Present and Potential Impacts of Changing Climate on Maize-based Cropping Systems in Asia: Strategies for Adaptation

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Introduction

The 20-to-30 year lag in the global climate system means that regardless of any measures that may be taken now or in the future to stabilise greenhouse gas emissions, we are already committed to a warmer world. Global temperature will be, on average, 0.6°C warmer by the end of the century and this will be accompanied by changes in rainfall patterns although the precise nature of this is presently difficult to predict. According to the regional climate analysis given in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2014) for Asia, warming trends and increasing temperature extremes have already been observed across most of the Asian region over the past century (high confidence). Precipitation trends are less clear with both increasing and decreasing trends observed in different parts and seasons of Asia.

Associated with changes in climate, parts of Asia have already experienced a decrease in agricultural yields as a result of rising temperature and weather extremes. There is evidence that climate change is already affecting yields of maize in the region and will continue to do so with predicted losses up to 2080 of, on average, more than -15% (Knox et al., 2012).

In addition to the direct impact of increasing temperatures and changes in rainfall distribution patterns on crop growth, Asian irrigated agriculture is also particularly vulnerable to upstream climate change effects on surface and groundwater hydrological cycles. According to Immerzeel et al. (2010), upstream snow and ice reserves of these basins, important in sustaining seasonal water availability, are likely to be affected substantially by climate change. This will lead to increasing cross-sectorial competition for water and potential for conflict at local, national and transnational levels (Hanjra and Qureshi, 2010).

This paper summarises the key issues relating to climate change and maize production in Asia, by evaluating the evidence that climate is already impacting on yield, predictions of how future climate will change in the coming decades and the implications for maize production. Finally, strategies for adapting maize to both near-term and long-term climate change are discussed.

Evidence that the climate is changing in Asia

The recent IPCC AR5 (2014) report concludes with a high degree of confidence that:

- Mean annual temperature has increased during the past century over most of Asia as have the number of warm days and temperature extremes.
- Across Southeast Asia, temperature has been increasing at a rate of 0.14°C to 0.20°C per decade since the 1960s, coupled with a rising number of hot days and warm nights and a decline in cooler weather.
- Precipitation trends are highly variable with both increasing and decreasing trends observed in different parts and seasons of Asia.

Taking India as a case study, an analysis of data for the period 1901-2009 suggests that annual mean temperature has risen by 0.56°C and has generally been above normal (normal based on the period, 1961-1990) since 1990. This warming is primarily due to an increase in maximum temperature across the country but there has also been a steady rise in minimum temperature (IMD Annual Climate Summary, 2009).

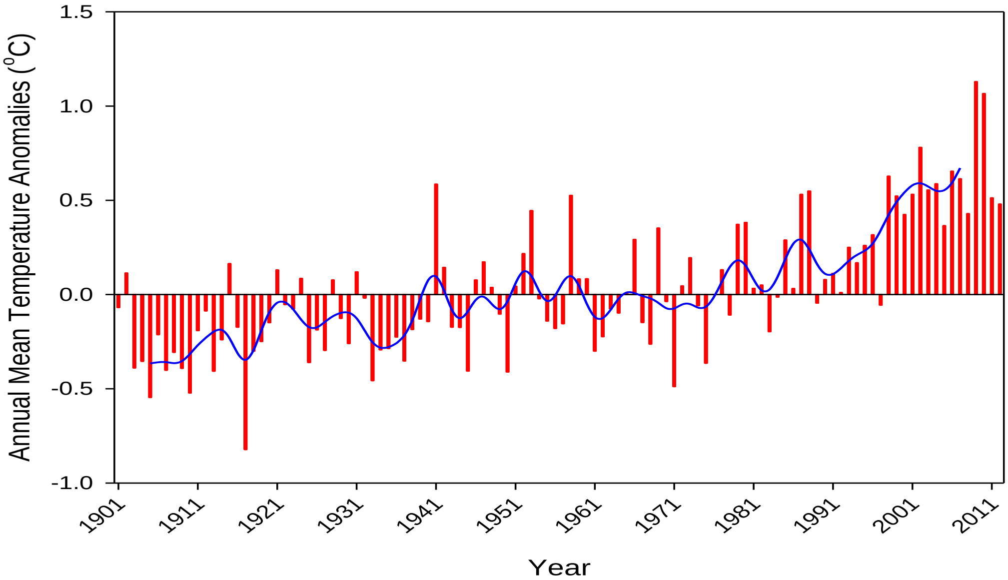

Figure 1. All India differences in annual mean temperature for the period 1901-2012 relative to the average for 1961-1990. Based on CRU TS 3.21 dataset (University of East Anglia Climatic Research Unit (CRU), 2014).

