Evaluation of Methods to Assess Termination Rates of Cover Crops Using Visual and Non-Visible Light Active Sensors

T. S. Kornecki, F. J. Arriaga, A. J. Price

Abstract. *Determination of cover crop termination rate has been based exclusively on visual evaluation of color by a trained evaluator to describe the life state of the plant. However, visual color-based assessment is a subjective method and can vary from one evaluator to another. If several skilled individuals are involved in the plant evaluation process in the same field, most likely a deviation associated with the cover crop evaluation will occur due to differences in eye response to colors. To remedy this problem, two experiments over three growing seasons were conducted in Alabama to evaluate cover crop termination rates using three different evaluation methods: (1) the visual method and manual data generation, (2) a chlorophyll meter with built-in data logger, and (3) an active light sensor (Greenseeker meter) with an iPAQ to store data. The instruments have the advantage of performing these evaluations quickly and effectively, and assessments can be performed by relatively unskilled personnel in the field. A linear correlation procedure was employed to develop relationships between observed termination rates and data collected with the instruments. The goal was to establish relationships between visual determination and instrument readouts, and to use these results for developing a procedure for future cover crop senescence assessment (termination rate in percentage of cover crop). Two cover crops were evaluated: cereal rye (*Secale cereale *L.) and crimson clover (*Trifolium incarnatum *L.). Results from three years of data (2009-2011) from two sites showed that there were strong linear relationships between visual observation and data obtained from the instruments, with* R^2 *values ranging from 0.713 to 0.945. Models were developed to predict termination rates for the two cover crops using the Greenseeker and chlorophyll meters, which are being used in agricultural research for different plant evaluation purposes.*

Keywords. *Chlorophyll meter, Cover crop, Greenseeker, NDVI, Roller/crimper, Termination rate.*

Visual methods for plant evaluation are subjective and depend mainly on the evaluator's skills. In addition, because the color sensing ability of the human eye varies from person to person, even two skilled evaluators could evaluate differently the same plant condition or status. In contrast, instruments can measure without bias or subjectivity, and often can produce data faster and more consistently. Further, data can be automatically stored in data loggers without the need to manually input the data into a spreadsheet, thereby reducing labor.

Assessment of cover crop termination rates in no-till conservation agriculture has been exclusively based on visual assessment (Ashford and Reeves, 2003; Raper et al., 2004; Kornecki et al., 2006; Kornecki et al., 2009; Kornecki and Price, 2010; Kornecki et al., 2010; Price et al., 2010). Roller crimping technology was introduced in the southern U.S. from South America (Derpsch et al., 1991). However, the roller designs used in South America are not suitable for many U.S. farmers since they transfer unpleasant and dangerous vibrations to the tractor's frame, which also limits the speed at which these rollers can effectively be operated (Kornecki et al., 2006; Kornecki et al., 2009; Kornecki and Price, 2010). Therefore, techniques for accurate and unbiased assessment of cover crop termination (i.e., senescence) are needed to evaluate and improve current roller designs. Enhanced roller designs that are more effective in terminating cover crops are needed in conservation agriculture and organic farming. Methods to measure cover crop termination can help to identify the optimum cash crop planting time in cover crop residue, and serve as an indicator of roller design performance to further improve cover crop rolling equipment. The necessary accuracy and precision of the visual method requires an experienced professional in order to provide repeatable results from one growing season to another over various experiments and weather conditions. It is recommended that the same evaluator perform the visual ratings for the duration of an experiment to maintain consistency and to avoid significant discrepancies in termination rates, especially for long-term, multi-year experiments. Another key aspect is that visual assessments are subjective in nature, and because these assessments are based on the limited ability of

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the human eye to distinguish between colors that are close in their color range, inconsistent ratings can easily be generated. Mitcham et al. (1996) stated that the main disadvantages in evaluating color by the human eye are the variation in color assessment due to differences in color perception between individuals and human error, especially since available light quantity and quality can significantly influence color perception. According to Gunasekaran et al. (1985), eye fatigue, lack of color memory, variation between individuals in color assessment, and personal bias influence the quality of evaluated products. Furthermore, light condition has a significant impact on color perception by humans since visible colors occupy a very narrow wavelength band (400 to 700 nm).

From a logistics standpoint, using the same person to conduct visual ratings for an experiment that extends for several growing seasons might not be feasible. Different people could be trained to perform visual ratings to address this issue; however, difference in skill level and other factors could result in differences in the data, which might affect the overall quality of the experiment. Mizrach (2008) stated that humans base their evaluation of agricultural products, including fruit, on combined sensory inputs from several senses and that these evaluations can be inconsistent, leading to erroneous determination of the quality of agricultural products, given that human judgments are in general subjective. These inconsistencies (errors) are skill-dependent, since they are associated with the different expertise levels of the evaluators, and also skill-independent, given variations in the ability of different human eyes to distinguish between colors. For example, even if several similarly skilled persons evaluated plant status at different locations and with different ambient light conditions, they could see differently the same color and plant appearance, and these different visual detection abilities would most likely produce different results. Because of these inconsistencies, evaluation of cover crop termination by several professionals (i.e., using different evaluators for the same experiment in different plots, or using different evaluators in different weeks of the experiment) would almost certainly produce different relative readings for the same cover crop termination phase. Moreover, ambient light conditions (sunny weather versus overcast) might increase the deviation between assessments.

