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REVIEW

Climate Change and Pulses: Approaches to Combat Its Impact

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Abstract The global climate change and extreme weather fluctuations are the most threatening challenges of this century to agriculture and allied activities. Impact of climate change due to increased intensity and frequency of storms, drought and flooding, precipitation variance, and increase in temperature and CO_2 have serious implications for global food production and food security (IWGCC in Adaptation to climate change in agriculture, forestry, and fisheries: perspective, framework, and priorities, 2013). Agriculture in India will be under severe constraints as the productivity of crops is predicted to depress by 10–40 % by 2080–2100. This will not only put a severe strain on national economy but will also pose a formidable challenge to achieving food security at the national level. Most of the standard climate models predict rise in temperature across the regions where pulses are grown. With rising temperature, the host of biotic and abiotic stresses is predicted to become more severe in terms of their scope and spectrum, and adversely impacting productivity and stability of production of pulse crops. Such a scenario emanating from the climate change presents a veritable challenge to food and feed economy of the country as large population of India is heavily dependent on agriculture for food and income. To meet these emerging challenges of climate change, there is an urgent need for developing policy framework for implementing approaches for mitigation and adaptation to combat adverse impacts of climate change and climate variability on Indian agriculture especially dryland areas which account for 40 % of the total food production of the country. Therefore, a strong institutional support is required to strengthen the existing research system and infrastructure exclusively targeted to rainfed crops like pulses which are more vulnerable to climate change. Crop production management technology involving judicious use of integrated disease and pest management combined with improved agricultural practices may be used to develop integrated packages for pulse crops to ensure sustainable production under adverse impacts of climate change.

Keywords Climate change · Pulses · Impact of climate change · Mitigation and adaptation

Introduction

There is now unequivocal evidence that global climate is changing and it poses the gravest challenge to agriculture and allied activities that are vulnerable to climatic hazards. Due to climate change and associated environmental stresses, agriculture in general and pulses [26, 28] in particular, are likely to be confronted with new forms of risks and uncertainties which have serious implications for global food security. By 2080, the concentration of CO_2 in the atmosphere is accepted to increase to 735 ppm from the present level of 380 ppm and the temperature may rise by 3–4 °C which may result in 10–40 % reduction in crop production in South Asia (IPCC). Though impact of climate change is global, its adverse effects are likely to be more severe under Indian agro-ecological conditions as nearly 60 % of the net area sown in the country is under dryland farming and most of the standard climate models

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predict severe impact of climate change to this sector [21]. The net result of this will be decreased productivity and stability of field crops of dryland farming, particularly pulses which are more sensitive to weather fluctuations and changes. Negative effects of climate change on dryland crops will pose a serious threat of food and livelihood insecurity.

Though global level simulations using climate models can be used with high level of confidence for predicting consequences of climate change, there are difficulties in reliably simulating and attributing the observed temperature changes at smaller scales [11]. Despite limitations associated with the use of climate models, it is widely recognized that regions of South Asia and Southern Africa are particularly sensitive to the impacts of climate change which would be more severe on grain legumes as they are more vulnerable to the negative effects of climate change [25]. In the Indian sub-continent, pulses are grown predominantly as crops of dryland farming and are mostly concentrated in the marginal areas of low rainfall without irrigation or as dry season rotation crops on the receding soil moisture after a cereal crop grown during the kharif season. Particular mention may be made of the adverse effect of early withdrawal of monsoon on the productivity of lentil crop grown under depleting moisture conditions in the Indo-Gangetic plains. In contrast to this decreased yields in pulse crops grown in the rainfed regions of peninsular, India often results from prevailing high temperature during the crop growth period leading to drought particularly when the length of the growing period of long duration pulse crops is likely to get reduced under these unfavorable environments. Under these risk-prone and non-congenial agricultural environments, the emerging climatic changes are likely to impact severely the dynamics of crop production and the country will face difficult task of adapting to this changed climatic scenario. The paucity and erratic nature of rainfall during monsoon season of the year 2012 is the recent example of the emerging climate change and the challenges, and opportunities it provides to the agricultural scientists to develop adaptive measures to increase agricultural resilience with particular emphasis on dryland sector of the arable land of the country. There is an urgent need to develop strategies to overcome the growing threat to dryland crops like pulses and to sustain the potential of crop production under unfavorable and unforeseen conditions. Possible adaptation strategies to offset the negative effects of precipitation variance and increased temperature on grain legumes include crop relocation, changes in sowing date, use of more stress tolerant genotypes, genetic adjustment of crops to increase their tolerance of stress, and intercropping with other crops to lower the risk of total crop failure under adverse conditions [10, 11, 19, 20].

