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Food Security and Climate Change: Evaluating the Mismatch between Crop Development and Water Availability

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Introduction

Plant breeding and crop selection involves optimizing yield for different agro-ecological zones. Soil and climatic parameters are the major matching factors, with temperature, photoperiod and water availability being major climatic factors influencing crop adaption and productivity. Under climate change scenarios, it is proposed that average temperatures will increase while there will be changes in both the amount and distribution of rainfall. Because of these changes, it is probable that mismatches will arise between crop phenology (the growth stages of the crop) and environmental factors, resulting in yield decreases. This will occur through, for example, water or temperature stresses at critical periods of crop yield determination (Huda *et al*., 2011; Mei, 2005; Sadras and Monzon, 2006; Goswami *et al*., 2006 and Wani *et al*., 2008).

A project has been developed with APN ARCP funding to examine mismatches between crop phenology and climate (particularly water availability) arising from recently realized climate trends and proposed climate change. Research collaborators are UWS and South Australian Research and Development Institute (SARDI), International Crops Research Institute for the Semi Arid Tropics (ICRISAT), and Chinese Academy of Agricultural Sciences (CAAS). The project commenced in September 2010 and major coordination activities have been workshops in China, India and Australia to plan and achieve the desired project research outcomes.

Possible mismatches arising from realized warming were the subject of the project planning workshop, held in Beijing in September 2010. The workshop designed case studies in China, India and Australia, and realized a significant input to the project that would be made by young researchers in China and India. Strategies have been developed to enhance capacity building of these researchers during the project, including their involvement in the final project workshop in Australia.

Research approach

Research is focussing on crops of local importance including rice, wheat, sorghum, soybean, groundnut and chickpea at key sites. The Australian research is based on six sites along a north-south transect representing the range of environments for wheat growing in eastern Australia. Rainfall varies from summer dominant in the north (about 23° south) to winter dominant in the south (about 36° south).

In India there are two sites in semi-arid to sub-humid climates (600–1200 mm rainfall per year), coinciding with World Bank projects to rejuvenate tank storage for irrigation, to maximize runoff to tanks during excess rainfall and to improve in-field water management. Sites are at Dharwad in Karnataka state and at Guna in Madhya Pradesh. Dharwad is in the southern part of India and Guna is in the central part. The two regions have different annual rainfall but similar soil type. In Dharwad, annual rainfall is 600–750 mm while in Guna it is 1000–1200 mm, and the soil type is vertisol (heavy cracking clay soil) in both regions. Crops grown at Dharwad are sorghum, soybean, groundnut and chickpea.

In China, research is covering some 72 winter wheat-growing sites on the Huang-Huai-Hai (3H Plain) in Central China, with monitoring of climate and crop growth over the period 1971–present. The growth data of winter wheat involved in this study includes sowing stage, returning green stage, jointing stage, heading stage and maturity.

Methodology is mainly based on the use of cropping systems simulation models to analyze crop growth and yield under existing and predicted climates in the three countries. However, in India, this analysis is complemented by field studies of different water management technologies, while in China climate and phenology data for field monitoring sites is available for the period 1971–present.

Some Preliminary Results

India

Some data is presented for two cropping systems in Dharwad, Karnataka (soybean-chickpea and groundnut-sorghum). As can be seen in Figure 1, yields of different rainy season and post-rainy season crops vary significantly from year to year with, for example, groundnut varying from 0.4–1.1 tonne/ha. Computer simulations were carried out using the DSSATv4.5 model for the present climate (P), and for a number of future scenarios based on climate change predictions. These scenarios were increased average temperature of +1, +2, and +3 °C individually and coupled with a 20% increase and 20% decrease in rainfall.

