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Wheat yield prediction through agrometeorological indices for Hamedan, Iran

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Abstract

Yield prediction before harvesting is one of the tools in order to planning food production supply in future.Yield prediction was carried out for Wheat(Triticum aestivum) using different meteorological variables with agrometeorological indices in Hamedan district during 2003-04 and 2004-05. According to correlation coefficients, standard error of estimate as well as relative deviation of predicted yield from actual yield using different statistical models, the best subset of agrometeorological indices were selected including daily minimum temperature (T_{min}), accumulated difference of maximum & minimum temperatures (TD), growing degree days (GDD), accumulated water vapour pressure deficit (VPD), sunshine hours (SH) & potential evapotranspiration (PET). Yield prediction was done two months in advance before harvesting time which was coincide with commencement of reproductive stage of wheat (27th of May). It revealed that in the final statistical models, 83% of wheat yield variability was accounted for variation in above agrometeorological indices.

*Keywords:*Wheat yield prediction; Agrometeorological indices; Statistical models

1. Introduction

Crop yield prediction is important for advanced planning, formulation and implementation of policies relating to food procurement, distribution, and import-export decision. Since crop yield is the culmination of many temporal plant processes and is affected by various external factors related to soil, weather and technology, parameterization of these factors and investigation of their relationship with yield are essential for crop yield modeling (Baier, 1977; Koocheki et al., 1993).

Agrometeorological wheat yield forecasting models were developed for the Ludhiana district of Punjab by Bal et al (2004). The multiple regression technique has been employed based on weather parameters, and both weather parameters and technological trend. The result showed that the regression models based on weather parameters explained 69% of variation in yield whereas inclusion of technological trend in the model improved the prediction considerably (R^2=87%). Bazgeer (2005) showed a significant relationship between wheat yield and minimum and maximum temperature, cumulative sunshine hours, temperature difference and pan evaporation in Hoshiarpur and Rupnagar districts of Punjab, India. Hodges and Kanemasu (1977) developed a model to estimate photosynthesis, respiration and dry matter accumulation as functions of LAI and meteorological variables for winter wheat. They derived daily growth equations based on net CO_2 exchange measurements and daily maximum and minimum temperature for incorporation into an evaporation-growth-yield model.

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The duration of post-anthesis development was studied in eight spring wheat cultivars under field conditions by Marcellos and Single (1972). Variation in post-anthesis environment was achieved by varying the date of anthesis through the use of seed vernalization, extended photoperiod and serial sowing. The results showed that multiple correlation and regression analysis of phase duration on temperatures and photoperiod was able to account for 75-97% of the variation in duration of the post-anthesis phase. They concluded that air temperature was the principle affecting factor the rate of development in post-anthesis phase. Williams (1969) estimated Prairie wheat yield during the 1952 and 1967 period using regression equations based on precipitation and both precipitation and potential evapotranspiration (PE). He pointed out that June appeared to be the most important month because June rainfall was usually higher and the most rapid vegetation growth of wheat occurred in June. Hence, Increasing the PE and rate of soil moisture depletion usually depressed yields, and June PE seemed to be the most important single element.

This study has been carried out to establish relationship among wheat yield and meteorological variables as well as agrometeorological indices to predict wheat yield of Hamedan district, in coming years.

2. Materials and Methods

Nineteen years (from 1984-85 to 2002-03) historical yield data of wheat (Triticum aestivum) published by the Ministry of Jehad Keshavarzi (MJK) for Hamedan district were used to develop agrometeorological-yield models. To integrate various meteorological variables and agrometeorological indices over different growth phases, wheat growing season was divided into six phenological stages, starting from the sowing of crop on October 8th up to harvesting on July 29th including: i)Early Seedling stage (from October 8th to December 5th), ii) the first stage of Active Vegetative before dormancy stage (from December 6th to January 11th), iii) Dormancy stage (from January 12th to March 16th), iv) the second stage of Active Vegetative after dormancy stage (from March 17th to May 27th), v) Reproductive stage (from May 28th to June 28th), and vi) Maturity stage (from June 29th to July 29th).In order to select the best yield predicted model, the statistical analysis was calculateded for each phonological stages.

