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Review Article

On the climate risks in crop production and management in India: A review

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Abstract

There is growing evidence that, as a result of global climate change, temperature increase is likely to be 1.8-5.0^{o}C. This would lead to more frequent hot extremes, floods, droughts and cyclones and gradual recession of glaciers in India over the next 20-50 years, which in turn would result in greater instability in food production. Of the total annual crop losses in agriculture, many are due to direct weather and climatic effects such as droughts, flash floods, frost, storms, hail, heat and cold wave. It is estimated that crop production loss in India by 2100 AD could be 10-40% despite the beneficial effects of higher CO_2 on crop growth. Dynamic of pests and diseases will be significantly altered. A wide variety of adaptation options like change in planting dates, varieties, crop diversification have been proposed as having the potential to reduce vulnerability of agricultural systems to risks related to climate change. The paper aims to discuss, (i) weather extremes causing the agro-meteorological risks in different parts of country, (ii) their impact on crop production and, (iii) strategies for management of these climatic risks for better crop production.

Keywords: Extreme weather events, Crop production, Food security, Weather risks, Climate change mitigation.

Introduction

The climate is changing in many ways, people all over the world have to face the reality of climate change and its extremes and there is a growing body of literature documenting these changes. Recent observations (Harmeling and Eckstein, 2013) in German watch Global Climate Risk Index (GCRI) shows that more than 530,000 people died as a direct consequence from almost 15,000 extreme weather events, and losses of more than 2.5 trillion USD in purchasing power parities (PPP), occurred from 1992 to 2011 (USD 1.68 trillion overall losses in original values). Honduras, Myanmar and Nicaragua were the countries most affected by extreme weather events from 1992 to 2011 followed by Bangladesh, Haiti and Vietnam. But in year 2012, the ranking of the most affected countries is led by Thailand, Cambodia, Pakistan, El Salvador and the Philippines. India ranked 46 in the GCRI for the year 2012, a position definitely better than it had in year 2011 with rank 18. But in year 2013, India had series of the cyclonic storms, notable storms were, 'Mahasen' over Bay of Bengal (10-16, May), Uttarakhand disaster (14-17, June), the cyclone 'Phailin' (08-14 October), 'Helen' (19-23 November), 'Lehar' (23-28 November) and 'Madi' (06-13 December), over the Bay of Bengal, resulted in severe loss and damage, which might climb India higher for the disaster in 2014 ranking (IMD, 2013). Although India does better in GCRI in the year 2012 but weather related risks like heat and cold waves, drought and flood has now become norm rather than exception in view of their increasing occurrence during recent past (Mahdi et al., 2013). This was evident when we analysed the extreme weather (ever recorded) data of temperature (minimum and maximum) and rainfall from 1930-2010 of India. Results revealed that all India total number of events has increased significantly (R^2 = 0.70) from about 30 in year 1930 to about 358 in the year 2010 (Fig. 1). A significant increasing linear trend was observed, pose added challenge to food security, particularly, in a country where economy rely heavily on agriculture dominated by small scale and subsistence farming (Singh, 2012). While change in long-term mean climate will have significance for food production and may require on-going adaptation, greater risks to food security may be posed by changes in year-to-year variability and extreme weather events and many of the largest falls in crop productivity have been attributed to anomalously low precipitation events (Kumar et al., 2004; Sivakumar et al., 2005). However, even small changes in mean annual rainfall can impact on productivity. Lobell and Burke, (2008) report that a change in growing season precipitation by one standard deviation can be associated with as much as a 10 per cent change in production (e.g. millet in South Asia). For the Indian region (south Asia), the IPCC, (2007) has projected 0.5-1.2^{o}C rise in temperature by 2020, 0.88-3.16 ^{o}C by 2050 and 1.56-5.44 ^{o}C by 2080. This would lead to more frequent heat extremes, floods, droughts, cyclones and gradual recession of glaciers, which in turn would result greater instability in food production (Aggarwal, 2008). Under this situation, potential approaches and simple

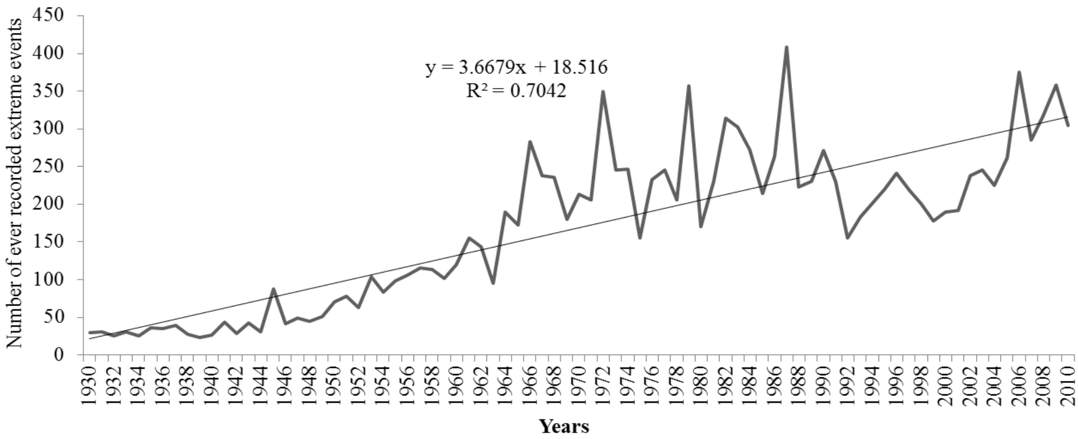

Fig 1. Number of ever recorded events of temperature (maximum and minimum) and rainfall are increasing in India

