J. Farm Sci., 33(4) : (464-469) 2020

RESEARCH PAPER

Yield gap analysis of major crops grown in northern transition zone of Karnataka

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(Received: March, 2020 ; Accepted: October, 2020)

Abstract: There exists a huge yield gap between given cultivar's potential yield and on-farm experimental station's yield as well as actual yield on farmers' field. It is essential to quantify the difference between these to devise strategies to fill the gap, and recommend the same to farmers to realize higher yield. This is very important especially for the crops grown under rainfed conditions as yield is often limited by water stress due to erratic rainfall patterns.Yield gap analysis studies are more effectively done using crop simulation models. A calibrated and validated DSSAT-CERES and DSSAT-CROPGRO models were used to run from 1985 to 2016 (32 years) for greengram (DGGV-2), soybean (JS 93), maize (BRMH-1) during *kharif* season, and for sorghum (CSH-15R), chickpea (BGD-103) and wheat (DWR-162) during *rabi* season under potential (no water stress) and on-farm rainfed conditions on black clay soil in Northern Transition Zone (NTZ) of Karnataka. Results showed that during calibration and validation the model simulated the phenology, growth, yield and yield attributes of all the tested cultivars with high accuracy. The average of 32 years simulated outputs revealed that among the three *kharif* crops the highest yield gap between potential and on-farm yields was noticed in maize (29.45 %) followed by soybean (16.45%) and greengram (14.97%). Among the three *rabi* crops tested the highest yield gap between potential and on-farm yields was noticed in chickpea (18.25%) followed by wheat (17.67%) and sorghum (10.28%). This study showed that even under NTZ where *kharif* season is believed to be more assured and more often than not enable take up double cropping, crops do experience moisture stress and give lower than potential yield. Thus needs strategies to narrow the gap.

Key words: Calibration, Potential yield, Validation, Yield gap

Introduction

By 2020 in India, some 600 million people would still be living in rainfed regions along with a 650 million of cattle population (Rao *et al*., 2015). The current level of productivity of rainfed cereals in India ranges from 520 to 1320 kg ha^{-1} and that of pulses from 540 to 650 kg ha^{-1}, which is quite low compared with the potential yield achievable (Singh *et al.,* 2009). The per capita land availability in rainfed areas is expected to fall from 0.28 ha in 1990 to 0.12 ha by 2020 (Singh *et al.,* 2000). It means more food has to be produced from each unit of land to meet the growing demand for food. Identifying the yields at different production levels *viz.,* potential, water unlimited, nutrient unlimited, and quantifying the yield gaps 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 environment and level may not be possible in field experiments. Several process based dynamic crop simulation models have been developed that 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 simulation models are being increasingly used in the yield gap analysis by assessing the water non-limited, water limited or nutrient-limited yields for a particular region with given environmental conditions (Aggarwal and Kalra, 1994; Lansigan *et al.,* 1996; Naab *et al.,* 2004).

Such studies help in quantifying the yield gaps, yield limiting factors and in developing suitable strategies to fill the gap in the productivity of crops. By 2025, India's population is expected to reach 1.45 billion and 1.50 billion by 2030 (United Nations, 2006). It is necessary that to feed this projected population the food production in India must increase by about 5 million tons annually to ensure food and nutritional security (Kanwar, 2000). It is believed that rainfed areas, which cover almost 70% of the total arable land in India, would have a greater share in meeting the future food needs of the country due to increasing population (Kanwar, 2000; Singh *et al.,* 2000). Therefore, modelling study was undertaken to study and quantify the yield gap between water non-limiting potential yield and on-farm experimental yields for NTZ of Karnataka on clay soils.

Material and methods

The experimental data required to run model for the six chosen crops were collected from on-farm field experiments grown with respective All-India Coordinated Research Project (AICRP) schemes during *rabi* season of 2017-18 (sorghum, wheat and chickpea) and *kharif* season of 2018-19 (greengram, soybean and maize,) under rainfed condition on black soil at Main Agricultural Research Station of University of Agricultural Sciences, Dharwad. This station is located at 15^0 26' N latitude, 75^0 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 collected included phenology *i.e.,* days to 50% flowering and days to maturity, and yield attributes *i.e.,* grain yield, total biomass and test weight. In addition to the data collected from the on-farm field experiments during *rabi*

Table 1. Name of variety or hybrid chosen for each crop and the dataset used for model calibration and validation.

