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Full Length Research Paper

The relationship between ground based multi-spectral radiometer sensor derived ndvi and agronomic variables of flue cured tobacco for in-season crop monitoring.

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In-season tobacco crop status monitoring is used to evaluate the effect of cultural practices and environmental interactions that ultimately determine crop yield. In this experiment the relationship between hand-held Multispectral Radiometer (MSR 5) derived Normalized Difference Vegetation Index (NDVI) and tobacco biophysical parameters were established. From 100 Ha of tobacco crop, sampling sites were randomly selected for reflectance measurements and corresponding leaf length, leaf width, plant height, leaf number counts and above ground biomass. The biophysical parameters data was collected for 12 weeks from the age of 1 week after planting. The coefficients of determination between NDVI and leaf number (R2= 0.88), leaf length (R2 = 0.89), leaf width (0.82), plant height (0.86), Geometric mean length (0.863) and above ground dry mass (0.888) were high enough to allow for accurate assessment of crop health using NDVI. In-field variations in crop parameters were also observed on tobacco planted on different dates. Crop biophysical parameters are, hence, positively related to NDVI, and these results can be used in making in-season assessment of tobacco crop health, growth vigor and hence in yield estimation.

Keywords: Crop status monitoring, normalized difference, vegetation index, crop biophysical parameters, yield estimation

INTRODUCTION

In-season tobacco crop status monitoring is an important management tool required to evaluate the physiological crop status of tobacco during a growing season (Garvin, 1986). It is used to evaluate the environmental interactions that ultimately determine the yield of flue cured tobacco (Garvin, 1986). An effective in-season crop monitoring tool should be able to delineate a healthy crop from a stressed crop relatively fast and accurately, such that any management decisions required can be made timely to ensure that maximum yields and crop performance are achieved (Gausman and Escobar, 1973).

NDVI obtained from similar hand held instruments such as the Crop-scan Multispectral Radiometer (MSR 5) has been correlated with crop nutrient status and physiological development (Osborne et al., 2002), the NDVI has also been related to the final yield in maize (Manatsa et al., 2011), wheat and sorghum, as well as, with such stress factors as Nitrogen (Blackmer et al., 1996: Toulios et al., 1998) and water stress (Shoko et al., 2009). However, NDVI does not exclusively reflect the effect of one parameter (Hatfield et al., 2008). The index has to be considered as a measurement of the consolidated plant growth that combines several plant growth factors (Verhulst and Govaerts, 2010) rather than a universal descriptor of plant growth (Hatfield et al., 2008). The physical characteristics detected by the index are related to some measure of canopy density, measured as leaf number and geometric mean leaf area or total biomass (Araus et al., 2001) and will likely differ with plant species (Curran et al., 2001: Carlson and Ripley, 1997). . The geometric mean leaf area is the square root of product of leaf length and leaf width.

The underlying factor for variability in a typical vegetation index cannot be blindly linked to a management input without some knowledge of the primary factor that limits growth (Verhulst and Govaerts, 2010). For example, in a field where nitrogen is the limiting factor to growth, the NDVI may show a strong correlation with the N availability in the soil. However, in another field, where water is the limiting factor, the NDVI may be just as strongly correlated with plant-available soil moisture (Araus et al., 2001). Based on this, there is need for careful interpretation of remotely sensed data such that an observed characteristic is correctly attributed to a known and quantifiable agronomic factor. This can be achieved partly by assessing several NDVI-Crop responses and identifying common traits. Such responses include leaf number, leaf length, leaf width, plant height, dry mass and geometric mean leaf area to observed NDVI.

The total number of leaves permitted on a tobacco crop is dependent on a combination of crop management by the farmer and the varietal characteristics of the variety under cultivation (T.R.B, 2013). In Zimbabwe, the general topping height recommendation is between 18 to 20 leaves so as to maximize translocation of nutrients within the leaves for maximum weight attainment (T.R.B, 2013). Exceeding 20 leaves usually results in thin underweight leaves while topping with fewer than 18 leaves appears to have no significant leaf mass advantage (T.R.B, 2013). A crop under severe nutrient or environmental stress, however, tends to have stunted or retarded growth such that it does not attain the required number of leaves (Svotwa et al., 2012, TRB, 2013). The number of leaves on a plant directly affects the absorption and reflection of electromagnetic energy and should directly affect NDVI (Gausman and Escobar, 1973). The topping of the apical region greatly influences the maximum achievable height that a tobacco crop can achieve (T.R.B, 2013). Since leaf body may continue to increase under conditions of adequate nutrient supply, the effect of topping a healthy crop could potentially be different from that of a stressed crop.