Intergovernmental Panel on Climate Change (IPCC) has reviewed the effects of climate change on crop/food production and risks of hunger in different regions of the world under different climate change scenarios between 1906 and 2005. The average surface temperature of the earth increased progressively by approximately 0.7 °C, with greater part of this increase occurring during the last 50 years [10, 11]. Based on the projections of IPCC, the mean temperature in India is projected to increase up to 1.7 °C in kharif (July–October) and up to 3.2 °C during rabi (November–March) season, while mean rainfall is expected to increase by 10 % by 2070 [8]. Probability of 10–40 % loss in crop productivity in India expected by 2080–2100 is attributed to increase in temperature, variable rainfall and its time of occurrence. and decrease in irrigated water supplies [2]. In fact, the climate anomalies like drought, floods, and changes in precipitation pattern observed during the last decade (2001–2010) are potent examples of weather aberrations indicating growing threat to achieve national food security.

Agriculture being the mainstay of India's large and growing population, any adverse impact on the productivity and stability of crop production due to climate change will have serious implications for national economy, livelihood, and food and nutrition security. Among the food grains, though cereals constitute staple Indian diet, pulses which are rich in dietary protein, are important ingredients in the cereal-based diet of the substantial proportion of the population of the Indian sub-continent. Pulses are also rich source of essential vitamins, minerals, and important amino acids which tend to meet the nutritional requirements of the vegetarians. Leguminous crops differ from cereals because of their unique ability to fix atmospheric nitrogen and thus play an important role in enhancing soil fertility of different cropping and farming systems. By virtue of this property, pulses help in attaining sustainability of production particularly in less intensive agriculture where these crops are often grown.

As compared to other crops, pulses are intrinsically low yielders which make them less competitive to input-responsive cereals and are, therefore, often relegated to less endowed and marginal areas. Range and intensity of abiotic and biotic stresses under these fragile and low fertile soils tend to be more severe. With the emerging climatic changes, probability of prevalence and severity of stress factors are predicted to intensify because of alterations in thermal and moisture regimes and new pathogens and pests might develop [15]. Despite this gloomy outlook, there are reports which suggest that legumes will be less affected by the climate change because of expected rise in nitrogen fixation associated with an increase in CO_2 level [16, 17, 27]. However, the beneficial effects of elevated CO_2 may be offset by negative effects of heat- and soil-related stresses.

Approaches to Combat Adverse Effects of Climate Change

The emerging negative impacts of climatic and environmental changes will put pressure on productivity and production of field crops particularly pulses because they are more sensitive to fluctuations due to climate change and associated factors. For example, between 1965 and 1990, the total production of pulses in the country remained around 12 million tons (MT) with marginal weather-related increases and decreases which ranged between 1.4 and −1.6 MT [30]. More recently, during the decade ending 2010–2011, the annual production of pulses was hovering around 14 MT, mostly because of technological advances including availability of better seeds. However, in the year 2002–2003, pulse production came down to 11.13 MT because of decrease of average annual rainfall from 1100 to 935 mm indicating thereby the importance of weather elements in the productivity of pulse crops. There is a need to develop and implement adaptation and mitigation strategies to alleviate the consequences of climatic changes and climatic variability. Various approaches dealing with the adaptation and mitigation strategies are discussed below.

Government Policies and Initiatives

Climate changes are occurring globally and many countries have either documented the changes or predicted them through climate modeling [10, 11]. Based on these changes and predictions, respective governments of several countries have already initiated policy decisions to combat influence of climate change. To confront the likely adverse effects of climate change, government of India in the year 2008 [26] introduced legislative amendment to overcome the impact of climate change on agriculture and allied activities. Realizing the veritable challenge to arable land due to climate change, Indian Council of Agricultural Research in the year 2010–2011 launched a project entitled "National Initiative on Climate Resilient Agriculture (NICRA)". The NICRA is planned to be a multi-disciplinary project with the main objective for evolving climate resilient agricultural technologies. Two important components of NICRA are as follows: (a) plan and implement strategic research on adaptation and mitigation, and (b) demonstrate climate coping technologies on farmers' fields to combat adverse impacts of climatic variability.