Crops	Varieties or hybrids	Calibration year (data borrowed from AICRP schemes)	No. of observations collected and used	Validation year (data collected from AICRP experiments)	No. of observations collected and used
Greengram	DGGV-2	2016	15	2018	15
Soybean	JS 93-05	2017	15	2018	15
Maize	BRMH-1	2016	15	2018	15
Sorghum	CSH-15R	2015	15	2017	15
Wheat	DWR-162	2015	15	2017	15
Chickpea	BGD-103	2015	15	2017	15

2017-18 and *kharif* 2018-19, additional data on above parameters were also borrowed from the respective AICRP crop schemes form previous years (2015 and 2016) so that the dataset was large enough to be used for thorough calibration and validation of DSSAT model before used for yield gap analysis.These dataset were used to built time-series (T-file) and end-of-season (A-file) files whereas information on the crop management practices followed to lay out on-farm experimentation was used to built X-file within DSSAT model.

The data on daily weather parameters required to build weather module using Weather Man software within the DSSAT model were recorded at Meteorological Observatory, Main Agricultural Research Station, University of Agricultural Sciences, Dharwad for the experimental years 2017 and 2018, as well as for the historic period of 32 years (1985-2016) to run DSSAT model. A detailed physico-chemical data on representative soil profile from the MARS, Dharwad was used to build the soil module within the model.

Model calibration

GenCalc software operating within DSSAT model followed by manual method was used to optimize the genetic coefficients of chosen cultivars of all the crops listed above until the predicted values matched with the measured values (Hunt *et al.,* 1993). The DSSAT-CERES and DSSAT-CROPGRO model were calibrated using borrowed data from AICRP schemes *i.e.,* Greengram DGGV-2 variety was calibrated with 2016 data from MULLaRP scheme, soybean JS 93-05 variety was calibrated with 2017 data from AICRP on soybean, maize crop BRMH-1 hybrid was calibrated with 2016 data from AICRP on maize scheme, sorghum CSH-15R hybrid was calibrated with borrowed data of 2015 from AICRP sorghum scheme, wheat DWR-162 variety was calibrated with 2015 borrowed data from AICRP on wheat scheme, chickpea BGD-103 variety was calibrated with 2015 borrowed data from Regional Research Station (RRS) on chickpea scheme, MARS, Dharwad (Table 1).

Model validation

During validation the model was run for each crop's cultivar to compare model predicted output with another independent dataset without changing the genetic coefficient sderived during calibration stage. The model was validated using the data collected from AICRP experiments during *kharif* 2018 and *rabi* 2017-18. Greengram DGGV-2, soybean JS 93-05 and maize BRMH-1 cultivars were validated with *kharif* 2018 experimental data. Similarly, sorghum CSH-15R, wheat DWR-162 and chickpea BGD-103 cultivars were validated with the data collected from experiment during *rabi* 2017. On average, some 15 set of observations on

Table 2a. Optimized genetic coefficients after calibration for greengram, soybean and chickpea varieties

Sl. No.	Crop Coefficient Codes	Greengram DGGV-2	Soybean JS 93-05	Chickpea BGD-103
1	CSDL	13.17	12.56	7.941
2	PPSEN	0.016	0.285	0.430
3	EM-FL	39.60	25.35	36.51
4	FL-SH	4.50	8.30	9.00
5	FL-SD	14.40	27.63	28.22
6	SD-PM	14.22	7.635	25.45
7	FL-LF	12.10	54.52	78.83
8	LFMAX	1.33	3.701	4.867
9	SLAVR	396.00	749.80	323.00
10	SIZLF	154.00	180.00	10.00
11	XFRT	1.40	1.00	0.95
12	WTPSD	0.252	0.3319	0.2759
13	SFDUR	177.00	3.997	0.2954
14	SDPDV	14.30	3.636	2.005
15	PODUR	4.80	0.3558	0.3880
16	THRSH	82.00	77.00	85.00
17	SDPRO	0.235	0.405	0.216
18	SDLIP	0.040	0.205	0.48

Table 2b. Optimized genetic coefficients after calibration for sorghum, wheat and maize hybrid/variety

Sl. No.	SorghumCSH-15R		Sl. No.	WheatDWR-162		Sl. No.	MaizeBRMH-1	
1	P1	32.27	1	P1V	60.00	1	P1	154.20
2	P2	145.00	2	P1D	132.70	2	P2	0.1522
3	P2O	7.988	3	P5	998.00	3	P5	874.00
4	P2R	18.32	4	G1	52.00	4	G2	783.30
5	PANTH	600.50	5	G2	86.00	5	G3	13.68
6	P3	148.50	6	G3	8.00	6	PHINT	56.21
7	P4	95.50	7	PHINT	148.00	-	-	-
8	P5	633.50	-	-	-	-	-	-
9	PHINT	112.10	-	-	-	-	-	-
10	G1	189.00	-	-	-	-	-	-
11	G2	27.871	-	-	-	-	-	-

