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*Full Length Research Paper*

# Development of mathematical models for estimating tobacco crop biophysical parameters using multispectral radiometer and upscaled Modis derived NDVI

**[1]Munyaradzi Shamudzarira, *[2]Ezekia Svotwa, and [3]Walter Manyangarirwa**

[1]Tobacco Research Board, Kutsaga Research Station, Harare, Zimbabwe
[2]Department of Crop Science and Postharvest Technology, Chinhoyi University of Technology, Box 7724, Chinhoyi, Zimbabwe
[3]Faculty of Agriculture and Natural Resources, Africa University, Off Nyanga Road, Mutare, Zimbabwe

Corresponding Author's E-mail: esvotwa2@gmail.com

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**Research on assessing flue cured tobacco canopy response to cultural management using remote sensing was done using the multispectral radiometer (MSR 5) derived NDVI. MODIS satellite platforms provide adequate spatial resolution for large scale crop assessments but have a low spectral resolution and are susceptible to atmospheric interference. This experiment sought to develop estimation models for flue cured tobacco agronomic parameters based on established relationships with MSR 5 and MODIS derived NDVI and field measured agronomic parameters. MSR 5 and MODIS reflectance readings were collected weekly from six tobacco fields, between 1 and 12 weeks after planting. Satellite data was ordered from the USGS Glovis Website using the Earth Explorer interface to identify the experimental fields. The linear models for estimating biophysical parameters like leaf length, leaf width, plant height, leaf number and geometric mean leaf area were developed. Using a simple function relating MSR 5 and MODIS derived NDVI, and by substitution of $NDVI_{MSR}$ with the $NDVI_{MOD}$, the estimation models for the tobacco biophysical plant parameters were also derived. The results from the study can improve the accuracy of tobacco crop monitoring and vigor assessment on a large scale.**

**Keywords:** multispectral radiometer, satellite platforms, spatial resolution, biophysical parameters, crop monitoring

## INTRODUCTION

The Normalized Difference Vegetation Index (NDVI) is an important spectral index for the assessment of the health and vigor of agronomic crops (Huete, 2002). Traditionally, NDVI has been calculated from radiometric measurements collected from ground based sensors such as the Cropscan Multispectral Radiometer (MSR 5) (Bronson, 2003) and, has been used to describe crop response to fertilizer and agronomic management practices (Svotwa, 2012). NDVI can also be obtained from space borne satellite platforms such as the Moderate-resolution Imaging Spectoradiometer (MODIS) (Baez-Gonzalez, 2005), Landsat ETM (Rajapakse, 2008) and QuikBird (Wu, 2007). Most researchers have focused on the use of either ground sensor derived NDVI [3, 2] or satellite derived NDVI (Rajapakse, 2008) independently, to estimate yields of various crops with little emphasis on the in season biophysical crop responses (Svotwa et al, 2013).

The application of NDVI as the primary tool for the retrieval of plant canopy agronomic parameters has been studied widely in recent years, (Hatfield and Prueger, 2010; Huete, 2000). Several other vegetative indices such as Transformed Adjusted Vegetative Index (TSAVI) (Baret, 1989) proved useful in crop status evaluations. Although they have largely shown positive and encouraging results, few indices have been applied as consistently as the NDVI for agronomic management (Hatfield and Prueger, 2010), while other vegetation indices such as Enhanced Vegetation Index (EVI) have been criticized for their inability to capture subtle differences that occur during early development of crops (Wardlow, 2006).

A major consideration of NDVI solely as a predictor of biophysical properties in this research was that it is universally calculated from spectral data collected by most of the major satellite remote sensing platforms (Wardlow, 2006; Wang, 2010; Jayroe, 2005 and Wu, 2007). In the case of Cropscan Multispectral radiometer 5 instrument, TSAVI and SAVI are difficult to derive due to limited electromagnetic wavebands and broad waveband channels, thereby introducing substantial noise to the observed data (ICT, 2000). In this research, we accepted that NDVI is not a universal predictor of crop biophysical parameters, but offered the most consistent data source for meaningful analysis of crop canopy characteristics.. Such consistent data is essential for the simplification of crop monitoring tools and data retrieval in developing turn-key solutions for varying space and time situations as was suggested by Hatfield (2008).

