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Analysis of Potential Yield and Yield gap of Kharif Rice in Prayagraj district of Uttar Pradesh using CERES-Rice Model

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ABSTRACT

The study explains the modelling strategy used to calculate the yield gap in the Prayagraj district of Uttar Pradesh. CERES Rice model was calibrated and validated for all the cultivars. Eight years of (2012-2019) Prayagraj district yields were collected from College of Forestry, SHUATS, Prayagraj. The difference between potential and actual yield served as the basis for the yield gap estimation. The average yield gap for Prayagraj condition of Swarna sub-1, Sarjoo-52, Pant dhan 4 and NDR – 359 was 819.375 kg/ha, 1178.75 kg/ha, 605.875 kg/ha and 1034.375 kg/ha respectively. Among all the four varieties Pant dhan 4 is having least yield gap. The results suggest that there is plenty of scope to increase farmers' yields by improving crop management.

Key words: *Yield gap, Crop simulation model, Potential yield.*

Introduction

Since the expanding global population and average income, demand for both food and energy is rapidly increasing and will do so in the future. By 2030, global cereal demand for food and animal feed alone is expected to total 2.8 billion tons per year, or 50% higher than in 2000 Bruinsma (2003). 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 2021-22 was 515.3 million metric tons USDA (2022). In India rice production during the year 2021-2022 was 129.66 million tons India stat (2021-22). In the year 2020 & 2021, rice production across the northern state of Uttar Pradesh in India amounted to over 15.52 million metric tons (Statista). The state has 5.6 million ha under rice cultivation, which covers irrigated and rainfed areas. The current state average productivity of rice is about 2 tons/ha (ICAR). By filling the loopholes, rice production might become more productive and efficient. The yield gap is the difference between the maximum yield that can be produced and the yield at the farm level. There are number of empirical evidences regarding yield gap analysis of different food crops like Rice, Wheat, Maize etc. Agrawal *et al*. (2008) and Elsamma (2006).

Yield gaps exist as a result of farmers not implementing the best production technologies in their fields Zegeye *et al*. (2020) and Zhijuan *et al*. (2012). This could be due to farmers' personal traits like, 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*. (2015).

Many crop simulation models may predict crop growth and potential yields for single crop types as well as for combinations of many different crops by factoring in location-specific physical factors. A well-known crop simulation model called DSSAT is used all over the world to simulate the growth and production of 30 different crops, including rice, in specified soil and daily weather conditions. DSSAT 4.7.5 CERES-Rice model, which simulates rice development and production under various environmental conditions and management techniques, is based on physiological principles.

Several studies have shown that assessment of potential yield and yield gaps can help in identifying the yield limiting factors and in developing suitable strategies to improve the productivity of a crop Aggarwal and Kalra (1994); Lansigan *et al*. (1996); Evenson *et al*. (1997); Naab *et al.* (2004). Understanding crop growth and development, which in turn depends on a number of climatic, edaphic, hydrological, physiological, and managerial aspects, is necessary to calculate potential yield and the differences between potential and actual yields. Field studies may require several years of data gathering in order to identify the yields at various production levels and quantify the yield gaps in order to draw conclusions that are useful.

In recent years, in order to anticipate crop growth, development, and yield, a number of process-based dynamic crop simulation models have been created. These models use a systems approach that combines knowledge of the underlying processes and interactions of various crop production components Boote *et al*. (1996). These simulation models are being used more and more in the yield gap analysis, which evaluates the yields for a specific region with given environmental conditions that characterize the elements that define crop growth and development, such as water non-limiting potential, water limiting potential, or nutrient-limiting potential Aggarwal and Kalra (1994); Lansigan *et al.* (1996); Naab *et al*. (2004). However, before a model is put to use, it needs to be thoroughly tested and validated for given region to establish its credibility Boote *et al.* (1996).

