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Short communication: A New Approach To Tobacco Yields Estimation In Zimbabwe And The Recommended Further Work

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Abstract

Farmers need obtain early estimates of final crop yield. The unavailability of a comprehensive method for estimating crop yield leads to contradicting estimates, subjective national statistics and general planning inefficiency by stakeholders. It is hypothesised that canopy spectral refelectance can be used to assess crop responses to management factors and that spectral indices can be used to estimate crop yield. In this study, experiments were conducted at Kutsaga Research Station in Zimbabwe using a hand-held multispectral radiometer, to select a suitable index for assessing varietal, planting date and fertiliser management influence on tobacco canopy refelectance and to establish the relationship between canopy reflectance and inseason drymass and final crop yield. The selected spectral index (NDVI), was used in identifying tobacco in the field and to estimate crop area using satellite remote sensing. The relationship between reflectance measurements by hand-held multispectral radiometer and those from satellite were used in up-scaling the hand-held derived yield estimation models for application on a large scale on the sampled tobacco fields within a radius of 150 km from Harare. The simple ratio index (SRI) had a stronger relationship with biophysical parameters like above-ground dry mass, plant population and plant height than NDVI, the latter was selected for use in later experiments because of its stronger relationship with Total N. Planting dates, varieties, and fertilizer levels could be distinguished using spectral data between 9-12 weeks after planting, thus demonstrating this as the optimum stage for collecting spectral data for tobacco yield estimation. The best fitting curves, for all the varieties, planting dates and fertiliser management levels for the yield-NDVI regressions, were quadratic. Tobacco yield could be estimated through operational crop area estimation using NDVI, followed by use of long-term yield areal models to estimate the final yield, and through use of direct yield-NDVI models and then multiplying the result by known crop area. The new approach could be applied to crops such as leaf vegetables where the harvestable part is the leaf. It is recommended that similar work be done for crops like maize, wheat and sorghum where the leaf, detected by remote sensing, contributes to final yield, but is not the harvestable part.

Key Words: crop yield estimates multispectral radiometer NDVI spectral separability yield-NDVI regression models

1. Introduction

Crop forecasting is the art of estimating crop production and yields (tonnes/ha) and production before the harvest, typically months in advance. An accurate crop forecast helps to stabilise prices on the market and provides useful information for both suppliers and buyers of the crop (Jayne *et al.,* 2010). Crop pricing depends on the interplay between supply and demand of the crop. Buyers allocate money for buying the crop according to the crop volume expected on the market. The expected volume is essentially the quantity that is predicted by crop forecasters. If the predicted crop volume is less than the actual, a general shortage on the market will push crop prices up, while the reverse occurs for a higher crop volume than the estimated. Errors in crop estimation normally results in price distortions and general planning inefficiencies (Jayne *et al*., 2010).

A traditional approach to yield estimation involves two stages. The first stage involves the estimation of area under crop while the second stage involves the forecasting of yield per unit area. The product of the two results is multiplied to give a yield estimate. In the estimation of area under the crop, forecasters use subjective methods, based upon the area judgement of individuals involved in carrying out the crop surveys. They also use visual assessments of crop status to estimate the expected yield/ unit area. These subjective results are usually extrapolated to estimate the national crop volumes. A more subjective, but tedious approach is the collection of crop area estimates from ward level, to district and provincial levels before final compilation of national crop area statistics, followed by use of the long-term average yield to get the expected volume.

The limitations of these methods are in the lack of emphasis on random selection of the samples. Also, some inaccessible areas can easily be left out leading to underestimations. The Department of Agriculture and Extension (AGRITEX) in the Ministry of Agriculture, Mechanisation and Irrigation Development has the mandate to carry out tobacco crop forecasts but is generally, poorly equipped in terms of transport. This could compromise the representativeness of the selected samples. The visual assessors of the selected samples may be inadequately experienced to relate the qualitative results from their observations to the actual yields. A large number of assessors often with different levels of experience with the crop are involved in forecasting, making it difficult to standardise the approach. The hyperinflationary period of 2008-2009 led to a brain-drain in Government, leaving a large number of new and inexperienced officers. Routinely, there is more emphasis on crop area alone, and less detail on varieties, planting date, fertiliser management levels, plant population, and the farmers' management capabilities, which all combined, have an effect on the final yield. The need for a more objective approach thus becomes critical.