When remote sensing data is collected from ground based sensors, the sensitivity of the instruments to agronomic variations is higher than that observed from satellite borne platforms due to reduced atmospheric interference. (Ma, 2001). As a result, low spatial resolutions from ground sensors require an up-scaling exercise to a higher spatial resolution of satellite platforms that can enable large scale observations to be conducted simultaneously and in near real-time (Williams, 2008; Toomanian, 2004). Up-scaling techniques allow for more accurate comparisons of crop responses observed from two different platforms and for consistent conclusions be derived (Wang, 2010).

Tobacco in-season crop assessment at national scale is essential for the development of remote sensing based yield estimation and crop vigor assessment models (Svotwa et al, 2013). The leaf number, leaf length, leaf width and stem length of flue cured tobacco are closely related to the attainable yield of the crop (Garvin, 1986). Satellite sensors differ considerably in acquisition cost (Svotwa et al, 2013) and resolution capabilities (Short, 2008). Usually, high resolution platforms such as Quick Bird, IKONOS and WorldView would be most applicable for crop assessment. However, they have considerably high image acquisition costs (Marumbwa, 2006). The lower resolution satellites that are freely available tend to have either course resolution or low temporal resolution (Jayroe, 2005). As a result, vegetation indices obtained from ground based and satellite based sensors may differ considerably when observing a specific phenomenon (Wang, 2010). In such cases, there is need for special calibration of estimation models to ensure consistent interpretation using up-scaling techniques.

Up-scaling is defined as a technique of extrapolating information from a low spatial resolution site-specific scale at which direct field observations have been made, to a smaller previously resolved scale (Williams, 2008). Tobacco crop fields are characterized by spatial heterogeneity in soil types, climatic conditions and, agronomic management practices differ from one field to the next. Non-linear crop responses are common when agronomic parameters are observed. It is therefore important to determine whether any relationships that are determined at ground level scales in field research are applicable directly at coarser satellite platform scales (Williams, 2008). Without sufficient scaling procedures, direct field measurements and experimental models can introduce a considerable amount of error during operational crop assessment for yield estimation. (Gallo and Flesch, 1989). In the case of flue cured tobacco, heterogeneity is commonly brought about by different crop husbandry practices such as topping, fertilizer application, is weed and pest control, and such factors as soil type, and to a limited extend, by the variety (Svotwa, 2012).

Previous studies have attempted to correlate ground measurements of Leaf Area Index against satellite derived NDVI (Carlson, 1997) in non commercial cropping systems with higher degrees of heterogeneity. According to William (2008), these studies did not adequately account for the differences in scales between satellite pixels and ground data collections, nor did they assess the relationship between the NDVI and field measured agronomic parameters for direct comparison with satellite data. This study sought to compare the canopy reflectance responses of flue cured tobacco through different satellite and ground based platforms so as to derive a single means of interpreting data, observed in future, by any one of the selected instruments. In this study, a direct relationship between ground based instruments is assumed to be higher than the relationship observed on the same fields using satellite instruments.

Research conducted on flue cured tobacco optical responses has shown a strong positive relationship between NDVI derived from tobacco varieties to above ground dry mass using the MSR 5 (Svotwa, 2012). The research, however, was limited by the low spatial resolution of the ground based instrument, such that it was impractical to conduct large scale crop monitoring exercises. MODIS satellite platforms provide adequate spatial resolution for large scale crop assessments. However, because of its courser resolution, and susceptibility to atmospheric interference (Svotwa et al, 2013), there is need to upscale the data to MSR 5 scale that best estimates tobacco phenology.

In this research it was hypothesized that both the relationship between tobacco crop biophysical parameters and MSR 5 derived NDVI, and an up-scaling relationship between MSR 5 derived NDVI and MODIS derived NDVI can be established. In addition, it was also hypothesized that the preceding the two preceding relationships can be used in the development of MODIS based models for estimating flue cured tobacco crop biophysical. Although the experimentation was done using tobacco, the information from this research can be used in large area in-season assessment of crop status for yield estimation purposes.

## MATERIALS AND METHOD

The study was carried out at the Tobacco Research Board's Kutsaga Research Station during the 2012- 13 and 2013-2014 season. Kutsaga lies in Natural Region II at an altitude of 1 479 meters above sea level. The station is found on latitude 17`55``S, longitude 31`08``E and receives a mean annual rainfall of 800-1000mm. Rainfall is normally received during the period November to March. Average temperature is 180C in winter and 320C 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. They 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.