The strategic research under NICRA is being carried out with multi-institutional participation in a network mode covering agricultural crops and allied sectors. Core sets of genetic resources have been assembled and phenotyped in major agricultural crops at different institutions. So far more than 100 promising genotypes in these crops with multiple abiotic stress tolerance have been identified and these will serve as potential parental lines for crop breeding programs. The technology demonstration component is being implemented in 100 climatic vulnerable districts of the country to demonstrate integrated package of proven technologies to farmers to minimize losses due to climatic variability [32]. These policy actions and initiatives are being usefully employed to capacitate farmers to help them to withstand the pressures emanating from the growing threat due to climate change.

Breeding Strategies and Development of New Crop Varieties

To overcome the adverse impact on agriculture due to climate change, plant breeders are required to accelerate efforts to identify/develop germplasm lines/varieties that can withstand or take advantage of climatic anomalies in respect of temperature extremes, moisture stress, disturbed pattern of rainfall, increased CO_2 level, etc. While addressing effects of climate change, resistance to diseases and insect pests is also considered of paramount importance to ensure yield stability. To help achieve these objectives, diverse germplasm lines including wild species should be characterized and evaluated for resistance/tolerance to various abiotic and biotic stresses under appropriate and suitable environments and hot spots of diseases and insect pests. Information relating to genetic resources including wild species resistant/tolerant to abiotic stresses in major grain legumes besides resources of primary, secondary, and tertiary gene pools of these crops have been given in detail [29]. Multiple crosses involving several sources of resistance/tolerance to abiotic and biotic constraints may be used to pyramid desirable genes from many parental lines in one plant. Thereafter screening of segregating populations under stress environments and selecting for multiple-traits would help to pick up desirable segregants possessing better adaptation to climate-related developments [33].

It is imperative to complement conventional breeding approaches with modern biotechnological tools like marker-assisted selection (MAS) to overcome multiple stresses under climate change. Marker-assisted selection program offers better possibility to breed for quantitative traits with low heritability where traditional phenotypic selection is difficult and often lacks precision. In fact, genomic resources developed in major cereal crops have been successfully used in MAS breeding programs leading to the availability of a number of improved cultivars world over for farmers [13]. Of late, considerable progress has been made in the development of genomic resources in several pulse crops like, chickpea, pigeon pea, lentil, common bean, and faba bean [5]. Adoption of genomic information has already resulted in the development of improved varieties/lines/hybrids in several legumes [31]. Soybean is reported to be the first legume crop where MAS was used to develop soybean cyst nematode-resistant lines [7]. Thereafter several reports are available in respect of food legumes where MAS has been used successfully to breed for improved genotypes.

Incorporation of Drought Resistance/Tolerance in Pulses

Pulses are the predominant components of rainfed agriculture where water deficit is the key limitation to productivity. Warmer climate, rising temperature, and solar radiation during crop growth period result in limited water availability to the crop [24]. Water deficit for a prolonged period leads to drought. Terminal drought stress has been identified as the major yield reducing factor in chickpea and lentil.

To mitigate the adverse effects of warmer temperatures, reduced moisture and drought-like conditions which are likely to get intensified due to climate change, plant breeders and plant physiologists will be required to make collective efforts to design the hybridizations and practice precise selection procedures under field conditions. Screening technique for selecting drought-adapted plants is the primary factor to achieve desired results aiming at producing varieties suitable for moisture deficit conditions. This is because special management practices have to be designed and adopted at field level to cope up with the pressure of climate change because of water deficit conditions.

Water Use Efficiency of Crop Plants

The changing pattern of soil water availability and potential evapotranspiration during crop growth are the dominant factors influencing plant growth in the rainfed farming systems. In the context of crop improvement, inter-relationships between water use efficiency, dry matter production and evapotranspiration have been previously reviewed [4]. Across the regions where pulses are grown in India, often the crop suffers from receding soil moisture at the time of planting, and rising temperature and drought during grain development stage resulting in low and unstable grain yield. The severity of pressure on the productivity of the crop plants due to climate change will depend upon the extent of drought stress, the agro-ecologies of the region, and the crop species involved.

