Sustainable Maize Based Cropping Sequences for Northern Transition Zone of Karnataka, India

ABSTRACT

Maize in SW monsoon and sorghum, wheat and chickpea during winter are the important crops in Northern Transition Zone (NTZ) of Karnataka, India. But, due to rising temperature and erratic rainfall patterns the productivity and profitability of maize based cropping sequences are being threatened under rainfed condition. As a result, a modelling research was conducted utilising the DSSAT model's seasonal analysis tool to test and determine sustainable and profitable cropping sequences for current climates of NTZ in Karnataka state. Field experiments were conducted from 2015 to 2018 to calibrate and validate the DSSAT model for four crop cultivars (maize, chickpea, wheat, and sorghum) grown under rainfed conditions on deep black soils, and then the DSSAT model's sequential analysis tool was run for 32 years (1985-2016) for three cropping sequences (maize-sorghum, maize-wheat, and maize-chickpea). The yield, number of years the crop failed throughout different seasons, and the B:C ratio of each sequence were used in the simulated output study. Out of 32 years maize crop, grown during *kharif*, failed three times whereas, during *rabi* season wheat, sorghum and chickpea failed nine, eight and five years, respectively. Out of 32 years maize-sorghum sequence recorded the highest B:C ratio (2.86) followed by maize-chickpea (2.82) and maize-wheat (2.66). Considering chances of crop failure, B:C ratio and owing to cereal followed by short duration legume, maize-chickpea sequence under rainfed condition was proven to be the most reliable and profitable system for NTZ of Karnataka under of current climate.

Keywords: B:C ratio, cropping sequence, DSSAT, profitability and sequential analysis.

Introduction

The state of Karnataka in India with a total cultivated land of 12.16 m ha is located between 11.50 □ to 18.50 □ N latitudes and 74.25 □ to 78.50 □ E longitudes. Out of 12.16 m ha of total cultivated area, 8.60 m ha is under rainfed cultivation (70.72 %) and it ranks second in terms of rainfed agricultural area only next to arid state of Rajasthan in India (Anon., 2018). Rainfed agriculture accounts for around 55% of total food grain production and 74% of oilseed production in Karnataka. This state is predominantly semi-arid, and being situated in tropics, rainfall and temperature dominate all other climate parameters vis-a-vis crop growth and yield. South West Monsoon (SWM; June-September) also called *kharif* accounts for 70 to 75 per cent of total annual rainfall of the Northern Interior Karnataka (NIK) covering 12 drought prone districts, hence spatial and temporal variation in rainfall during this period greatly influences crop yield. The long-term average rainfall variability (CV in %) during SWM season in NIK is much higher (21 %) than that of Karnataka state (15 %) and India (11 %) as a whole (Jayasree and Venkatesh, 2015). Whereas, Northern Transition Zone (NTZ) coming under NIK has sub-humid, hot and dry climate and the long term annual rainfall average is 728 mm. About 430 mm of rainfall (60 %; June-September) is received in the *kharif*, 130 mm in the summer (18 %; March-May) and 168 mm in the *rabi* (22 %; October-December). Because of this bimodal rainfall pattern double cropping is possible in NTZ. However, in recent decades the monsoon has become even more erratic in its spatial and temporal distribution, thus increasing the risks of crop failures. Under these circumstances, farmers are uncertain of choosing right cropping sequences. In this context, maize crop assumes importance due to wider adaptability under varied ecologies, seasons and regions in the country.

Maize is a major food, feed, and industrial raw material crop for billions of people. Currently, nearly 1147.7 million MT of maize is being produced together by over 170 countries from an area 193.7 million ha with an average productivity of 5.75 t ha^{-1} (Anon. 2020). India is fourth in terms of area and seventh in terms of production among maize-growing countries. In India, it is cultivated on area of 9.38 million ha with a production of 28.75 million MT at a productivity of 3065 kg ha^{-1} (Anon. 2019), which is nearly half of the global average. In Karnataka, maize is cultivated on area of 1.3 m ha with a production of 3.85 million t at an average productivity of about 2948 kg ha^{-1} (Anon. 2019). Karnataka stands second in maize production in India with a share of 13.85 per cent in total area and 13.39 per cent of the total maize production of the country. It is cultivated on all the districts of Karnataka exposing to different agro-climatic zones (Savitha and Kunnal, 2015).

