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Wheat Yield Modelling Using Remote Sensing and Agrometeorological Data in Haryana State

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SUMMARY

Spectral-trend-agrometeorological yield models for four zones in Haryana state were developed using district level area weighted Normalized Difference Vegetation Index (NDVI), trend predicted yield and meteorological indices like Growing Degree Days (GDD), Temperature Difference (TD) and Rainfall Accumulated over critical growth phases of wheat. Meteorological indices calculated were integrated over seven phenological stages of wheat viz. (i) Crown Root Initiation Stage (ii) Tillering Stage (iii) Jointing Stage (iv) Flowering Stage (v) Milking Stage (vi) Dough Stage and (vii) Maturity stage. Districts in Haryana were grouped into four zones (clusters of districts) based on their physiography/soils and agro-climatic conditions.

Trend predicted yields were obtained using historical yield time series data and spectro-trend yield relationship incorporated in the agro-meteorological yield models. Remote sensing based model predicted yield were compared with Bureau of Economic & Statistics (BES) by computing Relative Deviation (RD%). The results indicated that the prediction capability for district level wheat yield has improved significantly using these zonal yield models.

Key words : Growing degree days, Temperature difference, accumulated rainfall, Spatial resolution, Normalized difference vegetation index, Agroclimatic zones.

1. Introduction

Various organizations in India and abroad are engaged in developing methodology for pre-harvest forecasting of crop yield using various approaches. Crop yield is a complicated process which is governed by a number of factors. The main factors affecting crop yield are weather variables. Use of these factors,

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form one class of models for forecasting crop yields. Weather plays a dominant role in crop growth and development and hence can be conveniently used as indicator of change in crop yield modelling. Principal Component method offers considerable improvement over least squares method when multicollinearity is present. The other approach uses plant vigour measured through plant characters. Yet another approach is the measurement of crop vigour through remotely sensed data.

Appa Rao [1] reported crop weather model for providing real time crop estimates for wheat. Jain [5] developed forecast models using growth indices/ principal components of the biometrical characters correlated with yield. Some countries like Canada, USA, India and Russia are using weather based yield estimates on an experimental or operational basis (Merritt [8]). Stephens *et al.* [11] attempted forecasting of Australian wheat yields with a weighted rainfall index. One of the first attempts directed towards wheat production forecast using remote sensing based acreage estimates and yield from Crop Cutting Experiments (CCE) was in Patiala Tehsil (Punjab State) during 1984-85 cropping season (Kalubarme and Mahey [6]). Saini and Dadhwal [10] studied the effect of temperature on wheat in India. The operational utility of CCE based yield relation was found to be limited, therefore, further studies were carried out, using direct regression of district yields with corresponding area weighted average spectral indices (Dubey *et al.* [3]). Kalubarme *et al.* [7] developed agromet-spectral wheat yield models in Punjab. Indian Meteorological Department (IMD) and Indian Agircultural Statistics Research Institute (IASRI) have made significant contributions in forecasting crop yields using weather variables in India. During the last decade, considerable work has been carried out in India in the spectral response and yield relationships of different crops at Space Application Centre, Ahmedabad, under Crop Acreage and Production Estimation (CAPE) project. The present study has been carried out on wheat crop using time series data on weekly weather parameters to create meteorological data base at different stages of crop growth and to obtain the yield forecasts for wheat of rabi season 2000-01 in Haryana state at agroclimatic zonal level.

2. *Study Area and Data Used*

The Haryana state comprising of nineteen districts is situated between 74°25'E to 77°38'E longitude and 27°40'N to 30°55'N latitude. The total geographical area of the state is 44212 sq. km. Indian Remote Sensing Satellite digital data of IRS LISS-I (spatial resolution 72.5 m), LISS-II (spatial resolution 36.25 m) and LISS-III (spatial resolution 23.5 m) sensors were used for the computation of area weighted average spectral indices for the last 8/9 years at HARSAC, CCS HAU, Hisar. Department of Agriculture (DOA) yield estimates for past 22 years (1978-79 to 1999-2000), published by Bureau of Economics and Statistics (BES) have been used for computing trend based yield. The meteorological data like daily minimum and maximum temperatures, rainfall etc. for the last 15 years were collected from different meteorological observatories in Haryana and IMD, Delhi.

