

COMPARATIVE PERFORMANCE OF DIFFERENT REMOTE SENSING (RS) AND GEOGRAPHIC INFORMATION SYSTEM (GIS) TECHNIQUES OF WHEAT AREA AND PRODUCTION ESTIMATES

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ABSTRACT

The major wheat producing countries in the world are India, China, USA, France, Russia, Canada and Australia. Global demand for wheat is growing at 1 per cent per year. Crop growth and productivity are determined by a large number of factors such as genetic potential of crop cultivar, soil, weather and management variables, which vary significantly across time and space. Early prediction of crop yield is important for planning and taking various policy decisions. Many countries use the conventional techniques of data collection for crop monitoring and yield estimation based on ground – based visits and reports. These methods are subjective, costly and time consuming. Empirical models have been developed using weather data which is also associated with a number of problems. With the launching of satellites, satellite data are being used for crop monitoring and yield prediction. Most studies have revealed a strong correlation between remotely sensed NDVI and crop yield. GPS/sensor based on-the-go yield monitors are being used in the developed world for yield mapping. The diverse techniques and their utilities are presented in this paper. Liu et.al., (1999) estimated production of winter wheat in North China plain with 96% accuracy by using Landsat Thematic Mapper(TM) data and Advanced Very High Resolution Radiometer (AVHRR) time series data. Sehgal et.al. (2002) reported the development of a prototype Crop Growth Monitoring System (CGMS) for wheat using WTGROWS simulation model in GIS environment for generating daily crop growth maps and predicting district-wise grain yield. GIS techniques and Clustering analysis were used to carry out the crop division for yield estimation by remote sensing and a two-level division was obtained by Zhou et.al.(2003). Remote Sensing (RS) – Crop Simulation Model (CSM) approaches have been demonstrated through case studies on wheat in India at different spatial scales. CSM-RS linkage has a number of applications in regional crop forecasting, agro-ecological zonation, crop suitability and yield gap analysis (Dadhwal, 2004). Two AVHRR-based Vegetation Health (VH) based indices such as Vegetation Condition Index (VCI) and Temperature Condition Index (TCI) characterizing moisture and

thermal conditions respectively were tested as predictors of winter wheat in Kansas, USA by Salazar et.al.(2007). Winter wheat was more sensitive to moisture conditions and wheat yield could be estimated from the VCI index approximately four weeks prior to harvest time. Patil (2009) reported that a multiple regression model based on NDVI and LAI was better than simple regression models based on NDVI and LAI alone. The estimated acreage, productivity and production through RS were found to be deviating by +3.19 per cent, +10.76 per cent and +13.61 per cent respectively, with that of State Department of Agriculture. A critical analysis of these techniques helps in identification of the most accurate and useful ones. An effort has been made for comparative assessment of these techniques the details of which are discussed in the paper.

Keywords: Image analysis, RS, GIS, wheat, area and production estimation

INTRODUCTION

With world commodity markets becoming competitive, prior knowledge of likely production and its geographical distribution at various scales has become highly sought – after information. Generating objective estimates of planted area will allow near real – time production estimates, which can then be used in updating supply chain information at the regional, state and national levels. Crop acreage estimation and early prediction of crop yield is important for planning and taking policy decisions. In many countries, conventional techniques of data collection based on field visits and reports are used for crop inventory. These methods are subjective, very costly and time consuming. For example, the crop acreage estimates of principal agricultural crops in India are usually made through complete enumeration, while the production is estimated as a product of area under the crop and the average yield per unit area of the crop. The crop yield is estimated through General Crop Estimation Surveys (GCES) on the basis of crop cutting experiments conducted on a number of randomly selected fields in sampled villages of the district. However, the crop acreage records maintained by the village revenue officials is not reliable on most occasions. Hence the production estimates which are based on the crop acreage estimates are also not completely reliable. All the rural development plans which are based on such unreliable crop acreage and production estimates become unrealistic leading to faulty decisions and actions and subsequent uncertainties in agricultural sector. In order to improve the accuracy of estimates, empirical models were developed using weather data,

which are complex and associated with problems due to scant spatial distribution of weather stations. Advent of Remote sensing (RS) and Geographic Information System (GIS) techniques of great potential have opened up newer avenues of improving agricultural statistics system as they offer accelerated, repetitive spatial and temporal data acquisition possibilities.

