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Yield gap and trend analysis of wheat using CERES-wheat model in three districts of Gujarat state

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ABSTRACT

CERES-wheat (ver. 3.5) model was calibrated for genetic coefficients of wheat (cv. GW-496) through conduct of a field experiment during the *rabi* seasons of 2001-2002 and 2002-2003 at Anand which were used to estimate the yield gap in wheat yield in three districts of Gujarat state. Historical actual wheat yield of Anand, Mehsana and Junagadh districts failed to exhibit any significant trend during the study period (1995-2002). The trend of potential yield was found positive with the rate of change of 28 $kgha^{-1}yr^{-1}$ in Anand district but remained non-significant may be the fact that yield was found stable on account of good irrigation potential. The attainable yields were estimated by imposing the management constraint of delayed sowing by 15 days from the optimum time (15th Nov.). This constraint decreased the wheat yield irrespective of the agro-climatic zone. This was due to spilling over the days to anthesis phase from January to February with relatively higher average temperature under delayed sowing. Delay in sowing by 15 days later than optimum sowing, wheat yield decreased to the tune of 95, 110 and 65 $kgha^{-1}day^{-1}$ in Anand, Mehsana and Junagadh districts of Gujarat respectively.

Key words: CERES-wheat, simulation, yield gap, potential yield, long term experiments

Crop simulation models have been used to estimate potential yields of a crop and thereby, the yield gap in a given environmental situation can be determined and opportunities for yield improvement can be assessed. Wheat productivity may be enhanced by minimizing "Research yield gap" (Potential yield - experimental or attributable yield) and "Management yield gap" (Attainable yield - Actual yield) through improving efficiency with appropriate management practices. Aggarwal and Kalra (1994) used WTGROWS model to evaluate the climatic potential wheat yield at 138 sites across India and concluded that yields (with no water or N deficit) increased with higher latitude and with more inland sites, primarily because of variation in temperature. The predicted yield decreased by 428 $kgha^{-1}$ for each degree increase in temperature (°C). Muchow *et al.* (1997) used a CERES-maize crop growth model to evaluate corn (*Zea mays* L.) yields across tropical, subtropical and temperate locations in the USA and Australia and concluded that much of variation in yield was associated with variation in temperature and solar radiation, but decreased as temperature increased. Aggarwal and Kalra (1994a) made such a comparison of climatic potential versus actual wheat yields in New Delhi India. Pathak *et al.* (2003) studied trends of climatic potential and on-farm yield of rice and wheat in the Indo-Gangetic Plains in India. Aggarwal (2000) studied climatically potential grain yield of wheat and yield gaps in India. Results showed that yield gaps were small in irrigated regions of Northwest India but significantly larger in Eastern regions. Yield gap could be around 35-50 % if the sowing was delayed. Bell and Fischer (1994) studied potential yields of wheat in the Yaqui valley of Maxico for the period 1968-90 by CERES-wheat model. The predicted potential yields showed a significant linear decline over the study period apparently due to a small increase in temperature.

MATERIALS AND METHODS

The CERES-wheat model was calibrated and validated with the data sets generated during *rabi* seasons of 2001-2002 and 2002-2003, through field experiment laid out in strip plot design with four replications on loamy sand soils of the Agronomy Farm, B.A. College of Agriculture, Anand Agricultural University, Anand. The main treatments were three dates of sowing with an interval of two weeks from 1st Nov. to 30th Nov. (D_1-1st Nov., D_2-15th Nov. and D_3-30th Nov.) and the sub plot treatments were irrigation levels ranging between three irrigations in I_1 and six irrigations in I_4 coinciding with critical stages of crop growth. The sub plot details were: I_1-CRI, BT and ML, I_2-CRI, TL, FL and DS, I_3-CRI, TL, BT, FL and ML and I_4-CRI, TL, BT, FL, ML and DS (CRI- Crown Root Initiation, TL- Tillering, BT-Booting, FL-Flowering, ML-Milking and DS- Dough Stage).

Yield gap analysis

The historical weather data for wheat producing potential areas of Gujarat state viz., Anand, Vijapur and Junagadh of respectively Anand, Mehsana and Junagadh districts have been used. The analysis was undertaken for eight consecutive years (1995-2000) depending upon the availability of all the weather parameters as required to simulate CERES-wheat model.