In contrast, instruments can measure the status of a plant's life stage without bias and can perform faster and more consistently. An additional benefit is that relatively unskilled labor with respect to plant knowledge can successfully collect plant status data. Only basic knowledge of how to operate the instrument would be required. Because of these concerns associated with visual plant evaluation, a straightforward, repeatable, and reliable instrument-based method needs to be developed to evaluate cover crop termination rates. Portable electronic tools are currently available on the market that are used for different purposes in agricultural research, such as non-destructive evaluation of plant health based on chlorophyll activity and assessment of nitrogen deficiencies in row crops. An example of such an instrument is the chlorophyll meter, which can identify the failing health of a plant based on the chlorophyll content up to 16 days before it is physically detectable by the human eye (NASA, 2003). Poor health and plant stress are a result of unfavorable growing conditions, such as lack of nutrients, insufficient water, disease, or insect damage. Murdock et al. (2004) indicated that chlorophyll meters are faster than tissue testing for nitrogen, and that non-destructive measurements can be taken often and repeated if results are questionable. The authors also indicated that there is a close correlation between leaf chlorophyll content and leaf nitrogen content because much of the leaf nitrogen is contained in the chlorophyll. This type of sensor could potentially be used to evaluate cover crop termination or senescence. With this approach, we hypothesize that dead plants have 0% chlorophyll activity, whereas green healthy plants before termination should have maximum chlorophyll activity.

Another type of instrument commonly used in precision agriculture to identify nitrogen deficiencies and biomass production, or to spot weeds for selective weed control, is the active light sensor, which measures reflectance in the red-to-infrared portion of the light spectrum. One such instrument is the Greenseeker RT100 (NTech Industries, Inc., Ukiah, Cal.), which is used by crop researchers and consulting businesses to measure light reflectance and calculate the normalized difference vegetative index (NDVI). This index can be used to specify basic nutrient response, crop condition, yield potential, stress, and disease impact in a quantitative manner. The Greenseeker is normally used to monitor changing crop conditions during the growing season and the effects of different levels of an input compared to a local standard. Similarly as with chlorophyll meters, active light sensors used to generate NDVI could potentially be used to evaluate cover crop termination in a range from 0 (dead plant or low chlorophyll activity) to 1 (live plant with an optimum nutrient content and no pest pressure).

The objectives of this study were to (1) establish relationships between visual termination rates and output indices from two sensors (a chlorophyll meter and an active light sensor) by creating regression equations for different cover crops, and (2) evaluate the feasibility of using photometric sensors in assessing cover crop termination rates, as these instruments are already available for agricultural research.

Methods and Materials

To provide an adequate database for this study, cover crop termination rates were obtained by three different assessment methods using two experiments at the E.V. Smith Research Center near Shorter, Alabama. The two experiments were designed primarily to evaluate two roller/crimper implement designs on a weekly basis, and the results assessing the effectiveness of the rollers in terminating cereal rye (*Secale cereale* L.) and crimson clover (*Trifolium incarnatum* L.) are either already published (Kornecki and Price, 2010; Kornecki et al., 2012) or in process to be published. Thus, this work concentrated only on termination rates and the three methods used to assess these rates (visual, chlorophyll meter, and Greenseeker), regardless of data collection time (weekly measurements) and equipment used. The first experiment used two cover crops (rye and crimson clover) and one-section roller/crimpers. The second experiment used rye as the cover crop and three-section roller/crimpers. These experiments were conducted over three years (from 2009 to 2011); thus, the data presented here represent six site-years for rye and three site-years for crimson clover. In each growing season, termination rates were evaluated on the day the rolling/crimping treatment was applied, immediately before rolling/crimping of cover crops (0 days), and then one week (7 days), two weeks (14 days), and three weeks (21 days) after rolling/crimping.

Two different roller designs were used. The first consisted of a single section, two-stage roller/crimper (Kornecki et al., 2009; Kornecki et al., 2012), and the second was a three-section, straight bar roller/crimper (Kornecki et al., 2006; Kornecki and Price, 2010). The rye cover crop was terminated at the milk to soft dough growth stage, and crimson clover was terminated at the flowering growth stage. The first assessment method was a visual rating of cover crop senescence, determined by observing the relative greenness of plants. The visual evaluation method is based on assessing the color of the plant (from green to yellow and brown) and is based on the methodology described by Frans et al. (1986), which estimates visual desiccation on a scale of 0 (no injury symptoms) to 100 (complete desiccation of all plants). This method has previously been used in cover crop termination assessment (Ashford and Reeves, 2003; Kornecki et al., 2006; Kornecki et al., 2009; Kornecki and Price 2010; Raper et al., 2004). During the evaluation process from 2009 to 2011, and in the model validation, the visual termination rates of cover crops were assessed by the same evaluator.