Table 3. The management practices followed for each crop in the model

Practices followed	Greengram	Soybean	Maize	Sorghum	Wheat	Chickpea
Variety/hybrid	DGGV-2	JS 93-05	BRMH-1	CSH-15R	DWR-162	BGD-103
Spacing (cm)	30×10	30×10	60×20	45×15	23×7.5	30×10
Planting date	10 June	15 June	20 June	20 Sept.	15 Oct.	15 Oct.
Plant population at sowing (m^{-2})	33	33	9	15	62	33
Plant population at emergence (m^{-2})	32	32	8	14	60	32
Planting depth (cm)	4	5	5	4	4	5
Irrigation*	As and when crop needed only for potential yield simulation					
Fertilizer NPK (kg ha^{-1}) for actual conditions	25:50:00	40:80:25	100:50:25	50:25:00	50:25:00	10:50:00
FYM (kg ha^{-1})	5000	7500	7500	3000	7500	5000
Harvest	At maturity simulated by the model					

*Model was set for no water stress for simulating water non-limiting potential yield.

phenology and yield data were used separately for calibration and validation.The optimized genetic coefficients of all the six crop's chosen cultivar are presented in Tables 2a and 2b.

Yield gap analysis

The water non-limiting potential yielding ability of a chosen cultivar (variety/ hybrid) will be known only when they were grown under no water stress condition. For this, 12 experimental files, one for each of six crops and separately for potential and actual condition were built following the practices from package of practice of UAS, Dharwad (Table 4). The 32 year's weather file was attached and also representative black soil profile of 0-180 cm from MARS, Dharwad was used to run the model. The model simulated yield was extracted and compared with the actual yield under actual weather, per cent yield gap was calculated as the difference between potential and actual yield. Among the 32 years the highest and lowest yield were also extracted to record range.

Results and discussion

Calibration and validation

During calibration and validation the model simulated the phenology, growth, yield and yield attributes very satisfactorily *i.e.,* the observed values matched very well with the simulated one during both calibration and validation steps (Table 4). These results are also in confirmation with the findings of Sagar Kumar *et al.* (2017) who used CROPGRO-model for optimization of genetic coefficients of cotton varieties by using GenCalc and the results showed that model performance in respect of phenology, yield and attributes was good with an error of only ±5 per cent and ±10 per cent, respectively for all the three cotton cultivars and growing environments. Similarly, DSSAT-CERES model was calibrated and validated by Pradeep (2017) and Achenef (2017) for maize hybrids, and Sannagoudar *et al.,* (2019) for *kharif* sorghum and the per cent error was well within acceptable range.

Yield gap analysis

Average water non-limited potential yield of 32 years and the range as well as average actual yield under rainfed condition of 32 years and the range are given Table 5. The difference between potential and actual yield gave the gap in yield levels for all six crops under current climates ran from 1985-2016 and averaged over 32 years (Table 5; Figure 1a and 1b). In greengram crop the simulated mean potential yield of 32 years was

Table 4. Simulated and Observed phenology (anthesis and maturity) and yield during calibration and validation steps

Sl. No.	Crops	Parameters	Calibration			Validation		
			Sim	Obs	% D	Sim	Obs	% D
1	Greengram	Anthesis (days)	48	44	9.09	48	46	4.34
		Maturity (days)	77	77	0.00	76	75	1.33
		Yield (kg ha^{-1})	979	918	6.64	624	670	-6.86
2	Soybean	Anthesis (days)	40	38	5.26	40	43	-6.97
		Maturity (days)	85	82	3.65	85	86	-1.16
		Yield (kg ha^{-1})	1644	1410	16.59	1948	2068	-5.80
3	Maize	Anthesis (days)	56	56	0.00	56	60	-6.66
		Maturity (days)	113	112	0.89	113	116	-2.58
		Yield (kg ha^{-1})	7598	7148	6.29	8364	8672	-3.55
4	Sorghum	Anthesis (days)	61	62	-1.61	66	68	-2.94
		Maturity (days)	109	110	-0.90	117	118	-0.84
		Yield (kg ha^{-1})	3612	3959	-8.76	4528	4651	-2.64
5	Wheat	Anthesis (days)	56	55	1.81	58	58	0.00
		Maturity (days)	108	106	1.88	109	110	-0.90
		Yield (kg ha^{-1})	2066	2248	-8.09	2714	2674	1.49
6	Chickpea	Anthesis (days)	43	42	2.38	44	45	-2.22
		Maturity (days)	92	92	0.00	96	96	0.00
		Yield (kg ha^{-1})	1522	1734	-12.22	1884	1926	-4.25

