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Contingency crop planning for dryland areas in relation to climate change

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ABSTRACT

Scientific evidence about the seriousness of the climate threat to agriculture is now unambiguous, but the exact magnitude is uncertain because of complex interactions and feedback processes in the ecosystem and the economy. Climate-related factors that would affect agricultural productivity in coming decades are: changes in temperature, precipitation, carbon dioxide (CO_2), fertilization, short-term weather variability and surface water run-off. Simulation of future climate in India under A2 scenario by IITM, Pune and Hadley Centre, UK, indicate that during the last quarter of present century the country will experience an increase in mean annual temperature by 3-5°C. Summer monsoon rainfall will increase by 20%, and extreme rainfall events would rise sharply in western and south-central parts. However, the arid western Rajasthan and the adjoining Punjab and Haryana will possibly experience notable decline in summer monsoon, and slight increase in winter rainfall, with pronounced variability in rainfall and fewer rainy days. Consequently, there will be higher incidence of droughts and floods in arid western India, affecting both rainy (*kharif*) and winter (*rabi)* season crops. Since a number of high-value crops are grown during the *rabi*, the negative impact on farmers' economy would possibly be higher. Change in CO_2 concentration too can show uncertainty in crop yields, but studies on the interrelationship between changes in rainfall, temperature and CO_2 concentration and their effect on yield changes are quite few. Adaptation and mitigation strategies to address the impact of climate change on agriculture are needed urgently through new research and proper interpretation of the accumulated research results from the decades of dryland research under different agro-climatic settings. Use of alternative crops or cultivars adapted to the likely changes, alteration in the planting date, and management of plant spacing and input supply might help in reducing the adverse impact. Use of resource-conservation technologies and a shift from sole cropping to diversified farming system is highly warranted. Horticulture and agro-forestry need to be given more encouragement. Enabling policies on crop insurance, subsidies and pricing related to water and energy uses need to be strengthened at the earliest. Policies that would encourage farmers to enrich organic matter in the soil need emphasis. Also, it is necessary to develop a robust early warning system of spatio-temporal changes in weather as well as other environmental parameters. Contingency crop planning will require greater attention. Long-term strategic approaches to efficiently conserve and utilize rain water on the one hand and in-season tactical approaches to mitigate the adverse effects of weather aberrations on the other are also needed. Consideration of depletion rate of soil water is more important when the crops are grown primarily on stored soil water. Under such situations, wide rows and low plant populations are highly desirable. Water-conservation practices will become economically feasible when nutrient deficiencies are also corrected. Late onset of monsoon rains often leads to delayed planting and specific crop contingency plans have been developed for different agro-climatic zones to address the issue.

Key words: Adaptation strategy, Arid area, Climate change, Contingency crop planning, Dryland

Dryland agriculture is largely rainfall-dependent, especially in India where the quantity and distribution of summer monsoon rain decides the crop production. Since the food production in India depends largely on the monsoon behaviour, many efforts have been made to understand and predict the monsoon variability. Yet the variability of summer monsoon is still less predictable, except in very recent years when the onset and distribution of summer monsoon rains are measuring up to the numerical predictions. Numerical prediction of climate variability has gained high importance in recent decades, as the global climate has started showing signs of abnormalities upon accumulated anthropogenic forcings, with impacts on all aspects of life, especially agriculture and allied activities. The results of climate - simulation models are therefore keenly studied by agricultural scientists to find out their likely impacts on future production and to suggest adaptation measures to maintain crop production.

Agriculture is not only sensitive to climate change but is also one of the major drivers of climate change. Scientific evidence about the seriousness of the climate threat to agriculture is now unambiguous, but the exact magnitude

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is uncertain because of the complex interactions and feedback processes in the ecosystem and the economy. In India, agriculture sector contributes ~22% of the total greenhouse gases (GHG) emissions (Sharma *et al.*, 2006). The emissions are primarily due to methane emitted from rice paddies, enteric fermentation in ruminant animals, and nitrous oxides from application of manures and fertilizers to agricultural soils.