In Dharwad, groundnut showed no response in days to flowering to increasing

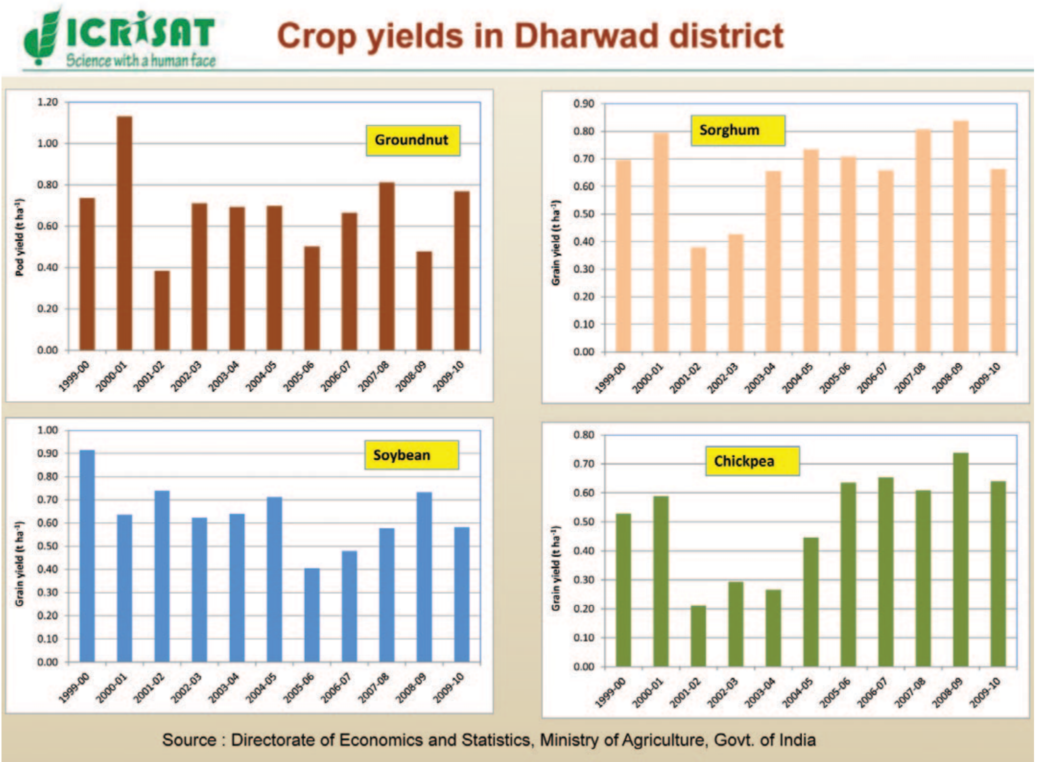

Figure 1. Yields for four crops in the last eleven years at Dharwad, Karnataka

temperature or low rainfall while flowering to maturity duration was reduced from 81 (P) to 78 (P+3) days. Sorghum maturity duration was reduced with warming. Flowering was reduced from 67 days (P) to 57 days (P+3) and flowering to maturity was reduced from 41 days (P) to 35 days (P+3). In both crops, addition and reduction of rainfall did not show any prominent effects on phenology. In the soybean-chickpea system, warming coupled with low rainfall decreased crop duration markedly for soybean by reducing both stages; flowering by 4 days and flowering to maturity by 5 days. In chickpea, warming and rainfall did not show any effect on time to flowering, while warming coupled with low rainfall reduced flowering to maturity from 39 days (P) to 36 days (P+3, -20% RF).

Increased temperature decreased simulated yields of the crops in both cropping systems, and warming coupled with low rainfall increased the reduction. The impact of temperature and rainfall was more pronounced on the soybean-chickpea system and hence, the groundnut-chickpea system is likely to perform better in a changing climate compared with the soybean-chickpea system.