Sim: Simulated Obs: Observed % D: Per cent of deviation

1022 kg ha^{-1} against the simulated mean actual yield of 869 kg ha^{-1}. The yield gap was 14.97 per cent. The yield during 32 years ranged from the lowest of 714 to the highest of 1498 kg ha^{-1} under potential conditions whereas it ranged from the lowest of 456 to the highest of 1244 kg ha^{-1} under actual conditions.

In soybean the simulated mean potential yield of 32 years was 2188 kg ha^{-1} against the simulated mean on-farm actual yield of 1828 kg ha^{-1}with a yield gap of 16.45 per cent. The yearly yields ranged from the lowest of 1748 to the maximum of 2658 kg ha^{-1} under potential conditions where as it ranged from the lowest of 1485 to the highest of 2366 kg ha^{-1} under actual conditions over 32 years. This trend was supported by earlier work by Singh *et al.* (2009) who for the states of Madhya Pradesh and Maharashtra reported a rainfed yield potential of more than 2000 kg ha^{-1}, which is more than double as compared with the existing national productivity of less than 1000 kg ha^{-1}. The potential yield was found to be marginally low in Karnataka *i.e.,* 1750 kg ha^{-1}, while Rajasthan showed a very low simulated potential rainfed yield of 1340 kg ha^{-1}. The experimental station yields were also above 2000 kg ha^{-1}and ranged from 2080 to 2600 kg ha^{-1}.

In maize crop the simulated mean potential yield was 9688 kg ha^{-1} against the simulated mean on-farm actual yield of only 6834 kg ha^{-1} with a yield gap of 29.45 per cent. The yearly yields ranged from the lowest of 6062 to the highest of 13476 kg ha^{-1} under potential conditions, whereas it ranged from 5677 to 11852 kg ha^{-1} over 32 years (Table 5 and Figure 1b). Singh *et al.*(2009) also working for maize reported that the simulated maize yields for most of the states were higher than the experimental yield sacross states, which very much supported the findings of this study. They reported the highest yield gap for Madhya Pradesh and the lowest for Andhra Pradesh and compared with experimental yield, the yield gap across locations ranged from 1430 to 2840 kg ha^{-1} across states. These results show that the farmers' yields under rainfed situations can be more than doubled in the states through proper agronomic and resource management practices.

In sorghum crop the simulated mean potential yield predicted was 5184 kg ha^{-1} against simulated mean on-farm actual yield of 4651 kg ha^{-1}. The predicted yield gap was 10.28 per cent. The yield ranged from 3588 to 6022 kg ha^{-1} under potential conditions whereas it ranged from 3258 to 5692 kg ha^{-1} under actual conditions over 32 years. Murty *et al.* (2007) used CERES-Sorghum model for yield gap analysis of sorghum in India. The results showed that the farmer's average yield was 970 kg ha^{-1} for *kharif* sorghum and 590 kg ha^{-1} for *rabi* sorghum, but model predicted rainfed potential yield in various production areas ranging from 3210 to 3410 kg ha^{-1} for *kharif* sorghum and 1000 to 1360 kg ha^{-1} for *rabi* sorghum. Total yield gap ranged from 2130 to 2560 kg ha^{-1} for *kharif* sorghum and 280 to 830 kg ha^{-1} for *rabi* sorghum. This showed that yield of both *kharif* and *rabi* sorghum on farmers' field needs to be increased through proper resource management.

In wheat crop the simulated mean water non-limited potential yield was 3248 kg ha^{-1} against the simulated mean on-farm actual yield of 2674 kg ha^{-1}. The predicted yield gap was 17.67 per cent and the yearly yields ranged from 2589 to 4644 kg ha^{-1} under potential conditions, whereas it ranged from 2059 to 4012 kg ha^{-1} under actual conditions over 32 years. Chapagain