Materials and Methods

Prayagraj is taken as the representative experimental site in Uttar Pradesh. The experiment was carried out at College of Forestry, SHUATS, Naini, Prayagraj is situated at 25.4358° N latitude, 81.8463° E longitude. Its elevation is over 90 m above sea level. The climate of Prayagraj has a humid subtropical climate. The annual mean temperature is 26.1 °C. Precipitation occurs from June to September, supplying the city with annual rainfall of 1,027 mm.To use CERES Rice model weather data, soil data, and crop management data of about 8 years (2012-2019) were taken as input. Weather file includes maximum temperature, minimum temperature, solar radiation and rainfall data of the experimental area. As soil is a major component for the growth of crop, soil file includes the details of soil like soil characteristics such as, soil type and soil series, pH, soil texture and soil N and C content. DSSAT crop simulation model required some of crop management data like (crop, cultivar, planting date, row and plant spacing, fertilizer levels, irrigation, transplanting details, tillage practices and organic manure applications) in experimental/seasonal file to simulate crop productivity.

CERES is a process-based, dynamic and mechanistic model which can simulate the growth and development of cereal crops under varying weather, soil and management levels. The various processes simulated by this model are phenological development of the crop; growth of leaves, stems and roots; biomass accumulation and partitioning among leaves, stem, panicle, grains and roots; soil water balance and water use by the crop; and soil nitrogen transformations and uptake by the crop. This model is running under the DSSAT include the CERES (Crop Estimation through Resource and Environment Synthesis) for model cereal such as, rice, wheat, maize, sorghum, pearl millet etc.

The DSSAT was originally developed by an international network of scientists, cooperating in the International Benchmark Sites Network for Agrotechnology Transfer project IBSNAT (1993); Tsuji (1998); to facilitate the application of crop models in a systems approach to agronomic research.

Varieties: There were four varieties used i.e., Swarna sub-1, Sarjoo-52, Pant dhan 4 & NDR-359. The genetic coefficients of varietieswere calibrated for Prayagraj condition via trial-and-error method, which is presented in the Table below.

Calibration and Validation

Before applying the model, they were first calibrated and verified for the pertinent types and environment. Validation is decided using statistics. It is used to assess the model's accuracy. An objective technique for assessing the performance of the models is provided by statistically based criteria Ducheyne (2000). For the validation of the model in this work, only agricultural yield data is employed. Percent Error, RMSE, and nRMSE calculations were made for the model's validation.

$$Percent\ Error = \frac{|E - T|}{|T|} \times 100$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(O_i - M_i)^2}$$

$$nRMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(O_i - M_i)^2} \times \frac{100}{\bar{O}}$$

Where, E = Experimental Value, T = Theoretical Value, M_i = model output, O_i = observations value & $\bar{O}$ = mean of the observations.

Potential Yield: By nullifying the nitrogen and water stress in simulation option Potential yield was estimated by model. This is the yield of the cultivar with no limiting factors.

Yield gap: Yield gap analysis is a powerful method to reveal and understand the biophysical opportunities to meet the projected increase in demand for agricultural products and to support decision making on research, policies, development and investment that is needed. The yield gap is the difference between potential and actual farm yields. Yield potential and yield gaps are site-specific because they depend on local climate, soil properties, and cropping system in terms of when each crop is planted and reaches maturity. Patel *et al.* (2006) and Patel *et al.* (2008) analyzed the yield gap in different districts of Gujarat and suggested the subsequent adjustment of appropriate sowing window to provide possibilities for obtaining potential yields.

Experimental yield gap = experimental potential yield–measured yield

Results and Discussion

Calibration and Validation: To assess the model's accuracy in Prayagraj conditions, the model was calibrated for two years 2012 to 2013, and then validated from 2014 to 2019. For each of the four varieties, the actual and simulated yield data from the years 2012 to 2019 are shown in Table 2. Average percent error, RMSE, and nRMSE were determined to evaluate the models' performance. The model assessment demonstrated satisfactory performance with calibration (PE =2.43, 6.26, 4.31, 3.79, RMSE=132.79, 345.13, 237.44, 237.85, nRMSE=2.53, 7.31, 4.46,3.97) and validation (PE=3.58, 10.03, 4.28,6.09; RMSE=197.88, 456.35, 238.37, 366.52; nRMSE= 3.95, 10.55, 4.67, 6.39) for Swarna sub-1, Sarjoo-52, Pant Dhan 4 and NDR-359 cultivars respectively, demonstrating good agreement between expected and actual values. It proves the model is appropriate for these cultivars in the Prayagraj environment.

