

Application of CERES-Rice model in Yield gap analysis of rice

ABSTRACT

Aim: This study aimed to quantify and to identify the trends in the yield gaps over the 15 years (2006-07 to 2020-21) in the Karimnagar district of Telangana State. The DSSAT v4.7.5 CERES-Rice model was used to calculate the potential yields and then yield gaps were calculated. Linear and compound growth rates for the yield gaps were calculated.

Result: CERES-Rice model has simulated the potential yields with the given weather and soil data of Karimnagar district. Yield gap I has recorded positive trend, whereas the yield gap II and total yield gaps have recorded negative trend. Linear and Compound growth rates for yield gap I, yield gap II and total yield gaps were calculated in which only yield gap I showed positive growth rates whereas yield gap II and total yield gaps showed negative growth rates. However, the growth rates in yield gap-II are significant at 5% level.

Conclusion: It has been observed that, in Karimnagar district of Telangana, the production of rice has increased during the period under study, however there are yield gaps in rice. Potential yields of rice in Karimnagar district were simulated through the DSSAT model. There was no much variation in the yield gap I and it was noticed negative trends in yield gap II and total yield gaps. These gaps are to be filled to boost the productivity.

Key words: Rice, Growth rate, potential yield, potential farm yield, yield gaps, CERES-Rice model.

1. INTRODUCTION

Rice is a staple food for more than 3.5 billion people worldwide and for about half of the world's population (USDA 2022). Rice production in the world in 2021-2022 was 515.3 million metric tons (USDA 2022). In India rice production during the year is 129.66 million tons (Indiastat 2021-2022). Over the last six years, Telangana has emerged as a key rice-producing State in the country. Since the irrigation facilities and its affiliated irrigation systems are improved, the farmers have taken up paddy cultivation on a large scale. In Telangana rice is grown in around 2.1 million hectares in the year 2020-2021 and rice production during the year in *Kharif* season was 9.63 million tons. In Karimnagar district of Telangana rice area in *Kharif* season was 0.35 million hectares and production was 1.63 million tons (Telangana Statistical Abstract 2020-2021).

It is projected that there would be 60% increase in demand for agricultural production by 2050 (FAO, 2020) which is very large, but not unreachable. The actual farmers yield is much lower than the potential yield of the paddy crop and there is a huge 'yield gap'. Closing these gaps could improve not only the productivity but also the efficiency of rice production. The yield gap

is defined as the difference between the maximum-attainable yield and the farm level yield. There are number of empirical evidences regarding yield gap analysis of different food crops like Rice, Wheat, Maize etc. (Aggrawal, *et al.*, [1] and Elsamma [2]).

Yield gaps exist because the best available production technologies are not adopted in farmers' fields which could be due to farmers' personal characteristics like lack of knowledge and skills, risk bearing ability etc and farm characteristics like soil quality, land slope, poor road etc and unsuitability of the technology to farmers' circumstances like labour intensive, requirement of high initial investment, poor access to inputs.

There are many crop simulation models that can incorporate location specific physical conditions to estimate crop growth and potential yields for particular crop types, as well as for combinations of many crops. DSSAT is a popular crop simulation model that is used worldwide for modeling growth and yield of 30 different crops including rice, under given soil and daily weather conditions. DSSAT v 4.7.5 CERES-Rice model is a physiologically based rice model used as a tool for simulating growth and yield of rice under different environment and management strategies.

2. MATERIALS AND METHODS

2.1 Study area

This study was conducted in Karimnagar district of Telangana State. The latitude and longitude of Karimnagar district are 18.4386⁰N and 79.1288⁰E. This district was purposefully selected as the productivity of rice was more (>3 t/ha) in this district when compared to all other districts in Telangana.

2.3 Methodology

Growth Rates:

Linear growth rate (LGR) and compound growth rates (CGR) were calculated by fitting the linear and exponential functions given below.