adaptation strategies could help in reducing the impacts of climate change and its extremes. Additional strategies for increasing our adaptive capacity include development of adverse climate-tolerant genotypes and land use system, providing value-added climatic risk management services to farmers, and improved land use policies and risk management through early warning system.

Extreme weather events

Extreme climate or weather event is defined as "the occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable" (IPCC, 2012). But what is called an extreme weather or climate event will vary from place to place in an absolute sense (e.g. a hot day in the tropics will be a different temperature than a hot day in the mid-latitudes). India had a history of extreme weather events, for example, in recent past, the drought of July, 2002, where rainfall deficiency dropped to 51%, surpassing all previous droughts, food grain production dropped to 183 million tonnes as against 212 million tons in 2001. Worst cold wave of 2002-03 in Northern India, where day temperature fell lower than 15°C while night temperature was below 0°C, crop yields were estimated lower by 10-40% in wheat, 25-30% in gram, 50-70% in mustard and 60-95% in amla as compared to previous normal year of 2001-02 in Agra, India. In addition, Bihar (popular for winter maize production) witnessed 70-80% loss in seed setting in winter maize. Devastating tsunami of year 2004, over South-eastern coast and Andman and Nicobar Islands of India, where almost 11,000 people died and over 50, 000 fishing vessels were damaged. The year 2005 was warmest ever recorded and declared as the year of hurricanes as it also witnessed one of most deadliest and most destructive Hurricane 'Katrina' on August 31. Most of Indian states were gripped by premonsoon heat waves which started at the end of May, have claimed more than 200 lives. In the same year, Maharashtra and Gujarat states of India witnessed devastating floods caused death of more than 5, 000 people. In the year 2006, cyclone 'Ogni' hit Andhra Pradesh and drowns Andhra's summer crop. In year 2007, South Asian floods, a series of floods hit India, Nepal, Bhutan, Pakistan and Bangladesh, the year was declared as flood year. Unusual rains in February and March, 2008 in southern states of India caused unprecedented crop damage in AP, Karnataka, Tamil Nadu and Kerala. The year 2009 was the all Indian extreme drought year, with its Standardized Precipitation Index (SPI) value of -2.02. India had four times such type of extreme droughts in years-1877, 1899, 1918 and 1972 with SPI values -3.47, -3.01, -2.48 and -2.37 respectively (Attri and Tyagi, 2010). Rainfall deficit of 23% was recorded, the food grain loss was about 10-15 million tonnes. The year 2012 witnessed unique anomalies in terms of onset and advancement of rains, frequent breaks, overall drought in early part of the season with high rainfall and even floods and cyclones elsewhere during the extended withdrawal phase. As a result of drought 5.68 million hectare of area was not sown during summer season resulted a loss of 12.76 million tonnes of summer food grain production. India has now become extremely vulnerable to the impact of climate events. Every year, it faces extreme weather events in the one and another form, which take lives, destroy homes and agricultural yields, and result in huge revenue losses and climatic model predictions indicate that occurrence such extreme events will remain continue in future with significant magnitude and frequency (Turner and Silango 2009; Field et al., 2012; Kumar et al., 2012) and will lead to drastic reduction in overall agricultural production particularly in rice and wheat production across the India (Aggarwal et al., 2010; Haris et al., 2013). Adaptation to these weather risks can be more challenging than adaptation to gradual changes in mean climate states. Extreme events can disproportionately affect vulnerable populations that experience higher exposure (e.g., extreme heat and low-income populations without access to air conditioning or individuals living in flood-prone areas) or higher susceptibility (e.g., extreme heat and elderly individuals) to such events. Changes in climate may not only change the frequency and magnitude of individual extreme events, but may also change the likelihood of extreme climate events occurring concurrently. Vulnerability to and impacts of repeated and coincident extreme events are generally expected to be higher than similar events occurring individually. For these reasons, extreme value analyses of rainfall, temperature at regional scale uniquely contribute to impact assessments and adaptation planning.