Potential yield

Potential yield is defined as the maximum yield of a variety restricted only by the season-specific climatic conditions without limitation of water and nutrients and with optimum cultural management. Model simulated yield for 15th November (optimum sowing date) sowing with six irrigations at critical growth stages of wheat crop was considered as potential yield treatment for Anand location. Similar procedure was followed for other locations.

Actual yield

The crop yield data for the

Table 1: Input data used in the model

Parameters	Anand	Mehsana	Junagadh
Weather station	Anand	Vijapur	Sagdividi farm
Latitude	22°35'	23°37'	21°31'
Elevation (AMSL, m)	45.1	94.0	61.0
Type of soil	Sandy loam	Sandy loam	Clayey soil
Soil depth (m)	1.70	1.50	1.65
No. of horizons	4	4	4
Thickness of horizons (m)	0.00 to 0.18 0.18 to 0.42 0.42 to 1.50 1.50 to 1.70	0.0 to 0.24 0.24 to 0.60 0.60 to 0.92 0.92 to 1.50	0.0 to 0.22 0.22 to 0.62 0.62 to 1.04 1.04 to 1.65
Volumetric soil fraction (a) Saturation (b) Field capacity (c) Wilting point	 0.24 0.17 0.04	 0.31 0.15 0.06	 0.54 0.32 0.19
Bulk density (g/cc)	1.5	1.34	1.21
Sand (%)	82	78	15
pH	8.48	8.30	8.50
Soil organic N (%)	0.016	0.049	0.061
Soil mineral N, $kgha^{-1}$	30.27	28.00	37.50
Organic carbon (%)	0.152	0.410	0.610

Source: Patel *et al.* (1996)

respective districts as obtained from the reports of The Directorate of Agriculture, Government of Gujarat were considered as actual yield correspondingly to delayed sowing for the respective district.

Attainable yield due to delayed sowing

As the major emphasis was on quantifying the yield gap due to delayed sowing. Model simulated wheat yield in 30th Nov. sowing was taken as "Attainable" i.e., yield potential for delayed sowing date. For one reason or other sowing by farmers gets delayed to last week of November, though 15th Nov. is considered as the optimum sowing date.

Input data for CERES-wheat model

The pertinent soil data of the respective weather station representing the districts were used for the study (Table:1). Daily weather records of

Agrometeorological Observatory, Anand Agricultural University, Anand, Wheat Research Station, Sardar krishinagar Dantiwada Agricultural University, Vijapur and College of Agriculture, Junagadh Agricultural University, Sagadividi farm, Junagadh have been used for model simulation.

RESULTS AND DISCUSSIONS

Estimation of yield gap in wheat production for Anand district

Actual yield

The reported actual wheat yields of Anand district ranged from 2205 kgha^{-1} (1997) to 2922 kgha^{-1} with an average of 2466 kgha^{-1} (Table 2) for the period 1995 to 2002. During the year 2001 the highest actual yield (2922 kgha^{-1}) was recorded, which was comparable to the yields of irrigated wheat in Punjab and Sindh during 1999-2000 (Sinha *et al.*, 1998). The smooth line (Fig. 1) represents the three year moving average of actual yield, which shows increasing trend and this was well supported by values for the individual years. The linear trend showed increased rate of change by 39 kgha^{-1}yr^{-1} (Table 2); which however, was found non-significant. The increasing rate in actual yield could be attributed to high irrigation potential due to Mahi canal. The moving average almost remains more or less same as the average yield for the district suggesting a plateau in yield. The productivity of rice and wheat has shown either a decline or stagnation in several intensive farming districts of Punjab and Haryana (Sinha *et al.*, 1998; Aggarwal *et al.*, 2000). The data on past crop performance during several decades in some regions of the world suggest that year to year variation of wheat growth and development was mostly due to weather changes particularly in the temperature (Pathak *et al.*, 2003).

Potential yield

The potential yield of irrigated wheat simulated by CERES-wheat model at Anand ranged from 4521 kgha^{-1} (2002) to 5849 kgha^{-1} (2000) with an average value of 5145 kgha^{-1}. The potential yields for the Anand district simulated by the model was about 2.08 times higher than actual yield since the potential conditions were assumed to be free of biotic and abiotic stresses. Potential yields of wheat in India were similarly three times higher than their current actual yield levels, whereas, in Northwest India, this difference was smaller (Aggarwal *et al.*, 1995). The potential yield as simulated by model was for the period 1995 to 2002 found non-significant at Anand, however, it showed the increasing rate of change to the tune of 28 kgha^{-1}yr^{-1}.

