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Measuring the Influence of Weather Variables on Productivity of Food-grain Crops in India: An Application of Just & Pope's ProductionTechnique

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Abstract

The present study investigates the impact of weather factors on mean yield and variability of food-grain crops during sowing, growing and harvesting time.

Design/Methodology/Approach: It used linear and log-linear regression models under stochastic production function technique. Mean yield and yield variability of wheat, chickpea, rice and maize crops are compiled as state-wise panel during 1971-2012.

Major Findings: It shows that mean yield and yield variability of food-grain crops are climate sensitive, and climate change have a negative impact on yield of aforesaid crops. It ascertained that fluctuation in weather factors would increase food insecurity in India.

Research Limitations/Implications: Agriculture is a significant cause for climate change and environmental degradation, however the study avoid this fact. It assumes that all varieties of a crop similarly get affects due to climate change.

Practical Implications: It emphasized that Indian farmers need to adopt crop specific policies to mitigate the adverse effects of climate change. It provides conclusive policy recommendations to moderate the negative effects of climate change in agriculture.

Originality/Value: It estimate the influence of climatic factors on mean yield and yield variability of major food-grain crops at macro level. It also assesses the seasonal influence of weather factors on food-grain productivity.

Key Words: Climate change; Non-climatic variables; Linear and log-linear regression model Mean yield and variability; Food-grain crops; India.

Introduction

Climate is a historical weather condition of a particular place observed in several years. Weather is the state of atmospheric elements in relatively shorter time period of a geographical region. Temperature, rainfall, precipitation, cloud cover, humidity, solar radiation, sunshine and wind speedare the weatherfactors (Arndtet al., 2012; Kumar and Gautam, 2014). Climate of a region is helpful for farmers to choose crops production technologies and sowing time in cultivation(Paltasingh et al., 2012; Kumar and Gautam, 2014; Amin et al., 2015; Kumar et al., 2015b). Temperature, humidity and rainfall are the maindrivers of crop growth(Arndtet al., 2012; Paltasingh et al., 2012; Kumar and Gautam, 2014).However, high variation in temperatureand rainfall from normal have a negative impacts on crop production and agricultural practices(Gbetibouo and Hassan, 2005; Fischer et al., 2005; Mendelsohn et al., 2006; Arndtet al., 2012; Paltasingh et al., 2012; Kumar and Gautam, 2014; Lizumi and Ramankutty, 2015; Amin et al., 2015).

Accordingly, weather factors have a probability to increase or decrease crop production (Arndtet al., 2012; Paltasingh et al., 2012; Kumar and Gautam, 2014; Kumar et al., 2015b; Lizumi and Ramankutty, 2015; Kumar et al., 2016b). High variability in weather factors have a negative implication on food security of dwellers in large agrarian economies (Lizumi and Ramankutty, 2015; Amin et al., 2015; Kumar et al., 2016b). There are several other inputs like arable land, soil fertility and quality, labour, high-yielding variety of seeds, fertilizer and pesticide, market structure, agricultural extension centres, irrigation facilities, modern techniques of farming, and farmer's experience have a critical impact on agricultural productivity (Paltasingh et al., 2012; Misra, 2014; Kumar et al., 2015b; Amin et al., 2015; Mârza et al., 2015; Kumar et al., 2016b). Few factors can control by farmers, but weather is not (Paltasingh et al., 2012), therefore high variabilityin weather factorsbrought variousissuesfor humanities at global level (Gbetibouo and Hassan, 2005; Fischer et al., 2005; Mendelsohn et al., 2006; Lizumi and Ramankutty, 2015).

Fluctuation in agricultural production due to variability in weather factors are critical concern. Around one billion peoplesare undernourished in the world and 850 million malnourished personslive in developing countries (FAO Statistics, 2012). Extreme variation in weather factors brought more food insecurity, hunger and poverty in large agrarian and developing economies. Lack of technological advancement, inappropriate financial and physical resources to adapt the negative effect of climate change and high dependency of people on agriculturehave increased morevulnerabilities in developing countries(Mendelsohn et al., 2006; Kumar et al., 2016a). As developing countries are located at lower latitudes, therefore these economies are more climate sensitive (Gbetibouo and Hassan, 2005; Mendelsohn et al., 2006; Lizumi and Ramankutty, 2015). Several studies have observed that crop yield is expected to decline in developing countries (Mendelsohn et al., 2006; Kumar and Gautam, 2014), consequently it would increase more disparities in cereal production among developed and developing countries(Fischer et al., 2005).

In India, most studies have shown that variability in weatherfactors would decrease agricultural productivity, employment opportunities and food security (Hundal and Prabhjyot-Kaur, 2007; Paltasingh et al., 2012; Birthal et al., 2014; Singh et al., 2014; Kumar et al., 2014, Kumar and Sharma, 2014; Kumar and Gautam, 2014; Mondal et al., 2014; Birthal et al., 2014; Mondal et al., 2015; Kumar et al., 2015a,b,c; Kumar et al., 2016a,b). Several studies have concluded that climate change have negative impact on yield of food-grain and commercial crops. However, limited studies estimates the association of weather factors with mean yield of food-grain crops.In addition, few studies are used robust empirical model to evaluate the relationship between weather factors and mean yield and yield variability of cropsin different stages of crop growth (Paltasingh et al., 2012; Lizumi and Ramankutty, 2015; Kumar et al., 2016b). Hence, it is indispensable to take this aspect also in empirically investigation to get an insightful idea for the impacts of weather factors on crop growth.Therefore, the present study exploresthe impact of weather factors on mean yield and yield variability of food-grain crops during sowing, growing and harvesting time. It focus on following research questions:

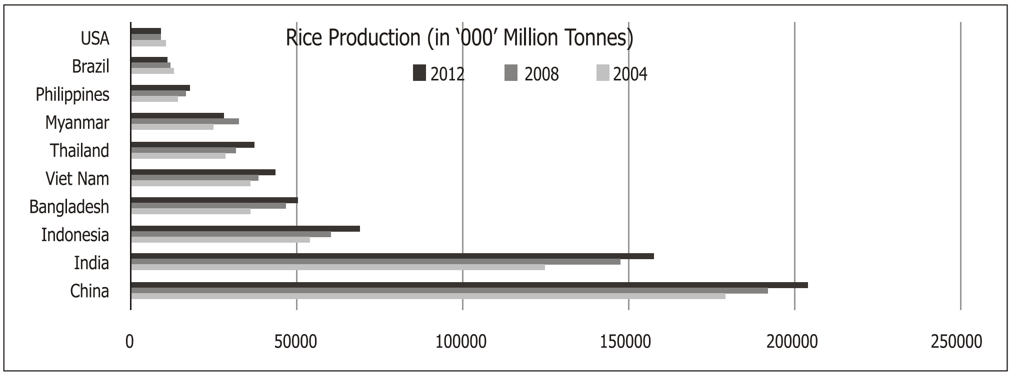
- Which food-grain crop is more climate sensitive?
- What is association of weather factors with mean yield and yield variability of food-grain crops?
- Which weather factordoesaffects crop growth during sowing, growing and harvesting time?
- What could be adaptation techniques to mitigate the adverse effect of weather factorson crop growth?

Relevant to said research questions the prime aim of the study is to assessthe influence of weather factors on mean yield and yield variability of wheat, chickpea, rice and maizecrops. Thereupon, it also identifies the seasonal influence of weather factors on mean yield and yield variability of saidcrops.

India's position in Food-Grain Production

In India, food-grain farming play animportant role to feed the world's second populated country. India has a dominant position in rice, maize, wheat and chickpea production in the world's larger agrarian economies like China and Brazil. It is second largest rice producing country of the world and occupies around 23% cropped area of India. In India, rice crop cultivates during Kharif and Rabi crop season (CMIE, 2012). Large Indian population consume rice as a staple food-grain product. In 2012, China and India have first and second position respectively, which contributed 27.90% and 21.40% rice production respectively of the world (FAO Statistics, 2012). Figure: 1, demonstrates that India's position among ten top rice producing country in various years. It infers that China, India, Indonesia, Bangladesh and Vietnam are the five largest rice producing country in the world.

