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FARM-LEVEL YIELD MAPPING FOR PRECISION CROP MANAGEMENT BY LINKING REMOTE SENSING INPUTS AND A CROP SIMULATION MODEL

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ABSTRACT

A study aimed at generating wheat yield maps of farmer's fields by using remote sensing (RS) inputs was undertaken during the rabi season of 1998-99 in six villages of Alipur Block of Delhi State. RS derived leaf area index (LAI) were linked to wheat simulation model WTGROWS by adopting a strategy christened "Modified Corrective Approach". This essentially uses an empirical relation of grain yield and LAI, which was derived from WTGROWS simulation model by running model for a combination of input resources, management practices and soil types occurring in the area. This biometric relationship was applied to all the wheat fields of the study area for which the LAI was derived from single acquisition of IRS LISS-III data (Jan 27, 99). The LAI–NDVI relation adopted was logarithmic in nature (R^2=0.83) and was based on ground measurements of LAI in farmer's fields in the same area. A comparison of predicted grain yield by the modified corrective approach and actual observed yield for the 22 farmer's 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. Thus linking of 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).

Introduction

Precision crop management (PCM) involves collecting information and managing farm or a group of farms, in the dimensions of both space and time, to make practical, economical and environmentally sound crop production decisions. Pierce and Nowak (1999) have noted that any component of crop

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production – from natural resources to plants, production inputs, farm machinery and farm operators – that is variable in some way is included in the realm of PCM. Robert *et al.* (1995) defined PCM as an *information- and technology-based agricultural management system to identify, analyze and manage site-soil spatial and temporal variability within fields for optimum profitability, sustainability, and protection of the environment.* It embodies the practice of applying crop inputs in each field or its part according to its unique set of conditions. The enabling technologies of PCM can be grouped into five major components: computers, GPS, GIS, sensors and application control. The remote sensing technology is part of both sensors and GIS.

Moran *et al.* (1997) listed three basic type of information required for PCM: (1) information on seasonally stable conditions, (2) information on seasonally variable conditions, and (3) information required to diagnose the causes of the crop yield variability and develop a management strategy. They showed that all these three types of information could be obtained from image-based remote sensing. Yield mapping and soil sampling are the first stages in generating some of the information in implementing PCM. When the yield/soil variability is significant, there is need of practicing PCM. In developed countries, with large farm sizes practicing mechanized field operations, yield maps are produced by processing data from an adapted combine that has a vehicle positioning system integrated with a yield recording system (Lamb, 1995). Under Indian farming conditions, due to the low level of mechanization, small field sizes and heterogeneous farming practices, such yield recording systems are neither practical nor economical.

Because the remote sensing systems directly view the above-ground component of crop canopy over large areas with the possibility of deriving parameters for each field, they could be primary source for collecting information on crop growth variability on a quantitative and regular basis. The linking of remote sensing information and crop simulation model provides an alternative for mapping crop yield at farm level and determining the cause of the variability in crop production. The different ways to combine a crop model with remote sensing observations (radiometric or satellite data) were initially described by Mass (1988) and his classification scheme with examples was revised by Delecolle *et al.* (1992) and by Moulin *et al.* (1998). In India, the linking of remote sensing inputs and wheat simulation model has been demonstrated at the scale of experimental farm and farmer's fields (Sehgal, 2001) and also at district level (Sehgal *et al.*, 2002; Dadhwal *et al.*, 2003). Nain *et al.* (2001) used crop simulation model to normalize the NDVI of wheat to peak vegetative stage for developing farm level spectral yield model.

This paper describes the results of a study undertaken on wheat crop during rabi 1998-99 in Alipur block (Delhi), which aimed at generating the wheat yield maps of farmer's fields in the selected villages by linking remote sensing inputs and wheat simulation model WTGROWS and validating this approach with actual farmer's fields observations. A new linking strategy, christened "Modified Corrective Approach" by Sehgal (2001), was adopted. This strategy is empirical in nature where biometric relation of grain yield and leaf area index (LAI) is derived from simulation model by running model for a combination of input resources, management practices and soil types occurring in the area. Then this biometric relationship is applied to all the crop fields of the study area for which the LAI is computed from remote sensing data. For developing LAI-YIELD biometric relationship, the LAI of that day was chosen for which satellite derived remote sensing data was available for the study area.

Material and Methods

The study was undertaken for wheat crop during the rabi season of 1998-99 in the six villages of Alipur Block of Delhi State. Leaf area index (LAI), phenological development and agronomic practices (fertilizers and irrigation) were monitored at regular intervals for the 22 fields selected in the study area to study the farmers' fields wheat yield variability and to validate the modified corrective approach. Above ground biomass and grain yield were recorded at harvest. LAI measurements were taken with the help of plant canopy analyzer LAI-2000 (LI-COR).