The second assessment method consisted of a light sensor-based evaluation technique using the SPAD 502 chlorophyll meter (Konica-Minolta, Ramsey, N.J.). This portable chlorophyll meter is capable of instantly measuring the chlorophyll content or "greenness" of plants. Originally, the meter was used to evaluate the chlorophyll activity in plant tissue in an attempt to reduce the risk of yield-limiting deficiencies or costly over-fertilization. The SPAD 502 quantifies slight changes or trends in plant health long before they are visible to the human eye, and provides a non-invasive measurement. The meter is clamped over leafy tissue, and an indexed chlorophyll content reading (usually from 0 to 50.00) is recorded in less than 2 s. The data logging version of the SPAD 502 (item 2900DL) allows for easier compiling of readings for statistical analysis. Since the state of the plant greenness is related to chlorophyll activity (e.g., >50 for healthy plants, 60 for a dark green plant with full chlorophyll activity, and 0 for a dead plant with no chlorophyll activity), this concept was used to detect different stages of cover crop termination due to plant senescence from injury caused by mechanical termination using roller/crimpers or by glyphosate treatment. To obtain an average reading per plot, eight readings of plant tissue were collected in each plot by manually clamping the chlorophyll meter on randomly selected plants and storing the readings in the data logger. Similarly as with visual evaluation, SPAD measurements were obtained on a weekly basis: at zero (immediately before rolling), one, two, and three weeks after the rolling/crimping treatment.

The third assessment method used was a portable, handheld, active light sensor, the Greenseeker RT100 data collection and mapping unit (NTech Industries, Ukiah, Cal.). Data were collected continuously by walking with the unit through the length of each plot. The Greenseeker data were obtained exactly in the same time frame as the visual evaluations and the chlorophyll meter measurements. The Greenseeker generates light at two specific wavelengths and measures the light reflected off the target (plants). The microprocessor within the unit analyzes the reflected light and calculates an NDVI. The NDVI data from the sensor were transmitted to an HP iPAQ personal digital assistant for storage, and were then exported to a desktop computer for analysis.

Visual termination data were compared separately to chlorophyll meter data and to Greenseeker data. The indices for both sensors have an inverse relationship, indicating that 100% cover crop termination by the visual method is theoretically equal to an index near 0 for both instruments. Relationships between the visual and instrument data were determined with Table Curve 2-D (version 5.01, Systat Software, Inc., San Jose, Cal.). The process involved finding the best fit for *x-y* data sets with the highest coefficient of determination from which a Pearson correlation coefficient can be derived. The *x* parameter was associated with either the chlorophyll meter index (between 0 and ≥50) or the Greenseeker NDVI (theoretically between 0 and 1, but collected values were between 0.1 for a dead plant and 0.8 for a healthy plant). The *y* parameter was associated with visual assessment data. Based on the *x-y* relationship, the predicted values of *y* were calculated from the linear equations having the strongest relationship of cover crop termination. To determine if different years had an impact on Pearson correlation values, collected weekly data were combined and each year was analyzed separately. For overall comparison, data were combined across years and weeks for each cover crop separately. The prediction equations were validated against a single year of the visual data from two separate research experiments: 2008 rye visual data from an experiment near Cullman, Alabama, and 2011 visual data for crimson clover from an experiment near Auburn, Alabama.

Results and Discussion

2009-2011 One-Section Roller Experiment

Chlorophyll Meter vs. Visual Evaluation for Rye and Crimson Clover

Overall correlation coefficients (R values) between visual evaluations and chlorophyll meter indices during the 2009 to 2011 growing seasons ranged from 0.897 to 0.951 for rye and from 0.851 to 0.948 for crimson clover. Linear correlation results for each growing season are shown in table 1, where *a* is the constant and *b* is the slope of the linear equation $y = a + bx$. The variable *y* is the visual ter min-

Table 1. Linear correlation results for the chlorophyll meter index vs. visual termination rate for rye and crimson clover from the one-section roller/crimper test at the E.V. Smith Research Center.

	Cover Crop					
	Rye			Crimson Clover		
Year	*a* (constant)	*b* (slope)	R	*a* (constant)	*b* (slope)	R
2009	109.173	-2.233	0.951	105.575	-1.989	0.914
2010	100.814	-2.101	0.897	96.750	-1.891	0.851
2011	102.986	-2.037	0.912	105.653	-1.966	0.948

Table 2. Linear correlation results for the Greenseeker index vs. visual termination rate for rye and crimson clover from the one-section roller/crimper test at the E.V. Smith Research Center.

	Cover Crop					
	Rye			Crimson Clover		
Year	*a* (constant)	*b* (slope)	R	*a* (constant)	*b* (slope)	R
2009	149.671	-233.899	0.873	178.914	-226.830	0.918
2010	172.071	-363.396	0.913	161.681	-241.513	0.935
2011	153.299	-249.522	0.946	163.608	-210.252	0.973

ation rate for rye and crimson clover, and x is the chlorophyll meter index value.

Figures 1 and 2 show the linear relationships between visual termination and chlorophyll meter indices for three years of data for rye and crimson clover, respectively. The corresponding R values were consistently high (0.919 for rye and 0.908 for crimson clover). In addition, coefficients a and b were similar to these obtained for each single growing season. The main source of deviation was from the variable x rather than from the sensor outputs. The sensors were more capable of detecting differences at weeks 0 and 3 of the evaluation, whereas the visual observations did not show significant deviations during the same periods of time.