Weather risks impact on crop production

Weather risks can affect agricultural production significantly, for instance heat waves, high temperature and droughts (Ciais et al., 2005 and Vander Velde et al., 2010), excessive cold (Xin and Browse, 2001; Sanghera et al., 2011) and heavy and prolonged precipitation (Rosenzweig et al., 2002; Thakur et al., 2010; Chakrabarti et al., 2011). The diverse nature of weather risks leads to variable effects on different aspects of the crop growth cycle and associated field management. These extreme weather risks can in fact impact crops both via negative impacts on plant physiological processes and direct physical damage, as well as by affecting the timing and conditions of field operations. For instance, above-threshold temperatures and precipitation lows, leading to heat and drought stress, can negatively affect crop photosynthesis and transpiration (Porter and Semenov 2005), as well as increased pest and disease incidence (Bale et al., 2002). On the other hand, heavy rain, hail storms and flooding lead to crop failures by physically damaging crop canopies, or via anoxic soil conditions limiting root and plant function (Rosenzweig et al., 2002). Extremely wet conditions can also delay key field operations such as planting and harvesting. Systematic studies on extreme weather risks and their impact on Indian agriculture are relatively few. Crop responses in terms of yield and quality to climatic variation have remained very little on focus. The issue of food quality has not been given sufficient importance when assessing the impact of climate change on crop production. Crops can respond nonlinearly to changes in their growing conditions, exhibit threshold responses and are subject to combinations of stress factors that affect their growth, development and yield. Thus, climate variability and changes in the frequency of extreme events are important for yield, its stability and quality.

Drought

Drought is one of the short term extreme events and is a period of abnormally dry weather long enough to cause a serious hydrological imbalance. An all-India drought year, according to Indian Meteorological Department (IMD), is when the nationwide monsoon shortfall is more than 10 per cent, and 20 per cent to 40 per cent of the country faces drought conditions. Based on this criterion, 17% of the years during the period 1901–2010 were drought years (Kumar et al., 2013). Out of net sown area of 140 million hectares about 68% is reported to be vulnerable to drought in varying degrees, and in arid, semi-arid, semi humid and western India, the frequency of below normal rainfall is 54-57%, causing regular droughts. Long term data of India indicates that rain-fed areas witnesses 3-4 drought year after every decade, with 2-3 moderate and one severe, however, occurrence of droughts did not show any trend in frequency over the country. This calls for its in depth analysis at regional or zonal level to know spatial distribution of drought events in the country. Occurrence of drought has direct impact on country's summer food basket, which in turn depends on the onset of monsoon and its further behaviour. The year 2002 was a classic example to show how Indian food grains production depends on monsoon rainfall. The summer food grains production was adversely affected by a whopping fall of 19.1% due to all-India drought during monsoon 2002, brought down GDP of the country by 1 % (approximately 5.22 billion dollars) (Gadgil et al., 2003). A recent analysis under different agro-ecologies of India on effect of changing rainfall during winter and summer seasons on national food grain production reveals that during winter season no correspondence was noticed when per cent change in food production from trend line was related with per cent change in rainfall from normal, which can be due to the reason that most of the winter crops are generally grown under irrigated condition, and the rainfall does not show any significant relationship with the food grain production on national scale (Fig 2a). But the results can be different in different segments of the country, particularly the rain-fed and dry land regions. During the summer season, 0.64 % increase in food grain production was noticed with every 1% increase in summer rainfall from the normal (Fig. 2b). Annual food grain production also showed one to one correspondence with the annual rains (Fig 2c), (Mahdi et al., 2013). On account of Impact of climate extremes viz. drought and flood on Indian food grain production, results has revealed that, impact of drought on Indian agriculture is more than that of flood (Singh et al., 2011). Variation of the GDP and monsoon study has also revealed that the impact of severe droughts on GDP has remained between 2.5 to 5% of GDP throughout (Gadgil and Gadgil, 2006). Summer droughts had catastrophic effects on agriculture, water resources, food security, economy and social life in the country. In spite of huge technological advancement, no single index has been able to adequately capture the intensity and severity of drought and its potential impacts on such a diverse group of users. For examining the future projections of droughts in the global warming scenario, drought indices that consider precipitation only like Palmer Drought Severity Index (PDSI) will not be sufficient. The index should account for changes in atmosphere demand for moisture due to increased surface warming (Dai, 2011). Recently a new drought index, the Standardized Precipitation-Evapotranspiration Index (SPEI) has been proposed (Begueria et al., 2010; Vicente-Serrano et al., 2010) to quantify the drought condition over a given area. The SPEI considers not only precipitation but also temperature data in its calculation, allowing for a more complete approach to explore the effects of climate change on drought conditions.

To deal with drought, the aim should be to create local drought history (how often drought occurs in an particular region? how severe and widespread have the droughts been? how long the droughts lasted? which is one of the cornerstones of effective drought planning and will be valuable for us to design our operation or activity to withstand such departures from the average if any. What changes would we have to make in our activities to survive a 50 per cent reduction in annual precipitation if there is, what about a 25 per cent departure from average over a period of five years or longer?.

