greater than that of the Manhattan replicated test. Coefficient of variation was also higher for the short-row test (Table 5).

With a single genotype, KS831374, reflectance data were significantly related to yield on several days, the highest occurring at day 139 (R^2=0.77), at Manhattan. This supports previous work (Aase and Siddoway, 1981; Tucker et al., 1980; Aase et al., 1984). When all genotypes were considered, no relationship between single day ND values and actual grain yield was found for any of the nine days (Table 3). This agrees with Hatfield (1981) in that across genotypes, spectral reflectance data alone could not predict grain yield.

When data were analyzed by family, the best model contained the five variables ND101, ND139, ND151, heading date, and plant height (Table 6). All were significant at the .01 level. The model was strongly related to actual grain yield (R^2=0.81) (Figure 1). The three days of reflectance data coincided with stages of growth that appear critical in determining grain yield. We theorize that the reflectance data from day 101 gave some measure of stand establishment. Plots were planted in wet soil and stand density was not uniform for all plots. Reflectance readings at early stages of growth may have detected differences in stand density. Measurements at day 139 occurred close to anthesis when maximum leaf area is present. Reflectance readings at this stage should be able to differentiate between genotypes for amount of photosynthetically active biomass present, which is basic to production of grain. The coefficient for ND139 was negative, which we were unable to explain. When ND131 was substituted for ND139 the coefficient for ND131 was positive and the model remained significantly related to grain but with a lower R^2 value, 0.63. Since ND131 is closer to anthesis than ND139 further studies may indicate that a reading coinciding with anthesis may be the most beneficial. Day 151 occurred when leaves were beginning to senesce. Measurements at this stage may estimate leaf area duration, which has been shown to be related to grain yield (Barojevic and Williams, 1982). Even though the range in yield was only 104 g/m^2, the model ranked the families correctly except for reversing the top two entries (Table 7).

When analyzed by entry the same variables were used in the model, but not the same coefficients (Table 6). The model was significantly related to actual grain yield

($R^2=0.40$) (Figure 2) but not as strongly as on a family basis. When the coefficients from the model used to analyze data by family were used to analyze data on an entry basis $R^2=0.41$.

In early generation testing many genotypes are tested and often selections with identical pedigrees are included, similar to the families in this experiment. These tests are not normally harvested for yield; therefore, yield is visually selected. At this stage of testing the determination of the highest yielding genotype is not as important as the selection of a group of genotypes with a high yield potential that can be advanced for further testing. Table 8 shows the top 30% yielding entries and their ranking based on predicted yield. The model correctly identified 9 out 15 genotypes. To compare this to visual selection a wheat breeder and four graduate students from the wheat breeding program visually selected what they thought to be the top 30% yielding entries. The number of entries correctly selected by visual evaluation ranged from 6 to 8. A yield component study showed that high yielding entries not selected by the model generally had a high seed weight (Table 9). Entries incorrectly predicted to be high yielding were normally genotypes with a high number of heads per area (Table 10). This resulted in higher ND values than expected.

Integration of ND over time, a method similar to that suggested by Tucker et al. (1980) was not found to be effective at predicting yield.

Stepwise regression was also used to analyze data from the non-replicated short rows. The full model included spectral reflectance data taken on seven dates, heading date, and plant height. When analyzed by family, the best-fit model contained the four variables ND121, ND125, ND131, and ND159(R^2=0.64). Analysis by entry using the same model resulted in an R^2 of 0.36. Using data that were taken at approximately the same time as the replicated test (ND106, ND131, ND151, heading date, and plant height) the model was unable to predict yield (R^2=0.18) analyzed by family. When six entries were eliminated based on thin stands the R^2 increased to 0.30 but still was not significant. Experimental error for yield was significantly greater for the short-row test when compared to the replicated test (Table 5). In addition, rank correlations for yield between the two tests were low (r=-0.17). This indicates that for this experiment there are limitations on plot size in predicting grain yield using spectral reflectance data.

Reflectance readings were taken at Hutchinson on day 122 and 140, closely matching the growth stage of wheat at Manhattan on day 131 and 151 respectively. A model containing ND122, ND140, heading date, and plant height was used to predict yield. Analyzed by family $R^2=0.67$ and by entry $R^2=0.52$ (Table 11).

To determine the contribution of reflectance data to the prediction of grain yield a model containing only heading date and plant height was used. For Manhattan data R^2 values were 0.35 analyzed by entry and 0.43 by family (Table 6), much lower than values obtained from the model containing reflectance data. These values are significant but are too low to provide a reliable method of predicting yield. For the Hutchinson data set R^2 values for the models containing heading date and plant height were only slightly lower than values from the models containing reflectance data ($R^2=0.41$) for entries and ($R^2=0.65$) for families (Table 9). Plots at Hutchinson were not sprayed with a fungicide therefore a great deal of leaf rust was present. This caused premature loss of leaves reducing the effectiveness of spectral reflectance data. Using six genotypes which had some level of resistance to leaf rust, the model containing reflectance data was almost twice as effective ($R^2=0.64$) as the model containing heading date and plant height ($R^2=0.38$), a difference similar to that found for the Manhattan data, however degrees of freedom for testing these models was low. In a breeding program leaf rust susceptible genotypes would be eliminated by visual evaluation and reflectance data could be used to select high yielding genotypes from those with a desirable level of foliar disease resistance.

A main objective of the Hutchinson test was to determine if the model developed at Manhattan could be used in a different environment. This would give an indication of whether the model would be stable across years. The coefficients from the model developed at Manhattan containing the variables ND131, ND151, heading date, and plant height were used to predict yield using Hutchinson data. Using this method R^2 values were 0.48 analyzed by entry and 0.65 when analyzed by family. These values indicate that it may be possible to predict yield using models developed in previous seasons, even when conditions vary from one season to the next. However, because heading date and plant height had such a strong influence, the heading date and plant height model from Manhattan predicted grain yield at Hutchinson nearly as well as the model containing reflectance data. If leaf rust had not been present at Hutchinson, we believe that the model containing reflectance data would have been more effective than the model containing heading date and plant height.

Reflectance data combined with heading date and plant height are related to yield. Identification of high yielding families which have the greatest chance of containing high yielding genotypes could benefit plant breeders. A large number of families could be eliminated well before harvest enabling the plant breeder to concentrate his efforts on the high yielding families. Individual lines can be selected, although not as effectively as families, but perhaps equally as well as visual selection. Although the model was not accurate enough to justify the use of remote sensing in a breeding program at the current time, it did show enough promise to continue further studies. Further studies need to be undertaken to determine the stability of the model across environments and genotypes.

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TABLES AND FIGURES

Table 1. Entries from each family and number of released or advanced experimental lines grown at Manhattan and Hutchinson, KS in 1985.

SELECTION	PEDIGREE	ENTRIES
XGH80167	TX71A916/KS79468	11
X81125	KS79468/NEWTON//ND7735/TX71A916	9
X7878	NEWTON/DAVID	7
X789-16	PLAINSMAN V/TAM 105	6
X7866	NEWTON/NE76698	5
RELEASED OR ADVANCED EXP. LINES		14
	TOTAL	52

Table 2. Days and growth stage when radiometer data were collected from the replicated test at Manhattan.

Day of Year	GROWTH STAGE
	FEEKES
101	7
110	7-8
112	8-9
121	9-10.1
125	10.2-10.5
131	10.5.1-10.5.4
139	10.5.3-11.1
151	11.1-11.2
159	11.2

Table 3. Coefficient of Determination values for ND and grain yield for each of the 9 days spectral reflectance data were collected when analyzed by family and by entry for Manhattan replicated test.

