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Yield Gap Analysis in *Kharif* Sorghum Hybrid CSH-16 across 12 Districts of North Interior Karnataka, India

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ABSTRACT

In North Interior Karnataka (NIK) sorghum is grown during both *kharif* and *rabi* seasons and CSH-16 is a nationally released hybrid for *kharif* season. The yield gap analysis is very essential to quantify the difference between potential yield and actual yield of a given crop cultivar under rainfed conditions so that agronomic adaptations are devised to fill the gap. This plays very important role under rainfed conditions because the yield is often limited by water stress followed by N stress. For this, calibrated and validated DSSAT-CERES was used to run simulations from 1988 to 2018 (31 years) for the *kharif* sorghum hybrid CSH-16 under potential and rainfed conditions on two predominant soils (black clay and red loamy) across 12 districts of NIK. The results showed that average grain yield for NIK in rainfed condition was 2734 kg/ha, with 2272 kg/ha on black clay soil and 3195 kg/ha on red loamy soil. When crop was grown under potential conditions the yield level improved, on average, by 13.0 % to 3079 kg/ha, with 2630 kg/ha on black clay soil and 3528 kg/ha on red loamy soil, indicating that there is a scope to improve grain yield by providing irrigation at critical stages. Across 12 districts of NIK under current climate (1988-2018) on black clay soils the highest yield gap (76 %) was simulated for Koppal district and the lowest yield gap (0.8 %) simulated for Bidar district. Similarly, on red loamy soils the highest yield gap (25 %) was simulated for Vijayapura district and the lowest yield gap (0.1 %) simulated for Bidar district indicating higher yield gap on black clay soil than on red loamy soil.

KEYWORDS

DSSAT, yield gap, simulation, kharif sorghum, potential yield

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INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is one of the world's most important nutritional cereal crops and also the major staple food crop of millions of people in semi-arid tropics (SAT). It is extensively grown in Africa, India, China, USA and Mexico. In India, sorghum is grown during both *kharif* and *rabi* seasons, and its major area is concentrated in the Deccan Plateau, Central and Western India apart from a few patches in Northern India. More than 90 % of the total area is rain-fed (Sandeep *et al*, 2017), and about 85 % of total production is concentrated in the semi-arid regions of Karnataka, Maharashtra, Telangana and Andhra Pradesh. The per capita land availability in rainfed areas is expected to fall from 0.28 ha in 1990 to 0.12 ha by 2020. It means more food has to be produced from each unit of land to meet the growing food needs in future. Hence it is important that production per unit land is enhanced by achieving potential yield of each crop sown. Potential yield is the highest yield possible of a crop cultivar under optimum management conditions for a given location. Identifying the yields at different production levels and quantifying the yield gaps among them through field experiments requires many years of data collection to come up with meaningful inferences. Besides total elimination of factors other than the ones governing growth and development, and their interactions for a given production level may not be possible in field experiments. Several process-based dynamic crop simulation models (CSMs) have been developed to predict crop growth, development and yield using systems approach by integrating the knowledge of the underlying processes and interaction of different components of crop production (Boote *et al*, 1996). These CSMs are being increasingly used in the yield gap analysis by assessing the water non-limiting, water limiting or nutrient-limiting yields for a particular region with given environmental conditions (Aggarwal and Kalra, 1994) , (Lansigan *et al*, 1996; Naab *et al*, 2004).

The NIK is a geographical region consisting of mostly semi-arid plateau from 300 to 730 metres (980 to 2,400 ft) elevation that constitutes the northern part of the South Indian state of Karnataka. It includes 12 districts namely Bagalkote, Belagavi, Ballari, Bidar, Dharwad, Gadag, Haveri, Kalaburgi, Koppal, Raichur, Vijayapura and Yadagir. This region is largely covered with rich black cotton and red loamy soils, gently sloping lands and plains, summits of plateau, and table

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lands. Crops in NIK experience moisture stress either due to low rainfall or untimely rain or long dry spells during crop season, thus greatly reduce yields and large gap exists between rainfed and potential yields. In this study calibrated and validated DSSAT-CERES Sorghum model was used to estimate yield gap under rainfed and potential conditions for kharif sorghum hybrid CSH-16 under current climate (1988-2018) across 12 districts NIK both on black and red soils.