Heat wave (HW)

There is no universal definition of a HW. In general, a HW over a region refers to a prolonged period of excessively hot weather (above certain threshold temperature value) over the region, which may be accompanied by high humidity. According to the criteria (IMD, 2002), for declaration of HW condition the maximum temperature of a station must reach at least 40ºC for plains and 30ºC for Hilly regions and

i) When the normal temperature of a station is <40ºC:

Heat wave: Departure from normal is +5º C to 6ºC

Severe heat wave: Departure from normal is +7ºC or more

ii) When the normal temperature of a station is ≥ 40ºC:

Heat wave: Departure from normal is +4º C to 5º C.

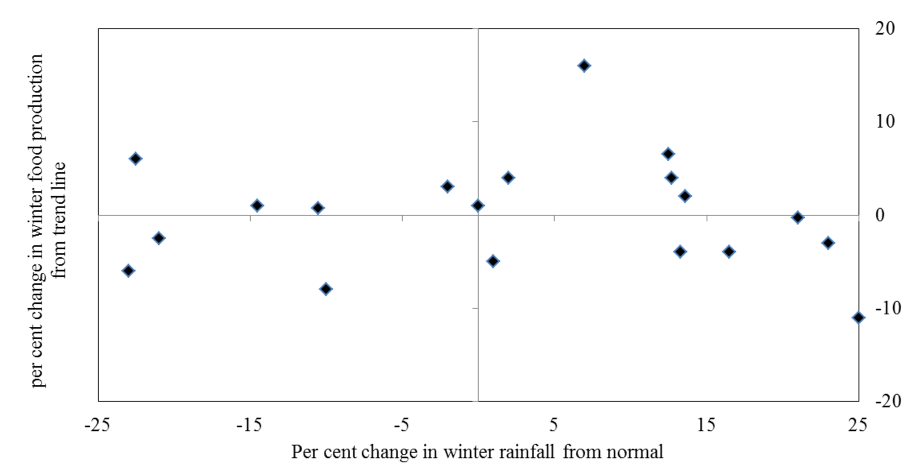

Fig 2a. Effect of Rabi (winter) rainfall on food production under different agro-ecologies of India

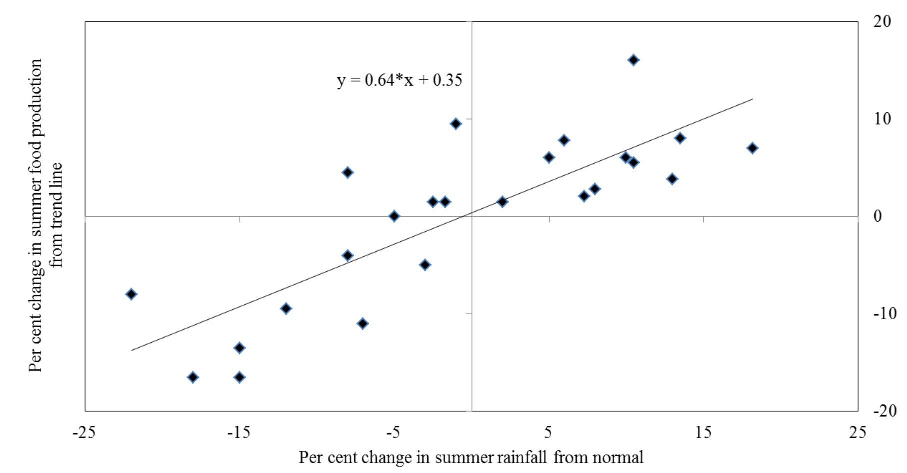

Fig 2b. Effect of Kharif (summer) rainfall on food production under different agro-ecologies of India

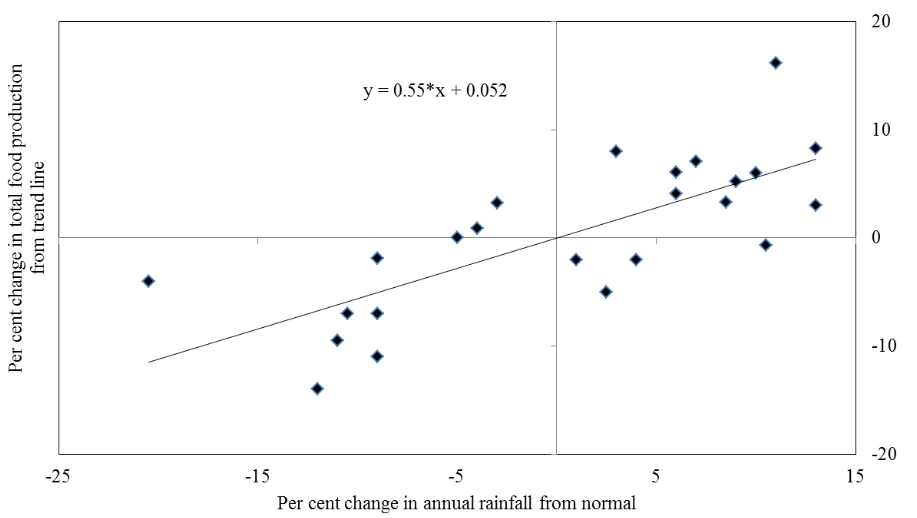

Fig 2c. Effect of annual rainfall on food production under different agro-ecologies of India

Fig 2. Effect of change in rainfall over normal on food production in India.