Linear Function:

The linear function is $y = a + bt$

Where, y = farmers yield (dependent variable)

t = time in years (independent variable)

a and b are the constants or parameters

The above function is fitted using the ordinary least square method. The linear growth rate is calculated by using the formula:

$$\text{Linear Growth Rate (LGR)} = \frac{b}{y} \cdot 100$$

Compound Function:

The exponential function is used to estimate the compound growth rate which is represented by the equation $y = a \cdot b^t$ or in logarithmic form

$$\log(y) = \log(a) + t \log(b)$$

Where y = yield gap if the rice crop (dependent variable),

t = time in years (independent variable)

a and b are parameters and these parameters are estimated by the method of Ordinary Least Squares (OLS).

The Compound Growth Rate is calculated by the formula:

$$\text{Compound Growth Rate (CGR)} = (b - 1) \cdot 100$$

Potential yield (Y_p)

Potential Yield is the yield of a current cultivar “when grown in environments to which it is adapted; with nutrients and water non-limiting; and with pests, diseases, weeds, lodging, and other stresses effectively controlled” (Evans and Fischer [3]). Potential yield depends on location as it relates to weather but is independent of soil, which is assumed to be physically and chemically favorable for crop growth. In this study potential yield is simulated using DSSAT v4.7.5 CERES-Rice model.

DSSAT v4.7.5 CERES-Rice model

DSSAT v4.7.5 CERES-Rice modeling system is an advanced physiologically based rice growth simulation model used to predict rice growth, development, and response to various climatic conditions. This was through determination of duration of growth stages, dry matter production and partitioning, root system dynamics, effect of soil water and soil nitrogen contents on photosynthesis, carbon balance, and water balance (Ritchie *et al.*, [7]), followed by sensitivity analysis to assess the effects of change in weather conditions on the yield.

Potential yield is mainly dependent upon photosynthetically active radiation (PAR), light interception and the light conversion efficiency, while actual growth is a constraint of crop management, soil and weather interactions (Hoogenboom *et al.*, [4]). Thus, potential yield of rice in Karimnagar district of Telangana was simulated by giving the minimum data requirement needed by the model.

Potential Farm Yield (Y_d)

Attainable yield/Potential farm yield is the best yield achieved through skillful use of the best available technology (research station yields or demonstration plot yields). For this study potential farm yields were taken for the major rice growing cultivars in Karimnagar district given by the breeders from the published sources of DRR, PJTSAU. Table 1 depicts the Potential farm yields.

Table 1. Potential farm yield of rice crop

Cultivar name	Yield range (kg/ha)	
	From	To
JGL-1798	6000	6500
MTU-1010	5000	6500
MTU-1075	6000	6500
WGL-915	7000	7300
KNM-733	7300	7500
WGL-739	6500	7000
JGL-24423	7000	7500
WGL-347	6500	7000
JGL-18047	6300	6500
KNM-118	6800	7000
MEAN	6440	6930
OVERALL MEAN	6685	

Actual Yield (Y_a)

It reflects the current state of soils and climate, average skills of the farmers, and their average use of technology. To represent variation in time and space in a defined geographical region, it is defined as the average yield (in space and time) achieved by farmers in the region under the most widely used management practices (sowing date, cultivar maturity, and plant density, nutrient management and crop protection). We have collected the district average yields of Karimnagar district of Telangana from the DES (Directorate of Economics and Statistics) from 2015 to 2021.

Table 2. District average yields of Karimnagar

Year	Yield kg/ha
2006-07	2444
2007-08	2872
2008-09	2910
2009-10	2448
2010-11	2775
2011-12	2305

2012-13	2683
2013-14	2839
2014-15	2601
2015-16	2233
2016-17	2698
2017-18	2448
2018-19	2676
2019-20	3304
2020-21	5014

Yield gap

The yield gap comprises of two components, where the first component is yield gap I, it is the difference between Potential yield (Y_p) and Potential farm yield (Y_d) and the second component is yield gap II, it is the difference between the Potential farm yield (Y_d) and the Actual farmers yield (Y_a) (Nirmala [6]).