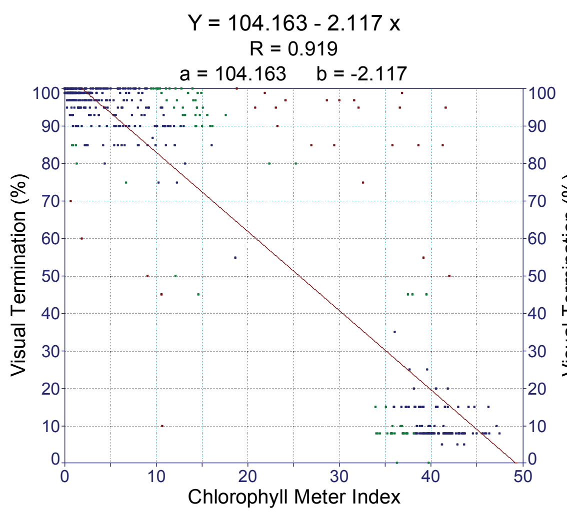

Figure 1. Linear relationship between chlorophyll meter index and visual termination rate for rye during 2009 to 2011 for the one-section roller/crimper test at the E.V. Smith Research Center.

Greenseeker vs. Visual Evaluation for Rye and Crimson Clover

Overall correlation (R values) between visual evaluations and Greenseeker indices during the 2009 to 2011 growing seasons ranged from 0.873 to 0.946 for rye and from 0.918 to 0.973 for crimson clover. The linear relationship results for each year are shown in table 2.

These findings are similar to the chlorophyll meter results, with high correlations for each growing season obtained between the Greenseeker NDVI readings and visual termination rates for both cover crops. In examining the linear relationships for three years' combined data, high correlation coefficients were found: 0.893 for rye (fig. 3) and 0.914 for crimson clover (fig. 4). The visual data for weeks 0 and 3 did not show deviations, whereas the Greenseeker was able to detect differences and provide a range of values for the single visual data point. This highlights the lack of perception of visual evaluation compared to the greater sensitivity of optical instrumentation.

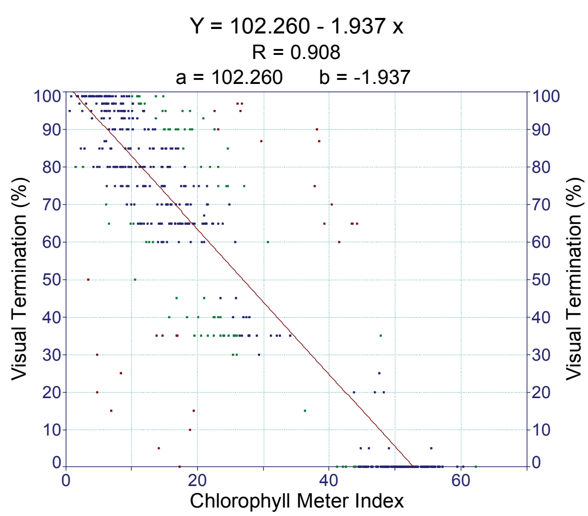

Figure 2. Linear relationship between chlorophyll meter index and visual termination rate for crimson clover during 2009 to 2011 for the one-section roller/crimper test at the E.V. Smith Research Center.

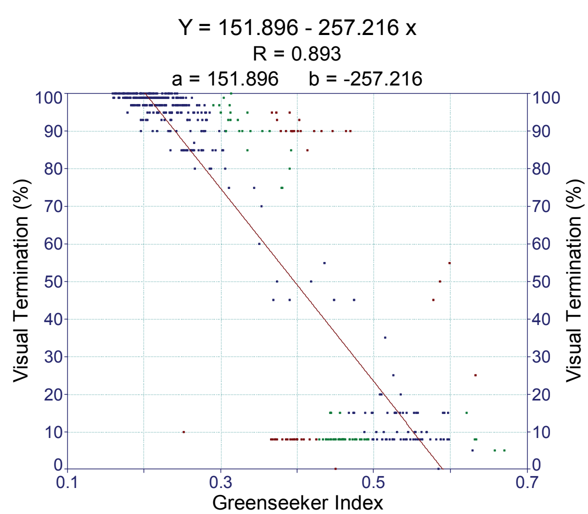

Figure 3. Linear relationship between visual termination (%) and Greenseeker index for rye data from three growing seasons (2009, 2010, and 2011).

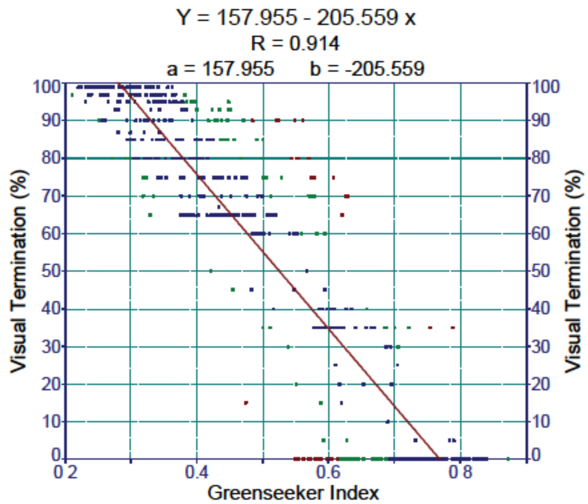

Figure 4. Linear relationship between visual termination (%) and Greenseeker index for crimson clover data from three growing seasons (2009, 2010, and 2011).