There are many challenges in the estimation of crop volume by conventional methods. The area planted for harvest of a given crop may change throughout the growing season due to abandonment, weather damage, or unusual economic conditions leading to the neglect of the crop (Craig and Atkinson, 2013). It is usually necessary to make estimates several times throughout the crop season even for a given crop and there could be a need to measure prospective or intended plantings before they actually take place (Vogel, 1985).

Remote sensing can provide information on near real-time and actual status of agricultural crops (Jiao *et al.*, 2006) and measurements can be updated several times during the season (Marshal, 2011). Vegetation indices calculated from remote sensing can be used in estimating biophysical values regularly during the growing season, and can be used in calibrating crop growth models based on these estimates (Bouman, 1991; Clevers *et al.*, 1994) or relating remotely sensed data to above-ground biomass (Price, 1993; Qi *et al.*, 1995; Toulios *et al.*, 1998; **Serrano *et al.*, 2000**).

The application of the regression approaches is based on the fact that the reflectance in the red spectral region decreases while that in the near-infrared (NIR) region increases when the vegetation density increases (Jackson and Huete, 1991). A large number of measurements is, however, needed for a regression model for biomass estimation to be derived and, the relationship is vegetation-type dependent (Toulios *et al.*, 1998) while noise from such factors as soil substrate effect, atmospheric effect, and bidirectional properties of the vegetation can pose a challenge (Weigand *et al.*, 1991).

The national crop yield has to be correctly estimated by reliable and accurate methods and, in this regard, remote sensing becomes an important tool (Bauer, 1975). In this study the objectives were to: (1) identify a suitable spectral index for use in assessing the response of tobacco varieties’ response to fertiliser management levels; (2) assess the spectral separability of tobacco established on different planting dates, different varieties and with different fertilizer management levels; (3) derive the relationship between tobacco canopy reflectance, leaf chemical composition, leaf dry mass and cured leaf yield; (4) determine the relationship among hand-held multispectral radiometer measurements with moderate and high resolution satellite spectral reflectance; (5) estimate tobacco crop area and yield using crop canopy spectral reflectance and (6) develop a model for estimating tobacco yield using optical satellite data.

The general basis of the study was that a reliable model for estimating yield for any crop depends on the correct selection of a suitable spectral index for assessing the general crop status in response to management in the field. The most suitable index could then be used to separate crop varieties, different planting dates and fertiliser management levels. Through the use of a suitable index the most suitable temporal windows for spectral data collection are then identified. Using the inseason spectral indices, the volume of the area under crop and the yield/ unit area would be estimated. Two approaches can then be applied to estimate the final crop yield: (1) the final yield can be estimated through fitting the remotely-sensed crop area into the long-term yield-area model or (2) relate the canopy average maximum satellite derived NDVI to the final yield, and multiply the result by either remotely sensed or crop survey crop area estimate to get the final yield.

2. Methods

The study focussed on three tobacco varieties, four planting times and three fertiliser levels. The four varieties used in the research were Kutsaga root-knot resistant 26 (K RK 26), Kutsaga root-knot resistant 66 (T 66) and Kutsaga white mould (*Erisiphe cichoracerum var nicotiana*) resistant 1 (K E 1). K RK 26 and T 66 are currently the most popular varieties among growers, with an adoption rate of 63.5 % and 5.2 % respectively (TRB, 2012). T 66 is still at the testing stage and was envisaged to become popular because of its higher yielding potential of upto 4.5 t/ ha compared to 3.5 – 4 t/ ha for K RK 26 (TRB, 2012). K E1 is an old variety, rarely grown commercially, which at Kutsaga, is used as a standard in all tobacco variety trials.