The Crop-scan MSR radiometer (MSR 5) is a handheld field level remote sensing radiometer with spectral bands similar to the first 5 bands of the Landsat Thematic Mapper. The MSR 5 obtains passive reflective electromagnetic energy emitted from vegetative surfaces and expresses it as a proportion of the amount of electromagnetic energy that interacts with the vegetative surface, thereby allowing it to characterize unique features of the vegetation with reasonable accuracy (Ma and Dwyer, 2001). The instrument has been used successfully to estimate the yield (Short, 2008) and to evaluate disease incidence and yield loss caused by Sclerotinia Stem Rot of Soybeans (Daughtry et al., 2000). Recently it was used to estimate tobacco leaf nitrogen content and biomass of flue cured tobacco varieties (Svotwa et al., 2012). Despite its success, the MSR 5 does have the limitation of very low spatial resolution and is therefore is very difficult to employ it singularly as a yield estimation tool in large area yield estimation exercises. It is therefore limited mainly to ground truthing exercises (Svotwa et al., 2012).

The objective of this research was to establish a correlation between ground based (MSR 5) sensor derived NDVI with agronomic variables (stem height, leaf diameter, total leaf number and geometric mean) of flue cured tobacco. It is hypothesized that tobacco crop canopy refelectance, expressed as the NDVI is correlated with crop biophysical parameters and, the relationship can be used in making inseason crop health and growth vigour assessments for crop yield estimation purposes.

MATERIALS AND METHOD

The study was carried out at the Tobacco Research Board's Kutsaga Research Station during the 2012/13 season. Kutsaga lies in Natural Region II at an altitude of 1 479 meters above sea level. The station is located on latitude 17`55``S, longitude 31`08``E and receives a mean annual rainfall of 800-1000 mm. Rainfall is normally received during the period November to March. Average temperature is 18^0C in winter and 32^0C in summer. The area has light, well drained, sandy soils of granite origin and are Kaolinitic belonging to group 6 which comprises Paraferrallitic soil with a coarse-grained sand fraction derived from granite (T.R.B, 2013). The soils are position two on the soil catena. These are typically moderately deep to deep well drained soils. The soils are very low in clay content and have low water holding capacity. They are slightly acidic (pH 5.2). The experiment was carried out on lands that are rotated with a Katambora Rhodes grass after every 3 years of tobacco cultivation.

Cultural practices and treatment application

The land was early ploughed (January to end of March) using a tractor- drawn plough to a depth of 38 cm. Ridging and Nematicide Ethylene Di Bromide (EDB) 98% application at a rate of 125 ml/100 m were done prior to planting. The Nematicide was applied 38 cm below the ridge by an injector gun in the planting station. The ridges were spaced at 120 cm and a plant spacing on the ridge was 56 cm. Compound C (N6: $P_2O_5$18: K_2O17) fertilizer was applied at a standard rate of 750 kg/ha as recommended by the soil fertility analysis laboratory.

