

Use of Multispectral Radiometer and Modis Satellite Data Correlations in Developing Models for Tobacco Yield Estimation

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Abstract – The multispectral radiometer (MSR5) and MODIS satellite data correlations were used in developing models for flue-cured tobacco yield estimation. A field experiment was set and a field survey and satellite Earth observations were carried out. Radiometric measurements from the experiment were used to relate normalized vegetation index (NDVI) from the multispectral radiometer to tobacco yield. Ground based MSR5 and MODIS satellite based data correlations were developed using radiometric and satellite spectral measurements collected from a 100 ha tobacco field. NDVI's were also extracted from the freely downloaded images from 38 randomly selected tobacco fields of at least five hectares in area in the tobacco growing regions of Zimbabwe. The MSR5 based yield-NDVI correlations for the September to October planted tobacco ranged between 0.78 and 0.81, while those for the December planted and the pooled data were 0.91 and 0.51 respectively. The upscaling factor for $NDVI_{MSR5}$ from the $NDVI_{MODIS}$ was developed, and this, in turn was used to develop the final tobacco yield estimation model. The predicted average flue cured tobacco yield (2.72 tons/ ha) was 88% of the actual yield (3.08 t/ ha) from the project area, and a performed t-test for comparison of means showed that the two were statistically similar ($p > 0.05$). It is recommended that the model undergoes further test and recalibration before the tobacco sector fully relies on it for crop yield estimation.

Keywords – NDVI, Satellite Data Correlations, Upscaling, Yield Estimation Model.

INTRODUCTION

The Cropscan multispectral radiometer (MRS5) is a handheld field level remote sensing instrument with spectral bands that are similar to the first 5 bands of the Landsat Thematic Mapper [1]. The MSR5 obtains passive reflective electromagnetic energy emitted from vegetation surfaces and, expresses it as a proportion of the amount of electromagnetic energy that interacts with the vegetation surface. This therefore, enables it to characterize unique features of the vegetation with reasonable accuracy [2].

The theory of operation, as summarised in ICT [3], is based on the fact that every substance emits, absorbs, transmits or reflects electromagnetic radiation in a manner that is unique to that substance. The characteristics of the target substances can be defined by measuring the quantity

of radiation in each of the wavelengths. The narrow band interference filters in the MSR5 system select certain electromagnetic bands in the visible and near infrared (NIR) regions and, these are useful for quantifying the reflectivity of canopies as affected by various kinds of stresses. The filters of wavelengths range from 450 up to 1720 nm [3].

Reflectance of radiation wavelengths, as influenced factors that affect the normal growth of plants, makes the radiometer useful in assessing the effects of such conditions as nutrient deficiency, diseases, waters stress, herbicide damage, varietal differences or general cultural practices on crop vigour, yield, or quality. The MSR5 derived spectral data is, therefore, applicable as inputs for models that describe normal plant growth for estimating crop yield and quality. Also important is its application in ground truthing for remote sensing based data collection exercises [3].

The MRS5 was successfully applied in assessing plant diversity and productivity relationships in a northern mixed grass prairie in the United States of America [4]. Dudka, et al. [5] used the digital imagery from the MSR5 to evaluate disease incidence and yield loss caused by *Sclerotinia* stem rot of soybeans, while Ma et al [2] applied the MSR5 derived NDVI ($NDVI_{MSR5}$) for early prediction of soybean yield. Other areas where it has been successfully applied include the detection and monitoring of defoliation, mortality and disturbances over forested landscapes [6], in the estimation of forage production [7] and in spatial analysis of white mold infection in soybean [8].

The Moderate-resolution Imaging Spectro-radiometer (MODIS) is a key instrument aboard the Terra and Aqua earth observation satellites. The two are timed in such a way that they pass from north to south (Terra), and from south to north (Aqua), across the equator in the morning and in the afternoon respectively [9]. The 250 m spatial resolution band is the one commonly used for agricultural applications, and because of its 2330 - km swath, a large area of the earth's surface monitored. This relatively high temporal resolution that makes it a potential candidate for flue cured tobacco assessments at national scale. Although in this research tobacco was used as a reference crop, the

approach can be applied in developing yield estimation models for other crops.