Fertiliser is the main determinant of yield and, up to 1999, the large-scale commercial farming subsector accounted for most of the fertilizer consumption and fertiliser application rates in the large-scale commercial farming subsector were comparable with those in developed countries (Mashingaidze, 2004). Generally, the resource poor small scale commercial and communal tobacco growers use low fertiliser rates, which in this experiment were assumed to be 0 – 50 % of the levels recommended by the results of soil analysis (Mashavave, 2003). The resettled and commercial tobacco growers generally strive to adhere to the recommended rates and they collect soil samples from their fields for testing in soil testing laboratories and some among this group may even apply higher rates than recommended, according to their yield expectations and the general history of the tobacco lands (Mashingaidze, 2004).

Four planting times from September to December represent the normal, conventional planting times for tobacco (TRB, 2010). September and October are for the irrigated and the supplementary irrigated tobacco crop respectively, while November and December planting times are for the rainfed crop. Planting time generally affects yield in that the earlier the crop is planted the higher the yield and quality and the reverse is generally true (Fankow-Lindber, 1993; Kgasago, 2006). However, the earlier planted summer crop is subjected to periods of stress, which stimulate the development of a dense and deep root system. The crop becomes vigorous when the first rains are received during mid October and the dense root system will promote nicotine manufacture as well as fertiliser and water uptake (Werner et al., 2010). The November and the December dryland crops, on the other hand, are generally subjected to high incidences of pests and diseases, and the heavier rains during this period increase and promote high weed growth which compete with tobacco (TRB, 2010). Consequently the quality and yield of tobacco is lower than that for September and October crops..

The study area was Kutsaga Research Station for the experimental work because of the availability of facilities such as the experimental fields, appropriately demarcated for tobacco research, new and old tobacco varieties, the analytical chemistry laboratories for soil and plant tissue analysis and availability of a purpose-purchased hand-held multispectral radiometer.

The survey project area lies between 29.6812 S and 32.2783S latitude and between -18.734 E and -7.65 E longitudes, at an altitude of 1300 m to1500 m (TRB, 2010).

The five band CROPSCAN, Inc. Multispectral radiometer (MRS 5) system (Cropscan, 2013) was selected as the instrument to use in collecting radiometric data from the experimental tobacco canopy. The radiometric data was to be used for calculating refelectance ratios for assessing flue-cured tobacco response to fertiliser and planting date differences and all these would be related to the final crop yield. The MSR 5 has been used for similar work (Belford *et al.*, 1993; Bronson *et al.*, 2003) and is compatible with the Landsat 7 TM spectral bands (Cropscan, 2013), a feature which would enable later up-scaling and modelling.

As summarised by NASSA (2013), the Moderate-resolution Imaging Spectro-radiometer (MODIS) is a key instrument aboard the Terra and Aqua, Earth Observation Satellites that are timed so that it passes from north to south and south to north across the equator in the morning and in the afternoon, respectively. Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands. MODIS was chosen for this research because of its spatial resolution of 250 m by 250 m which was considered detailed enough for the quantification of variability within flue-cured tobacco fields. For modelling purposes, the extent of the study area was suitable enough to cover all the four farming sectors, commercial, small scale commercial, resettled farmers and the communal farmers that participate in tobacco production.

Regression analysis was mainly relied on for this study. Similar approaches were applied in relating canopy reflectance of wheat (Huang *et al*., 2012, Huang *et al*., 2013), maize (Prasad *et al*., 2005; Baez-Gonzalez *et al*., 2005; Sibley *et al*. 2014), grapes (Liu, 2013) and sugarcane (Lumsden *et al*., 1998; Lofton *et al*. 2012) to yield. In this study a similar approach was employed. Historical statistical information on the relationship between land area and yield were later incorporated, and the weekly crop assessment and inventory reports that are currently issued by the Ministry of Agriculture, Mechanisation and Irrigation Development (Crop Production Branch) and the Tobacco Industry and Marketing Board were used as standards.