Severe heat wave: Departure from normal is +6º C or more

The HW spells occur every year during March to July in different parts of India. There has been noticeable increase in the HW/SHW days over the country during the recent decade of 2001-2010 (Pai et al., 2013). During the period, many crops are especially sensitive to extreme temperatures that occur just prior to or during the critical pollination phase of crop growth. Investigations have amply proved that yields of important field crops like rice, wheat, green gram, ground nut and mustard have been reduced due to increase in temperature from 1-4 ^{o}C, (Yan et al., 2010; Mahdi et al., 2013; Singh et al., 2013; Rehmani et al., 2014). Wheat being more thermal sensitive, its grain yields has been observed significantly lower in the treatments receiving high temperatures of 25^{o}C at anthesis and 35^{o}C at double ridge stage. The major yield component reduced by the treatment of heat stress was the harvest index, because grain number per plant was reduced by 60% (Porter and Semenov 2005). However, Duncan et al., (2014), in a recent study have found that warming average minimum temperatures across the north west Indo-Gangetic plains of India, during the thermo-sensitive periods (anthesis and grain filling) had a greater negative impact on wheat crop yield than warming maximum temperatures. In general, higher temperature has resulted in reduction of tillers in wheat, and thus spike and floret numbers per plant, as well as spikelets per spike, (Prasad et al., 2006; Rang et al., 2011 and Harsant et al., 2013). Apart from reducing yield, it is up to now rarely reported that issue of crop quality is also affected by climate variability (Rehmani et al., 2014). Simulation model studies in wheat and rice, has showed that longer periods of hot dry weather has raised the variability of both yield and grain protein concentration by 70–80% compared to a baseline, (Porter and Semenov 2005; Song et al., 2013). In fruit crops like strawberry and mulberry, decreased total soluble protein content in their leaves has been reported under heat stress which has often been attributed to the denaturation of proteins and reduced protein synthesis under high temperature stress (Gulen and Eris 2004). The issue of food quality has not been given sufficient importance when assessing the impact of climate change for food which needs to be addressed.

Cold wave

Conditions of cold wave should only be considered when wind chill effective minimum temperature (WCTn) is 10°C or less. The cold wave as per IMD, (2002) norms has been classified as:

a) When normal minimum temperature is equal to 10°C or more.

   Cold Wave: Departure from normal is -5°C to -6°C.

   Severe Cold Wave: Departure from normal is -7°C or less

b) When normal minimum temperature is less than 10°C.

   Cold Wave Departure from normal is -4°C to -5°C.

   Severe Cold Wave Departure from normal is -6°C or less

Cold wave which prevails in the India during winter months of December to March excluding the extreme southern peninsula, the entire country is susceptible to cold waves. A significant increase has been noticed in the frequency, persistency and spatial coverage of cold waves over the country (Attri and Tayagi, 2010). Cold temperature causes enormous agricultural losses, especially in sub-tropical and temperate grain crops (Thakur et al., 2010). The winter season of year 2002-2003 is notable example, when many parts of northern and eastern India witnessed severe cold wave conditions over a prolonged period for one to two weeks at a stretch, caused substantial reduction in crop yields by 10-40% in wheat, 10-15% in winter rice, 25-30% in gram, 50-70% in mustard, 60-95% in amla (Samra et al., 2003).

Temperature during ear emergence and anthesis is considered an important factor limiting yield of cereal crop (Luo, 2011). Rice and maize are sensitive to chilling temperatures, low temperature spell (below 10^{o}C) may disturb the formation of pollen mother cells and can thus cause sterility resulting in yield loss or crop failure (Nguyen et al., 2009; Chawade et al., 2013). Prevalence of very cold weather during the anthesis period of wheat (aestivum and durum var.) can cause pollen sterility as high as 98% (Subedi et al., 1998). In India, a study of Chakrabarti et al., (2011) has found wheat varieties where anthesis and flowering took place in the month of December and January (sown in October) experienced very low temperature leading to more number of sterile pollens and in turn, pollen germination has been found to be positively correlated with yield (R^2=0.63) as higher pollen germination (85.2%) obtained at temperature of 18.4 ^{o}C has resulted in better grain setting (Fig 3).

Adaptation strategies

The strong trends in climate variability and its extremes already evident, the likelihood of further changes occurring, and the increasing scale of potential climate impacts give urgency to addressing agricultural adaptation more coherently. As per recent report of IPCC, (2014), India over 1.2 billion people, is deemed one of the nation's most vulnerable to climate change impacts and by 2030 India would face an agricultural loss of over US $7 billion, affecting income of 10 per cent of the people. But if climate resilience measures in the form adaptive strategies are implemented, 80 per cent of the losses could be averted, the report adds. Study by Lobell et al. (2008) also confirmed that without sufficient adaptation measures, South Asia, dominated by Indian plate, will likely suffer negative impacts on several crops (wheat, rapeseed, rice, millets, and maize) that are important to large food-insecure human populations. Yet integration of several other studies through modelling and experimentation projects loss of 10-40% in Indian crop production by 2100 due to increasing temperature and CO_2, if no adaptation measures are taken (Agarwal, 2008; Kumar et al., 2011; NAAS, 2013).