MATERIALS AND METHODS

To calibrate and validate the DSSAT-CERES-Sorghum model, the experimental data of kharif sorghum hybrid CSH-16 were collected from the AICRP- Sorghum scheme during kharif season of 2016-17 and 2017-18 carried out under both rainfed and irrigated condition on deep black soils at Main Agricultural Research Station of University of Agricultural Sciences, Dharwad, which is located at 15 ° 26′ N latitude, 75 ° 07′ E longitude and at an altitude of 678 m above mean sea level, and comes under Northern Transition Zone (Zone-8) of Karnataka. The data on daily weather parameters required to build weather file within the DSSAT model were recorded from Meteorological Observatory, Main Agricultural Research Station, University of Agricultural Sciences, Dharwad for the experimental year 2016-17, and 2017-18 and used for calibration and validation process. The historical weather data from 1988-2018 (31 years) were downloaded from NASA power web portal (www.power.larc.nasa.gov) for subsequent seasonal analysis. Yearly weather files for 2016-17 and2017-18 were built as well as one combined file for the period of 1988-2018 (31 years) using WeatherMan software within the DSSAT ensemble. Soil profile data of both black clay and red loamy soils with a profile depth of 125 cm and 35 cm, respectively, for all 12 districts were collected from ICAR Krishi Geoportal website (http://geoportal.icar.gov.in). The texture, N, P and K (kg ha^{-1}) data for both the soils of all the 12 districts for initial status were collected from soil health card web portal of the Ministry of Agriculture and Farmers Welfare, Govt. of India (https://soilhealth2.dac.gov.in/Health Card). All these files were used to run the model for calibration using 2016-17 data and validation using 2017-18 data, and also sequential analysis for 31 years using 1988-2018 observed weather data for each district. Standard production practices recommended by UAS Dharwad for *kharif* sorghum in NIK were considered to run simulations.

A program named GenCalc (Genetic Coefficient Calculator) embedded within DSSAT-CERES model to optimise genetic coefficients was used. GenCalc was designed to iteratively run the related model on semi-auto mode with the approximate genetic coefficients and match the measured values, and under each iteration the genetic coefficients were changed until the predicted values matched the measured values within acceptable range of difference (Hunt *et al*, 1993). A total of 11 genetic coefficients were optimised by the DSSAT-CERES model for *kharif* sorghum hybrid CSH-16 and are represented in Table 1 .

Table 1: Optimized genetic coefficients after calibration for *kharif* sorghum hybrid CSH-16 with coefficient codes and description.

Coefficient Code	Description	CSH-16
P1	Thermal time (TT) from emergence to the end of the juvenile phase	214.10
P2	TT from the end of juvenile stage to tassel initiation under short days	80.00
P2O	Critical photoperiod or the longest day length (in hours) at which development occurs at a maximum rate.	12.46
P2R	Extent to which phasic development leading to panicle initiation (expressed in degree days) is delayed for each hour increase in photoperiod above P2O	88.16
PANTH	TT from the end of heading to fertilization stage	580.50
P3	TT from to end of flag leaf expansion to fertilization stage	133.00
P4	TT from fertilization to beginning grain filling stage	92.00
P5	TT from beginning of grain filling to physiological maturity stage	656.00
PHINT	Phylochron interval i.e., TT between successive leaf tip appearances	54.02
G1	Scale for relative leaf size	7.261
G2	Scale for partitioning of assimilates to the ear head.	5.652

The simulations were run for each of 12 districts of NIK both under rainfed and potential conditions (no moisture stress) using historic weather data of 31 years (1988-2018) to generate simulated yields of *kharif* sorghum hybrid CSH-16 for each district under rainfed and potential conditions grown across eight different dates of sowing at weekly interval from 22nd

May to 15th July on two predominant representative black clay and red loamy soils of NIK.