Date of Reflectance Measurement	ND R^2 VALUES	
	FAMILY	ENTRY
101	.14	.16**
110	.001	.012
112	.02	.000
121	.13	.011
125	.06	.06
131	.01	.01
139	.000	.000
151	.04	.03
159	.09	.02

** means significant at 1% level

Table 4. Analysis of variance for adjusted yield from replicated test grown at Manhattan and Hutchinson, KS.

Source	df	Significance
Genotypes	51	**
Replications	1	NS
Environment	1	**
G X E	51	NS
Pooled Error	102	

** means significant at 1% level NS- nonsignificant

Table 5. Analysis of variance for yield of checks in short-row and replicated test grown at Manhattan, KS.

Source	df	Mean Square
Short-Row Test		
Genotypes	3	7296.6
Replications	4	6502.1
Error	12	3118.0
CV = 12.6		
Replicated Test		
Genotypes	1	95.1
Replications	7	1057.0
Error	7	936.9
CV =5.9		

Table 6. Regression coefficients and coefficient of determination values for models from replicated test at Manhattan analyzed by family and by entry.

	REGRESSION COEFFICIENTS						
	B_o	ND101	ND139	ND151	PLANT HEIGHT	HEADING DATE	R^2
FAMILY	2450.8	2635.2	-1137.5	752.9	9.6	-37.8	0.81**
FAMILY	2757.0				10.9	-26.0	0.43**
ENTRY	1266.2	1616.3	-81.8	332.5	7.4	-24.4	0.53**
ENTRY	2313.6				8.6	-20.8	0..35*

** means significant at 1% level

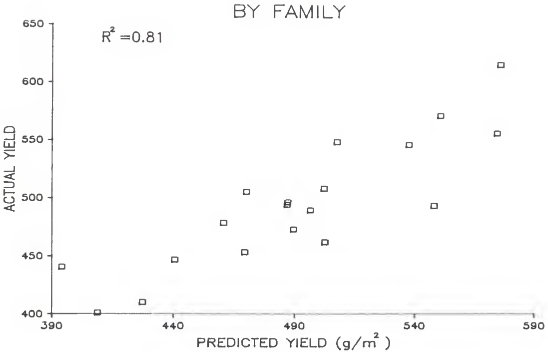

Figure 1. Actual grain yield from Manhattan replicated test versus predicted grain yield from model containing ND101, ND139, ND151, heading date, and plant height for the 19 families.

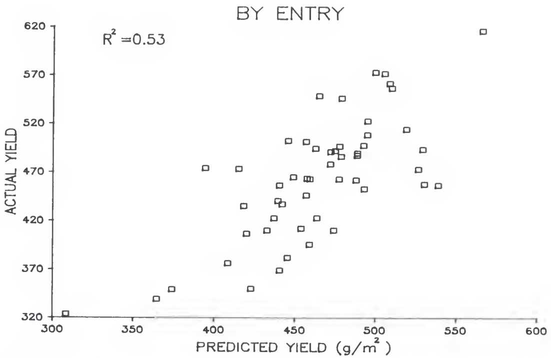

Figure 2. Actual grain yield from Manhattan replicated test versus predicted grain yield from model containing ND101, ND139, ND151, heading date, and plant height for the 52 entries.

Table 7. List of families and ranking based on actual harvested grain yield and rank based on predicted yield.

FAMILY	RANK BY YIELD	
	ACTUAL	PREDICTED
X7866	1	2
X81125	2	1
XGH80167	3	3
X789-16	4	4
X7878	5	5

Table 8. List of 15 highest yielding entries based on actual harvested grain yield and rank based on predicted yield from model.

ENTRY	RANK BY YIELD	
	ACTUAL	PREDICTED
BOUNTY 301	1 *	1
X81125-25	2 *	10
BOUNTY 122	3 *	9
X7866-11-8	4 *	8
KS831203	5 *	7
KS82H144	6	26
VICTORY	7	18
X7878-3-7	8 *	11
X81125-26	9 *	6
KS79238-2	10 *	12
X7866-11-4	11	36
XGH80167-2-18	12	33
X7866-11-7	13 *	14
KS831936	14	20
CHISHOLM	15	28

* entries model correctly selected

Table 9. Rank by actual yield, predicted yield, and kernel weight of high yielding entries model underestimated for yield grown at Manhattan, KS.

	RANK		
	ACTUAL YIELD	PREDICTED YIELD	200 KERNEL WEIGHT
X81125-25	2	10	5
KS82H144	6	26	3
VICTORY	7	18	2
X7866-11-4	11	36	20
XGH80167-2-18	12	33	6
KS831936	14	20	10
CHISHOLM	15	28	15

Table 10. Rank by actual yield, predicted yield, and heads/0.5 m row of entries model overestimated for yield grown at Manhattan, KS.

	RANK		
	ACTUAL YIELD	PREDICTED YIELD	HEADS/0.5 m ROW
XGH80167-23	32	2	3
X81125-60	31	3	8
PONY	16	4	7
X81125-30	25	5	14
KS82H4	19	15	2
KS831957	34	13	11

Table 11. Regression coefficients and coefficient of determination determination values for models from replicated test at Hutchinson analyzed by family and by entry.

	REGRESSION COEFFICIENTS					
	B_o	ND122	ND140	PLANT HEIGHT	HEADING DATE	R^2
FAMILY	2334.0	112.2	167.1	5.9	-21.3	0.67**
FAMILY	2536.2			7.0	-21.9	0.65**
ENTRY	2004.3	-227.0	158.3	2.3	-13.8	0.52**
ENTRY	1922.8			2.7	-14.1	0.50**

** means significant at 1% level

APPENDIX

MANHATTAN REPLICATED TEST

PLOT	ENTRY	YIELD (g/m^2)	HEADING DATE	HEIGHT (cm)
101	KS831957	432.3	122	94
102	X81125-55	491.4	126	94
103	XGH80167-2-5	424.8	125	81
104	X7878-3-7	520.8	125	92
105	X7878-6-9	329.3	130	93
106	STALLION	508.7	122	80
107	KS831374	528.3	122	82
108	XGH80167-2-31	452.3	125	86
109	XGH80167-2-28	432.8	126	83
110	XGH80167-2-18	505.9	127	92
111	X7866-11-5	491.3	125	89
112	ARKAN	514.7	123	86
113	BOUNTY 122	545.5	123	85
114	X789-16-9	465.4	124	86
115	X7866-11-7	497.0	125	90
116	KS82H144	557.6	125	88
117	KS831374	539.9	122	80
118	KS79238-2	524.6	124	90
119	XGH80167-2-26	451.9	125	88
120	BOUNTY 301	596.5	128	102
121	CHISHOLM	487.3	121	78
122	XGH80167-2-15	484.1	125	86
123	X789-16-5	439.8	126	81
124	X7866-11-8	536.2	125	92
125	PONY	547.4	122	80
126	COLT	468.2	127	87
127	X81125-28	421.2	124	80
128	KS82H4	510.6	126	90
129	X789-16-1	392.2	126	88
130	ARKAN	510.6	123	82
131	X81125-26	544.1	125	92
132	X7878-6-5	372.7	126	89
133	XGH80167-2-29	490.5	125	91
134	X7878-6-2	317.9	126	86
135	KS831203	515.2	127	93
136	KS831374	526.4	122	80
137	XGH80167-2-23	469.1	127	96
138	X81125-62	480.7	126	95
139	X81125-30	501.3	125	90
140	XGH80167-2-7	386.2	124	85
141	ARKAN	530.6	124	83
142	X7866-11-4	481.2	125	86
143	X81125-60	432.8	123	88
144	X81125-25	545.0	126	93
145	X7878-6-7	314.9	130	80