Adaptation to climate variability and extremes events serves as a basis for reducing vulnerability to long term climate change. It is understood that the patterns or trends of the past climate can tell us something about future climate. Strategies developed to manage year-to-year climate variability can go a long way towards building resilience and managing the risks of climate.

The different adaptation methods that we have collected from literature and have been found to serve as inputs for the national adaptation strategies have been discussed:

Use of stress tolerant crop varieties or climate ready crops

Development of new crop varieties with higher yield potential and resistance to multiple stresses (drought, flood, salinity) will be the key to maintain yield stability (Lobell et al., 2008). In India, some of candidate genotypes has been tested and screened for resilience to different stresses using 'Mother' and 'Baby trials' and the promising varieties/ genotypes were identified through 'Participatory Varietal Selection' (PVS) approach and are being promoted among farmers, as the adaptation strategy to reduce vulnerability. Genotypes in this context are (i) 'Swarna Sub 1' and 'IR 64 Sub 1' of rice, which were found best under submergence conditions during flood. Swarna Sub 1 has been reported to yield 3.20 t/ha even after 10 days of submergence compared to yield of control variety (1.70 t/ha) under eastern conditions of India (Yamano et al., 2013; Dar et al., 2013). (ii) Shushk Samrat, a drought tolerant rice variety has been found to perform better under drought conditions. With one irrigation the average yield of Shushk Samrat was found to be 3.12 t/ha, compared to only 1.43 t/ha of Moti-local and 2.75 t/ha of Sarju 52-local (DRR, 2011). (iii) CSR-1 and K-3119, salt-tolerant rice varieties; KRL 19 high salt tolerant variety of wheat; KRL 213 and KRL 210, mild salt tolerant varieties of wheat have been found to perform better under varied salinity condition. (iv) Similarly, for heat stress tolerance, NDW 1014, Halna, WR 544 and PBW 154 have been found to be highly productive and stable (Singh and Singh 2013).

Although the current research has divulged several key genes, gene regulatory networks and quantitative trait loci (QTLs) that mediate plant responses to various abiotic stresses, the comprehensive understanding of this complex trait is still not available. The discovery of genomic variations and genes associated with climate adaptation found in wild relatives of crop plants via whole-genome re-sequencing may be directly relevant for implementing breeding approaches to develop environmentally adapted crops (Garg et al., 2014).

Adjusting cropping season

Adjustment of planting dates to minimize the effect of temperature increase induced spikelet sterility can be used to reduce yield instability, by avoiding of having the flowering period to coincide with the hottest period. There exists a strong correlation between yield declines in rice and wheat and the shortening of crop duration under high temperature, whereas shifting the transplanting date seems to be an effective measure to reduce the shortening of crop duration for both crops (Jalota et al., 2013). The study further confirms that yield declines are found to be smaller (in the range of -2.4 per cent for 2020, -13.3 per cent for 2050, and -26.6 per cent for 2080, when the transplanting date is shifted by +7 days for rice in comparison to the yield declines (in the range of -4.6 per cent for 2020, -16.1 per cent for 2050, and -29.1 per cent for 2080 under A2 SRES scenario. Likewise, yield declines were found to be smaller in wheat (in the range of -4.3 from -8.8 per cent for 2020, -13.6 from 22.5 per cent for 2050, and -28 from 41 per cent) when the transplanting date is shifted by +15 days under same emission scenario. Sorghum yields which were projected to decline by 16 per cent in Madhya Pradesh and Karnataka and by 4-5 per cent in Andhra Pradesh by 2020 are now expected to decline by only 1-2 per cent with low cost adoptive measure and shifting in sowing dates (Srivastava et al., 2010).

Conservation agriculture (CA)