### Data processing and model development

1. The experiment sought to develop estimation models for flue cured agronomic parameters (Leaf length, leaf width, plant height, leaf number and geometric mean leaf area) based on established relationships between low spatial resolution MSR 5 derived NDVI ($NDVI_{MSR}$) and field measured agronomic parameters. The expected basic linear functions the following basic linear functions:

**Equation 1:** $L_L = K_2NDVI_{MSR} + b$
**Equation 2:** $L_W = K_3NDVI_{MSR} + c$
**Equation 3:** $L_N = K_4NDVI_{MSR} + d$
**Equation 4:** $P_H = K_5NDVI_{MSR} + e$
**Equation 5:** $G_M = K_6 NDVI_{MSR} + f$

Where: $K_2$, $K_3$, $K_4$, $K_5$, b, c, d, e and f are constants
$NDVI_{MSR}$ is MSR 5 derived NDVI and $L_L$, $L_W$, $L_N$, $P_H$ and $G_M$ are Leaf Length, Leaf Width, Leaf Number, Plant Height and Geometric mean Leaf Area respectively. The Geometric mean leaf area is calculated from the square root of the product of leaf length and leaf width.

2. The following stage sought to establish the up-scaling factor in the relationship between MSR 5 derived NDVI ($NDVI_{MSR}$) and MODIS derived NDVI ($NDVI_{MOD}$) with the expected linear function of: $NDVI_{MSR} = KNDVI_{MOD} + a$.

**Up-scaling factor:** $NDVI_{MOD} = KNDVI_{MSR} + a$
Where: $NDVI_{MOD}$ is up-scaled $NDVI_{MSR}$
$NDVI_{MSR}$ is MSR 5 derived NDVI
**K** and **a** are constants

3. By substitution of $NDVI_{MSR}$ with the $NDVI_{MOD}$, the estimation models for the tobacco biophysical plant parameters were expected to be as follows:

$$L_L = K_2 (KNDVI_{MOD} + a) + b$$
$$L_w = K_3 (KNDVI_{MOD} + a) + c$$
$$L_N = K_4 (KNDVI_{MOD} + a) + d$$
$$P_h = K_5 (KNDVI_{MOD} + a) + e$$
$$G_M = K_6 (KNDVI_{MOD} + a) + f$$

### Data collection

MSR 5 reflectance readings were collected from 6 tobacco fields weekly from one week after transplanting to 12 weeks when reaping was initiated. Each week, the MSR 5 was calibrated for height adjustment using the manufacturer assumption of the sensor height position being twice the radius of the field of view (spatial coverage) so as to eliminate any errors associated with the vertical growth and canopy expansion of the tobacco.

Satellite data was ordered from the USGS Glovis Website using the EarthExplorer interface to identify the experimental fields. The data obtained from the Bulk Download Application program was geo-referenced and preprocessed with the NDVI data calculated.

Weekly plant height, Leaf length, leaf width and leaf number measurements were collected simultaneously with MSR 5 reflectance readings to increase data accuracy. The plant position for agronomic measurements was marked using a GARMIN Global Positioning Satellite Receiver to ensure repeated sampling positions. Regression analysis and goodness of fit tests were calculated using Microsoft excel 2007 package.

## RESULTS

$NDVI_{MSR}$ (**Figure 1**) showed a corresponding increase as leaf length increased with a linear relationship:
$L_L = 61.929*(NDVI_{MSR}) - 7.716$
Where:
$L_L$= leaf length and $NDVI_{MSR}$ are as earlier defined
A positive relationship is observed between $NDVI_{MSR}$ and $NDVI_{MOD}$ with strength of determination of 0.81. Therefore, the up-scaling function for $NDVI_{MSR}$ to $NDVI_{MOD}$ scale as obtained in Figure 2 above is:
$NDVI_{MOD} = 1.5935*(NDVI_{MSR}) - 0.0919$
Where $NDVI_{MOD}$ and $NDVI_{MSR}$ are as defined earlier.
The following stages demonstrate the stages involved to develop an estimation model for flue cured tobacco.