Currently, MODIS data are free, and have been successfully used in monitoring forest fires, post-fire burn area mapping, vegetation classification, biomass estimation, and soil degradation [10]. Sibanda and Murwira [11] applied multi-temporal MODIS derived NDVI ($NDVI_{MOD}$) with ground data to distinguish cotton from maize and sorghum fields in smallholder agricultural landscapes of Southern Africa.

Other satellite sensors are Advanced Space-born Thermal Emission and Reflection Radiometer (ASTER), Advanced Land Imager (ALI), Advanced Very High Resolution Radiometer (AVHRR), Landsat 5 TM (Thematic Mapper), Landsat 7 ETM+ (Enhanced Thematic Mapper Plus), Spot 4 and 5, Quickbird-2, and IKONOS-2 [10]. Each sensor has its own advantages and disadvantages in spatial and temporal resolutions, cost, and acquisition time. An understanding of satellite sensors is necessary in deciding on which satellite to choose, according to the required applications.

Zimbabwe has a potential tobacco production area of nearly 150000 m² and, and has an ever increasing crop area and number of registered tobacco producers [12]. Stakeholders in the tobacco industry need a reliable crop monitoring approach and reliable crop size estimates. The current conventional crop yield forecasts mostly rely on seed purchase records, land area estimates and visual assessment of the crop. Since farmers' records may not be exhaustive, the current forecasts may not be accurate. Yield estimation models can be employed to avoid these problems.

Some existing models relate meteorological parameters to crop yield and production, while others are purely statistical in nature [13]. Although use of models has allowed fairly accurate yield estimation result [14], the nature and relationship between crop yield and some parameters may not be easily determined. Statistical models, for example, are location specific, and the use of averages in developing a yield model may not reflect conditions in extreme situations. The process of collecting data can be tedious and time consuming, and thus preclude large-scale investigations [14]. A more objective and practical model for yield estimation could assist tobacco stakeholders with more precise data on crop growth characteristics, hectareage and final yield that would be available for export.

Remote sensing can complement or even improve conventional yield prediction. This is because remote sensing and can be used to provide useful information on near real time crop condition, as well as for yield forecasting. With the difficulty and time-consuming nature of the use of field surveys in crop monitoring, alternative approaches, with quick and reliable performance, must be considered and tested, as in the case of remote sensing based monitoring. Tobacco crop monitoring based on remotely sensed imagery becomes logical, because the tobacco crop area is vast, with records showing 90000 ha, 80000 and 70 000 during the 2012 - 13, 2011 - 12 and 2012 - 11 respectively [15].

Vegetation indices, calculated from remote sensing data are important in assessing crop growth and health status as well as the effect of crop management practices. In addition, they are applicable in yield estimation [16]. The application of NDVI for characterizing plant canopy agronomic parameters has been widely studied [17; 18] and other vegetation indices such as Transformed Adjusted Vegetation Index (TSAVI) [19] proved useful in crop evaluations. Although many developed indices have largely shown positive and encouraging results, few indices have been used as consistently as the NDVI for agronomic management [17].

Earlier work on developing tobacco yield estimation models using remote sensing was done using a Cropscan multispectral radiometer (MSR5). From this work it was established that the tobacco canopy seasonal maximum $NDVI_{MSR5}$ is highly correlated with inseason dry mass and yield [20; 21], models relating seasonal maximum $NDVI_{MSR5}$ and crop yield were developed [21]. Recommendations were also made that for the data to be applicable in tobacco yield estimation using satellite remote sensing there is need for upscaling these $NDVI_{MSR5}$ based models using MODIS data.

Spatial scaling takes information at one scale and uses it to derive processes at another scale [22]. Upscaling is when information at a lower spatial resolution is taken and transformed to the higher spatial resolution or downscaling, which works in opposite direction [22]. The MSR5 used for model development has low spatial resolution and a high revisit frequency according to the researchers' design. The information derived using this has to be scaled up so that it can be applied for large area crop status monitoring and yield estimation.

In this research, models for estimation tobacco yield using MODIS satellite data were explored, using upscaled ground based yield - $NDVI_{MSR5}$ relationships. It was hypothesized that the tobacco yield is positively correlated with $NDVI_{MSR5}$ and, that the relationship between $NDVI_{MSR5}$ and yield can be upscaled to develop $NDVI_{MODIS}$ based models for large area crop assessment and yield estimation purposes.