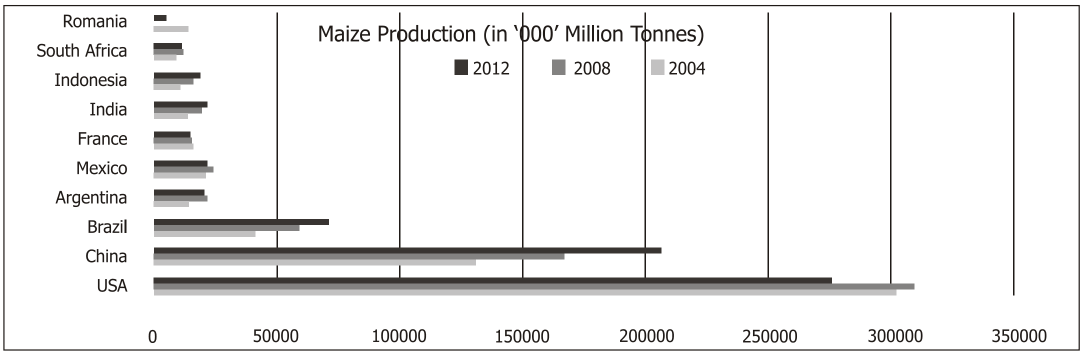
Figure 1: Top ten rice producing economies of the world



Source: FAO Statistics.

Maize is also an important food-grain crop which grows in most of agriculture intensive economies. In India, approximately 4.5% cropped area is used for maize cultivation every year (CMIE, 2012). Maize crop grows during Kharif season in India, and India is the 5th largest maize producer which contributed 2.55% world's maize production in 2012 (FAO Statistics, 2012). USA, China, Brazil, Argentina and India are the five top maize producing country (see Figure: 2).

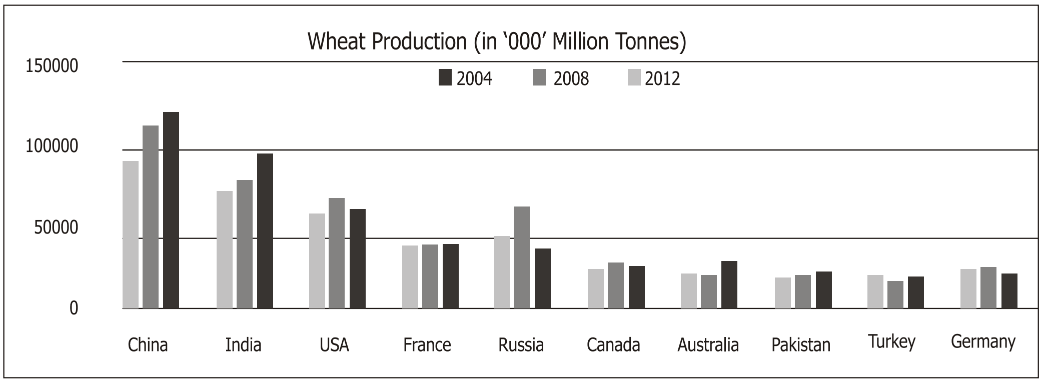
Figure 2: Top ten maize producing economies of the world



Source: FAO Statistics.

Wheat is most important food-grain crop, approximately 15.50% cropped area is using for wheat farming in India (CMIE, 2012). It is staple food-grain crop in China, USA, Russia, Canada, Australia, Pakistan, Turkey and Germany. China and India have first and second position respectively in wheat production at global level (FAO Statistics, 2012). India has contributed around 14.13% share in world's wheat production in 2012 (FAO Statistics, 2012). India's position in wheat production is given in Figure: 3.

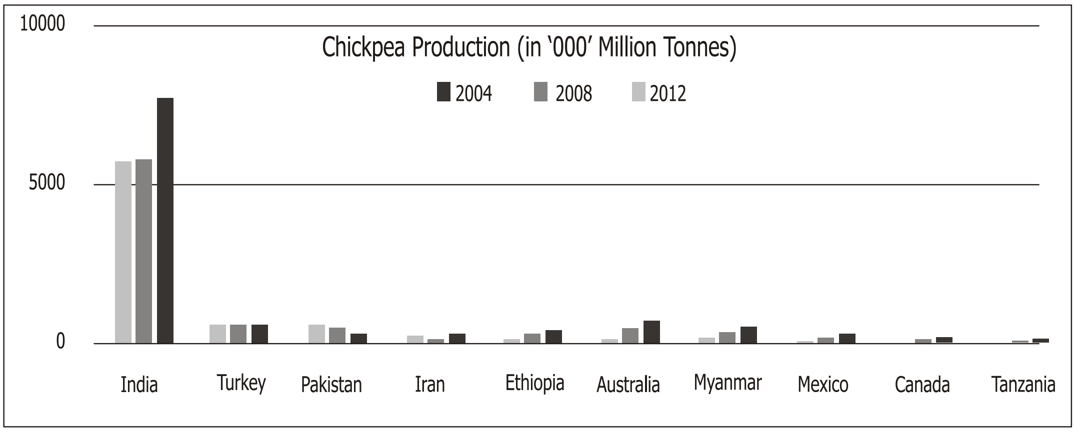
Figure 3: Top ten wheat producing economies of the world



Source: FAO Statistics.

Chickpea is a cereal crop and meets the nutritional security to human. India is the largest producer of chickpea crop and contributes around 40% share in world's chickpea production (FAO Statistics, 2012). Chickpea crop cover about 4.24% arable area of India (CMIE, 2012). It also grows in Turkey, Pakistan, Iraq, Ethiopia, Australia, Myanmar, Mexico, Canada and Tanzania. India's position in chickpea production is given in Figure: 4.

Figure 4: Top ten chickpea producing economies of the world



Source: FAO Statistics.

Material and Methods

Brief description of study area and data sources

The present study comprises a time series of 42 years (1971-2012) data on yield of wheat, chickpea, rice and maize crops with weather factors and control variables. It complies panel of fifteen states of the country (i.e., Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Gujarat, Madhya Pradesh, Maharashtra, Rajasthan, Haryana, Punjab, Uttar Pradesh, Bihar, Odisha, West Bengal and Assam). Dataon area sown, irrigated area, application of fertilizerand farm harvested price of crops aretaken from Centre for Monitoring Indian Economy (CMIE). Information on weather factors like minimum temperature and maximum temperature, and rainfallare derived from the Indian Meteorological Department (GoI) database. Information on sowing, growing and harvesting time for crops are takenfrom the official website of the Indian Council of Agricultural Research (Crop Science Division) New Delhi. Minitab, SPSS and STATA statistical software are used to estimate the regression coefficients of weather factors and control variables in the plannedempirical models. The brief explanation of the variables are presented in Table: 1.