IRS LISS-III image of January 27, 1999 was acquired, geo-referenced and overlaid with village boundaries. Using ground truth information and maximum likelihood supervised classification, the study area was classified into wheat and non-wheat classes. The 22 agricultural fields were identified on the image and their mean NDVI values were computed.

The model WTGROWS used in the study is an indigenously developed detailed mechanistic model that simulates the potential production, phenology, soil water balance, soil and plant nitrogen balance and effects of water and nitrogen stress on wheat growth and development (Aggarwal *et al.*, 1994). Using the weather recorded by Indian Agricultural Research Institute observatory, the model was run for a range of combinations of inputs representative of the study area. The combinations were (1) two dates of sowing, (2) five irrigation levels, (3) four N fertilizer rates and (4) two soil type viz., sandy and coarse loamy. Illogical input combinations such as high N fertilizer with no irrigation and vice versa were avoided. For developing LAI-YIELD biometric relationship from model simulations, the LAI of that day was chosen for which satellite derived remote sensing data was available for the study area.

The two steps followed in producing a spatial wheat yield map were, (i) generating a LAI map using locally developed LAI-NDVI model for the date of satellite pass and (ii) using the simulated LAI (on date of satellite acquisition) – simulated final grain yield relationship, converting wheat LAI map to predicted grain yield map. The predicted average grain yield values for 22 fields were compared with the observed yield values.

Results and Discussion

Date of sowing and management practices varied widely among the study fields. The sowing dates varied from as early as November 1, 1998 (305 Julian day) to as late as December 16, 1998 (350 Julian day) with a median sowing date of November 22, 1998 (326 Julian day). The rate of N fertilizer application and number of irrigations varied in the range of 70 – 140 kg N ha^{-1} and 2 – 4, respectively. The observed grain yield varied between 2100 and 4600 kg ha^{-1} with a mean value of 3300 kg ha^{-1}.

Statistical analysis based on regression indicated that while date of sowing explained 44 per cent variability in grain yield and was followed closely by nitrogen fertilizer application rate, which explained 40 per cent of yield variability. The number of irrigation did not show any significant effect on wheat grain yield.

A highly significant relation between reflectance-based NDVI and LAI was observed which was logarithmic in nature with a $R^2 = 0.83$. The NDVI-LAI relation was inverted and applied to generate LAI map of all the wheat pixels in the study area. The inverse relationship is given below:

$$LAI = 0.5829 * \exp(3.787*NDVI) \quad (1)$$

The wheat LAI map showed a wide range of LAI of 1.0 to 5.4 on January 27, 1999 with majority of the fields showing LAI between 3.0 and 5.4.

The WTGROWS simulated grain yield for the combination of inputs showed yields varying between 1.1 and 4.9 t ha^{-1}. The corresponding range of simulated LAI on 27 Jan 99 was 0.6 to 4.2. The regression equation fitted between simulated LAI on 27 Julian day (i.e. January 27, 1999) and simulated grain yield showed saturating logarithmic nature with a $R^2 = 0.81$. The relationship is shown in Figure 1 and the regression equation is as given below:

$$\text{Yield (kg/ha)} = 1571.2 * \ln(\text{LAI}) + 2033.6 \qquad (2)$$

This empirical biometric relation was applied to the LAI map of the wheat pixels and grain yield map was generated which is shown in Figure 2. The predicted yields ranged from 2.1 to 4.8 t ha^{-1}. The inset of Figure 2 also highlights the within field yield variability predicted by this approach. Since the ground information comprised of average yield of the selected fields only, the within-field variability of yield could not be validated in this study.

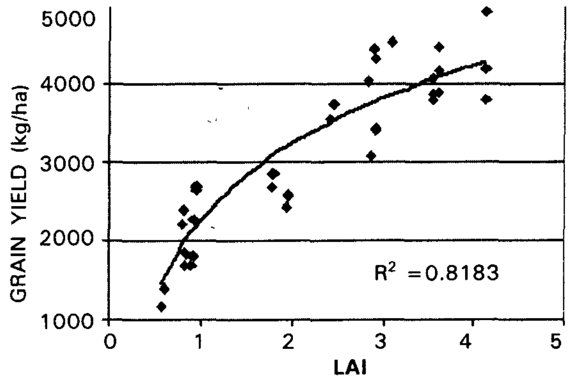

Fig. 1. Relationship between model simulated LAI of Jan. 27, 1999 and model simulated final grain yield.