According to Attri and Tyagi (2010), there was no significant trend in either the all-India annual or monsoon rainfall for the period 1901-2009. However, there has been a significant trend towards increased frequency of extreme rainfall ($\geq$ 124.4 mm) during the southwest monsoon season from June to September as well as the contribution of extreme rainfall events (during the same period) to the total rainfall (Figure 2).

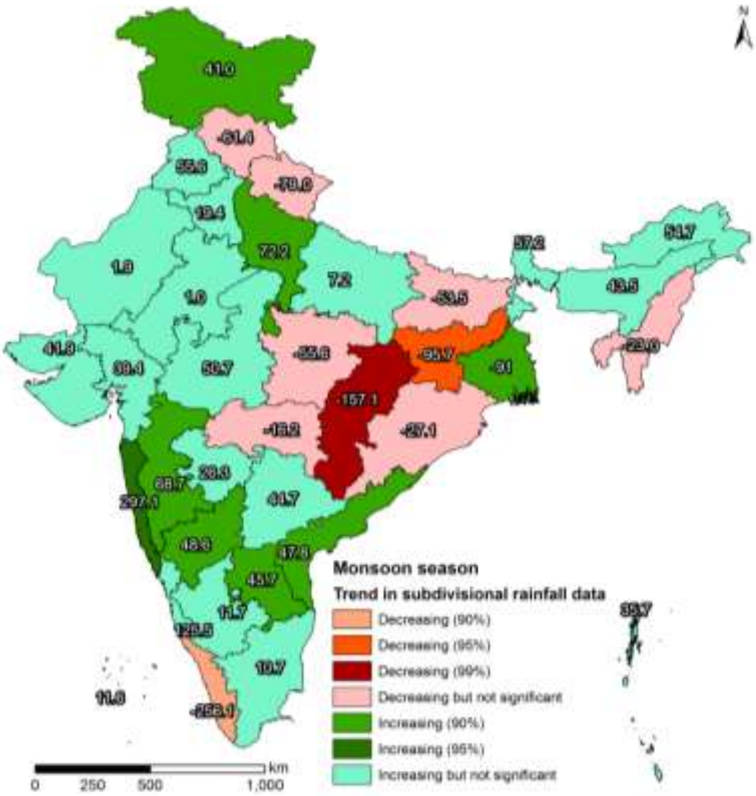

Figure 2. Trend in sub- divisional rainfall data (increase/decrease in rainfall in mm) for the monsoon season (1901-2003) in India. Different levels of significance are shaded with colours. Adapted from Attri and Tyagi (2010).

Evidence that current maize production is being impacted upon by climate change

Understanding past trends in climate and crop production can help, to some extent, determine the scale and location of probable future impacts of climate change and suitable adaptation strategies, at least in the near-term. A global analysis by Lobell et al. (2011b) showed that temperatures had significantly increased since 1980 for most major maize-growing regions and was associated with a global net loss of nearly 4% in production relative to that which would have been achieved in the absence of climate change. In absolute terms, this loss equates to the annual production of maize in India.

The majority of the impact was driven by trends in temperature rather than precipitation, with the latter showing much more variability so that trends were not significantly different relative to natural variability. This finding is consistent with models of future yield impacts of climate change which indicate that changes in temperature are more important than changes in precipitation, at least at the national and regional scales (Lobell and Burke, 2008; Schlenker and Lobell, 2010). However, increasing intra- and inter-season rainfall variability has major negative livelihood implications for rainfed smallholder farmers (Cooper et al., 2008; Thomas et al., 2007).