Table 1: Brief description of dependent and explanatory variables

Symbol	Variables	Units	Brief description
lp	Output (Yield)	Kg./Ha.	Production/hectare land
as	Cropped sown	'000' Ha.	Cropped sown
ia	Irrigated area	'000' Ha.	Irrigated area
af	Application of fertilizer	Kg.	Utilization of fertilizer
fhp	Farm harvest price	Rs./Qtl.	Rupees at constant level with 1993-1994 prices
arfst	Rainfall	mm	Actual rainfall during sowing time
arfgt	Rainfall	mm	Actual rainfall during growing time
arfht	Rainfall	mm	Actual rainfall during harvesting time
amintst	Minimum temperature	0C	Average minimum temperature during showing time
amintgt	Minimum temperature	0C	Average minimum temperature during growing time
amintht	Minimum temperature	0C	Average minimum temperature during harvesting time
amaxtst	Maximum temperature	0C	Average maximum temperature during sowing time
amaxtgt	Maximum temperature	0C	Average maximum temperature during growing time
amaxtht	Maximum temperature	0C	Average maximum temperature during harvesting time

Hypothetical outline of stochastic production function approach

Stochastic production function is a noteworthy functional framework to measure the risk decreasing or increasing inputs in crop production exploration (Just and Pope, 1979). The approach comprises production function as integration of two components, first is associated with output and second relating to variability in output (Koundouri and Nauges, 2005). These terms are known as deterministic and stochastic terms (Poudel et al., 2014) and these aremean yield and yield variability respectively (Koundouri and Nauges, 2005; McCarl et al., 2008; Kim and Pang, 2009; Cabas et al., 2010; Kumar et al., 2015b).The present study is given importance to aforesaid approach to examine the impacts of weather factors on mean yields and yield variability of food-grain crops. The approachcontains response function and heteroskedastic error-term as:

$$Y_{it}=f(X_{it},\beta)+\mu_{it} \tag{1}$$

$$Y_{it} =f(X_{it}, \beta) +h^{1/2}(X_{it}, \alpha)\varepsilon_{it};\ E(\varepsilon_{it})=0,\ Var\ (\varepsilon_{it})=1 \tag{2}$$

Here, Y_{it} is crop yield for state i and year t; X_{it} is the vector of explanatory variables that containweather and control variables. μ_{it} is a heteroskedastic disturbance termwith mean zero; β and α are the vector of regression coefficient of corresponding variables. ε_{it} is a random error-term with mean zero and constant variance σ^2. In equation (2), 1st term, $f(X_{it}, \beta)$states the mean yield (deterministic) function and explained by independent variables (X_{it}), 2nd term, $h(X_{it}, \alpha)$ specifies the yield variability (stochastic) function that is related to X_{it} (Cabas et al., 2010). In this formulation weather and control variables have an independent influence on mean yield and yield variability of crops. If [$\delta h/\delta X>0$], input would be risk increasing; and if [$\delta h/\delta X<0$], input would be risk decreasing factor for yield variability (Kim and Pang, 2009; Carew et al., 2009; Aye and Ater, 2012; Kumar et al., 2015).

Empirical Analysis

Formulationof Econometric Model

Cobb-Douglas production function model producesbetter results than other functional form (Just and Pope, 1979; Chen et al., 2004; Kumar et al., 2015b; Kumar et al., 2016b). The present study is used linear and Cobb-Douglas production function model to capture the effect of weather and control variables on mean yield and yield variability of crop (Kim and Pang, 2009; Kumar et al., 2015b; Kumar et al., 2016b). Akaike Information Criterion (AIC) and Schwarz Information Criteria (SIC)/Bayesian Information Criterion (BIC)/Schwarz-Bayesian Information Criteria (SBIC)statistical techniques are applied to select a reasonable and consistent model (Kim and Pang, 2009; Kumar et al., 2016b). The model accepts that mean yield is a function of cropped area, irrigated area, application of fertilizer and farm harvest price and given as:

$$(lp)_{it}=\beta_0+\beta_t(ttf)+\beta_1(as)_{it}+\beta_2(ia)_{it}+\beta_3(af)_{it}+\beta_4(fhp)_{it}+\beta_5(arfst)_{it}+\beta_6(arfgt)_{it}+\beta_7(arfht)_{it}+\beta_8(amintst)_{it}+\beta_9(amintgt)_{it}+\beta_{10}(amintht)_{it}+\beta_{11}(amaxtst)_{it}+\beta_{12}(amaxtgt)_{it}+\beta_{13}(amaxtht)_{it}+\varepsilon_{it} \tag{3}$$

Here, lp is mean yield; i is cross-sectional state; t is time period (1971-2012); ttfis time trend factor that is included to capture the impact of technological change on output(Kim and Pang, 2009; Carew et al., 2009; Paltasingh et al., 2012; Kumar et al., 2015b; Amin et al., 2015). as is cropped area; iais irrigated area;afis consumption of fertilizer; fhp is farm harvest price; arfstis actual rainfall in sowing time; arfgt is actual rainfall in growing time; arfhtis actual rainfall in harvesting time;amintst is average minimum temperature in sowing time; amintgtis average minimum temperature in growing time; aminthtis average minimum temperature in harvesting time; amaxtstis average maximum temperature in sowing time; amaxtgt is average maximum temperature in growing time;amaxtht is average maximum temperature in harvesting time; β_0 is constant term; β_t is regression coefficient of time trend factor; and $\beta_1 ... \beta_{13}$ are regression coefficient of associated variables; and ε_{it}error-term. Yield variance function is considered as:

$$(e^2)_{it}=\alpha_0+\alpha_t(ttf)+\alpha_1(as)_{it}+\alpha_2(ia)_{it}+\alpha(af)_{it}+\alpha_4(fhp)_{it}+\alpha_5(arfst)_{it}+\alpha_6(arfgt)_{it}+\alpha_7(arfht)_{it}+\alpha_8(amintst)_{it}+\alpha_9(amintgt)_{it}+\alpha_{10}(amintht)_{it}+\alpha_{11}(amaxtst)_{it}+\alpha_{12}(amaxtgt)_{it}+\alpha_{13}(amaxtht)_{it}+\mu_{it} \tag{4}$$

Here,$(e^2)_{it}$ is the squareof residuals that is estimated through equation (3);α_0 is constant coefficient; ttfis time trend factor; α_t is regression coefficient of time trend factor; $\alpha_1 ... \alpha_{13}$ are the regression coefficients of corresponding variables; and μ_{it} is random error-term in equation (4). While residuals are estimated as:

$$(e)_{it}=(lp)_{it}-\{\beta_0+\beta_t\ ttf)+\beta_1(as)_{it}+\beta_2(ia)_{it}+\beta_3(af)_{it}+\beta_4(fhp)_{it}+\beta_5(arfst)_{it}+\beta_6(arfgt)_{it}+\beta_7(arfht)_{it}+\beta_8(amintst)_{it}+\beta_9(amintgt)_{it}+\beta_{10}(aminth t)_{it}+\beta_{11}(amaxtst)_{it}+\beta_{12}(amaxtgt)_{it}+\beta_{13}(amaxtht)_{it}\} \quad (5)$$

Here, e is estimated residual for i th state during 1971-2012 (Kumar et al., 2015b). Natural logarithms of dependent and explanatory variables are included in the regression model under Cobb-Douglas production function approach.

Selection of PCSEs model

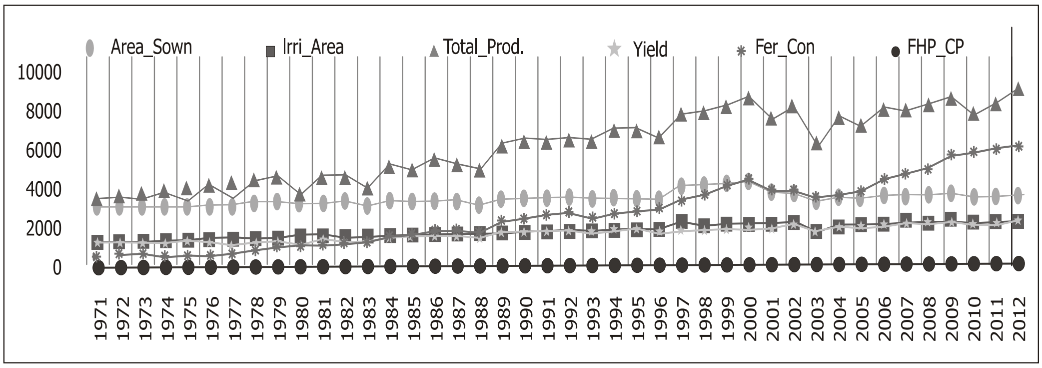
Existing studies claim thatmaximum likelihood estimation model produce better results than others under stochastic production function framework (Chen et al., 2004; McCarl et al., 2008; Kim and Pang, 2009). As our panel data for mean yield and yield variability function for all crops showed existence of heteroskedasticity, serial-correlation and auto-correlation. So, the study is given preference to PraisWinsten models with panels corrected standard errors (PCSEs), Driscoll-Kraay standard errors (D-KSE) and feasible generalize least square estimations to investigate the regression coefficients (McCarl et al., 2008; Poudel et al., 2014; Kumar and Sharma, 2014; Kumar et al., 2014; Kumar et al., 2015a,b; Kumar et al., 2016a,b). As PCSEs model produces better results, thus we have presented results based on this model.