Water is the most critical input in any crop production program as it is directly or indirectly involved in all the physiological processes during the life cycle of the plant. Thus, the topic of increasing efficiency of water use by the crop under emerging climate change assumes special importance. It is therefore imperative to develop crop varieties that would have efficient root system for extracting water and for absorption of nutrients from deeper layers of the soil. For example, in case of chickpea, out of more than 1500 genotypes when subjected to field screening for drought tolerance [22, 23], only one genotype ICC 4958 had higher root mass and it gave the best performance at many locations for coping with terminal drought [3, 9]. Potential adaptation strategy to deal with the soil water availability should include changing of the cropping calendar to take advantage of wet period and avoiding adverse weather events during the growing period [8]. Substantial and sustainable improvement in water use efficiency can also be achieved through better crop selection, improved genetic make-up, appropriate cultural practices, and timely socio-economic interventions [18].

Integrated Management Packages for Pulse Crops

Notwithstanding the important role of pulses as human food and animal feed and their contribution in maintaining the productivity of soil through biological nitrogen, they are considered secondary crops being economically less competitive to other major food crops. This is because pulses are intrinsically susceptible to large number of biotic and abiotic factors including diseases, insect pests, drought, temperature extremes, salinity, etc., which prevent the full realization of their yield potential. Improving resistance/tolerance level of these crops against diseases, insect pests, and multiple abiotic constraints would enhance their yield as well as stability.

To overcome biotic stresses, during the last 50 years, focus has been on the use of chemical pesticides and/or host plant resistance. The single-factor management studies to cope up with biotic constraints have often been studied in isolation from other related factors. Instead of single-factor management, there is greater scope to combat biotic constraints through integrated disease and pest management with emphasis on the use of tolerant varieties, biological control in conjunction with appropriate cultural practices. Integrated management package for individual pulse crops based on the judicious use of integrated disease and pest management combined with integrated production management technologies will ensure sustainable crop production [33]. Besides, integrated management packages provide opportunity for combining different technologies including irrigation and weed management, fertilizer management, socio-economic interventions, crop diversification, etc. This practice is in vogue in Australia where integrated management packages are being developed for pulse crops [14].

Conclusions

There is growing realization that climate change is an emerging threat to food production across the globe due to increased incidence of drought, temperature extremes, soil stresses, precipitation variance, and biotic constraints which seriously impact productivity and stability of crop production. The World Bank has projected that climate change will reduce crop yields by 20 % by the year 2050. Though impact on agriculture due to climate change is global, its ramification will be deep in Indian agriculture because of the predominance of the rainfed farming which accounts for nearly 60 % of the net area sown which is highly vulnerable to climate change as drought and heat stress, and incidences of diseases and insect pests are predicted to intensify in the dryland sector. This will impinge on the sustainable development of pulses and other dryland crops which are considered vital for food and livelihood security.

Among the food grain crops, pulses play an important role in the sustainable production system due to their inherent capacity to maintain soil fertility, in addition to their role as rich source of protein in the human food and animal feed. Therefore, pulses have a key role in achieving food and nutritional security while addressing effects of climate change. Notwithstanding the importance of food legumes in maintaining production system and improving ecosystem resilience, global production of food legumes has not kept pace with the increase in global population. Taking into account the medium growth of population in South Asia, the demand of grain legumes in this region will increase by 30 % between 2010 and 2030 [1]. It is indeed a daunting challenge to meet this projected goal as pulses in India are integral part of rainfed farming system where agro-ecologies are highly fragile and small, and marginalized farmers who grow rainfed crops on this degraded resource base primarily depend on low-input agriculture. Yields of these crops get further depressed by host of abiotic and biotic stress factors in these non-congenial and risk-prone environments. Interplay of biotic, abiotic, and soil and environmental related stresses are likely to become more severe in future because of climate change unless resilience of rainfed sector of arable land is improved.

To alleviate the adverse consequences of climate change, there is an urgent need to take strategic decisions for developing policy framework and to adopt relevant approaches to combat and mitigate emerging challenges to Indian agriculture particularly to its dryland sector in which pulses along with other rainfed crops play a vital role in the agricultural production of the country. Any adverse impact of climate change on rainfed farming system will have serious implications for national economy, livelihood, and food and nutrition security. In order to face this veritable challenge, a proactive policy and an institutional support are essential to create research infrastructure on long-term basis specially targeted for dryland sector. To help achieve this objective, trained manpower may be needed with clear mandate to generate appropriate technologies and approaches to meet the emerging challenges of climate change. Better supported and better integrated crop improvement program involving different disciplines will be of paramount importance to screen, identify, and evaluate diverse genetic resources both in domestic and wild germplasm to combat multiple stresses. Negative impact of climate change will ultimately depend on the effectiveness of adaptation and mitigation strategies put in place to counter its adverse effects.

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