### Stage 1

An estimation model for tobacco leaf length based on the relationship between $NDVI_{MSR}$ and measured leaf length obtained in Fig 1 is as follows:
$= L_L = 61.929*(NDVI_{MSR}) - 7.71$

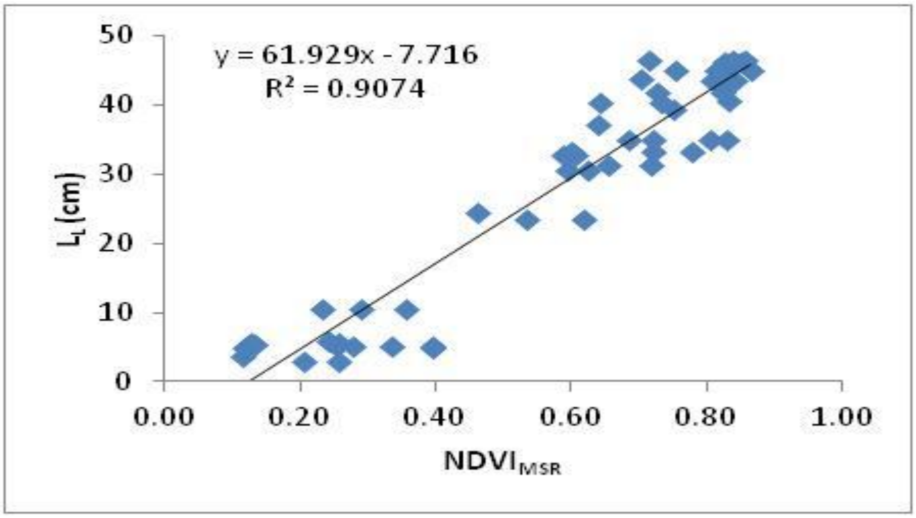


**Figure 1:** the relationship between $NDVI_{MSR}$ and $L_L$

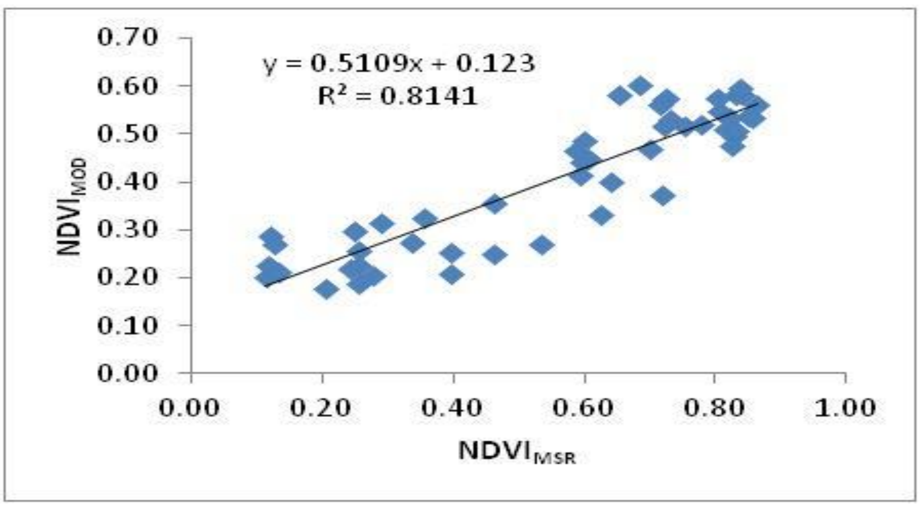


**Figure 2:** the relationship between $NDVI_{MSR}$ and $NDVI_{MOD}$

**Stage 2**

By substitution of $NDVI_{MSR}$ with the up-scaling factor obtained in Figure 2
**$L_L$ =** 61.929*(1.5935*$NDVI_{MOD}$ - 0.0919) - 7.716
The leaf length estimation model can be simplified to:
**Equation 1:** $L_L$ = 98.68*($NDVI_{MOD}$) - 13.41
Where: $NDVI_{MSR}$, $NDVI_{MOD}$ and $L_L$ are as defined earlier (Figure 3). As leaf width expanded, $NDVI_{MSR}$ responded positively with 81% of the variation being accounted for ($r^2$=0.81). The following relationship was observed:
**$L_W$ =** 44.19*($NDVI_{MSR}$) - 6.86
By substitution of $NDVI_{MSR}$ by $NDVI_{MOD}$ as in stage 2 earlier, the estimation model for Leaf width can be simplified as equation 2 below:
**Equation 2:** $L_W$ = 70.42*($NDVI_{MOD}$) – 10.92
Where: $L_W$, $NDVI_{MSR}$ and $NDVI_{MOD}$ are as defined earlier
As leaf number increased (figure 4 below), $NDVI_{MSR}$ also increased following a linear relationship with a coefficient of determination of $r^2$ = 0.89. The $NDVI_{MSR}$ estimation function for leaf width is summarized as:
**$L_N$ =** 26.32*($NDVI_{MSR}$) – 2.71
By repeating the substitution of $NDVI_{MSR}$ as demonstrated in stage 2 earlier, a model for estimating leaf number can be simplified as equation 3 below:
**Equation 3:** $L_N$ = 41.61*($NDVI_{MOD}$) - 5.02
Where $L_N$ and $NDVI_{MOD}$ are as defined earlier