The model simulated highest yield in the year 2000 and did not match with the highest actual yield because November 15 was considered as optimum sowing period for modelling but as mentioned earlier majority of the farmers might have taken up sowing later to this period. Thus, these results conveyed the message that, other conditions being assumed constant the variation was due to weather elements.

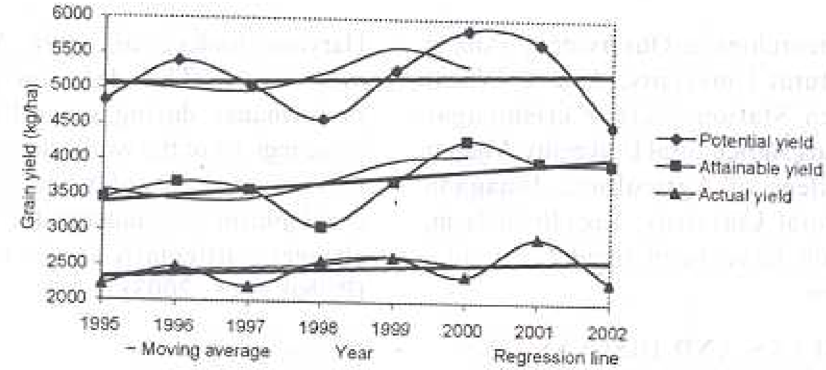

Fig. 1 : Simulated wheat yield in Anand district

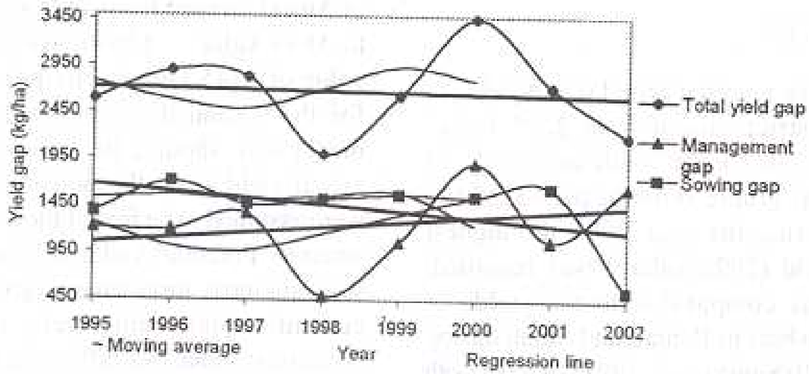

Fig. 2 : Yield gap between wheat production levels in Anand district

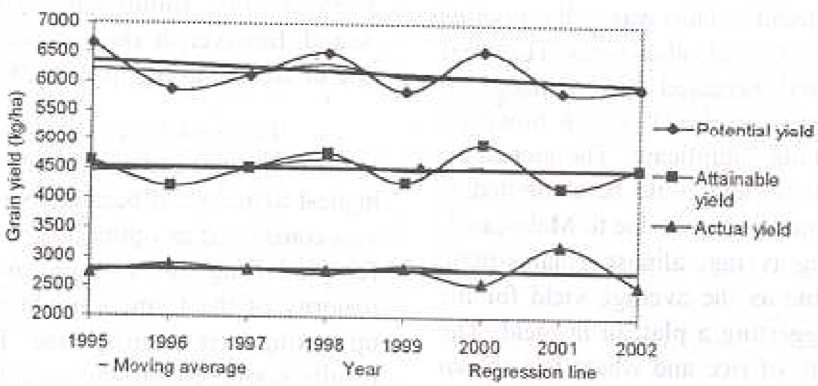

Fig. 3 : Simulated wheat yield in Mehsana district

Agrometeorological Observatory, Anand Agricultural University, Anand, Wheat Research Station, Sardar krishinagar Dantiwada Agricultural University, Vijapur and College of Agriculture, Junagadh Agricultural University, Sagadividi farm, Junagadh have been used for model simulation.