3. Results

3.1 From a suitable reflectance index to above-ground biomass estimation

In this study the spectral indices for assessing tobacco in the field were identified (Chapter 3). Using the multispectral radiometer, all the five channels of the radiometer, NDVI and the SRI had a strong relationship with fertiliser rate, with both NDVI and SRI for the T 66 variety being greater than those for K RK26 and KE1. Although the SRI had a stronger relationship with the biophysical parameters of above-ground dry mass, plant count/ unit area and plant height than NDVI, the NDVI was selected for later activities because of a stronger relationship the index showed with total N than the SRI. The minimum threshold SRI and NDVI values for optimum growth (100% fertiliser) were 6.1 and 0.72 respectively, meaning that any crop that showed values less than these would not be optimally growing and would also produce less than optimum yields.

The different planting dates, crop varieties and fertilizer management levels could be spectrally separated. The assessment of the influence of these factors on crop yield can, therefore, be done separately. The September, October, and November-planted crops showed significant variety and fertilizer treatment differences from 10 weeks after planting, with the varieties T 66 and K RK26 showing similar reflectance values that were greater than those for K E1. The 100% and the 150% fertilizer treatments were similar and both had greater reflectance values than the 50% fertilizer treatments. All of the fertilizer and variety treatments in the December-planted crops had similar reflectance characteristics, which were lower than for the September and October plantings.

At 9-12 weeks after planting which were the optimal times for separating the varieties, planting dates and fertiliser effect coincided with the 3rd to 4th week of November, up to the 4 th week of February. The 3rd to 4th week of November was optimal for separating the irrigated September-October-planted crop from the rainfed November and December-planted crops, while the later period was important for separating the December from the November-planted crop. One can, therefore, focus on collecting satellite imagery for the two temporal windows, and calculate the reflectance values for use in estimating the whole crop area, leading to savings in time and costs reduction in data collection. There is, however, a possibility for error in separating the November from December-planted crops due to spectral confusion arising from interference of adjacent vegetation and other field crops like cotton, soybeans and maize, which could also be dominant during this later time of the growing season. However, using a combination of NDVI temporal profiles and instantaneous NDVI values as suggested by Rembold et al (2013), this problem of spectral confusion can easily be overcome.

The relationship between tobacco canopy reflectance, leaf dry mass and cured leaf yield was investigated and the results largely confirmed the hypothesis that crop canopy spectral reflectance characteristics are directly related to biomass and final yield; and that the strength of the relationship between in-season dry mass and yields expressed as mass at untying with NDVI was not affected by tobacco variety, planting date, and fertiliser application rate. The best fitting curves for the yield-NDVI regressions were quadratic. The reflectance values for the September and the October-planted crops were statistically similar, and were greater than those for the November and the December-planted crops. The reflectance value for the November-planted crops was greater than that for the December-planted crop. At 9–12 weeks after planting, with the highest dry mass-NDVI coefficient of determination was the optimum stage for collecting spectral data for tobacco yield estimation was the weeks after planting, thus confirming the earlier findings.

NDVI can be deployed to assess crop status and the October-November crops can be combined, while the November and December-planted crops can also be combined and estimated separately. Since the average Yield-NDVI gradients for the studied varieties with NDVI range of 0.65 to 0.75 were statistically similar, a pooled yield estimation model for the varieties can be applied without compromising the accuracy of the forecast. Similarly the average Yield-NDVI gradients for the fertiliser levels between NDVI ranges of 0.65 to 0.75 were statistically similar; hence a pooled yield estimation model for the tobacco under the different fertiliser levels could be similarly applied.

3.2 A new approach to area and yield forecast

Using a suitable index, NDVI (Chapter 3), it was established that although the varieties and fertiliser management levels could be spectrally separated the two agronomic factors had no influence on the Yield-NDVI relationship. In crop assessments for yield estimation these can be disregarded. It was established that planting date effect can be separated and, the levels of accuracy of the Yield-NDVI regression models for the September-October were comparable, but different from those for the November and the December-planted crops. The optimum times for collecting the imagery for such assessments were the 4th week of November to the 3rd week of March (Chapters 4 and 5).