Maize is grown in sequence or as companion crop under different production systems with a range of crops. The geographical distribution of distinct maize-based rotations, on the other hand, is principally determined by suitability for a cropping window under current ecology, land topography, soil type, moisture availability, and market conditions. Traditionally being a monsoon season crop, maize-wheat is still the predominant maize based system (1.8 m ha) and is third major crop-rotation in India and contributes ~3.0 % in national food basket (Anon., 2013). The other major maize based system is maize-chickpea which occupies 5.4 lakh hectares and contributes 0.65 per cent of total food grain production of the country (Anon., 2006). In the malaparabha command area of Karnataka, maize-chickpea is the most profitable cropping system occupying nearly one lakh ha (Anon., 2006). Maize-sorghum sequence is also grown in parts of northern Karnataka. Traditional agronomic research efforts are being done to identify economically profitable and sustainable cropping sequences, and in this effort crop modeling comes as handy and efficient tool to test and identify large number of crops/cropping sequences across soils and climate in a very limited time. However, most of the modeling studies in India have focused the work only on individual crops and their management, and very limited research work is being done using models on cropping systems. Therefore, this study was taken up to test and identify sustainable and remunerative maize based cropping sequences for current climates in NTZ under rainfed condition. For this work a DSSAT model (Jones *et al*., 2003) based study was taken up to identify the most reliable and economically profitable maize based cropping sequence for NTZ of Karnataka.

Material and Methods

The experimental data required to calibrate, validate and run DSSAT crop simulation model for seasonal analysis were collected from the four chosen crops grown in respective All India Co-ordinated Research Projects (AICRP) during *rabi* season of 2017-18 (sorghum, wheat and chickpea) and *kharif* season of 2018 (maize) under rainfed condition on deep black soils from the Main Agricultural Research Station of University of Agricultural Sciences, Dharwad, India. This station is located at 15 26' N latitude, 75 07' E longitude, and 678 m above mean sea level and comes under Zone-8 of Karnataka. In addition to the data collected from field experiments during *rabi* 2017-18 and *kharif* 2018, additional data were acquired from respective AICRPs from previous years (2015 and 2016) for model calibration and validation.

Model calibration and validation

The DSSAT-CERES for maize, sorghum and wheat, and DSSAT-CROPGRO for chickpea were calibrated using GenCalc (Hunt *et al*., 1993), a semi-automated program embedded within DSSAT to optimize genetic coefficients, followed by manual method i.e., alteration in the genetic coefficients in cultivar file within acceptable range of difference. Then the model was validated using the data collected from AICRP experiments during *kharif* 2018 and *rabi* 2017-18 for four chosen crops (maize, chickpea, wheat and sorghum). The details on selected cultivars and optimized genotypic coefficients for each crop used in the project are presented in the Tables 1 and 2.

Sequential analysis

After calibrating and validating the model, it was utilised to perform sequential analysis on three cropping sequences *i.e.*, maize-sorghum, maize-wheat and maize-chickpea by creating four X-files with recommendations as per the package of practice of UAS, Dharwad (Table 3) and these were linked with the past weather data from 1985 to 2016 (32 years) and representative deep black soil profile of MARS, Dharwad. The purpose of using past weather data of 32 years (1985-2016) period was to expose the crop and each cropping sequence to mean changes and naturally observed variability of weather, as well as any extremes encountered during the past 32 years. It helps in identifying most consistently performing crops and cropping sequence under current climate. Later, the required simulated yearly outputs were extracted viz., grain yield and total biomass for each crop and were averaged for 32 years for presentation.

Identification of sustainable and profitable maize based cropping sequence

This was done by running each cropping sequence for 32 years for yield and the current market price was considered for estimation of gross return, cost of cultivation, net return (₹ ha^{-1}), B:C ratio, and based on model outputs on number of years crop failed in only *kharif* season, in only *rabi* season and both in *kharif* and *rabi* seasons were calculated for three cropping sequences. Considering both B:C ratio and frequency of crop failure over 32 years period, the profitable sustainable cropping sequence was identified.