II. METHOD

A. Study Area

This study was done through a field experiment, a field survey and satellite Earth observations. The experiment and the field survey were carried out at Kutsaga Research Station from 2010 to 2012. Kutsaga is located between Longitude 31° 08' E, Latitude 17° 55' S, and at an altitude of 1000 m to 1500 m [23].

During February of 2010 the experimental plots were disced to incorporate grass, after a three years under Katambora grass fallow period. Agricultural lime was applied using recommendations as given by soil test results, to raise the soil pH from 5.3 to 6.3 levels. Recommended cultural and management practices were done [23], except as regards N: P: K levels and planting times, which were treatments in the experiment.

B. Fertilizer Treatments

In order to establish the relationship between spectral data and yield, there was need to create variable growth conditions [24] and, three varieties, four planting dates and three fertilizer levels were tested. The varieties x fertilizer treatments were applied by hands (table 1). Four planting dates; September 15, October 15, November 15 and December 15 were used, while fertilizer treatments were as shown (Table 1). The N:P:K treatment were hand-applied in bands of about 10 cm deep and 30 cm to each side of a row at planting, while N treatments were applied at about 4 weeks after transplanting and after topping (at 6 weeks after planting). The recommended compound fertilizer rate from soil test results was 700 kg/ ha, while that for Ammonium Nitrate (34.5% N) was 96 kg/ ha at 4 weeks after planting and 75 kg/ ha after topping.

Table 1: Variety – fertilizer treatments

Treatment	Description
1.	KRK - 26 50 % Recommended Fertiliser
2.	KRK 26 Recommended Fertiliser
3.	KRK - 26 150 % Recommended Fertiliser
4.	T 66 - 50 % Recommended Fertiliser
5.	T 66 - Recommended Fertiliser
6.	T 66 - 150 % Recommended Fertiliser
7.	KE1 - 50 % Recommended Fertiliser
8.	KE1 - 26 Recommended Fertiliser
9.	KE1 - 150% Recommended Fertiliser

C. Data Collection

Data used for this study can be categorized in the following two types: Experimental data, Earth Observation Data and Field Survey Data.

D. Experimental data collection

Previous research established that the maximum NDVI for flue cured tobacco is attained between 9 and 12 weeks after planting [23] Radiometric measurements were made on 5 m x 5 m square sampling plots, using a hand held multispectral radiometer (Cropsan MSR5-5, 450 – 1720 nm), with the FOV centering over rows. Each sampling plot measured consisted 3 rows; each with 32 plants spaced 56 cm. The interrow distance was 1.2 m. Normalized Difference Vegetation Indices (NDVI_{MSR5}) was calculated from the spectral bands obtained in the Channel 3 and 4 of the MSR5 which correspond to the Red (630 - 690 nm) and Near Infra Red (760 - 900 nm) respectively using the following formula:

$$NDVI = (NIR - RED) / (NIR + RED)$$

The MRS 5 was positioned facing vertically downward at 1 m above crop canopies, and measurements were taken around solar noon to minimize the effect of diurnal changes in solar zenith angle. In total, 10 measurements were taken per sampling area and reflectance measurements were then be averaged for each sampling plot to estimate a single reflectance value. Mature leaves were harvested from one row, cured and mass determined at untying to determined crop yield before handle losses during crop grading.

Three dimensional positions; latitude, longitude and altitude for the whole experimental area and for each treatment plot will be taken using a Garmin Personal

Navigator (GPS V) to enable repeated sampling at the same location. Yield data collected from the plots was regressed with maximum NDVI_{MSR5}.

E. Field Survey Data

In order to correlate the reflectance calculated from MODIS data with that calculated from the MSR5 data, a 100 Ha commercial tobacco, established on 4 planting time blocks of September (26 ha), October (22 ha), November (30 ha) and December (22 ha) at Kutsaga Research Station in Zimbabwe, near the capital city of Harare was used. The land blocks were sufficiently large to allow for data collection from MODIS which has a spatial resolution of 250 m.

From each of the four blocks, 100 plants per block were systematically selected and, reflectance measurements were taken at 7 day intervals from the time of planting to 12 weeks after planting using the MSR5. A Personal Global Positioning Satellite Receiver (Garmin GPS V) was used to mark tobacco plants so as to allow repeatability. At almost the same period, MODIS data for the four fields were downloaded and NDVI's extracted.