2.1. Meteorological parameters

Daily meteorological data of Hamedan-Nojeh meteorological station located in the study area were used from 1984-85 to 2004-05. Daily maximum (T_{max}) and minimum (T_{min}) temperatures, accumulated rainfall (ARF), evaporation data of US Weather Bureau Class A Pan Evaporimeter and sunshine hours (SH) were used as meteorological parameters.

2.2. Agrometeorological indices

2.2.1. Growing Degree Days (GDD)

The heat unit or growing degree-days concept was proposed to explain the relationship between growth duration and temperature. This concept assumes a direct and linear relationship between growth and temperature (Nuttonson, 1955). It has been reported that accumulated GDD is the best index to predict various phenophases in wheat crop under Punjab conditions (Hundal et al 1997).

A degree-day or a heat unit is the mean temperature (T_{mean}) above base temperature, i.e. the lowest temperature below which it is assumed that there is no growth. A base temperature of 5°C was selected to determine GDD for different growth stages of wheat (Sharma et al., 2004; Dubey et al., 1987).

2.2.2. Temperature Difference (TD)

Temperature difference was computed using following expression:

$$TD = \sum_{a}^{b} \left(T_{max} - T_{min}\right) \quad (1)$$

Where,
TD = Temperature difference

2.2.3. Photothermal Units (PTU) and Heliothermal Units (HTU)

Because of the phasic changes taking place due to the influence of both temperature and photoperiod, it is better to calculate photothermal units (PTU) instead of heat units for accurate prediction of flowering and maturity. Therefore, photothermal units are proposed, where in, the degree days are multiplied by length of the night in case of short- day plants and length of the day for long-day plants (Reddy and Reddi 2003).

In general, PTU is product of GDD and day length (maximum possible sunshine hours, N) and HTU is the product of GDD and bright sunshine hours (actual sunshine hours, n). Therefore, they can be computed using following expressions:

$$PTU = \sum_{a}^{b} (GDD \text{ x N}) \quad (2)$$

$$HTU = \sum_{a}^{b} (GDD \text{ x n}) \quad (3)$$

Where,
PTU= Photothermal units (°C day hours)
HTU= Heliothermal units (°C day hours)
GDD= Growing degree days (°C day)
N= Maximum possible sunshine hours which collected from Doorenbos and Pruitt, 1975)
n= Actual sunshine hours

2.2.4. Vapour Pressure Deficit (VPD)

Vapour pressure deficit plays a significant role in crop evapotranspiration. At constant temperature, changes in atmospheric humidity affect transpiration by changing actual vapour pressure of the air (e_a) and modifying the vapour pressure gradient from leaf to air (Rao, 2003; Kramer, 1997). The difference between the saturation vapour pressure (e_s) and its actual water vapour pressure is termed as vapour pressure deficit and it can be worked out using following expressions:

ea= (RHmean x es) / 100
VPD= es - ea (4)

Where,
e_a= Actual water vapour pressure (millibar)
RH_{mean}= Mean relative humidity (%)
e_s= Saturated water vapour pressure (millibar) as a function of mean air temperature which collected from Michael (1978)
VPD= Vapour pressure deficit (millibar)

2.2.5. Potential Evapotranspiration (PET)

Baier and Robertson (1967) demonstrated that crop yield was closely related to the physical environmental parameters, like evapotranspiration (ET) and soil moisture than simple meteorological variables, such as rainfall or temperature. CropWat for windows package version 4.2 developed by Clarke et al (1998) was used to compute PET during different phenological stages. CropWat for windows is a programme that uses the modified Penman-Monteith method for calculating reference crop evapotranspiration. The method supersedes the FAO Irrigation and Drainage Paper No. 24 (Doorenbos and Pruitt, 1975). Monthly maximum and minimum temperature (°C), mean relative humidity (%), sunshine hours, and wind speed (m/s) at two meter height above the ground were used to run the model.