PLOT	ENTRY	YIELD (g/m^2)	HEADING DATE	HEIGHT (cm)
146	X7866-11-9	538.1	126	87
147	XGH80167-2-9	469.1	126	82
148	KS831374	560.4	122	79
149	X789-16-7	402.9	127	84
150	NEWTON	484.9	127	90
151	X81125-54	476.1	128	83
152	XGH80167-2-8	465.4	126	91
153	VICTORY	566.0	126	86
154	ARKAN	534.8	124	83
155	KS831936	512.0	124	81
156	X789-16-10	414.6	127	87
157	X7878-6-4	380.5	126	81
158	X7878-3-4	486.3	126	92
159	X789-16-6	450.9	125	87
160	X81125-64	421.2	128	91
201	X81125-26	512.9	127	88
202	X789-16-6	388.1	127	87
203	X81125-55	505.0	127	91
204	X7866-11-7	519.4	125	88
205	X7878-6-7	360.5	129	88
206	KS831936	528.7	125	85
207	X7878-6-2	389.3	128	86
208	XGH80167-2-5	467.2	126	87
209	X7866-11-4	552.1	126	91
210	XGH80167-2-31	495.2	126	85
211	KS831374	493.3	122	82
212	XGH80167-2-26	499.4	126	95
213	X81125-30	473.7	126	93
214	XGH80167-2-7	380.6	125	83
215	ARKAN	581.7	124	82
216	KS79238-2	457.5	124	89
217	KS831957	435.7	123	90
218	ARKAN	464.0	124	85
219	X7866-11-8	552.5	126	95
220	KS831374	491.4	122	87
221	BOUNTY 122	560.0	124	86
222	CHISHOLM	466.7	123	85
223	XGH80167-2-29	460.3	125	90
224	X789-16-9	423.5	124	85
225	KS831203	567.0	127	97
226	XGH80167-2-28	475.9	126	87
227	KS82H144	505.4	126	89
228	X7878-6-5	348.9	128	86
229	X789-16-1	465.3	126	87
230	X7878-3-4	473.7	126	94
231	PONY	420.6	122	86
232	X81125-25	585.1	126	95
233	ARKAN	466.4	123	82

PLOT	ENTRY	YIELD (g/m^2)	HEADING DATE	HEIGHT (cm)
234	X789-16-7	364.2	126	88
235	XGH80167-2-23	428.1	128	103
236	BOUNTY 301	616.4	129	105
237	X81125-28	372.2	125	86
238	X7878-3-7	501.3	126	88
239	KS82H4	449.0	128	92
240	X81125-54	456.4	128	96
241	X81125-60	466.7	124	90
242	X7878-6-9	345.7	126	86
243	X7878-6-4	442.5	124	93
244	X81125-64	427.6	129	92
245	KS831374	519.0	122	84
246	XGH80167-2-8	391.4	126	88
247	X789-16-10	318.1	127	84
248	X789-16-5	415.5	126	83
249	KS831374	513.9	123	85
250	X7866-11-9	442.1	126	84
251	X81125-62	445.3	128	95
252	XGH80167-2-9	437.5	126	86
253	COLT	423.0	128	85
254	ARKAN	530.6	124	87
255	VICTORY	559.0	126	91
256	NEWTON	471.5	126	100
257	XGH80167-2-15	347.0	126	90
258	STALLION	454.4	122	85
259	X7866-11-5	498.9	125	93
260	XGH80167-2-18	503.1	126	96

PLOT	ND101	ND110	ND112	ND121	ND125
101	0.8936	0.8858	0.8746	0.9451	0.9215
102	0.9029	0.9115	0.9292	0.9228	0.9026
103	0.8933	0.9148	0.8928	0.8851	0.8573
104	0.8880	0.9039	0.9154	0.8447	0.8681
105	0.8603	0.8857	0.8347	0.8647	0.8864
106	0.9024	0.8917	0.9140	0.9210	0.9121
107	0.8897	0.9045	0.9203	0.9280	0.9027
108	0.8976	0.8748	0.9034	0.9275	0.9318
109	0.8891	0.9045	0.8608	0.9210	0.8638
110	0.8917	0.8771	0.8525	0.8941	0.8529
111	0.8893	0.9052	0.7820	0.9307	0.8486
112	0.8901	0.9235	0.8457	0.8523	0.8610
113	0.9050	0.9363	0.8938	0.9227	0.8913
114	0.9001	0.9320	0.8856	0.8593	0.8443
115	0.8858	0.8996	0.8870	0.8583	0.9007
116	0.8932	0.9076	0.8909	0.9177	0.8729
117	0.8879	0.9243	0.9398	0.8732	0.8890
118	0.8955	0.9250	0.8747	0.9287	0.9040
119	0.8937	0.9022	0.9009	0.9051	0.9106
120	0.8970	0.8716	0.8902	0.8987	0.8738
121	0.8990	0.9229	0.9096	0.9407	0.9196
122	0.8992	0.9058	0.8779	0.8997	0.8814
123	0.9070	0.9045	0.9169	0.9017	0.8595
124	0.8923	0.9008	0.9109	0.8315	0.8402
125	0.9031	0.9135	0.9414	0.9260	0.9410
126	0.9149	0.9309	0.9104	0.8942	0.8901
127	0.9053	0.8586	0.8666	0.9316	0.8808
128	0.9100	0.9348	0.8546	0.8869	0.8782
129	0.9059	0.9121	0.8897	0.9250	0.9046
130	0.8877	0.8798	0.8504	0.8431	0.8418
131	0.9103	0.9025	0.8984	0.9239	0.9207
132	0.8704	0.9031	0.9013	0.8874	0.8411
133	0.8924	0.9164	0.9178	0.9186	0.9341
134	0.8873	0.8721	0.8297	0.8789	0.8910
135	0.9029	0.9151	0.8842	0.9248	0.8841
136	0.8953	0.8682	0.8936	0.9097	0.9120
137	0.8978	0.9092	0.8809	0.9229	0.9168
138	0.8984	0.8157	0.8515	0.9135	0.8851
139	0.8925	0.8770	0.8982	0.8896	0.8735
140	0.8945	0.9348	0.8935	0.9037	0.9031
141	0.8889	0.8363	0.8891	0.8989	0.8748
142	0.8893	0.8188	0.8892	0.8911	0.9204
143	0.8875	0.8604	0.8182	0.8665	0.8982
144	0.8888	0.8725	0.8817	0.9048	0.9077
145	0.8547	0.8214	0.8658	0.8892	0.8382
146	0.8892	0.9070	0.8647	0.9300	0.8915
147	0.9061	0.9474	0.8714	0.9067	0.8937
148	0.8919	0.8969	0.8139	0.9126	0.9049
149	0.9019	0.9379	0.9161	0.9296	0.8667