Greenseeker vs. Chlorophyll Meter for Rye and Crimson Clover

To determine the level of correlation between both sensors, data from the two instruments were compared and R values were calculated for each growing season (table 3).Measurements between instruments had high correlations, ranging from 0.900 to 0.946 for rye and from 0.852 to 0.930 for crimson clover.

The R values obtained from combining the data from three growing seasons were 0.903 for rye (fig. 5) and 0.899 for crimson clover (fig. 6). From these figures, one can see that, during all three growing seasons, there was a strong relationship between the chlorophyll meter and Greenseeker for both cover crops, indicating that these instruments consistently generated similar readings. Some data points located away from the equation line can be explained by the non-selective data collection by the Greenseeker compared to the chlorophyll meter. Some of the plots contained weeds that were actively growing during the evaluation periods. Because of the non-selective nature of the Greenseeker, which takes measurements as it is driven over the crop, readings for those plots also measured the greenness of the weeds, causing higher NDVI values than would have been obtained from only a senescing cover crop. The chlorophyll meter, which required manual insertion of plant material into the meter, only assessed cover crop plant tissue in those plots.

Table 3. Linear correlation results for the Greenseeker index vs. chlorophyll meter index for rye and crimson clover from the one-section roller/crimper test at the E.V. Smith Research Center.

	Cover Crop					
	Rye			Crimson Clover		
Year	*a* (constant)	*b* (slope)	R	*a* (constant)	*b* (slope)	R
2009	-17.434	102.588	0.900	-26.944	96.976	0.852
2010	-28.629	153.853	0.946	-25.919	108.473	0.930
2011	-20.443	109.073	0.922	-24.528	96.618	0.926

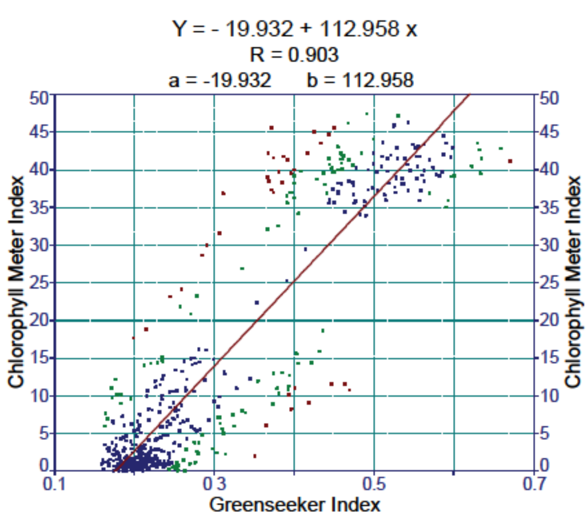

Figure 5. Linear relationship between Greenseeker index and chlorophyll meter index for rye cover crop termination during three growing seasons (2009, 2010, and 2011).

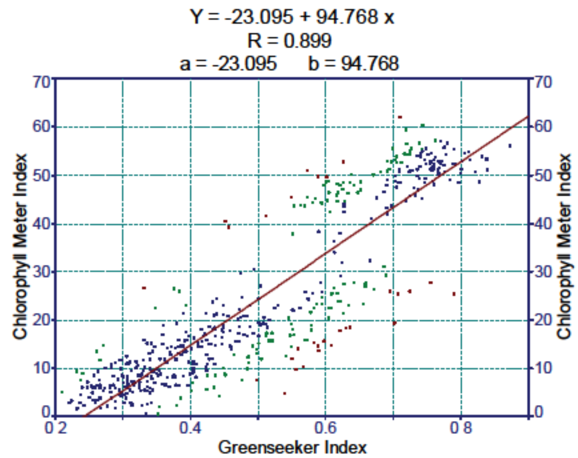

Figure 6. Linear relationship between Greenseeker index and chlorophyll meter index for crimson clover cover crop termination during three growing seasons (2009, 2010, and 2011).

2009-2011 Three-Section Roller Experiment

Rye was the only cover crop used in the three-section roller/crimper experiment. Correlations for the chlorophyll meter and Greenseeker for each year during 2009 through 2011 are shown in table 4. Stronger correlations between visual rye termination rates were found in 2009 and 2011 compared to 2010. In 2009, the resulting R values were 0.943 and 0.904 for the chlorophyll meter and Greenseeker, respectively. In 2011, the R values values were slightly higher than in 2009 and were 0.969 for the chlorophyll meter and 0.952 for the Greenseeker. In 2010, there was a weaker correlation between visual termination and both sensors, with R values of 0.807 and 0.783 for the chlorophyll meter and Greenseeker, respectively (table 4).

Table 4. Linear correlation results for rye termination, where *x* is the variable for chlorophyll meter and Greenseeker indices for the three-section roller/crimper test.