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Attainable yield

The various management factors play an important role in estimation of attainable yields. Hence, numbers of irrigations were cut down to six, without skipping irrigation at any critical stage of crop growth. Farmers generally cannot opt for more than six irrigations due to constant on water supply and electricity. The management constraint was late sowing (November 30 and onwards), a common practice by farmers for several reasons, particularly land availability due to standing kharif crops such as paddy, groundnut etc. and also due to irregular electricity and canal water supply. The attainable yield for late sowing simulated by the model ranged from 3060 kgha^{-1} (1998) to 4291 kgha^{-1} (2000) with an average of 3716 kgha^{-1}. The variation in attainable yield was found significant and followed similar trend as that of potential yield. The moving average of attainable yields exhibited significant linear trend. The lower attainable yield as estimated by the model was only due to delayed sowing. The days to anthesis had spilled over from January to February because of delayed sowing and thereby prevalence of rise in both maximum and minimum temperatures might have resulted in reduction in total duration of crop growing season and ultimately resulting in low yield.

Total yield gap

The average total yield gap (potential-actual) as simulated by CERES-wheat model was 2679 kgha^{-1} (Table 2 and Fig. 2) ranging from 2010 kgha^{-1} (1998) to 3477 kgha^{-1} (2000). The linear trend of total yield gap indicated a rate of change of 12 kgha^{-1}yr^{-1} but it was statistically found non-significant.

Management gap

This is defined as the yield gap between attainable yield at late sowing and actual yield. The management gap for Anand district as simulated by the model ranged from 489 kgha^{-1} (1998) to 1919 kgha^{-1} (2000) with an average of 1250 kgha^{-1} (Table 2) with rate of change of 57 kgha^{-1}yr^{-1}. The management gap was found non-significant but showed increasing trend at a rate of 57 kgha^{-1}yr^{-1} clearly suggesting the poor and untimely management operations followed by the farmers for one or other reasons.

Sowing gap

This is defined as the difference between potential yield and attainable yield due to delayed sowing by 15 days. The sowing gap for Anand district varied from 553 kgha^{-1} (2002) to 1711 kgha^{-1} (1996). The estimated average sowing gap was 1429 kgha^{-1} with the CV of 24 per cent. The higher CV value indicated the variability in weather, more so the temperature, the most influencing factor in wheat production. The linear trend was found non-significant and negative (69 kgha^{-1}) suggesting the negative impact of delayed sowing. The estimated sowing gap was recorded as 95 kgha^{-1}day^{-1} by the model. Aggarwal and Kalra (1994a) have quantified wheat yield gap of 50 kgha^{-1}day^{-1} delay in sowing.

Estimation of yield gap in Mehasana district

Actual yield

Mehsana is potential wheat producing district of North Gujarat Agro-climatic zone. Deep sandy loam soil coupled with nearly 42 per cent irrigation potential by tube wells in the district (ICAR, 2000) are the major yield optimizing factors for the district to be the second highest wheat producer after the Junagadh district. Despite the average actual yield of 2806 kgha^{-1} (Table 2) for the distri-t the year wise trend of actual wheat yields was found non-significant with decreasing trend at the rate of –3 kgha^{-1} (Fig. 3). The reason that can be ascribed for declining yields were: depletion of organic carbon in the soil due to high cropping intensity as the district possess ample irrigation facility, inadequate electricity supply and preference towards cultivation of other cash crops. The actual yield of the district ranged from 2560 kgha^{-1} (2002) to 3234 kgha^{-1} (2001) with an average of 2806 kgha^{-1}.

Potential yield

The district recorded highest potential yield capacity which ranged from 5866 kgha^{-1} (1999) to 6658 (1995) with an average of 6176 kgha^{-1} with very low CV per cent (5) as compared to Anand and Junagadh district (Table 2 and Fig. 3). However, linear trend was found non-significant and showed a negative rate of change (-52 kgha^{-1}yr^{-1}). The potential yield of rice and wheat crop have shown the signs of stagnation/decline as evidenced from a recent analysis of several long term experiments (LTE) carried out throughout Asia (Bhandari *et al.*, 2002; Regmi *et al.*, 2002 and Yadav *et al.*, 2000). Similar results were observed by Akula (2003) when simulation was carried out through WTGROWS and INFOCROP model at Anand for wheat. Ladha *et al.* (2002) analyzed 33 rice-wheat LTE in Indo-Gangetic Plains and China revealed that yields of wheat and rice stagnated in 82 and 72 per cent of LTE, respectively, while 6 and 22 per cent of LTE showed a significant declining trend for wheat and rice respectively, despite application of recommended rates of N, P and K nutrients to the crop.