With the use of grain yield, the DSSAT CERES - rice model was calibrated and validated for all four cultivars. According to the findings, all values fell within desirable ranges of less than 10% for the nRMSE and within respectable limitations of fewer than 15% for the percent error. As a result, under Prayagraj circumstances, the CERES-Rice crop model may be used to precisely estimate the yield and growth of all four varieties of rice. Of the four varieties for the Prayagraj region, NDR 359 yields the most, followed by Pant Dhan 4, Swarna Sub 1, and Sarjoo-52.

Potential yield of Rice: The Table 3 shows the potential yield and actual yield as a percentage of potential yield for 2012 – 2019. Average potential yield shows maximum for variety NDR-359 with 6829.375 kg/ha followed by Swarna sub-1 with 5882.875 kg/ha, Pant dhan 4 with 5760.75 kg/ha and Sarjoo-52 with 5599.625 kg/ha. The potential yield was maximum in year 2014 for cultivar Swarna sub-1, NDR-359, Sarjoo-52 and 2013 for Sarjoo-52. The production yield of the varieties for Prayagraj condition

Table 1. Genetic coefficient of varieties used in DSSAT

Varieties	P1	P2R	P5	P2O	G1	G2	G3	G4
SWARNA SUB 1	750.0	150.0	400.0	11.3	59.0	0.0220	1.00	1.00
SARJOO - 52	450.0	170.0	365.0	12.2	47.0	0.0238	1.00	1.00
PANT DHAN 4	830.0	160.0	300.0	11.4	45.0	0.0300	1.00	1.00
NDR 359	500.0	200.0	450.0	12.5	62.0	0.019	1.00	1.00

Table 2. Comparison of cultivars observed value with simulated value of grain yield for the year 2012 – 2019.

Year	Swarna Sub 1			Sarjoo-52			Pant Dhan-4			NDR- 359		
	Actual Yield (Kg/ha)	Simulated Yield (Kg/ha)	Percent Error %	Actual Yield (Kg/ha)	Simulated Yield (Kg/ha)	Percent Error %	Actual Yield (Kg/ha)	Simulated Yield (Kg/ha)	Percent Error %	Actual Yield (Kg/ha)	Simulated Yield (Kg/ha)	Percent Error %
					Calibration							
2012	5118	5023	1.85	4796	4688	2.25	5349	5060	5.40	5725	5558	2.91
2013	5371	5209	3.01	4635	5111	10.26	5283	5454	3.23	6238	6530	4.68
Avg P.E (%)	2.43	6.26	4.31	3.79								
RMSE	132.79	345.13	237.44	237.85								
nRMSE	2.53	7.31	4.46	3.97								
					Validation							
2014	5246	5552	5.83	4581	5196	13.42	5472	5636	2.99	6021	6545	8.70
2015	5460	5236	4.10	4093	4644	13.46	5016	5393	7.51	6107	5726	6.23
2016	5127	5310	3.56	4412	4939	11.94	5164	5395	4.47	5514	5847	6.03
2017	4813	4930	2.43	4257	4649	9.20	4837	4902	1.34	5397	5110	5.31
2018	4941	5139	4.00	4329	4584	5.89	5320	5505	3.47	6202	5815	6.23
2019	4432	4501	1.55	4264	4531	6.26	4798	4515	5.89	5156	5364	4.03
Avg P.E (%)	3.58			10.03			4.28			6.09		
RMSE	197.88			456.35			238.37			366.52		
nRMSE	3.95			10.55			4.67			6.39		
Average Yield (2012-19)	5063.5	5112.5	3.29	4420.87	4792.75	9.08	5154.87	5232.5	4.29	5795	5811.87	5.52

