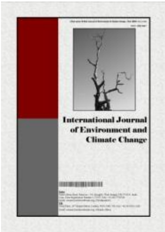


*International Journal of Environment and Climate Change*

***12(11): 3471-3478, 2022; Article no.IJECC.93177***
***ISSN: 2581-8627***
*(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)*


# Application of the CERES-Rice Model for Rice Yield Gap Analysis


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***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*


***Article Information***

DOI: 10.9734/IJECC/2022/v12i111396

**Open Peer Review History:**
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/93177

***Original Research Article***

***Received 20 August 2022***
***Accepted 26 October 2022***
***Published 01 November 2022***


## ABSTRACT


**Aim:** This study aimed to quantify and identify the trends in the yield gaps over the 15 years (2006-07 to 2020-21) in the Karimnagar district of Telangana State in India. The DSSAT v4.7.5 CERES-Rice model was used to calculate the potential yields and then yield gaps were calculated. For the yield gaps, linear and compound growth rates were determined.
**Results:** (Crop Environment Resource Synthesis) CERES-Rice model has simulated the potential yields with the given weather and soil data of Karimnagar district in India. 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, at 5% level, the growth rates in yield gap-II are significant.
**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. Using the



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DSSAT (Decision-support system for Agro-technology Transfer) model, potential rice yields in the Karimnagar district were predicted. 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.

*Keywords: 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). Telangana has become one of the nation's top producing States of rice over the past six years. Farmers have started cultivating paddy on a wide scale now that irrigation facilities and related irrigation systems are better. In Telangana rice was 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).

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 difference between the greatest yield that can be achieved and the yield at the farm level is known as the yield gap. There are number of empirical evidences regarding yield gap analysis of different food crops like Rice, Wheat, Maize etc. (Agrawal, et al*.* [1] and Elsamma [2]).

Yield gaps exist as a result of farmers not implementing the best production technologies in their fields (Zegeye et al*.* [3] and Zhijuan et al. [4]). This could be due to farmers' personal traits like a lack of knowledge and skills, an inability to accept risk, etc., as well as farm traits like soil quality, land slope, poor roads, etc., as well as the technology's suitability to farmers' circumstances like labour intensive, requiring a high initial investment, and having limited access to inputs (Rimal et al*.* [5])

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. An advanced physiologically based crop growth simulation model is the Decision Support System for Agrotechnology Transfer (DSSAT) modelling system (Tsuji et al*.* [6] and Hoogenboom et al*.* [7]). 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 $18.4386^0$N and $79.1288^0$E. This district was purposefully selected as the productivity of rice was more (>3 t/ha) in this district.

### 2.2 Methodology

#### 2.2.1 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:

Linear Growth Rate = $(\mathrm{LGR}) = \frac{b}{y}.100$

**Compound function:** The exponential function is used to estimate the compound growth rate which is represented by the equation $y = a.b^t$ 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:

Compound Growth Rate (CGR) = $(b-1).100$'

### 2.2.2 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 [8]). Potential yield is not influenced by soil, which is thought to be physically and chemically conducive for crop growth, but rather by location and weather (Wart et al. [9]). In this study potential yield is simulated using DSSAT v4.7.5 CERES-Rice model.

### 2.2.3 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 done by measuring the length of the growth phases, the production and partitioning of dry matter, the dynamics of the root system, the impact of the soil water, and the soil nitrogen concentration (Ritchie et al. [10]), followed by sensitivity analysis to assess the effects of change in weather conditions on the yield.

Potential production is primarily influenced by photosynthetically active radiation (PAR), light absorption, and the efficiency of light conversion, whereas actual growth is a constraint of crop management, soil and weather interactions (Hoogenboom et al. [7]). Thus, potential yield of rice in Karimnagar district of Telangana was simulated by giving the minimum data requirement needed by the model.

### 2.2.4 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 IIRR (Indian Institute of Rice Research), PJTSAU (Professor Jayashankar Telangana State Agricultural University). 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 | |

#### 2.2.5 Actual yield ($Y_a$)

It reflects the current state of soils and climate, average skills of the farmers, and their average use of technology. It is defined as the average yield (in location and time) attained by farmers to represent variation in time and place in a specific geographic area 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 |

#### 2.2.6 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 [11] and Sunandhini et al. [12]).

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. [13] and 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. It was discovered that the average Yield gap I for all years was 1748 kg/ha. It was seen that the yield gap I changed with time. Fig. 1 shows the yield gap I trends over the period under study.

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.