Descriptive Findings

Non-climatic, Climatic Factors and Rice Production in India

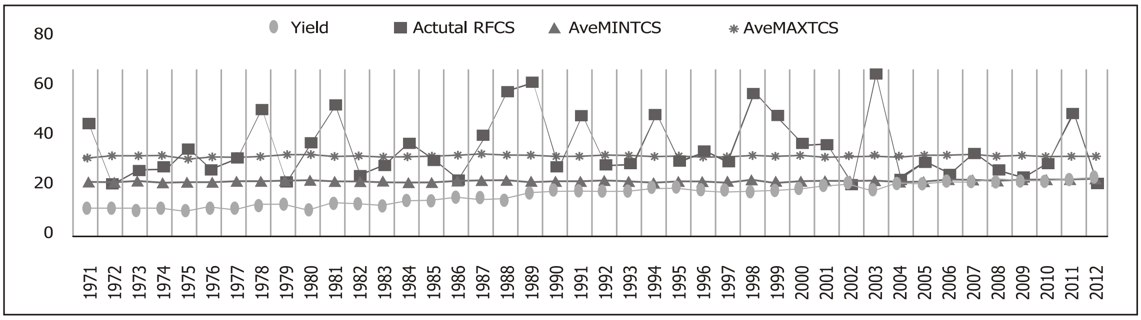
Trend in rice production and mean yield with respect to cropped area, irrigated area, application of fertilizer and farm harvest price is given in Figure: 5. It infers that rice production and yield are varied due to variation in cropped area, irrigated area, fertilizer consumption and farm harvest price. Results based on correlation coefficients indicate that rice production is positively associated with cropped area (r=0.817), irrigated area (r=0.862), farm harvest price (r=0.198) and application of fertilizer (r=0.907). Rice mean yield has positive association with irrigated area (r=439), farm harvest price (r=0.393) and application of fertilizer (r=0.495). In contrary, rice mean yield has a negative relationship with cropped area (r=-0.029) and implies that increase in cropped area would be ineffective to improve rice mean yield. Figure: 6, demonstrates the tendency in climatic factors with relation to rice mean yield.

Figure 5: Trend in rice production and yield, and non-climatic variables



Note: The data for Figure: 5-12 are taken from Directorate of Economics, Statistics, Ministry of Agriculture (GoI) and Indian Institute of Tropical Meteorology (IIMT) New Delhi; and Total Production is in '0000' tonne; Yield is in Kg/Hectare; Area Sown is in '0000' Hectare; Irrigated Area is in '0000' Hectare; Fertilizer Consumption is in '000' Kg; Farm Harvest Price is in Rupees at constant level with 1993-1994 prices; Actual RFCS (Actual Rainfall during Crop Season)is in '0' mm; AveMINTCS (Average Minimum Temperature in Crop Season) is in '0C'; AveMAXTCS (Average Maximum Temperature in Crop Season) is in '0C'.

Figure 6: Trend in rice yield and climatic factors



Non-climatic, Climatic Factors and Maize Production in India

Figure: 7, presents that maize production and yield are fluctuated due to variability in cropped area, irrigated area, fertilizer consumption and farm harvest price. Estimated correlation coefficient recommended that total production is positivelyrelated with area sown (r=0.753), irrigated area (r=0.686), farm harvest price (r=355), and application of fertilizer (r=0.871). Maize mean yield is also positively associated with irrigated area (r=0.329), farm harvest price (r=0.443) and consumption of fertilizer (r=0.396). Estimates imply that maize yield has a high tendency to increase as cropped area, farm harvest price, application of fertilizer increase in maize farming. Cropped area could not be useful to increase maize yield. Figure: 8, show the trend in maize mean yield with respect to climatic factors during 1971-2012.

Figure 7: Trend in maize production, yield, and non-climatic variables

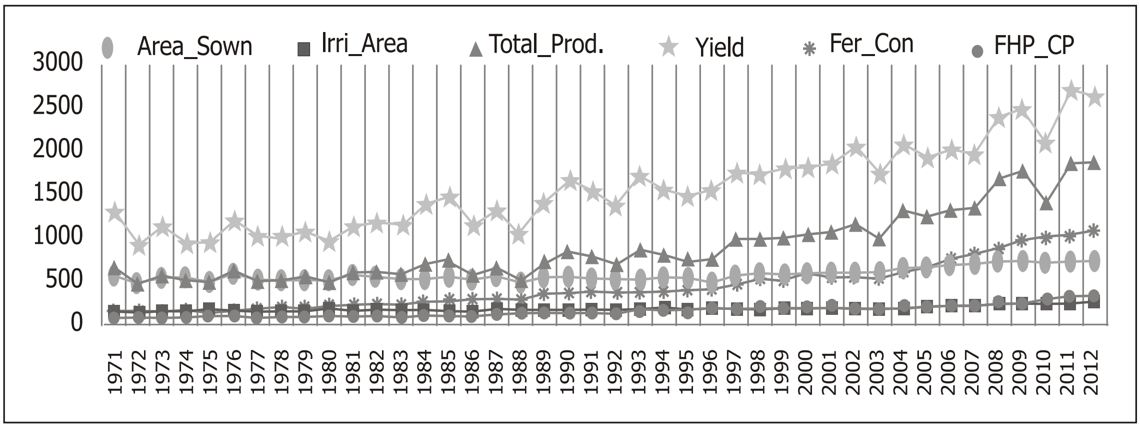
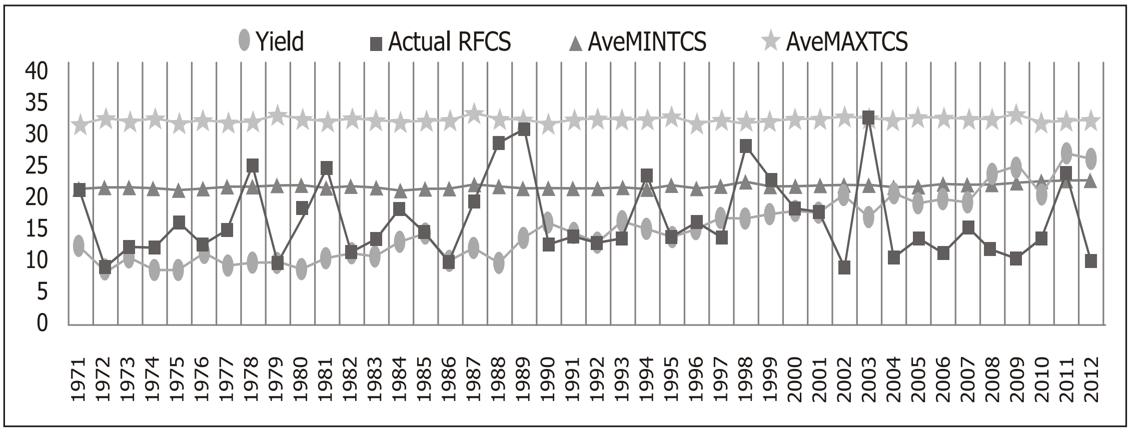


Figure 8: Trend in maize yield and climatic factors



Non-climatic, Climatic Factors and Wheat Production in India

Figure 9, presents the trend in wheat production and yield with respect to area sown, irrigated area, fertilizer and farm harvest price. Estimated correlation coefficients infer that wheat production has high propensity to increase as increase in area sown, irrigated area and fertilizer consumption in wheat farming. It would also improve with increase in farm harvest price. Wheat production has a positive and significant association with area sown (r=0.918), irrigated area (r=0.958), application of fertilizer (r=0.154) and farm harvest price (r=0.959). Wheat mean yield has positive correlation with area sown (r=0.419), irrigated area (r=0.499), utilization of fertilizer (r=0.240) and farm harvest price (r=0.598). Figure: 10, also indicates the trend in wheat mean yield with regards to climatic factors.