PLOT	ND101	ND110	ND112	ND121	ND125
150	0.8990	0.9095	0.9296	0.8738	0.9037
151	0.9010	0.8401	0.8776	0.9228	0.8886
152	0.8994	0.8731	0.8689	0.9281	0.8707
153	0.9043	0.9385	0.9107	0.8813	0.8951
154	0.8919	0.9103	0.8573	0.8611	0.8940
155	0.8977	0.8787	0.9004	0.8989	0.9396
156	0.9104	0.8647	0.9019	0.9077	0.9038
157	0.8640	0.8672	0.8861	0.9197	0.8733
158	0.9008	0.9185	0.8669	0.8974	0.8038
159	0.9041	0.9119	0.9047	0.8869	0.9109
160	0.8999	0.9245	0.8947	0.8797	0.8967
201	0.9091	0.8883	0.9156	0.8909	0.8776
202	0.9005	0.9101	0.9182	0.9052	0.9101
203	0.8985	0.9056	0.8759	0.9316	0.8625
204	0.8893	0.8406	0.8536	0.9010	0.8731
205	0.8549	0.8281	0.8629	0.8687	0.8989
206	0.8915	0.9135	0.8837	0.9167	0.8743
207	0.8500	0.8827	0.8490	0.8182	0.8674
208	0.8833	0.9058	0.9181	0.9057	0.8898
209	0.8874	0.9183	0.8491	0.9052	0.8918
210	0.8974	0.9015	0.9241	0.8998	0.9169
211	0.8869	0.8899	0.8629	0.8238	0.8718
212	0.8905	0.9241	0.8494	0.9244	0.8863
213	0.8891	0.8534	0.8812	0.9269	0.8737
214	0.8914	0.9145	0.9317	0.9456	0.9154
215	0.8897	0.9093	0.8534	0.9230	0.8549
216	0.8941	0.9070	0.8938	0.9167	0.8894
217	0.8954	0.8964	0.9586	0.9317	0.9046
218	0.8853	0.8808	0.9085	0.8632	0.8113
219	0.8943	0.8525	0.9061	0.8701	0.8730
220	0.8869	0.8965	0.8741	0.8911	0.8781
221	0.9125	0.9149	0.8926	0.9316	0.9468
222	0.8932	0.9317	0.8984	0.9015	0.8957
223	0.8961	0.9048	0.9492	0.9059	0.9099
224	0.9024	0.9255	0.8724	0.9020	0.8954
225	0.8977	0.9191	0.9024	0.8936	0.8260
226	0.8950	0.9247	0.8895	0.8674	0.9017
227	0.8954	0.8465	0.9230	0.9387	0.8845
228	0.8708	0.9050	0.8414	0.8564	0.8791
229	0.8995	0.8792	0.8973	0.9159	0.8706
230	0.8997	0.8541	0.8926	0.9194	0.9168
231	0.9000	0.9528	0.8998	0.9356	0.8737
232	0.8831	0.9242	0.8789	0.8433	0.9200
233	0.8851	0.9150	0.8864	0.9015	0.8868
234	0.9045	0.8978	0.8919	0.9337	0.8752
235	0.8967	0.9334	0.9291	0.9093	0.9162
236	0.9048	0.8802	0.9054	0.8725	0.9023
237	0.9028	0.8948	0.8750	0.8886	0.8831
238	0.8929	0.8972	0.9165	0.8876	0.9095

PLOT	ND101	ND110	ND112	ND121	ND125
239	0.9078	0.9100	0.8973	0.9007	0.8864
240	0.8945	0.8723	0.9472	0.8968	0.8537
241	0.8877	0.8922	0.8312	0.9064	0.9058
242	0.8571	0.8540	0.8667	0.8829	0.8308
243	0.8705	0.8668	0.8807	0.9007	0.8568
244	0.8954	0.9075	0.8879	0.8937	0.8835
245	0.8880	0.9131	0.8904	0.8730	0.9130
246	0.8901	0.8866	0.9078	0.8580	0.8715
247	0.9001	0.9140	0.9058	0.8836	0.9088
248	0.9007	0.9116	0.8976	0.8860	0.9040
249	0.8792	0.8821	0.8636	0.8598	0.9161
250	0.8759	0.8038	0.7934	0.9250	0.8260
251	0.8819	0.8430	0.8622	0.9283	0.8773
252	0.8924	0.8716	0.8787	0.8728	0.8946
253	0.9090	0.9091	0.9304	0.8689	0.9070
254	0.8827	0.8802	0.8774	0.8078	0.8856
255	0.8914	0.8853	0.8709	0.9044	0.8852
256	0.8907	0.8920	0.9181	0.8846	0.8556
257	0.8921	0.8974	0.8893	0.9153	0.9090
258	0.8974	0.8913	0.9178	0.8513	0.8481
259	0.8775	0.8748	0.8857	0.8644	0.8930
260	0.8939	0.9044	0.8925	0.9009	0.8858

PLOT	ND131	ND139	ND151	ND159
101	0.8782	0.8779	0.5694	0.5275
102	0.9104	0.9086	0.7783	0.5200
103	0.8926	0.9309	0.6698	0.6154
104	0.9049	0.8637	0.7755	0.5943
105	0.9059	0.8596	0.7308	0.5200
106	0.8930	0.8955	0.6188	0.3280
107	0.9310	0.8714	0.6897	0.1974
108	0.9454	0.9324	0.8409	0.3628
109	0.9305	0.9106	0.7203	0.4372
110	0.8804	0.8794	0.7160	0.5667
111	0.9036	0.8172	0.6394	0.3028
112	0.8709	0.9012	0.8099	0.5986
113	0.8526	0.9101	0.7222	0.5296
114	0.9230	0.9144	0.6741	0.5332
115	0.9411	0.7960	0.7409	0.2931
116	0.8572	0.8431	0.6419	0.5113
117	0.8741	0.9278	0.6967	0.6492
118	0.8799	0.8995	0.6693	0.5661
119	0.8885	0.8192	0.7261	0.3872
120	0.8793	0.9208	0.8185	0.7039
121	0.9135	0.8241	0.5802	0.3232
122	0.9329	0.9057	0.7690	0.4851
123	0.9031	0.8466	0.7454	0.7042
124	0.9103	0.9047	0.7305	0.6597
125	0.8892	0.9125	0.6852	0.3915
126	0.9182	0.8946	0.7059	0.5110
127	0.9182	0.8725	0.4542	0.4405
128	0.9415	0.8674	0.7955	0.4793
129	0.9359	0.8760	0.7155	0.4410
130	0.8146	0.8043	0.7244	0.4750
131	0.9174	0.9359	0.7742	0.7077
132	0.9077	0.9001	0.8162	0.7040
133	0.9016	0.9038	0.7051	0.3308
134	0.9098	0.8597	0.5987	0.6315
135	0.9352	0.8872	0.8080	0.6004
136	0.9187	0.8763	0.7750	0.6732
137	0.8949	0.8843	0.8172	0.7095
138	0.9040	0.7446	0.5372	0.0438
139	0.8462	0.8885	0.8341	0.6678
140	0.9252	0.8744	0.7714	0.3367
141	0.8730	0.8764	0.7933	0.4224
142	0.9362	0.9096	0.6976	0.2842
143	0.8275	0.6440	0.8730	0.5944
144	0.9134	0.8869	0.7314	0.4553
145	0.8617	0.8614	0.7949	0.4114
146	0.8896	0.9242	0.5640	0.2556
147	0.8881	0.8858	0.7188	0.5487
148	0.8740	0.9129	0.8194	0.3772
149	0.8940	0.8724	0.6675	0.6179

