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Measurement of technical efficiency of climatic and non-climatic factors in sugarcane farming in Indian States: Use of stochastic frontier production function approach

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Extensive research studies have estimated the influence of climate change on sugarcane yield in India. However, most studies concise their investigations up to one state or group of few states of the nation. Limited studies assessed the impact of climatic factors on sugarcane production and yield at national level. Also, inadequate studies estimate the technical efficiency (TE), and impact of climatic and non-climatic factors on sugarcane farming across Indian states. Therefore, the present study estimates the influence of climate variability on sugarcane yield and production using state-wise panel data during 1971-2014. For this, it used stochastic frontier production function approach through log-linear regression model. Climatic factors (i.e., maximum temperature, minimum temperature and precipitation) are segregated for summer, spring, autumn and winter seasons to assess their impact on growth of sugarcane crop in different weather seasons. Empirical findings of the study implies that climatic factors in different weather seasons have negative and statistically significant impact on sugarcane production and yield. Most states (except Tamil Nadu) are observed technically inefficient to produce sugarcane production. There is existence high variation in TE of sugarcane production across Indian states, thus these states have effective opportunity to increase TE in sugarcane farming. Empirical results of this study provides several policy suggestions to mitigate the negative consequences of climate variability in sugarcane farming.

INTRODUCTION

Climate change has become a greater challenge, which has a negative impact on all economic activities especially on agricultural sector, and it has also become a global environmental threat (Zulfqar et al. 2016; Ali et al. 2017). While, variability in climatic factors has identified in term of change in rainfall patterns, increase in minimum and maximum temperature, fluctuation in floods, drought and other weather factors (Zhao and Li 2015; Kumar et al. 2015b; Shrivastava et al. 2015;Abeysingha et al. 2016; Zulfqar et al. 2016; Ali et al. 2017). Most studies have arrived at that climatic factors are changing due to increasing greenhouse gas (GHGs) emission in the atmosphere worldwide (Zhao and Li 2015; Shrivastava et al. 2015; Ali et al. 2017). High GHGs emission is a significant cause for global warming and climate variability (Ali et al. 2017). Climate variability brought several negative implications on all sectors of the economy. However, agriculture is most vulnerable sector which directly gets influenced due tovarious activities in an economy such as: **(1)** Variability in climatic factors (i.e., maximum temperature, minimum temperature, precipitation, humidity, solar radiation, sun intensity, drought, flood, wind speed, etc.) (Kumar and Sharma 2013; Kumar and Sharma 2014; Kumar et al. 2015b,c,d; Zhao and Li 2015; Yohannes 2016; Kumar et al. 2016; Abeysingha et al. 2016; Zulfqar et al. 2016; Singh et al. 2017; Sharma and Singh 2017; Ali et al. 2017); **(2)** Change in quality and quantity of ecosystem service (i.e. land, water, forest, air quality) (Kumar et al. 2015a; Zaveri et al. 2016; Yohannes 2016; Kumar et al. 2017); **(3)** Change in socio-economic variables (i.e. urbanization, industrialization, high population growth, migration of population from rural to urban area, extensive population pressure on agriculture, credit accessibility to farmers, additional income generating opportunities for farmers, public spending on rural development, government expenditure on agricultural, irrigation and flood control, government expenditure on environmental protection activities, educational level of farmers, etc.) (Khanna 2006; Kumar and Sharma 2014; Kumar et al. 2015b; Singh et al. 2017; Kumar et al. 2017; Sharma and Singh 2017); **(4)** Agricultural inputs (i.e., arable land, agricultural workers, mechanization in cultivation, irrigated area, fertilizer, pesticides, organic fertilizer, etc.) (Khanna 2006; Kumar et al. 2015a; Abeysingha et al. 2016; Sharma and Singh 2017); **(5)** Infrastructure facilities (i.e., transport facility,

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innovation in market and proper road connectivity between rural to urban areas) (Kumar et al. 2015a; Singh et al. 2016); **(6)** Government policies (i.e., subsidy for specific crops, government financial support to grow a particular crop, decision on minimum support price, import and export policies of government for agricultural products in international market, transparency in agricultural marketing system, etc.) (Kumar et al. 2015a); **(7)** Institutional change (i.e., cooperative societies, agricultural extension offices, NGOs, association of farmers with ago-industries, etc.) (Kumar et al. 2015a; Kumar and Gena 2015); **(8)** Changes in farm management practices (i.e., preparation of land for seed planting, selection of appropriate planting and irrigation time, etc.), (Kumar et al. 2015a; Singh et al. 2016; Singh et al. 2017; Sharma and Singh 2017); **(9)** Technological change (i.e., training to farmers, water harvesting and conservation techniques, new varieties of seed, advance techniques for planting, changing planting time, selection of genotype, crop diversification, mixed or dual cropping system, financial support for agricultural R&D by public and private sector, researchers and scientists in agriculture) (Khanna 2006; IISR 2011; Kumar et al. 2015a; Singh et al. 2017); and **(10)** Geographical location (i.e., latitude, longitude and altitude) and agro-ecological zone (Kumar et al., 2017; Sharma and Singh 2017).

Most of aforementioned activities (except climate variability, geographical location and ecosystem service) can be control by farmers (Singh et al. 2017), therefore change in climatic factors play a critical to increase or decrease crop productivity (Kumar et al. 2015a). It has identified that high variability in climatic factors have a negative implications in agricultural production system (Gbetibouo and Hassan 2005;Kim and Pang 2009; Masters et al. 2010; Fofana 2011; Zulfqar et al. 2016). In addition, change in climatic factors have negative impacts on water resource, hydrological process and water availability for irrigation (Abeysingha et al. 2016; Zulfqar et al. 2016; Ali et al. 2017). Subsequently, agricultural productivity would be declined due to variability in climatic factors (Abeysingha et al. 2016; Ali et al. 2017). Productivity of food-grain and cash crops are negatively impacting due to climate variability world-wide (Gbetibouo and Hassan 2005;Mendelsohn et al. 2006; Lee 2009; Zhai et al. 2009; Masters et al. 2010; Fofana 2011; Kumar and Sharma 2013; Kumar and Sharma 2014; Kumar et al. 2015a; Singh et al. 2017). Sugarcane is an annual crop that takes more time to growof sugarcane plant on field as compared to other food-grain crops (e.g., rice, wheat, sorghum, millet, maize, chickpea, gram, etc.) and commercial crops (e.g., cotton, soybean, mustard, groundnut, potato, sesame, etc.). Hence, sugarcane crop is highly sensitive to climate change and it tolerates all weather effects on its growth in all weather seasons (i.e., winter, spring, summer and autumn) (Kumar and Sharma 2014; Kumar et al. 2015a). It is evident that sugarcane productivity is being negatively impacting due to climate change and change in socio-economic factorsin most sugarcane growing countries as Fiji, Brazil, Zimbabwe, India, China, Thailand, Pakistan, USA, South Africa and Australia (Deressa et al. 2005; Bonnett et al. 2006; Cardozo and Sentelhas 2013; Marin et al. 2013; Kumar and Sharma 2013; Chandiposha 2013; Kumar and Sharma 2014; Zhao and Li 2015; Kumar et al. 2015a; Zulfqar et al. 2016; Ali et al. 2017; Ali and Jan 2017). Variability in climatic factors may be causedto increase biotic factors like diseases, insects and weeds in sugarcane crop (Mali et al. 2014; Zulfqar et al. 2016). It is expected that productivity and juice quality sugarcane crop may be declined due to change in rainfall patterns and humidity during monsoon season (Mali et al. 2014; Shrivastava et al. 2015). Sugarcane physiology may be negatively impacted due to extreme fluctuation in minimum and maximum temperature during various weather seasons (Mali et al. 2014; Zulfqar et al. 2016).

In India, extensive research studies have estimated the influence of climatic and non-climatic variables on sugarcane yield and production across Indian states and across districts of a state(e.g., Subbaramayya and Kumar 1980; Ramulu 1996; Khanna 2006; Shrivastava et al.2011; Srivastava and Rai 2012; Devi et al. 2012; Kumar and Sharma 2013; Mali et al. 2014; Samui et al. 2014; Kumar and Sharma 2014; Solomon 2014; Shrivastava et al. 2015; Abnave 2015; Kumar et al. 2015a; Bhosale et al. 2015; Chandran and Anushree 2016; Parag and Priyanka 2016; Singh and Katiyar 2016; Mishra et al. 2016). Most studies addressed their investigation to assess the effect of climatic and socio-economic variables on sugarcane yield or production based on one state of India or district of an individual state. Also, no study estimate the technical efficiency (TE) of climatic and non-climatic factors in sugarcane farming. Therefore, there needs a robust empirical exercise to investigate the climatic change impact on sugarcane farming with TE of climatic and non-climatic factors in India. Hence, the present study is addressed following research questions with regards to association of climatic and non-climatic factors with sugarcane production and yield in India: (1) What is the effect of climate variability on sugarcane farming in different weather seasons across Indian states? (2) What types of adaption techniques would be beneficial to mitigate the adverse effect of climate change on sugarcane farming? (3) Is impact of climatic variation on sugarcane farming varied across Indian states? (4) In which state sugarcane farming is highly climate sensitive? (5) Whether technical efficiency of climatic and non-climatic factors in sugarcane farming are varied across Indian states? (6) How does the production activities in sugar industries get influences due to variation in sugarcane production? (7) Whether ecological factor have a statistically significant association with sugarcane farming or not? Based upon the aforesaid research questions, the present study aims to achieve the following objectives: **(1)** To investigate the influence of climate variability and non-climatic factors on sugarcane yield and production using a state-wise panel data during 1971-2014 in India. **(2)** To measure the technical efficiency of sugarcane production and yield with climatic and non-climatic factors and without climatic variables across Indian states during 1971-2014. **(3)** To bring outsome policy suggestions to mitigate the negative impact of climate variability on sugarcane farming.

Significance and Contribution to Literature

This study is comprehensive study which observed the impact of climatic factors on sugarcane farming at national level in India. Also, it also estimate the technical efficiency of climatic and non-climatic factors in sugarcane farming. Based on empirical findings, the present study provide the conclusive and decisive policy suggestions to increase the yield and production of sugarcane crops in near future. Estimates also provide the expected reasons which negatively affect the technical efficiency of climatic and non-climatic factors in sugarcane farming. Estimated technical efficiency of climatic and non-climatic factors in sugarcane crop farming also increase the attention of researchers and scientists to take a significant action to improve the yield and production of sugarcane production. The present study also provide the authentic research gap to estimate the technical efficiency of climatic and non-climatic factors in cultivation of food-grain and commercial crops. Hence, this study provide the effective contribution in research field and existing literature.