CA practices, considering the three main components, i. Minimal soil disturbance (disturbed area must be less than 15 cm wide or 25% of cropped area), ii. Soil cover (ground cover must be more than 30%). iii. Crop rotation (rotation should involve at least three different crops) is steadily gaining acreage worldwide to about 124 million hectare (Friedrick et al., 2012) and in south Asia to about 3.90 million hectares (Jat et al., 2011). CA has been adopted in tropics/sub-tropics and temperate regions of the world for both rain-fed and irrigated eco-systems in view of its pronounced effects to mitigate the greenhouse gases emission and adaptation to climatic variability (Malik et al., 2005; Gupta et al., 2010; Pathak et al., 2011). By adopting CA practices, agricultural soils in the world are estimated to have the potential to sequester 0.4-0.8 Pg C per year (Lal, 2004). Improved agricultural management practices such as conversion from conventional to no-till or reduced tillage, residue retention, conversion to permanent pasture, crop rotation and fertilizer application have shown to increase soil C in various countries, including India (West and Marland 2002; VandenBygaart et al., 2003; Lal 2004; Patle et al., 2013). However, contradictory results are common in the literature. For example, a meta-analysis based studies in North America and South America indicated that adoption of no-till did not increase soil C stock down to 40 cm (Luo et al., 2010). This is true under Indian conservation agriculture, where CA sequesters maximum soil organic carbon near soil surface layer up to 10 cm (Patle 2013). Review suggests that soil at 0-10 cm depth is most responsive to the targeted management practices, what we did in CA. Increase in soil C as a result of these management practices can be attributed to enhanced biomass production, litter fall and hence returns of crop residues to the soil and also to improved soil aggregation that protects the C compounds from rapid decomposition. Carbon accumulation can be increased in the surface 0-10 cm of soil, but that is also the layer from which it can be most readily lost from agricultural soils. It is therefore necessary to examine whether an agricultural practice sustains surface soil C over time or not. Does it mean that potential for C sequestration in Indian agricultural soils is technically limited?. More in-depth analysis is therefore required in this aspect.

Crop diversification

Crop diversification has proven to be one of the most popular farm level responses to climatic variability and change particularly in countries which are predominantly of rural economics and are at most risk (Bradshaw et al., 2004). Apart from buffering crop production from the effects of greater climate variability and extreme events, crop diversification improves resilience by engendering a greater ability to suppress pest outbreaks and dampen pathogen transmission, which may worsen under future climate scenarios, (Lin, 2011). In India, review from the published reports suggested, that fewer attempts have been made to quantify the benefits of diversification in relation to coping with climate change and its risks. Diversification is commonly studied to meet demand fluctuations and stabilize farmer’s income. Attempts are needed to identify least impacted cropping systems and promote those which improve carbon sequestration, like maize-wheat and agroforestry systems had 65–88% higher soil organic carbon stocks than the rice-wheat system, Benbi et al., (2012), under other conditions it can add to them (Waha et al., 2013). Results from study by Saha, (2013) has shown that crop diversification in India has taken place in western and south-western states, while as crop specialization has occurred in states like West Bengal, Assam, Manipur and Mizoram. Because of changing rainfall patterns and water resources depletion, the traditional cropping pattern is becoming less productive. Thus crop intensification, through mixed cropping and integration of high-value crops such as horticultural production, is gaining prominence as a climate change adaptation strategy. A re-evaluation of cropping patterns can provide higher risk security.

Local weather information

Local weather information and its early warning systems will be very useful in minimizing risks of climatic adversaries.

Table 1. Crop yields and farm incomes for farmers taking management decisions with and without agro-meteorological information in Mali, Africa and Kalyani, India.

Country	Crop	Field type	Average yield (kg/ha)	Gross income US$/ha	Income gain in agro-met fields (%)
Mali, Africa	Pearl millet	Agromet	1, 204	175	26
		Non Agromet	957	139	
	Sorghum	Agromet	1, 427	193	42
		Non Agromet	1, 005	136	
	Maize	Agromet	1, 984	249	80
		Non Agromet	1, 105	139	
	Groundnut	Agromet	874	237	25
		Non Agromet	702	190	
Kalyani, India	Oil seed mustard	Agromet	1, 595	666	10
		Non Agromet	1, 468	604	
	Jute	Agromet	7, 871	1140	8
		Non Agromet	6, 943	1059	
	Winter rice	Agromet	9, 999	837	12
		Non Agromet	9, 625	747	

(Adopted from Hellmuth et al., 2007; Maini and Rathore, 2011).

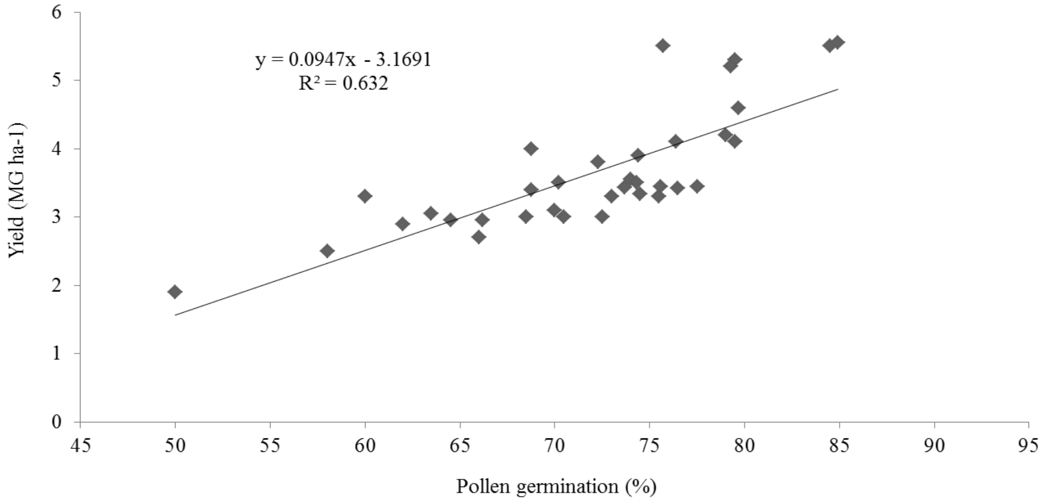

Fig 3. Relationship between pollen germination percentage and yield of wheat

Source: Chakrabarti et al. (2011).