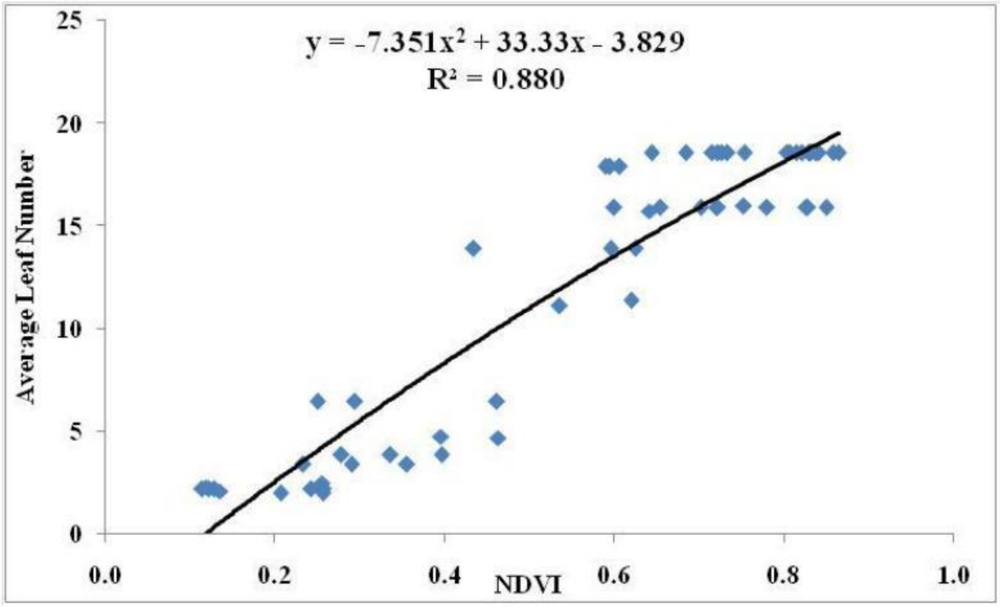

Figure 1: The relationship between Leaf Number and Crop-scanTM derived NDVI

Measurements

A total land area of 100 Ha of tobacco crop was planted in four main planting time blocks, with 33 Ha in September, 25 Ha in October and 33 Ha in November for each block, three dimensional positions latitude, longitude and altitude for the whole experimental area and for each treatment plot were be taken using a Garmin Personal Navigator (GPS V) to enable repeated sampling at the same location. 10 sub blocks were selected with an area of 5 Ha each within each main block. Ten points were selected randomly from each sub block in order to create variable growth conditions that are necessary to establish the relationship between spectral data, biophysical variables and above ground biomass. In each sub block measuring 5 Ha, stratified GPS assisted random sampling was done to select 10 plants for weekly sampling for leaf variables and NDVI measurements. The measurement taken from 10 samples were averaged to a single unit and, corresponding leaf length, leaf width, plant height, leaf number counts and above ground biomass sampling were also collected at the same time from the 10 plants selected randomly within the 5 Ha blocks and were averaged. This was repeated at weekly intervals up to 12 weeks after planting when reaping intensified. The data analysis and graph plotting was done using Microsoft Excel 2007 package.
MSR 5 was used to obtain canopy reflectance values in the wavelength ranges of 450–1750 nm using the Crop Canopy Reflectance Procedure. The measurements were taken around solar noon to minimize the effect of diurnal changes in the solar zenith angle in the 10 selected plants at weekly intervals. The NDVI was computed from the reflectance values obtained in the Channel 3 and 4 of the MSR 5 which correspond to the Visible (RED) and Near Infra Red (NIR) respectively using the following formula:

$$NDVI = \frac{nir - red}{nir + red}$$

RESULTS

Leaf number

The relationship between leaf number and NDVI of flue cured tobacco is summarized by the diagram (Figure 1).
A positive polynomial relationship was observed between NDVI and leaf number per plant with a correlation co-efficient of $R^2 = 0.88$ (P<0.001) (Figure 1). NDVI continued to increase until a maximum level of 0.86 despite the leaf number becoming constant at 18 leaves (Appendix 2).

Leaf length

The relationship between NDVI and the leaf length of flue cured tobacco is illustrated in figure 2 below.
NDVI increased as the average leaf length of tobacco leaves increased (Figure 2). A coefficient of determination of $R^2 = 0.888$ (P<0.001) between average leaf length and crop scan derived NDVI was observed.