The cloud free MODIS images covering the period September to end of March between 2010 and 2013 were downloaded and georeferenced, and NDVI from the sampled tobacco field was estimated (Chapter 6). The results of this study confirmed that, based on MODIS NDVI data, the third to fourth week of November and the third to fourth week of February are the optimal times for discriminating the irrigated from the non-irrigated tobacco crops. The crop areas for the three studied seasons were estimated and yield estimates calculated from the long-term yield- area regression model. The three-season average yield estimates were 98.8 % accurate (Chapter 6). The approach assumed that the yield-NDVI response was not affected by variety, fertiliser and planting date as established and the level of accuracy was in the ‘good’ category, as asserted by Parolo *et al.*, 2008.

3.3 The tobacco yield-NDVI model

An attempt to establish a direct yield NDVI model was made through up-scaling the multispectral radiometer based yield-NDVI models using MODIS imagery. Using a field experiment, a field survey and satellite observations, radiometric measurements from the experiment were used to relate $NDVI_{msr}$ to tobacco yield and, from a 100 ha tobacco field, ground and satellite-based data. The relationships were developed. The tobacco yield- $NDVI_{mod}$ relationship was finally developed using NDVI’s extracted from the freely downloaded images from 38 randomly selected tobacco fields. The derived up-scaling factor for $NDVI_{msr}$ from $NDVI_{mod}$ was developed, used to develop the final tobacco yield estimation model. The predicted average flue-cured tobacco yield (2.721 tons/ ha) was 88% of the actual yield (3.081 t/ ha) from the project area and a performed t-test for comparison of means showed that the two were statistically similar ($p > 0.05$). The model could be adopted to complement current methods so that its precision can be refined.

3.4 A summary of the findings

In this study, NDVI was selected as the optimum vegetation index for monitoring tobacco growth as opposed to the SRI and the other channels of the radiometer, because of the strong relationship with leaf N.

Using NDVI, flue-cured tobacco varieties, fertiliser management levels and planting dates were separated at 9 – 12 weeks after planting. This period is the optimal time for conducting spectral data collections for crop area determination.

The relationships among NDVI, leaf dry mass and cured leaf yield were determined. A strong relationship between NDVI and flue-cured tobacco yield was established and the strength was independent of variety and fertiliser management level, indicating the need to pool the NDVI and yield from the different varieties and fertiliser levels. The pooled Yield NDVI regression had a strong coefficient of determination ($R^2 = 0.918$).

A sample of 203 tobacco field, representing at least 12 fields from each of the 16 growing districts, were used to develop an algorithm in estimating the total cropped area using MODIS imagery. The 250 m spatial resolution of MODIS imagery could have underestimated crop areas smaller than 6.25 ha, and to address this problem, individual areas for a subsample of 19 fields were estimated using both MODIS and Landsat TM. The results were then used to develop a logistic regression equation relating area estimates from the two satellite platforms. The resultant regression function was then applied to the MODIS-derived tobacco area estimates for both September-October tobacco crops and those for the November and December-planted crops. Due to the spectral confusion associated with the November-December-planted crop resulting from weeds and other crops, a longer MODIS time series (September to April) and a Maximum Entropy Method (Maxent) algorithm were used to map the November-December-planted crop. Using the crop area obtained, the yield was estimated through multiplying this by the long term average yield, with an estimated accuracy level of 98.8%.

From the spectral data collected from the same 100 ha commercial tobacco fields at Kutsaga using Cropscan multispectral radiometer and MODIS satellite, an up-scaling factor was developed relating the two remote sensing instruments. A model for estimating tobacco yield using optical satellite data was also subsequently developed.

This new approach to crop yield estimation can be applied to other crops where the leaf is the harvestable part. However, similar research, involving an experimental phase of developing the models, a calibration phase through use of field-level crop yields, and finally an operational application phase should the development of crop specific yield estimation models for key food security and economic crops.

