APN
Asia-Pacific Network for Global Change Research

FINAL REPORT for APN PROJECT

Project Reference Number: ARCP2011-08CMY-Huda

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

The following collaborators worked on this project:
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Final Report submitted to APN

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OVERVIEW OF PROJECT WORK AND OUTCOMES

Non-technical summary

Crop adaptation to environmental stresses is central to sustainable agriculture. In eastern Australia, central India and China temperature has increased over the past 40 years. Cropping systems and varieties are designed so that water availability and crop water requirements are well matched, and crops are not exposed to extreme temperature and water supply conditions during critical crop development phases. Mismatches between crop and environment occur when the critical period of crop yield determination coincides with stressful conditions. Possible mismatches arising from realized and predicted warming are the focus of this project.

Project activities have been of three types:

- Workshops in China, India and Australia to plan and monitor technical activities, and to ensure that project outcomes were achieved
- Case studies in the three countries to allow us to draw conclusions on similarities and differences in the responses of cropping systems to realized and in some cases predicted climate change, and
- A specific Early Career Researchers' Program for professional development within the project.

The project demonstrated that, in some cases, the effect of regional warming can be positive, for example in northern China where the extended growing season leads to increased productivity in the winter wheat-maize system. We also identified examples of adaptation such as supplementary irrigation, breeding new varieties with better adaption to the new Climate, or concentrating agriculture in areas more suited following Climate Change.

Objectives:

The main technical objectives of the project were:

1. To determine expected temporal shifts in crop phenology under realized climate change and future climates
2. To assess likely shifts in the pattern of rain and water availability
3. T estimate elements of climate change that will contribute to any mismatch between crop phenology and water availability, and

~~4.~~ To evaluate expected consequences of this mismatch and other shifts associated with climate change for food security

Amount received and number years supported

The Grant awarded to this project was:
US$ 59, 643 for Year 1:
US$ 59, 700 for Year 2:

Activity undertaken

a) **Case studies in China, India and Australia**:

Australia

In Australia, APN funding contributed to two separate Case Studies. In both studies, cropping systems simulation models were used to assess the effects of climate on crop growth, water stress and yield. One study concentrated on realized Climate Change, and the other on predicted Climate Change up to the year 2050.

China

In China, APN funding also contributed to two separate Case Studies. In both studies, cropping systems simulation models were used to assess the effects of realized climate on crop growth, water stress and yield. To examine historical changes in climate, the first study used measured climate data for the period 1961-2010. The other case study focused on the mismatch of water availability and winter wheat water requirement. Simulated crop growth parameters were assessed using the Agricultural Production Systems Simulator (APSIM) model and the data set was split into two time periods (1961-1985 and 1986-2010) to allow comparison.

India

During the first year of our project two contrasting locations, one in Central India (Guna) and the other in southern part of India (Dharwad), were used to study the impact of climate change on two cropping systems at each location. During the second year three additional stations were analyzed. These stations are in the southern part of India, representing arid and semi-arid climates. A Peanut-fallow system at Anantapur, a peanut-chickpea system at Kurnool and post-rainy season sorghum at Bijapur were used for studying the impact of climate change. Ten different climate change scenarios of increased temperature, and increased and decreased rainfall were applied. Historical climate data procured from the India Meteorological Department and soil profile information from the soil survey reports of the National Bureau of Soil Survey and Land Use Planning were used. The Sequence Analysis module in the Decision Support System for Agro technology Transfer (DSSAT) was used for estimating the impact of climate change.

b) **Workshops**

Four workshops were conducted for project planning, monitoring and preparation of outputs. They were - China (September 2010), India (January 2012), Australia (March 2013), and China (July 2013). Reports on the last two workshops are given in Appendix 1. Earlier workshops have been described in previous reports

c) **Early Career researchers program:** Realizing the significant input to the project that would be made by early career researchers in China and India, Mr Srinivas from ICRISAT, India and Mr Liu from IEDA, China were invited to spend six weeks in Australia in 2012. Strategies were developed to enhance capacity- building of these researchers during the project, including training in Australia and their involvement in the final international project workshop.

Results

Our Case Studies of the effects of Climate Change on crop production in three countries has provided some valuable lessons, and led to some important conclusions. They include:

1. In assessing Climate Change effects, it is important to assess the effect on the crop production cycle, and not just on individual crops. For example, negative effects on one crop may be overridden by positive effects on another in the cycle
2. Mismatches were identified in both water availability and extreme temperatures during critical growth phases
3. In some cases, the effect of regional warming can be positive, for example in northern China where the extended growing season leads to increased productivity in the winter wheat-maize system
4. Simulation of future climates in Australia suggests that serious adverse effects on yields will not be evident till about 2050. This will allow researchers and farmers to develop adaptation strategies. In fact farming is a continual response to changing conditions (market, climate variability, climate change).
5. Examples of adaptation are supplementary irrigation if feasible, breeding new varieties with better phenology adaption, or concentrating agriculture in areas more suited following Climate Change. In China, wheat-maize systems in the north are favoured and rice-based systems in the south disadvantaged by increasing temperatures.

Relevance to the APN Goals, Science Agenda and to Policy Processes

An understanding of the impact of climate change on key crops enabled the Asia-Pacific farmers, community workers and policy agencies to better prepare and adapt to climate change, through changes to existing policy and practices, as described above

Self-evaluation

The project members worked well as a team, and enhanced the integration and communication between disciplines required in the area of food security and climate variability. Highlights of the project have been the Young Researchers program for capacity building and the consultations with stakeholders, including policy makers.

Potential for further work

Thanks to APN for their support in funding this current research project. Our work on food security and better crop management in a variable climate will continue through the following project funds:

- US $1.028 million over the period of 2013-2016 for a related research project "Improving Food Security in Qatar: Assessing Alternative Cropping Systems Feasibility and Productivity in Variable Climates, Soil and Marketing Environments". Funding Source: Qatar National Research Fund (QNRF), National Priority Research Program
- A $ 149, 057 over the period of 2013-2014 for a related research project "Better understanding constraints to smallholder adoption of agricultural technologies in Cambodia: Funding Source: the Australian Centre for International Agricultural Research (ACIAR). Assoc. Prof. Samsul Huda is leading both of these projects.

- US $500,000 over period of 2012-2016 for a related research project “the 12th five-year plan of the National Key Technologies R&D Program (No. 2012BAD09B01)”. Prof. Changrong Yan is leading this project in collaboration with Qingdao Agricultural University, Liaoning Academy of Agricultural Sciences, Funding source: Ministry of Science and Technology of the People’s Republic of China.
- US $42,857 over period 2014-2016 for a related research project “Modeling studies on soil water carbon quantitative relationship and crop water productivity in the Black soil in Songnen plain, China”. Mr. Qin Liu is co-leading this project in collaboration with Jilin Academy of Agricultural Sciences, Funding source: Ministry of Agriculture (MOA).

Publications

Selected Scientific Papers:

1. Huda, A.K.S., Wani, S.P., Mei, X., and Sadras, V, 2012. Food Security and Climate Change in the Asia-Pacific Region: Evaluating Mismatch between Crop Development and Water Availability. **APN Science Bulletin**, Issue 2: 42-48, Asia-Pacific Network for Global Change Research; ISSN 2185-761X. http://goo.gl/xL5hl (PDF, 18.5M)
2. Huda, A.K.S., Sadras, V, Wani, S. and Mei, X. 2011, Food Security and Climate Change in the Asia-Pacific Region: Evaluating Mismatch between Crop Development and Water Availability, **International Journal of Bio-resource and Stress Management (IJBSM**), 2(2): 137-144. http://pphouse.org/uploads/abstract/FullView/3_144_general_huda_food%20security.pdf; Print ISSN 0976-3988. Online ISSN: 0976-4038.
3. Huda, A.K.S., Wani, S.P., and Sadras, V, and Mei, X., 2012. Food Security and Climate Change in the Asia-Pacific Region: Evaluating Mismatch between Crop Development and Water Availability (ARCP2011-08CMY-Huda): Proceedings of the Workshop held at ICRISAT, Hyderabad, India, 8-14 January 2012 (Eds: Huda, Wani, Sadras, Mei and Coughlan) ISBN: 978-92-9066-554-0. 48 pp.
4. Huda, A.K.S., Sadras, V, Wani, S. and Mei, X. 2011. Food Security and Climate Change in the Asia-Pacific Region: Evaluating Mismatch between Crop Development and Water Availability, pages 1357-1367 in Climate change: Agriculture, Food security and Human Health The Proceedings of the 9th International Farming Systems Association Europe Group Symposium (eds: Ika Darnhofer and Michaela Grötzer), the Universität für Bodenkultur, Vienna (ISBN 978-3-200-01908-9). International Farming Systems Association Europe Group Symposium, 4-7 July 2010, Vienna, Austria http://ifsa.boku.ac.at/cms/fileadmin/Proceeding2010/2010_WS3.1_Huda_Sadras.pdf

Acknowledgments

The Support from APN and the participating institutions including UWS, SARDI, ICRISAT and IEDA CAAS for this project is acknowledged. Due acknowledgement has been made in all technical presentations, written reports and publications.

TECHNICAL REPORT

Preface

Crop adaptation to environmental stresses is central to sustainable agriculture. In eastern Australia, central India and China temperature has increased and phonological patterns of major grain crops have shifted over the past 40 years. Cropping systems and varieties are designed so that water availability and crop water requirements are well matched, and crops are not exposed to extreme temperature conditions during critical crop development phases. Mismatches between crop and environment occur when the critical period of crop yield determination coincides with stressful conditions. Possible mismatches arising from realized and predicted warming are the focus of this project.