2.2.6. Relative Diviation

In order to evaluate the performance of different yield models for prediction of yields, predicted yield for the years 2003-04 and 2004-05 were compared with corresponding MJK estimates using relative deviation (RD) as a measure of predication accuracy.
RD (%) = ((Model predicted Yield-MJK Estimate)/MJK Estimate)) x 100

3. Results

Various possible ways using meteorological parameters/ agrometeorological indices for wheat yield modelling have been attempted. The simple, multiple-linear and stepwise regression analysis has been developed (Data not given due to briefness). In conformity with examination of correlation coefficients (R), standard error of estimate (SEOE) as well as relative deviation (RD) values resulted from different agromet models, the best agromet subset were selected to develop agromet-yield models for Hamedan district. Accordingly, the suitable time of prediction was found to be at the beginning of reproductive stage i.e., May 28th (2 month before harvesting) using meteorological and agrometeorological data of the second stage of Active Vegetative after dormancy stage (from March 17th to May 27th).

Meteorological and agrometeorological data used for this phenological stage of wheat are presented in table 1. The best agromet subset to incorporate agromet-yield model were selected as T_{min}, TD, GDD, VPD, SH and PET.

The final regression equation to predict wheat yield (Y) is given below:

Y=7140.665-985.988Tmin-7.034TD+
14.929GDD+1.251VPD-
429.499SH+72.858PET
(R= 0.909, R^2= 0.826, SEOE= 114.73 kg/ha,
F= 7.45**, n= 19)

The results revealed that minimum temperature showed negative relationship with grain yield. It might be due to high night temperature associated with accelerated respiration, which decreases translocation of photosynthates from leaf to grain and hence reduced the yield (Marcellos and Single, 1972; Asana and Williams, 1965). GDD showed positive significant relationship with yield. It could be due to the more GDD the greater will be grain filling period and hence yield increases (Hundal, 1997). VPD and PET showed a linear relationship with wheat yield. Abbate et al (2004) and Musick et al (1994) found, increasing VPD and consequently PET during day resulting in closure of stomata to limit evapotranspiration for increasing water use efficiency (WUE) and wheat yield will be increased. The result showed that agromet-yield model explained 83% of yield variability due to variations in minimum temperature (T_{min}), temperature differences (TD), growing degree-days (GDD), vapour pressure deficit (VPD), sunshine hours (SH) and potential evapotranspiration (PET) during second stage of active vegetative after dormancy stage (from March 17th to May 27th).

In order to evaluate model validity, model predicted yields were compared with corresponding MJK (The Ministry of Jehad Keshavarzi) estimates using relative deviation values (RD) for the years 2003-04 and 2004-05 (Table 2), in Hamedan district.

Table 1. Meteorological and agrometeorological together with yield data used for model development of wheat during the second stage of Active Vegetative after dormancy stage, from March 17th to May 27th
(Source: Hamadan agrometeorological research center)