F. Earth Observation Data

Thirty eight (38) fields of at least 5 ha were selected the tobacco growing regions of Goromonzi, Seke, Marondera and Beatrice and Banket farming areas of Zimbabwe. This was above the n = 30 threshold, recommended by Gomez and Gomez [26] as the minimum required sample size for the statistical data to approximate normal. Only tobacco fields of at least 5 ha were selected so as to avoid the problems associated with mixed pixels.

The project area lies between 29.6812 S and 32.2783S latitude and between -18.734 E and -7.65 E longitudes. After the centers of the fields were marked using a personal Global Positioning Satellite Receiver (Garmin GPS V), growers' contact details were taken for later communication on crop status and yields and for ground truthing purposes. Satellite images were freely downloaded from the USGS Glovis website: www.earthexplorer.usgs.gov between the 2012-2013 and 2013-2014 tobacco seasons. HDF Modis 16 day NDVI data products were selected because of their high data return rates.

G. Data Analysis

The simple linear, quadratic, and linear regressions were done following the procedure outlined by Gomez and Gomez [25] to develop relationships between experimental tobacco yield and NDVI_{MSR5}.

$$1. Y = a NDVI_{MSR5}^m + b NDVI_{MSR5}^{m-1} + \dots + g NDVI_{MSR5}^{m-m}$$

Where Y = tobacco yield

NDVI_{MSR5} = Cropsan derived NDVI

a, b, c, m and g are constants

From the field data regression analysis was also performed to establish the relationship between NDVI_{MSR5} and NDVI_{MOD}

$$2. NDVI_{MSR5} = k NDVI_{MOD} + e$$

Where NDVI_{MSR5} and NDVI_{MOD} are as defined above k and e are constant

3. Substituting 1 by 2:

$$Y = a (k \text{NDVI}_{\text{MOD}} + e)^m + b (k \text{NDVI}_{\text{MOD}} + e)^{m-1} + \dots + g (k \text{NDVI}_{\text{MOD}} + e)^{m-m}$$

Where Y = Tobacco yield estimate

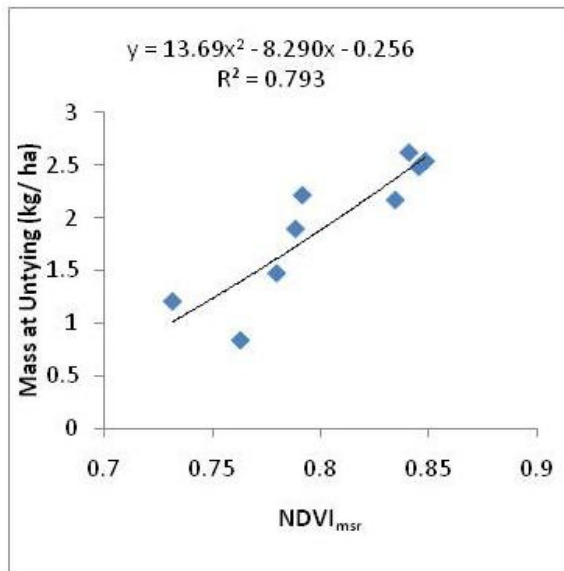
All other constants as defined above

T- tests calculations were done to compare the predicted and the actual yields from the sampled fields, graphs were plotted using Excel 2007.