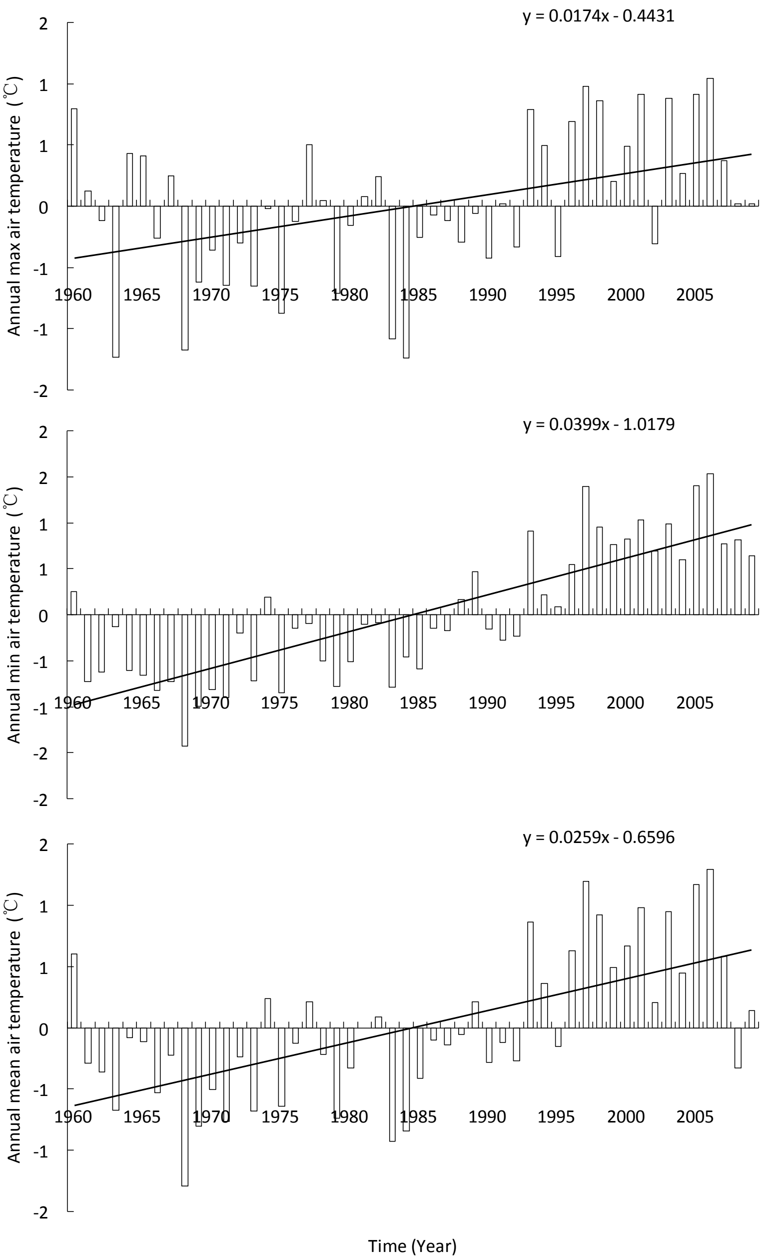

Figure 2. Annual trend in anomaly of max, min and mean air temperature during the period 1961–2010 in 3H Plain in China

China

The Chinese work to date has concentrated on analysis of a significant data set on realized changes in climate and crop growth over the last 40 years. The max, min and mean air temperature increased by 0.17°C, 0.40°C and 0.26°C per decade, respectively, during the 1961–2010 in the 3H Plain, as can be seen in Figure 2. We can conclude that the rate of increase in minimum temperature is greater than that of maximum temperature. There was no significant change in rainfall over the period.

Between the two periods 1971–80 and 2000–2010, rainwater deficit in the period between heading and maturity stages increased by about 15 mm. This phenological stage is important in yield determination, so more attention should be paid to supplementary irrigation in this period, provided that it is available.

Australian Case Study

APN funding was used strategically to link with a larger initiative led by Dr. A. Potgieter (University of Queensland) with the collaboration of colleagues from the Tasmanian Institute of Agriculture Research (H. Meinke), University of Queensland (A. Doherty, G. Hammer, D. Rodriguez) and CSIRO (S. Crimp).

We used OzWheat, a shire scale dynamic stress-index model that accounts for the impacts of rainfall and temperature on wheat yield and a range of climate change projections from CSIRO Cubic Conformal model (CCAM). We modelled five scenarios;

a baseline climate (climatology, i.e. 1901–2007), and two emission scenarios, i.e. "low" and "high" CO_2 for two climate projections of 2020 and 2050. These projections did not account for CO_2 effects on crop growth.

The potential benefits from CO_2 fertilization were analyzed using the daily-time step model APSIM in a latitudinal transect in eastern Australia. Locations were Emerald (23°31'25.05" S, 148°9'31.61" E), Dalby (27°11' S, 151°16' E), Moree (29°27' S, 149°50' E), Dubbo (32°11' S, 148°35' E), Wagga Wagga (35°07' S, 147°20' E) and Corowa (35°59' S, 146°23' E). These locations represent a transect of increasing yield potential as driven by the gradients in total radiation, proportion of diffuse radiation, temperature, vapour pressure deficit and rainfall patterns.

Flowering time was advanced by increasing temperature up to 15% relative to the baseline. Under the worst case scenario, in-season crop rainfall was reduced by 12–15% whereas off-season rainfall was reduced by 5–10%. The differential trends for in-season and off-season rain, together with the shifts in phenology, suggest a mismatch between projected climate trends and crop development, which are likely to be relevant for yield.

Irrespective of the emissions scenario, the 2020 projection showed negligible changes in the modelled yield relative to baseline climate, both at the shire or point scale levels. For 2050-high emissions scenario, changes in modelled yield relative to the baseline ranged from negligible (-5%) to +6% in most of Western Australia, and parts of Victoria and Southern New South Wales; and from -5% to -30% in northern New South Wales, Queensland and the drier environments of Victoria, South Australia, and in-land Western Australia (Figure 3).

Carbon dioxide fertilization effects across a North-South transect through eastern Australia cancelled most of the yield reductions associated with increased temperatures and reduced rainfall by 2020, and attenuated the expected yield reductions by 2050.