IMPORTANCE OF SUGARCANE CROP IN INDIA

In India sugarcane crop grows in tropical and subtropical agro-ecological zones. Tropical and subtropical zones account around 45% and 55% sugarcane production respectively of the country. Sugarcane is a prime source to meet the requirement of sugar, gur, khandasari, bio-energy and ethanol in the domestic and international market (IISR 2011; Parag and Priyanka 2016). By-products of sugarcane crop uses as fodder to feed the livestock mostly for cow and buffalo in sugarcane growing states of India. Therefore, it has crucial contribution in livestock-rearing sector in India. Also, it produces bio-fuel, fibre, organic fertilizer, plastics, furfural, eathyl alcohol, butyl alcohol, citric acid and myriad of byproducts (Zulfqar et al. 2016). Sugarcane crop is also essential to maintain soil health and improve productivity of other crops (IISR 2011), thus it is a renewable and natural agricultural resource that maintains ecological sustainability (Singh and Katiyar 2016). Sugarcane is prime crop for earning foreign currency in India (Singh and Katiyar 2016). In India, sugarcane crop covers around 2.57% area of gross cropped area and contributes 6% share in agricultural output (Abnave 2015). Around 7.5% of rural population directly and indirectly gets involve in sugarcane farming for their basic livelihood (Parag and Priyanka 2016). The crop also provides the raw materials to second largest agro-based industries after textiles in India (Singh and Katiyar 2016), which also generates around Rs.3,000 Crore (approximate US Dollar 468.06 Crore) revenue as tax for GoI (Abnave 2015; Parag and Priyanka 2016). In addition, it has observed that sugar industries create jobs for around 6 million sugarcane farming community and 0.5 million skilled and unskilled industrial workers (IISR 2011; Abnave 2015; Shrivastava et al. 2015). In India, cropped area and irrigated areas under sugarcane crop were significantly fluctuated during 1971-2015 (Refer Figure-1). It infers that area sown and irrigated area under sugarcane crop were significantly increased after 1971. Sugarcane production, sugarcane yield and cane crushed were also significantly improved during 1971-2015 (Refer Figure-2). It implies that arable land and irrigation facilities were the crucial determinants in sugarcane cultivation.

Sugar production and sugar consumption were also showed the increasing trends during 1971-2015 (Refer Figure-3). However, sugar production and sugar consumption was consistently increased in given period. Number of sugar factories was consistently increased due to increase in sugarcane production in the similar period (Refer Figure-4). Average crushing duration in a year and sugar recovery/quintal sugarcane were varied in the same period. Here, it is clear that cropped area and irrigated area under sugarcane crop, sugarcane production and yield, cane crushed, sugar production, sugar consumption, sugar factories, average crushing duration and sugar recovery were also significantly fluctuated during 1971-2015.

India's Position in Sugarcane Production in World's Top 10 Economies

Sugarcane crop grows around 120 economies of the world. Brazil, India, China, Thailand, Pakistan, Mexico, Colombia, Indonesia, Philippines and United States of America are the top 10 sugarcane crop growing economies in the world. Harvested area under sugarcane crop, sugarcane production and sugarcane yield for these economies during 2012-2014 are given in Figure-5, Figure-6 and Figure-7 respectively. India is the 2ndlargest producer of sugarcane, while it has a largest number of consumers who consume products developed by sugarcane crop (IISR 2011; Kumar et al. 2015a; Singh and Katiyar 2016). India is estimated 2nd largest producer of sugar after Brazil, which contribute 15% share in world's sugarcane production in 2015-16. However, India has lower productivity of sugarcane crop as compared to Brazil, Colombia, USA, Thailand, Mexico and China. India has a significant possibility to increase sugarcane production through improving productivity in sugarcane cultivation.

MATERIAL AND METHODOLOGY

The present study was used information on climatic and non-climatic factors for 44 years during 1971-2014 at state-wise panel data. It includes 14 states which contributes around 99% sugarcane production and 98% cropped area under sugarcane crop of India. These states have good natural resource which are suitable for farming and large portion of population of these states depend on agriculture for their daily livelihood. These states are also major agricultural intensive states of the country and located in agro-ecological zones: **(i) South:** Andhra Pradesh, Karnataka and Tamil Nadu, (ii) **West:** Gujarat, Madhya Pradesh, Maharashtra and Rajasthan, (iii) **North:** Haryana, Punjab and Uttar Pradesh, **East:** Bihar, Orissa and West Bengal, and **North-East:** Assam.

Descriptions and Data Sources

Agricultural Data:

State-wise sugarcane production, cropped area and irrigated area under sugarcane crop, sugarcane yield, number of sugarcane industries, sugar recovery, average crushing duration, sugarcane consumption and sugar production were derived from the official website of Indian Institute of Sugarcane Research (IISR), Lucknow. Forest area, irrigated area, consumption of fertilizer were taken from the Centre *for Monitoring Indian Economy* (CMIE) database. Interpolation and extrapolation techniques were used to complete the time series for those factors that had missing values in the data set (Mondal et al. 2015; Kumar et al. 2015a,b; Singh et al. 2017).

Climatic Variables:

Information on climatic factors (i.e. minimum temperature, maximum temperature and precipitation) during 1971-2014 were taken from the Indian Meteorological Department (IMD) (GoI), Geographic Information System (GIS) and Indian Institute of Tropical Meteorology (IITM). Above-mentioned data was available on daily intervals with latitude and longitude ($1^0 \times 1^0$ grid-scale) information of monitoring stations. Due to inaccessibility of city-wise data of climatic factors, the stations relating to specific latitude and longitude were recognized. Based on this, geographical locations were identified, thereafter from the groups of such stations; different geographical regions were linked to arrive at the state-wise data. These data were converted into monthly city-wise and after that these were transformed into state-wise monthly climatic variables (For more detail see Singh et al. 2017).

Existing Models in Agricultural Production Analysis

There are many models (i.e. production function, Ricardian cross-sectional, Crop-Simulation, Agronomic-economic, Agro-ecological zone, integrated assessment and compute general equilibrium models) which can be used to assess the impact of climatic and non-climatic factors on agricultural production and crop productivity (United Nations Report 2011; Kumar and Sharma 2014; Ali et al. 2017). In India, most agricultural economists and social scientists have used production function approach to investigate the climate change impact on agricultural production, crop productivity and agricultural GDP. However, these models cannot measure the technical efficiency (TE) of

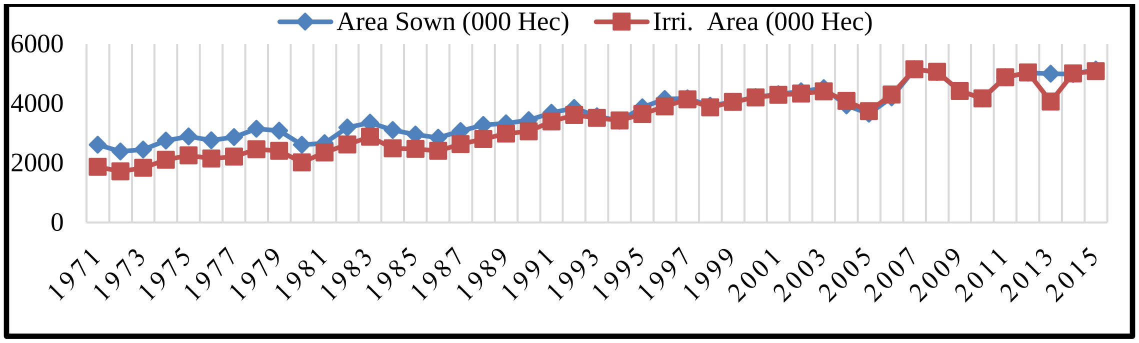

Figure 1 Area sown and irrigated area under sugarcane crop in India
Source: IISR, Lucknow; CMIE.

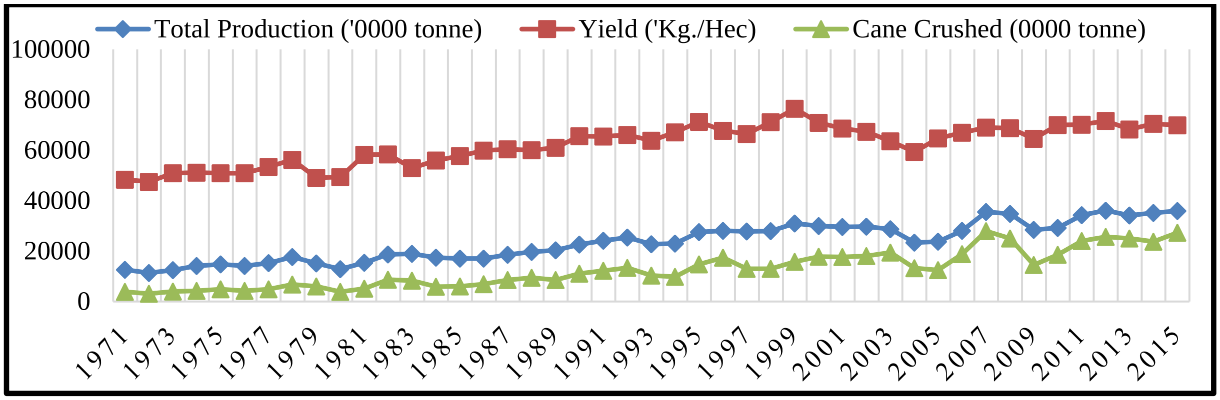

Figure 2 Total production and yield of sugarcane and cane crushed in India
Source: IISR, Lucknow; CMIE.

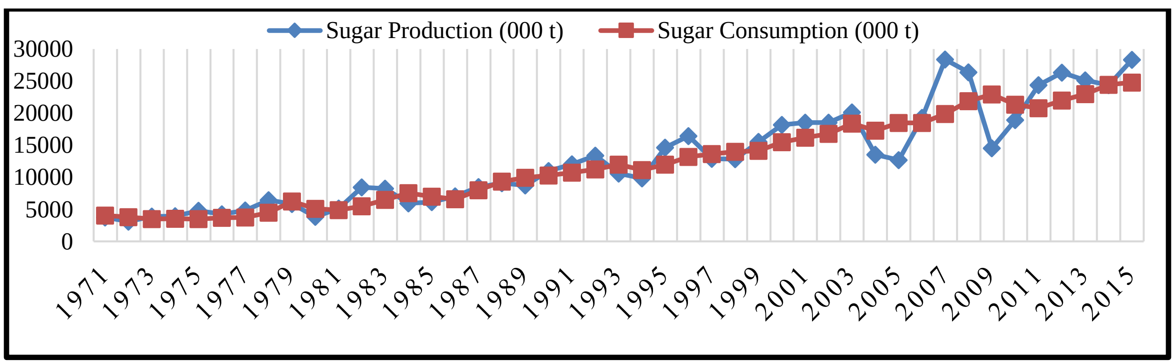

Figure 3 Sugar production and sugarcane consumption in India
Source: IISR, Lucknow; CMIE.