Yield gap I = Potential yield (Y_p) – Potential farm yield (Y_d),

Yield gap II = Potential farm yield (Y_d) – Actual yield (Y_a)

Total Yield Gap = Potential Yield (Y_p) – Actual Yield (Y_a) = Yield gap I + Yield gap II

3. RESULTS AND DISCUSSION

3.1 Potential yield

Potential yield of rice in Karimnagar district was calculated by using the DSSAT v4.7.5. CERES-Rice model for 15 years (2006-07 to 2020-21), as in the similar lines of potential yields of sugarcane simulated by Singh *et al.*, [8]. The potential yields of rice crop in Karimnagar district are presented in the Table 3. The mean potential yield for 15 years (2006-07 to 2020-21) was found to be 8433 kg/ha. The lowest potential yield 7728 kg/ha was simulated in the year 2019-2020 and the highest potential yield 9504 kg/ha was simulated in the year 2016-2017.

Table 3 Potential yields of rice in Karimnagar district

Year	Potential Yield
2006-07	8257
2007-08	8186
2008-09	9103
2009-10	7752
2010-11	7975
2011-12	8634
2012-13	8403

2013-14	8123
2014-15	8470
2015-16	8621
2016-17	9504
2017-18	8552
2018-19	8099
2019-20	7728
2020-21	9082
Mean	8433

3.2 Yield gap I

The Yield gap I of rice crop in Karimnagar district of Telangana state for 15 years (2006-2007 to 2020-2021) is given in Table 4. It was low (1043 kg/ha) in the year 2019-20 and high (2819 kg/ha) in the year 2016-17. The mean of the Yield gap I for all the years was found to be 1748 kg/ha. It was observed that yield gap I was fluctuating over the years. Fig.1 shows the yield gap I trends over the period under study.

Table 4. Yield gap I of rice in Karimnagar district

Year	Potential yield	Potential farm yield	Yield gap I
2006-07	8257	6685	1572
2007-08	8186	6685	1501
2008-09	9103	6685	2418
2009-10	7752	6685	1067
2010-11	7975	6685	1290
2011-12	8634	6685	1949
2012-13	8403	6685	1718
2013-14	8123	6685	1438
2014-15	8470	6685	1785
2015-16	8621	6685	1936
2016-17	9504	6685	2819
2017-18	8552	6685	1867
2018-19	8099	6685	1414
2019-20	7728	6685	1043
2020-21	9082	6685	2397
Mean	8433	6685	1748
LGR of Yield gap I			1.19

CGR of Yield gap I	0.97
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However, it was recorded that yield gap I showed non-significant positive linear (1.19) and compound (0.97) growth rates of rice crop in the selected district of the Telangana State. This might be due to the favorable environmental conditions to the rice crop in the district.