Figure 9: Trend in wheat production, yield, and non-climatic variables

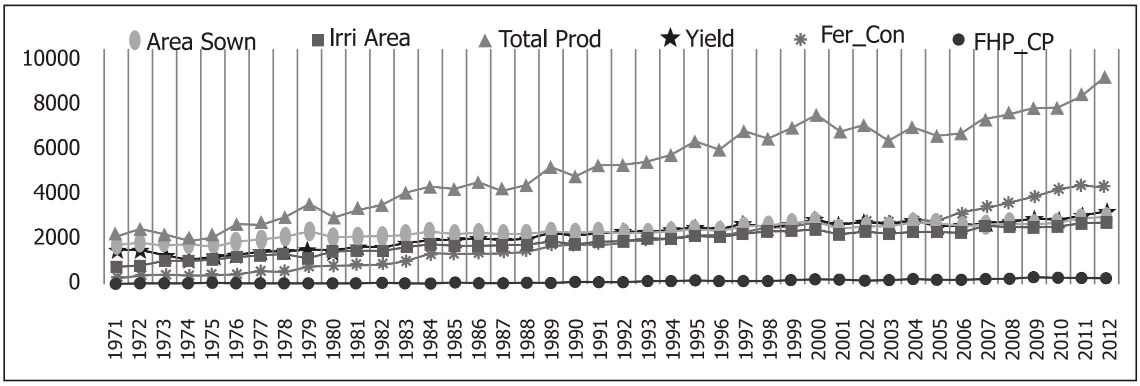
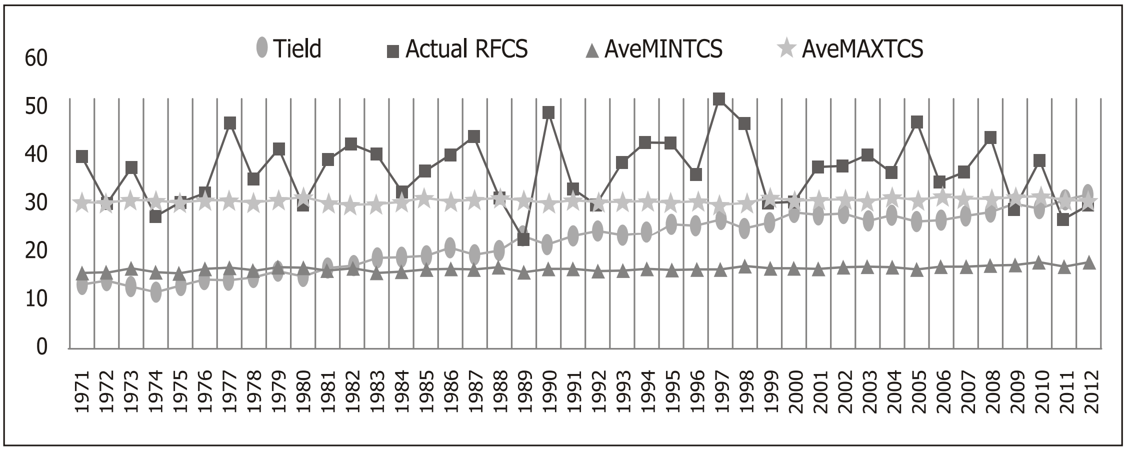


Figure 10: Trend in wheat yield and climatic factors



Non-climatic, Climatic Factors and Chickpea Production in India

Figure 11, shows the trend in chickpea production and yield with respect to cropped area, irrigated area, consumption of fertilizer and farm harvest price. It shows that chickpea production and yield is fluctuated due to variability in area sown, irrigated area, application of fertilizer and farm harvest price. Estimated correlation coefficients indicates that chickpea production has positive association with area sown (r=0.968), irrigated area (r=0.893), farm harvest price (r=-0.012), and application of fertilizer (r=0.748). Chickpea mean yield is positively related with area sown (r=0.172), irrigated area (r=0.186), farm harvest price (r=0.367) and consumption of fertilizer (r=0.369). Trend for chickpea mean yield and climatic factors isspecified in Figure: 12.

Figure 11: Trend in chickpea production, yield, and non-climatic variables

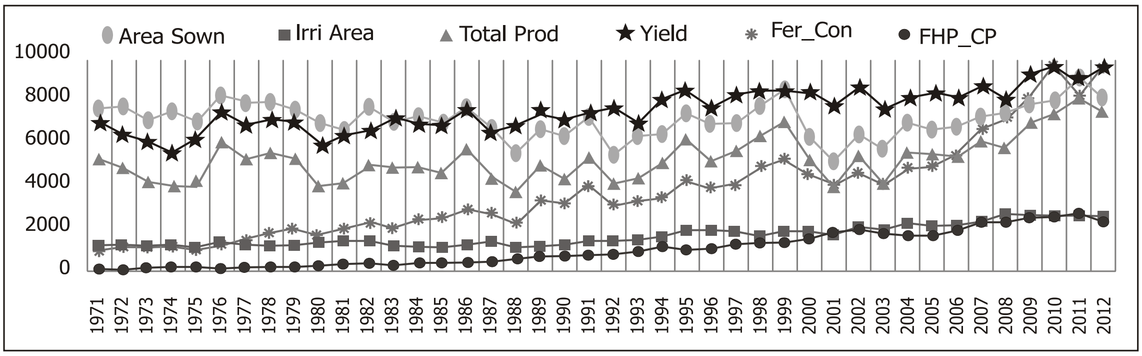
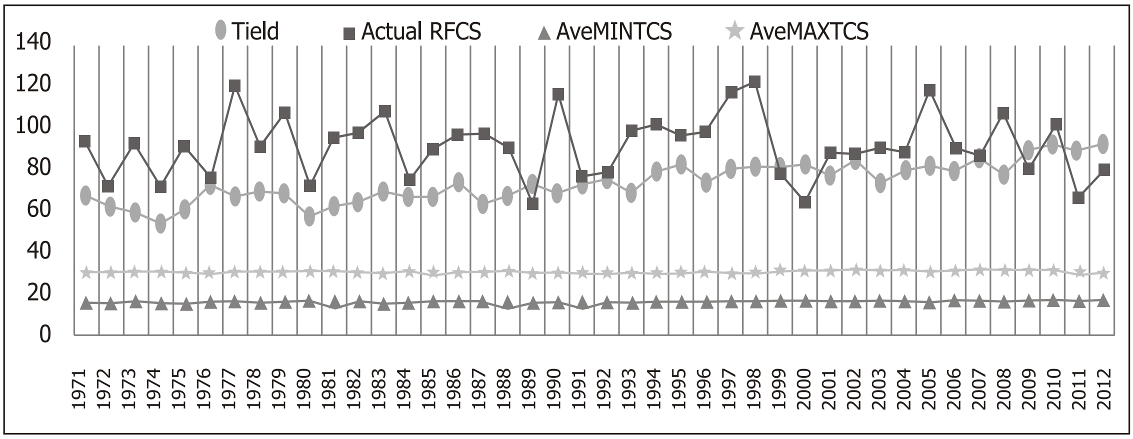