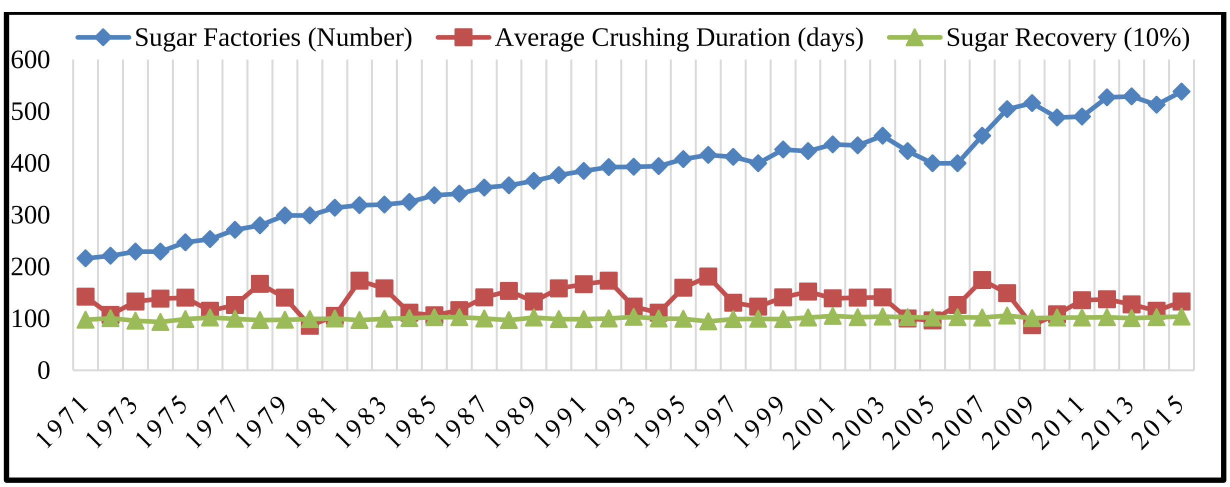

Figure 4: Sugar factories, average crushing duration and sugar recovery in India
Source: IISR, Lucknow; CMIE.

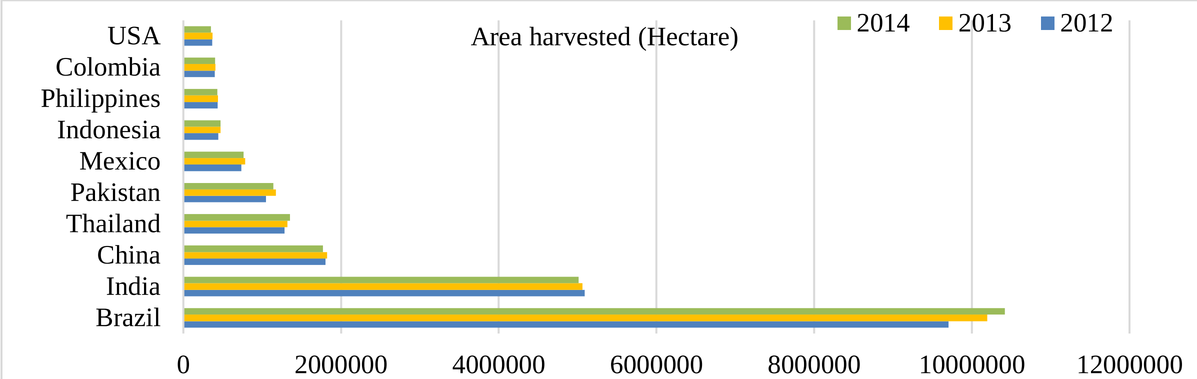

Figure 5 Harvested area under sugarcane crop in India and world's top ten economies
Source: FAO.

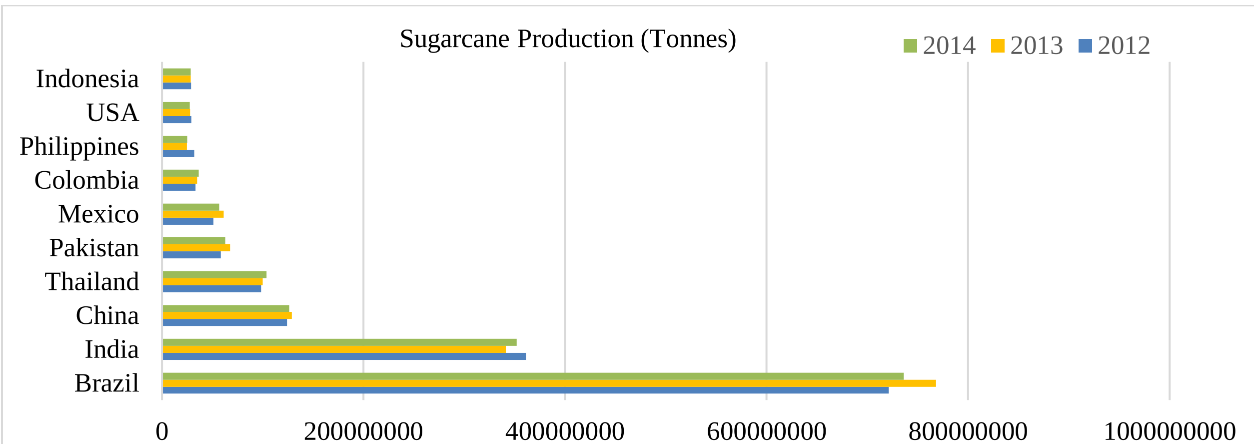

Figure 6 Sugarcane production in India and world's top ten economies
Source: FAO.

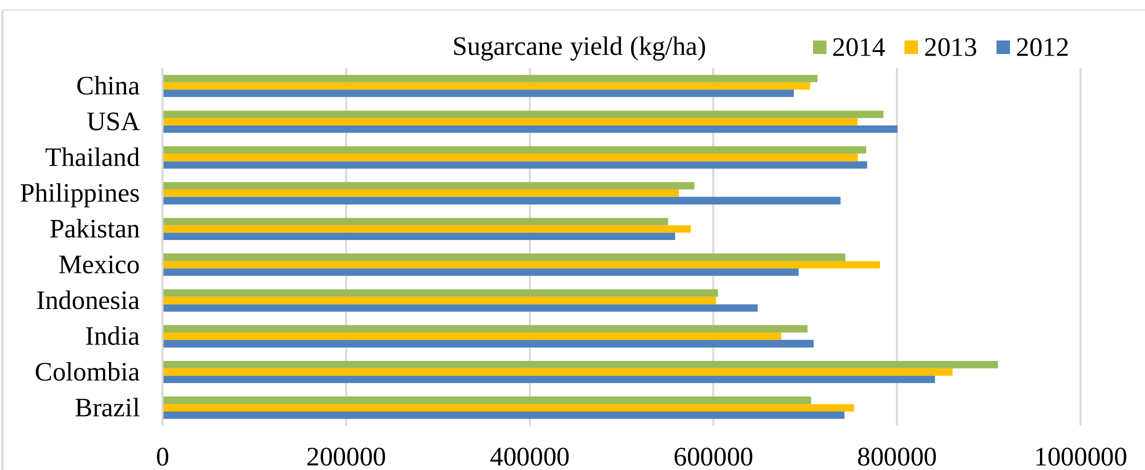

Figure 7 Sugarcane yield in India and world's top ten economies
Source: FAO.

climatic and non-climatic factors in crop farming. Stochastic frontier production function approach (SFPFA) and Data Envelopment Analysis (DEA) are proficient to estimate the TE of inputs in agricultural production analysis (Girel et al. 2013; Hussain et al. 2014; Hamjah 2014; Ng'ombe and Kalinda 2015; Yang et al. 2016; Kea et al. 2016; Okoye et al. 2016; Ali and Jan 2017).These analytical techniques can be used in case of parametric and non-parametric conditions (Ng'ombe and Kalinda 2015; Ali and Jan 2017). SFPFA model includes parameters of production function and inefficiency function simultaneously in an empirical model. Therefore, the present study has applied SFPFA model to investigate TE of climatic and non-climatic factors in sugarcane farming.

ANALYTICAL FRAMEWORK OF STOCHASTIC FRONTIER PRODUCTION FUNCTION APPROACH (SFPFA)

SFPFA and DEA are useful to estimate TE in agricultural production analysis (Khanna 2006; Ng'ombe and Kalinda 2015; Okoye et al. 2016; Ali and Jan 2017). Technical, allocative and economic efficiencies are the various types of efficiencies (Girel et al. 2013). Efficiency shows that a production system produces optimum output using minimum quantity of inputs and technologies (Girel et al. 2013; Hamjah 2014; Hussain et al. 2014; Kea et al. 2016; Yang et al. 2016). Allocative efficiency indicates the ability of a firm to produce high-level of output using the minimum cost of inputs (Hamjah 2014; Hussain et al. 2014). Technical efficiency is the ratio of observed output to maximum output under the assumption of fixed inputs (Kea et al. 2016). Economic efficiency measures the highest level of satisfaction that is obtained from the given resource in a production unit. All above-mentioned efficiencies are crucial to measure the production efficiency of the process and inputs which are used to converts these into output in agricultural farm or industry or firm (Kea et al. 2016). In the present study, regression coefficient of explanatory variables were estimated using SFPFA under non-parametric condition (Khanna 2006; Ng'ombe and Kalinda 2015; Okoye et al. 2016; Ali and Jan 2017). SFPFA model was introduced by Aigner et al. (1977); Meeusen and Van de Broeck (1977) to estimate the TE of production units. It includes production function as a common regression with a composite error term that is equal to sum of two components (Aigner et al. 1977; Meeusen and Van de Broeck 1977; Girel et al. 2013; Hussain et al. 2014). For this study, SFPFA model was adopted from Crisci et al. (2016) and given as:

$$Y_{it} = \alpha + f(X_{it},\beta) + \varepsilon_{it} \qquad (1)$$

$$Y_{it} = \alpha + f(X_{it},\beta) + (v_{it} - u_{it}) \qquad (2)$$

Here, Y_{it} is the output for i^{th} entity in time t; α is the constant coefficient; i=1, 2, 3 ... N; t=1, 2, 3 … T. X_{it} is a $(k*1)$ vector of inputs; β is the vector of unknown parameters or explanatory variables (Baten et al. 2009). ε_{it} (composite error term)=v_{it}- u_{it}, where v_{it} is random variables (natural error term) that is assumed to be $iid\ N^{+}(0, \sigma_v^2)$, and independent of the u_{it} that is non-negative random variable (technical-error term). It accounts technical inefficiency in production function (Baten et al. 2009; Hussain et al. 2014; Crisci et al. 2016; Yang et al. 2016). SFPFA may be segregated into time-invariant model (that assumes that technical inefficiency is constant over time, consider as u_i) and time-varying model (that allows that technical inefficiency changes over time, given as u_{it}) (Crisci et al. 2016). Here, both possibilities may be given as:

$$u_{i1} = u_{i2} = \ldots = u_{iT} = u_i \text{ (Time-invariant model)} \qquad (3)$$
$$u_{i1} = u_i g(1) = \ldots = u_{iT} = u_i g(T) \ i.e.\ u_{it} = u_i g(t) \text{ (Time-varying model)} \qquad (4)$$