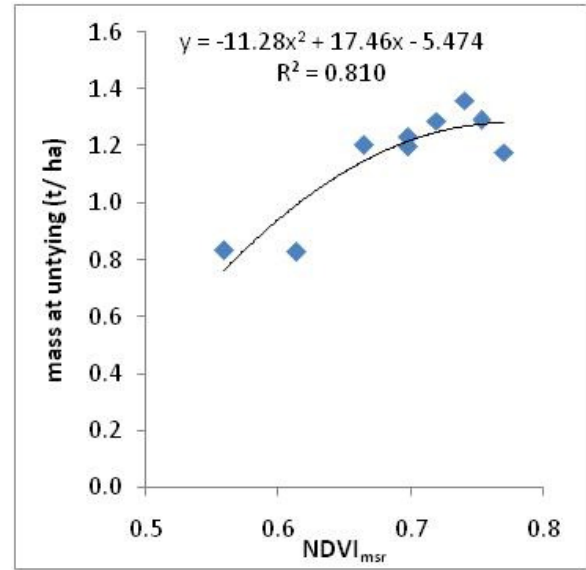
III. RESULTS

3.1 Canopy reflectance and yield relationship

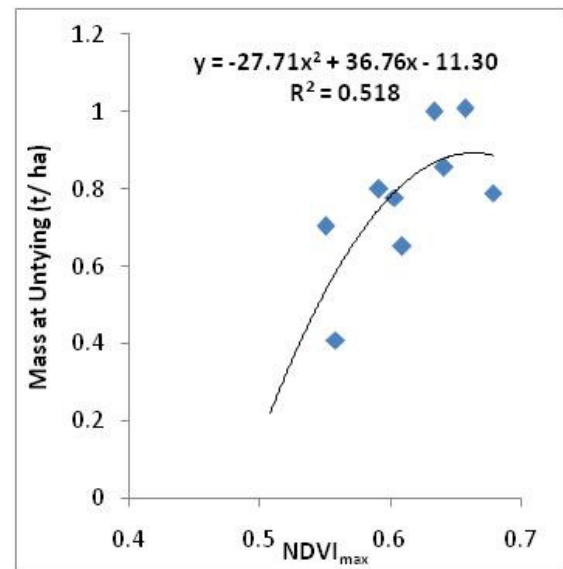
The best fitting models for the flue cured tobacco yield expressed as mass at untying, versus maximum canopy reflectance (NDVI) was quadratic. This was true for all planting times and for the pooled results. The coefficients of determination between maximum NDVI and mass at untying ranged between $R^2 = 0.787$ in October and 0.81 in September (Figure 1). The December value of $R^2 = 0.51$ was the lowest.



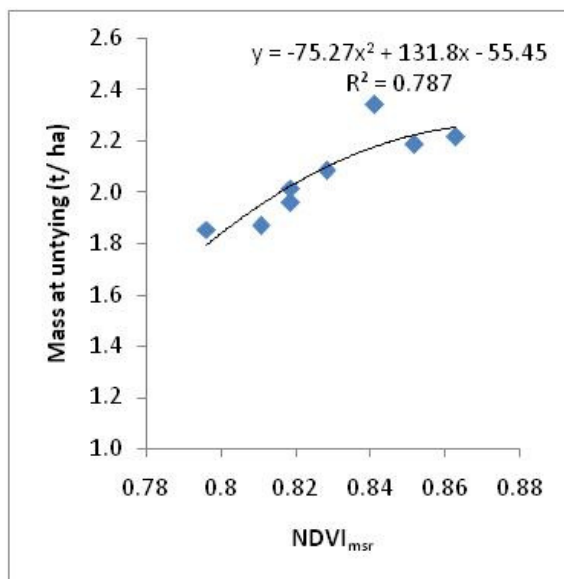
(a)



(c)



(d)



(b)

Fig.1. The comparison of the relationship between (a.) the September (b) October (c) November and (d) December planted flue cure tobacco yield and seasonal maximum $\text{NDVI}_{\text{MSR5}}$.

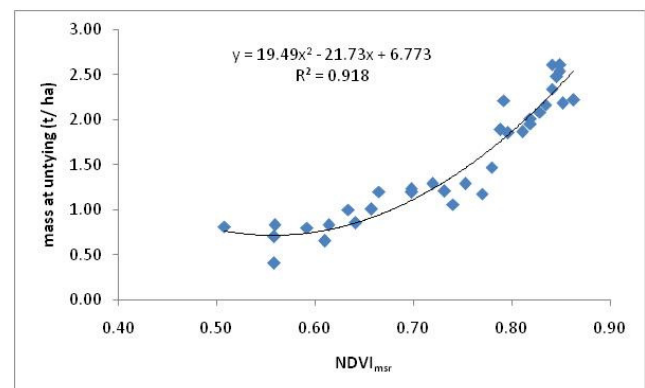


Fig.2. The relationship between the pooled flue-cured tobacco yield (mass at untying) and seasonal maximum $\text{NDVI}_{\text{MSR5}}$

As in figure 2, the pooled results showed the strongest positive relationship ($R^2 = 0.918$) which can be expressed as