Studies so far suggest that following 5 main climate-related factors would affect agricultural productivity in the coming decades: changes in temperature, precipitation, carbon dioxide (CO_2), fertilization, short-term weather variability and surface water run-off. The major drivers of the changes are increased levels of GHGs due to burning of fossil fuels, increased use of refrigerants and increased agriculture-related practices etc. The atmospheric concentration of carbon dioxide (CO_2) is now increasing at an alarming rate of 1.9 ppm/year. The atmospheric concentration of methane was 1774 ppb in 2005, whereas the nitrous oxide has increased from the pre-industrial value of 270 ppb to 319 ppb in 2005. Simulation results from IPCC, Cambridge (2007) indicate that the average global surface temperature could rise by 0.6 to 2.5°C in the next 50 years, and by 1.4 to 5.8°C in the next century.

Climate-change scenario for India

Simulation of future climate in India under A2 scenario by Indian Institute of Tropical Meteorology (IITM), Pune, and Hadley Centre, UK, indicate that by the last quarter of the present century the mean annual temperature in the country will most likely increase by 3-5°C. The spatial average for the increase in annual rainfall during the period is 7-10% (Rupakumar *et al.,* 2006).

There will be high disparity in the changes in distribution of rainfall and temperature. North India is expected to be warmer than the south but more importantly, night temperature and winter temperature would register higher of 5°C increases over the most part. It is also predicted that by 2071 the overall summer monsoon rainfall in India will increase by 20%, extreme rainfall events would rise sharply especially in parts of Gujarat, Maharashtra, Madhya Pradesh, Karnataka and Andhra Pradesh. Incidence of tropical storms in the Arabian Sea coast is also likely to increase. The onset of summer monsoon could become more variable. Overall the changes are likely to have more adverse effects than benefits. Increase in temperature is likely to be less during the rainy (*kharif*) season and more during the winter (*rabi)* season, whereas the *rabi* rainfall will be more uncertain. The *kharif* rainfall is likely to increase by 10%. The likely changes in temperature and rainfall in the country from the present are presented in Table 1.

Likely changes in arid western part of India

Analysis of rainfall trend during the last 100 years by Indian Institute of Tropical Management (IITM) revealed that the summer monsoon rainfall, which contributes more than 85% of the total annual rainfall in the region, has increased marginally (< 10%) in the southern and eastern parts of Thar Desert, but has already declined by 10-15% in its north-western part. Rainfall trend in arid Kachchh and Banaskantha did not show much change, but arid Saurashtra experienced 10-25% increase. Earlier studies on changes in rainfall and air temperatures of north–west India showed that the rainfall increased marginally by 141 mm in the past 100 years (Pant and Hingane, 1988), especially in the irrigated belt of Ganganagar region particularly during the past 3 decades (Rao, 1996).

Simulation results of future climate change in the arid western part of Rajasthan and adjoining parts of Punjab and Haryana indicate that by the last quarter of this century, summer monsoon would decline notably in large parts of these areas (up to 30%), especially during July-August. Winter rainfall may increase slightly, and the variability in rainfall will be more pronounced. Along with these variabilities, the rainy days are likely to decline by 10 in north-western Rajasthan and adjoining Punjab plains, and by 5 in arid Gujarat. Consequently, there will be higher incidence of droughts and floods in arid parts of western India. Based on the current understanding of simulation results of climate change, Kar (2007) broadly divided the north-western hot arid zone into 3 major subzones: (i) the hotter and very dry north-west Rajasthan and adjoining Punjab; (ii) the warmer and moderately wetter arid Gujarat and adjoining south Rajasthan; and (iii) the hotter and slightly wetter eastern fringe of arid Rajasthan and adjoining Haryana.

The predicted changes - when viewed in the perspective of current trends in human and animal population growth - expansion of crop land, reduction in fallow land system, fast-declining ground-water reserve due to over