Results and Discussion

Farmers have been growing maize based cropping sequences in NTZ of Karnataka, but with the changing climate in recent decades the performance, productivity and uncertainty have increased. These cropping systems have wide adaptability and compatibility under diverse soil and climatic conditions but climate change is threatening the sustainability and profitability of these systems. The vulnerability of cropping sequences to adverse climatic change has become an important issue and therefore, a research priority.

Sequential analysis and crop yields

When all the three cropping sequences were exposed to 32 years historic weather condition, the phenology, yield and yield attributes varied every year depending on the climatic condition prevailed during each year of 32 years period and is represented in Table 4.

The simulated mean seed yield of maize crop was 6834 kg ha^{-1} and it ranged from 5677 to 11852 kg ha^{-1} over 32 years across the cropping sequences. For sorghum simulated mean yield was 3227 kg ha^{-1} with a range from 2698 to 4255 kg ha^{-1}. When it comes to wheat average yield was 2748 kg ha^{-1} with the lowest and highest being 2522 to 3596 kg ha^{-1}, respectively. Similarly with chickpea the model simulated yield 1579 kg ha^{-1} with a range from 1377 to 2144 kg ha^{-1}. Similar average yield patterns and range was simulated for total biomass as well. The reason for the wide variation in grain yield and biomass simulated for different crops over 32 years is due to environmental factors, especially rainfall (Fig. 1), the moisture stress during the vegetative stage affects the grain filling and maturation (Stockle and Campbell, 1985). The nutrient uptake and soil moisture extraction pattern differ from crop to crop and the crops grown during *kharif* season affect the succeeding crop in relation to nutrient and water uptake, this lead to variation in yields of *rabi*/following crops.

Identification of profitable and sustainable cropping system

Sustainable and profitable cropping sequence is used as one of the adaptation strategies to increase the farmer's income under the current climates and the results are furnished in Table 5. The B:C ratio of each sequence averaged over 32 years and number of years crop failed during *kharif* and *rabi* seasons were considered as criteria to identify the most reliable and profitable cropping sequence (Table 5). Out of 32 years of simulation period maize crop failed three years during *kharif* among all the three cropping sequences, based on historical weather data of 32 years (1985-2016), out of total annual rainfall, more than half of it was received during *kharif* season (June-September) (Fig. 2) and it follows the trend of annual rainfall. The crops grown in *kharif* season receive precipitation throughout the season with favorable mild temperature. So, it leads to the availability of sufficient soil moisture to the crop during entire growing period; hence the probability of crop failure during *kharif* season is very less as compared to *rabi* season crops. Whereas wheat crop in *rabi* failed nine years in maize-wheat cropping sequence and the lowest number of years crops failed during *rabi* was five years for chickpea in maize-chickpea cropping sequence (Table 5). The highest number of years crop failed during *rabi* season was with wheat *i.e*. 9 years and number of years crop failed during *kharif* season was three years. The number of year's crop failed in *rabi* season varied from five to nine. The important crops grown in *rabi* season in NTZ are sorghum, wheat and chickpea, and these crops experience both moisture and heat stress during their life cycle. The average rainfall received during *rabi* season is very less (22 % of total) compared to *kharif* season (60 %) and this results in the low moisture availability to the crops grown during the *rabi* season under much hotter and drier weather, and these crops mainly complete their life cycle using residual soil moisture. Therefore, the probability of crop failure is much higher than the *kharif* crops, and also the crops give lower yields.

The average B:C ratio of maize-sorghum sequence (2.86) was the highest, closely followed by maize-chickpea (2.82) and the least was with maize-wheat (2.66). Out of 32 years, even though maize-sorghum sequence recorded the highest B:C ratio, the probability of crop failure with chickpea (5 years) is much less than sorghum (8 years) and its B:C ratio is almost near to maize-sorghum sequence.