In Figure 3, historic data sets and statistical modelling approaches were used to construct the relation between average growing season temperature and average yield for individual countries over the past two decades (Lobell and Gourdji, 2012) . The size of the symbol indicates the relative contribution to global maize production so that the USA has the largest followed by China. There is a clear tendency for yields to decline above the optimum temperature which is about 20°C for maize. Also evident from the figure, is that all of the largest producers of maize have average season temperatures that are above the optimum. Even though warming would likely benefit countries to the left of the optimum, total global production will tend to decrease from warming. For a 1°C warming, yield losses in the tropics vary from a few percent for crops that are currently growing near their optimum, to as much as 10% or more for crops growing well beyond their optimum. There are many reasons for temperature-related yield losses; maize is particularly sensitive to hot daytime temperatures, with rapid losses when temperature exceeds 30°C (Challinor et al., 2014; Lobell et al., 2011a; Schlenker and Roberts, 2009).

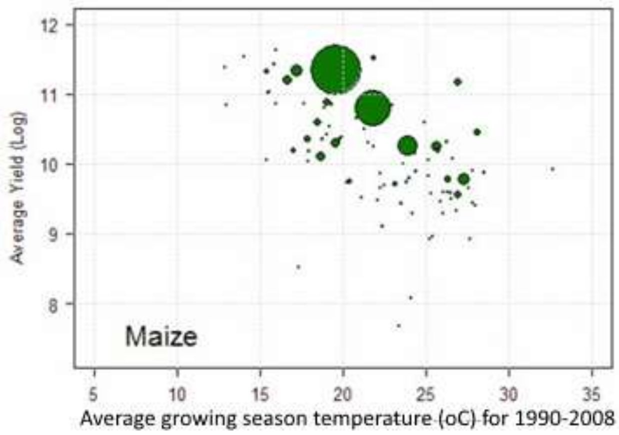

Figure 3. Average yield of maize, per country, for a range of average growing season temperatures. Size of dots is scaled to total production of country (Source: Lobell et al., 2012).

Predicted impacts of climate change on future maize production

Despite impressive growth in the last decade, the average maize yields in many Asian countries still remain low compared to the global average of 5.02 t/ ha^{-1} in 2012. Countries with a sizeable maize area but that produce less than 3 t/ha^{-1} yields include India, Indonesia, Philippines, Pakistan and Nepal, while Vietnam and Thailand have recorded maize yields in the range of 4-5 t/ha^{-1} in 2010. China recorded an average yield of 5.33 t/ha^{-1} in 2010. Maize is grown throughout China but more than 60 percent is produced in temperate, high-potential environments in the north and the rest is grown in the sub-tropical and tropical environments of the south. Drought is recognised as the most important constraint across the rainfed lowland and upland environments, accounting for about 70 percent of the maize production area in Asia. This situation is likely to become worse in the coming decades due to climate change leading to inadequate and/or uneven distribution of rainfall during the growing season along with changes in temperature (IPCC, 2014).

It is predicted that by the end of the century, growing season temperature will exceed the most extreme seasonal temperatures recorded during the past century (Battisti and Naylor, 2009). Using CIMMYT data from more than 20,000 historical maize trials in Africa, combined with daily weather data, Lobell et al. (2011) it is estimated that each degree day above 30°C reduced the final yield by 1 percent under optimal rainfed conditions and by 1.7 percent under drought conditions.

Warmer temperatures and more frequent exposure to high temperature events are the major drivers of yield loss with climate change. In maize, this can be mainly attributed to:

- More rapid crop development: Warmer temperatures will reduce the size and duration of organs, and consequently resource capture (light, water and nutrients) and assimilate production for growth and grain fill.
- Reproductive failure: High temperatures can harm crop growth at different stages of development, with reproductive tissues being the most sensitive to damage by heat stress.
- Harmful effects of daytime warming: High temperature damage to maize yields is associated with increased pollen sterility.

Knox et al. (2012) undertook a systematic review and meta-analysis of the projected impacts of climate change on crop productivity in Africa and South Asia over a range of time scales. The impact of climate change on productivity was expressed as the ‘productivity impact’. This was calculated as the projected yield for a given future scenario expressed as a percentage change against current, or baseline, yield. Figure 4 summarises the projected climate impacts by crop type for S. Asia (southern and southeast) where data included both biophysical-based crop modelling studies and statistical studies using GCM climate projections. The significance of the mean yield reduction, compared to zero change, was tested using Student’s t-test. Overall, a mean yield reduction of <8% was observed for S. Asia, with significant reductions projected for maize (<7%), wheat (<12%), sorghum (<3%) and millet (<9%). However, when the data were broken down by time scale, only projections beyond the 2050s for maize were found to be significantly different from zero.