NOTE: Avg P.E (%)= (Average Percent Error), RMSE=(Root Mean Square Error), nRMSE =(Normalised Root Mean Square Error).

were worked out using DSSATmodel. The results are shown in Table 3. The minimum potential yield for the varieties of Swarna sub-1 with 5672 kg/ha, Sarjoo-52 with 5301 kg/ha, Pant dhan 4 with 5660 kg/ha and NDR-359 with 6194 kg/ha. As we see the maximum potential yield for every year compare with all other varieties as taken and the average potential yield is highest in NDR-359 variety.

Average potential yield for each cultivar Swarna sub-1, Sarjoo-52, Pant dhan 4, NDR-359 were shown as 5882.875 kg/ha, 5599.625 kg/ha, 5760.75 kg/ha and 6829.375 kg/ha respectively. The average highest potential yield is in NDR-359 and lowest potential yield found in Sarjoo-52 rice variety. The actual yield as percentage of potential yield showed as 86.04%, 79.07%, 89.48%, 84.83% respectively for Swarna sub-1, Sarjoo-52, Pant dhan 4 and NDR-359 varieties.

Yield gap analysis: Yield gap of varieties Swarna sub-1, Sarjoo-52, Pant dhan 4, NDR- 359 is shown in Figure 1 below. Yield gap graph shows the increasing trend for Swarna sub-1 and Pant dhan 4 variety. Decreasing trend of Yield gap shows for Sarjoo-52 and NDR-359 cultivar as in the graph. R^2 value for Swarna sub-1, Sarjoo-52, Pant dhan 4 and NDR-359 were 0.429, 0.182, 0.160 and 0.009 respectively.The average yield gap for Prayagraj condition of Swarna sub-1, Sarjoo-52, Pant dhan 4 and NDR-359 was 819.375 kg/ha, 1178.75 kg/ha,605.875 kg/ha and 1034.375 kg/ha respectively. The least average yield gap was seen for cultivar Pant dhan 4 followed by Swarna sub-1, NDR-359 and more yield gap found for Sarjoo-52. This shows that Pant dhan 4 is near to its potential yield when compared to other varieties as seen in Table 3.

As we can see in Table 3, from 2012-2019, in year 2018 Pant dhan 4 and NDR-359, Sarjoo-52 in 2012 and in 2015 Swarna sub-1 shows least yield gap difference between actual and potential yield. Among the four varieties Pant

Table 3. Potential yield (kg/ha) of rice varieties

YEAR	Potential yield of SWARNA SUB 1 (Kg/ha)	Actual yield as % of potential yield	Potential yield of SARJOO-52 (Kg/ha)	Actual yield as % of potential yield	Potential yield of Pant Dhan-4 (Kg/ha)	Actual yield as % of potential yield	Potential yield of NDR-359 (Kg/ha)	Actual yield as % of potential yield
2012	5903	86.70	5304	90.42	5714	93.61	6807	84.10
2013	6171	87.03	5922	78.26	5867	90.04	6941	89.87
2014	6232	84.17	5826	78.63	6006	91.10	7381	81.57
2015	5892	92.66	5558	73.64	5859	85.61	7090	86.13
2016	5789	88.56	5808	75.96	5768	89.52	6834	80.68
2017	5672	84.85	5301	80.30	5484	88.20	6494	83.10
2018	5705	86.60	5363	80.71	5660	93.99	6894	89.96
2019	5699	77.76	5715	74.61	5728	83.76	6194	83.24
Average	5882.87	86.04	5599.62	79.07	5760.75	89.48	6829.37	84.83