Inclusion of chickpea in cereal based cropping systems has shown to improve the efficiency of nutrient (Walley *et al.*, 2007) and improvement in soil fertility (Meena *et al.*, 2015). Larger yields were obtained in crop sequences after leguminous fore crops (Berzsenyi *et al.*, 2000). In cereal–legume rotation like Maize–Chickpea–Greengram, the biological N-fixation probably enhanced the availability of N (Halvorson *et al.*, 2002) and maintenance of soil fertility and crop productivity (Rahman *et al.*, 2013). N availability increased even in the sub-layer in Maize–Chickpea–Greengram, when compared to other cropping systems. Chickpea, being a deep-rooted (tap root) crop, possibly improved N availability even in the sub-surface layer (Meena *et al.*, 2015). Ndukhu and Wahome (2014) used APSIM model to quantify soil nutrients and maize yield under different cropping systems and organic amendments to changes in rainfall and temperatures in Kiserian and Kabete region of central Kenya. The results showed that maize-chickpea cropping system with application of Minjingu Rock Phosphate (MRP) and FYM gave higher yields compared to the mono-cropping. Hence, this study showed that maize-chickpea sequence is more consistent, reliable and profitable under current climates in NTZ of Karnataka to sustain farmers' income.

Conclusion

The calibrated and validated DSSAT model was used to run sequential analysis of three cropping sequences; maize-chickpea, maize-wheat and maize-sorghum for 32 years. The simulated average grain yield and total biomass of maize crop was 6834 kg ha^{-1}, whereas for sorghum, wheat and chickpea it was 3227, 2748 and 1579 kg ha^{-1}, respectively. Out of 32 years, maize crop failed three times during *kharif* season of 2001, 2002 and 2003 whereas, during *rabi* season the highest number of years crop failed was noticed in wheat (9 years) followed by sorghum (8 years) and chickpea (5 years). Among the three cropping sequences, the maize-sorghum sequence recorded the highest B:C ratio of 2.86 closely followed by maize-chickpea sequence (2.82) and the least was found with maize-wheat sequence (2.66). Under rainfed conditions of NTZ in Karnataka, maize-chickpea was the most consistent and profitable sequence, with the number of years crop failed as an index of reliability and the B:C ratio as an indicator of profitability.

Table 1: Selected cultivars for each crop in the study

No.	Crops	Cultivar	Calibration year (data borrowed from AICRP experiments)	No. of observations collected and used	Validation year (data collected from AICRP experiments)	No. of observations collected and used
1	Maize	BRMH-1	2016	15	2018	15
2	Sorghum	CSH-15R	2015	15	2017	15

3	Wheat	DWR-162	2015	15	2017	15
4	Chickpea	BGD-103	2015	15	2017	15

Table 2: Package of practices followed for each cropping sequence under rainfed condition

Practices followed	***Kharif* crop**	***Rabi* crops**		
	Maize	**Sorghum**	**Wheat**	**Chickpea**
Variety/hybrid	BRMH-1	CSH-15R	DWR-162	BGD-103
Spacing (cm)	60×20	45×15	23×7.5	30×10
Seed rate (kg ha^{-1})	25	7.5	50	50
Date of sowing	20 Jun	20 Sept	15 Oct	15 Oct
Fertilizer NPK (kg ha^{-1})	100:50:25	50:25:00	50:25:00	10:50:00
FYM (kg ha^{-1})	7500	3000	7500	5000

Table 3: Optimized genetic coefficients after calibration for chickpea, sorghum, maize and wheat cultivars

No.	**Chickpea**		**Sorghum**		**Maize**		**Wheat**	
	Coefficient Codes	**BGD-103**	**Coefficient Codes**	**CSH-15R**	**Coefficient Codes**	**BRMH-1**	**Coefficient Codes**	**DWR-162**
1	CSDL	7.941	P1	32.27	P1	154.20	P1V	60.00