Table of Contents

1. Introduction

Crop adaptation to environmental stresses is central to sustainable agriculture. In eastern Australia, central India and China temperature has increased and phonological patterns of major grain crops have shifted over the past 40 years. Cropping systems and varieties are designed so that water availability and crop water requirements are well matched, and crops are not exposed to extreme temperature conditions during critical crop development phases. Mismatches between crop and environment occur when the critical period of crop yield determination coincides with stressful conditions. Possible mismatches arising from realized and predicted warming are the focus of this project.

The main objectives of the project were to:

1. To determine expected temporal shifts in crop phenology under realized climate change and future climates
2. To assess likely shifts in the pattern of rain and water availability
3. To estimate elements of climate change that will contribute to any mismatch between crop phenology and water availability, and
4. To evaluate expected consequences of this mismatch and other shifts associated with climate change for food security

2. Methodology

Project activities have been of three types:

- Workshops in China, India and Australia to plan and monitor technical activities, and to ensure that project outcomes were achieved
- Case studies in the three countries to allow us to draw conclusions on similarities and differences in the responses of cropping systems to realized climate change
- A specific Early Career Researchers' Program for professional development within the project.

2.1: Workshops:

Four workshops were conducted for project planning, monitoring and preparation of outputs. They were - China (September 2010), India (January 2012), Australia (March 2013), and China (July 2013). Workshops and research activities were enhanced by the input from young researchers from India and China. Reports on the last two workshops are given in Attachments 1a and 1b. The two earlier workshops have previously been described in the following reports submitted to APN:

- Year 1 Progress Report-Beijing Workshop
- Hyderabad Workshop Proceedings provided to APN as a separate publication

- Science Bulletin (2011) – ARCP2011-08CMY-Huda Food Security and Climate Change: Evaluating mismatch between crop development and water availability. This Bulletin provides information on both the Beijing and Hyderabad workshops

On the last day of the Final Workshop in China, the project team met with stakeholders and users of project outputs from the Chinese Government. Information on this highly successful meeting is provided in Appendix 1a.

2.2: Research Activity:

Research activity consisted of Case studies in China, India and Australia:

2.2.1: Australia

In Australia, APN funding contributed to two separate Case Studies. In both studies, cropping systems simulation models were used to assess the effects of climate on crop growth, water stress and yield. The first study analyzed the effects of realized climate change over the period 1957-2011 using both measured climatic data and simulated data on crop phenology, water stress and yield. The second case study analyzed future climate change scenarios using simulation modeling.

Case Study 1:

To examine historical changes in climate, the first study used measured data (daily temperatures, daily rainfall, wind speed, solar radiation, sunshine hours, relative humidity, Vapor Pressure Deficit and open pan evaporation) for the period 1957-2111. The data set was split into two time periods (1957-1983 and 1984-2011) to allow comparison. Simulated crop growth parameters were assessed using APSIM (Agricultural Production Systems Simulator). This study was used as part of our Early Career Researchers Program, and researchers from India and China visited Australia for a period of six weeks to work on analysis and interpretation of local climate and computer simulation data.

The following questions were asked to address possible mismatches that may occur between crop and environment when the critical window of grain yield determination coincides with stressful conditions:

- How did rainfall and temperature patterns change between 1957 and 2011?
- How did these changes affect the stress conditions during the critical window of yield determination of wheat?
- How did changes in rainfall features (amount, seasonality and size of events) and temperature extremes influence the crop performance?

In this study of realized climate change we used a transect of six sites in eastern Australia from Emerald (23.5degrees S) in the north to Corowa (36 degrees S) in the south, covering the range of wheat growing environments. Average annual rainfall ranged from 540-680 mm, with rainfall summer dominant in the north and winter (growing season) dominant in the south. Details of the sites are shown in Fig 1 and Table 1.

(Australia Map)

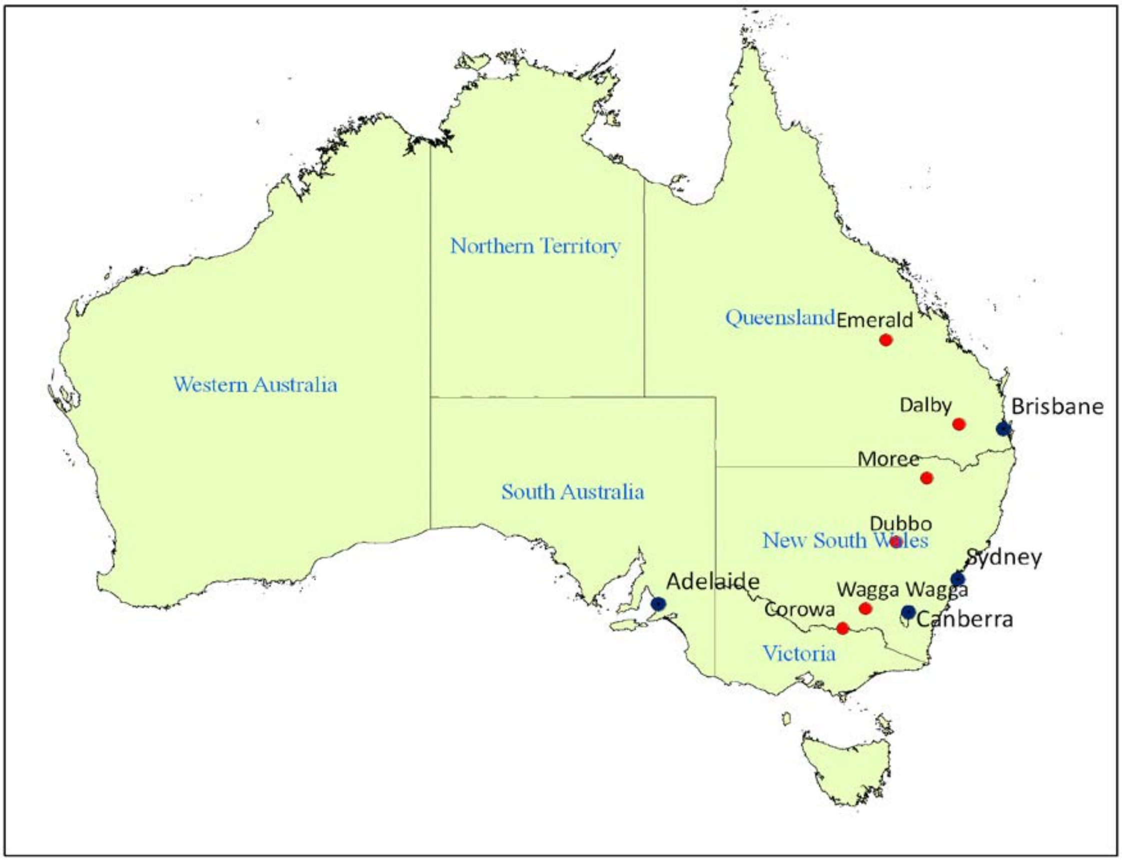


Figure 1. Location of Transect Sites for climatic analysis in eastern Australia

Site No.	Location	Latitude (°S)	Longitude (°E)	Mean Annual Rainfall (mm)	Mean Annual Maximum t (°C)	Mean Annual Minimum t (°C)
1	Emerald	23.53	148.16	635	29.6	15.8
2	Dalby	27.18	151.26	675	26.3	12.1
3	Moree	29.50	149.90	585	26.3	12.2
4	Dubbo	32.24	148.61	591	24.1	10.5
5	Wagga Wagga	35.13	147.31	559	22.9	9.6
6	Corowa	35.99	144.36	541	22.3	8.9

Table 1. Details of locations selected for climatic analysis in eastern Australia

Analyses based on measured rainfall (for the period 1950-2011) and temperature (1957-2011) for the wheat-cropping season (Apr–Oct for Emerald and May-Oct for rest of the locations) are reported in Section 3.1. Data reported include maximum and minimum temperatures, extreme temperature (>=35 degrees C) and rainfall probabilities (days with rainfall >2.5 mm) during the cropping season.

The following criteria were used for APSIM analysis:

A 1 Apr-30 June sowing window for Emerald and 1 May to 30 Jun for other sites; 20 mm rainfall over 7 consecutive days as a planting criterion; *Hartog* wheat cultivar; no Nitrogen stress; Soil Grey Sodosol (Wagga Wagga type - 1.6m deep; 146mm AWHC) for Wagga, Dubbo and Corowa; Black Vertisol-Bongeen (Dalby No 027 - 1.8m deep; 387 mm AWHC) for Dalby, Emerald and Moree.