RESULTS AND DISCUSSION

Considerable difference in yield, as expected, was simulated between rainfed and potential conditions among the districts as well as between black clay and red loamy soils across NIK. Simulated grain yield of *kharif* sorghum hybrid CSH-16 under current climate (1988-2018) on black clay soils in rainfed conditions was the highest in Bagalkote district (3265 kg/ha) followed by Gadag (3041 kg/ha) and Dharwad (3028 kg/ha) districts, whereas the lowest yield was simulated for Haveri district (1122 kg/ha) followed by Koppal (1257 kg/ha) and Belagavi (1549 kg/ha) districts among the 12 districts of NIK. The difference between the highest (3265 kg/ha) and lowest yielding (1122 kg/ha) district was 65.6 % in black clay soil. When the moisture limitation of rainfed condition was overcome by simulating crops with irrigation as and when crop required (potential conditions), the yield levels varied from the respective districts, a reduction by 28 percent for Belagavi district to increase by 76 percent for Koppal district compared to yields under to rainfed conditions. In Belagavi district yield level declined under potential condition compared to rainfed condition due to excess rain resulting in nitrogen leaching with projected increase in rainfall by 6.2 per cent. Grain yield under current climate (1988-2018) on black clay soil in potential conditions was the highest in Bagalkote (3768 kg/ha), followed by Vijayapura (3629 kg/ha) and Gadag (3249 kg/ha) districts and the lowest yield was simulated for Haveri (893 kg/ha) followed by Belagavi (1115 kg/ha) districts among 12 districts of NIK. Some 15.7 per cent yield improvement averaged across 12 districts of NIK was simulated when the crop was grown under potential condition than under rainfed conditions on black clay soils (Figure 1 and Table 2).

Except for Belagavi and Haveri, two districts with high rainfall districts, yields increased under potential conditions on both black clay and red loamy soils.

Table 2: Simulated rainfed yield (A), potential yield (B) and yield gap (B-A) between the two for *kharif* sorghum hybrid CSH-16 under current climate (1988-2018) on both black clay and red loamy soils across 12 districts of NIK averaged for 31 years (values in parenthesis indicates standard error with n=248).

Districts	Black soils				Red soils			
	1988-2018		% D	R	1988-2018		% D	R
	Potential (B)	Rainfed (A)	B-A		Potential (B)	Rainfed (A)	B-A	
Bidar	2472 (±255)	2452 (±260)	0.8	-	3677 (±84)	3682 (±93)	0.1	-
Kalaburgi	3112 (±220)	2866 (±216)	09	-	3320 (±70)	3116 (±102)	07	-
Vijayapura	3629 (±192)	2563 (±236)	42	III	3830 (±73)	3064 (±173)	25	I
Yadgiri	2973 (±189)	2279 (±193)	30	V	3267 (±62)	2805 (±119)	16	IV
Belagavi	1115 (±224)	1549 (±277)	-28	-	3787 (±80)	3768 (±80)	0.4	-
Bagalkote	3768 (±175)	3265 (±205)	15	-	4043 (±69)	3687 (±140)	10	-
Raichur	2661 (±160)	1904 (±146)	40	IV	3191 (±63)	2693 (±121)	19	III
Dharwad	2573 (±301)	3028 (±286)	-15	-	3973 (±78)	3804 (±105)	04	-
Gadag	3249 (±250)	3041 (±243)	07	-	3501 (±79)	3167 (±136)	11	V
Koppal	2209 (±149)	1257 (±101)	76	I	2972 (±68)	2378 (±124)	25	I
Haveri	893 (±228)	1122 (±263)	-20	-	3731 (±83)	3717 (±83)	0.3	-
Ballari	2908 (±192)	1942 (±152)	50	II	3041 (±66)	2463 (±130)	23	II
Average	**2630 (±115)**	**2272 (±215)**	**15.7**	**-**	**3528 (±356)**	**3195 (±117)**	**10.4**	**-**

% D = Difference, B-A= % yield difference between potential & rainfed crop

When it comes to red loamy soil grain yield under current climate (1988-2018) in rainfed conditions was the highest in Dharwad district (3804 kg/ha) followed by Belagavi (3768 kg/ha) and Bagalkot (3687 kg/ha) districts, and the lowest yield was simulated in Koppal district (2378 kg/ha) followed by Ballari (2463 kg/ha) and Raichur (2693 kg/ha) districts among 12 districts of NIK. The difference between the highest (3804 kg/ha) and lowest (2378 kg/ha) yielding district was 37.4 per cent on red loamy soils compared to 65.6 per cent on black clay soils. However, both the highest and the lowest yields simulated on red loamy soils were higher than the one on black clay soils. When crop was simulated under poten-