2	PPSEN	0.430	P2	145.00	P2	0.1522	P1D	132.70
3	EM-FL	36.51	P2O	7.988	P5	874.00	P5	998.00
4	FL-SH	9.00	P2R	18.32	G2	783.30	G1	52.00
5	FL-SD	28.22	PANTH	600.50	G3	13.68	G2	86.00
6	SD-PM	25.45	P3	148.50	PHINT	56.21	G3	8.00
7	FL-LF	78.83	P4	95.50	-	-	PHINT	148.00
8	LFMAX	4.867	P5	633.50	-	-	-	-
9	SLAVR	323.00	PHINT	112.10	-	-	-	-
10	SIZLF	10.00	G1	189.00	-	-	-	-
11	XFRT	0.95	G2	27.871	-	-	-	-
12	WTPSD	0.2759	-	-	-	-	-	-
13	SFDUR	0.2954	-	-	-	-	-	-
14	SDPDV	2.005	-	-	-	-	-	-
15	PODUR	0.3880	-	-	-	-	-	-
16	THRSH	85.00	-	-	-	-	-	-
17	SDPRO	0.216	-	-	-	-	-	-
18	SDLIP	0.48	-	-	-	-	-	-

Table 4: Simulated grain yield, total biomass (kg ha^{-1}), their range and per cent deviation for all three cropping sequences averaged over 32 years (1985-2016)

Cropping sequences	Crops	Grain yield	Range	% Range	Total biomass	Range	% Range
Maize-sorghum	Maize	6834	5677 - 11852	83.06-173.42	11450	8245-14568	72.00-127.23
	Sorghum	3227	2698 - 4255	83.60-131.85	8054	6892-11074	85.57-137.49
Maize-wheat	Maize	6834	5677 - 11852	83.06-173.42	11450	8245-14568	72.00-127.23
	Wheat	2748	2522 - 3596	91.77-130.08	5888	4612-7959	78.32-135.17
Maize-chickpea	Maize	6834	5677 - 11852	83.06-173.42	11450	8245-14568	72.00-127.23
	Chickpea	1579	1377 - 2144	87.20-135.78	2914	2416-3375	82.91-115.82

Table 5: Market price, gross return, cost of cultivation, net returns (all in ₹ ha^{-1}), B:C ratio, number of years crop failed only in *Kharif* season, *Rabi* season and during both *Kharif* and *Rabi* seasons for the selected crops under current climates from 1985-2016 (average of 32 years)

Cropping sequences	Crops	Market price	Gross return	Cost of cultivation	Net return	B:C ratio	B:C ratio of cropping sequence	No. of years crop failed *in Kharif*	No. of years crop failed *in Rabi*	No. of years crop failed during both *Kharif* and *Rabi*	Years of crop failure (Rainfall during crop season)
Maize-sorghum	Maize	1800	126243	38235	88008	3.30	2.86	3	-	3	2001(400.1), 2002(394.4), 2003(430.7)
	Sorghum	1800	62913	25834	37079	2.43		-	8		1985(95.4), 1997(204),1989(93.5), 1999(98.8), 2001(64.1), 2002(83.3), 2003(99.4), 2016(20.1)
Maize-wheat	Maize	1800	126243	38235	88008	3.30	2.66	3	-	3	2001(400.1), 2002(394.4), 2003(430.7)
	Wheat	2150	60966	30002	30964	2.03		-	9		1985(95.4), 1988(83.3), 1997(204), 1989(93.5), 1999(98.8), 2001(64.1), 2002(83.3), 2003(99.4), 2016(20.1)
Maize-chickpea	Maize	1800	126243	38235	88008	3.30	2.82	3	-	3	2001(400.1), 2002(394.4), 2003(430.7)
	Chickpea	4600	74236	31480	42756	2.35		-	5		1985(95.4), 1999(98.8), 2001(64.1), 2002(83.3), 2003(99.4), 2016(20.1)