But climate/weather information is often available only as raw observations or in the form of tables, graphs, or written summaries, which is becoming difficult for users particularly by progressive farmers who are not well-versed in climate science to fully interpret. To bridge this gap, there is need to translate climate data into accessible, useful, and accurate products; and to better understand what the information means and how it can be used most effectively. Having access to relevant and easily understandable weather and climate information is essential to effectively managing the risk and optimizing agricultural production. Examples of the successful utilization of meteorological information for the benefit of food production can be seen from the results of a case study in Mali, Africa (Hellmuth et al., 2007) and Kalyani, India (Maini and Rathore, 2011), where crop yields and farm incomes were compared for farmers taking management decisions with and without agro-meteorological information (Table 1). Results revealed that crop yields and farmer's incomes were significantly higher in fields where agro-meteorological information was used compared with those where it was not used. The increase in income was substantial, notably for maize in Mali, (where farmers earned 80% more income from agro-meteorological fields) and for oilseed mustard in India, (where, farmers earned 12% more income from farmers using agro-meteorological advisory services). Likewise, in Finland, early information to farmers on prevalence of extreme low temperature has prevented the loss of more than 50% of citrus yield, which was vulnerable to the premature fruit drop disease caused by fungus under low temperature (Tolat, 2013).

Improved pest management

Healthier crops are more likely to withstand the adverse effects of increased temperatures, droughts and unreliable or more intense precipitation. Changes in temperature and variability in rainfall would affect incidence of pests and disease and virulence of major crops, like at higher temperature, declined survival rate of brown plant hopper and rice leaf folder has been observed in rice ecosystem. (Karuppaiah and Sujayanad, 2012). In Sub-Saharan Africa, changes in rainfall patterns are driving migratory patterns of the desert locust (Cheke and Tratalos, 2007). It is because climate change will potentially affect the pest/weed-host relationship by affecting the pest/weed population, the host population and the pest/weed-host interactions. Some of the potential adaptation strategies in this context could be: (i) developing cultivars resistance to pests and diseases; (ii) adoption of integrated pest management with more emphasis on biological control and changes in cultural practices, (iii) pest forecasting using recent tools such as simulation modelling, and (iv) developing alternative production techniques and crops, as well as locations, that are resistant to infestations and other risks.

Water saving technologies

Water saving/conservation technologies acts as buffer against production risk in the face of climate change and its variability (Kato et al., 2011), and could be part of the country's climate proofing strategy. In view of increasing frequency of droughts, warm days and warm nights which are likely to increase further in the next decades (IPCC, 2013 for India), water-saving technologies (WST) are going to contribute substantially against production risks. In addition, WST reduces the greenhouse gas emissions, which can ease the negative effects of climate change on agricultural production (Karimi et al., 2012). However, In India, the cost and effectiveness of using WST to cope with climate change has remained few in literature. The cost and effectiveness are very important factors relevant to the willingness of farmers to adopt. Zou et al., (2013), while studying the cost-effectiveness analysis of water-saving irrigation technologies based on climate change response has concluded that water-saving irrigation (WSI) is cost-effective in coping with climate change, and has benefits for climate change mitigation and adaptation, and for sustainable economic development compared to sprinkler irrigation which has highest incremental cost for mitigation (476.03–691.64 US$/t), as it may need additional energy to meet water pressure requirements, which may increase greenhouse gas emissions compared to traditional irrigation. The results suggest that for mitigation and adaptation objectives, micro-irrigation performs best. From an economic perspective, channel lining has been recommended. Therefore, a balanced development of channel lining and micro-irrigation according to different geographical conditions must recommend.

Conclusion

From the foregoing discussion it is clear that episodes of weather risks like droughts, floods, heat and cold waves are increasing in India. Their impact on agricultural economy is tremendous. The phenomenon is more acute at regional level, where they are likely to increase in ensuing decades, posing additional threat to food security. As per Food and Agricultural Organization of United Nations (FAO), India stands to lose 125 million tonnes, equivalent to 18% of its rain-fed cereal production from climate change and its risks by 2015 which would cause a worldwide drop in cereal crops, put 400 million more people at risk of hunger. The effects of extreme weather events on agricultural demands documentation so that it will be handy to decision makers/planner in such re-occurring events for mitigating its ill-effects. Also, there is need to chalk out the strategies on mitigation and adaptation against weather risks at regional level. Adaptation option like conservations agriculture needs to be tested for its technical and economic feasibility of actually increasing the permanent soil carbon stock. Farmers and land managers need this information to determine whether they can earn carbon credits under CA. In addition, the adoptive capacity of dry land farmers, forest and coastal communities are low, needs to be strengthened.

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