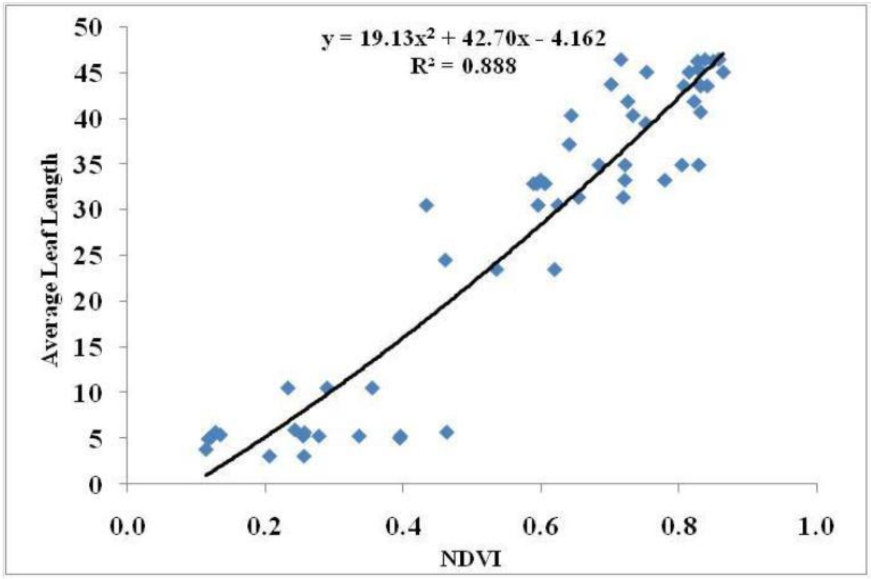

Figure 2: The relationship between leaf length and MSR 5 derived NDVI

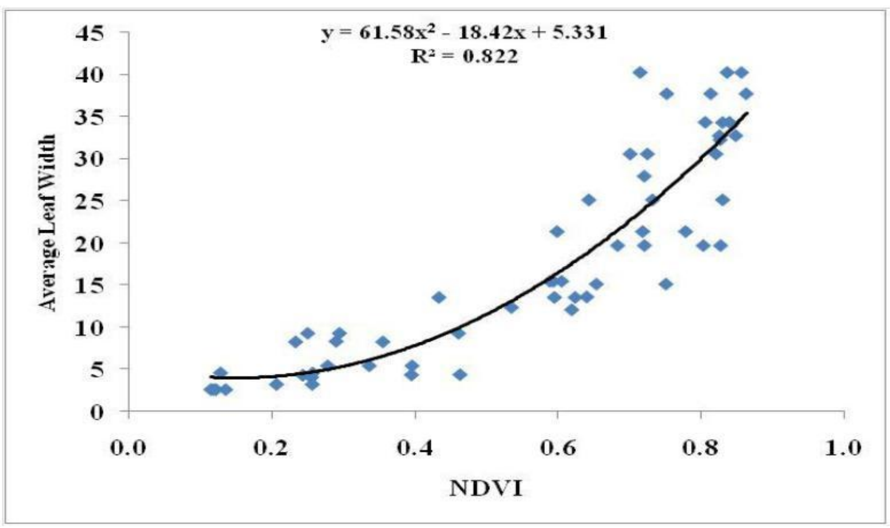

Figure 3: The relationship between leaf width and MSR 5 derived NDVI

Leaf width

The response of NDVI to the changes in flue cured tobacco leaf width is shown in figure 3.
The leaf width NDVI relationship showed a positive relationship ($P<0.001$) ($R^2=0.822$). The correlation coefficient was notably lower than that of leaf length to NDVI

Plant height

The response of flue cured tobacco plant height in relation to NDVI is shown in figure 4.
A positive relationship was observed between plant height and NDVI with a coefficient of determination of $R^2 = 0.86$ ($P<0.001$) (Figure 4). An important observation was that there was considerable variation in NDVI beyond 0.6 despite the plant height being constant.

Geometric mean leaf area

The geometric mean leaf area relationship to NDVI is illustrated in figure 5.
The relationship between NDVI and geometric mean area also showed a positive relationship with a coefficient of