	Chlorophyll Meter vs. Visual Termination			Greenseeker vs. Visual Termination		
Year	*a* (constant)	*b* (slope)	R	*a* (constant)	*b* (slope)	R
2009	112.421	-2.609	0.943	145.819	-231.035	0.904
2010	99.906	-2.058	0.807	135 314	-208.044	0.783
2011	104.855	-2.176	0.969	143 142	-216.956	0.952

Table 5. Linear correlation results between Greenseeker and chlorophyll meter for each growing season for rye cover crop (three-section roller/crimper test).

Year	Greenseeker Index vs. Chlorophyll Meter Index a (constant)	b (slope)	R
2009	-9.888	80.044	0.865
2010	-13.988	91.513	0.877
2011	-16.006	94.527	0.932

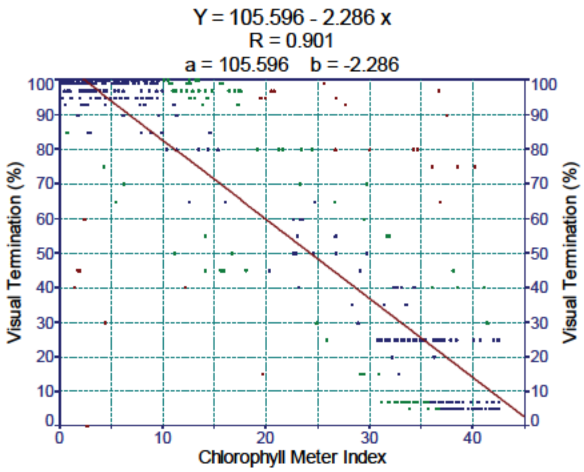

Figure 7. Linear relationship between visual termination (%) and chlorophyll meter index for rye data from three growing seasons (2009, 2010, and 2011) for the three-section roller test at the E.V. Smith Research Center.

Direct correlation comparison between the chlorophyll meter and Greenseeker was conducted to determine the source of this weaker relationship in 2010. As shown in table 5, the correlation (R value) between the sensors was higher (0.877) than the correlation between the visual termination data and the chlorophyll meter (0.807) or Greenseeker (0.783) shown in table 4. The higher correlation between the sensors suggests that the visually obtained rye termination ratings were a source of greater error in assessing cover crop senescence.

In examining the linear relationship for the combined data from the three growing seasons, high correlation coefficients of determination were maintained: 0.901 for the chlorophyll meter (fig. 7) and 0.876 for the Greenseeker (fig. 8). Visual data for weeks 0 and 3 had little deviation, whereas the chlorophyll meter and Greenseeker were able to generate a range of index values for a single visual data value.

In examining the level of correlation between the Greenseeker and chlorophyll meter from the three-section roller test, it is noted that the generated R value of 0.890 (fig. 9) was slightly lower than that from the one-section roller test in figure 5 (R = 0.903). The source of the deviation between these sensors can be associated with differences in how the data were obtained: for the Greenseeker, non-selective data were collected, including ground surface and weeds; for the chlorophyll meter, the measurements were targeted to measure the cover crop plant material only. When significant weeds are present, the chlorophyll meter would be the best sensor to use for evaluating the cover crop termination separately from the weeds. If the focus of

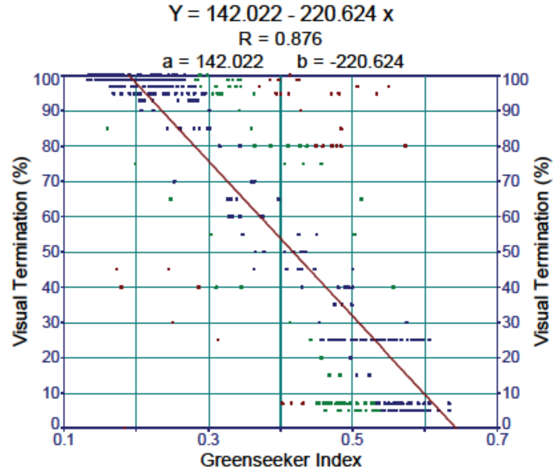

Figure 8. Linear relationship between visual termination (%) and Greenseeker index for rye data from three growing seasons (2009, 2010, and 2011) for the three-section roller test at the E.V. Smith Research Center.

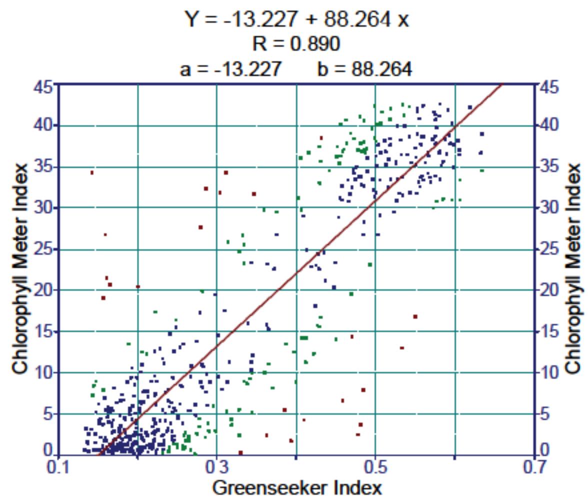

Figure 9. Linear relationship between Greenseeker index and chlorophyll meter index for rye cover crop during 2009, 2010, and 2011 growing seasons from the three-section roller test at the E.V. Smith Research Center.

a study is to determine the average termination of a mixture that includes rye or clover, as well as weeds, then the Greenseeker meter would be the best option. If there is an interest in determining termination as a separate percentage for a rye or clover cover crop, distinct from weeds, then both sensors could be used and the estimated percentage termination of weeds present within the cover can be determined by the difference in percent termination measured by each sensor.