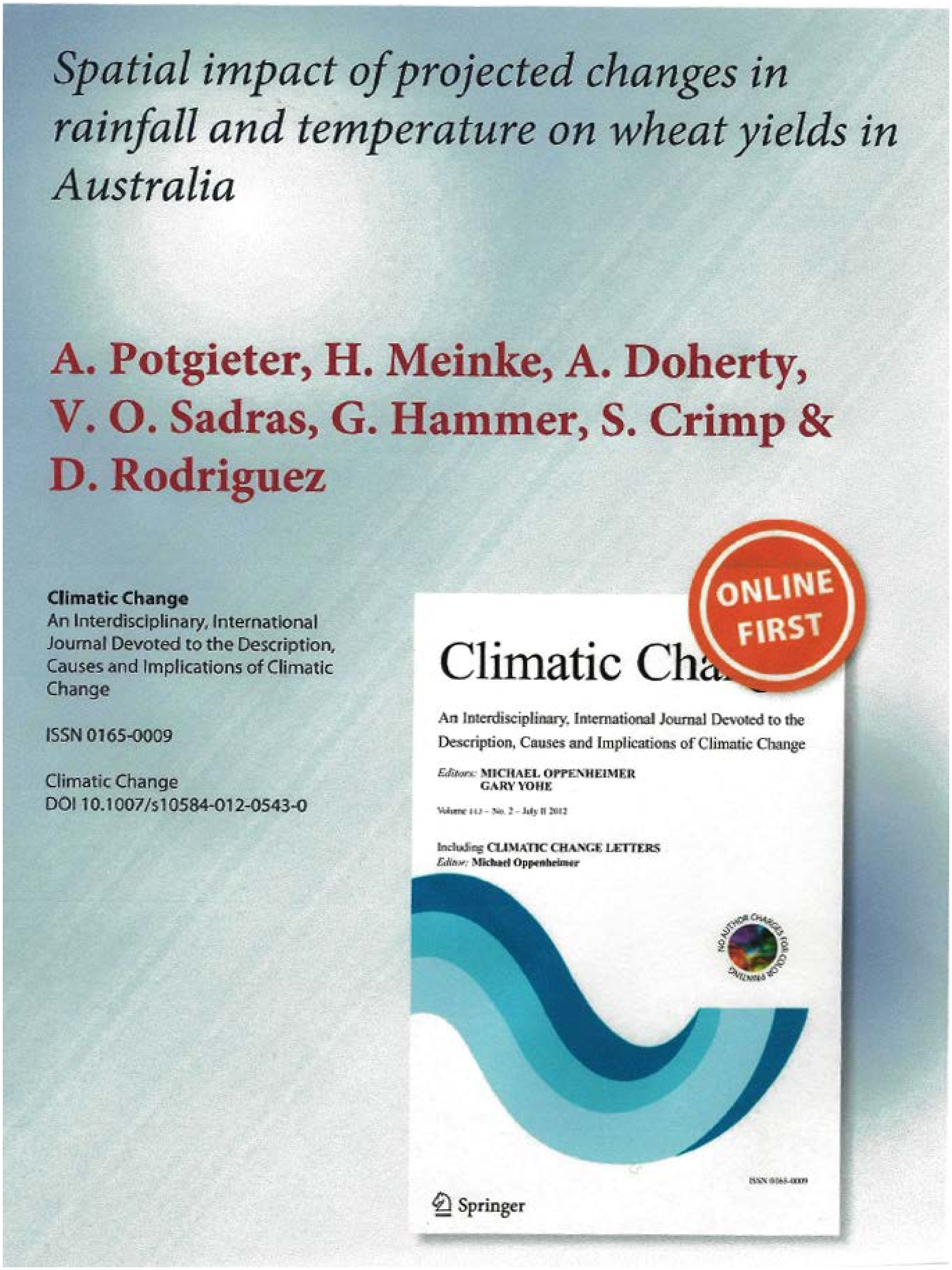
Trends over time (1957-2011) and probability distributions were carried out for a number of crop phenology parameters. Two time periods (1957-1983 and 1984-2011) were used to illustrate changes over time in the probability distributions. Parameters were:

- Sowing date
- Days to flowering from sowing
- Days to maturity from sowing
- Days flowering to maturity
- Soil water stress for three growth stages (pre-flowering; 30 days prior to flowering to 10 days after flowering; post-flowering)— daily values for probability distribution analysis, and
- Grain yield

Case Study 2:
APN funding also contributed to a study of the effect of predicted climate change on wheat growth and yield involving project collaborator Victor Sadras and other Australian researchers. The title page of the publication arising from this study is shown in Fig 2.

Climate projections over the next two to five decades indicate that most of the Australian wheat-belt is likely to become warmer and drier. In this study we used 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 global circulation models, to spatially estimate yield changes assuming no adaptation.

Cropping systems simulations for baseline climate data (1901-2007) were compared with those based on Climate predictions for 2020 and 2050. Future Climates based on high and low CO_2 emission scenarios were calculated using the CSIRO Cubic Conformal model (CCAM), while future crop yields with or without the incorporation of CO_2 fertilization and its stimulation of crop growth were calculated using the OzWheat model. Results were assessed for 245 wheat-producing shires in Australia.



Spatial impact of projected changes in rainfall and temperature on wheat yields in Australia

A. Potgieter, H. Meinke, A. Doherty, V. O. Sadras, G. Hammer, S. Crimp & D. Rodriguez

Climatic Change
An Interdisciplinary, International Journal Devoted to the Description, Causes and Implications of Climatic Change

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ONLINE FIRST

Climatic Cha

An Interdisciplinary, International Journal Devoted to the Description, Causes and Implications of Climatic Change

Editors: **MICHAEL OPPENHEIMER**
GARY YOHE

Volume 113 – No. 2 – July II 2012

Including **CLIMATIC CHANGE LETTERS**
Editor: **Michael Oppenheimer**

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Figure 2: Title page of a recent publication arising from collaboration between Victor Sadras of the APN project team and other Australian researchers

2.2.2: China

In China, APN funding also contributed to two Case Studies. In both studies, cropping systems simulation models were used to assess the effects of climate on crop growth, water stress and yield.

To examine historical changes in climate, the first study used measured data (Daily temperature (max, min and mean), daily rainfall, wind speed, solar radiation, sunshine hours, and relative humidity, Vapor Pressure Deficit and open pan evaporation) for the period 1961-2010. This study was used as part of our Early Career Researchers program.

2.2.3: India

During the first year of our project two contrasting locations were used, in Central India (Guna) and one in southern part of India (Dharwad), were used to study the impact of climate change on two cropping systems at each location.

During the second year three additional stations were analyzed. These stations are in the southern part of India, which represent arid and semi-arid climates. Peanut-fallow system at Anantapur, peanut-chickpea system at Kurnool and post-rainy season sorghum at Bijapur were used for studying the impact of climate change. Ten different climate change scenarios with increasing temperatures of 1, 2 and 3 °C and increased and decreased rainfall by 20% were applied. Historical climate data procured from the India Meteorological Department and soil profile information from the National Bureau of Soil Survey and Land Use Planning. The Sequence Analysis module in DSSAT was used for estimating impact of climate change. Results for the three sites and cropping systems are described below in Section 3.3.

Five locations in India representing typical arid, semi-arid and dry sub-humid agro-eco regions were selected for assessing impacts of climate change on crops and cropping systems. One location falls in central India and the other four in southern part of India. Annual rainfall in these regions ranges from 400 to 900 mm. Soils are VERTISOLS and ALFISOLS with water holding capacities ranging from 100 to 200 mm. Most prevailing cropping systems are selected for studying the impacts of climate change using crop simulation models. Locations and prevailing cropping systems are shown in Figure 3. Detailed geographic and climatic features of these locations are given in the table 2.

- **Dharwad**
    - Groundnut-Sorghum
    - Soybean-Chickpea
    - Sorghum-Wheat
- **Guna**
    - Soybean-Chickpea
    - Soybean-Wheat
- **Anantapur**
    - Groundnut-Fallow
- **Kurnool**
    - Groundnut-Chickpea
- **Bijapur**
    - Fallow-Sorghum

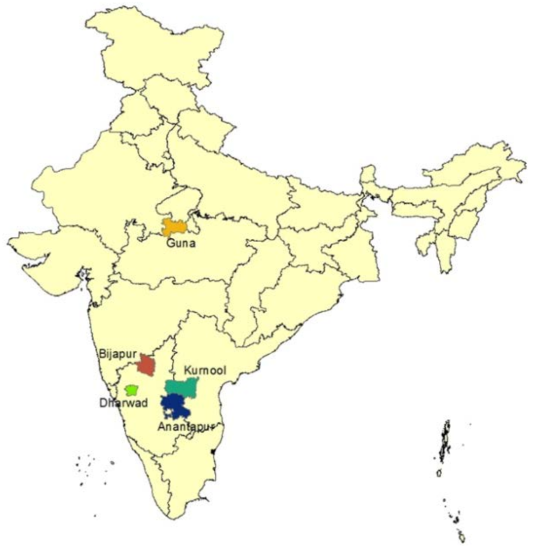


Figure 3. Locations and cropping systems in India.

S.No.	Location	Latitude (°N)	Longitude (°E)	Rainfall (mm)	Max T (°C)	Min T (°C)
1	Dharwad	15.43	75.13	720	31.8	20.3
2	Guna	24.60	77.40	950	32.4	18.5
3	Anantapur	14.68	77.62	550	34.1	22.6
4	Kurnool	15.80	78.03	650	35.0	22.4
5	Bijapur	19.30	83.55	620	32.8	20.4

Table 2. Mean annual climatic features of locations for climate change studies in India

Data and methods

Crop simulation models are appropriate tools for assessing impacts of climate change on crops and cropping systems. Decision Support System for Agrotechnology Transfer (DSSAT) is a software application program that comprises crop simulation models for over 28 crops, database management tools for soil, weather, and crop management and experimental data, and utilities and application programs. The crop simulation models in DSSAT simulate growth, development and yield as a function of the soil-plant-atmosphere dynamics. Crop models in DSSAT are extensively used for many applications ranging from on-farm and precision management to regional assessments of the impact of climate variability and climate change. We used CropGro and CERES models under DSSAT software in this study to estimate the impacts of climate change. Data requirements for DSSAT crop models are daily weather data such as temperature, rainfall and solar radiation, layered soil profile information, cultivar coefficients and crop management data. Historical daily climate data on rainfall and temperatures were procured from the India Meteorological Department (IMD) for the target locations. Daily solar radiation which is very important parameter for the crop simulation model was estimated using Bristow-Campbell (1998) method. Soil profiles information for target locations was collected from the soil survey reports of National Bureau of Soil Survey and Land Use Planning (NBSS&LUP). Water holding capacities in different layers of the soils were estimated using pedo-transfer techniques using SBuild utility in DSSAT. Cultivar coefficients are estimated using field observed data of different crops. Standard crop management practices were followed. The Sequence Analysis module in DSSAT which is meant to simulate cropping sequences over multiple years was used for assessing impacts of climate change. Ten different climate change scenarios which include present, increasing temperatures of 1, 2 and 3 °C and increased and decreased rainfall by 20% are applied.