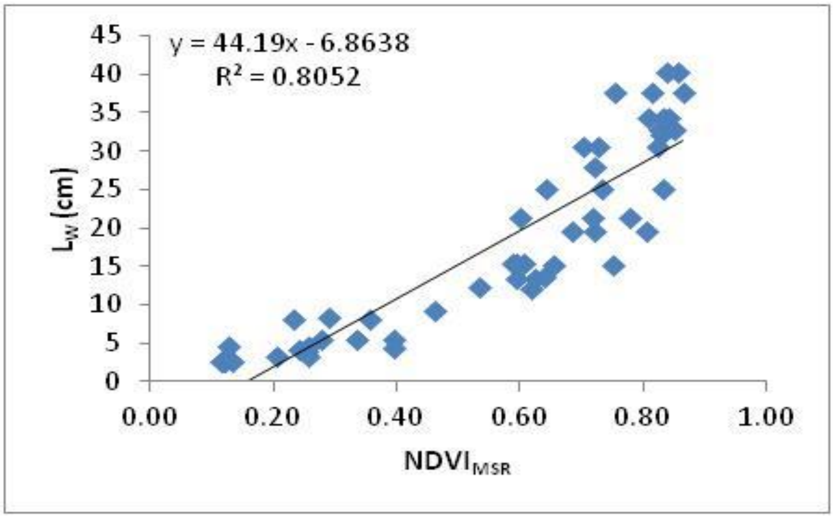


**Figure 3:** the relationship between $L_W$ and $NDVI_{MSR}$

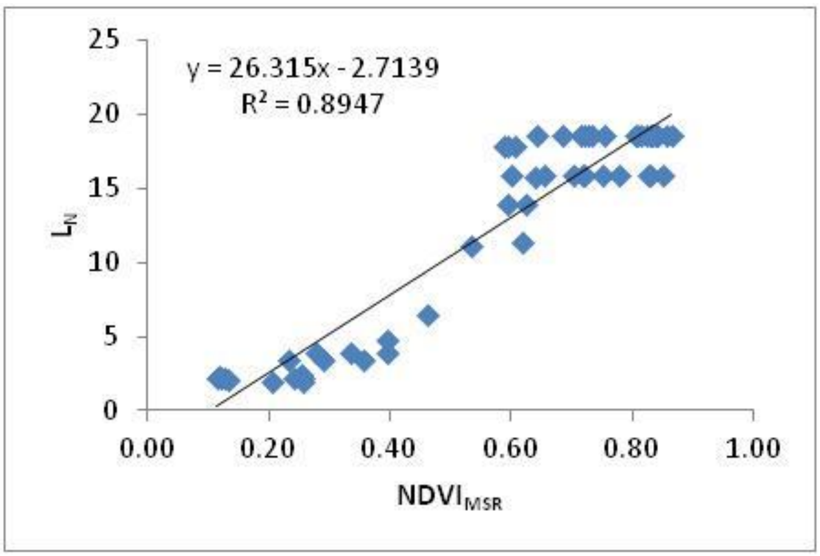


**Figure 4:** the relationship between $NDVI_{MSR}$ and $L_N$

The variation between plant height and $NDVI_{MSR}$ is best explained by a quadratic relationship rather than linear (figure 5). There is no observed change in plant height beyond 62cm despite an increase in $NDVI_{MSR.}$ The; the estimation function for plant height is as follows:

$\mathbf{P_H} =$ 106.19*($NDVI_{MSR}$)$^2$ - 22.19*($NDVI_{MSR}$) + 2.8

By repeating stage 2 and simplifying, the estimation model for plant height is shown as equation 4 below:

**Equation 4:** $P_H$ = 269.64*($NDVI_{MOD}$)$^2$ – 66.46*($NDVI_{MOD}$) + 5.74

Where PH and $NDVI_{MOD}$ are as earlier defined

The geometric mean leaf area (Geo Mean) of flue cured tobacco correlated positively with NDVI with an $r^2$ of 0.87 (figure 6 below). Based on the above relationship, a linear function for estimating geometric leaf mean area is:

$\mathbf{G_M} =$ 52.27*($NDVI_{MSR}$) - 7.23

By substitution of $NDVI_{MSR}$ with $NDVI_{MOD}$ obtained from Figure 2 as in stage 2 previously, an estimation model for $G_M$ is summarized as equation 5.