Strategies for adapting to climate change

Farmers have always faced challenges with variable weather and have continuously adapted in order to survive. As weather becomes increasingly variable and more extreme with climate change the scale and pace of adaptation required is likely to be without precedent. Currently and in the near-term, farmers are likely to 'autonomously' adapt to climate change, a term referring to incremental change in existing systems such as adjusting practices and technologies in response to perceived or real climate change. More extreme changes in climate will require systems adaptation (e.g. changes in production systems, introduction of new crop types, precision agriculture) and ultimately transformative adaptation which may involve uptake of new products (e.g. development of new crop varieties such as water-efficient maize) or changes in land use with the extreme being moving out of agriculture. Transformative change is proactive by nature and includes long-term investment in research and changes in policies, institutions and infrastructure to bring about broader system changes.

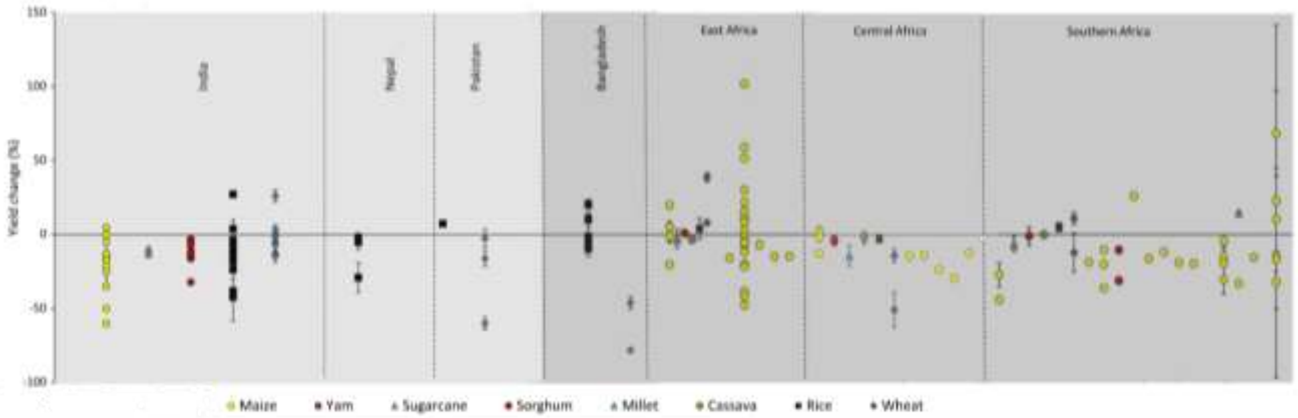

Figure 4. Summary of reported mean yield variations (%) in South Asia and Africa. Data are shown for all observations for each crop type, for all crop modelling approaches, all GCM climate models and all timescales. Where published the confidence intervals for specific studies are shown. Adapted from Knox et al. (2012).

Incremental adaptation to climate change

When it comes to near-term adaptive responses, many of the management-level adaptation options available to farmers are largely extensions or intensifications of existing climate-risk management options or yield enhancement activities that have been developed over the past decades in response to climate variability. Significant advances can be made in improving farmers' adaptive capacity in the near-term through the systematic raising of awareness and knowledge of the most appropriate adaptive measures for their circumstances. This raising of farmer awareness forms a central part of CIMMYT's work under the Climate Change, Agriculture and Food Security (CCAFS) project, in which we are working with farmers and national partners to try and test a combination of climate-adapted practices in different agro-ecologies. These near-term adaptive responses are generally achieved at the farm level and do not involve other sectors (e.g. policy, research, etc.) in their development and implementation.

There are a number of changes that farmers can make, and there is evidence that in some regions they are already making in response to changes in climate. The most relevant in relation to maize growers are:

- Altering the timing of cropping activities (e.g. planting date) to better match shifting seasons.
- Changing to varieties with increased resilience to high temperature, drought and/or flooding.
- Shifting to early or very early maturing varieties to balance shorter and/or drier seasons.
- Increasing use of weather forecasting to reduce production risks.
- Replacing water-demanding crops such as rice (and to a lesser extent wheat) with maize in areas where water scarcity is increasingly a problem.
- Adopting sustainable land use practices including conservation agriculture.