Table 1. Expected changes in temperature and rainfall in India

Year	Season	Temperature change (°C)		Rainfall change (%)	
		Lowest	Highest	Lowest	Highest
2020s	Annual	1.00	1.41	2.16	5.97
	Rabi	1.08	1.54	1.95	4.36
	Kharif	0.87	1.17	-1.81	5.10
2050s	Annual	2.23	2.87	5.36	9.34
	Rabi	2.54	3.18	-9.22	3.82
	Kharif	1.81	2.37	7.18	10.52
2080s	Annual	3.53	5.55	7.48	9.90
	Rabi	4.14	6.31	-24.83	-4.50
	Kharif	2.91	4.62	10.10	15.18

irrigation etc., indicate that agriculture will be more challenging here, through direct and indirect impacts on crops, livestock, pests and diseases, and soils, thereby threatening the food security and livelihood security of farming communities. Both *kharif* and *rabi* crops are likely to be affected by the changes, especially due to changes in temperature regime, but also due to shifts in rainfall distribution. Higher temperatures and likely faster soil-moisture depletion may offset the slight gains of rainfall increase in the eastern fringe of arid Rajasthan and adjoining semi-arid tract.

Since a number of high-value crops are grown during *rabi*, with higher input cost to farmers, and since the crops are more temperature-sensitive than the common *kharif* crops, the negative impact on farmers' economy would possibly be higher during *rabi*. A recent simulation study has shown that a rise in temperature by 1°C can lead to a decline in wheat production by ~250 kg/ha in Rajasthan and by 400 kg/ha in Haryana. In Indian mustard the decline was ~100 kg/ha/degree rise in temperature in Rajasthan, and by 200 kg/ha in Haryana, whereas in chickpea (gram) the decline was ~200 kg/ha in Rajasthan and 500 kg/ha in Haryana. There are concomitant declines in biomass yield also. The declines tended to taper off eastward in Uttar Pradesh (Kalra *et al.*, 2008). Such a scenario for crop yields warrants careful crop planning and management, as well as development of suitable varieties.

Another uncertainty in crop yields is likely to be introduced by the change in CO_2 concentration. Usually a higher concentration of CO_2 leads to an increase in biomass yield due to better performance by the crop growth regulators and faster maturity, but adequate studies are lacking on the interrelationship between changes in rainfall, temperature and CO_2 concentration to predict the kind of yield changes expected. With increase in both rainfall and temperature, it is necessary to ascertain whether the impact of increased rainfall and CO_2 will overwhelm the impact of increased temperature and hence evapo-transpiration over specific regions for specific crops.

Strategies for Adaptation to Climate Change

Adaptation strategies to address the climate change impacts on agriculture are needed urgently through new research and proper interpretation of the accumulated research results from the decades of dryland research under different agro-climatic settings. Development of crop varieties capable of withstanding temperature increases and aberrations in temperature need a greater attention, whereas the understanding of crop-growth regulators and soil-water-plant relationship under changed CO_2 levels in grain and biomass production of individual crops require research. Current research on improving the water-use efficiency of crop plants, their drought and pest resistance and also the agronomic practices need more emphasis. The following adaptation strategies are suggested on the basis of research carried out so far.

Altered agronomy of crops: Change in planting date, and the management of the plant spacing and input supply may help reduce the adverse impact of changes in some climatic parameters. Alternative crops or cultivars more adapted to changed environment can further ease the pressure.

Development of resource-conserving technologies: Use of resource-conservation technologies like surface seeding or zero-tillage not only restrict the release of soil carbon in the atmosphere, but also sometimes help partially withstand the adverse climate, and provide better yield or stabilize it. For example, surface seeding or zero-tillage of upland crops after rice gives yields similar to that when planted under normal conventional tillage over a diverse set of soil conditions. However, more research is needed for their applicability in the arid lands.

Diversified farming: A shift from sole cropping to a diversified farming system is highly warranted. Horticulture and agro-forestry need to be given more encouragement, whereas in the drier western part of the arid lands greater emphasis is required on pasture or biomass development for the livestock, which becomes a major component of the individual farmer's economy. Use of farm-level land in the more vulnerable arid areas should be optimized to sustain production and manage risk, rather than to increase productivity.

Increase in income from agricultural enterprises: Location-specific fertilizer practices, improvement in extension services, fertilizer supply and distribution, and development of physical and institutional infrastructure can improve the efficiency of fertilizer use and reduce the cost of production.