PLOT	ND131	ND139	ND151	ND159
150	0.8987	0.8664	0.7461	0.3626
151	0.8994	0.8951	0.8302	0.5254
152	0.9033	0.8804	0.7621	0.6145
153	0.8798	0.8424	0.8609	0.6058
154	0.8103	0.8974	0.7200	0.6633
155	0.9431	0.8541	0.7119	0.4476
156	0.9432	0.9174	0.7623	0.6674
157	0.9044	0.8639	0.6379	0.3659
158	0.9104	0.8596	0.6995	0.3253
159	0.9033	0.8797	0.5873	0.3263
160	0.8827	0.9360	0.7799	0.6325
201	0.8943	0.8954	0.8219	0.5115
202	0.9302	0.8050	0.7823	0.6565
203	0.9079	0.8531	0.7123	0.4034
204	0.8909	0.8546	0.8092	0.5146
205	0.8758	0.8195	0.8058	0.3723
206	0.8543	0.8745	0.8123	0.4566
207	0.8567	0.7605	0.7386	0.6717
208	0.8700	0.8876	0.7611	0.7063
209	0.8219	0.7122	0.6057	0.4004
210	0.9012	0.7885	0.6561	0.4488
211	0.8425	0.8261	0.5773	0.3836
212	0.9214	0.8237	0.5369	0.4182
213	0.8911	0.8689	0.8323	0.6363
214	0.8870	0.8260	0.5280	0.6544
215	0.8641	0.7498	0.7728	0.5167
216	0.9122	0.8287	0.6815	0.5344
217	0.9269	0.8634	0.5562	0.2893
218	0.8266	0.8608	0.6509	0.5815
219	0.9296	0.7968	0.7541	0.6938
220	0.8916	0.8565	0.8141	0.4333
221	0.9007	0.8225	0.7727	0.4443
222	0.8928	0.8256	0.6052	0.3402
223	0.8754	0.8796	0.6955	0.2925
224	0.8906	0.8571	0.6862	0.5759
225	0.8734	0.7871	0.8301	0.1948
226	0.9053	0.8683	0.7919	0.5085
227	0.9112	0.8007	0.7755	0.6687
228	0.8300	0.6228	0.7929	0.6002
229	0.8670	0.8876	0.7207	0.7681
230	0.9069	0.8885	0.6764	0.7076
231	0.8979	0.8416	0.6741	0.5624
232	0.8908	0.8565	0.7654	0.6527
233	0.8756	0.7782	0.7153	0.5272
234	0.8870	0.8586	0.7247	0.6752
235	0.9188	0.7475	0.7535	0.6393
236	0.9124	0.8854	0.8279	0.6596
237	0.8931	0.8219	0.5746	0.5668
238	0.8828	0.8273	0.7839	0.4564

PLOT	ND131	ND139	ND151	ND159
239	0.8843	0.8505	0.6184	0.4437
240	0.8736	0.8195	0.6970	0.6759
241	0.8886	0.8003	0.5718	0.4461
242	0.8278	0.8947	0.8126	0.6021
243	0.8795	0.7640	0.7382	0.6164
244	0.8623	0.9050	0.8523	0.6150
245	0.8881	0.8649	0.5199	0.3816
246	0.8691	0.8778	0.5842	0.4439
247	0.9109	0.8997	0.6348	0.4899
248	0.8307	0.8744	0.7014	0.4165
249	0.9001	0.8355	0.6519	0.3787
250	0.8988	0.8598	0.7267	0.3601
251	0.8549	0.8019	0.6573	0.5562
252	0.8623	0.8093	0.7413	0.3653
253	0.8677	0.8892	0.7348	0.4069
254	0.8626	0.8108	0.7382	0.2092
255	0.8587	0.8003	0.6222	0.4341
256	0.8910	0.8209	0.6165	0.4888
257	0.8352	0.8671	0.6545	0.5428
258	0.8687	0.8253	0.5795	0.3381
259	0.9338	0.8264	0.7812	0.4850
260	0.8861	0.8546	0.6142	0.4709

PLOT	BIO MASS (g)	HEADS	SPIKELETS/ HEAD	200 SEED WEIGHT (g)
101	225.1	103	13.8	6.01
102	113.8	35	14.1	6.46
103	164.5	68	16.3	5.53
104	252.5	99	16.1	5.91
105	186.8	70	18.1	5.48
106	163.4	83	14.8	5.52
107	151.6	58	15.8	6.63
108	164.4	63	16.2	5.88
109	201.0	87	14.3	5.99
110	151.2	49	14.6	7.13
111	161.0	58	16.2	6.76
112	191.8	83	15.5	6.36
113	213.8	74	13.6	8.27
114	119.3	56	15.5	5.81
115	157.0	58	15.4	6.81
116	135.4	40	15.9	7.02
117	114.0	43	15.0	6.48
118	209.5	81	16.1	5.91
119	181.0	69	15.3	5.97
120	206.5	69	16.0	7.23
121	149.6	75	14.8	6.64
122	227.4	96	16.8	6.28
123	199.4	101	14.3	5.85
124	162.0	63	15.7	6.58
125	133.9	58	15.5	5.30
126	271.8	118	15.7	6.16
127	169.2	85	16.7	4.58
128	160.6	75	13.0	6.17
129	116.0	49	14.7	5.59
130	174.7	81	14.2	6.03
131	161.3	53	16.6	5.47
132	172.2	68	18.4	5.01
133	170.0	67	15.7	5.54
134	178.2	71	17.8	4.94
135	229.6	83	15.7	6.51
136	161.4	74	15.4	6.32
137	217.6	81	15.7	5.79
138	163.2	52	15.6	6.65
139	215.3	71	17.3	6.37
140	160.7	71	15.8	5.19
141	160.8	73	15.7	5.81
142	209.7	82	15.7	6.05
143	218.5	95	14.6	6.69
144	140.6	43	17.7	7.07
145	136.0	53	18.4	5.07
146	139.1	49	15.0	5.85
147	111.8	39	15.7	5.58

PLOT	BIO MASS (g)	HEADS	SPIKELETS/ HEAD	200 SEED WEIGHT (g)
148	199.0	86	17.7	6.37
149	183.7	84	15.6	5.32
150	153.9	56	17.0	6.03
151	133.0	43	17.2	5.74
152	210.8	73	16.5	5.69
153	189.0	61	16.4	7.08
154	137.1	58	13.3	6.33
155	136.8	53	14.9	6.76
156	221.2	113	15.5	4.99
157	142.1	57	18.4	4.61
158	183.0	66	16.8	5.29
159	122.2	56	14.4	4.81
160	212.9	70	17.5	5.55
201	215.9	70	18.4	5.60
202	117.0	54	15.6	4.58
203	202.5	76	17.2	5.84
204	194.0	72	13.9	6.25
205	177.9	67	18.0	6.06
206	138.2	52	13.9	6.08
207	152.4	51	18.5	5.59
208	164.5	62	18.2	5.74
209	234.7	84	16.4	6.16
210	150.5	58	17.2	5.47
211	131.6	54	15.7	6.11
212	204.3	67	16.8	6.34
213	257.7	88	17.5	6.23
214	148.7	59	16.0	5.12
215	155.4	66	15.6	6.30
216	177.1	71	16.4	6.06
217	162.1	68	15.3	6.10
218	187.3	86	16.4	6.54
219	177.9	63	15.3	6.88
220	151.8	70	15.4	6.05
221	159.5	56	14.1	7.55
222	219.2	108	14.3	5.90
223	164.7	61	16.5	5.25
224	231.2	119	14.7	5.89
225	135.3	43	17.0	6.16
226	186.2	70	16.4	6.24
227	200.1	74	16.3	7.24
228	172.4	66	16.8	5.45
229	114.4	48	15.9	4.94
230	183.8	62	19.1	6.03
231	205.8	122	15.5	4.79
232	176.0	61	15.3	6.97
233	151.8	78	14.9	5.53
234	156.1	75	15.5	4.98