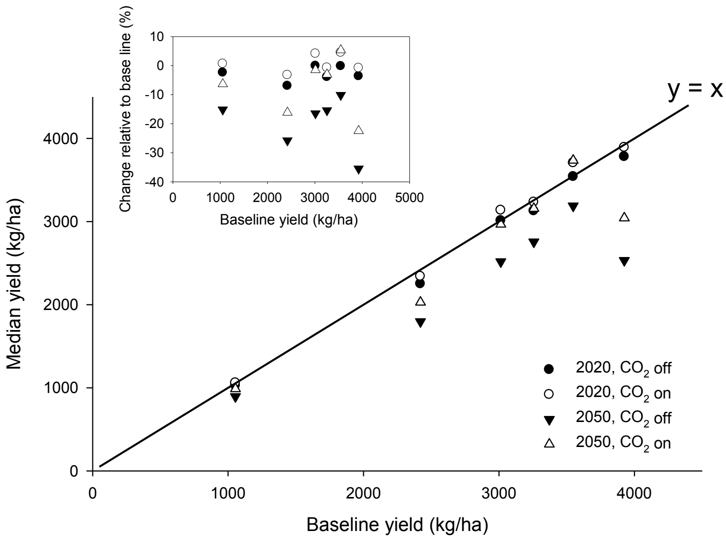

Figure 3. Baseline and median yield data for selected locations and scenarios for Australia

The Hyderabad workshop

The second workshop of the project was held at ICRISAT, Patancheru near Hyderabad, India from 9–13 January, 2012 (Figure 4). Unfortunately, due to visa

Figure 4. Meeting of APN project partners at ICRISAT, Patancheru, India, 9–13 Jan 2012

problems, the Chinese collaborators were not able to attend. However, their paper was provided and they were available electronically during the Workshop. They will also be contributing to the further development of project plans discussed at the workshop. Major outputs of the workshop were paper structures for comparative case studies and strategies to involve young researchers from India and China to complete and present project outputs.

As part of the workshop, we undertook a two-day field trip to the University of Agricultural Sciences, Dharwad and to one of the project field sites some 15 km from the city (Figures 5 to 8). As mentioned earlier, the catchment tank management project is funded by the World Bank. The project has a range of strategies to improve the efficiency of water use, including repair of tanks and other hydrologic structures, and demonstrations of improved agronomic practices.

The strategies are therefore consistent with those required for adaptation to water shortages and excess arising from climate change. Significant rising trends in the frequency and the magnitude of extreme rain events (> 100 mm per day) and a significant decreasing trend in the frequency of moderate events over central India during the monsoon seasons from 1951 to 2000 were observed (Goswami *et al.,* 2006). The seasonal mean rainfall does not show a significant trend, because the contribution from increasing heavy events is offset by decreasing moderate events. This creates threats of waterlogging, but also increased opportunities for off-field storage in village tanks.

Day-to-day decisions regarding new local infrastructure and fair allocation of water are made by a village-based "Tank Users Group". Women's Groups are also associated with the project, and they provide small loans for medical, educational and agricultural purposes.

In addition to these operational strategies, the University of Agricultural Sciences, Dharwad and ICRISAT are collaborating in field research on improved in-field water management. The research is part of the PhD studies being undertaken by two students from the University of Agricultural Sciences, Dharwad. Bed and furrow management systems and crop residue retention have increased profile water storage and soil organic carbon. The students, supported by the Model watershed project funded by the Government of India, are contributing to fulfil the objectives of the current APN project.

Figure 5. Interaction of APN Project team with Women's self-help group, Catchment management project, Dharwad

Planned Project Outputs

Three types of outputs are envisioned:

1. Papers for different countries will present comparative case studies. The papers will address the following questions:

In the past:

- What are the realized long-term climate trends (particularly rainfall and temperature?)
- What observed effects have these trends had on crop phenology or productivity?

And in the future:

- What models/scenarios are being used to predict future climate scenarios?
- Using these predictions, what are the expected temporal shifts in crop phenology under future climate scenarios?
- What are the likely shifts in the pattern of rain and water availability?
- To what extent will climate change contribute to any mismatch between crop phenology and water availability?
- What are the expected consequences of this mismatch for food security?
- What adaptation strategies and policies can be developed to build the resilience of communities and natural resources?

Information on strategies can only be general at this stage, since some proposed strategies will require field testing, which is beyond the scope of this project. Strategies will include use of different crop varieties to avoid water and temperature stress, moving growth of a given crop to another more suitable geographic area, landform treatments, integrated water management, and watershed management to remove excess water during wet periods and store in tanks for later use.

2. Young researchers trained in report preparation and presentation. As part of this strategy the young researchers will carry out literature reviews of past work for India and China under the key words "climate change, crops, India/China". They will also be actively involved in the writing up of country case studies, with local and Australian senior researchers acting as mentors. Finally the young researchers will visit collaborating institutes in Australia and will be involved in the final project workshop.

3. Increased international collaboration and proposals for future collaborative research.

Figures 6 and 7. Group photographs of project team in field at Dharwad

Figure 8. PhD students from an Agricultural University discuss issues with farmer cooperator

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PROJECT TITLE

Food Security and Climate Change in Asia-Pacific Region: Evaluating Mismatch between Crop Development and Water Availability

COUNTRIES INVOLVED

Australia, China, India

PROJECT DURATION

2 years

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