4. Contribution of the study

4.1 Crop science and Agronomy

This study identified NDVI as the most suitable spectral index for assessing plant growth in response to fertiliser management. The index was highly correlated with such biophysical parameters as plant height and stem thickness as well as total nitrogen, which are also measures of crop status and quality in the field. A rapid assessment of optimum plant growth and an assessment of fertiliser needs can be done using spectral techniques, with information from remote sensing being used as base maps in variable rate applications of fertilizers. This could allow stakeholders, including farmers, to focus on affected areas of the field, district or province. Problems within fields or districts can be identified remotely and remedial measures can be taken before the crop is negatively affected.

The study also established a strong relationship between crop canopy reflectance to plant growth stage and density, thus providing a rapid and reliable method for assessing plant phenology and plant population in the field. NDVI increased with progression of vegetative growth up to 9 -12 weeks, where it plateaued before a decline. The highest The relationship of NDVI with tobacco leaf yield was found at between 9 -12 weeks after planting. From a standard NDVI seasonal profile, comparison of specific profiles for crops under study can be made to ascertain the management interventions required, thus providing a fast method for assessing fertiliser, crop maturity rate and planting date differences.

It was established that tobacco varieties and fertilizer management effect can be distinguished using spectral data after the attainment of peak canopy reflectance. This makes the findings applicable in plant breeding and variety trials.

The study also established temporal windows for collection of satellite imagery for use in yield estimation using remote sensing. Models were developed, which showed that the vigour of the crop canopy, observed in the spectral remote sensing data, is directly related to the yield of the given crop. The models are relatively simple to routinely adopt for practical use because the remote sensing data–yield relations derived were expressed in formulae, facilitating wider application.

The study established a rapid method of assessing cropped area and for crop yield estimation. Remote sensing technology is non destructive, with data obtained systematically and repeatedly over very large geographical areas rather than just single point observations, enabling the acquisition of information from sites and fields that are not easily inaccessible.

4.2 Remote sensing

The study has established a wider application of remote sensing technology in agronomy. In addition a fast, more reliable and accurate method developed can be effective from farm level, to district, provincial, national or even regional level crop yield estimation. The developed models formed a good basis for developing other crop specific models for national and regional food security assessment. These results provide a strong foundation for the use of vegetation indices to supplement, complement or even as alternatives to field-based methods for crop status monitoring and yield estimation purposes over large areas.

5. Future Research

The current study has highlighted a number of possible aspects for further research. First, there is a lack of observational studies on inventory and mapping of agricultural lands using remote sensing. Future studies could focus on mapping agricultural lands and determining the total arable land in the country. The proportion of the arable land under different cash and food crops can then be determined. The information would be useful for food security assessment and would generate more accurate national statistics for policy and planning purposes.

Assessments of changes in the use in agricultural land would be quick and enable detection of expansion of a particular crop into agro-ecological zones where it was previously not grown. Second, national soil categorization and mapping, are recommended research areas that would assist in identifying areas for potential expansion for production of crops of economic interest.

Third, the investigation of the applicability of other spectral indices in the discrimination of crops can improve the accuracy of crop monitoring and yield estimation for Zimbabwe and the region. These include the Blue Normalised Difference Vegetation Index (BNDVI) and Green Normalised Difference Vegetation Index (GNDVI) (Wang *et al*. (2007)), Nitrogen Reflectance Index (NRI) (Penuelas *et al*., 1994), Chlorophyll Index (CI) (Gitelson *et al*., 2001), Soil Adjusted Vegetation Index (SAVI) and Transformed Soil Adjusted Vegetation Index (TSAVI) (Ricky et al 1998).

Fourth, further study is required on the applicability of other choices of temporal *NDVI* integration, ranging from maximum *NDVI* value of the season, the average of the peak values (plateau) to the sum of the *NDVI* values of the total crop cycle. Instead of using a fixed value from instantaneous measurements, the integral could be computed between the start of the growing period and the beginning of the descending phase.

Fifth, research on the use of remote sensing for routine crop production management and crop condition assessment is recommended as part of the ultimate goal in crop yield estimation. Such studies should include use of remotely sensed images to identify nutrient deficiencies, diseases, water deficiency or surplus, weed infestations, insect damage, hail damage, wind damage, herbicide damage, and plant populations as well as estimation of agro meteorology parameters. The final yield estimate would then pool the effects of all these factors.