The above farm-level responses have the potential, if widely adopted, to offset to some extent, the negative impacts of climate change in the near-term and under scenarios of low-to-medium temperature increases (i.e. up to a 2°C increase in local temperature) and can be viewed as 'buying time' according to Howden et al. (2007).

The following provides some examples of autonomous near-term adaptation responses available to maize growers.

Changing varieties and planting date

The IPCC (2014) states that there is medium confidence that optimisation of crop varieties and planting date are effective adaptations to climate change, increasing yields by up to 23 percent compared with current management practices and when aggregated across studies. Shifting planting dates is a useful adaptation to ongoing climate change and particularly in the case of temperate maize where cool temperatures can often limit germination and growth. In a recent study by Tao et al. (2014) they found that for the period 1981-2009, the planting date of maize had been advanced significantly at 26 percent of the 112 experimental stations located across China. Their results indicated that maize production is already adapting to ongoing climate change with a shift in both planting date and an increased in adoption of longer duration varieties.

In tropical rainfed maize production systems where planting is typically limited by moisture rather than temperature, it is less clear that shifts in planting date will be effective against the damage caused by climate change mainly because climate change is expected to decrease the length of the growing season.

Crop diversification towards maize

High temperatures during grain filling of wheat, particularly in eastern India, declining yield of *Boro* rice in West Bengal and Orissa and water shortages in India affecting yield of *Rabi* rice have in recent years seen more farmers in India diversifying away from rice, and to a lesser extent wheat, towards maize which has the potential to yield better under sub-optimal conditions. This has led to the development of several maize-based systems in non-traditional maize ecologies. For example rice-maize (ca. 0.5 m ha) has emerged as a potential maize system replacing winter rice in water scarce areas of double rice ecologies. Maize is also replacing wheat in terminal heat-prone shorter wheat season ecologies. Recent studies by CIMMYT have shown that substituting rice with zero till maize in a rice-wheat-mungbean system resulted in 88-95 percent less irrigation water use and with no penalties for profitability (Gathala et al., 2013). Direct seeded rice or mechanically transplanted rice also offer significant water savings (Humphreys et al., 2005).

Precision agriculture

The current research efforts to develop new crop varieties that require less water and fewer inputs (see section below) must be complimented with the full range of agriculture innovation and technology. Some elements of precision agriculture are already available to farmers in the form of equipment such as the laser-assisted land leveller, which offer a means of improving production without placing increased pressure on limited natural resources. The Laser-Assisted Precision Land Levelling (LLL) can be seen as a precursor technology which improves the performance of a number of other climate-smart technologies. When land is flood-irrigated, any undulation in the soil surface can seriously reduce both water and land productivity. The exceptionally flat surface achieved through LLL has three main advantages:

1. Increased productivity and profitability through improved crop establishment, reduced weed infestation, improved uniformity of crop maturity, decreased time requirements, reduced volume of water for land preparation, improved crop yields, increased cultivated area (due to elimination of bunds), and reduced water requirements for irrigation.
2. Significantly reduced water requirements thereby improving the conservation of natural resources and climate change adaptation.
3. Reduced greenhouse gas emissions from decreased pumping of irrigation water thereby contributing to mitigation of climate change.

LLL is more beneficial to crops such as maize that are sensitive to excess water/soil moisture and where furrow irrigation is used as a more uniform application can be achieved. Studies have shown that 30-50 percent of water can be wasted when land is poorly levelled (Ahmad and Tinnermeier, 1974; Jat et al., 2006). In South Asia, the estimated area under laser levelling (irrespective of crops) is nearly 3.5 mha (Jat et al., in prep.).

Conservation agriculture

Rising concern over natural resource degradation, mainly soil and water, and the need to maximise profits has led to increasing interest in conservation agriculture-based practices such as no-till and permanent raised beds with residue retention and crop rotation. No-till is now being widely used by farmers in many parts of the world to reduce soil erosion, save costs and improve soil health. Permanent raised beds have traditionally been associated with water management issues, either by providing opportunities to reduce the adverse impact of excess water on crop production or to irrigate crops in semi-arid and arid regions (Bhushan et al., 2007; Connor et al., 2003; Gathala et al., 2011; Sayre and Hobbs, 2004).