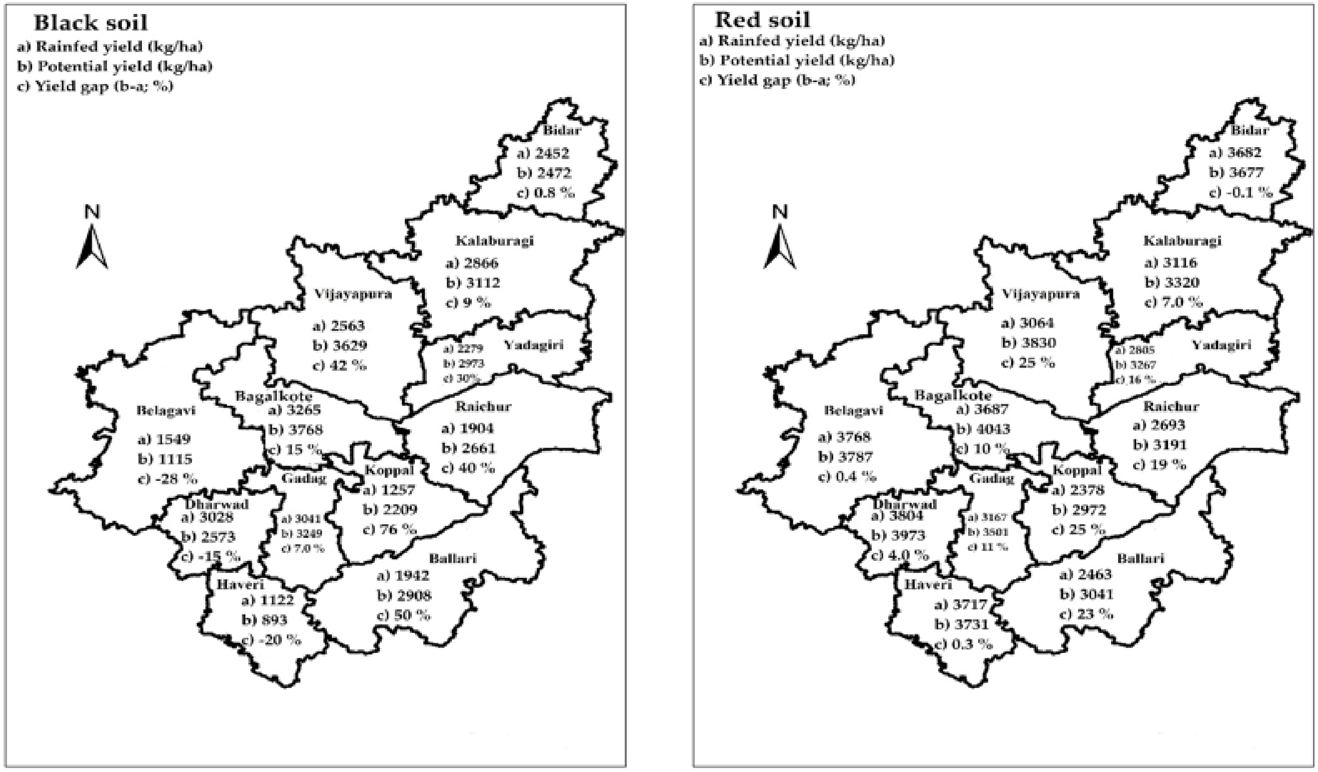

Fig. 1: Simulated difference (c) in grain yield (in %) of *kharif* sorghum hybrid CSH-16 under current climate (1988-2018) on black clay (left side) and red loamy (right side) soils between rainfed (a) and potential (b) conditions (kg ha^{-1}) across 12 districts of NIK (average of 31 years)

tial condition, the yield levels improved anywhere between no change (-0.1) for Bidar district and increase by 25 per cent for Vijayapura and Koppal districts compared to rainfed conditions on red loamy soils of NIK. However, grain yield in potential conditions under current climate (1988-2018) on red loamy soils was the highest in Bagalkote (4043 kg/ha) followed by Dharwad (3973 kg/ha) and Vijayapura (3830 kg/ha) districts and lowest yield was recorded in Koppal (2972 kg/ha), followed by Ballari (3041 kg/ha) and Raichur (3191 kg/ha) districts among 12 districts of NIK. On an average across 12 districts of NIK 10.4 per cent yield improvement on red loamy soil was simulated when the crop was grown under potential conditions than under rainfed conditions (Figure 1 and Table 2). On average 27.0 % higher yield was simulated on red loamy soils across NIK compared to the one on black clay soils, suggesting that *kharif* sorghum hybrid CSH-16 performs better on red loamy soils than on black soils. Simulated grain yield averaged across both the soils and all across 12 districts in rainfed conditions was 2734 kg/ha, and when the crop was grown on moisture stress free conditions the yield level improved to 3079 kg/ha i.e., 13.0 per cent increase (Figure 2 and Table 3).