Figure 12: Trend in chickpea yield and climatic factors



Empirical Resultsand Discussion

Regression results of mean yield of food grain crops

Regression results which investigate the impact of control and weather factors on mean yields of rice, maize, wheat and chickpea crops are given in equation 6-13.Log-linear regression model has a lowest value of AIC and BICthan linear regression model, therefore this model produce better and consistent results. Note: *, ** and *** indicate that the regression coefficients of corresponding variables are statistically significant at 1%, 5% and 10% significance level respectively. While, N is number of observation, R2 is coefficient of determination, AIC is the estimated value of Akaike Information Criterionstatistics, BIC/SIC is the estimated value of Bayesian Information Criterion/Schwarz-Bayesian Information Criteriastatistics, Mean VIF is the average value of all estimated variance inflation factors in all equations (6-21). The regression coefficient of time trend factor has positive impact on mean yield of all crops. Estimates indicate that rice, maize, wheat and chickpea mean yield would increase as adoption of modern technologies in cultivation. Application of modern technology would reduce the adverse effect of weather factors in farming. Modern technologies can be used as change in cropping pattern, farm practices, seed replacement, platting of modern varieties of seed which are less climate sensitive, extension in irrigation areas, application of organic fertilizer, and transformation in land management policies (Paltasingh et al., 2012; Kumar, 2016a,b). Cropped area under rice and wheat crop has a negative impact on mean yield of these crops. In contrary, cropped area has a positive association with maize and chickpea mean yield. Estimates imply that maize and chickpea mean yield has a high possibility to be increased as cropped areaincreases.

Rice

$$(lp)_{it}=-45516.52^{*}+24.813^{*}(ttf)-0.1940^{*}(as)_{it}+0.381^{*}(ia)_{it}+0.001^{**}(af)_{it}+0.051(fhp)_{it}+0.001(arfst)_{it}-0.051^{*}(arfgt)_{it}+0.004(arfht)_{it}-311.173^{*}(amintst)_{it}+110.440^{*}(amintgt)_{it}+29.751^{*}(aminth t)_{it}+92.250^{*}(amaxtst)_{it}+67.767^{**}(amaxtgt)_{it}-90.891^{*}(amaxtht)_{it}+\varepsilon_{it}[(N=615)\ (R^2=0.671)\ (Wald\ Chi^2=1766.58)\ (AIC=-9283.168)\ (BIC/SIC=-9349.493)\ (\text{Mean } VIF=3.57)] \quad (6)$$

Rice

$log(lp)_{it}$=-4.654*+0.007*(ttf)-0.286*$log(as)_{it}$+0.333*$log(ia)_{it}$-0.017$log(fhp)_{it}$+0.375*$log(af)_{it}$-0.058*$log(arfst)it$-0.067*$log(arfgt)_{it}$-0.013*$log(arfht)_{it}$-2.466*$log(amintst)_{it}$-0.300$log(amintgt)_{it}$+0.147$log(aminth t)_{it}$+0.071$log(amaxtst)_{it}$+0.794$log(amaxtgt)_{it}$ -2.179*$log(amaxtht)_{it}$+ε_{it}[(N=615) (R^2=0.720) ($Wald\ Chi^2$=1508.96*) (AIC=-992.559) (BIC/SIC=-926.234) (Mean VIF=4.03)] (7)

Maize

$(lp)_{it}$=-66461.41*+38.031* (ttf) -0.386$(as)_{it}$+1.500**$(ia)_{it}$ -0.227 $(fhp)_{it}$+0.004$(af)_{it}$-0.003 $(arfst)it$-0.179* $(arfgt)_{it}$+0.004 $(arfht)_{it}$-172.281* $(amintst)_{it}$-79.200* $(amintgt)_{it}$+93.336* $(aminth t)_{it}$+177.455$(amaxtst)_{it}$-141.717* $(amaxtgt)_{it}$-145.682* $(amaxtht)_{it}$+ε_{it}[(N=574) (R^2=0.535) ($Wald\ Chi^2$=751.48*) (AIC=-8995.534) (BIC/SIC=-9060.823) (Mean VIF=3.44)] (8)

Maize

$log(lp)_{it}$=-8.373*+0.010*(ttf) -0.225**$log(as)_{it}$+0.020$log(ia)_{it}$-0.108*** $log(fhp)_{it}$-0.040$log(af)_{it}$ -0.133* $log(arfst)_{it}$-0.014 $log(arfgt)_{it}$-0.046* $log(arfht)_{it}$-2.483$log(amintst)_{it}$-2.705* $log(amintgt)_{it}$+1.116* $log(aminth t)_{it}$+3.610*$log(amaxtst)_{it}$ -2.562*$log(amaxtgt)_{it}$-3.071* $log(amaxtht)_{it}$+ε_{it}(N=574) (R^2=0.594) ($Wald\ Chi^2$=979.92*) (AIC=-562.535) (BIC/SIC=-497.245) (Mean VIF=3.79) (9)

Wheat

$(lp)_{it}$=-49976.59*+29.5112* (ttf) -0.0339 $(as)_{it}$ -0.0970 $(ia)_{it}$+0.1666 $(fhp)_{it}$+0.0024**$(af)_{it}$-0.2120*$(arfst)_{it}$-0.7304*$(arfgt)_{it}$-0.6953*$(arfht)_{it}$+56.9590*$(amintst)_{it}$-78.1970*$(amintgt)_{it}$+120.186*$(aminth t)_{it}$+45.8803**$(amaxtst)_{it}$-281.1073* $(amaxtgt)_{it}$-79.2319*$(amaxtht)_{it}$+ε_{it}[(N=574) (R^2=0.7526) ($Wald\ Chi^2$=1168.40*) (AIC=-8785.733) (BIC/SIC=-8851.023) (Mean VIF=7.30)](10)

Wheat

$log(lp)_{it}$= -3.032* +0.005*(ttf)-0.093**$log(as)_{it}$+ 0.141*$log(ia)_{it}$-0.007$log(fhp)_{it}$-0.022$log(af)_{it}$-0.023*$log(arfst)_{it}$-0.003$log(arfgt)_{it}$ -0.0212***$log(arfht)_{it}$-0.565*$log(amintst)_{it}$-0.606**$log(amintgt)_{it}$ +1.427* $log(aminth t)_{it}$+1.421*$log(amaxtst)_{it}$-3.508*$log(amaxtgt)_{it}$-1.815*$log(amaxtht)_{it}$+ε_{it}[(N=574) (R^2=0.770) ($Wald\ Chi^2$=1746.43*) (AIC=-702.770) (BIC/SIC=-637.480) (Mean VIF=10.73)](11)

Chickpea

$(lp)_{it}$=-14759.08*+7.9872* (ttf) -0.0258 $(as)_{it}$ +0.0015 $(ia)_{it}$-0.0428$(fhp)_{it}$ +0.0031*$(af)_{it}$-0.0267$(arfst)_{it}$-0.0847$(arfgt)_{it}$-0.1374*$(arfht)_{it}$ +4.2413$(amintst)_{it}$ -9.2587* $(amintgt)_{it}$ +31.2890*$(aminth t)_{it}$-3.3419$(amaxtst)_{it}$ -37.4089* $(amaxtgt)_{it}$+3.0708 $(amaxtht)_{it}$+ε_{it}[(N=574) (R^2=0.4747) ($Wald\ Chi^2$=636.05*) (AIC=-7462.336) (BIC/SIC=-7527.626) (Mean VIF=6.22)](12)

Chickpea

$$log(lp)_{it}= -7.637* +0.005*(ttf)+0.028log(as)_{it} +0.015log(ia)_{it}-0.157*log(fhp)_{it} +0.091log(af)_{it}-0.008log(arfst)_{it}0.008log(arfgt)_{it} -0.001log(arfht)_{it}-0.170log(amintst)_{it} +0.036log(amintgt)_{it} +0.323log(aminths)_{it}+0.183log(amaxtst)_{it}- 1.811*log(amaxtgt)_{it}+1.502*log(amaxtht)_{it}+\varepsilon_{it}[(N=574)\ (R^2=0.470)\ (Wald\ Chi^2=1746.43*)\ (AIC=-930.206)\ (BIC/SIC=-864.917)\ (\text{Mean } VIF=7.15)](13)$$

As irrigation area is positively associated with mean yields of these crops. Thus it is a crucial factor to increase rice, maize, wheat and chickpea mean yield. Farm harvest price is negatively related with rice, maize, wheat and chickpea mean yields. Estimates can be interpreted that these are major food-grain crops and perception of farmers would be unchanged with price variation. Consumption of fertilizer has a positive effect on rice, wheat and chickpea mean yield. It shows that consumption of fertilizer can increase the yield of these crops. Application of fertilizer would be effective in those areas in which farmers are using less fertilizer, otherwise it would decrease quality of environmental factors like soil and water quality, and air quality (Kumar et al., 2014; Kumar et al., 2016a,b). It can also increasesmore water requirement for irrigation in farming (Kumar and Gautam, 2014).Furthermore, estimates indicate that actual rainfall during sowing, growing and harvesting time are observed negative influence on mean yield of rice, maize, wheat and chickpea crop. These results can be interpreted in two ways: first, high rainfall can decrease cropped area, and second plant growth may decline and seed can lost due to splash effects.