Recent studies by CIMMYT, on the effects of tillage, residue management, legumes and nutrient management, indicated significant gains in terms of nutrient use efficiency, productivity and economic returns from site-specific nutrient management (SSNM) and conservation agriculture (CA) (Figure5). CA-related benefits in terms of improved nutrient use efficiency and reduced energy and labour costs through no till (Jat et al., 2014) have clear benefits also in terms of climate change and most particularly in terms of mitigation of greenhouse gas emissions (Sapkota et al., 2014).

Although the potential benefits on soil water balance have been the basis for promoting CA as a technology to cope with a changing climate (Verhulst, 2011), a recent meta-analysis of CA studies in Sub-Saharan Africa found no convincing evidence of improved CA

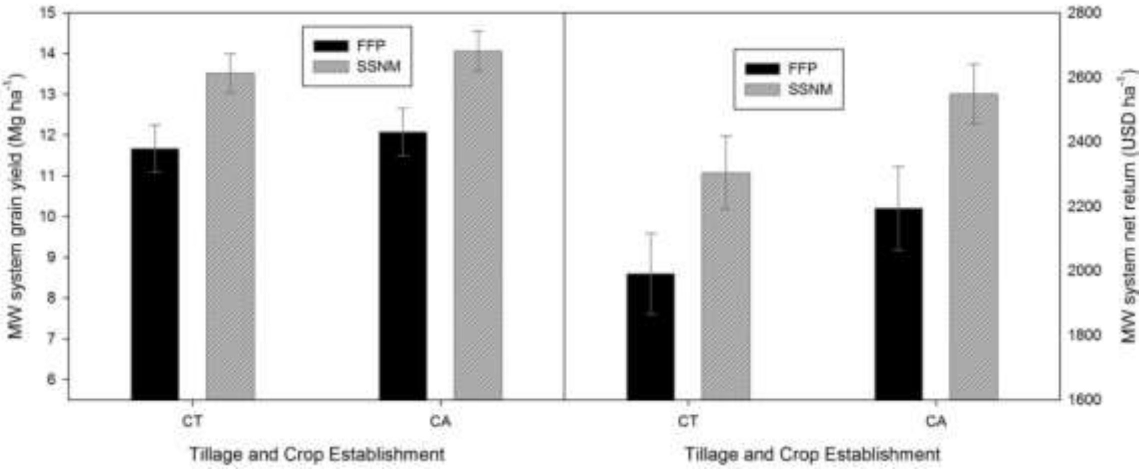

Figure 5. System grain yield (top) and net returns (bottom) of a maize-wheat (MW) system under different tillage, residue and nutrient practices where: CT - Conventional till ridge seeding of maize, rotavator tillage broadcast seeding of wheat. CA - Both maize and wheat on permanent beds, retaining 50% maize straw, retain of wheat stubble after straw retrieval, retaining all green gram residues. FFP - farmer practice involving removal of all maize residues, removal/burning of wheat stubble after straw retrieval. SSNM - Site specific nutrient management using the Nutrient Expert DSS for maize and wheat.

performance under low versus wetter rainfall conditions (Corbeels et al., 2014). However, importantly, the study found less variation in productivity under no-tillage systems with rotations compared to the other systems without rotation suggesting that crop yield was more stable with the use of crop rotations. This implies that CA (including crop rotation) serves as a potentially important means of adapting to more variable and extreme conditions associated with climate change.

Planned, long-term, adaptation to climate change

Incremental adaptive changes are unlikely to be sufficient to cope with extreme weather events and long-term systematic planning will be required to ensure the timely delivery of climate-adapted technologies. In terms of practices and technologies, the ones that are likely to bring the greatest benefits are new crop varieties and access to improved technologies and infrastructure (e.g. irrigation).