**Equation 5:** $G_M$ = 83.29*($NDVI_{MOD}$) – 12.04

## DISCUSSION

The positive relationships observed between NDVI and biophysical parameters are consistent with findings form researches conducted on corn (Yin, 2011) as well as in Wheat (Araus, 2001). The linearity of the relationship between $NDVI_{MSR}$ and canopy biophysical parameters is

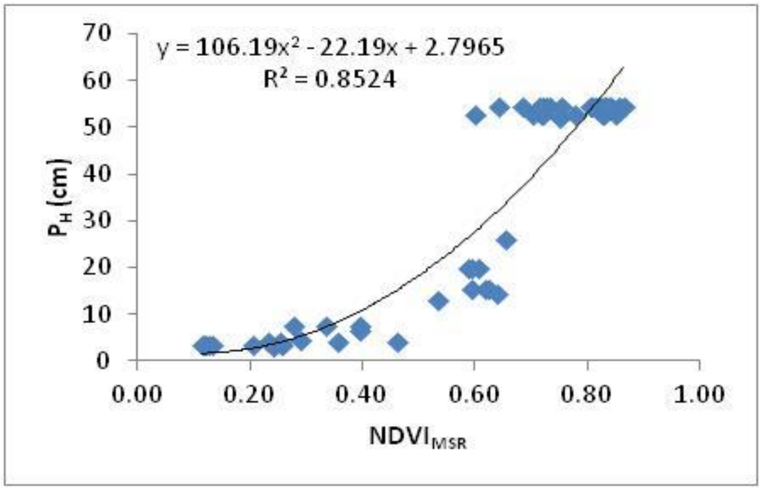


**Figure 5:** the relationship between $NDVI_{MSR}$ and $P_H$

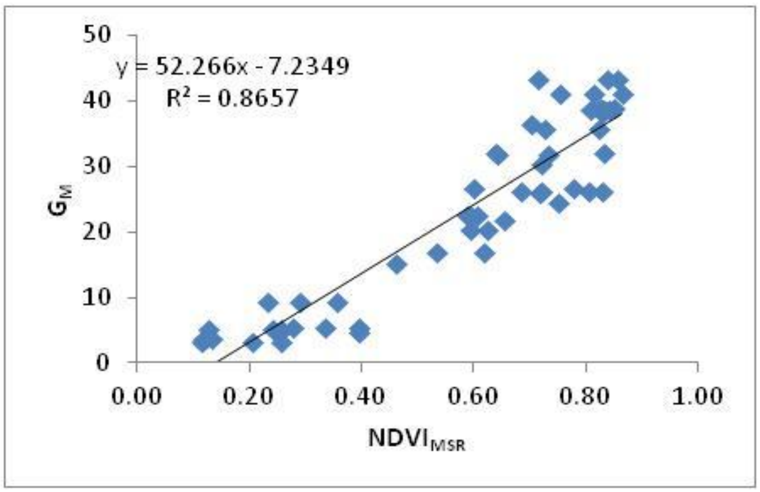


**Figure 6:** the relationship between $NDVI_{MSR}$ and $G_M$

also consistent with results from biomass accumulation monitoring studies done using NDVI in maize varieties (Verhulst, 2010). More recently, biomass assessment of flue cured tobacco for yield prediction purposes was attempted on flue cured tobacco (Svotwa, 2012). Other studies have developed less direct methods of crop biophysical estimation with NDVI through use of indices that are closely linked to biophysical parameters such as Leaf Area Index has been successfully attempted in tea (Jajapakse, 2008) and Soyabean (Haboudane, 2004).

The continued increase in $NDVI_{MSR}$ when plant height remained constant can be attributed to the effect of topping. Topping is done after the crop has achieved between 18 and 22 leaves (TRB, 1986) so as to arrest any further apical growth of the crop. This practice promotes carbohydrate storage in the remaining leaves to enhance the quality and biomass (TRB, 1986). Carbohydrate and nicotine accumulation along with other leaf chemicals explain the further increase in $NDVI_{MSR}$ that is observed after topping. Similar findings by Verhust (2010) in maize crop that showed an increase in NDVI when stem thickness had reached maximum. The leaf number to $NDVI_{MSR}$ relationship shows a similar response to plant height due to the same effect of topping as explained earlier.