3: Results & Discussion

3.1: Australia

Case Study 1:

Temperature data over the last five decades have shown a consistent significant ($P<0.05$) increase in both maximum and minimum temperatures during the growing season at all sites. Rates of increase varied from 0.01-0.035 ° C /year. Illustrative data for Emerald, the most northerly site, is shown in Figs 4a and 4b.

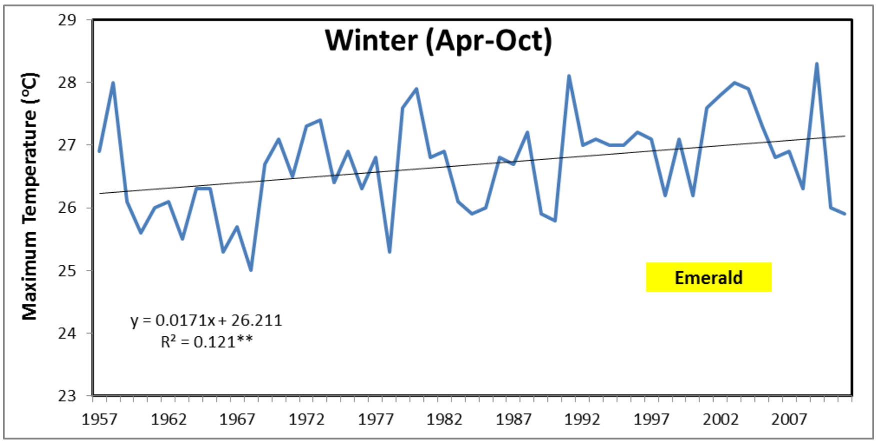


Figure 4a. The growing season average maximum temperature trend from 1957-2011 for Emerald

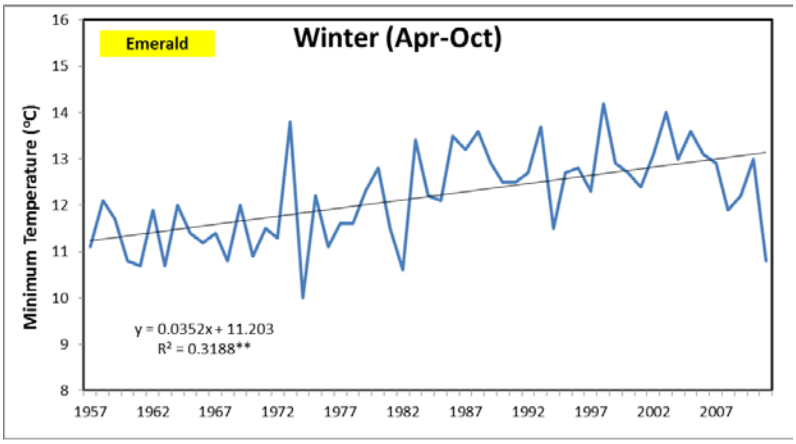


Figure 4b. The growing season average minimum temperature trend from 1957-2011 for Emerald

Looking at changes in growing season rainfall, in the southern areas of eastern Australia winter rainfall is as expected higher than in the north, with average values over the last century ranging from 220-300 mm. There is a slight drying trend over time in the south, with a trend towards increased growing season rainfall in the north. However, the changes are small and sometimes not statistically significant.

To assess rainfall trends more accurately, we calculated the probability of occurrence of rainfall events >2.5 mm (effective rainfall less likely to be lost by evaporation) during two time periods- 1950-1979 and 1980-2011. As expected, the average occurrence of rainfall events >= 2.5 mm was greater in southern sites compared with northern sites, with median values ranging from 18 at Dalby to 32 at Corowa. However, we also observed a decrease in the probability of effective rainfall events at all sites in the period 1980-2011 compared with

1950-1979. As illustrated in Fig 4 the shift in median value is from about 20 to 18 days at Moree and 26 to 24 at Dubbo.

It is expected that these changes in temperature and rainfall could have significant effects on crop phenology

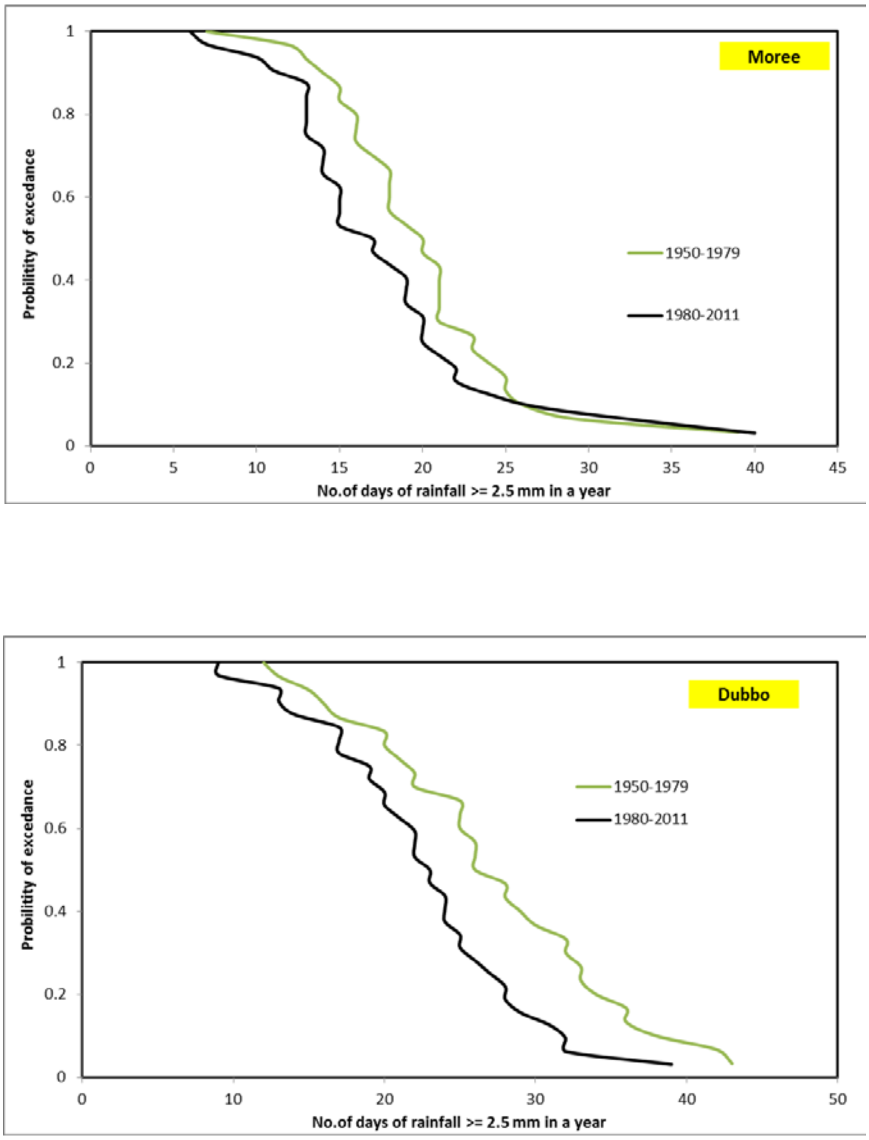


Figure 5. Probability distributions of the occurrence of rainfall events >= 2.5 mm during two time periods- 1950-1979 and 1980-2011

Simulation using the APSIM model showed decreases in time to flowering and time to maturity in the 1984-2011 period compared with the 1957-1983 period. Median time to maturity was reduced from 122 to 115 days at Emerald and from 155 to 150 days at Moree.

The Probability distributions for grain yield for the six sites over the two time periods are shown in Fig 5. Cumulative Probabilities of grain yield were similar for the two periods for the four southern sites, but Emerald and particularly Dalby in the north showed a shift to decreasing simulated grain yield in the later period. For example the median grain yield at Dalby was reduced from 4000 kg/ha to a little over 3000 kg/ha.

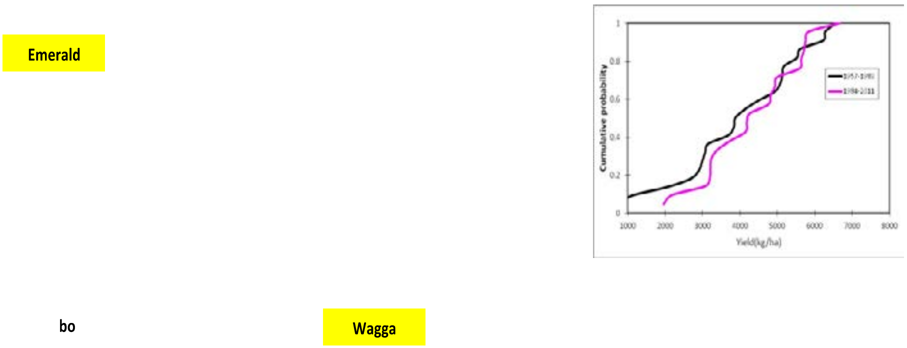


Figure 6. Probability distributions for grain yield for the six sites over the two time periods 1957-1983 and 1984-2011

The most likely causes of yield reduction are water stress and high temperatures during the critical phases of yield determination. Fig 6 shows the Cumulative probabilities of soil water stress index for the six sites over the two time periods 1957-1983 and 1984-2011. For four of the six sites the probabilities of water stress are very similar and Dalby is the only site showing an increase in median water stress index over time, increasing from about 0.4 for 1957-1983 to over 0.6 for 1984-2011. Water Stress is thus the most likely cause of yield reduction at Dalby.