6. References

Bauer, M. E. (1975). The Role of Remote Sensing In Determining The Distribution and Yield of Crops. *Advances in Agronomy.* Volume 27, 1975, Pages 271–304

Bouman, B.A.M. (1991). *Linking X-band radar backscattering and optical reflectance with crop growth models.* Ph.D. study, Wageningen Agricultural University, Wageningen, The Netherlands.

Clevers, J. G. P. W., Buker, C., van Leeuwen, H. J. C. and Bouman, B. A. M. (1994). A frame work for monitoring crop growth by combining directional and spectral remote sensing information. *Remote Sensing of Environment* . 50 161-170.

Gitelson A. A, Merzlyak, M. N, Chivkunova, O. B. (2001). Optical properties and nondestructive estimation of anthocyanin content in plant leaves**.** *Photochemistry and Photobiology* **74** 38–45. 2001

Jackson, R. D and Huete, A. R. (1991). Interpreting Vegetation Indices. Preventive *Veterinary Medicine*, vol 11, pp 185 – 200. 1991.

Jayne, T. S. and Rashid, S. (2010). "*The Value of Accurate Crop Production Forecasts*," Food Security International Development Working Papers 97032, Michigan State University, Department of Agricultural, Food, and Resource Economics.

Jiao, X.; McNairn, H.; Yang, B.; Jiali S., and Zhiyuan P. Z. (2006) Operational crop acreage estimation at a national scale based on statistics and remote sensing. *ISPRS WG VIII/10 Workshop 2006, Remote Sensing Support to Crop Yield Forecast and Area Estimates*, Stresa, Italy.

Marshall, M. (2011) *A High Resolution Satellite Interpretation Technique for Crop Area Monitoring in Developing Countries*. Report to the Climate Hazards Group, University of California, Santa Barbara.

Peñuelas, J., Gamon, J. A., Fredeen, A. L., Merino, J. and Field, C. B. (1994). Reflectance Indices Associated with Physiological Changes in Nitrogen- and Water-Limited Sunflower leaves. *Remote Sensing of Environment* . 48:135-146.

Price, J. C. (1993). Estimating leaf area index from satellite data. *IEEE Trans. Geosci. Remote Sens*. 31 (3) 727-734.

Qi, J., Cabot, F., Moran, M. S. and Dedieu, G. (1995). Biophysical parameter estimations using multidirectional spectral measurements. *Remote Sensing of Environment*. 54 71-83.

Rembold, F., Atzberger C., Savin I., and Rojas O. (2013). Using low resolution satellite imagery for Yield prediction. and yield anomaly detection. *Remote Sensing*, vol. 5, no. 4, pp. 1704–1733. 1704-1733; doi:10.3390/rs5041704

Rick L. L. and Ripple, W. J. (1998). Comparisons among Vegetation Indices and Bandwise Regression in a Highly Disturbed, Heterogeneous Landscape: Mount St. Helens, Washington. *Remote Sensing of Environment* . 64:91–102 (1998)

Toulios, L., Toulios, M. and Zerva, G. (1998). Spectral data analysis for cotton growth monitoring. Proceedings of the World Cotton Research Conference - 2, Edited by F.M. Gillham, Athens, Greece, pp. 534-539.

Wang, F., Huang, J., Tang, Y., Wang, X. (2007). New vegetation index and its application in estimating leaf area index of rice. *Rice Science*, 2007, 14(3): 195-203

Wiegand, C.L., Richardson, A.J., Escobar, D. E. and Gerbermann, A.H. (1991). Vegetation indices in crop assessments. *Remote Sensing of Environment* . 35 105-119.

Serrano, L., Filella, I. Peñuelas, J. (2000). Remote sensing of biomass and yield of winter wheat under different nitrogen supplies. *Crop Science* 40:723-731 (2000). Crop Science Society of America

Vogel, F. A. (1985). Crop forecasting methodology current and future procedure in the US. *Proceedings of the 45th session of the International statistical institute, Amsterdam: 12.1 – 1 to 13.1 – 15*