Combined Data from the One-Section and Three-Section Experiments for Rye

Results from the one-section and three-section roller/crimper tests were combined for all three growing seasons of 2009 to 2011 (six site-years) to determine the linear correlation for rye from these six site-years of data generated by both sensors. The resulting R value between the Greenseeker and visual assessment was 0.882 (fig. 10),

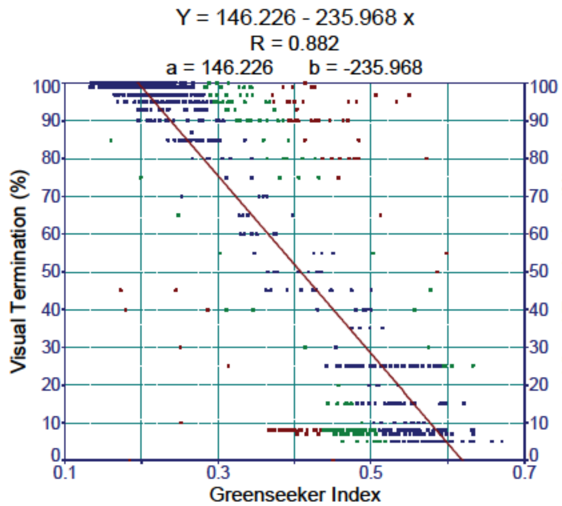

Figure 10. Results from three years of study at two sites (six site-years) for rye using the Greenseeker vs. visual termination.

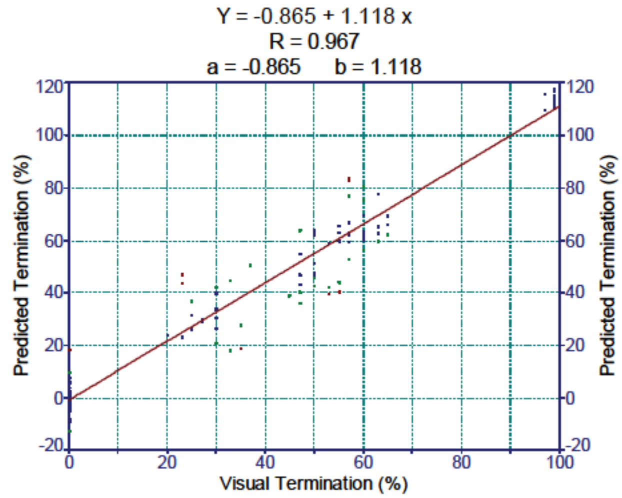

Figure 12. Visual termination vs. predicted termination for rye from 2008 study in Cullman using the Greenseeker.

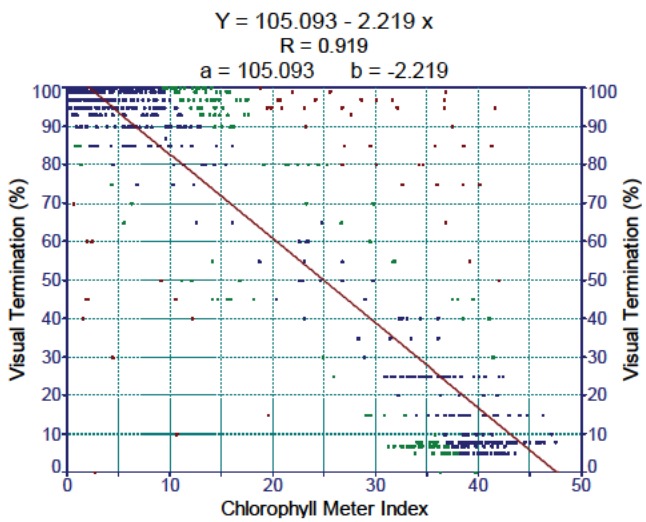

Figure 11. Results from three years of study at two sites (six site-years) for rye using the chlorophyll meter vs. visual termination.

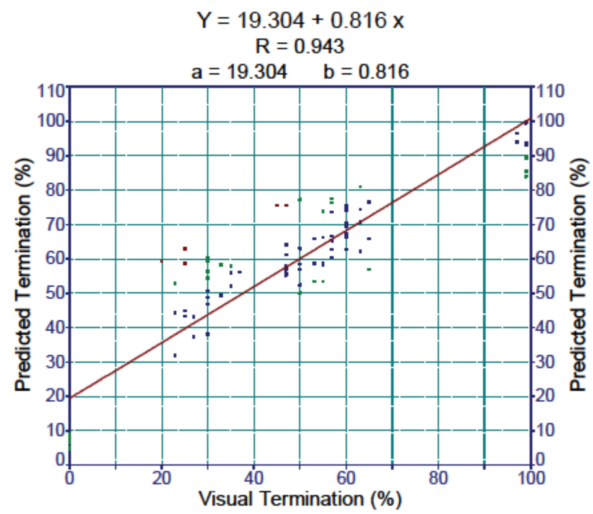

Figure 13. Rye visual termination from 2008 study in Cullman vs. predicted termination using the chlorophyll meter.

whereas the R value between the chlorophyll meter and visual assessment was slightly higher at 0.919 (fig. 11). These high correlation coefficients (R values) indicate that there were strong correlations between the visually observed termination rates and both sensor indices with long-term data.