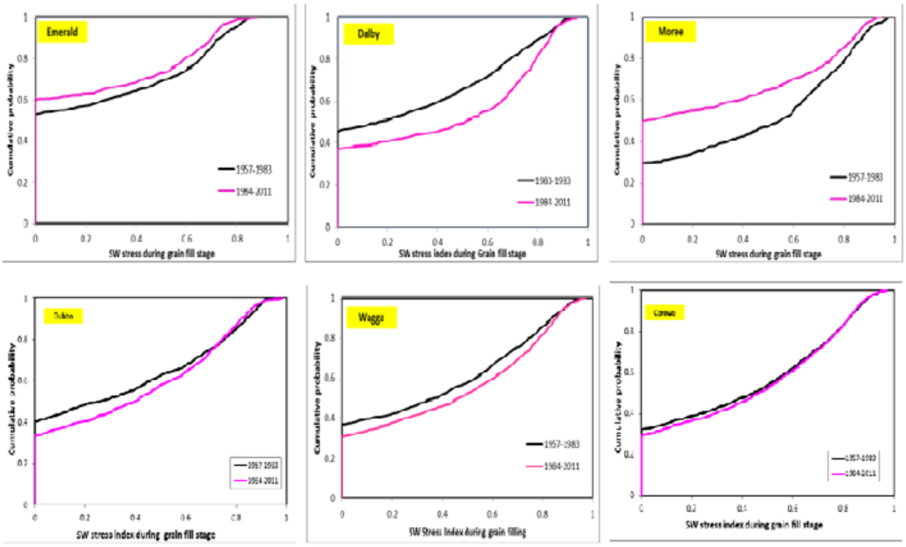


Figure 7. Cumulative probabilities of soil water stress index for the six sites over the two time periods 1957-1983 and 1984-2011

The smaller simulated yield reduction at Emerald, which is the most northerly and hottest site in the transect, may be explained by heat stress. Fig 7 shows the Cumulative probabilities of the number of days with maximum temperature >=35 ^{o}C for three sites in eastern Australia. At Emerald there was an increase in the median number of days with maximum temperature > 35 degrees (about 8 in 1984-2011 compared with 5 in 1957-1983), with no consistent variation at the other two sites, and these extreme temperatures may affect grain filling.

Probabilities of no. of days with maximum temperature >= 35^{o}C in a year

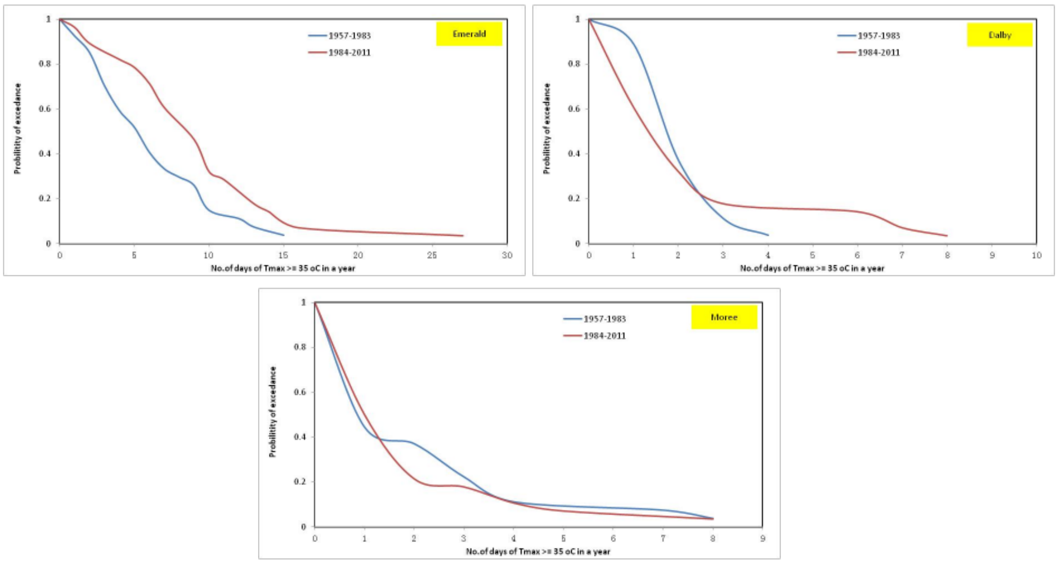
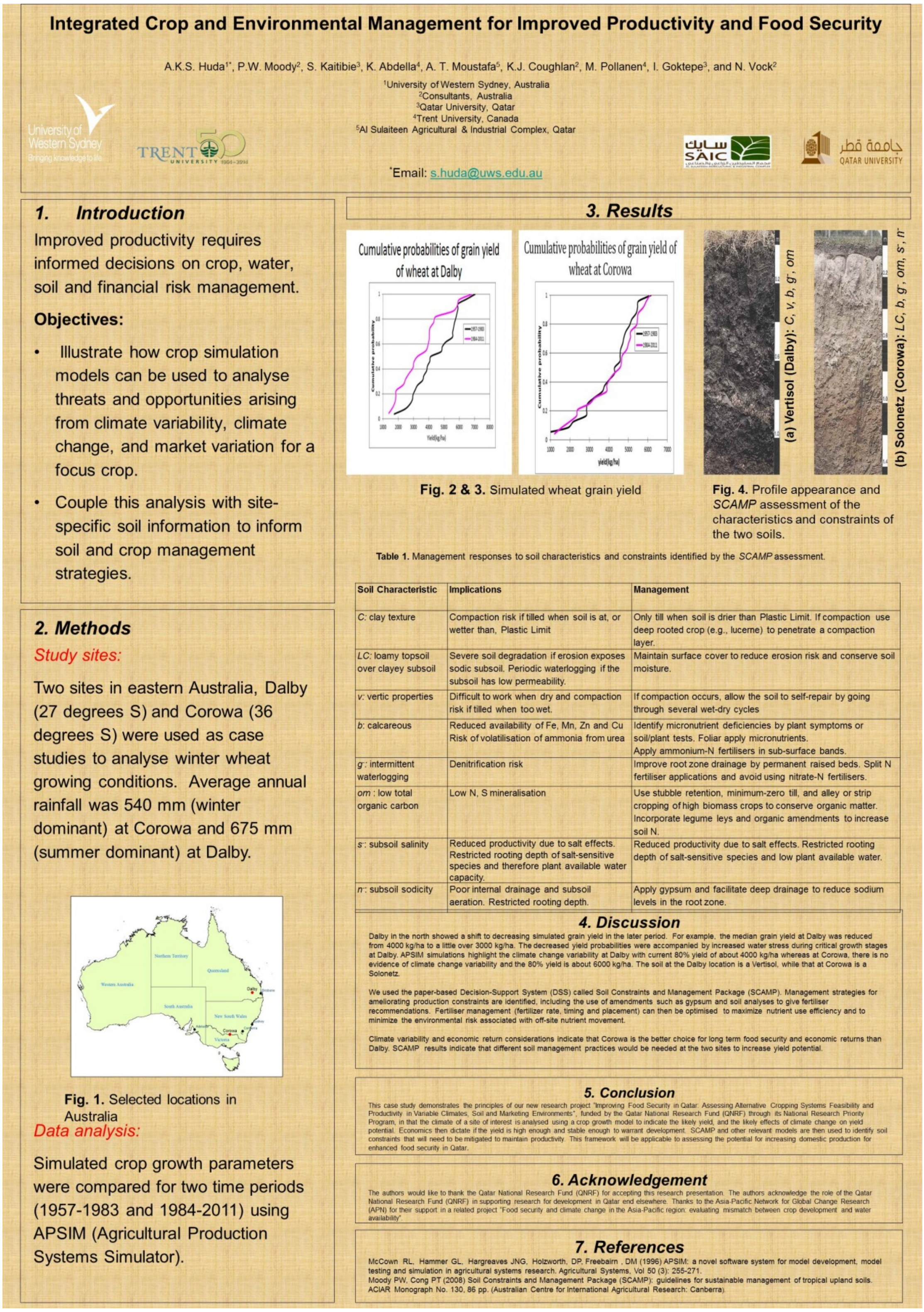


Figure 8. Cumulative probabilities of the number of days with maximum temperature >=35 ^{o}C for three sites in eastern Australia over the two time periods 1957-1983 and 1984-2011

These results on realised climate change over the last five decades are not consistent with predictions that the most serious effect of future changes will be in southeast Australia.

Although these data illustrate the adverse consequences of realized climate change in some sites in eastern Australia, their effects on yields would have been largely counteracted by improvements in productivity arising from used of new cultivars and management practices since the 1950s.

One spinoff from this Case Study late in the APN Project period was a more complete analysis of the feasibility of wheat production under a changing climate at two of our transect sites. Assoc. Prof. Samsul Huda worked with Dr. Phil Moody from the Queensland Government in preparing a poster paper for the Qatar Foundation Annual Research Conference, held in November 2013. This poster paper is shown below in Fig 9. Two sites in eastern Australia, Dalby (27 degrees S) and Corowa (36 degrees S) were used as case studies to analyze winter wheat growing conditions.



Integrated Crop and Environmental Management for Improved Productivity and Food Security

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1. Introduction

Improved productivity requires informed decisions on crop, water, soil and financial risk management.

Objectives:

- Illustrate how crop simulation models can be used to analyse threats and opportunities arising from climate variability, climate change, and market variation for a focus crop.
- Couple this analysis with site-specific soil information to inform soil and crop management strategies.

2. Methods

Study sites:

Two sites in eastern Australia, Dalby (27 degrees S) and Corowa (36 degrees S) were used as case studies to analyse winter wheat growing conditions. Average annual rainfall was 540 mm (winter dominant) at Corowa and 675 mm (summer dominant) at Dalby.

Fig. 1. Selected locations in Australia

Data analysis:

Simulated crop growth parameters were compared for two time periods (1957-1983 and 1984-2011) using APSIM (Agricultural Production Systems Simulator).