3. Grouping of Districts

Nineteen districts in Haryana State have been grouped into four zones (clusters of districts) based on their physiography/soils and agroclimatic conditions. Since climatic data from adequate number of stations in defined agro-climatic zones is not available, districts having equable climatic conditions have been grouped to define the zones. Four agroclimatic zones considered for the analysis are Zone I (Ambala, Panchkula, Yamuna Nagar & Kurukshetra), Zone II (Karnal, Kaithal, Zind, Panipat, Sonepat & Rohtak), Zone III (Mahendergarh, Rewari, Jhajjar, Gurgoan & Faridabad) and Zone IV (Sirsa, Fatehabad, Hisar & Bhiwani).

4. Crop Yield Modelling and Forecasting

Spectro-trend Analysis

Average wheat yield data of all the districts in Haryana have been used by considering time (year) as an independent variable and has been regressed against yield to get the trend equation of the form

$Y_t = a + b^* t$, where Y_t = Yield (q/ha), a = intercept, b = slope and t = year

The spectral index is a measure of the total green biomass at any given time. The Vegetation indices (Vi) deduced from Near Infra Red and Red bands are used as indicators of crop growth and have been related to the plant biomass and grain yields. Stratified random sampling was used for the generation of vegetation indices of the past years. In each district, five homogeneous strata were delineated on the basis of vegetation density observed on previous years FCC print. These strata were identified as A : > 75% aa, B : 50-75% aa, C : 25-50% aa, D : 5 – 25% aa and NA : < 5% aa (NA = non agricultural area, aa = agricultural area). Since the vegetation vigour is an indicator of the growing conditions of the crop, the total variations (bright to dull red) on the False Color Composite (FCC) of the study area were categorized into good (G), medium (M) and poor (P) strata. These strata were taken as parameters for generation of spectral indices. Spectral indices such as ratio of Near Infra Red (NIR) and Red (R) or Normalized Difference Vegetation Index (NDVI) = (NIR – R)/(NIR + R) from remotely sensed data and trend predicted yield have been used as regressors in the model.

5. Spectral-trend-agrometeorological Yield Analysis

Temperature is one of the important factor influencing crop growth through different physiological processes and the rate of phenological development. Significant correlations among yield and weather factors during successive periods of the crop growth have been observed; the derived meteorological parameters i.e. Growing Degree Days (GDD) and Temperature Difference (TD) are computed as follows

$$TD = \Sigma\,[T\max - T\min] \text{ and } GDD = [(T\max + T\min)/2 - Tb]$$

Where Tmax = Maximum Temperature, Tmin = Minimum Temperature, Tb = Base Temperature (5°)

The weekly Accumulated Rainfall (ARF) were also computed to study its effect on yield. To integrate GDD, TD and ARF over different growth phases, wheat period was divided into seven phenological stages, viz. (i) Crown Root Initiation Stage (Meteorological week numbers 44-46), (ii) Tillering Stage (Meteorological week numbers 47-49), (iii) Jointing Stage (Meteorological week numbers 50-52), (iv) Flowering Stage (Meteorological week numbers 1-3), (v) Milking Stage (Meteorological week numbers 4-6), (vi) Dough Stage (Meteorological week numbers 7-9) and (vii) Maturity stage (Meteorological week numbers 10-14). Critical phenological periods have been identified, because of significant effect on yield due to weather parameters.

The models developed are at different agro-climatic zonal level. Four districts Ambala, Gurgaon, Rohtak & Hisar in different zones, where meteorological data are available in season, have been selected for the purpose. In each zone, at least one district has the meteorological observatory and agromet data from this station is used for adjoining districts in that particular zone, however, spectral indices and trend yield are available for all the districts. Of course, a particular zone comprising of 4/5 districts, will include all the observations regarding spectral-trend-agromet variables in correspondence to all 4/5 districts considered under the zone. The trend predicted yield along with twenty one meteorological indices were used in the development of trend-agromet yield relationship but for spectral-trend agromet yield analysis, the agromet indices alongwith spectro-trend have been used as regressors in the model. Variables have been selected using stepwise regression programme, in which variables are included or excluded one at a time with decisions at any particular step conditioned by previous step. The multiple regression for various combinations of spectral-trend-agromet variables defined preferably after taking care of critical phenological periods were carried out. The final yield equation was selected based on the highest adjusted R^2 and lowest Standard Error of Estimation (SEOE). The spectro-trend, trend-agromet and spectral-trend-agrometeorological yield models developed for all the four zones are provided below.