RS AND GIS BASED WHEAT AREA ESTIMATION AND PRODUCTION FORECASTING IN MAJOR WHEAT PRODUCING COUNTRIES:

United States of America

Since the inception of civilian RS programme in the USA in the early 1960s, Large Area Crop Inventory Experiment (LACIE) was the first worldwide experiment to demonstrate the operational capability of RS technology for wheat acreage estimation and production forecasting (MacDonald and Hall, 1980). It featured use of Landsat MSS data for wheat acreage estimation and agro-meteorological models for production estimation. Since then, several attempts to use RS and GIS techniques in crop acreage estimation and production forecasting have been made in many other countries. McCarty (2006) developed a technique for estimating winter wheat acreage in Great Plains, USA. He used 30 – m Landsat image in a supervised classification of a MODIS dataset to create temporal endmembers for winter wheat. This endmembers was then used in ENVI's Mixture Tuned Match Filtering (MTMF) process to unmix MODIS imagery and estimated 2001 winter wheat acreage in Kingfisher county, Oklahoma, USA, with 93.3 per cent accuracy. Salazar et. al (2007) developed an algorithm for estimating winter wheat yield in Kansa, USA, using RS data based Vegetation Health (VH) indices such as Vegetation Condition index (VCI) and Temperature Condition Index (TCI). The weekly indices computed over a period of 23 years (1982-2004) from Advance Very High Resolution Radiometer data were correlated with the winter wheat yield. A strong correlation was observed between winter wheat yield and VCI. The principal Components Regression (PCR) method was used to construct a model to predict yield as a function of the VCI. The accuracy of prediction was more than 92 per cent.

India

In India, early studies using space borne data (Landsat MSS data) employed visual interpretation technique for wheat inventory in four districts

of Punjab (Munshi,1982). The visual interpretation techniques have not been used for large scale adoption. With the launching of IRS – 1A, studies were initiated under IRS – Utilization Programme in 1983 that used digital analysis of space borne RS data. The promising results from the first satellite based study on wheat acreage estimation in Karnal by Dadhwal and Parihar (1985) led to state level wheat acreage estimation using Landsat MSS data for Haryana and Punjab (Dadhwal, 1986) adopting a sample segment based approach of 10 m x 10 m segments and 10 per cent sampling fraction. Based on the encouraging results of this study a project called Large Area Crop Acreage (LACA) was initiated to which yield forecasting was later on included. This project was subsequently known as Crop Acreage and Production Estimation (CAPE) since 1988. The procedures developed under CAPE used single date high resolution RS data. Various limitations of CAPE project led to the development of a project called “Forecasting Agricultural Output Using Space, Agro - meteorology and Land – based Observations” (FASAL) for nationwide multi – crop forecasts. This project adopted an integrated approach using inputs from the three types of observations namely field survey, weather and space to make multiple, in-season forecasts of desired coverage, accuracy and timeliness. FASAL project utilizes multi-date WiFS data and weather based models for national level wheat acreage estimation. Use of coarse resolution and high repetitive WiFS data has been explored for national scale wheat inventory since 1995-96 season (Oza et al., 1996). The procedure uses a national level sampling frame and coarse sample segment grids (20x20 km or 15x15 km). Use of Arc/Info GIS in national level wheat estimation was made for making area sampling frame and storing segment-wise crop proportions. Due to shift in emphasis of planning from a macro to micro level, there is a strong need to estimate the production at small area levels such as tehsils, blocks and even villages. Sehgal, et.al., (2002) reported the development of a prototype Crop Growth Monitoring System (CGMS) for wheat using WTGROWS simulation model on a 5’X5’ grid in GIS environment for generating daily crop growth maps and predicting district-wise grain yield prediction for Haryana State during 2000-01 crop season. Nain et.al.,(2002) made real time wheat yield assessment using technology trend and crop simulation model with minimal data set. A simple technology trend model in conjunction with crop simulation model(CERES-Wheat in DSSAT environment) was used for early wheat yield prediction at six locations representing the six major wheat growing states, which contribute about 93 per cent to Indian national wheat production. The study demonstrated the possibility of wheat yield prediction early in the season (before harvesting) by using in - season weather data up to the time of prediction and the average /normal weather data for the rest of the period. Sehgal, et.al., (2005) developed wheat yield maps of farmer’s fields by using remote sensing (RS) inputs during the rabi season of 1998-99 in six villages of Alipur Block of Delhi State. RS (LISS-III) derived leaf area index (LAI) were linked to wheat simulation model WTGROWS by adopting “Modified

Corrective Approach (MCA)”. A comparison of predicted grain yield by the MCA and actual observed yield on 22 farmers' fields showed high correlation coefficient of 0.8 and a root mean square error (RMSE) of 597 kg ha⁻¹ which was 17% of the observed mean yield. MCA that links RS information and crop simulation model provides an alternative for mapping and forecasting crop yield under highly variable cropping environment of Indian farms, which is a pre-requisite for implementing Precision Crop Management (PCM). Rai et.al., (2007) demonstrated the potential of spatial models based on geo-statistical techniques of variogram and kriging for estimation of crop yields at small area level. The predicted yield / production of wheat using IRS – 1D satellite data in Rohtak district of Haryana state was comparable to the estimated production of wheat through large scale survey data.