The comparison of predicted grain yield by the modified corrective approach and actual observed yield for the 22 farmer's fields has shown 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 (Figure 3). Except for two

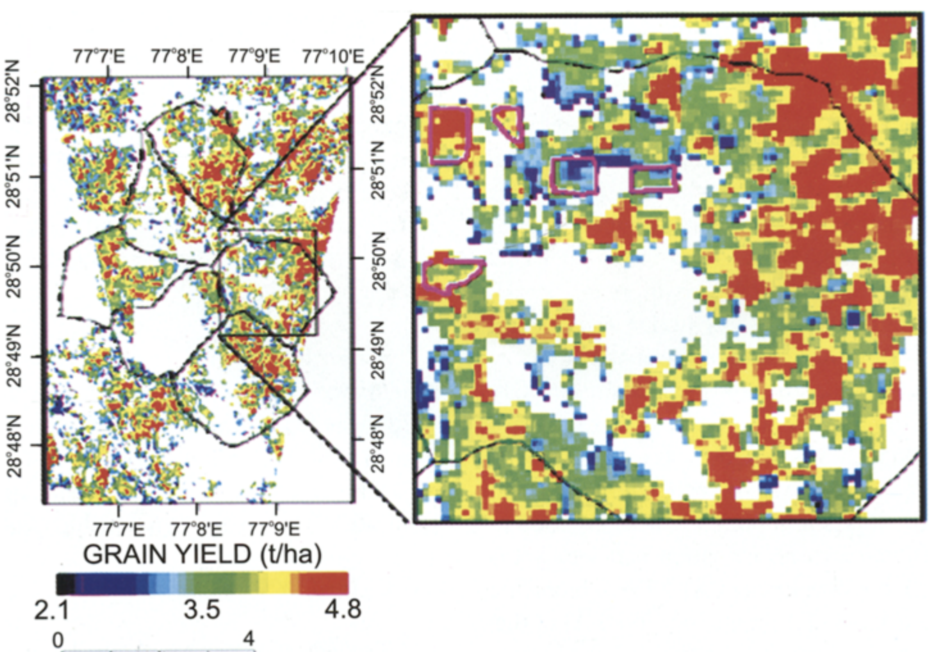

Fig. 2. Wheat grain yield map of the study area overlaid with village boundaries. The inset shows zoomed up area of Hamidpur village showing grain yield variability within some selected farmer's fields.

cases, there was overestimation of grain yield in all the cases. Out of 22 farmer's fields, the predicted yield in 12 cases was within 15% of the observed values. A higher bias was observed for the farmer's fields where the observed yield values were below 2500 kg ha^{-1}. These were the fields in which weed infestation was observed due to very late sowing. Because model WTGROWS does not simulate the effect of biotic stresses (insects, weeds) on crop growth and yield, the overestimation in such cases was expected. The validation results proved the workability of modified corrective approach of linking remote sensing derived LAI and crop simulation model under highly variable cropping environment of Indian farms.

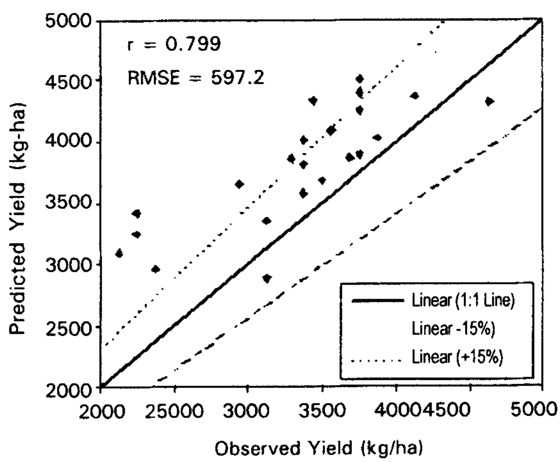

Fig. 3. Comparison of predicted grain yield by modified corrective approach and observed values for 22 farmer's fields. The 1:1 line and its ±15% band lines are also shown.

While PCM has attained operational status in West, it is still being debated and investigated in India due to constraints like small field sizes, diversity of crops, large variability in crop management, practices like inter-cropping and mixed cropping and socio-economic factors. Any operational adoption, even at the scale of a field would require the following, (a) crop identification, (b) measurements of crop variability by RS, (c) relating the variability to specific crop parameters, e.g., phenology, LAI, chlorophyll content etc., (d) estimate likely yield under current scenario and a number of possible interventions, and (e) suggest and implement most economic and sustainable solution. Dadhwal *et al.* (2002) have reviewed the Indian experience on crop identification for a range of spatial scales, while LAI retrieval over farmer's fields has been demonstrated with empirical (Pandya *et al.*, 2003) as well as simple physical models (Rastogi *et al.*, 2000). Yield prediction incorporating observed variability requires use of crop simulation models and WTGROWS has been linked with RS-derived LAI (Sehgal, 2001) and phenology (Sehgal *et al.*, 2002). While LISS-III data having a spatial resolution of 23 m has been used in these studies, with the availability of LISS-IV having a spatial resolution of 5.8, identification of within-field variability in farmer's fields and identification of crop growth in small fields not resolved by LISS-III will become routinely possible.

Thus linking of remote sensing information and crop simulation model provides an alternative for mapping crop yield at farm level under Indian conditions, which is a pre-requisite for implementing Precision Crop Management (PCM). The proposed linking strategy could capture wheat yield variability with-in and across the farmer's fields varying in crop growing condition and management practices with acceptable degree of accuracy.

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