Zonal spectro-trend, trend-agromet and spectral-trend-agromet wheat yield models

Zone I : (Ambala, Panchkula, Yamuna Nagar & Kurukshetra)

$$Y = -0.149 + 2.735^{*}Vi + 0.775^{*}Y_t$$

$R^2 = 0.820$, SEOE = 2.373

$Adj.R^2 = 0.806$, n = 32

$$Y = 26.57 - 0.632^{*}GDD_4 - 0.418^{*}ARF_3 + 0.845^{*}Y_t$$

$R^2 = 0.92$, SEOE = 1.612

$Adj.R^2 = 0.91$, n = 60

$$Y = 16.476 + 0.999^{*}Vi + 0.857^{*}Y_t - 0.450^{*}GDD_4$$

$R^2 = 0.880$, SEOE = 1.972

$Adj.R^2 = 0.866$, n = 32

Zone II : (Karnal, Kaithal, Zind, Panipat, Sonepat & Rohtak)

$$Y = -0.404 - 0.430^{*}Vi + 1.047^{*}Y_t$$

$R^2 = 0.658$, SEOE = 2.063

$Adj.R^2 = 0.646$, n = 60

$$Y = -7.545 + 0.158^{*}TD_3 + 1.019^{*}Y_t$$

$R^2 = 0.844$, SEOE = 1.394

$Adj.R^2 = 0.838$, n = 60

$$Y = -7.30 + 0.509^{*}Vi + 0.964^{*}Y_t + 0.163^{*}TD_3$$

$R^2 = 0.847$, SEOE = 1.394

$Adj.R^2 = 0.838$, n = 60

Zone III : (Mahendergarh, Rewari, Jhajjar, Gurgaon & Faridabad)

$$Y = 2.044 - 0.998^{*}Vi + 1.01^{*}Y_t$$

$R^2 = 0.980$, SEOE = 2.165

$Adj.R^2 = 0.978$, n = 32

$$Y = 34.14 - 0.345^{*}GDD_5 + 0.061^{*}ARF_3 + 0.884^{*}Y_t$$

$R^2 = 0.858$, SEOE = 1.730

$Adj.R^2 = 0.844$, n = 45

$$Y = 14.392 - 0.997^{*}Vi + 0.973^{*}Y_t - 0.275^{*}TD_5$$

$R^2 = 0.983$, $SEOE = 1.999$
$Adj.R^2 = 0.982$, $n = 32$

Zone IV : (Sirsa, Fatehabad, Hisar & Bhiwani)

$$Y = 0.208 - 1.438^{*}Vi + 1.104^{*}Y_t$$

$R^2 = 0.797$, $SEOE = 1.802$

$Adj.R^2 = 0.783$, $n = 33$

$$Y = -1.036 + 0.036^{*}TD_3 + 0.982^{*}Y_t$$

$R^2 = 0.844$, $SEOE = 1.394$

$Adj.R^2 = 0.838$, $n = 45$

$$Y = 3.837 - 1.596^{*}Vi + 1.095^{*}Y_t - 0.077^{*}GDD_5$$

$R^2 = 0.802$, $SEOE = 1.810$

$Adj.R^2 = 0.781$, $n = 33$

Where, Vi - Vegetation index
Y_t - Trend predicted yield
GDD_4 - Growing Degree Days at flowering stage (reproductive phase)
GDD_5 - Growing Degree Days at milking stage (reproductive phase)
TD_3 - Temperature Difference at jointing stage (vegetative phase)
TD_5 - Temperature Difference at milking stage (reproductive phase)
ARF_3 - Accumulated Rainfall at jointing stage (vegetative phase)
n - Total number of observations (over years) corresponding to different districts considered/merged under the zone

6. *Performance Evaluation of Yield Models*

Trend incorporated spectral yield model and zonal spectral-trend-agromet yield models were used to predict level wheat yields in Haryana state. The model predicted yields were compared with corresponding BES estimates. The accuracy of these estimates was evaluated by computing Relative Deviation (RD) as follows

$$RD\% = \frac{\text{Model predicted yield - BES yield estimate}}{\text{Model predicted yield}} \times 100$$

Comparison of predicted yield using both the models, with BES estimates is presented in Table 1 and Table 2.