Equation 1:

$$y = 19.49x^2 - 21.73x + 6.773$$

$$R^2 = 0.918$$

Where

$Y = \text{Tobacco yield (t/ha)}$

$X = NDVI_{MSR5}$

Therefore:

$$\text{Yield} = 19.49 (NDVI_{MSR5})^2 - 21.73 (NDVI_{MSR5}) + 6.773$$

3.2 The relationship between NDVIMSR5 and NDVI mod

In all lands both the $NDVI_{MSR5}$ and $NDVI_{MOD}$ values increased with crop age. At any stage $NDVI_{MSR5}$ was greater than $NDVI_{MOD}$. $NDVI_{MOD}$ reached a maximum of 0.6, as compared to a maximum of 0.86 for $NDVI_{MSR5}$. The overall mean $NDVI_{MOD}$ (0.42 ± 0.1), was less than $NDVI_{MSR5}$ (0.58 ± 0.25). The $NDVI_{MSR5} : NDVI_{MOD}$ ratio ranged from 1.00 to 2.13 and the mean ratio for the whole period was 1.37 ± 0.4 .

In all the planting time treatments (September, October, November, and December) there was a positive relationship between $NDVI_{MOD}$ and $NDVI_{MSR5}$. The coefficients of determination for $NDVI_{MOD}$ and $NDVI_{MSR5}$ in the September and the October planted crops were 0.876, 0.88 respectively, as compared to 0.866 in the November planted crop. In the December planted, the $NDVI_{MOD}$ and $NDVI_{MSR5}$ relationship had a coefficient of determination (R^2) of 0.818.

When the data from all the lands was pooled (Figure 3), the overall $NDVI_{MOD}$ and $NDVI_{MSR5}$ relationship was linear and positive ($R^2 = 0.73$) as in Equation 2.

Equation 2:

$$Y = 1.540x - 0.054$$

$$R^2 = 0.730$$

Where

$$Y = NDVI_{MSR5}$$

$$X = NDVI_{mod}$$

Therefore

$$\bullet NDVI_{MSR5} = 1.54 (NDVI_{MOD}) - 0.054$$

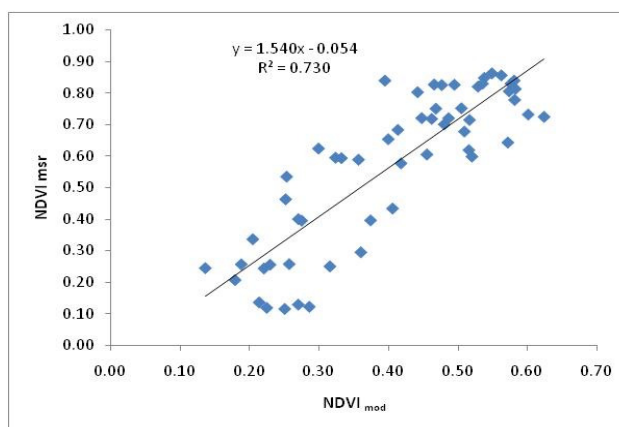


Fig.3. The relationship between pooled $NDVI_{MSR5}$ and $NDVI_{MOD}$

3.3 Model development

Substituting (1) by (2)

Equation 3

$$\text{Yield} = 19.49 * (1.54 NDVI_{MOD} - 0.054)^2 - 21.73 * (1.54 NDVI_{MOD} - 0.054) + 6.773$$

Simplified to

$$Y = 48.28 * NDVI_{MOD}^2 - 37.51 * NDVI_{MOD} + 8.003$$

3.4 Model testing

The model for estimating tobacco using upscaled $NDVI_{MOD}$ (Equation 3), tested using upscaled $NDVI_{MOD}$ data extracted from the 38 sampled fields, produced results as shown (table 2).