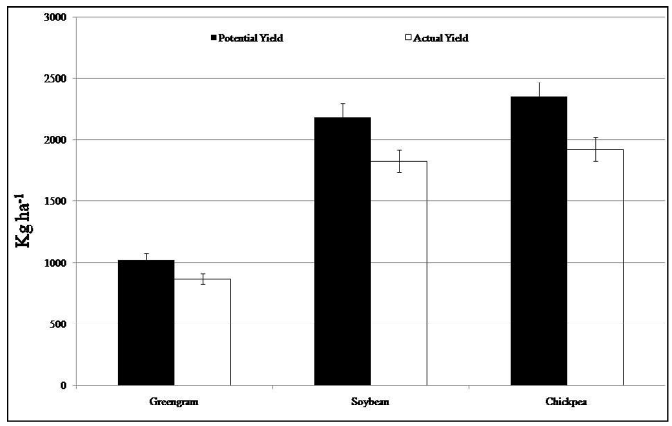

Fig.1a. Potential and actual yield of greengram, soybean and chickpea under current climates from 1985-2016 averaged over 32 years

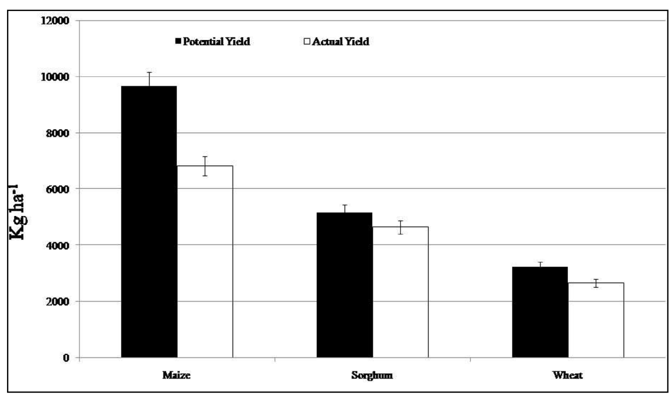

Fig.1b. Potential and actual yield of maize, sorghum and wheat under current climates from 1985-2016 averaged over 32 years

Table 5. Potential yield and their range, actual yield and their range and yield gap between potential and actual yield under current climates from 1985-2016 averaged over 32 years

Crops	Average potential yield (kg ha^{-1})	Range for potential yield	Average actual yield (kg ha^{-1})	Range for actual yield	Yield gap (%)
Greengram	1022	714-1498	869	456-1244	14.97
Soybean	2188	1748-2658	1828	1485-2366	16.45
Maize	9688	6062-13476	6834	5677-11852	29.45
Sorghum	5184	3588-6022	4651	3258-5692	10.28
Wheat	3248	2589-4644	2674	2059-4012	17.67
Chickpea	2356	1510-2862	1926	1342-2576	18.25

and Good (2015) used 10 years of data from 2005–2014 to know the input efficiency and yield variability at the specified management stage of a farmer, and potential yield under ideal practices to suggest suitable mechanisms to fill yield gaps. They reported yield gaps in Alberta up to 24 % between achievable and actual rainfed wheat yields.

In chickpea the simulated mean potential yield was 2356 kg ha^{-1} against the simulated mean actual yield of 1926 kg ha^{-1}. The predicted yield gap was 18.25 per cent. The yearly yield ranged from 1510 to 2862 kg ha^{-1} under potential conditions whereas it ranged from 1342 to 2576 kg ha^{-1} under actual conditions over 32 years. Singh *et al.* (2009) also worked with chickpea crop across Indian states and reported average potential yield of chickpea between 1250 and 2120 kg ha^{-1}. The average simulated yields in Madhya Pradesh, Maharashtra and Karnataka states were 1620, 1860 and 2120 kg ha^{-1}, respectively. The average experimental station yields for these states were 2060, 1460 and 1350 kg ha^{-1}, respectively. In general, the gap between experimental station yields and potential of rainfed chickpea in the major geographical regions was between 1250 and 2200 kg ha^{-1}, which is substantially higher than the present national average of about 800 kg ha^{-1}. They also opined that supplemental irrigation is essential to increase productivity of chickpea in India. Chickpea is grown during rabi on residual soil moisture, thus crop experiences terminal drought stress at or after flowering or at pod filling period, which is known to reduce yields severely (Soltani *et al.* 2001).

Conclusion

The DSSAT 4.7 model based yield gap analysis of six crops showed that after calibration and validation process the model was found to be very robust and was able to predict phenology and yield of all six crops quite satisfactorily with errors well within acceptable range. Hence, this model can be used to study the potential yield, yield gap analysis, nutrient management, irrigation management etc. This study taken up in the NTZ of Karnataka on six crops *i.e.,* three *kharif* and three *rabi*, showed that the highest yield gap between water unlimited potential yield and actual experimental yields under rainfed conditions was noticed in maize (29.45 %) and the least yield gap was recorded in sorghum (10.28%). Hence, models can be used further to devise agronomic and resource management strategies to fill this gap.

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