Time Invariant SFPFA Model: For time-invariant model, following function was applied in the present study (Crisci et al. 2016):

$$Y_{it} = \alpha + f(X_{it},\beta) + (v_{it} - u_i) \qquad (i=1, 2, \ldots N; t=1, 2, \ldots, T) \qquad (5)$$

Here, $u_i \sim iid\ N^{+}(0,\sigma_u^2)$ that is assumed to be normally distributed. The above equation may be transferred into standard panel data model that is given as:

$$Y_{it} = \alpha + f(X_{it},\beta) + v_{it} \qquad (i=1, 2, \ldots N; t=1, 2, \ldots, T) \qquad (6)$$

Time Varying SFPFA Model: It includes a time trend factor into production that permits the estimation of technical changes and changes in the technical inefficiencies over the period. Following functional form is considered in the present study (Crisci et al. 2016):

$$Y_{it} = \alpha_t + f(X_{it},\beta) + (v_{it} - u_{it}) = \alpha_{it} + f(X_{it},\beta) + v_{it} \quad (i=1, 2, \ldots N; t=1, 2, \ldots, T) \qquad (7)$$

Here, $\alpha_{it} = \alpha_t - u_{it}$ is the intercept for i^{th} entities in period t; and $u_{it} \sim iid\ N^{+}(\mu, \sigma_u^2)$.

True Fixed Effect and True Random Effect SFPFA Model: True fixed SFPFA model is specified as:

$$Y_{it} = \alpha_i + f(X_{it},\beta) + (v_{it} - u_{it}) \qquad (i=1, 2, \ldots N; t=1, 2, \ldots, T) \qquad (8)$$

Here, α_i is the unit fixed-effect specific term that captures all time invariant heterogeneities with $u_{it} \sim iid\ N^{+}(0, \sigma_u^2)$ and $v_{it} \sim iid\ N^{+}(0, \sigma_v^2)$ (Crisci et al. 2016). v_{it} is the idiosyncratic-error term; u_{it} is the one-side disturbance-error term that shows the inefficiency. v_{it} and u_{it} is independently distributed to each other and regressors (Ng'ombe and Kalinda 2015). Random effect model is given as:

$$Y_{it} = \alpha_i + f(X_{it},\beta) + (v_{it} - u_{it}) + \omega_i (i=1, 2, \ldots N; t=1, 2, \ldots, T) \qquad (9)$$

Here, ω_i is a time-invariant specific random term that captures cross unit invariant heterogeneity.

Measurement of Technical Efficiency (TE)

Technical Efficiency (TE) defines as the ratio of observed output to maximum feasible output in production frontier (Baten et al. 2009; Hamjah 2014; Hussain et al. 2014; Ng'ombe and Kalind 2015; Yang et al. 2016; Kea et al. 2016). TE is specified as:

$$TE_{it} = Y_{it} / [f(X_{it},\beta) exp(u_{it})] \qquad (10)$$

The value of efficiency lies between 0-1 (Kea at al. 2016). The value of TE_{it}=1 indicates that Y_{it} has achieved optimum output with highest efficiency, and TE_{it}<1 shows technical inefficiency in the sense that observed output is less than optimum output (Hamjah 2014; Okoye et al. 2016).

FORMULATION OF ECONOMETRIC MODELS

Empirical Model for Sugarcane Production

The present study examines the influence of climatic and non-climatic factors on sugarcane production. Therefore, sugarcane production was used as dependent variable and regressed with climatic and non-climatic factors as explanatory variables under SFPFA using log-linear regression model (Cobb-Douglas production function model) (Khanna 2006; Girel et al. 2013; Hussain et al. 2014; Hamjah 2014; Ng'ombe and Kalinda 2015; Yang et al. 2016; Kea et al. 2016; Okoye et al. 2016; Ali and Jan 2017). The model is given as:

$$log(TP)_{it} = \beta_0 + \beta_t(ttf) + \beta_1 log(AS)_{it} + \beta_2 log(FAAS)_{it} + \beta_3 log(IA)_{it} + \beta_4 log(CF)_{it} + \beta_5 log(ACD)_{it} + \beta_6 log(VAMaxTWiSe)_{it} + \beta_7 log(VAMaxTSpSe)_{it} + \beta_8 log(VAMaxTSuSe)_{it} + \beta_9 log(VAMaxTAuSe)_{it} + \beta_{10} log(VAMinTWiSe)_{it} + \beta_{11} log(VAMinTSpSe)_{it} + \beta_{12} log(VAMinTSuSe)_{it} + \beta_{13} log(VAMinTAuSe) + \beta_{14} log(VAPcpWiSe) + \beta_{15} log(VAPcpSpSe)$$

$+\beta_{16} \log(VAPcpSuSe) + \beta_{17} \log(VAPcpAuSe) + \beta_{18} \log(CVDaPcp) + \beta_{19} \log(CVDaMinT) + \beta_{20} \log(CVDaMaxT) + (v_{it} - u_{it})$ (11)

Here, *TP* is sugarcane production; *I* is the cross-sectional state and *t* is the time period. *Log* is logarithms of corresponding variables; *ttf* is time trend factor that is included to capture the impact of technological change on sugarcane production. β_0 is constant term; β_t is regression coefficient of time trend factor; $\beta_1 ... \beta_{20}$ are the estimated regression coefficient of explanatory variables; v_{it} is symmetric error term that accounts the influence of those factors on sugarcane production, which could not include in the model and u_{it} is non-negative random variable which represents the inefficiency in sugarcane production in equation (11). The explanation of independent variables is specified in Table-1.

Empirical Model for Sugarcane Yield

In this study, sugarcane yield was also used as dependent variable to examine the impact of climatic and non-climatic factors on sugarcane yield (Kumar and Sharma 2013; Kumar and Sharma 2014; Kumar et al. 2015b). The proposed model is applied in following functional form:

$\log(LP)_{it} = \alpha_0 + \alpha_t (ttf) + \alpha_1 \log(AS)_{it} + \alpha_2 \log(FAAS)_{it} + \alpha_3 \log(IA)_{it} + \alpha_4 \log(CF)_{it} + \alpha_5 \log(ACD)_{it} + \alpha_6 \log(VAMaxTWiSe)_{it} + \alpha_7 \log(VAMaxTSpSe)_{it} + \alpha_8 \log(VAMaxTSuSe)_{it} + \alpha_9 \log(VAMaxTAuSe)_{it} + \alpha_{10} \log(VAMinTWiSe)_{it} + \alpha_{11} \log(VAMinTSpSe)_{it} + \alpha_{12} \log(VAMinTSuSe)_{it} + \alpha_{13} \log(VAMinTAuSe) + \alpha_{14} \log(VAPcpWiSe) + \alpha_{15} \log(VAPcpSpSe) + \alpha_{16} \log(VAPcpSuSe) + \alpha_{17} \log(VAPcpAuSe) + \alpha_{18} \log(CVDaPcp) + \alpha_{19} \log(CVDaMinT) + \alpha_{20} \log(CVDaMaxT) + (v_{it} - u_{it})$ (12)

Here, *LP* is sugarcane yield (land productivity); α_0 is constant term; α_t is regression coefficient of time trend factor; and $\alpha_1 \dots \alpha_{20}$are regression coefficients of associated variables. Regression coefficients for sugarcane production and sugarcane yield function are estimated through time-invariant decay model and time-varying decay model using STATA statistical software.

Rationality of Dependent and Independent Variables

Dependent Variables:

In this study, sugarcane production and sugarcane yield were used as dependent variables to investigate the influence of climatic variables on sugarcane farming (Kumar and Sharma 2013; Kumar and Sharma 2014; Kumar et al. 2015a; Ali et al. 2017; Ali and Jan 2017).

Factor for Technological Change:

Time trend factor was considered as proxy to measure the impact of technological change on sugarcane farming (Kumar et al. 2015a; Crisci et al. 2016; Singh et al. 2016; Singh et al. 2017).

Non-climatic/Control Variables:

Irrigated area under sugarcane crop, application of fertilizer in sugarcane planting area and average crushing duration were used as explanatory variables (Deressa et al. 2005; Khanna 2006; Kumar and Sharma 2013; Kumar and Sharma 2014; Kumar et al. 2014; Kumar et al. 2015a; Mondal et al. 2015; Zulfqar et al. 2016; Mishra et al. 2016; Sharma and Singh 2017; Ali and Jan 2017).

Ecological Factor:

Forest area is crucial to maintain the environmental sustainability, it mitigates the negative impact of climate change on crop farming (MEA 2005; Dash 2011; Kumar and Sharma 2013; Maiti et al. 2015). It reduces high temperature impact on crop growth (Kumar et al. 2015d). So ratio of forest area with cropped area under sugarcane crop was used as proxy for ecological indicator to capture its impact on sugarcane production and yield.