Table 2: The $NDVI_{max}$, crop area, predicted and actual yield for the sampled fields

Planting time	Sample	$NDVI_{MOD}$	Upscaled $NDVI_{MOD}$	Area	Yield Estimate	Actual Yield/Ha
September		0.65	0.9691	23	4.01858	4.1
		0.66	0.98484	20	4.27597	4.2
		0.64	0.95336	10	3.77086	3.7
		0.67	1.00058	7	4.54301	4.6
		0.67	1.00058	21	4.54301	4.8
		0.68	1.01632	17	4.81971	4.7
		0.64	0.95336	30	3.77086	4.1
		0.62	0.92188	25	3.30437	3.4
		0.64	0.95336	40	3.77086	3.9
		0.6	0.8904	46	2.87652	3.6
October		0.64	0.95336	30	3.77086	4.2
		0.6	0.8904	25	2.87652	3.4
		0.6	0.8904	41	2.87652	3.3
		0.65	0.9691	40	4.01858	3.9
	0.65	0.9691	46	4.01858	3.6	

		0.64	0.95336	30	3.77086	3.7
		0.62	0.92188	20		
		0.6	0.8904	16		
		0.6	0.8904	23	2.87652	3.6
		0.53	0.78022	41	1.68323	3.3
		0.56	0.82744	30	2.13669	3.7
		0.54	0.79596	15	1.82472	2.4
		0.54	0.79596	30	1.82472	2.2
		0.51	0.74874	8	1.4292	2.6
		0.5	0.733	4	1.31667	2.6
		0.52	0.76448	8.5	1.55138	2.2
		0.52	0.76448	10	1.55138	2.5
		0.5	0.733	12	1.31667	2.5
		0.54	0.79596		1.82472	2.8
		0.57	0.84318	32	2.30716	2.9
November		0.58	0.85892		2.48729	2.4
		0.59	0.87466	6	2.67708	2
		0.59	0.87466	7	2.67708	2.3
		0.58	0.85892	4.8	2.48729	1.8
		0.47	0.68263	6	1.02148	1.5
		0.5	0.72723	5	1.27783	1.5
		0.51	0.74349	5	1.39062	1.4
December		0.49	0.72395	5	1.25634	1.5
				mean	2.72066	3.080556
				sd	1.144042	0.978868
				n	38	38

The average cropped area of the sampled fields was 20.5 ± 13.33 . From these, the average maximum extracted $NDVI_{MOD}$ was 0.584 ± 0.06 . The results of the upscaled $NDVI_{MOD}$, the predicted yield and actual yields collected from the growers are shown in table 2 and the comparison of the predicted and the actual is graphically shown (Figure 4). Tobacco yield from the project area was calculated by just multiplying the estimated yield per hectare by the area (equation3)

Equation 3:

$$Y_{tot} = A (48.28 * av NDVI_{MOD}^2 - 37.51 * av NDVI_{MOD} + 8.003)$$

Where

Y_{tot} is the total yield from a cropped area of A hectares, $av NDVI_{MOD}$ is the average maximum MODIS derived NDVI from the sampled fields.

Model was validated using student T- test, comparing the yield from the farm owner and those estimated by the model. A t-test for the comparison of the predicted (2.72066 t/ ha; n = 38) and actual total yields (3.080556 tons; n= 38) showed that these were statistically similar (p > 0.05). The calculated p - value for (0.00296) is less than the tabulated p value (0.1096). Therefore the null hypothesized cannot be rejected and can be conclude that there is no significant difference between actual predicted yield levels. Therefore the model developed for estimate flue cured tobacco yield by using upscaled MODIS derived NDVI values is valid within 95% significant level.

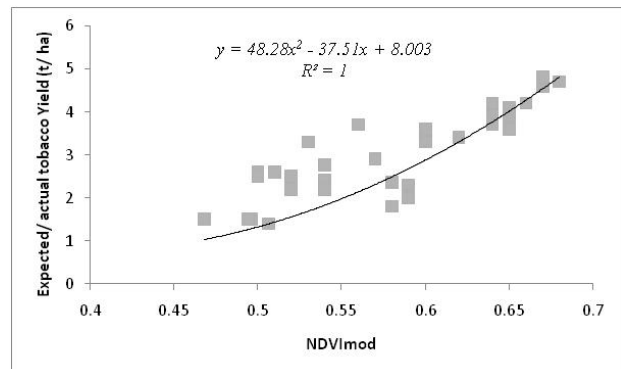


Fig.4. The comparison of the predicted (quadratic curve) and actual (squares) yield of flue cured tobacco.

IV. DISCUSSIONS

The coefficients of determination among the September, October and the November tobacco yield and $NDVI_{MSR5}$ were comparable and had a range of 2.3%. Generally, the first two months of the tobacco season are fairly dry with low weed pressure and, the high coefficients of determination during this period could be due to absence of interference by weeds. The increase wet conditions in late November to December, which promote weed growth, could result in spectral confusion, thus lowering the coefficient of determination in the Yield - $NDVI_{MSR5}$ relationship of the December planted crop.