Attainable yield

The attainable yield for the district ranged from 4216 kgha^{-1} (1996) to 4949 kgha^{-1} (2000) with an average yield of 4521 kgha^{-1} with 5.55 per cent of CV (Table 2). The linear trend in attainable yield was found non-significant and showed the rate of change to the tune of 1.8 kgha^{-1}yr^{-1}. The three-year moving average did not show any specific trend and followed similar variation as actual yield.

Total yield gap

The total yield gap as obtained by difference between potential and actual yield as estimated by CERES-wheat model ranged from 2633 kgha^{-1} (2001) to 3976 kgha^{-1} (2000) with an average value of 3370 kgha^{-1} with CV of 13.26 per cent. Higher

Table 2: Estimation of wheat yield gap by CERES-wheat model in different districts of Gujarat state

Param-eters	Yield (kg ha^{-1})			Yield gap (kg ha^{-1})		
	Actual	Potential	Attainable	Total	Manag-ement	Sowing
Anand						
Mean	2466	5145	3716	2679	1250	1429
SD	225	455	354	417	399	344
CV%	9.1	8.8	9.5	15.6	32.0	24.1
Slope	39.38	27.66	96.40	11.73	57.02	-68.75
R^2	0.16	0.01	0.39	0.00	0.10	0.21
Mehsana						
Mean	2806	6176	4521	3370	1715	1655
SD	196	323	251	447	412	165
CV%	7.0	5.2	5.6	13.3	24.0	10.0
Slope	-2.66	-52.37	1.82	-49.70	4.48	-54.19
R^2	0.00	0.14	0.00	0.06	0.00	0.56
Junagadh						
Mean	3247	4843	3870	1596	623	973
SD	470	510	203	645	389	525
CV%	14.5	10.5	5.2	40.4	62.5	54.0
Slope	-118.58	-132.20	-45.00	-13.61	73.58	-87.20
R^2	0.35	0.35	0.26	0.00	0.19	0.14

management (1715 kgha^{-1}) and sowing gap (1655 kgha^{-1}) were recorded as compared to other districts (Fig. 4 and Table 2). This categorically meant that delayed sowing; a management parameter reduced the yield to the tune of about 110 kgha^{-1}day^{-1} delay sowing.

Estimation of yield gap in wheat production at Junagadh district

Actual yield

The district recorded the highest average actual yield (3247 kgha^{-1}) as compared to Anand and Mehasana under study period (Table 2 and Fig. 5). This may be attributed to clayey soil with rich organic matter, high percentage of lime, groundnut-wheat sequential cropping system besides irrigation through open wells and canals (under limited area) which provided ample scope to the crop to express its performance in terms of high yield potential. The actual yield of the district ranged from 2386 kgha^{-1} (2000) to 3744 kgha^{-1} (1998) with CV of 14 per cent. However, the linear trend of