Rainfall during growing time has positive influence on chickpea mean yield. Vegetation growth of crop can decline due to high rainfall, therefore rainfall during growing time shows negative impact on mean yields of these crops.Crops growth might be affected due to uncertainty in rainfall or changing rainfall pattern during growing time of crops (Kumar et al., 2016a). Actual rainfall during harvesting time have a negative impact on mean yield of rice, maize, wheat and chickpea. In harvesting time the crops are final stage of production and rainfall during this time would decrease total output, quality and actual nutrition content. Thus, it is concluded that excessive and uncertainty inrainfall would be harmful for yield of food-grain crops. Average minimum temperature during sowing time is seen negative effect on mean yield of rice, maize and chickpea crops. Average minimum temperature during sowing time have positive association with wheat mean yield. It implies that wheat crop is required low minimum temperature during seed germination.

Average minimum temperature during growing time has a negative association with mean yield of rice, maize and wheat.Estimates give confirmation that these crops are needed minimal minimum temperature for plant growth. However, minimum temperature during harvesting time would be helpful to increase yield of all crops. Maximum temperature during sowing time is positively associated with rice, maize, wheat and chickpea yield. While, maximum temperature during growing time is appeared negative effect on mean yields of maize, wheat, chickpea. Furthermore, maximum temperature during harvesting time is performed negative influence on rice, maize and wheat mean yield. Estimates imply that these crops are required temperature between 32-380C during harvesting time to produce higher production. Here, it can be arguedthat weather factors during various stages of crop growth has a significant influence on mean yield of thesecrops.

Regression results of yield variability of food-grain crops

Empirical results that estimates the influence of weather and control factors on yield variability of food-grain crops are presented in equation (14-21). Time trend factor shows a negative effect on yield variability of maize, wheat and chickpea. It implythat adoption of modern technology would be risk decreasing input for these crops. Maize yield variability would be in risk due to application of modern technology in maize crop farming. In contrary, rice yield variability does not found statistically significant association with time trend factor. Cropped area, irrigated area and farm harvest prices are witnessed statistically insignificant relationship with yield variability of these crops. Thus, it is reasonable to accept that yield variability of these crops would be ineffective with increase in cropped area, irrigated area and farm harvest price. However, application of fertilizer is negatively associated with rice yield variability, which indicates that utilization of fertilizer would reduce yield variability of rice.

Rice

$(e^2)_{it}$ = -834819.6 +205.823 (ttf)-58.998*$(as)_{it}$ +95.462*$(ia)_{it}$-18.997$(fhp)_{it}$ -0.8561**$(af)_{it}$ -1.4072$(arfst)_{it}$-20.4219$(arfgt)_{it}$-1.0178 $(arfht)_{it}$ +23350.46$(amintst)_{it}$ +74782.85*$(amintgt)_{it}$ +7506.53$(aminth t)_{it}$-22673.44*$(amaxtst)_{it}$-9157.358$(amaxtgt)_{it}$-20455.51***$(amaxtht)_{it}$ +ε_{it} [(N=615) (R^2=0.1115) ($Wald\ Chi^2$=111.20*) (AIC=-17437.29) (BIC/SIC=-17503.61) (Mean VIF=3.49)] (14)

Rice

$log(e^2)_{it}$= -0.2674+0.001 (ttf)+0.037$log(as)_{it}$ -0.207$log(ia)_{it}$+0.125$log(fhp)_{it}$ -0.778*** $log(af)_{it}$+0.019$log(arfst)_{it}$-0.381***$log(arfgt)_{it}$ +0.159***$log(arfht)_{it}$ +4.857$log(amintst)_{it}$ +10.639**$log(amintgt)_{it}$ +0.181$log(aminth t)_{it}$-4.679***$log(amaxtst)_{it}$-3.754$log(amaxtgt)_{it}$-6.5689**$log(amaxtht)_{it}$+ε_{it}[(N=615) (R^2=0.0919) ($Wald\ Chi^2$=104.09*) (AIC=-1649.289) (BIC/SIC=-1715.614) (Mean VIF=4.03)] (15)

Maize

$(e^2)_{it}$=-3.19e+07*+15893.54*(ttf)-883.319***$(as)_{it}$+1858.342$(ia)_{it}$+529.499**$(fhp)_{it}$ +6.554$(af)_{it}$ -4.512$(arfst)_{it}$-130.056***$(arfgt)_{it}$+123.2316$(arfht)_{it}$ +50821.54***$(amintst)_{it}$ -51447.97***$(amintgt)_{it}$ +72992.52**$(aminth t)_{it}$ +7987.429$(amaxtst)_{it}$ +10861.800 $(amaxtgt)_{it}$-40219.33** $(amaxtht)_{it}$ +ε_{it}[(N=574) (R^2=0.205) ($Wald\ Chi^2$=78.27*) (AIC=-17093.48) (BIC/SIC=-17158.77) (Mean VIF=3.44)] (16)

Maizelog

$log(e^2)_{it}$= -27.1936* +0.009* (ttf) +0.724 $log(as)_{it}$ +0.067 $log(ia)_{it}$ +0.591 $log(fhp)_{it}$ -0.812 $log(af)_{it}$+0.180***$log(arfst)_{it}$-0.250$log(arfgt)_{it}$ -0.074$log(arfht)_{it}$ +0.676$log(amintst)_{it}$ +0.452$log(amintgt)_{it}$+2.593**$log(aminth t)_{it}$-2.408$log(amaxtst)_{it}$+5.442$log(amaxtgt)_{it}$-1.3185$log(amaxtht)_{it}$+ε_{it}[(N=574) (R^2=0.075) ($Wald\ Chi^2$=57.34*) (AIC=-1523.377) (BIC/SIC=-1588.667) (Mean VIF=3.79)](17)

Wheat

$(e^2)_{it}$ = -9614619*+5386.306*(ttf)+58.006$(as)_{it}$ -109.435*$(ia)_{it}$+65.077$(fhp)_{it}$ -1.765***$(af)_{it}$ -14.815$(arfst)_{it}$-161.634$(arfgt)_{it}$+126.230*$(arfht)_{it}$ +40774.89*$(amintst)_{it}$ -2049.141$(amintgt)_{it}$ -39193.590*$(aminth t)_{it}$ -39379.850** $(amaxtst)_{it}$-64086.010* $(amaxtgt)_{it}$+62993.46* $(amaxtht)_{it}$ +ε_{it}[(N=574) (R^2=0.1847) (*Wald Chi* ^{2}=96.96*) (AIC=-16253.08) (BIC/SIC=-16318.37) (Mean VIF=7.30)] (18)