The relationship between Leaf length and $NDVI_{MSR}$ was comparably stronger than that of Geometric mean leaf area and $NDVI_{MSR}$. Despite this, the Geometric mean leaf area is sufficient in explaining changes in tobacco crop canopy. Wu, (2007), argued that indices that summarize crop canopy dynamics based on the photosynthetic area available such as LAI tend to become less predictive as canopies become denser.

It is our view that should Geometric mean leaf area be considered as a means for estimating tobacco crop vigor and should be applied mainly as an attempt to reduce any noise that may be brought about by the effects of varietal differences in leaf expansion rates and overall leaf shape.

$NDVI_{MSR}$ was comparably higher than $NDVI_{MOD}$ for simultaneous crop measurements during the entire growing period of tobacco. The relationship between $NDVI_{MSR}$ and $NDVI_{MOD}$ was linear in nature and the coefficient of determination was sufficiently strong for an up-scaling model to be developed. Williams (Williams, 2008) had similar findings when NDVI from different scales were regressed. Svotwa et al, (2013) argued that atmospheric interference would be a likely factor when NDVI from space borne sensors is used for agronomic crops such as tobacco.

Although the results demonstrate saturation of NDVI when biophysical parameters reach certain levels, we argue that a linear relationship be adopted rather than exponential or logarithmic functions so that differences in biophysical conditions brought about by different locations and environmental conditions on the vigor of the crops can be accounted for. The linear functionality of the models attempt to optimize the algorithms for situations that may influence tobacco crop development differently than as under experimental differences as was suggested by Hatfield (2008).

## CONCLUSION

The research carried out led to the development of an up-scaling factor for MODIS derived products using ground based Multispectral Radiometer to improve the accuracy of crop vigor assessment at large scale as well as the following crop biophysical estimation models for flue cured tobacco.

**Equation 1:** $L_L = 98.68*(NDVI_{MOD}) - 13.41$

**Equation 2:** $L_W = 70.42*(NDVI_{MOD}) – 10.92$

**Equation 3:** $L_N = 41.61*(NDVI_{MOD}) - 5.02$

**Equation 4:** $P_H = 269.64*(NDVI_{MOD})^2 – 66.46*(NDVI_{MOD}) + 5.74$

**Equation 5:** $G_M = 83.29*(NDVI_{MOD}) – 12.04$

**Up-scaling factor:** $NDVI_{MOD} = 1.5935*(NDVI_{MSR}) - 0.0919$

Where: $L_L$, $L_W$, $L_N$, $P_H$ and $G_M$ and $NDVI_{MOD}$ are as defined earlier

## RECOMMENDATION

We recommend that validation exercises be conducted on the above models across different growing conditions and farmer cultural practices to improve the accuracy of estimation of the models. We also recommend that other vegetation indices be considered and evaluated against the NDVI for efficiency in crop vigor assessment. Lastly, we recommend that the approach be adopted for other high resolution satellite platforms for more accurate crop assessment methods.

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## REFERENCES

Araus JL, Casadesus J, Bort J (2001). Recent tools for the screening of physiological traits determining yield," Application of physiology in wheat breeding. Mexico, D.F.: CIMMYT. Pp. 59-77,

Baez-Gonzalez AD, Kiniry JR, Maas SJ (2005). Large-area maize yield forecasting using leaf area index based yield model. Agron. J. 97(2): pp. 418–425.

Baret F, Guyot G, Major DJ (1989). TSAVI: A vegetation index which minimizes soil brightness eff ects on LAI and APAR estimation. Proc. IGARRS 0/12th Canadian Symposium on Remote Sensing, Vancouver, Canada. (3):1355–1358.

Bronson KF, Chua TT, Booker JD, Keeling JW, Lascano RJ (2003). In-Season Nitrogen Status Sensing in Irrigated Cotton. Soil Science Society, Am. J. 67:1439-1448

Carlson TN, Ripley DA (1997). On the relation between NDVI, fractional vegetation cover, and leaf area index. Remote Sensing of Environment, 62(3): pp. 241–252

Gallo KP, Flesch TK (1989). Large-area crop monitoring with the NOAA-AVHRR: Estimating the silking stage of corn development. Remote Sensing of the Environment. 27:73–80

Garvin RT (1986). Yield estimation—a tool for reducing Losses. Zimbabwe Tobacco Today, 9(12): pp. 32–35,

Haboudane D, Miller JR, Pattey E, Zarco-Tejada PJ, Strachan IB (2004). Hyperspectral vegetation indices and novel algorithms for predicting green LAI of crop canopies: modeling and validation in the context of precision agriculture. Remote Sensing of Environment, 90: pp. 337–352

Hatfield JL, Prueger JH (2010). Value of using different vegetative indices to quantify agricultural crop characteristics at different growth stages under varying management practices. Remote Sensing 2:562-578. doi:10.3390/rs2020562.