Climatic Variables:

Average maximum temperature, average minimum temperature and average precipitation during winter, spring, summer and autumn season were used as climatic factors (Kumar and Sharma 2014; Kumar et al. 2015a; Ali et al. 2017). The actual value of a climatic factor was subtracted from the mean value of associated climatic factor during 1971-2014. Thereafter, the square root of this climatic factor was used to capture the influence of this factor (as variability impact of this factor) on sugarcane production and yield (Singh et al. 2017). Hence, the variability in all climatic factors are estimated as:

$$Variation = \sqrt{[(Xit - X)]^2} (13)$$

Here, X_{it} is actual value of climatic factor in state *i* and year *t*; and *X* is mean value of particular climatic factor during 1971-2014 (Singh et al. 2017). Coefficient variation *(CV)* in daily maximum temperature in a year is also used to capture the influence of annual variation in this factor on sugarcane farming. Similarly, *CV* in daily minimum temperature and *CV* in daily precipitation are used to capture their effect on sugarcane farming (Cabas et al. 2010; Kumar et al. 2015a).

$$CV = \left[\left(\frac{SD}{X}\right) * 100\right] (14)$$

Here, *CV* is coefficient variation in a specific climatic factor, *SD* and *X* are standard deviation and mean value of daily climatic factor respectively in a year. There are additional climatic factors such as sun intensity, solar radiation, cloud coverage, wind speed, relative humidity, soil moisture, soil quality and salinity, hail storm, humidity, fog, concentration of carbon dioxide and other weather patterns (Cardozo and Sentelhas 2013; Marin et al. 2013; Hamjah 2014; Kumar et al. 2015a; Shrivastava et al. 2015; Abeysingha et al. 2016; Zulfqar et al. 2016; Ali et al. 2017), and natural disasters such as floods, drought, cyclone, earthquakes, and crop disease which have a negative impact on crop production and productivity. However, the study could not include these indicators in empirical investigations due to unavailability of data, which might be useful to arrive at more logical conclusions.

DISCUSSION ON EMPIRICAL RESULTS

Effect of Climatic and Non-climatic Factors on Sugarcane Production

The regression coefficients of climatic and non-climatic factors which measured their impact on sugarcane production were estimated through time-invariant decay and time-varying decay models. Two separate regression models were regressed for each aforesaid model. In first model, all factors were considered, while in second model only non-climatic factors were used. Estimates based on both the models, indicate that all non-climatic factors have statistically significant impact on sugarcane production (Refer Table-2 and 3). The values of sigma2were found statistically significant for all the models, therefore log-linear regression model produced better results. The Gamma values were 88% and 84% under time-invariant decay model and time-varying decay model respectively in first estimation (Refer Table-2), while these were observed 91% and 85% under time-invariant decay model and time-varying decay model respectively in second estimation for sugarcane

Table 1 Brief explanation of dependent and independent variables

Symbol	Units	Brief Description
TP	000 t	Sugarcane production
LP	t/ha	Sugarcane yield (land productivity)
ttf	Number	Years
AS	000 ha	Cropped area under sugarcane crop
FAAS	Number	Ratio of forest area with cropped area under sugarcane crop
IA	000 Hec	Irrigated area under sugarcane crop
CF	Kgs/Hec	Applications of fertilizer in sugarcane farming
ACD	(days)	Average crushing duration in a year
VAMaxTWiSe	%	Variation in average maximum temperature in winter season
VAMaxTSpSe	%	Variation in average maximum temperature in spring season
VAMaxTSuSe	%	Variation in average maximum temperature in summer season
VAMaxTAuSe	%	Variation in average maximum temperature in autumn season
VAMinTWiSe	%	Variation in average minimum temperature in winter season
VAMinTSpSe	%	Variation in average minimum temperature in spring season
VAMinTSuSe	%	Variation in average minimum temperature in summer season
VAMinTAuSe	%	Variation in average minimum temperature in autumn season
VAPcpWiSe	%	Variation in average precipitation in winter season
VAPcpSpSe	%	Variation in average precipitation in spring season
VAPcpSuSe	%	Variation in average precipitation in summer season
VAPcpAuSe	%	Variation in average precipitation in autumn season
CVDaPcp	%	Coefficient variation in daily precipitation in a year
CVDaMinT	%	Coefficient variation in daily minimum temperature in a year
CVDaMaxT	%	Coefficient variation in daily maximum temperature in a year

Table 2 Impact of non-climatic and climatic factors on sugarcane production

Types of Models	Time-invariant decay model [Model: 1]		Time-varying decay Model [Model: 2]	
No. of Obs.	564		564	
Wald Chi^2	6485.11		11206.28	
Prob > Chi2	0.0000		0.0000	
Log likelihood	360.76969		388.39248	
Variables	*Estimate*	*Std. Err.*	*Estimate*	*Std. Err.*
Time Trend	0.0074965*	0.0010399	0.0014789	0.0012984
log(AS)	0.8907636*	0.0307003	0.890814*	0.0323492
log(FAAS)	0.0400296**	0.0173643	0.0357004**	0.0160857
log(IA)	0.0585331*	0.0141753	0.096941*	0.0132398
log(CF)	-0.0302779***	0.0158245	-0.0329959**	0.0171828
log(ACD)	0.0890333*	0.0164093	0.0851685*	0.0156429
log(VAMaxtWiSe)	-0.004058	0.0051981	-0.0035899	0.0049257
log(VAMaxtSpSe)	-0.0044252	0.0052109	-0.0009477	0.0049571
log(VAMaxtSuSe)	-0.0153895*	0.0052245	-0.0136898*	0.0049954
log(VAMaxtAuSe)	-0.0091433***	0.0051489	-0.0121428**	0.004908
log(VAMintWiSe)	0.0015815	0.0049893	-0.0003807	0.0047226
log(VAMintSpSe)	0.0020264	0.0052742	0.0057646	0.0049796
log(VAMintSuSe)	-0.0062237	0.0056077	-0.0031556	0.0053531
log(VAMintAuSe)	0.011919**	0.0050327	0.011452**	0.0047741
log(VAPcpWiSe)	-0.0016435	0.0054133	-0.0010329	0.0051391
log(VAPcpSpSe)	0.0049733	0.0053815	0.0020017	0.0051759
log(VAPcpSuSe)	-0.0049478	0.004914	-0.0045206	0.0046634
log(VAPcpAuSe)	-0.0061484	0.0052881	-0.0038436	0.0050251
log(CVDAPcp)	-0.0934602**	0.0464562	-0.0209884	0.0398963
log(CVDAMint)	-0.1733239*	0.0531039	-0.0885696***	0.0563125
log(CVDAMaxt)	-0.0283858	0.070755	-0.0167056	0.0675525
Con. Coef.	-9.321626*	2.01161	1.951195	2.536723
/mu	0.2709223	0.209195	0.2414061	0.1848436
/eta	-	-	0.0128849	0.0018072
/lnsigma2	-2.096855*	0.6616077	-2.516179	0.6073452
/ilgtgamma	2.020293*	0.752763	1.655969	0.7261907
sigma2	0.1228421		0.0807677	

gamma	0.8829113	0.8396962
sigma_u2	0.1084587	0.0678203
sigma_v2	0.0143834	0.0129474

Source: Author's estimation; *, **, and *** indicates the significant level at 1%, 5%, and 10%, respectively. **Note:** *sigma_v2* is the measure of σ_v^2; *sigma_u2* is the estimate of σ_u^2; *gamma* is the measure of $\gamma = \frac{\sigma_v^2}{\sigma_s^2}$; sigma2 is the estimate of $\sigma_s^2 = \sigma_v^2 + \sigma_u^2$; *ilgtgamma* indicates the inverse log it of γ and its value lies between 0-1; *lnsigma2* is in the term of $\log\left(\sigma_s^2\right)$ that must be positive; *mu* is the estimate of μ; and finally, *eta* indicates the estimate of η that is close to zero.

Table 3 Impact of non-climatic variables on sugarcane production

Types of Models	Time-invariant decay model [Model: 3]		Time-varying decay Model [Model: 4]	
No. of Obs.	616		616	
Wald Chi²	6760.96		11117.15	
Prob > Chi2	0.0000		0.0000	
Log likelihood	374.06604		406.91218	
Variables	*Estimate*	*Std. Err.*	*Estimate*	*Std. Err.*
Time Trend	0.0080127*	0.0010768	0.0018582	0.0012554
log(AS)	0.8827855*	0.0312772	0.9128985*	0.0301157
log(FAAS)	0.0382387**	0.0167511	0.0231175***	0.0148444
log(IA)	0.0647089*	0.0142311	0.0944646*	0.0127596
log(CF)	-0.0349643**	0.0160991	-0.0396586**	0.0162603
log(ACD)	0.0887991*	0.0159748	0.0848772*	0.0151876
Con. Coef.	-11.19903*	2.081566	0.861937	2.478302
/mu	0.4854667*	0.173807	0.345545**	0.1401291
/eta	-	-	0.0114858*	0.0013656
/lnsigma2	-1.798577*	0.5529645	-2.360162*	0.5355399
/ilgtgamma	2.284524*	0.612328	1.768853*	0.6296177
sigma2	0.1655343		0.094405	
gamma	0.9075872		0.854315	
sigma_u2	0.1502368		0.0806516	
sigma_v2	0.0152975		0.0137534	

Source: Authors' estimation; *, **, and *** indicates the significant level at 1%, 5%, and 10%, respectively.