PLOT	BIO MASS (g)	HEADS	SPIKELETS/ HEAD	200 SEED WEIGHT (g)
235	274.3	105	15.8	5.38
236	265.5	72	17.2	6.85
237	179.2	58	17.0	4.48
238	197.8	72	16.4	5.74
239	269.3	124	14.9	6.03
240	190.3	66	17.7	5.32
241	181.9	80	14.4	6.03
242	117.6	39	20.2	4.89
243	151.5	59	16.4	5.28
244	110.8	24	18.2	5.51
245	132.7	63	13.6	6.24
246	153.8	62	16.5	4.79
247	129.4	60	14.0	4.76
248	256.5	137	15.2	5.10
249	190.3	91	15.3	6.52
250	165.7	56	16.6	6.61
251	179.6	51	17.0	5.92
252	200.9	75	16.2	4.87
253	139.2	62	15.8	5.93
254	178.9	87	15.7	5.91
255	179.7	63	16.0	7.25
256	213.1	86	16.2	5.53
257	211.3	89	16.4	4.90
258	145.9	73	14.8	4.97
259	184.3	65	15.1	6.18
260	228.1	74	16.4	6.61

HUTCHINSON REPLICATED TEST

PLOT	ENTRY	YIELD (g/m^2)	HEIGHT (cm)
101	KS831936	463.9	70
102	X7866-11-5	405.7	85
103	BOUNTY 122	508.2	80
104	X7878-3-7	340.8	84
105	X81125-30	378.4	85
106	XGH80167-2-7	327.4	80
107	KS831374	434.0	73
108	VICTORY	510.0	80
109	X7878-6-5	329.0	85
110	KS831203	482.0	87
111	ARKAN	453.1	80
112	BOUNTY 301	547.8	90
113	XGH80167-2-15	363.9	83
114	X7866-11-8	463.9	82
115	COLT	420.6	73
116	ARKAN	463.4	86
117	CHISHOLM	473.7	80
118	X789-16-7	258.6	85
119	KS82H4	436.6	90
120	KS79238-2	476.8	88
121	X81125-25	409.3	90
122	KS831374	461.8	79
123	XGH80167-2-23	341.8	97
124	X7866-11-9	448.4	83
125	X789-16-9	355.2	84
126	X81125-64	276.5	85
127	KS831957	353.7	85
128	X7866-11-4	394.4	83
129	STALLION	446.4	84
130	XGH80167-2-18	412.9	90
131	ARKAN	513.9	80
132	X81125-60	408.3	87
133	KS831374	417.5	73
134	X789-16-1	278.5	85
135	X81125-55	354.2	84
136	X7866-11-7	426.8	85
137	X81125-54	317.7	83
138	X7878-3-4	438.1	88
139	X7878-6-4	391.8	84
140	XGH80167-2-26	419.1	87
141	X789-16-6	344.5	78
142	XGH80167-2-5	332.6	84
143	X789-16-5	394.4	74
144	XGH80167-2-29	382.6	79
145	XGH80167-2-9	329.0	81

PLOT	ENTRY	YIELD (g/m^2)	HEIGHT (cm)
146	X81125-28	349.1	79
147	ARKAN	573.6	83
148	X7878-6-7	323.3	79
149	PONY	606.1	77
150	KS82H144	486.5	82
151	XGH80167-2-28	333.6	81
152	XGH80167-2-8	416.5	90
153	X81125-62	285.7	85
154	X7878-6-2	339.4	84
155	KS831374	388.7	77
156	X81125-26	402.6	84
157	X789-16-10	319.2	81
158	X7878-6-9	291.9	80
159	NEWTON	431.8	85
160	XGH80167-2-31	392.3	76
201	KS831374	485.5	80
202	X789-16-7	313.0	81
203	X7878-6-9	289.9	84
204	X81125-55	410.3	85
205	XGH80167-2-9	373.8	79
206	X7878-3-7	403.1	86
207	X7878-6-5	316.7	86
208	PONY	483.0	75
209	X81125-54	338.8	81
210	X81125-60	426.3	84
211	CHISHOLM	490.2	78
212	COLT	439.0	78
213	X789-16-5	381.6	86
214	XGH80167-2-5	389.2	77
215	ARKAN	508.2	85
216	ARKAN	392.3	80
217	X81125-25	471.1	92
218	XGH80167-2-31	369.2	80
219	XGH80167-2-8	343.4	81
220	XGH80167-2-29	332.6	82
221	KS831203	377.9	85
222	KS831374	526.7	82
223	X789-16-9	342.9	82
224	X7866-11-9	365.5	79
225	XGH80167-2-23	353.7	93
226	X7866-11-5	426.8	85
227	X7878-6-7	287.3	79
228	KS79238-2	476.8	85
229	X7878-6-2	302.7	79
230	BOUNTY 301	489.2	97
231	KS82H144	465.5	82
232	XGH80167-2-7	377.4	80
233	ARKAN	577.2	83

PLOT	ENTRY	YIELD (g/m^2)	HEIGHT (cm)
234	X7866-11-4	457.7	84
235	KS831374	503.0	75
236	X7866-11-7	464.4	82
237	X789-16-1	346.5	82
238	X7878-6-4	345.5	87
239	X81125-62	400.0	92
240	KS82H4	510.8	88
241	XGH80167-2-26	367.6	90
242	XGH80167-2-18	407.8	88
243	X789-16-10	337.3	84
244	XGH80167-2-15	379.5	84
245	KS831936	416.0	80
246	VICTORY	507.7	87
247	X81125-30	350.1	88
248	KS831957	492.2	85
249	KS831374	471.1	78
250	X7878-3-4	480.4	86
251	XGH80167-2-28	393.9	82
252	X789-16-6	408.8	80
253	STALLION	533.9	78
254	ARKAN	557.1	86
255	NEWTON	404.7	84
256	X81125-26	392.8	83
257	X81125-28	391.3	78
258	X81125-64	354.8	81
259	X7866-11-8	496.4	88
260	BOUNTY 122	642.6	86

PLOT	HEADING DATE	ND122	ND140
101	121	0.8804	0.7976
102	122	0.8756	0.8222
103	120	0.8290	0.8239
104	121	0.8888	0.7620
105	121	0.8519	0.7968
106	122	0.8885	0.6896
107	118	0.8520	0.7725
108	122	0.8725	0.7344
109	126	0.8485	0.6942
110	124	0.8843	0.7676
111	120	0.8145	0.7490
112	124	0.9205	0.8659
113	123	0.9279	0.8520
114	122	0.9115	0.7522
115	125	0.9242	0.8293
116	120	0.8587	0.8463
117	118	0.8773	0.5714
118	127	0.8825	0.5427
119	127	0.8903	0.7621
120	121	0.9183	0.8422
121	123	0.8686	0.8105
122	118	0.8729	0.7419
123	127	0.9245	0.7153
124	123	0.7420	0.7363
125	123	0.9516	0.7556
126	130	0.8282	0.7959
127	118	0.8705	0.7743
128	124	0.9148	0.7608
129	118	0.9192	0.7926
130	124	0.9546	0.8962
131	120	0.8913	0.8451
132	119	0.8092	0.6552
133	118	0.8335	0.7607
134	130	0.9073	0.7302
135	126	0.8536	0.8010
136	121	0.8871	0.7266
137	126	0.9236	0.8291
138	122	0.9133	0.8351
139	128	0.9321	0.7244
140	124	0.9152	0.8113
141	126	0.9170	0.7321
142	127	0.9127	0.6719
143	123	0.9425	0.8112
144	124	0.8880	0.6877
145	124	0.8996	0.5963
146	123	0.9175	0.6583
147	120	0.8475	0.8239
148	131	0.8344	0.6398