Hatfield JL, Gitelson AA, Schepers JS, Walthall CL (2008). Application of Spectral Remote Sensing for Agronomic Decisions. Agron. J. 100:S-117-S-131.

Huete A, Didan K, Miura T, Rodriguez EP, Gao X, Ferreira LG (2002). Overview of the radiometric and biophysical performance of the MODIS Vegetation indices. Remote Sensing of Environment, 83:195–213,.

Jayroe CW, Baker WH, Greenwalt AB (2005). Using multispectral aerial imagery to evaluate crop productivity. Online Crop Management: 10.1094/CM-2005-0205-01-RS

Ma BL, Dwyer LD, Costa CCR, Carlos, Malcolm M (2001). Early Prediction of Soybean Yield from Canopy Reflectance Measurements. Agron. J. November- December, 93(6):93:1227-1234

Marumbwa FM, Murwira A, Madamombe EK, Kusangaya S, Tererai F (2006). Remotely sensing of irrigation water use in Mazowe Catchment. Zimbabwe. Zimbabwe National Water Authority (ZINWA), PO Box CY 726 Causeway, Harare, Zimbabwe, Department of Geography and Environmental Science, University of Zimbabwe, P. O. Box MP167, MT Pleasant, Harare

Rajapakse RMSS, Tripathi KN, Honda K (2008). Modelling Tea (Camellia (L) O. Kuntze) yield using satellite derived LAI, landuse and meteorological Data. (2008). GISdevelopment.net. http://www.gisdevelopment.net/aarc/2000/index.htm. Downloaded on 13 may 2008.

Short NM (2008). Vegetation Applications: Agriculture, Forestry, and Ecology. Remote Sensing Tutorial. http://www.rst.gsfc.nasa.gove/htm,

Svotwa E,. Masuka AJ, Maasdorp B, Murwira A, Shamudzarira M (2013). Remote Sensing Applications in Tobacco Yield Estimation and the Recommended Research in Zimbabwe. Hindawi Publishing Corporation ISRN Agronomy, 2013,

Svotwa E, Maasdorp B, Murwira A, Masuka A (2012). Selection of Optimum Vegetative Indices for the Assessment of Tobacco Float Seedlings Response to Fertilizer Management. ISRN Agronomy,

Tobacco Research Board (TRB) (1986). Flue cured Tobacco recommendations," TRB, Harare

Toomanian N, Gieske ASM, Akbary M (2004). Irrigated area determination by NOAA-Landsat up-scaling techniques, Zayandeh River Basin, Isfahan. Iran Int. J. Remote Sensing, 25(22)

Verhulst N, Govaerts B (2010). The normalized difference vegetation index (NDVI) GreenSeeker™ handheld sensor: Toward the integrated evaluation of crop management Part A: Concepts and case studies. Mexico. International Maize and Wheat Improvement Center (CIMMYT.)

Wang TW, Sammis VP, Gutschick M, Gebremichael S, Dennis O, Harrison RE (2010). Review of Satellite Remote Sensing Use in Forest Health Studies. The Open Geo. J. 3:28-42

Wardlow B, Stephen L,. Kastens JH (2006). Analysis of time-series MODIS 250 m vegetation index data for crop classification in the U.S. Central Great Plains. Remote Sensing of Environment 108 (2007):290–310

Williams M, Bell R, Spadavecchia L, Street LE, Wijk MK (2008). Up-scaling leaf area index in an Artctic landscape using multi-scale reflectance observations. Global Change Biology

Wu J, Wang D, Bauer ME (2007). Assessing broadband vegetation indices and Quickbird data in estimating leaf area index of corn and potato canopies. Field Crops Res. 102(2007):33–42. www.elsevier.com/locate/fcr.

Yin X, McClure MA, Ngowari J, Tyler DD, Robert M, Hayes (2011). In-Season Prediction of Corn Yield Using Plant Height under Major Production Systems. Agron. J. 103:923-929