Developing new 'climate-adapted' varieties

In terms of new climate-adapted maize varieties, some of the most valued traits will be tolerance to drought and heat. Compared to other abiotic stresses associated with climate change, the development and deployment of heat stress-tolerant tropical/subtropical maize is still in its infancy. A recent study by the CIMMYT Global Maize Program, in collaboration with partners worldwide, has shown that tolerance to drought and heat stress in maize is genetically distinct from tolerance to individual stresses, and tolerance to either stress alone did not confer tolerance to combined drought and heat stress (Cairns et al., 2013). This has important implications for breeding as current tropical/subtropical maize germplasm developed for drought tolerance may not perform well under drought stress at high temperatures. Indeed, studies by the CIMMYT-Asia team (Zaidi, 2014) have shown that most of the tropical maize germplasm, including commercial cultivars in South Asia, are highly vulnerable to heat stress during the reproductive stage. Some promising lines with tolerance to high-temperature stress (coupled in a few cases also with drought tolerance) have been identified among the Asian-adapted maize germplasm for further evaluation and utilization. CIMMYT is implementing two major research projects, supported by USAID, for developing and deploying heat-resilient maize in Sub-Saharan Africa and Asia.

A recent study by CIMMYT assessed the biophysical impact of heat-tolerant maize varieties in South Asia and results showed that while all maize growing areas in South Asia will experience an increase in temperature in the near future, areas in South India, North West India and Southern Pakistan will experience the highest increase and this is where the largest yield losses will occur (Figure 6). Preliminary simulation results indicated that heat-tolerant maize varieties (simulated by increasing the temperature tolerance of existing calibrated varieties by 2^{o}C) could provide a yield advantage of 16-35% over that of conventional ones and the benefit from heat tolerant varieties increased with the degree of heat stress (Figure 6).