Model Validation

The models for the chlorophyll meter and the Greenseeker developed for rye (based on six combined site-years of data) were tested against one year of data from another experiment in 2008 in Cullman, in northern Alabama (Kornecki et al., 2012). Similarly, the models for the chlorophyll meter and the Greenseeker developed for crimson clover (based on three combined site-years of data) were tested against one year of visual termination data obtained in 2011 from a research site near Auburn, Alabama. Model validation was performed using coefficients *a* (constant) and *b* (slope) from the above-specified linear equations and independent values (x) obtained by the chlorophyll meter and Greenseeker. Predicted termination values from the two sensors were tested against visual termination data for rye and resulted in high correlation coefficients (R values) of 0.967 for the Greenseeker (fig. 12) and 0.943 (fig. 13) for the chlorophyll meter.

Similarly, examining the linear relationships between visual termination rates and predicted termination rates for crimson clover resulted in high correlation coefficients (R values) of 0.927 for the Greenseeker (fig. 14) and 0.947 (fig. 15) for the chlorophyll meter. Overall, these strong correlations between visual observations of rye and crimson clover termination and predicted terminations indicate that both sensors could be used in the future for rye and crimson clover termination assessment.

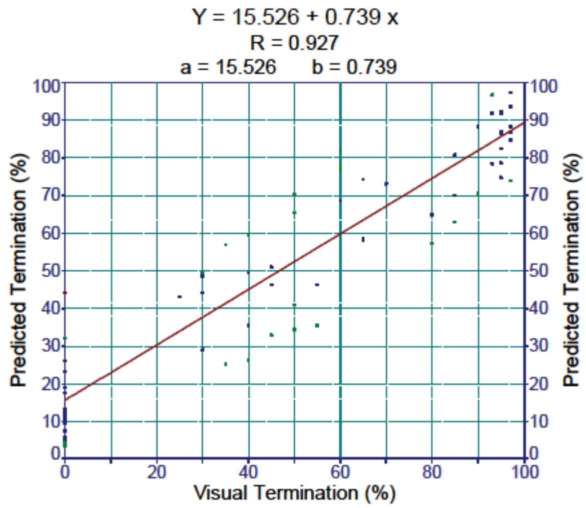

Figure 14. Crimson clover visual termination vs. predicted termination rates from 2011 study near Auburn using the Greenseeker.

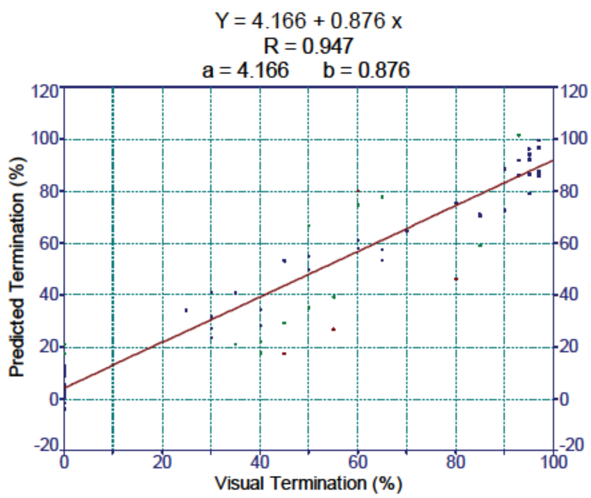

Figure 15. Crimson clover visual termination vs. predicted termination from 2011 study near Auburn using the chlorophyll meter.

Summary and Recommendations

High correlations were obtained between visual termination and sensor data from two plant monitoring instruments used in two different experiments conducted for three years. Similarly, high correlation coefficients were obtained from model validations using coefficients *a* (constant) and *b* (slope) from specified linear equations and *x* values generated by both sensors. The following linear regression models were developed for predicting rye termination rates using the Greenseeker (R^2 = 0.777) and chlorophyll meter (R^2 = 0.844) and were based on the combined data from both roller/crimper designs and experiments (six site-years), as the equipment designs were not the main focus of this study.

Predicted rye termination rate *y* (%) using the regression model developed for the Greenseeker:

$$y = 146.226 - 235.968x$$

where *x* is the Greenseeker NDVI reading.

Predicted rye termination rate *y* (%) using the regression model developed for the chlorophyll meter:

$$y = 105.093 - 2.219x$$

where *x* is the chlorophyll meter index reading.

For predicting crimson clover termination rates, the following models were developed, with R^2 = 0.835 for the Greenseeker and R^2 = 0.823 for the chlorophyll meter:

Predicted crimson clover termination rate *y* (%) using the regression model developed for the Greenseeker:

$$y = 157.955 - 205.559x$$

where *x* is the Greenseeker NDVI reading.

Predicted crimson clover termination rate *y* (%) using the regression model developed for the chlorophyll meter:

$$y = 102.260 - 1.937x$$

where *x* is the chlorophyll meter index reading.

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