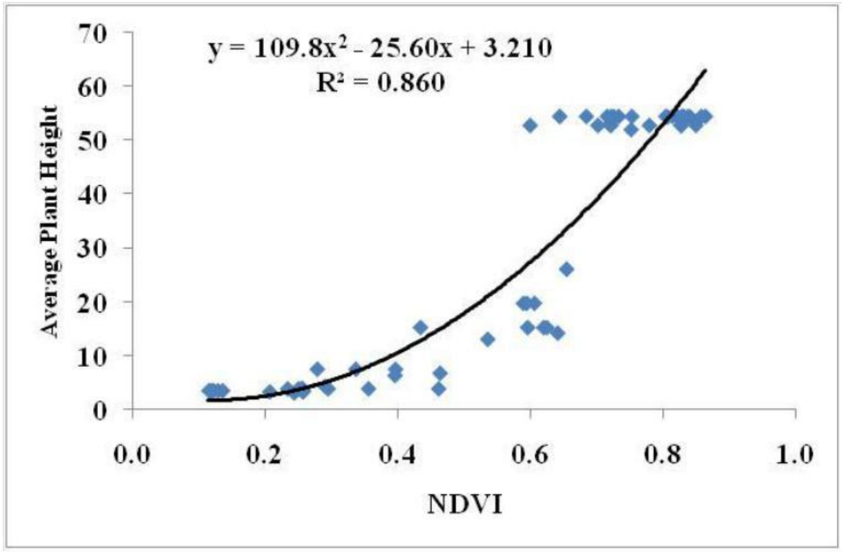

Figure 4: The relationship between plant height and MSR 5 derived NDVI

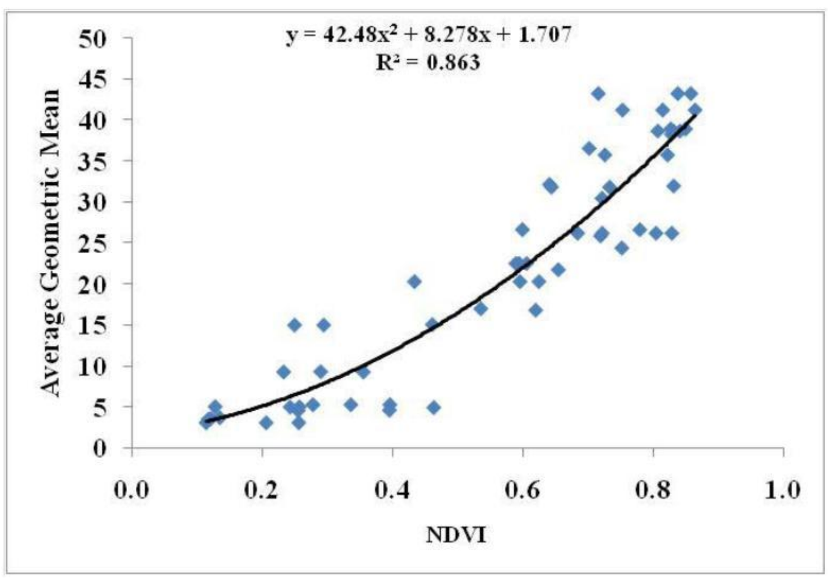

Figure 5: The relationship between geometric mean and MSR 5 derived NDVI

determination of 0.863 (P<0.001) (Figure 5). highest geometric mean leaf area achieved was 43.18 cm that corresponded with the highest NDVI observed of 0.86.

Dry mass

The response of total dry mass of tobacco to the measured NDVI is demonstrated in figure 6.
NDVI was positively correlated to above ground sampled dry mass of tobacco (R^2 =0.89) (P<0.001) (Figure 6). Maximum NDVI attained during the season was 0.85 which corresponded with the highest dry mass attained of 242.6 g

DISCUSSION

The strength of the relationship between leaf number and NDVI compares well with the LAI-NDVI relationship in maize (Osborne et al., 2002). Similar coefficients of determination of around 0.8 (Sims and Gamon, 2002) were also established in several crop species. The leaf is the photosynthetic machinery in plants and leaf area and is directly related to yield (Curran et al., 2001). The leaf number determines Leaf