3. Results

Cumulative probabilities of grain yield of wheat at Dalby

Cumulative probabilities of grain yield of wheat at Corowa

Fig. 2 & 3. Simulated wheat grain yield

(a) Vertisol (Dalby): C, v, b, g^-, om

(b) Solonetz (Corowa): LC, b, g^-, om, s^-, n^-

Fig. 4. Profile appearance and *SCAMP* assessment of the characteristics and constraints of the two soils.

Table 1. Management responses to soil characteristics and constraints identified by the *SCAMP* assessment.

Soil Characteristic	**Implications**	**Management**
C: clay texture	Compaction risk if tilled when soil is at, or wetter than, Plastic Limit	Only till when soil is drier than Plastic Limit. If compaction use deep rooted crop (e.g., lucerne) to penetrate a compaction layer.
LC: loamy topsoil over clayey subsoil	Severe soil degradation if erosion exposes sodic subsoil. Periodic waterlogging if the subsoil has low permeability.	Maintain surface cover to reduce erosion risk and conserve soil moisture.
v: vertic properties	Difficult to work when dry and compaction risk if tilled when too wet.	If compaction occurs, allow the soil to self-repair by going through several wet-dry cycles
b: calcareous	Reduced availability of Fe, Mn, Zn and Cu Risk of volatilisation of ammonia from urea	Identify micronutrient deficiencies by plant symptoms or soil/plant tests. Foliar apply micronutrients. Apply ammonium-N fertilisers in sub-surface bands.
g^-: intermittent waterlogging	Denitrification risk	Improve root zone drainage by permanent raised beds. Split N fertiliser applications and avoid using nitrate-N fertilisers.
om : low total organic carbon	Low N, S mineralisation	Use stubble retention, minimum-zero till, and alley or strip cropping of high biomass crops to conserve organic matter. Incorporate legume leys and organic amendments to increase soil N.
s^-: subsoil salinity	Reduced productivity due to salt effects. Restricted rooting depth of salt-sensitive species and therefore plant available water capacity.	Reduced productivity due to salt effects. Restricted rooting depth of salt-sensitive species and low plant available water.
n^-: subsoil sodicity	Poor internal drainage and subsoil aeration. Restricted rooting depth.	Apply gypsum and facilitate deep drainage to reduce sodium levels in the root zone.

4. Discussion

Dalby in the north showed a shift to decreasing simulated grain yield in the later period. For example, the median grain yield at Dalby was reduced from 4000 kg/ha to a little over 3000 kg/ha. The decreased yield probabilities were accompanied by increased water stress during critical growth stages at Dalby. APSIM simulations highlight the climate change variability at Dalby with current 80% yield of about 4000 kg/ha whereas at Corowa, there is no evidence of climate change variability and the 80% yield is about 6000 kg/ha. The soil at the Dalby location is a Vertisol, while that at Corowa is a Solonetz.

We used the paper-based Decision-Support System (DSS) called Soil Constraints and Management Package (SCAMP). Management strategies for ameliorating production constraints are identified, including the use of amendments such as gypsum and soil analyses to give fertiliser recommendations. Fertiliser management (fertilizer rate, timing and placement) can then be optimised to maximize nutrient use efficiency and to minimize the environmental risk associated with off-site nutrient movement.

Climate variability and economic return considerations indicate that Corowa is the better choice for long term food security and economic returns than Dalby. SCAMP results indicate that different soil management practices would be needed at the two sites to increase yield potential.

5. Conclusion

This case study demonstrates the principles of our new research project "Improving Food Security in Qatar: Assessing Alternative Cropping Systems Feasibility and Productivity in Variable Climates, Soil and Marketing Environments", funded by the Qatar National Research Fund (QNRF) through its National Research Priority Program, in that the climate of a site of interest is analysed using a crop growth model to indicate the likely yield, and the likely effects of climate change on yield potential. Economics then dictate if the yield is high enough and stable enough to warrant development. SCAMP and other relevant models are then used to identify soil constraints that will need to be mitigated to maintain productivity. This framework will be applicable to assessing the potential for increasing domestic production for enhanced food security in Qatar.

6. Acknowledgement

The authors would like to thank the Qatar National Research Fund (QNRF) for accepting this research presentation. The authors acknowledge the role of the Qatar National Research Fund (QNRF) in supporting research for development in Qatar end elsewhere. Thanks to the Asia-Pacific Network for Global Change Research (APN) for their support in a related project "Food security and climate change in the Asia-Pacific region: evaluating mismatch between crop development and water availability".

7. References

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Moody PW, Cong PT (2008) Soil Constraints and Management Package (SCAMP): guidelines for sustainable management of tropical upland soils. ACIAR Monograph No. 130, 86 pp. (Australian Centre for International Agricultural Research: Canberra).

Figure 9. A Poster based on data analysis from this project, presented by Assoc. Prof. Samsul Huda at the Qatar Foundation Annual Research Conference

Case Study 2:

Simulated yields under a number of climate change scenarios described earlier (shown in Fig 9) suggest little or no yield decline by 2020 compared with the baseline scenario (climate data 1901-2007), 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 NSW, Queensland and the drier environments of Victoria, South Australia, and inland Western Australia. Accounting for CO_2 fertilisation 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.

The fact that significant effects of climate change are not noticeable till 2050 suggests that there are many options in Australia for adaptation and research to overcome adverse consequences.

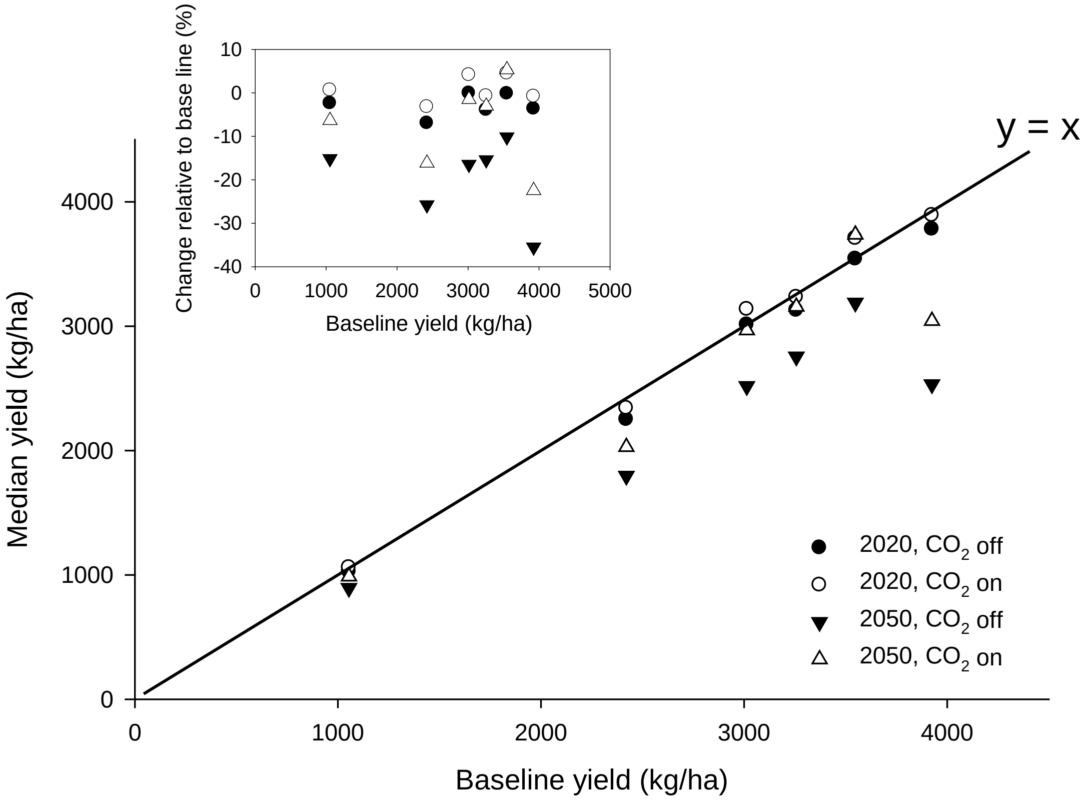
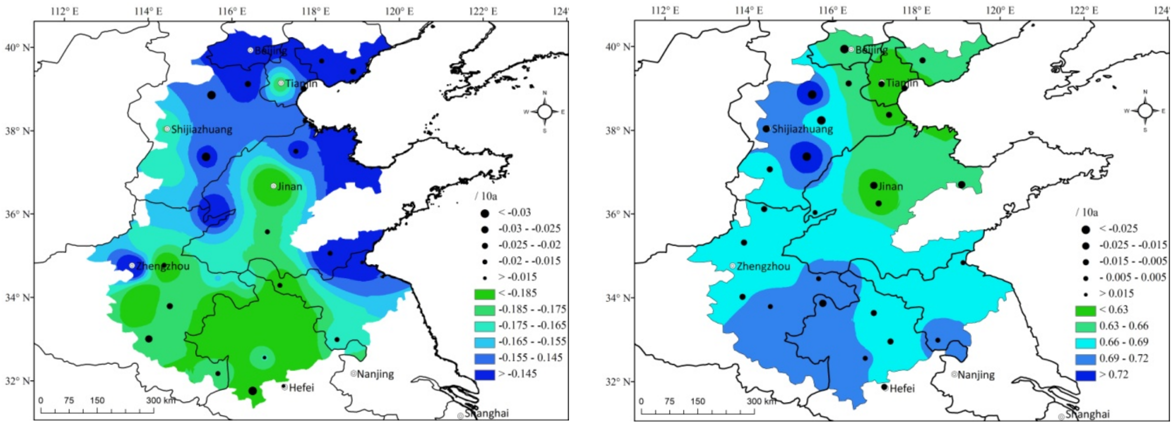