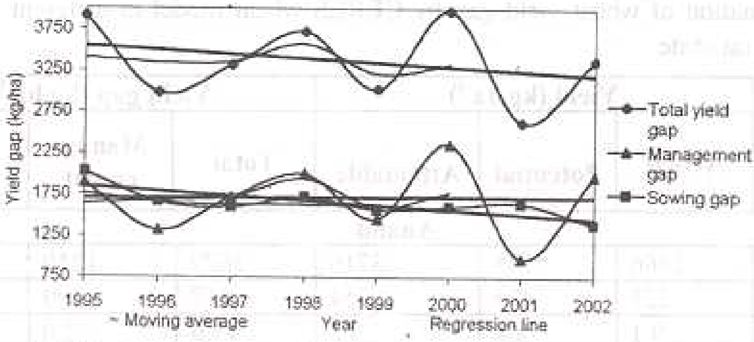

Fig. 4 : Yield gap between wheat production levels in Mehsana district

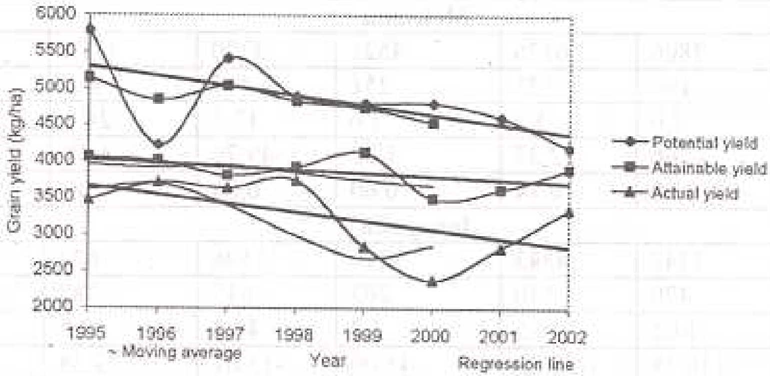

Fig. 5 : Simulated wheat yield in Junagadh district

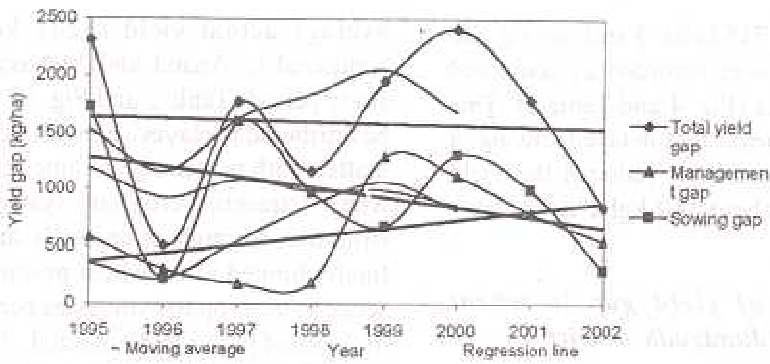

Fig. 6 : Yield gap between wheat production levels in Junagadh district

actual yield of the district was found to be non-significant with rate of change to the tune of –119 kgha^{-1}yr^{-1} suggesting a yield reduction trend. The three-year moving average also supports the results. Sinha *et al*. (1998); Dawe *et al*. (2000) and Dunbury *et al*. (2000) have clearly pointed out that, even with the best available cultivars and scientific management, cereal yields either have been stagnant or have started to decline. Higher average maximum temperature during January, February and March that prevailed as 29.3, 31.8 and 36.2 °C, respectively might be responsible for decreasing yield trend.

Potential yield

The average potential yield as simulated by the model was 4843 kgha^{-1} (Table 2) and ranged from 4200 kgha^{-1} (2002) to 5791 kgha^{-1} (1995). The average potential yield was higher only by 0.7 times the actual yield of the district because of lower potential yield. The linear trend of potential yield was found non-significant with the rate of change to the tune of –132 kgha^{-1}yr^{-1} suggesting yield decline trend and was supported by three year moving average with decreasing trend.

Attainable yield

The attainable yield of the district ranged from 3501 kgha^{-1} (2000) to 4056 kgha^{-1} (1995) with an average of 3870 kgha^{-1} (Fig. 5). The linear trend of attainable yield showed non-significant results with rate of change–45 kgha^{-1}yr^{-1} suggesting yield-declining trend and conformed with that of potential and actual yield.

Total yield gap

The total yield gap as estimated by the CERES-wheat model ranged from 510 kgha^{-1} (1996) to 2417 kgha^{-1} (2000) (Table 2 and Fig. 6) with an average of 1956 kgha^{-1}.

The linear trend of total yield gap showed non-significant results with the rate of change –14 kgha^{-1}yr^{-1} because of decreasing trend of potential yield of the district. High CV percent (40) in total yield gap reflected the large weather variability particularly in temperature. The management gap ranged from 174 kgha^{-1} (1997) to 1283 kgha^{-1} (1999) with an average of 623 kgha^{-1}. The linear trend of management gap remained positive (75 kgha^{-1}) suggesting good response of various management practices but it was found non-significant. The variation in sowing gap ranged from 211 kgha^{-1} (1996) to 1735 kgha^{-1} (1995) with an average value of 973 kgha^{-1}. Results with negative rate of change (-87 kgha^{-1}) showed negative impact of delayed sowing on wheat yield. The quantified estimated sowing gap was found to be 65 kgha^{-1}day^{-1} by the model.

The average sowing gap between modeled potential and attainable yield varied from 973 kgha^{-1} at Junagadh to 1655 kgha^{-1} at Vijapur. Reduction in yield due to delayed sowing was to the level of 1655 kgha^{-1}, 1429 kgha^{-1} and 973 kgha^{-1} at Mehsana, Anand and Junagadh district, respectively.

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