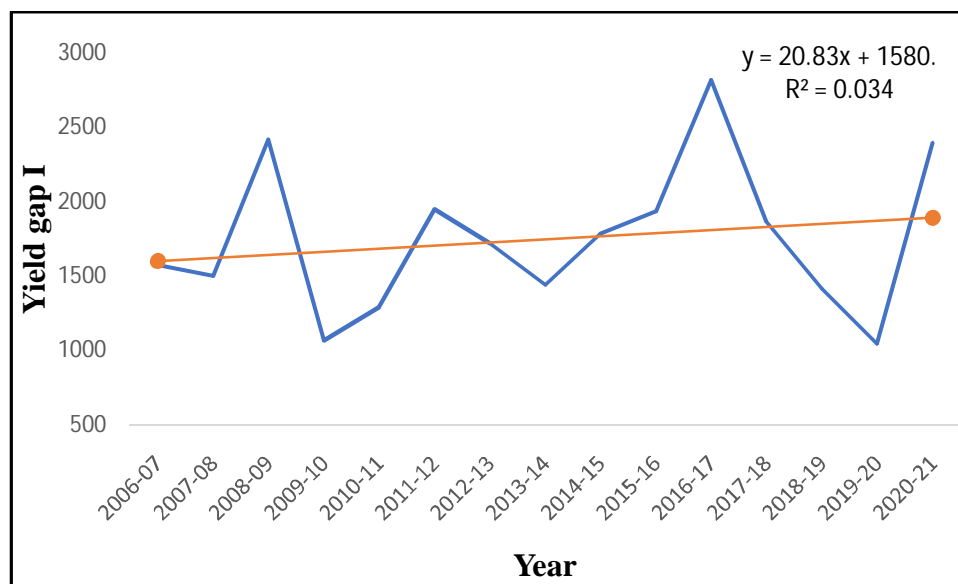


Fig.1 Yield gap I of rice in Karimnagar district

3.3. Yield gap II

Yield gap II of rice crop in Karimnagar district is depicted in the Table 5. Similar results were found by Nayak *et al.*, [5]. The mean of the yield gap II was 3211 kg/ha for 15 years. The highest and lowest values of yield gap II were 3551 kg/ha and 2792 kg/ha, in the years 2010-11 and 2020-21 respectively. The trends in the yield gap II is shown in the Fig.2. It was observed that, there was negative trend in the yield gap II which states that yield gaps are decreasing gradually over the years. It was observed that there were significant negative linear (0.91*) and compound (0.94*) growth rates in yield gap II during the period under study, which indicates that there was increase in farmers yield over the years in the selected area.

Table 5. Yield gap II of rice in Karimnagar district

Year	Potential farm yield	Actual yield	Yield gap II
2006-07	6685	3425	3260
2007-08	6685	3207	3507
2008-09	6685	3496	3218
2009-10	6685	3500	3214
2010-11	6685	3163	3551
2011-12	6685	3543	3171
2012-13	6685	3262	3452
2013-14	6685	3554	3160
2014-15	6685	3591	3123
2015-16	6685	3559	3155
2016-17	6685	3251	3463
2017-18	6685	3917	2797
2018-19	6685	3401	3313
2019-20	6685	3724	2990
2020-21	6685	3922	2792
Mean	6685	3501	3211
LGR of Yield gap II			-0.91*
CGR of Yield gap II			-0.94*

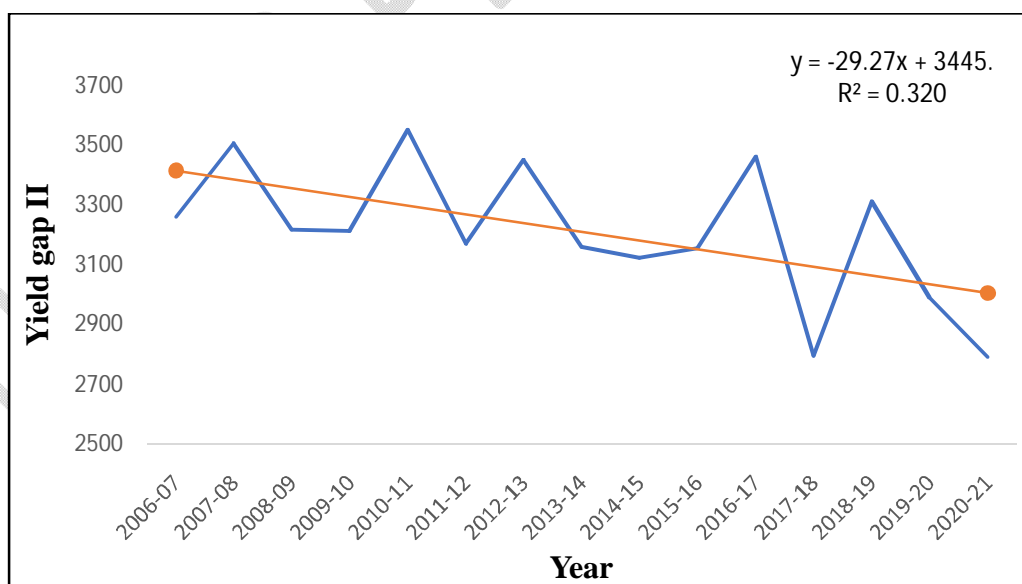


Fig.2 Yield gap II of rice in Karimnagar district

3.4. Total yield gap

The total yield gaps rice in Karimnagar were given in the Table 6. We can see that the mean total yield gap of Karimnagar district for 15 years was 4932 kg/ha. The total yield gap was least 4004 kg/ha) in the year 2019-20 and the highest (6253 kg/ha) was in the year 2016-17. These results are in accordance with Nayak *et al.*, [5]. The trends in total yield gaps are depicted in Fig.3. Negative trend in are observed in the total yield gaps. This indicates that the yield gaps are decreasing over the years. Total yield gaps showed non-significant negative linear (0.18) and compound (0.23) growth rates over the years in the Karimnagar district of Telangana. This states that farmers yields are increasing at a greater rate over the years in the selected district.