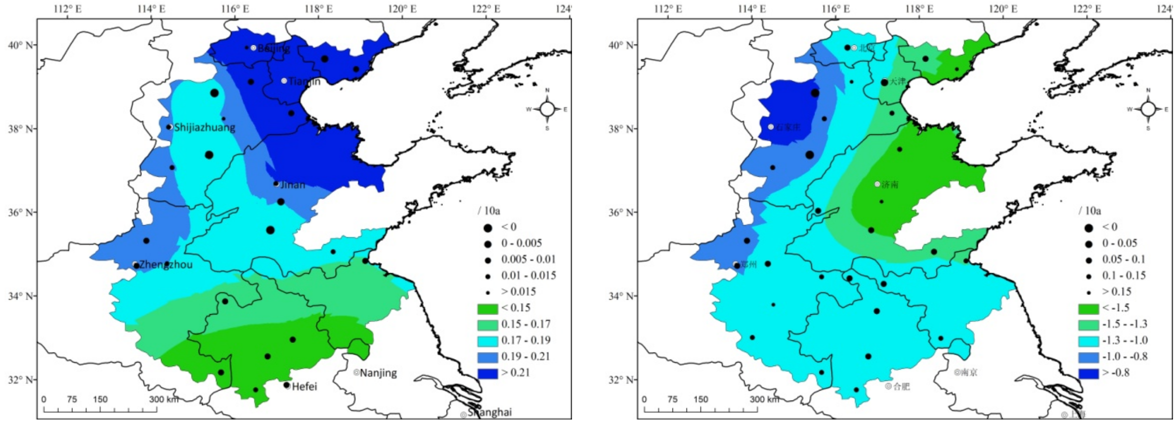
Figure 10. Modelled median wheat yield in four scenarios against the median baseline yield. Inset shows the percentage change between each scenario and the baseline yield.

3.2: China

In this study of realized climate change we used a transect of six sites on the Huang-Huai-Hai (3H) plain, China from Beijing (40 degrees N) in the north to Bengbu (33 degrees N) in the south, a typical area with two crops per year (Winter wheat and summer maize). The climate is temperate, sub-humid, and continental monsoon with a cumulative temperature (>0°C) of 4200 to 5500°C, average annual precipitation ranging from 500 to 800 mm. The annual rainfall is concentrated in the summer period, from July to September. Winter and spring is characterized by a lack of water available for agricultural production. Measured climate data suggests a trend to decreasing seasonal rainfall, and increased growing season maximum, minimum and mean temperatures at these six sites during 1961-2010. The 50-year Potential Evapo-Transpiration (ET_0) during winter wheat and summer maize growing seasons for the 3H plain was calculated from a data set of daily climate variables at 40 meteorological stations. Sensitivity maps for key climate variables in winter wheat and summer maize seasons were estimated from the interpolated meteorological surfaces using a Kriging method and the spatial pattern variability in sensitivity coefficients for these key variables was plotted in maps (Figs.10 and 11). Solar radiation is considered to be the most sensitive and predominant controlling variable for a negative trend in ET_0 for summer maize growing season, and more sensitivity to solar radiation and temperature was detected in eastern and southwest parts of the 3H plain. In the winter wheat growing season relativity humidity becomes the predominant factor (Table 2); furthermore, declining relativity also primarily controlled a negative trend in ET_0 .

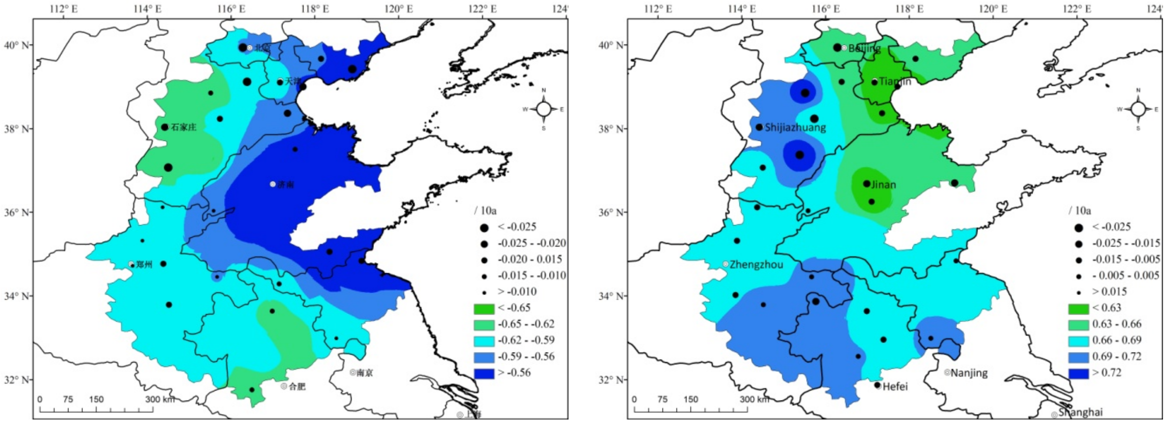


(a) S_T (b) S_{RS}

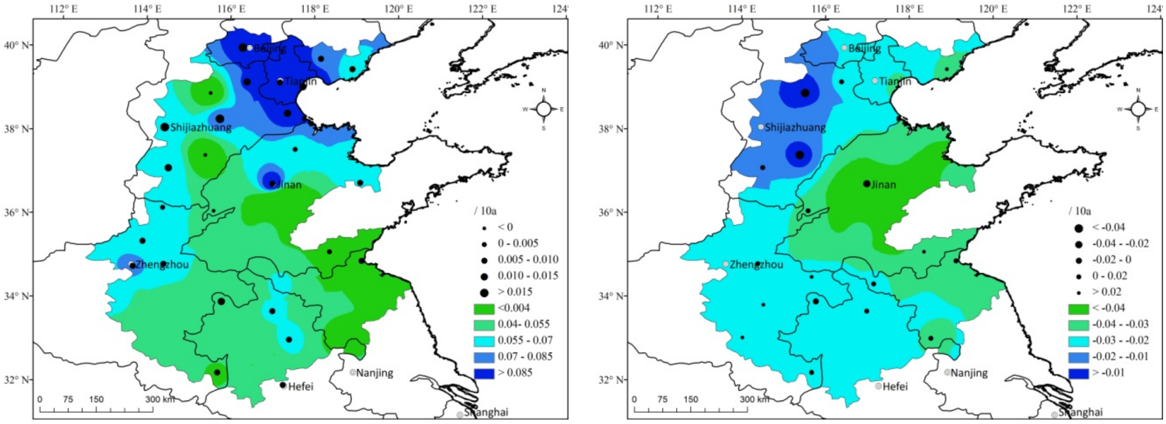


(c) S_{ws} (d) S_{RH}

Figure 11. Spatial variability in sensitivity coefficient of ET_0 in winter wheat season in 3H plain



(a) S_T (b) S_{RS}



(c) S_{ws} (d) S_{RH}

Figure 12. Spatial variability in sensitivity coefficient of ET_0 in summer maize season in 3H plain

	Mean temperature (℃)	**Solar radiation （MJ/（m^{2}year）**	**Relativity humidity (%)**	**Wind speed (m/s)**
Annual	0.26^{**}	-13.33^{*}	-0.44	-0.16^{**}
Winter wheat	0.33^{**}	-7.66^{**}	-0.52^{*}	-0.17^{**}
Summer maize	0.19^{**}	-5.67^{**}	-0.36	-0.15^{**}
Annual	0.04	0.69^{**}	0.57^{**}	0.54^{**}
Winter wheat	-0.09	0.10	0.58^{**}	0.35^{*}
Summer maize	0.16	0.66^{**}	0.19	0.62^{**}

Table 3. The trend and correlation coefficients between annual ET$_0$ with key climatic variables in 3H plain

The second case study is focused on the mismatch of water and winter wheat water requirement. The changes in the five growth stages of winter wheat were explored in this research including the sowing stage, returning green stage, jointing stage, heading stage and maturity stage. As described in Fig.12, compared to the 1970s, sowing date is advanced by approximately 5 to 10 days by 2010. The returning green stage shows an advancing trend in the north-eastern part, whereas it was delayed in the western part of the 3H Plain. Heading stage has been delayed by approximately 2-15 days. An analysis of the sensitivity of water requirement for winter wheat and regional response to climate change was investigated for selected sites in the 3H plain (Table 3 and 4), China. Temperature was the most sensitive variable, followed by solar radiation, wind speed and relative humidity. The decrease of sensitivity of ETc to solar radiation mainly occurred in the seedling to jointing and heading to maturity stages of winter wheat, sensitivity to temperature increased in Beijing, Xinxiang, Xuzhou and Yanzhou stations, while it decreased in Shijiazhuang stations.

Station	**Sowing to maturity**		**Sowing to seeding**		**Seeding to jointing**		**Jointing to heading**		**Heading to maturity**	
	mean	**Slope**	**Mean**	**slope**	**mean**	**slope**	**mean**	**slope**	**mean**	**slope**
Beijing	462.2	-0.67	8.42	-0.04	278.2	-1.81^{**}	79.78	0.50	95.74	0.69^{*}
Shijiazhuang	404.69	-0.44	6.01	0.05	194.68	-1.04^{*}	89.07	-0.42	114.92	0.96^{*}
Xinxiang	391.93	1.57^{**}	6.09	0.09^{**}	166.09	-0.26^{**}	92.17	0.13	127.58	1.61^{**}
Xuzhou	391.99	-0.59	6.85	0.01	152.13	-1.59^{**}	99.56	0.05	133.44	0.93^{*}
Yanzhou	396.00	-1.11^{*}	6.10	-0.01	171.12	-1.31^{**}	86.43	-0.35	132.34	0.57

Table 4. Long-term trends over the entire studied period of agriculture water requirement (ETc) in different phonological phases for the selected weather stations. (* and ** represent linear coefficients significant at $P < 0.05$ and $P < 0.01$, respectively.)