Wheat

$log(e^2)_{it}$= 24.140**-0.011** (ttf)-0.091$log(as)_{it}$ +0.098$log(ia)_{it}$-0.402$log(fhp)_{it}$ -0.064$log(af)_{it}$-0.012$log(arfst)_{it}$-0.012$log(arfgt)_{it}$ -0.0112$log(arfht)_{it}$ +2.014**$log(amintst)_{it}$ +1.458$log(amintgt)_{it}$-1.365$log(aminth t)_{it}$-4.894***$log(amaxtst)_{it}$-4.758$log(amaxtgt)_{it}$+ 4.716log $(amaxtht)_{it}$ +ε_{it}[(N=574) (R^2=0.040) (*Wald Chi* ^{2}=27.87*) (AIC=-1665.627) (BIC/SIC=-1730.917) (Mean VIF=10.73)] (19)

Chickpea

$(e^2)_{it}$=-802.985+539.722*(ttf)-4.119$(as)_{it}$+10.221$(ia)_{it}$+6.202$(fhp)_{it}$+0.362$(af)_{it}$ +4.780$(arfst)_{it}$-37.2051***$(arfgt)_{it}$-6.019$(arfht)_{it}$+776.246$(amintst)_{it}$-742.546$(amintgt)_{it}$ +4967.793* $(aminth t)_{it}$ +3466.864*** $(amaxtst)_{it}$ -1236.257 $(amaxtgt)_{it}$-802.985 $(amaxtht)_{it}$ +ε_{it}[(N=574) (R^2=0.074) (*Wald Chi* ^{2}=41.45*) (AIC=-14076.50) (BIC/SIC=-14141.79) (Mean VIF=6.22)] (20)

Chickpea

$log(e^2)_{it}$= 1.577 -0.006*** (ttf) -0.592 $log(as)_{it}$ -0.001 $log(ia)_{it}$+0.499$log(fhp)_{it}$ +0.758$log(af)_{it}$-0.068$log(arfst)_{it}$-0.074$log(arfgt)_{it}$ +0.021$log(arfht)_{it}$ +2.566$log(amintst)_{it}$ -0.590$log(amintgt)_{it}$+1.779$log(aminth t)_{it}$ +1.390$log(amaxtst)_{it}$+0.573$log(amaxtgt)_{it}$+ 0.633log $(amaxtht)_{it}$ +ε_{it}[(N=574) (R^2=0.046) (*Wald Chi* ^{2}=42.47*) (AIC=-1628.598) (BIC/SIC=-1693.887) (Mean VIF=7.15)] (21)

Few weather factors has statistically significant impact on yield variability of these crops. Actual rainfall during sowing time has a positive association with maize yield variability. It infers that it would be risk increasing input for maize yield variability. Rainfall in growing time is observeda negative impact on yield variability of rice. It expressthat rainfall would be risk decreasing input for rice yield variability.Actual rainfall during harvesting time shows a positive association with rice yield variability. It would be risk increasing input for rice yield variability. Maize yield variability is negatively impacted due to rainfall during sowing time and demonstrates that it would be risk decreasing input for this crop. Positive association of minimum temperature during sowing time with wheat yield variability, shows that it is risk increasing input for wheat crop. Minimum temperature during growing time is seen risk increasing input for rice yield variability. Minimum temperature during harvesting time is measured risk increasing input for maize yield variability. Furthermore, maximum temperature during sowing, growing and harvesting are expected risk decreasing input for rice yield variability. Maximum temperature during sowing time is found risk decreasing input for what yield variability. Remaining weather factors do not have statistically significant association with yield variability of crops.

Conclusion and Policy Suggestions

The present study estimatesthe impact of weather factors on mean yield and yield variability of rice, maize, wheat, chickpea crops in India. The regression of explanatory variables are estimated using linear and log-linear regression models under stochastic production function technique. It compiled 42 years (1971-2012) data on mean yield and yield variability of major food-grain crops, and weather and control variables. It comprises agrarian states of India as state-level panel.Empirical resultsof the study demonstrate that variability in weather factors like actual rainfall, maximum and minimum temperature duringsowing, growing and harvesting time have negative and significant influence on mean yield and variability of food-grain crop. The weather impact on mean yield and variability of food-grain crops varies across crops and within seasons. Estimates imply that mean yield of food-grain crops are climate sensitivein India. Mean yield and yield variability of undertaken crops are significantly influenced due to fluctuation in maximum and minimum temperatures, and rainfall pattern. It accomplished that climate change adversely affects yield of aforesaid crops. Hence, it ascertained that fluctuation in weather factors would have negative implications on food security.

Present study provides several policy suggestions to mitigate the negative consequences of climate change on crop farming. It recommended that Indian farmers need to adopt crop specific policies to mitigate the adverse effect of climate change in agriculture. It is essential to develop strategies to reduce yield variability of these crops. Otherwise, it would be a serious threat to sustain food security and rural development(McKune et al., 2015). Fluctuation in total productiondue to yield variability may be challenging for producers and consumers (Kumar et al., 2015b). High yield variability would be caused to collapses of government development policies, food price instability and market structure (Kim and Pang, 2009; Kumar et al., 2015b). High yield variability of crops would reducefarmer's income(Khajuria and Ravindranath, 2012). Therefore, Indian policy makers are desirable to give more attention towards risk increasing and decreasing inputs in crop farming (Kumar et al., 2015b). Planting technique of crops, selection of appropriate genotype (Birthal et al., 2014; Kumar et al., 2015b), applying modern technologies, application of bio-fertilizer and appropriate irrigation facilities in cultivation would be imperative to reduce negative impact of weather factors in agriculture (Singh et al., 2014; Mondal et al., 2015).

Mixed cropping system or dual cropping policy would be useful to improve agricultural productivity. Crop diversification would be crucial option to reduce risk in crop production induced by climate change (Misra, 2014; Kumar et al., 2015b). Farmers can give importance modern varieties of seed which are less sensitive to climatic change (Birthal et al., 2014).

The Government of India must provide high yielding varieties of seed, credit accessibility, proper irrigation facilities, bio-fertilizer and modern technology to farmers (Kumar et al., 2016a,b). Water harvesting and water conservation, and efficient use of water through micro-irrigation techniques like sprinkler and drip irrigation could be essential technique (Birthal et al., 2014; Misra, 2014; Kumar and Gautam, 2014; Kumar et al., 2016a,b). Well-organized land strategy and sustainable land management schemes would be helpful to sustain agricultural production. Crop insurance policies would increase farmer's economic capacity to adopt new techniques in cultivation (Birthal et al., 2014; Mondal et al., 2014; Mârza et al., 2015).

Agriculture is a significant contributor to global GHG emission (Khajuria and Ravindranath, 2012), therefore it is a cause for climate change and environmental degradation. Conversely, agricultural sector is negatively influenced due to variability in weather factors. Hence, the study is strongly argued that world's economies are compulsory to develop alternative techniques to reduce GHGs emission from various sectors (Kumar and Gautam, 2014; McKune et al., 2015; Kumar et al., 2015d). Additionally, the agriculture sector is required more financial support in research, education, extension, and laboratories to test soil, and water. Extensive public spending in agricultural R&Dwould stimulate for agricultural scientist and young researchers to do more research in this area (Kumar et al., 2015b; Mârza et al., 2015). Consequently, more R&D spending in agriculture would create innovative verities of seeds and cultivation techniques (Kumar et al., 2016a).

Agriculture Extension Offices, District Rural Development Agencies and local Non-governmental Organizations are mandatory to convey climate change related information to farmers on time. It would be beneficial for farmers to take precautionary actionin cultivation (Kumar et al., 2016a). Short-term training to farmers would increase their perception towards climate change(Khajuria and Ravindranath, 2012; McKune et al., 2015; Kumar et al., 2016a,b). Appropriate infrastructure facilities would avoid the communication gap of rural farmers with cities market. Researchers, environmentalistand agricultural scientists are unable to give practical adaptation techniques to cope with climate change in agriculture due to unavailability of farm level information.Therefore, appropriate ground level information is required to facilitates research at farming households to identify a conclusive decision (Khajuria and Ravindranath, 2012; Kumar et al., 2015b).

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