Table 4 Impact of non-climatic and climatic factors on sugarcane yield

Types of Models	Time-invariant decay model [Model: 1]		Time-varying decay Model [Model: 2]	
No. of Obs.	564		564	
Wald Chi²	383.89		129.36	
Prob > Chi2	0.0000		0.0000	
Log likelihood	360.62611		388.19457	
Variables	*Estimate*	*Std. Err.*	*Estimate*	*Std. Err.*
Time Trend	0.0074944*	0.0010403	0.0014862	0.0012985
log(AS)	-0.1085444*	0.0307192	-0.1086235*	0.0323654
log(FAAS)	0.0395712**	0.0173717	0.0353468**	0.0160906
log(IA)	0.0584726*	0.0141802	0.0969492*	0.0132462
log(CF)	-0.0303116***	0.0158306	-0.0331357***	0.0171895
log(ACD)	0.0889616*	0.0164143	0.0851091*	0.015649
log(VAMaxtWiSe)	-0.0041126	0.0051997	-0.0036415	0.0049275
log(VAMaxtSpSe)	-0.0043566	0.0052125	-0.0008931	0.004959
log(VAMaxtSuSe)	-0.0153917*	0.0052261	-0.013689*	0.0049974
log(VAMaxtAuSe)	-0.0091984***	0.0051504	-0.0122**	0.0049099
log(VAMintWiSe)	0.0015926	0.0049908	-0.00038	0.0047244
log(VAMintSpSe)	0.0020477	0.0052758	0.0057972	0.0049815
log(VAMintSuSe)	-0.0062361	0.0056094	-0.0031672	0.0053552
log(VAMintAuSe)	0.0119745**	0.0050342	0.0114997**	0.0047759
log(VAPcpWiSe)	-0.0016515	0.0054149	-0.0010283	0.0051411
log(VAPcpSpSe)	0.0050463	0.0053832	0.0020729	0.005178
log(VAPcpSuSe)	-0.0049523	0.0049155	-0.0045265	0.0046651
log(VAPcpAuSe)	-0.0061536	0.0052897	-0.0038513	0.005027

log(CVDAPcp)	-0.0927346**	0.0464695	-0.0202325	0.0399065
log(CVDAMint)	-0.1736931*	0.0531129	-0.0886917	0.0563277
log(CVDAMaxt)	-0.0300266	0.0707739	-0.0178892	0.067557
Con. Coef.	-9.318469*	2.01249	1.934961	2.536772
/mu	0.2692434	0.210096	0.2407679	0.1850581
/eta	-	-	0.0128932*	0.001808
/lnsigma2	-2.09743*	0.6630519	-2.516967*	0.6076598
/ilgtgamma	2.018939*	0.7545035	1.654116**	0.7267701
sigma2	0.1227716		0.080704	
gamma	0.8827712		0.8394466	
sigma_u2	0.1083792		0.0677467	
sigma_v2	0.0143924		0.0129573	

Source: Authors' estimation; *, **, and *** indicates the significant level at 1%, 5%, and 10%, respectively.

Table 5 Impact of non-climatic factors on sugarcane yield

Types of Models	Time-invariant decay model [Model: 3]		Time-varying decay Model [Model: 4]	
No. of Obs.	616		616	
Wald Chi²	349.38		99.81	
Prob > Chi2	0.0000		0.0000	
Log likelihood	373.86698		406.6634	
Variables	*Estimate*	*Std. Err.*	*Estimate*	*Std. Err.*
Time Trend	0.008011*	0.0010772	0.0018629	0.0012558
log(AS)	-0.1167009*	0.0312859	-0.086535*	0.0301268
log(FAAS)	0.0378915**	0.0167553	0.0227945	0.0148486
log(IA)	0.0646677*	0.0142357	0.0944338*	0.0127658
log(CF)	-0.0349603**	0.0161042	-0.0397799**	0.0162662
log(ACD)	0.0886687*	0.0159801	0.0847687*	0.0151937
Con. Coef.	-11.19667*	2.08223	0.8521619	2.479065
/mu	0.4858539*	0.1734892	0.3459328**	0.1399197
/eta	-	-	0.0114827*	0.001366
/lnsigma2	-1.799932*	0.5523844	-2.36076*	0.5349579
/ilgtgamma	2.28229*	0.6118167	1.767188*	0.6290908
sigma2	0.1653101		0.0943485	
gamma	0.9073996		0.8541076	
sigma_u2	0.1500023		0.0805838	
sigma_v2	0.0153078		0.0137647	

Source: Authors' estimation; *, **, and *** indicates the significant level at 1%, 5%, and 10%, respectively.

production function (Refer Table-3). These results indicate that up to 91% variation in sugarcane production can be explained through the chosen climatic and non-climatic variables. Positive regression coefficients of time trend factor, area sown, forest area, irrigated area and average crushing duration with sugarcane production, indicate that these factors have positive impact on sugarcane production. So, it is essential to use advanced technology in sugarcane farming to improve production (Khanna 2006; Devi et al. 2012; Kumar and Sharma 2014; Kumar et al. 2015a,c,d). Cropped area is positively associated with sugarcane production and estimate is consistent with earlier studies as Kumar and Sharma (2014); Kumar et al. (2015a). Sugarcane is water intensive crop which require around 15 irrigations in a year, thus irrigated area show positive impact on sugarcane production (Khanna 2006). It is also suggested that irrigation is a best source to boost growth of sugarcane plants. Thus irrigated area showed a positive impact on sugarcane production. Crushing time is an important factor to provide additional time to farmers to harvest sugarcane production from field. More crushing duration gives the appropriate time to sugar industries to produce additional products (e.g., ethanol citric acid, baggagse, etc.). It may improve production scales in sugar factories (Mishra et al. 2016).

Therefore, average crushing duration has shown a positive impact on sugarcane production. Forest area maintains the environmental sustainability and mitigates the temperature effects on crop growth. So, forest area have a positive impact on sugarcane production (Kumar and Sharma 2013). Application of fertilizer has a negative influence on sugarcane production. It can be interpreted that extensive application of fertilizer may be caused to decreases soil fertility and contents of soil (Chandiposha, 2013; Kumar and Sharma 2014; Kumar et al. 2014; Kumar et al. 2015b,c,d; Singh et al. 2016; Kumar et al. 2016; Singh et al. 2017; Sharma and Singh 2017). Therefore, consumption of fertilizer in cultivation would produce negative returns. However, Khanna (2006) empirically proved that fertilizer application would adjust the cost of production in sugarcane cultivation in India.

All climatic factors during various seasons have shown positive and negative impact on sugarcane production (Kumar and Sharma 2014; Kumar et al. 2015a; Shrivastava et al. 2015). Maximum temperature during autumn and summer seasons shows negative impact on sugarcane production (Zulfqar et al. 2016). Few climatic factors have a statistically significant association with sugarcane production. It is stated earlier that variability in maximum temperature during all the seasons have a negative impact on sugarcane production. Variation in maximum and minimum temperature during autumn season has a negative impact on sugarcane production. Variability in precipitation during winter, summer and autumn weather seasons also showed negative and statistically significant impact on sugarcane production. Coefficient variation in daily precipitation and daily minimum temperature were negatively associated with sugarcane production. Here, it is concluded that climate variability in different weather seasons have negative impact on sugarcane production in India. The values of log likelihood were observed statistically significant which implies that there exists high production inefficiency in sugarcane farming due to variability in climatic and non-climatic factors in India. It also implies that India has a high potential to increase sugarcane production using advanced technology in sugarcane farming (Khanna 2006; Kumar and Sharma 2014; Kumar et al. 2015a).

Effect of Climatic and Non-climatic Factors on Sugarcane Yield

Regression coefficients of climatic and non-climatic factors with sugarcane yield were estimated through time-invariant decay model and time-varying decay model (Refer Table-4 and 5). Two separate regressions were done for each aforesaid model to check the consistency of the regression coefficients of explanatory variables. In first estimation, climatic and non-climatic factors were used, while only climatic factors were included in second estimation. Sigma2 values were statistically significant at 1% significance level in both the estimations, which implies that log-linear regression model produces reliable results. The gamma values were estimated 88% and 83% under time-invariant decay and time-varying decay model respectively in first estimation (Refer Table-4), while these were observed 91% and 85% under time-invariant decay and time-varying decay model respectively in second estimation for sugarcane yield function (Refer Yable-5). Estimates indicate that around 91% variation in sugarcane yield may be explained by undertaken climatic and non-climatic variables. Regression coefficients of time trend factor, forest area, irrigated area and average crushing duration with sugarcane yield were found positive and statistically significant. So, sugarcane yield has a tendency to be improved as the contribution of these factors increase in sugarcane cultivation. Here, it can be interpreted that adoption of modern technology and irrigation facilities in cultivation would be useful to increase sugarcane yield (Khanna 2006; Devi et al. 2012; Kumar et al. 2015a,c,d; Singh et al. 2016; Abeysingha et al. 2016; Singh et al. 2017; Kumar et al. 2017; Singh and Sharma, 2017). Forest area maintains quality of environment through water conservation and purification, air pollution absorption, nutrient cycling, soil protection and erosion, flood protection, carbon fixation and clean oxygen released. Thus, forest area have positive association with sugarcane yield (Kumar and Sharma 2013). Increase in crushing duration provides more time to farmers to harvest sugarcane crop, consequently sugar industries also get appropriate time to produce additional materials from sugarcane crop (Mishra et al. 2016). Area sown and application of fertilizer have a negative impact on sugarcane yield. It has justified that sugarcane yield has a tendency to be decreased as area sown increases (Cabas et al. 2010; Kumar and Sharma 2014; Kumar et al. 2015a). Fertilizer application have negative impact on soil fertility, land quality and nutrient contents of soil (Kumar et al. 2014; Kumar et al. 2015a,c,d; Singh et al. 2016; Singh et al. 2017; Sharma and Singh 2017). It increases more water requirement for irrigation in crop cultivation (Chandiposha 2013). Regression coefficients of few climatic factor with sugarcane yield were observed statistically significant. Though, most climatic factors during winter, spring, summer and autumn seasons have a negative association with sugarcane yield. Furthermore, the impact of climatic variables on sugarcane yield were varied in different weather seasons (Kumar and Sharma 2014; Kumar et al. 2015a; Shrivastava et al. 2015). Variation in maximum temperature during summer and autumn seasons have a negative impact on sugarcane yield. While variation in minimum temperature during autumn season have a positive and statistically significant impact on sugarcane yield.

Coefficients of variation in daily precipitation and minimum temperature showed a negative and statistically significant impact on sugarcane yield. It implies that daily variation in climatic factors also play a crucial role to increase or decrease sugarcane yield. Here, it can be concluded that sugarcane yield is sensitive due to annual variability in climatic factors from mean in different weather seasons and daily variation in climatic variables in a year. Finally, the values of log likelihood were statistically significant for all models which indicates that there is a significant inefficiency in sugarcane yield in India.

Estimated State-wise Technical Efficiency of CF and NCF in Sugarcane Farming

State-wise technical efficiency (TE) of sugarcane production and yield were estimated through time-varying SFPFA model (Refer Figure-8 and Figure-9). It identified the trend in state-wise technical efficiencies of climatic and non-climatic factors in sugarcane farming. The mean values of technical efficiencies during 1971-1990 and 1991-2014 for all factors (i.e., climatic factors and non-climatic factors) (CF+NCF) and non-climatic factors (NCF) indicate that there is existence of high variation in technical efficiencies across Indian states. Tamil Nadu has a highest technical efficiency to produce optimum sugarcane production with better sugarcane yield. Maharashtra and Karnataka have 2nd and 3rd position in TE of CF+NCF in sugarcane farming among the other states. Uttar Pradesh has a largest cropped area under sugarcane crop, while it has 9th position in TE of CF+NCF in sugarcane production and yield. So, Uttar Pradesh needs to take an effective action to increase TE of CF+NCF in sugarcane farming. Bihar, Madhya Pradesh, Haryana, Assam, Rajasthan, Uttar Pradesh and Punjab have less than 65% TE, therefore these states were inefficient to produce optimum sugarcane production. Estimates also indicate that TE of sugarcane production and yield has increased during 1991-2014 as compared to 1971-1990. Here, it is recommended that these states have a potential to improve TE of CF+NCF in sugarcane farming.