### 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. [14]. 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. Fig. 2 depicts the trends in the yield gap II. It was shown that the yield gap II had a negative trend, indicating that yield gaps are increasingly shrinking over time. 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 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 |

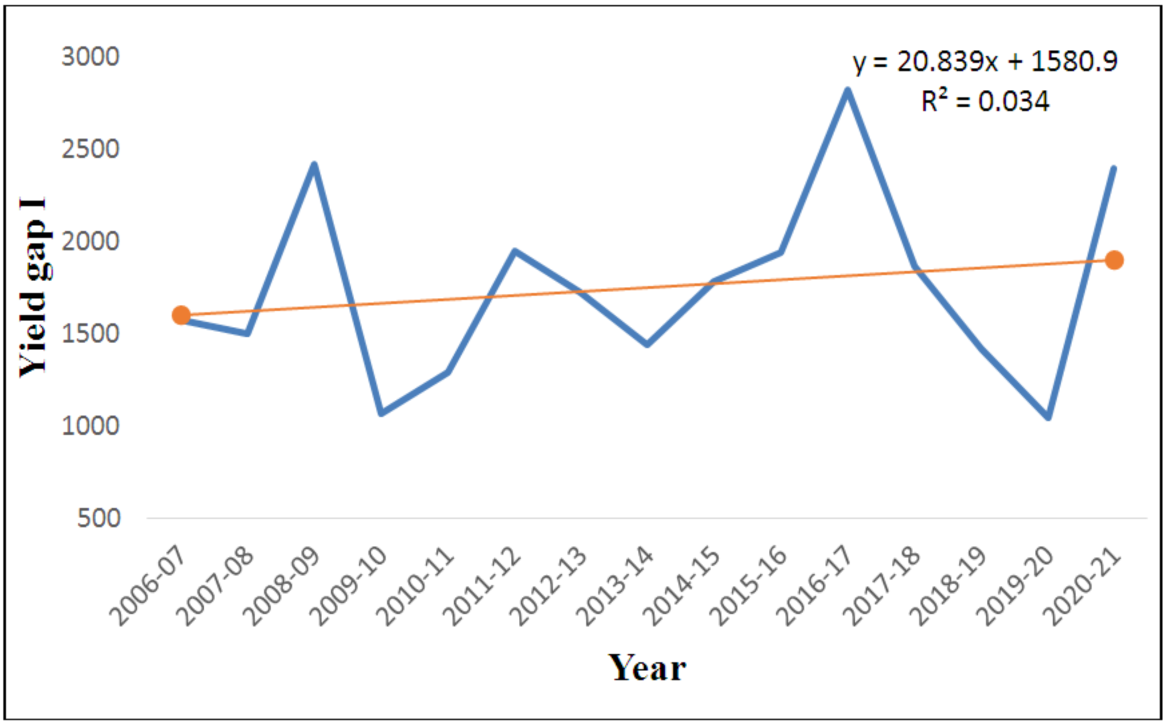


**Fig. 1. Yield gap I of rice in Karimnagar district**

**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* |

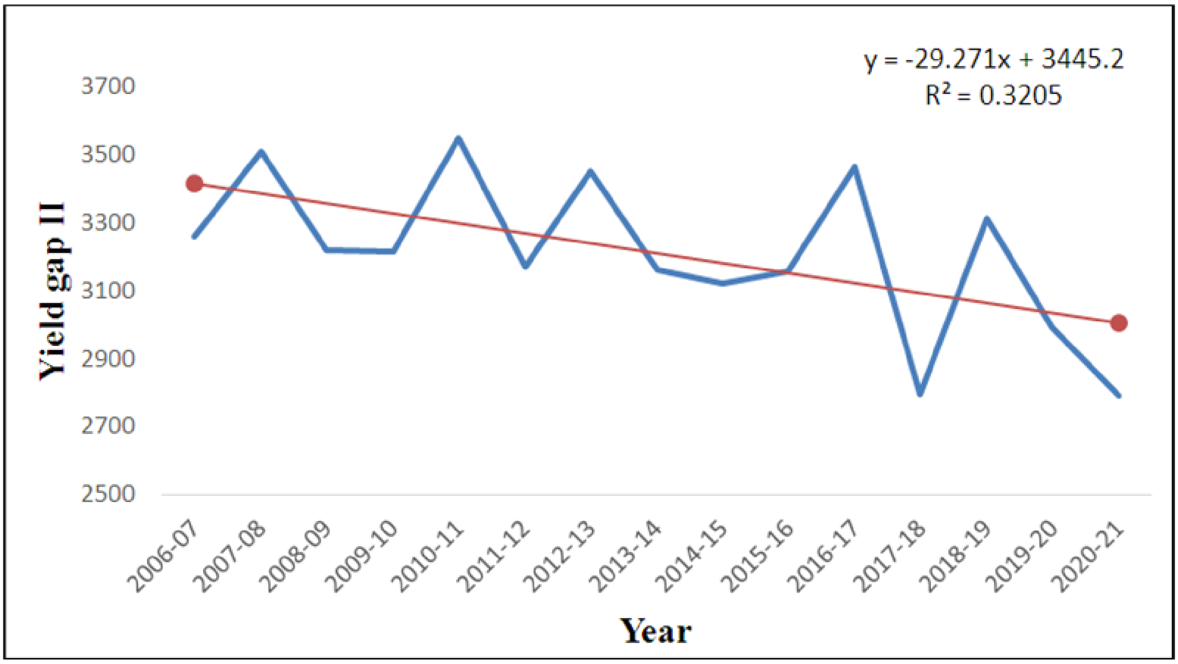


**Fig. 2. Yield gap II of rice in Karimnagar district**

## 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. [14].

Fig. 3 shows the trends in the overall yield gaps. There is a downward tendency in the total yield gaps. This suggests that yield gaps are getting less over time. 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 |

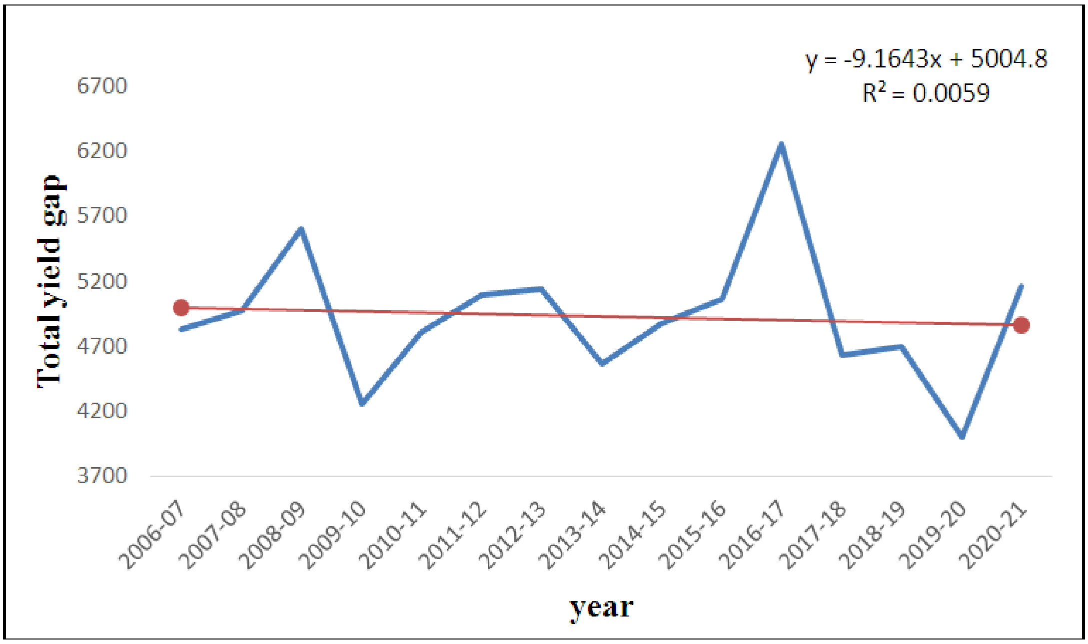


**Fig. 3. Total yield gap of rice in Karimnagar district**

## 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 the average of the major rice cultivars' potential yields in the Karimnagar district, as provided by the breeders, was used to calculate potential farm yields.

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 a result of the increased resources available to farmers, the introduction of high-yielding, disease-resistant varieties, enhanced management techniques, and greater extension operations. Additionally, the total yield gap displayed a downward trend and negative rates of linear and compound growth. 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 educating farmers about the benefits of applying fertilizer in the proper dosage, new techniques in agricultural production, and extension operations.

## ACKNOWLEDGEMENT

This study is a part of the first author's post graduate work at Professor Jayashankar Telangana State Agricultural University. The authors are highly grateful for the facilities provided by the College of Agriculture, Professor Jayashankar Telangana State Agricultural University and ICAR-Indian Institute of Rice Research, Rajendranagar, 500030.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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