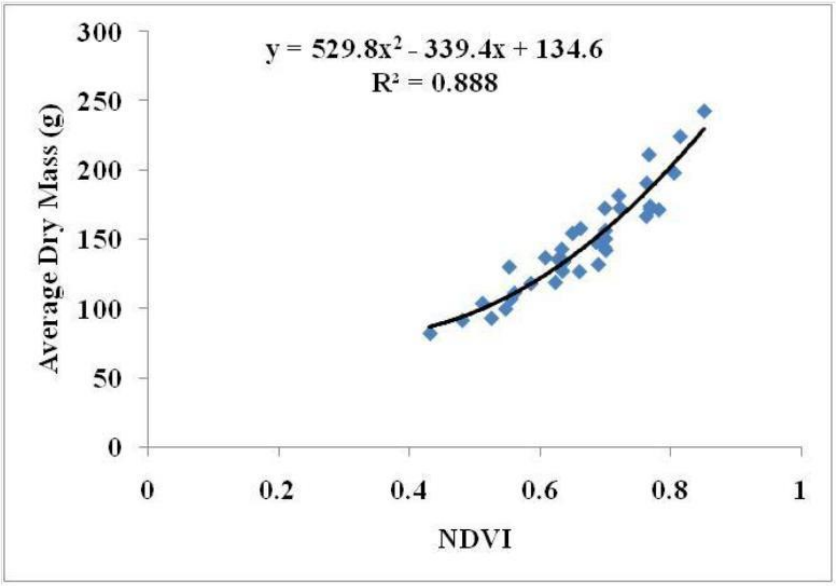

Figure 6: The relationship between above ground dry mass and MSR 5 derived NDVI

area index (*LAI*), the total one-sided area of leaf tissue per unit ground surface area (Ritchie and Bednarz, 2005). LAI is a key parameter in eco-physiology, especially for scaling up the gas exchange from leaf to canopy level. It characterizes the canopy– atmosphere interface, where most of the energy fluxes exchange (Ritchie and Bednarz, 2005). The linearity of the leaf number and NDVI would allow for the use of crop scan derived NDVI to be used in the estimation of crop yield. However, the two levels of constant leaf number suggest that the approach should target crops of similar planting times. At growth stages later than 10 weeks after planting the leaf number remained constant due to topping, as NDVI continued to increase, probably due to leaf expansion and resultant increase in canopy density as hypothesized by Hatfield *et al* (2008).

The relationship between leaf length and NDVI was also positive, showing an increase in light use efficiency as the crop leaf developed (Yin et al., 2011). Leaf expansion directly influences the surface area available for electromagnetic interactions and as a result, contributes sufficiently to the overall NDVI measured by a sensor (Campbell, 2002: Myeni et al., 1995). Gross leaf length is measured from the leaf butt, the point where lamina starts to the leaf tip. Leaf length development is used in the assessment of crop development (Yin et al., 2011).

The role of the leaf width biophysical factor is equally related to leaf length and it influences NDVI in a similar manner. Leaf width changes indicate canopy development and influence NDVI (Ritchie and Bednarz, 2005: Yin et al., 2011: Sellers 1985). At Kutsaga Research station, leaf length and leaf width are used to compute an index for estimating leaf area called Geometric Mean length (cm), which allows for the comparison of varieties with varying length-width ratios (T.R.B, 2013).

Although there was sufficient strength in the coefficient of determination for plant height and NDVI, it may not be an accurate assessment tool for in-season tobacco crop health assessments due to the observed variation in NDVI after crop height becomes constant because of topping. The limitation of NDVI as a universal plant indicator is supported by Hatfield et al., (2008) who argued against the use of NDVI alone as a predictor of agronomic variables in crop management. Similar findings were also observed in corn (Xinhua et al., 2010). The variation could be as a result of in-field variations of soil fertility and moisture such that biomass accumulation was not homogenous in the fields resulting in it being independent of the height at which the tobacco was topped, as evidenced by similar conclusions in research work on N use efficiency in corn (Tolulios et al., 1998).

Another argument could be made as to why NDVI varies after plant height was arrested by topping could be because of the effect of planting date as discussed by Svotwa *et al* (2012). September planted tobacco generally yield better cured leaf mass than subsequent plantings in October and November (T.R.B, 2013). Therefore, the height at which the tobacco is topped will influence the biomass attenuation of the crop and ultimately, the NDVI response observed.

The positive relationship between NDVI, leaf number, leaf dimensions and plant height is an indication of NDVI being an indicator of productivity and hence final biomass and yield. This makes the NDVI appropriate in in-season crop assessment as well as in identifying in field nutrient and environmental heterogeneity.

CONCLUSIONS

Leaf length, width, and plant height and above ground biomass can be estimated accurately with NDVI derived from MSR 5. There is merit in attempting to delineate stressed and healthy tobacco crops stands by observing and comparing their NDVI values to those obtained in this study. Corrective management measures that are employed once crop limitation is detected can also be feasibly measured by observing the NDVI changes that might occur due to the crops response to and managerial and environmental changes introduced to the crop stand. Also, field to field variation, in-field variations and environmentally introduced heterogeneity that potentially cause low productivity in tobacco farms can be investigated using the MSR 5 sensor.

There is potential for the application of Crop-scan derived NDVI in the in-season monitoring of biophysical crop variables which are related to yield. The usefulness of the MSR 5 however is limited to monitoring one field at a time. From past research, the MSR 5 was found very compatible with Satellite platforms like MODIS and Landsat. The MSR 5 is still limited in spatial coverage and other means such as Satellite platforms are required to meet national crop status evaluations simultaneously. However, although adequate for localized tobacco fields, this method is impractical for large scale tobacco crop status evaluation such as national tobacco evaluations.

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