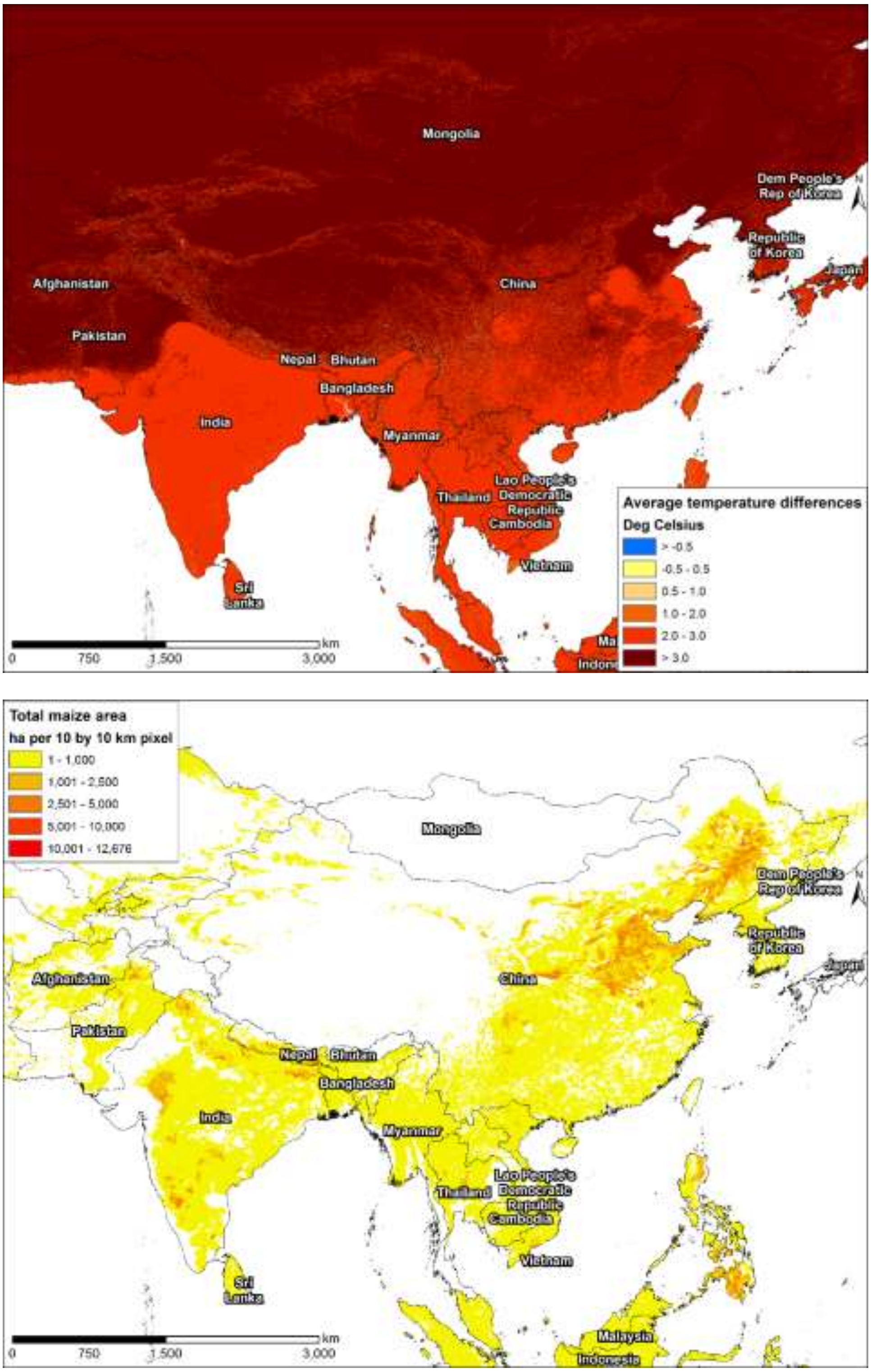

Figure 6. Maize growing areas (top) and predicted changes in maximum air temperature in 2050, compared with a baseline of 2000 in China, South-East Asia and South Asia. Maize growing areas based on SPAM dataset (You et al. 2012). Temperature changes for RCP 8.5 using an ensemble of 32 models for the 2050s compared to current baseline (1950-2000). Future models downscaled data from http://www.ccafs-climate.org/ (downscaled according to Ramirez-Villegas and Jarvis, 2010).

Perennial maize

Although still a rather distant goal, there are potentially many advantages to developing a perennial maize crop to address issues of climate change and sustainable intensification. Unlike annual crops which suffer from many negative externalities including high input costs, soil erosion and a limited growing season, perennial crops would increase production, reduce soil erosion and planting costs through increased vegetative cover over a longer growing period (Cox et al., 2006; Glover et al., 2012, 2007). Furthermore, the expanded root architecture of perennial crops could increase soil sequestration of carbon and increase access to water and nutrients among many other benefits (Pimentel et al., 2012).

The need for integrated multi-scale and multi-stakeholder approaches

Technical and agronomic options to adapt to climate change and climate variability must be framed in a wider context. In addition to climate, many drivers of change are shaping the evolution and dynamics of farming systems (Herrero et al., 2010) and explicit understanding of the concomitant impact of those drivers are required to develop adapted technical interventions, set future research priorities and develop more resource-friendly policies and subsidy schemes. Technical innovations need to be integrated and adapted to specific bio-physical, socio-economic, institutional and policy environments. There is clear need in the region to sustain/increase research investments in multi-disciplinary, multi-scale systems research. Multi-scale analysis would support concerted actions toward better targeting plant-field-farm-landscape-regional alternatives and improve the robustness and adaptive capacity of cereal-based farming systems in South Asia (Lopez-Ridaura and Gérard, 2012).

Conclusion

A review of the evidence suggests that climate change is already impacting yields of maize throughout Asia. In general, the effects of climate change on maize yields are, and will continue to be negative unless major steps are taken to adapt at the farm and landscape levels. As discussed, many of the options available for adaptation to climate change in the near-term comprise extensions or intensifications of existing management options aimed at reducing climate risk or increasing yield/profitability. The focus of effort here should be on raising farmers' and extension workers' awareness and knowledge of suitable options and adapting them to local conditions. In the longer term, more radical measures will be needed that will involve biophysical (e.g. development of new climate-adapted maize varieties that are heat- and drought-resistant), infrastructural (e.g. provision of irrigation), socio-economic, institutional and political (e.g. joined up policies that impact positively on both food security and protection of the environment) transformations.

Transformative change extends well beyond the bounds of a single cropping system or even a sector and will require a degree of coordination and planning that will, in itself, be transformative. The contribution that maize research can make to this global effort will be in the use of the best available climate information to plan and develop climate-adapted germplasm and its precision management in the field.

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