Crop-management strategies: Crop-management strategies to obtain high yields under rainfed conditions may vary depending on the climate, available resources and farmers' needs. However, the basic idea is to ensure that a maximum possible fraction of rainfall is used for crop growth and for reducing the effects of other limitations to crop production, to obtain high rainfall-use efficiencies. Joshi and Singh (1994) reviewed all the aspects of water-use efficiency in relation to crop production in the arid and semi-arid regions. They discussed crop-management practices like sowing of crops at optimum time, securing and maintaining adequate plant stands, nutrient management, tillage, improvement in plant characteristics, and the control of weeds, pests and diseases. They also highlighted the role of mulches, anti-transpirants and reflectants in reducing evapo-transpiration losses.

Maintenance of adequate and uniform plant stand is very essential for efficient use of rain-water and other inputs. Crop germination and seedling establishment are improved when seeds are planted in well-prepared seedbeds with suitable planting equipment. Use of high-quality seed improves the uniformity of crop establishment. Improved cultivars of various crops are available for cultivation in drylands, which are early and have high harvest index, and hence give higher grain yields than the local cultivators. Selection of cultivars resistant to pests and diseases and their timely control help in achieving high yield and water-use efficiency. Similarly, timely and efficient weed management is very essential.

Policy tools for resource management on a sustainable basis: Enabling policies on crop insurance (especially to withstand the impact of drought and flood), subsidies and pricing related to water and energy uses need to be strengthened at the earliest. Policies that would encourage farmers to enrich organic matter in the soil and thus improve the soil health need emphasis (e.g. financial compensation or incentive for green-manuring).

*Improved risk management through early warning and crop insurance***:** It is necessary to develop a robust early warning system of spatio-temporal changes in weather and other environmental parameters. The current medium-range weather forecasting system needs to be more refined and applicable at a finer spatial resolution, and the system of information dissemination needs to be more systematic. Modern tools of information technology could greatly facilitate this.

Contingency crop planning

Since *kharif* cropping is a primary activity in the rainfed areas of arid lands, where monsoon variability plays a crucial role in production, contingency crop planning will require a greater attention in these areas. Long-term strategic approaches are also needed to efficiently conserve and utilize rain water on the one hand and in-season tactical approaches to mitigate the adverse effects of weather aberrations on the other.

Water management: Efficient rain-water management acts as insurance for the crop during the rainfall-deficit periods. Management techniques that increase infiltration and soil-water storage, and decrease the water losses by run-off, evaporation, and evapo-transpiration from crop fields (e.g. inter-row and inter-plot water harvesting, area or strip water harvesting) need encouragement. Farmers have also developed their own systems of rainwater management, which deserves to be studied and refined. For example, if the onset of monsoon is late, farmers switch over from long-duration, high water-requirement cereal crops to short-duration, deep-rooted legumes. To cope with unpredictable mid-season droughts, they have adopted water-conservation practices like field bunding, creating dust mulches etc., and when the drought sets in they reduce the plant populations. Researchers have refined several traditional management practices and have developed new ones to mitigate the drought effects to a certain extent.

Crop-row management: When the crops depend on growing-season rainfall, narrow row spacing may help in quick coverage of soil surface, thereby reducing evaporation losses from the soil. High plant populations may use more soil water during early stages and hence the crop may suffer from water stress during reproductive and grain filling stages. Consideration of depletion rate of soil water is more important when the crops are grown primarily on stored soil water. Under such situations wide rows and low plant populations are highly desirable.

Nutrient management: Crops in the arid and semi-arid areas suffer not only from moisture stress but also from nutrient stress. Water conservation practices can become economically feasible on correction of nutrient deficiencies. Studies have shown high returns from the applied nutrients in different agro-climatic situations through quick establishment of crop canopy, consequent reduction in soil-water loss, better partitioning of ET, and deeper root development for extracting stored moisture and nutrients at depth, but the response to applied fertilizer varies with the soil type, available water storage at seeding and seasonal rainfall during the growing season.

Selection of crop variety: It has been observed that the duration of traditional crops or varieties grown in dryland areas is often longer than that of the effective growing season. These crops or varieties usually experience moisture stress, mostly during the grain-filling period. For example, the traditional varieties of pearl millet with 110 days duration usually suffered from drought stress at the later stages of crop growth in western Rajasthan. Introduction of a relatively short-duration cultivar HHB 67 (70 days duration) found favour with the environment in this pearl millet-growing area. In slightly wetter regions, intercropping is the best choice. In such a case, a short-duration and a long-duration crop may be intercropped to make the best use of resources. In addition to efficient resource use, intercropping imparts stability to productivity and reduces the risk of crop failure.