Classification of States based on Estimated Values of Technical Efficiency

State-wise average technical efficiency (TE) of climatic and non-climatic factors (CF+NCF) during 1971-2014 was given in Table-6. Estimated values of TE lie between45%-96% for all factors and between 40%-96% for non-climatic variables across Indian states. Estimates specify that all states (except Tamil Nadu and Maharashtra) were technically inefficient to produce optimum sugarcane production. Tamil Nadu has efficiency to produce optimum sugarcane production. Bihar, Madhya Pradesh and Assam have relatively lower position in TE of CF+NCF to produce sugarcane production as compared to other states. It implies that there are additional factors which are negatively affecting sugarcane production scale in these states. These states have less than 50% technical efficiency of sugarcane production and yield during 1971-2014. The technical efficiency of sugarcane production and yield were between 51%-070% in Uttar Pradesh, Punjab, Orissa, Gujarat and West Bengal. Andhra Pradesh, Karnataka and Maharashtra have 4th, 3rd and 2nd position respectively in TE. It was also observed that TE of climatic and non-climatic factors were greater than TE of non-climatic factors for all the states. So, it indicates that climate variability have a negative association with sugarcane production in India. It also indicates

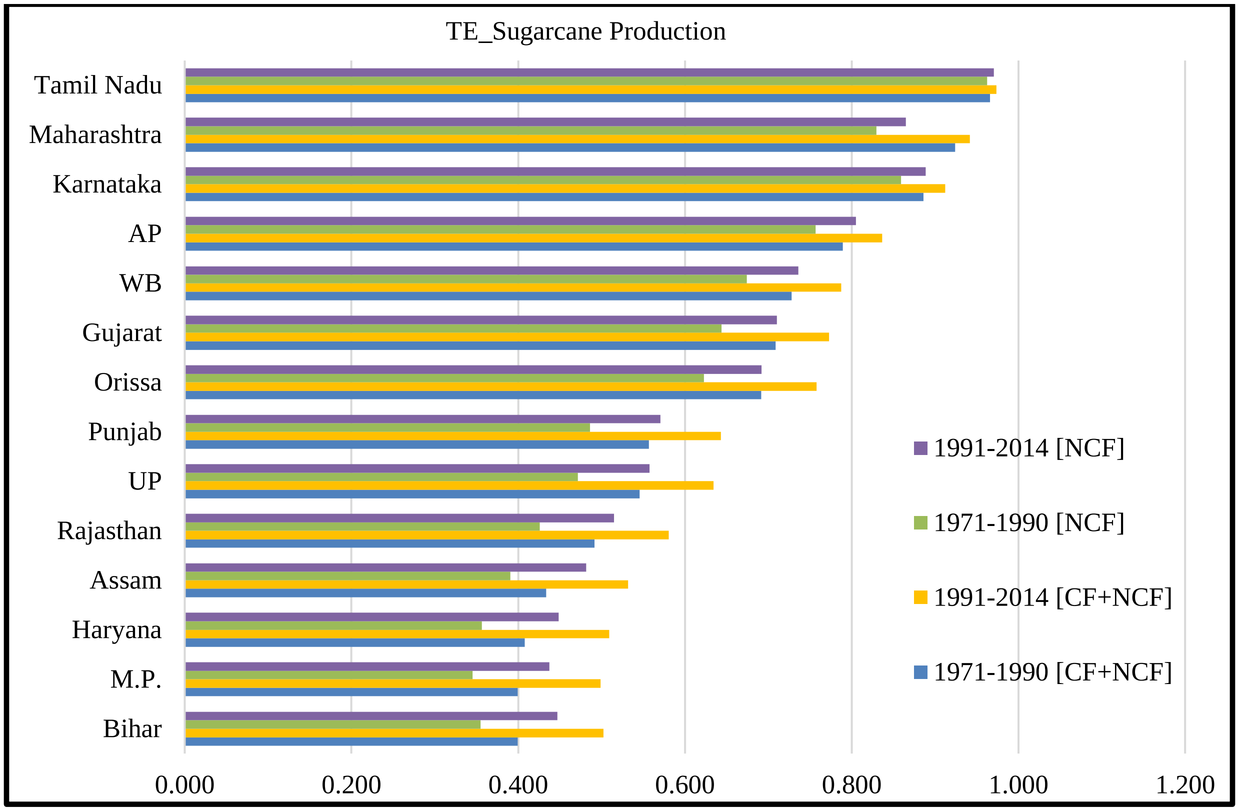

Figure 8 Trend in technical efficiency of sugarcane production
Source: Authors' estimation.

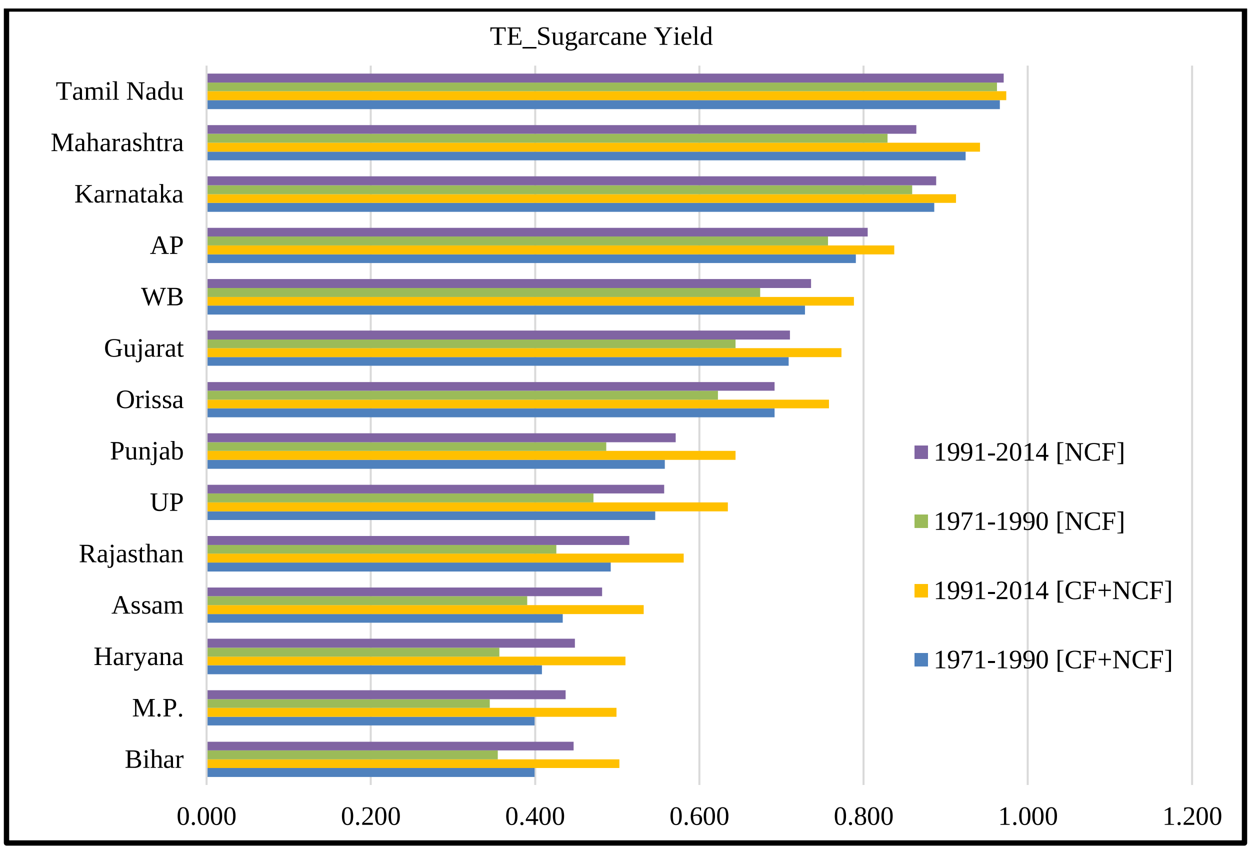

Figure 9 Trend in technical efficiency of sugarcane yield
Source: Authors' estimation.

Table 6 Mean technical efficiency of sugarcane production and yield during 1971-2014

Groups	States	Sugarcane Production		Sugarcane Yield	
		Climatic and Non-climatic Factors	Non-climatic Factors	Climatic and Non-climatic Factors	Non-climatic Factors
Lower	Bihar	0.4508	0.4010	0.4510	0.4008
	M.P.	0.4492	0.3914	0.4493	0.3911
	Haryana	0.4584	0.4024	0.4592	0.4026
	Assam	0.4827	0.4362	0.4830	0.4361
Medium	Rajasthan	0.5362	0.4704	0.5366	0.4703
	UP	0.5902	0.5145	0.5905	0.5142
	Punjab	0.6000	0.5284	0.6012	0.5288
Moderate	Orissa	0.7246	0.6575	0.7247	0.6571
	Gujarat	0.7409	0.6771	0.7410	0.6771
	WB	0.7578	0.7051	0.7583	0.7051
Better	AP	0.8131	0.7811	0.8139	0.7807
	Karnataka	0.8992	0.8741	0.8993	0.8738
	Maharashtra	0.9331	0.8473	0.9330	0.8468
Best	Tamil Nadu	0.9699	0.9666	0.9699	0.9666

Source: Author's estimation.