Table 3: Simulated average rainfed yield (A) and potential yield (B) and yield gap (B-A) between the two of *kharif* sorghum hybrid CSH-16 undercurrent climate (1988-2018) on both black and red soils across 12 districts of NIK averaged for 31 years (Values in parenthesis indicate standard error with n=2976).

Soil	1988-2018		% difference
	Potential (B)	Rainfed (A)	B-A
Black	2630 (±115)	2272 (±215)	15.7
Red	3528 (±356)	3195 (±117)	10.4
Average	**3079** (±131)	**2734** (±119)	**13.0**

CONCLUSION

Average yield of *kharif* sorghum simulated across predominant two soils and 12 districts of NIK under current climate (1988-2018) in rainfed conditions was 2734 kg/ha with 2272 kg/ha on black clay soil and 3195 kg/ha on red loamy soil. This study showed that *kharif* sorghum yields are higher on red loamy soils than on black clay soils across NIK. An increase of 345 kg/ha (i.e., 13.0 %) in yield was simulated under potential condition i.e., 3079 kg/ha when grown under no mois-

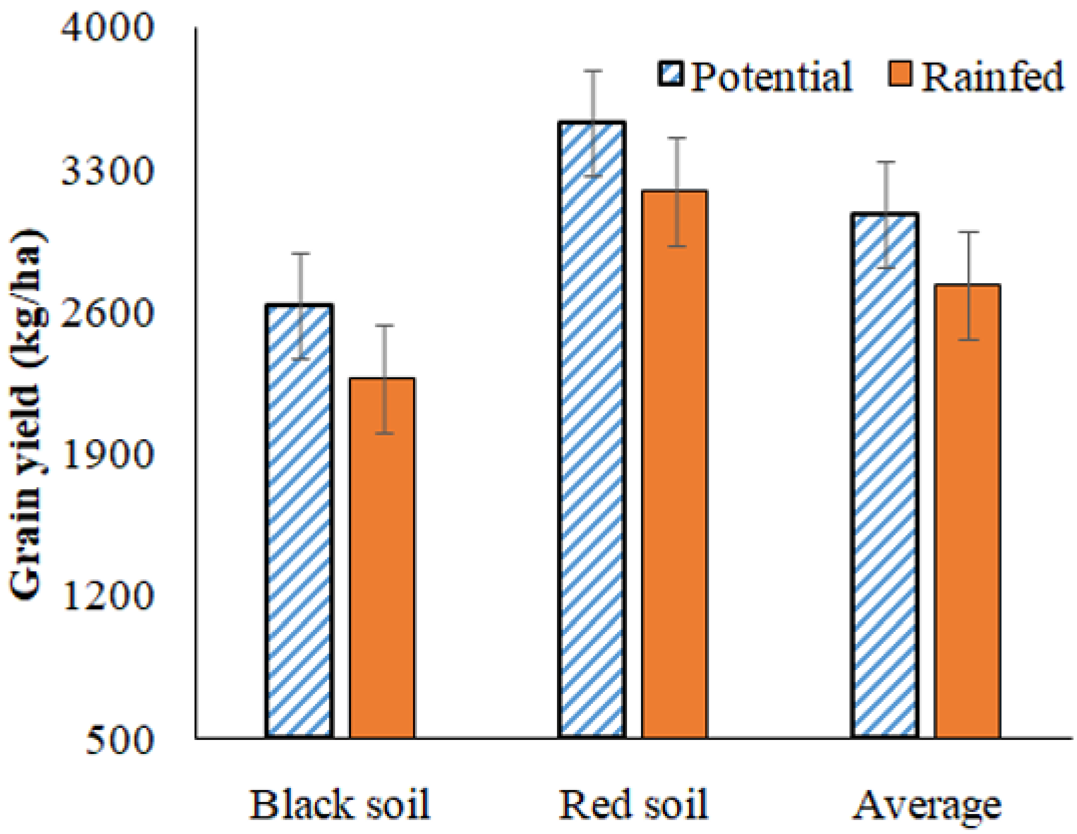

Fig. 2: Rainfed and potential yield of *kharif* sorghum hybrid CSH-16 undercurrent climate (1988-2018) on black and red soils, and averaged across soilfor 12 districts of NIK

ture stress situation. On both black clay and red loamy soils Bagalkote district simulated the highest yield of 3768 kg/ha and 4043 kg/ha, respectively, under potential conditions. This study showed that, averaged across 12 districts, 13 per cent yield gap exists between potential and rainfed conditions, which need to be filled with appropriate water management practices so that food production is increased without any other additional input cost.

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