In-season drought management: In-season drought is a potential stress for nearly all rainfed crops. Germination and crop establishment are the most sensitive periods when moisture stress can have devastating effect on crop production. Moisture stress during crop-growth stages of high leaf-area indices will show the greatest decrease in

Table 2. Alternate crops suitable for delayed sowing conditions in some arid areas

Locations	Suitable crops		
	Normal sowing	Delayed sowing	Both situation
Hisar (Haryana)	Pearl millet, clusterbean	Cowpea	Greengram, clusterbean
Anantpur (A.P.)	Sorghum, pigeonpea, greengram, castor	Foxtail millet, groundnut, sunflower, horsegram	Pearl millet
Dantiwada (Gujrat)	Pearl millet, castor, cotton	Castor, clusterbean, cowpea, minor millets	Sorghum, greengram
Jodhpur (Rajasthan)	Pearl millet, clusterbean,	Clusterbean, castor sesame	Greengram, cowpea, mothbean

yield. At high leaf-area indices, the rates of gas exchange of crops are high, as a result the water is lost at higher rates. Reduction in leaf-area indices by ratooning or thinning of the crop can partially mitigate the ill effects of drought. Timely weed control and use of mulches may also be useful in extending the period of moisture availability.

Choice of crops with changing sowing condition: Late onset of monsoon often leads to delayed planting, and specific crop-contingency plans have been developed for different agro-climatic zones to address the issue. For example, beyond the third week of July sowing of pearl millet gives poor yields in the Indian arid zone, but legumes like clusterbean and mothbean give good yields. In red soils of Telangana region, castor gives better yields than pigeonpea under late-sown conditions (Table 2).

Supplemental irrigation: Giving an irrigation to stabilize and improve the yield of a crop, which is otherwise dependent on rain water, is termed supplemental irrigation. Giving a supplemental irrigation during prolonged drought periods by using underground water (even of poor quality) or rain water harvested in tanks can make all the difference between a total crop failure and good yields. If the crops face drought at sensitive growth stages, application of supplemental irrigation during this period is the best potential use of limited water supplies.

It is concluded that climate change is now a reality, affecting different agriculture-production systems. To mitigate the effects of climate change on agricultural production and productivity, a range of adaptive strategies need to be considered. Change in cropping calendars and pattern involving some alternative crops and varieties could be the immediate option. Introduction of cropping sequences, late or early-maturing crop varieties based on the available growing season, conservation of soil moisture through appropriate practices and efficient water-harvesting techniques are also important. The long-term strategy should utilize genetic resources to develop heat-and drought-tolerant varieties that could be better adapted to new climatic and atmospheric conditions including greater availability of CO_2. There is thus an urgent need to address the climate change and variability issues holistically. The strategies to address the impacts of climate change on agriculture thus, should be built on the strength of the research results carried out so far. However, new researches are also needed urgently to address some of the issues like impacts of rise in temperature and atmospheric CO_2 levels.

Future thrusts

Considering the scenario simulated by different climate models for Indian subcontinent, it appears that the type and magnitude of changes in climatic variables would be somewhat different from the patterns seen so far. The response mechanism to the climatic pattern, developed by the farmers and the scientific communities for improved adaptation of crops for yield benefits, may not work well to the likely future changes. It is therefore necessary to monitor all the climate parameters at a higher spatial resolution as well as to monitor the changes in terrain parameters, so that the pattern of changes are understood properly for developing likely response mechanism for adaptation and yield benefits. The most crucial research intervention for crop-yield improvement would be to develop *kharif* and *rabi* varieties that can perform well under aberrant or increased temperature and under shorter or shifted rainy season. Agronomic practices, especially for pest and weed management, would need more attention, whereas programmes to control wind erosion might need strengthening. Over a longer time scale, the effects of increased CO_2 might be felt in grain vs leaf yield, as well as in calorific values of food grains, which will require higher research attention. Since the partitioning of the plant biomass would be influenced by the altered levels of CO_2, this will also have implications for food and feed availability, and will require proper estimation of these resources for planning to meet the requirements.

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