The pooled tobacco yield - $NDVI_{MSR5}$ ($R^2 = 0.918$) correlations were comparable with levels that were established by Nuarsa et al [26] when relating rice yield to $NDVI_{MOD}$. Similarly, high coefficients of determination were obtained between the average NDVI and rice age and the relationship was best described by a quadratic equation, with R^2 values ranging from 0.916 to 0.973. When the similar regression technique approaches were applied in relating canopy reflectance of wheat [27, 28], maize [29; 30; 31], grapes [32] and sugarcane [33; 34] comparable R^2 values were established.

The observed increase in NDVI with crop is indicative of the increase in the canopy chlorophyll content as the crop grows [35]. Fasheun and Balogun [36] suggested that the NDVI was related and sensitive to the biochemical properties of leaf and phenological stage of crop respectively. Chlorophyll is the most important part of plants in general for photosynthetic activity, which produces carbohydrates, and has a significant effect on the yield at harvest.

The lower values $NDVI_{MSR5}$, as compared to $NDVI_{MOD}$ could be result of atmospheric interference. The strength of the coefficient of determination between ground and satellite derived reflectance values in this research across all the planting time blocks (0.82 – 0.89) is comparable with the findings ($r^2 = 0.84 - 0.89$) of Wittamperuma [37]. 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 interaction influencing ground based sensors [2]. 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 real time [38; 39] The technique, thus, allows for more accurate comparisons of crop responses observed from two different platforms to be compared and consistent conclusions be derived [10].

A single upscaling model for the $NDVI_{MSR5} - NDVI_{MOD}$ data was finally used in the Yield -NDVI model because of the narrow range among the coefficients of determination obtained from the different land blocks that were used in the experiment. Both the number of data points used for the derivation of the pooled upscaling factor from the whole field survey area and the number of the fields used in the validation of the developed model ($n = 38$) were above the ($n = 30$) threshold, recommended by Gomez and Gomez [25] as the minimum required sample size for the statistical data to approximate normal.

The maximum $NDVI_{MOD}$ (0.6) was lower than the corresponding value for $NDVI_{MSR5}$ at peak crop canopy stage. Generally, the satellite derived NDVI limitations arise from spatial and temporal resolution differences as affected by sensors capabilities and environmental factors [40]. Common sources of error in satellite derived NDVI are mixed pixels, and these are pixels that contains reflective data of two or more heterogeneous surfaces that cannot be distinguished by the sensor [18]. The exhibited uncharacteristically low NDVI in the mixed pixel can be misleading [41].

Greater deviations of the actual from the expected were observed in the November and December than the September and the October planted crops. Generally, the November and December plantings are mostly common in the smallholder sector and, in these areas, crop records are less accurate than that of the commercial large scale tobacco growers [42], who, mainly establish their tobacco crops in September and October.

V. CONCLUSIONS

The yield $NDVI_{MSR5}$ relationship for the yield in the September, October and the November planted crop were strong enough for the results for the pooled. Although the December planted crop had a weak positive relationship, the pooled coefficient of determination ($R^2 = 0.92$) made the model potentially useful. The upscaling factor for the multispectral radiometer derived model to the MODIS derived was developed (Equation 2), and this, in turn was used to upscale the MODIS derived NDVI, which in turn was used to develop the tobacco yield estimation model (Equation 3). The predicted flue cured tobacco yield (2.72 t/ha) was 88.32 % of the actual yield (3.08 t/ha) from the project area and a performed t-test showed that the two were statistically similar ($p > 0.05$). The quadratic function gives a good relationship between NDVI and flu cured tobacco yield. This model can be used to estimate yield of particular tobacco field using NDVI value from satellite images. It is recommended that the model undergoes further test and recalibration before the tobacco sector fully relies on it for crop estimation.

ACKNOWLEDGMENT

The authors are grateful to the Tobacco Research Board/Kutsaga Research Station for funding this series of experiments. The authors declare that there is no conflict of interests. The Tobacco Research Board is a research institution that strives to publish all the research work that is carried out and not for financial gain.

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