Table 6. Total yield gap of rice in Karimnagar district

Year	Potential yield	Actual yield	Total yield gap
2006-07	8257	3425	4832
2007-08	8186	3207	4979
2008-09	9103	3496	5607
2009-10	7752	3500	4251
2010-11	7975	3163	4813
2011-12	8634	3543	5091
2012-13	8403	3262	5141
2013-14	8123	3554	4570
2014-15	8470	3591	4878
2015-16	8621	3559	5061
2016-17	9504	3251	6253
2017-18	8552	3917	4635
2018-19	8099	3401	4698
2019-20	7728	3724	4004
2020-21	9082	3922	5160
Mean	8433	3501	4932
LGR of Total yield gap			-0.18
CGR of Total yield gap			-0.23

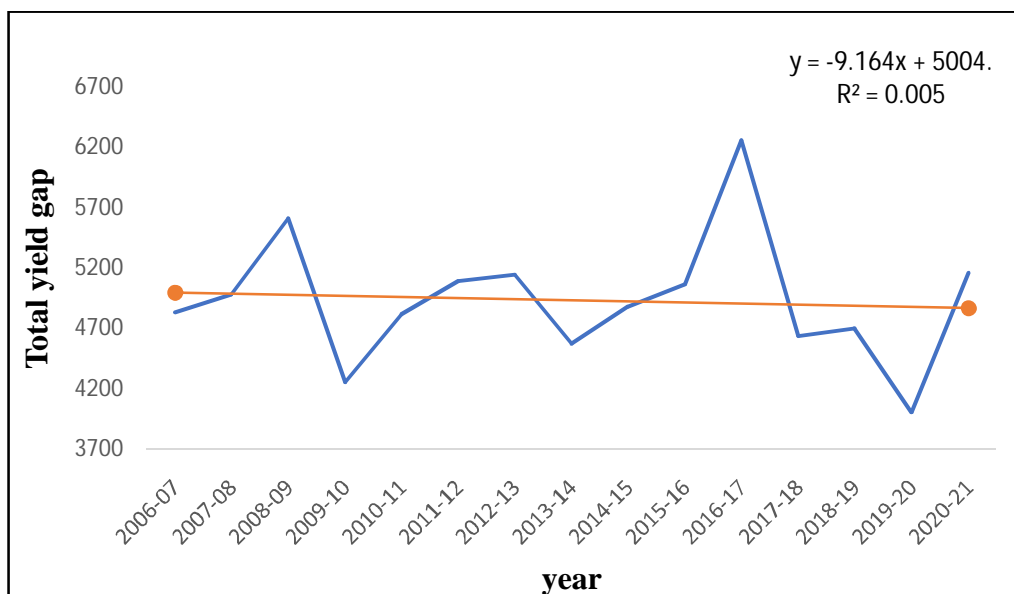


Fig.3 Total yield gap of rice in Karimnagar district

4. CONCLUSION

We have quantified the yield gaps of rice in Karimnagar district of Telangana state for 15 years (2006-2007 to 2020-2021). By using DSSAT v4.7.5 CERES-Rice model by giving the minimum data requirements we have simulated the potential yields of rice for Karimnagar district and potential farm yields were taken from the mean of major rice growing cultivars yield potentials in Karimnagar district given by the breeders.

Finally yield gaps were calculated. It was observed that there was no much difference in the yield gap I and the mean yield gap I was 1719 kg/ha. Yield gap I showed non-significant positive linear and compound growth over the years. The yield gap II showed decreasing trend. We have observed significant negative linear and compound growth rates in the yield gap II, from this we can say that there was increase in the productivity in farmer's fields. This is due to the increased availability of resources to farmers, release of high yielding varieties with disease resistance, improved management practices and increased extension activities. Total yield gap also showed negative trend and negative linear and compound growth rates. The mean total yield gap was 4932 kg/ha. But still the gap is huge which should be reduced. It can be reduced by increasing the extension activities and demonstrations for farmers about mechanization, new methods in crop production and educating farmers about the pros of application of correct dosage of fertilizers.

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