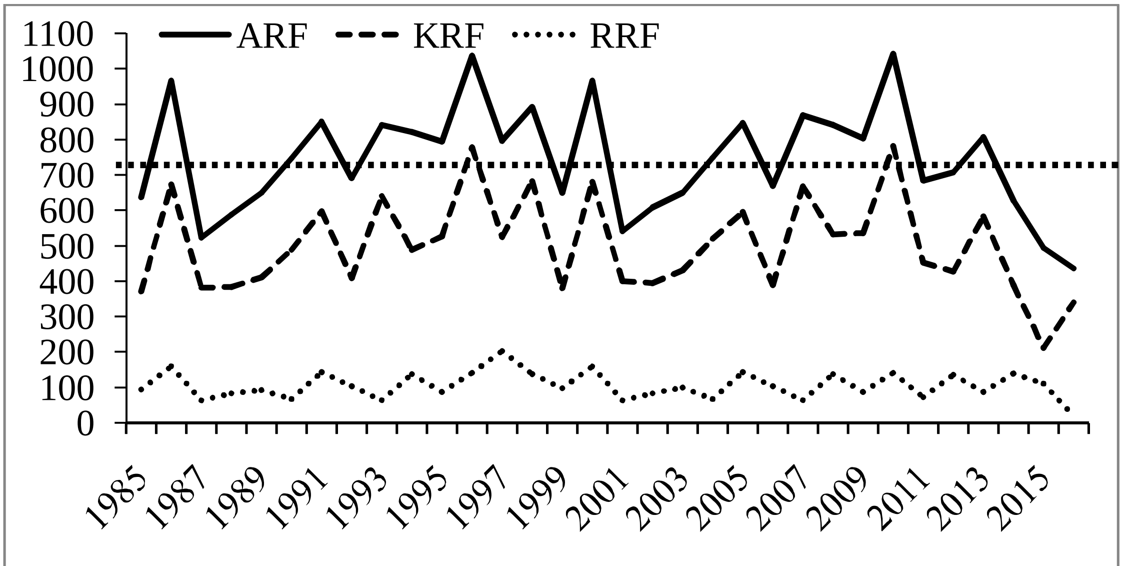

Figure 1: Contribution of *Kharif* (Jun-Sep; KRF) and *Rabi* (Oct-Dec; RRF) rainfall to the annual rainfall in mm (Jan-Dec; ARF) and their trend for the period from 1985 to 2016 for Dharwad, Karnataka, India.
(The dotted straight line represents the 32 years average annual rainfall)

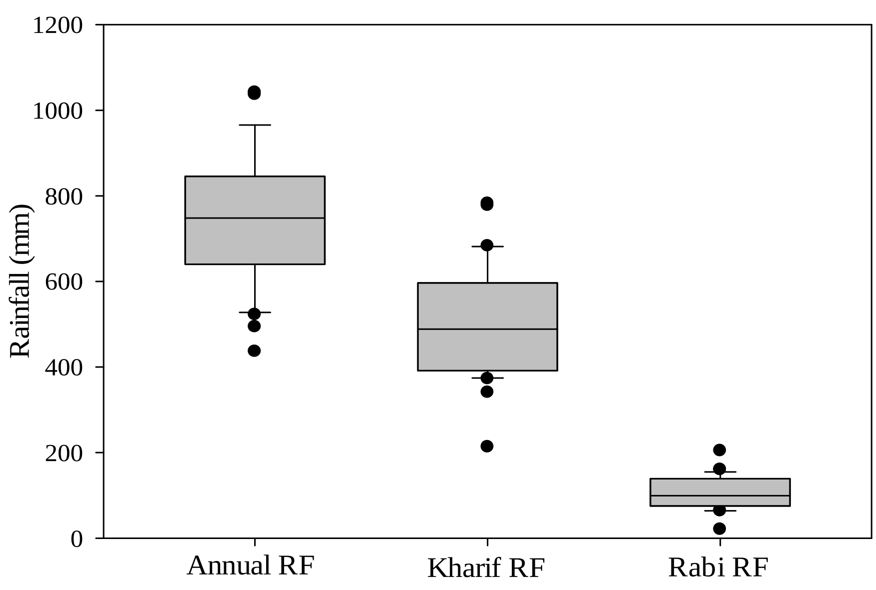

Figure 2: Variation in annual, *Kharif* (Jun-Sep) and *Rabi* (Oct-Dec) rainfall in mm for the period from 1985 to 2016 for Dharwad, Karnataka, India.

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