Table 1. Comparison of Spectral-trend yield estimates with Department of Agriculture (DOA) Estimates

District	BES yield (q/ha) 2k-01	Model predicted yield (q/ha) 2k-01	Relative deviation (%)
		Zone I	
Ambala	34.83	39.31	+11.40
Kurukshetra	46.41	42.46	–9.30
Panchkula	25.88	23.67	–9.34
Yamuna Nagar	37.06	41.35	+10.37
		Zone II	
Karnal	46.35	41.58	–11.47
Kaithal	44.98	43.98	–2.27
Jind	43.24	41.25	–4.82
Panipat	47.70	40.92	–16.57
Sonipat	39.86	40.02	+0.40
Rohtak	38.22	39.12	+2.30
		Zone III	
M. Garh	37.12	43.01	+13.69
Rewari	41.53	40.97	–1.37
Jhajjar	38.29	36.84	–3.94
Faridabad	40.22	41.79	+3.76
Gurgaon	35.07	36.11	+2.88
		Zone IV	
Sirsa	41.61	41.12	–1.19
Hisar	42.83	42.93	+0.23
Fatehabad	43.51	41.58	–4.64
Bhiwani	32.93	37.81	+12.91

Trend yield (Y_t) is an important parameter appearing in all the models, indicating that most of the variability in yield is explained by Y_t, which is an indication or technological advancement, improvement in fertilizer/ insecticide/ pesticide/weedicide used and increased use of high yielding varieties. Accumulated rainfall (ARF) does not seem to have significant effect on wheat yield in any of the models. This is because almost all the area under wheat in the state is irrigated and grown under assumed moisture supply. Temperature Difference during vegetative stages e.g. TD_3 seems to have a positive correlation with yield. TD_3 is an important parameter at the vegetative growth stage as it contributes into the Photosystem-I which is responsible for higher metabolite production, consequently helps in growth. High Temperature Difference (TD) or Growing Degree Days (GDD) at reproductive phases (TD_5, GDD_4, GDD_5 etc.) have negative correlation with wheat yield, which is expected. Evans [4] has indicated that rapidly rising temperature and increasing water stress at reproductive phase frequently terminate grain filling. The grain size is also reduced with rise in temperature from 25° to 31° C (Asana and Williams [2]). Peters *et al.* [9] found that a rise in night temperature from 9° to 26° C reduced grain yield of wheat almost by half by reducing the period of grain filling.

Table 2. Comparison of Spectral-trend-agromet yield with Department of Agriculture (DOA) Estimates

District	BES yield (q/ha) 2k-01	Model predicted yield (q/ha) 2k-01	Relative deviation (%)
	Zone I		
Ambala	34.83	38.86	+10.37
Kurukshetra	46.41	45.18	–2.72
Panchkula	25.88	24.40	–6.07
Yamuna Nagar	37.06	39.09	+5.19
	Zone II		
Karnal	46.35	42.50	–9.06
Kaithal	44.98	42.86	–4.95
Jind	43.24	41.94	–3.10
Panipat	47.70	41.38	–15.27
Sonipat	39.86	41.03	+2.85
Rohtak	38.22	39.76	+3.87
	Zone III		
M. Garh	37.12	42.12	+11.87
Rewari	41.53	40.15	–3.44
Jhajjar	38.29	38.13	–0.42
Faridabad	40.22	41.30	+2.62
Gurgaon	35.07	37.54	+6.58
	Zone IV		
Sirsa	41.61	41.96	+0.83
Hisar	42.83	42.36	–1.11
Fatehabad	43.51	43.02	–1.14
Bhiwani	32.93	36.88	+10.71

It has been observed that the district-level yield predictions have improved significantly using zonal spectral-trend-agrometeorological yield models and Relative Deviations are within aceeptable limit for almost all the districts. Incorporation of meteorological data has also significantly improved the prediction capability. Results indicate that instead of single district-level yield model, the zonal yield models perform better for district level yield predictions.

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