YEAR	Yield	T_{max}	T_{min}	T_{avg}	TD	GDD	HTU	PTU	P	VPD	SH	PET
1984-85	470	17.9	2.8	10.4	1087	385	2581	5046	134	379	6.7	4.6
1985-86	875	20.3	3.4	11.8	1217	493	3502	6461	86	455	7.1	4.5
1986-87	475	17.3	2.9	10.1	1037	367	2424	4810	174	261	6.6	3.5
1987-88	725	19.8	2.9	11.3	1217	457	3338	5989	60	433	7.3	4.9
1988-89	430	20.2	3.4	11.8	1210	490	4113	6414	84	441	8.4	5.5
1989-90	480	20.5	2.6	11.6	1289	472	3726	6178	57	434	7.9	4.6
1990-91	500	19.8	1.8	10.8	1296	418	3508	5471	67	431	8.4	5.2
1991-92	735	20.9	3.6	12.2	1246	522	4019	6838	36	455	7.7	5.4
1992-93	722	16.0	2.1	9.0	1001	292	1837	3820	161	300	6.3	4.1
1993-94	1020	18.6	2.4	10.5	1166	396	2653	5188	100	420	6.7	4.8
1994-95	900	20.2	3.5	11.9	1202	493	3600	6461	77	446	7.3	5.0
1995-96	660	18.6	3.4	11.0	1094	432	3197	5659	130	404	7.4	4.2
1996-97	408	18.0	3.8	10.9	1022	425	3059	5565	124	338	7.2	4.4
1997-98	675	17.3	2.8	10.0	1044	364	2691	4763	128	414	7.4	5.0
1998-99	650	19.4	4.4	11.9	1080	497	4024	6508	132	590	8.1	4.7
1999-2000	372	20.5	3.3	11.9	1238	497	4322	6508	64	547	8.7	6.0
2000-01	1012	21.8	4.5	13.2	1246	587	4812	7687	57	612	8.2	6.1
2001-02	759	21.8	4.1	13.0	1274	572	5094	7498	47	626	8.9	5.9
2002-03	1019	18.4	4.4	11.4	1008	461	3272	6036	133	382	7.1	4.9

T_{max}, T_{min}, T_{avg}: maximum,minimum and average temperature ; TD : Accumulated Temperature Differences; GDD: Growing Degree-Days; HTU: Accumulated Heliothermal Units; PTU: Accumulated Photothermal Units; P: Precipitation (mm); VPD: Accumulated Vapour Pressure Deficit (mb); SH; Daily average sunshine hours (hrs); PET; Daily average Potetial Evapotranspiration (mm/day).

Table 2. Performance evaluation of agromet -yield model at reproductive Stage of wheat for the years 2003-04 and 2004-05, Hamedan

2003-04			2004-05		
MJK Estimate (kg/ha)	Predicted yield (kg/ha)	RD (%)	MJK Estimate (kg/ha)	Predicted yield (kg/ha)	RD (%)
1120	622	-44	522	489	-6

In both years, the developed model using meteorological parameters as well as agrometeorological indices underestimated yield by 44% and 6% for the years 2003-04 and 2004-2005, respectively. The performance comparison between wheat yields prediction and its corresponding MJK estimates (Table 2) revealed that the predicted wheat grain yield computed for the year 2004-05 was closer to actual yield than 2003-04. because model has not very realistic estimate in years of extreme weather conditions as evident from actual yield in Hamedan district in the year 2003-04 which was 1120 kg/ha as compared to its difference from normal yields during 1984 to 2005 (692 kg/ha) whereas, in 2004-05 actual yield was 522 kg/ha. The response of crop meteorological conditions is not always the same during the entire life cycle of the crop and also during different ranges of the parameters (Mahey, 1999). Figure 1 shows estimated wheat yield of different years using the suitable model with good agreement to observed yield from MJK.

4. Conclusion

When meteorological parameters and agrometeorological indices used in model, wheat yield showed better predictions than their solely application. However, it may be possible to improve the accuracy of yield prediction in the future when agromet indices integrate with remotely-sensed based indices of high spatial resolution data.

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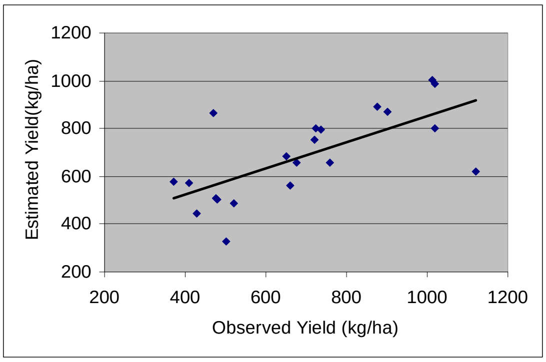

Fig. 1. Relationship between observed and estimated wheat yield of Hamedan

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