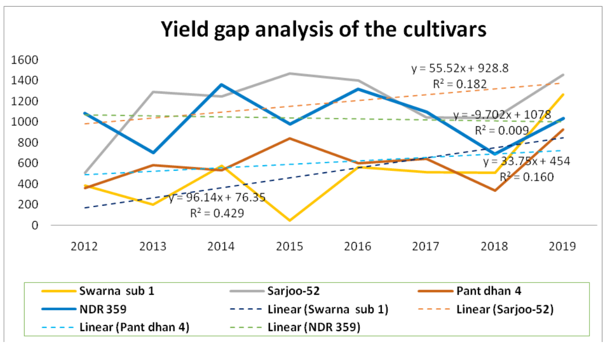

Fig. 1. Yield gap analysis for the cultivars of Swarna sub-1, Sarjoo-52, Pant dhan 4 and NDR-359

dhan 4 is having least yield gap.

Actual average yield of cultivar Swarna sub-1, Sarjoo-52, Pant dhan 4 and NDR-359 were shown as 5063.5 kg/ha, 4420.87 kg/ha, 5154.87 kg/ha and 5795 kg/ha respectively under Prayagraj condition. The average yield gap varied as per varieties like 819.37 kg/ha, 1178.75 kg/ha, 605.87 kg/ha and 1034.37 kg/ha for Swarna sub-1, Sarjoo-52, Pant dhan 4 and NDR-359 respectively. Pant dhan 4 variety showed very less yield gap which means its actual yield is near to its potential yield. As per analysis the value of R^2 for Swarna sub-1, Sarjoo-52, Pant dhan 4, NDR-359, were 0.429, 0.182, 0.160, 0.009 respectively.

Conclusion

Potential yield and yield gap analysis showed that all the four varieties were suitable for Prayagraj region. Among the four varieties NDR-359 shows more & cultivar Sarjoo-52 shows less potential yield. On the basis of yield gap analysis Sarjoo-52 variety has more and Pant dhan-4 has less yield gap for Prayagraj region. The DSSAT V4.7.5 model-based yield gap study of crops revealed that, following the calibration and validation processes, the model was found to be extremely robust and capable of accurately predicting the phenology and yield of every variety with errors well within acceptable range. The potential yield, yield gap analysis, nutrition management etc. may all be studied using this

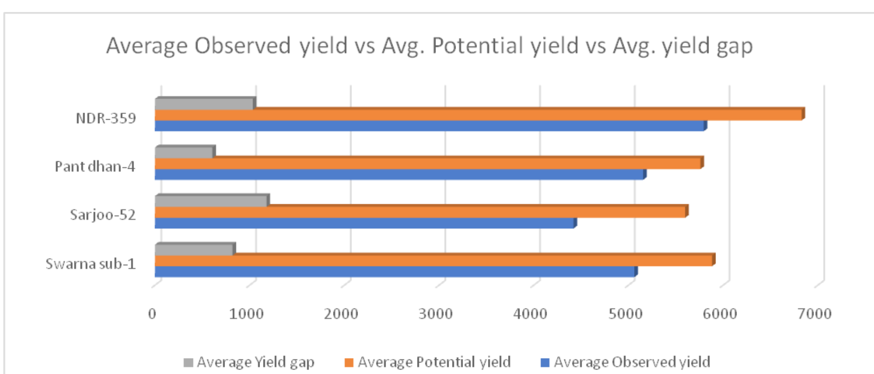

Fig. 2. Actual average yield vs potential average yield vs Average yield gap

model. According to the varieties, the average yield gap fluctuated, with values for Swarna sub-1, Sarjoo-52, Pant dhan 4 and NDR-359 being 819.37 kg/ha, 1178.75 kg/ha, 605.87 kg/ha, and 1034.37 kg/ha, respectively. However, there is still a significant gap that has to be closed. It may be decreased by better informing farmers about the advantages of using fertilizer in the right quantities, new methods for agricultural output, and extension activities. By better crop management, farmers may enhance their yields, and research should concentrate on maximizing yield and resource efficiency. Combining socio-economic research with simulation models like CERES Rice might be a successful strategy for doing this, but rigorous assessment is required before models can be used to help define recommendations and policies for sustainable cropping systems.

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