PLOT	HEADING DATE	ND122	ND140
149	118	0.9077	0.7845
150	123	0.8084	0.5713
151	128	0.8912	0.7377
152	130	0.8352	0.7730
153	131	0.9422	0.7216
154	125	0.8984	0.8371
155	118	0.9340	0.7657
156	126	0.9188	0.7692
157	127	0.8663	0.8183
158	131	0.7976	0.7178
159	124	0.9272	0.7386
160	122	0.8780	0.7699
201	118	0.8958	0.6886
202	127	0.9230	0.6914
203	131	0.8403	0.4900
204	126	0.8746	0.7264
205	126	0.7755	0.5916
206	121	0.9318	0.7788
207	126	0.8505	0.6547
208	118	0.8287	0.6490
209	126	0.8276	0.6977
210	119	0.9180	0.6785
211	118	0.7640	0.5771
212	125	0.8993	0.8302
213	124	0.9331	0.7814
214	123	0.8452	0.5975
215	120	0.8407	0.7447
216	120	0.8502	0.8243
217	123	0.9300	0.7754
218	131	0.8734	0.5842
219	125	0.8297	0.8159
220	124	0.7956	0.6661
221	124	0.8565	0.6653
222	118	0.8887	0.7414
223	123	0.8140	0.5972
224	123	0.8704	0.6464
225	127	0.8684	0.6931
226	122	0.9193	0.5433
227	131	0.7855	0.7092
228	121	0.8548	0.6959
229	131	0.9071	0.4737
230	124	0.9229	0.8477
231	123	0.8493	0.7106
232	122	0.8985	0.5973
233	120	0.8637	0.6839
234	124	0.8240	0.5710
235	118	0.8734	0.7328
236	121	0.8701	0.7829

PLOT	HEADING DATE	ND122	ND140
237	130	0.8880	0.6664
238	128	0.9134	0.7751
239	130	0.8728	0.7734
240	127	0.8814	0.6407
241	124	0.8885	0.7664
242	124	0.9346	0.8529
243	127	0.8921	0.6748
244	123	0.9119	0.7898
245	121	0.8952	0.5740
246	122	0.8967	0.6626
247	121	0.8797	0.7068
248	118	0.8925	0.7315
249	118	0.8841	0.7567
250	122	0.9097	0.8090
251	128	0.9305	0.8237
252	127	0.8979	0.7126
253	118	0.8664	0.6884
254	120	0.8616	0.6413
255	124	0.8725	0.6027
256	126	0.8485	0.7592
257	123	0.9138	0.7954
258	130	0.9269	0.8033
259	122	0.8787	0.8059
260	120	0.9326	0.8104

MANHATTAN SHORT-ROW TEST

PLOT	ENTRY	YIELD (g/m^2)	HEADING DATE	HEIGHT (cm)
1	KS79238-2	466.6	124	87
2	X7878-6-8	408.2	127	93
3	XGH80167-2-9	391.7	125	81
4	ARKAN	545.4	123	84
5	X7878-6-5	337.1	130	86
6	XGH80167-2-8	400.5	126	88
7	PONY	365.4	123	78
8	X81125-26	451.8	126	82
9	X81125-25	419.8	126	91
10	XGH80167-2-28	376.0	126	84
11	X7866-11-8	429.7	126	93
12	KS831374	435.6	122	89
13	TAM 107	470.1	121	76
14	VICTORY	468.3	126	90
15	KS831936	440.2	123	83
16	X7866-11-4	453.5	126	86
17	X7878-3-4	474.9	126	96
18	VICTORY	514.1	126	93
19	KS831203	416.8	127	93
20	X789-16-1	379.2	126	88
21	BOUNTY 122	505.5	124	85
22	COLT	395.6	128	86
23	TAM 107	421.6	122	78
24	KS831374	453.3	123	80
25	XGH80167-2-26	454.6	126	86
26	X789-16-6	372.4	126	85
27	X81125-28	386.7	125	85
28	CHISHOLM	441.2	122	80
29	ARKAN	475.5	124	82
30	X81125-60	408.7	124	94
31	KS82H144	477.4	126	92
32	X81125-55	394.0	127	87
33	VICTORY	476.2	126	87
34	XGH80167-2-29	388.2	126	89
35	X789-16-5	436.5	126	93
36	XGH80167-2-5	341.4	126	94
37	TAM 107	300.3	123	100
38	KS831957	389.8	123	86
39	XGH80167-2-31	373.5	126	88
40	BOUNTY 301	589.5	129	87
41	ARKAN	399.3	124	84
42	KS831374	368.8	123	81
43	X81125-63	398.5	130	100
44	X7866-11-9	440.5	126	92
45	X81125-62	442.1	127	78

PLOT	ENTRY	YIELD (g/m^2)	HEADING DATE	HEIGHT (cm)
46	VICTORY	566.0	126	91
47	TAM 107	448.0	122	80
48	KS831374	473.8	122	82
49	XGH80167-2-15	384.6	126	90
50	X789-16-7	352.5	126	83
51	KS82H4	414.7	127	93
52	X7866-11-7	459.6	125	88
53	XGH80167-2-27	404.7	126	85
54	X81125-54	402.1	126	87
55	XGH80167-2-7	367.8	124	83
56	X7878-6-9	283.1	128	80
57	ARKAN	370.0	124	85
58	X7878-3-7	486.7	125	85
59	X7878-6-4	334.2	125	80
60	XGH80167-2-18	513.7	127	90
61	X789-16-10	309.4	126	80
62	NEWTON	388.0	127	93
63	X81125-64	347.5	126	90
64	KS831374	429.5	123	81
65	XGH80167-2-23	451.7	128	98
66	VICTORY	466.3	126	92
67	ARKAN	317.8	124	85
68	TAM 107	436.8	122	77
69	X7878-6-2	431.4	130	80
70	STALLION	418.9	123	78
71	X7866-11-5	377.5	126	86
72	X81125-30	411.3	125	86
73	X789-16-9	430.0	124	82
74	X81125-69	421.2	130	92
75	X7878-6-7	319.0	129	85

PLOT	ND106	ND112	ND121	ND125
1	0.8676	0.8758	0.9026	0.9114
2	0.8687	0.8289	0.9218	0.8751
3	0.8992	0.9292	0.9404	0.9220
4	0.8568	0.9107	0.7946	0.9078
5	0.8347	0.9094	0.8540	0.7502
6	0.8807	0.8689	0.8899	0.8450
7	0.8836	0.8525	0.9225	0.9121
8	0.8958	0.9207	0.8967	0.8469
9	0.8560	0.8680	0.8750	0.8513
10	0.8867	0.9176	0.9322	0.8867
11	0.8584	0.9063	0.8943	0.9015
12	0.8705	0.8712	0.8681	0.8693
13	0.8883	0.9285	0.8977	0.8908
14	0.8677	0.9283	0.8696	0.8825
15	0.8772	0.9081	0.8261	0.8654
16	0.8661	0.8865	0.8331	0.8831
17	0.8754	0.9235	0.9367	0.8920
18	0.8712	0.8630	0.8419	0.8560
19	0.8750	0.8866	0.9228	0.8997
20	0.8923	0.9193	0.9004	0.9045
21	0.8787	0.9126	0.8845	0.9056
22	0.8905	0.9066	0.9177	0.8816
23	0.9049	0.9163	0.9164	0.9045
24	0.8773	0.8750	0.9224	0.9014
25	0.8812	0.8784	0.9208	0.8696
26	0.8902	0.9501	0.8785	0.8744
27	0.8859	0.8526	0.8881	0.8764
28	0.8915	0.8918	0.8894	0.9126
29	0.8544	0.7771	0.8645	0.9079
30	0.8562	0.9281	0.8863	0.8702
31	0.8717	0.9409	0.8726	0.9003
32	0.8775	0.9251	0.8799	0.8818
33	0.8715	0.8996	0.8501	0.8590
34	0.8846	0.9106	0.9180	0.8944
35	0.8875	0.9306	0.8952	0.9135
36	0.8715	0.9268	0.9252	0.8908
37	0.8982	0.9465	0.9005	0.9158
38	0.8704	0.8536	0.8839	0.9305
39	0.8820	0.9350	0.9188	0.8653
40	0.8724	0.8852	0.8741	0.9229
41	0.8572	0.8947	0.8823	0.8572
42	0.8781	0.9121	0.9041	0.9271
43	0.8721	0.9126	0.9272	0.8733
44	0.8529	0.8383	0.9068	0.8444
45	0.8595	0.8790	0.9035	0.8711
46	0.8719	0.8793	0.9243	0.8525
47	0.9001	0.9427	0.8971	0.9168
48	0.8706	0.8808	0.8887	0.8735
49	0.8794	0.9296	0.8857	0.8693