Europe

Monitoring Agriculture through Remote Sensing (MARS) project launched by European union in 1989, uses a sampling approach, multi-date crop identification and field survey information for making Europe – wide crop area estimates (Sharman,1993). Tsiligirides (1998) estimated acreage, productivity and production of soft and durum wheat for the Hellenic regions of Macedonia and Thrace, in Greece by using area frame of square segments methodology in combination with Landsat TM images. An operational remote sensing based Crop Monitoring and Production Forecast Program (CROPMON) was reported from Hungary by Csornoi et.al..(2008). The crop area estimation (including winter wheat) was based on the quantitative analysis of multispectral high resolution images (Landsat TM and IRS – 1C/1D LISS III) from early April to August. The differences in the crop area estimates based on remote sensing and the data of Central Statistical Office, Hungary (CSOH) were in the range of 0.8 to 3.7 per cent for the entire cropland in Hungary. The crop productivity forecast was accomplished by combining high resolution satellite (Landsat TM and IRS – 1C/1D LISS III or SPOT) data and NOAA AVHRR time series. The country average productivity data compared favorably with CSOH preliminary values that appeared six weeks later. The differences were less than one per cent for wheat.

China

Liu et al., (1999) predicted winter wheat production in North China plain with an accuracy of over 96 per cent compared with on the spot measurement by using Landsat Thematic Mapper (TM) data and Advanced Very High

Resolution Radiometer (AVHRR) time series data. Zhou et.al.,(2003) selected division indicators and used GIS techniques and clustering analysis for yield estimation. Based on the results they opined that crop divisions help in accurate yield estimation by remote sensing. Wenpeng et.al., (2008) estimated winter wheat yield in Hebei province, China by using a model with MODIS Normalized Near-infrared Spectral Index (NNSI). Three MODIS near infrared spectrum data were retrieved in heading stage with central wavelengths of 860nm, 1240nm and 1640 nm and(NNSI) was calculated from any two of the wavelengths, such as 860 and 1240 or 860 and 1640 or 1240 and 1640. Correlation coefficients between yield and NNSI were higher than between yield and NDVI. Correlation between yield and NNSI from 860 and 1640 was highest(0.815). Based on the results obtained they concluded that Normalized Index in near infrared spectrum was better and more reliable for winter wheat yield estimation than normalized index in visual and near-infrared spectrums. Recently, QuickBird imagery and a Production Efficiency Model (PEM) were used to estimate crop yields in Zhonglianchuan, a hilly area on Loess Plateau, China. Results showed that QuickBird imagery can improve the yield estimation accuracy. The information extracted from the image was highly correlated to estimated yields from ground data collection ($r^2 = 0.86$) (Pan *et al.*, 2009).

Canada

Techniques commonly employed in Canada, for wheat yield estimation employ weather data over the growing season. However yield estimates are also required before wheat is sown, particularly by grain exporting agencies. In such cases, time series techniques can be used for yield forecasting. Kumar (2000) tested few techniques such as linear trend, quadratic trend, simple exponential smoothening, double exponential smoothening, simple moving averaging and double moving averaging to model the average spring wheat yield series for Saskatchewan, Canada. Past yield data was used to obtain yield estimates. Based on a deterministic measure, it was found that quadratic model produced the most accurate forecast, during both the model development and model testing periods. Wall et.al.(2008) studied the explanatory power of Normalized Difference Vegetation Index(NDVI)for wheat yield modeling in 40 Census Agricultural Regions (CAR) in the Canadian Prairies during the whole growing season using 16 years of NOAA AVHRR satellite data (between 1987 and 2002). They compared the relative value and accuracy of NDVI with a land based measurement, Cumulative Moisture Index(CMI) by using weekly wheat models developed over the growing season. The results indicated that NDVI possesses explanatory power four weeks earlier in the season than CMI.

Australia

Potgieter et.al., (2005) used multi temporal Moderate Resolution Imaging Spectroradiometer (MODIS) imagery for determining winter wheat acreage in the Darling Downs region, Queensland, Australia. The 16- day aggregated MODIS Enhance Vegetation Index (EVI) imagery derived from combinations of the MODIS red, near infrared and blue spectral bands was subjected to different multivariate approaches such as Harmonic Analysis of Time Series (HANTS) and Principal Component Analysis (PCA). The results showed a significant potential to estimate wheat area at a regional level.

CONCLUSIONS

Remote sensing and GIS technologies have come a long way in crop inventories around the world. The coarse resolution single date satellite data were used in the initial years. Such inventories did serve the purpose of improving the reliability and accuracy of estimations, that helped considerably in planning supply chain management strategies. However, over the years, planning and management activities have downscaled from regional scale to individual field scale. Simultaneously, high resolution satellite imagery at much cheaper and affordable cost are becoming available for civilian use. These changes coupled with advances in techniques of RS and GIS have enabled scientists to develop individual farm-level crop inventories that would lead to a situation where precision crop management becomes a viable option in the near future.

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