Table 7 Correlation coefficients of error-term with its various lags for sugarcane production and yield function

	Sugarcane production				Sugarcane yield			
Lags	Model: 1	Model: 2	Model: 3	Model: 4	Model: 1	Model: 2	Model: 3	Model: 4
1	0.9883*	0.9886*	0.9891*	0.9892*	0.9128*	0.8606*	0.9617*	0.9185*
2	0.9761*	0.9765*	0.9770*	0.9774*	0.8955*	0.8191*	0.9430*	0.8809*
3	0.9740*	0.9742*	0.9740*	0.9743*	0.8920*	0.8228*	0.9463*	0.8884*
4	0.9739*	0.9740*	0.9745*	0.9747*	0.8970*	0.8343*	0.9498*	0.8982*
5	0.9704*	0.9701*	0.9708*	0.9709*	0.8976*	0.8303*	0.9458*	0.8891*
6	0.9659*	0.9658*	0.9658*	0.9660*	0.8865*	0.8287*	0.9358*	0.8759*
7	0.9628*	0.9627*	0.9633*	0.9634*	0.8873*	0.8254*	0.9330*	0.8678*
8	0.9587*	0.9582*	0.9600*	0.9599*	0.8857*	0.8179*	0.9392*	0.8766*
9	0.9531*	0.9526*	0.9550*	0.9550*	0.8757*	0.8065*	0.9388*	0.8801*

Source: Authors' estimation; Note: *, ** and *** indicate significant at 1%, 5% and 10% level respectively. Parentheses values are the standard error of respective variables.

that TE of sugarcane yield and production were also negatively impacted due to variability in climatic factors across Indian states. Thus, there is high possibilities to improve sugarcane production and yield through improvising technical efficiency of available inputs i.e. cultivated land, irrigation facility, technological upgradation, applications of fertilizers, and other natural resources in most sugarcane producing states in India.

Validity and Consistency of Empirical Results

As appropriate validation of empirical findings are useful to maintain unanimity among the researchers and policy makers to provide realistic interpretation of results. Thus, to check the validity of empirical finding is critical questions for researchers. Appropriate validation of empirical findings increase the unanimity among the researchers and policy makers to provide reasonable interpretation of empirical results in scientific way. Furthermore, a scientist or researcher would be in better position to come up with an appropriate policy suggestions to resolve a particular issue in society. Recently, Kumar et al. (2017) estimated the climate change impact of cash crops farming in India using Cobb-Douglas production function model. Thereafter, this study assessed projected yield, production and cropped area of various cash crops using marginal impact analysis technique. The study estimate the correlation coefficients between error term and its first two lags for validation of proposed empirical models. Similar process was also used by Maity and Chatterjee (2012) to test the validity of estimated empirical results. Existing studies highlighted that if the error-term (residuals) and its first two lags have a statistically significant and positive or negative correlation with each other, then it may be considered as viable and consistent model (Maity and Chatterjee 2012; Singh et al. 2017). Thereafter, regression coefficients of explanatory variables in a model can be used for further projection of output (Maity and Chatterjee 2012; Singh et al. 2017). Hence, in the present study, the correlation coefficients between error-term and its various lags were are estimated for sugarcane production and sugarcane yield production function. The correlation coefficients between error-term and its first two legs were found statistically significant for all the models (Refer Table-7). Estimated correlation coefficients provide an evidence that all proposed models produce valid and consistent results. It also provide the appropriate validity of empirical results.

CONCLUSION AND POLICY GUIDELINESFOR INDIAN SUGARCANE FARMERS

The main objective of this study was to assess the impact of climatic and non-climatic factors on sugarcane yield and production in India. For this, it compiled state-wise panel data of 14 states of India during 1971-2014. Stochastic frontier production function approach with log-linear regression model was considered to estimate the regression coefficients of climatic and non-climatic factors for sugarcane production and yield function. It also measures the technical efficiency (TE) of non-climatic variables and climatic factors in sugarcane production and sugarcane yield across Indian states during 1971-2014. Estimates imply that variability in climatic factors in different weather seasons have a negative impact on sugarcane production and yield. Therefore, it is essential for sugarcane farmers, sugar industries and policy makers to take an effective action to mitigate the adverse effects of climate variability in sugarcane farming. Otherwise, it is expected that global sugarcane production would be in an alarming position due to climatic change by 2050 (Zhao and Li 2015; Zulfqar et al. 2016). Kumar and Sharma (2014); Kumar et al. (2015a) also found that sugarcane production and productivity were negatively associated with climate change in India. Ali et al. (2017) also found negative association between climate change and sugarcane productivity in Pakistan. Climate change would be caused to reduce jobs for rural dwellers, income of sugarcane growers, output of sugar industries and Government's revenue in near future in India. So, it would also bring several negative implications for rural development and government policies due to high imbalance in sugarcane production. Moreover, it is evident that sugarcane production and yield have a tendency to be declined due to climate change in India. It may be serious threat for sugarcane farming community, agricultural worker and sugar industries. Most Indian are directly and indirectly habitual to consume sugarcane generated products and it is expected that per capita sugar consumption would be increased up to 35 Kilogram (including sugar and gur) by 2030(IISR 2011). Subsequently, it would also negatively affect the food security of populations who consumes sugar to meet their nutritional requirements in future. Decline in sugarcane production may be caused to increase the additional pressure on government to meet the sugar requirement of growing population in domestic market. Therefore, it would adversely affect other development policies in India. It would also increases imbalance in supply and demand of sugar in domestic market, consequently it may increase sugar price at unprecedented rate in India.

Technological change, irrigated areas, forest area and average crushing duration were identified crucial factors to increase sugarcane production and yield in India. Empirical results clearly indicate that adoption of modern technology would be useful to improve sugarcane production and yield. Advanced technology may be useful to manage planting, land management and sugarcane harvesting increase sugar recovery (Devi et al. 2012), which would provide better return to sugarcane farmers and sugar industries (Abnave 2015). It may be used in different ways like best time of planting, selection of planting material, chemical control for pests tolerant and diseases, fertilizer control, intercropping pattern, application of bio-fertilizer and removal of water shoots (IISR 2011; Devi et al. 2012; Kumar et al. 2015a,c,d; Zhao and Li 2015; Kumar et al. 2016; Kumar et al. 2017). For this, scientific research community is essential to discover indigenous technology for sugarcane cultivation in India.Sugarcane yield and production were negatively associated with consumption of fertilizer. Hence, it is recommended that farming community must avoid the extensive application of fertilizer in sugarcane cultivation. It would reduce GHGs emission that may be helpful to maintain environmental sustainability (Yohannes 2016; Kumar et al. 2016). Addition, soil fertility and nutrient content in soil would improve as recommended application of fertilizer. More irrigation facilities would be essential to increase cropped area for sugarcane crop (Deressa et al. 2005; Kumar et al. 2014;Abnave 2015; Ali et al. 2017). India has 60% of the total cropped area under rainfed or dependency on uncertainties of monsoon (CMIE 2016), thus improvement in irrigation facilities would be most crucial for sustainable agricultural development (Kumar et al. 2014; Kumar et al. 2015a; Singh et al. 2017; Sharma and Singh 2017). Indian farmers are utilizing largest quantity of ground water for irrigation in cultivation (Samui et al. 2014; Abeysingha et al. 2016).Therefore, India would have several challenges to meet the water requirement for irrigation in future (Zaveri et al. 2016). Hence, it is essential to adopt effective water management policies to meet the water requirement for irrigation in cultivation (Devi et al. 2012; Kumar and Sharma 2014; Kumar et al. 2015a,c,d; Abeysingha et al. 2016; Sharma and Singh 2017). More investment in agricultural R&D would be useful to increase the involvement of young scientists and researchers to undertaken excellent research project in this area (IISR 2011; Kumar et al. 2015a,c,d; Kumar et al. 2016; Kumar et al. 2017; Sharma and Singh 2017). It may be helpful to discover appropriate farm management techniques, climate tolerance seeds and high yielding varieties of seeds for cultivation.

Crop productivity would improve as increase in appropriate credit facilities to farmers, thereby farmers would be financially strong to use technologies, more irrigation facilities and high yield varieties (HYVs) of seeds in farming. There must be agricultural information centres at village level, so farmers can share their problems with agricultural scientists, researchers and local stakeholders. It would also be beneficial to researchers and agricultural scientists to do experimental work on field based data that would provide better research output with effective policy decisions. Collaboration among the farmers, local stakeholders, agricultural scientists, policy makers and representative of agricultural extension offices have high probability to facilitate favourable and adaptationtechnique to mitigate the negative implications of climate change in agriculture (Kumar et al. 2015a). Also, initiation of short programmes and trainings for farmers in rural area may be helpful to increase farmers' consciousness so as to take precautionary action to mitigate the adverse effects of climate change (Khanna 2006; Kumar et al. 2015c,d). There must be given appropriate time to farmers to harvest sugarcane crop, which may increase juice quality and quantity of sugarcane crop. It may be beneficial for sugar industries to make best utilization of sugarcane to produce alternative products. Farmers must be preferred to appropriate variety of sugarcane crop for cultivation which can tolerate climatic impact (Abnave 2015; Kumar et al. 2015a).Sugarcane growers also must be applied multi-cropping techniques to recover adjust high-cost of sugarcane cultivation (Abnave 2015; Kumar et al. 2015a; Zhao and Li 2015). Forest area may be considered as best technique to mitigate climate change impacts on crops farming. It also sustainswater conservation, water purification, nutrient cycling, atmospheric environmental purification, soil protection, erosion control, flood protection, carbon fixation and oxygen release(MEA2005; Dash 2011;Maiti et al. 2015). Effective policy action to achieve sustainable environmental development and sustainability in natural resource may be a better resilience technique to mitigate the negative consequences of climate change in agriculture (Zhao and Li 2015; Zaveri et al. 2016; Yohannes 2016; Kumar et al. 2017). Indian famers must be allocated some areas of their arable land under trees and plants to maintain environmental sustainability.

Estimated state-wise technical efficiency (TE) of CF and NCF in sugarcane production and yield during 1971-2014 imply that Tamil Nadu has higher TE to produce optimum sugarcane production as compared to other states. Maharashtra and Karnataka have 2nd and 3rd position in TE of sugarcane farming in 1971-2014. Estimated values of TE varies 45%-96% for all factors and 40%-96% for non-climatic variables across Indian states. It exhibits that there is high variation in TE of sugarcane farming in Indian states. Also, it shows that most Indian states have high potential to increase TE of climatic and non-climatic factors (CF and NCF) in sugarcane farming. Uttar Pradesh cover largest cropped area under sugarcane crop, while it has less than 60% TE to produce sugarcane production. Similarly, Bihar, Madhya Pradesh, Haryana, Assam, Rajasthan and Punjab also have less than 50% technical efficiency of CF and NCF in sugarcane farming. So all Indian states have inefficiency to produce optimum sugarcane production. However, estimates also indicate that TE of sugarcane production and yield were increased during 1991-2014 as compared to 1971-1990. Hence, it is essential for farmers to improve TE in sugarcane producing states through adopting conducive and effective technology. For this; large agrarian states need to increase sugarcane production using technological up-gradation methods in cultivation.

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Article Keywords

Climate change; Sugarcane production and yield; Technical efficiency; Regression model; SFPFA; Cobb-Douglas production function model.

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General Note
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