PLOT	ND106	ND112	ND121	ND125
50	0.8878	0.9063	0.8858	0.8261
51	0.8870	0.8834	0.8898	0.8991
52	0.8591	0.9200	0.8824	0.8367
53	0.8780	0.9195	0.8782	0.8781
54	0.8603	0.8971	0.8879	0.8664
55	0.8820	0.9137	0.8895	0.9144
56	0.8208	0.8112	0.9207	0.8660
57	0.8483	0.8969	0.8215	0.7813
58	0.8652	0.8417	0.8900	0.8991
59	0.8463	0.8659	0.9119	0.8677
60	0.8712	0.8857	0.9055	0.8906
61	0.8835	0.9277	0.9114	0.8907
62	0.8549	0.8216	0.8722	0.8823
63	0.8708	0.9003	0.9114	0.8291
64	0.8706	0.8514	0.8964	0.8978
65	0.8706	0.8771	0.8656	0.8710
66	0.8612	0.8428	0.8642	0.8944
67	0.8579	0.8505	0.8708	0.8213
68	0.8900	0.9035	0.9217	0.9142
69	0.8460	0.8588	0.8914	0.8750
70	0.8715	0.8319	0.8929	0.9079
71	0.8536	0.8144	0.8344	0.8499
72	0.8590	0.8780	0.8813	0.8472
73	0.8720	0.9059	0.8909	0.8883
74	0.8714	0.9237	0.8935	0.8812
75	0.8327	0.8827	0.9015	0.8805

PLOT	ND131	ND151	ND159
1	0.9194	0.6352	0.3164
2	0.8949	0.7747	0.5732
3	0.9266	0.7191	0.5620
4	0.8654	0.7375	0.3326
5	0.8692	0.6492	0.6444
6	0.9052	0.7563	0.6402
7	0.9087	0.7373	0.4875
8	0.8988	0.7376	0.6439
9	0.8902	0.7784	0.3941
10	0.9451	0.7255	0.6397
11	0.8475	0.8205	0.7282
12	0.9132	0.6674	0.2912
13	0.9066	0.5199	0.4653
14	0.9018	0.7775	0.5648
15	0.8604	0.5988	0.3660
16	0.8655	0.6676	0.7345
17	0.8978	0.7945	0.7394
18	0.8750	0.8562	0.6571
19	0.8814	0.8334	0.6989
20	0.8947	0.6685	0.5082
21	0.8768	0.7864	0.4102
22	0.9250	0.6661	0.6038
23	0.9231	0.6775	0.4990
24	0.8892	0.7749	0.3292
25	0.8746	0.7310	0.3794
26	0.9269	0.5866	0.5556
27	0.9322	0.7673	0.5511
28	0.9177	0.6122	0.2125
29	0.8576	0.7301	0.6667
30	0.8647	0.6806	0.5619
31	0.8871	0.6757	0.5448
32	0.9155	0.7552	0.6377
33	0.8363	0.6913	0.5341
34	0.9038	0.6422	0.4800
35	0.8759	0.7549	0.6527
36	0.8870	0.7748	0.5934
37	0.9016	0.5786	0.2340
38	0.8920	0.6896	0.3495
39	0.9008	0.7048	0.5425
40	0.9116	0.8848	0.7444
41	0.9044	0.8085	0.1007
42	0.9202	0.6522	0.2544
43	0.9437	0.7829	0.7249
44	0.8830	0.7868	0.5794
45	0.8596	0.7915	0.6398
46	0.8960	0.7333	0.5997
47	0.8871	0.4709	0.3894

PLOT	ND131	ND151	ND159
48	0.8780	0.7479	0.3160
49	0.9081	0.7414	0.4976
50	0.8517	0.6063	0.3546
51	0.8754	0.7147	0.5528
52	0.9123	0.8777	0.4937
53	0.8776	0.5927	0.4664
54	0.9283	0.7291	0.5063
55	0.8999	0.6717	0.4270
56	0.8969	0.6674	0.2647
57	0.7945	0.6527	0.3087
58	0.9157	0.7302	0.3054
59	0.8271	0.5219	0.3570
60	0.9396	0.7909	0.5026
61	0.8659	0.6567	0.4983
62	0.8860	0.8411	0.7312
63	0.8900	0.8278	0.6467
64	0.8815	0.5252	0.3548
65	0.9050	0.6901	0.7079
66	0.9091	0.7670	0.5452
67	0.8754	0.7843	0.6262
68	0.8971	0.4799	0.4832
69	0.8906	0.7598	0.4896
70	0.9348	0.5708	0.4596
71	0.8498	0.6951	0.5701
72	0.8611	0.7803	0.7036
73	0.8714	0.7291	0.5664
74	0.8984	0.8303	0.6797
75	0.8551	0.7787	0.6929

ESTIMATING GRAIN YIELD USING SPECTRAL REFLECTANCE DATA IN WINTER WHEAT GENOTYPES

by

Phil Shields

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ABSTRACT

Selection in the early generation stages of a breeding program is visual for both qualitative and quantitative traits. Remote sensing may provide a method by which early generation material could be rapidly and accurately screened for yield without the expense of yield testing. The experiment included sister lines from five different families and 14 released or advanced generation experimental lines, totaling 52 genotypes of winter wheat (Triticum aestivum L.). The experiment consisted of two replications in a randomized complete block augmented design planted at Manhattan and Hutchinson, KS and a short-row single replication augmented design planted at Manhattan in 1985. Canopy spectral reflectance was measured nine times throughout the growing season at Manhattan and twice at Hutchinson. Data were analyzed in two ways: (1) by family, in which sister lines within each family were averaged to obtain one value and (2) by entry, in which all genotypes were considered separately. A model containing spectral data, plant height, and heading date was significantly related to grain yield (R^2=0.81 at Manhattan and R^2=0.67 at Hutchinson) when analyzed by family. Analyzed by entry, values were lower but significant (R^2=0.53 and 0.52 for Manhattan and Hutchinson, respectively). The model was as efficient as visual selection for selecting high yielding

genotypes. Spectral reflectance may represent an additional tool that can assist plant breeders in visual observation and selection. Since measurements are taken prior to visual selection for yield, the breeder can utilize the data to complement his own choices.