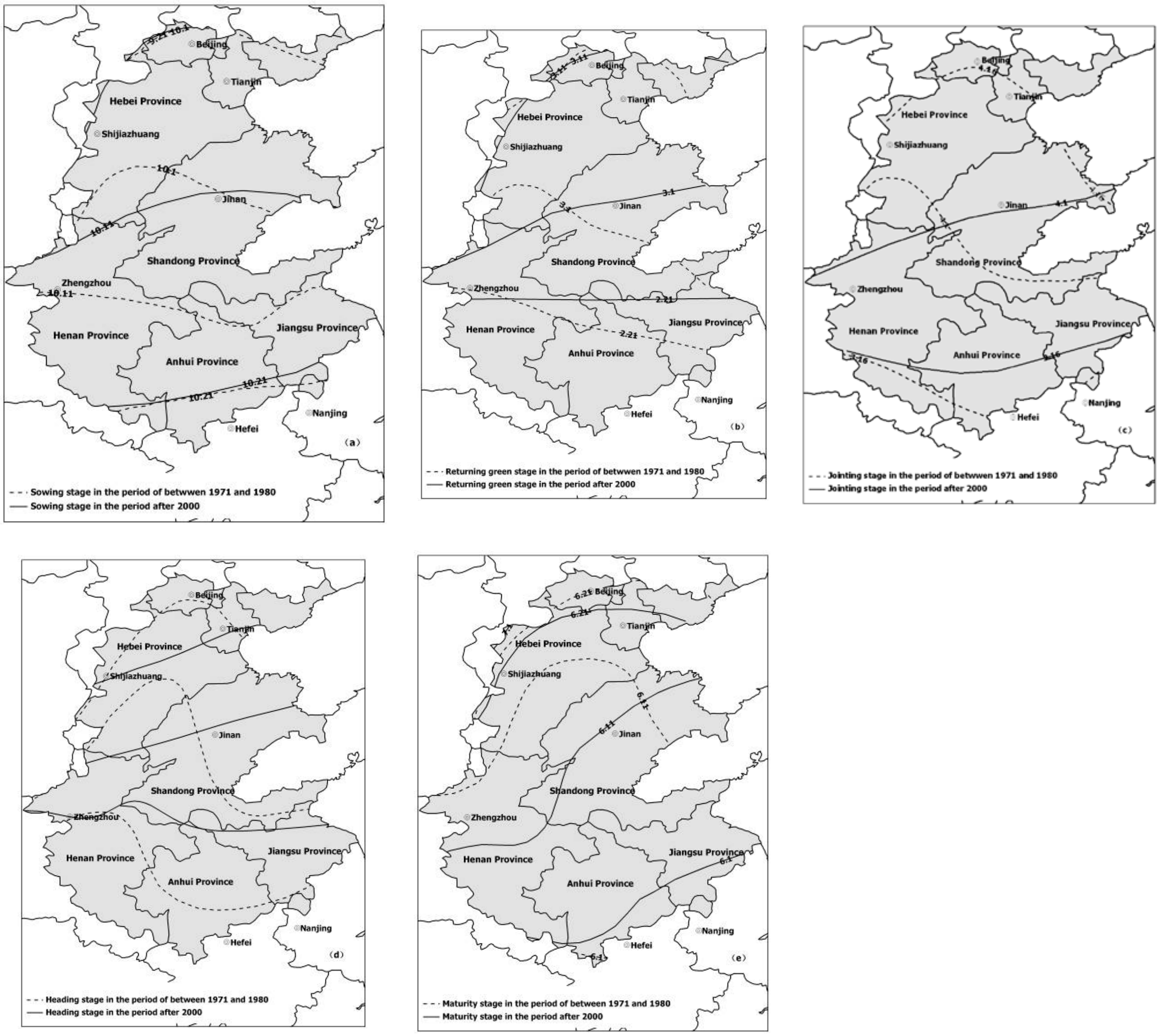


Figure 13. Comparison of changes in the sowing stage(a), returning green stage(b), jointing stage(c), heading stage(d) and maturity stage(e) of winter wheat between the 1970s (dotted lines) and the past ten years (solid lines) in the 3H Plain.*Error! Bookmark not defined.*

Station	Sowing to maturity		Sowing to seeding		Seeding to jointing		Jointing to heading		Heading to maturity	
	mean	slope	mean	slope	mean	slope	mean	slope	mean	slope
S_{RS}										
Beijing	0.19	-0.02**	0.41	-0.05**	0.09	-0.02**	0.42	-0.02	0.52	-0.03**
Shijiazhuang	0.26	-0.01	0.47	-0.01	0.15	-0.02**	0.46	0.00	0.57	-0.01
Xinxiang	0.31	-0.03**	0.48	-0.02	0.21	-0.03**	0.46	-0.05**	0.58	-0.04**
Xuzhou	0.33	0.00	0.50	0.01	0.24	0.00	0.46	-0.02**	0.56	0.00
Yanzhou	0.31	0.00	0.51	-0.01	0.22	-0.01	0.46	-0.01	0.57	0.00
S_{RH}										
Beijing	-0.01	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	0.00
Shijiazhuang	-0.01	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	0.00
Xinxiang	-0.01	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	0.00
Xuzhou	-0.01	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	0.00
Yanzhou	-0.01	0.00	0.00	0.00	-0.02	0.00	0.00	0.00	0.00	0.00
S_{Tmin}										
Beijing	0.34	0.02	0.53	0.07**	0.30	0.01	0.42	0.01	0.45	0.02*
Shijiazhuang	0.35	-0.02**	0.44	0.01	0.33	-0.03*	0.38	-0.02**	0.39	-0.02**
Xinxiang	0.45	0.04**	0.56	0.04	0.43	0.04**	0.45	0.03	0.47	0.05**
Xuzhou	0.53	0.01	0.55	-0.08	0.53	0.02	0.50	-0.01	0.54	-0.01
Yanzhou	0.53	0.02	0.54	0.04	0.54	0.03	0.47	0.00	0.52	0.00
S_{Tmax}										
Beijing	0.75	0.02	1.10	0.06	0.67	0.01	0.92	0.01	0.94	0.03
Shijiazhuang	0.76	-0.08**	0.95	-0.10**	0.73	-0.09**	0.84	-0.08**	0.83	-0.07**
Xinxiang	0.94	0.05*	1.11	0.06	0.93	0.05*	0.97	0.03	0.97	0.07**
Xuzhou	1.04	0.00	1.08	-0.14	1.04	0.02	1.02	-0.03	1.08	-0.05*
Yanzhou	1.20	0.04	1.19	0.02	1.23	0.06	1.11	0.00	1.14	-0.02
S_{WS}										
Beijing	0.34	0.02**	0.22	0.02*	0.38	0.02**	0.23	0.01	0.19	0.02*
Shijiazhuang	0.27	0.01	0.18	0.00	0.30	0.02	0.20	0.00	0.15	0.01
Xinxiang	0.21	0.02**	0.15	0.02	0.25	0.03**	0.17	0.03**	0.12	0.02*
Xuzhou	0.19	0.00	0.15	0.01	0.22	0.00	0.15	0.01	0.12	0.00
Yanzhou	0.20	0.00	0.14	0.00	0.24	0.00	0.15	0.01	0.10	-0.01

Table 5. Long term trends over the entire studied period of meteorological variables sensitivities in the selected weather stations, sensitivity coefficients for solar radiation (S_{RS}), relative humidity (S_{RH}), minimum temperature (S_{Tmin}), maximum temperature (S_{Tmax}),

wind speed (S_{WS}). (* and ** represent linear coefficients significant at $P < 0.05$ and $P < 0.01$, respectively.)

Simulated crop growth parameters were assessed using the APSIM model and the data set was split into two time periods (1961-1985 and 1986-2010) to allow comparison. As showed in Fig.13 Cumulative Probabilities of grain yield were similar for the two periods for Shijiazhuang and Xinxiang sites. Yield modeling for winter wheat was conducted under different irrigation strategies using DSSAT. Water stress during jointing and heading periods impacted greatly on yield for winter wheat. We also found that seeds were influenced by water stress during jointing and heading stages, and that grain weight was influenced by water stress during the filling period (Fig. 14).

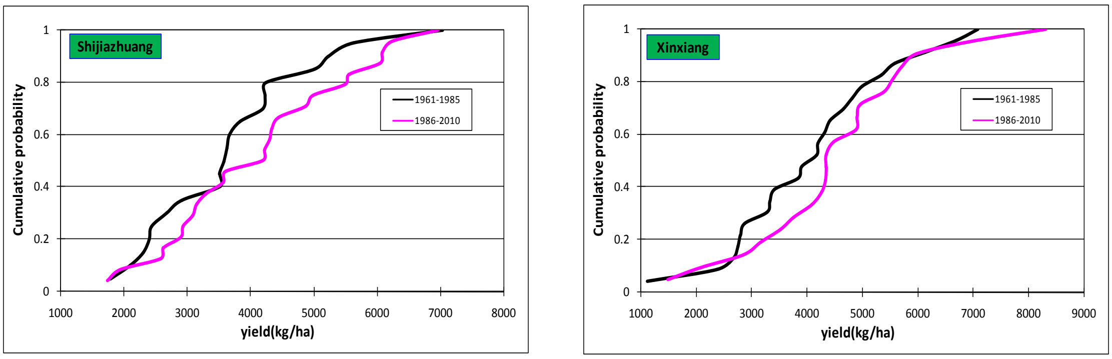


Figure 14. Probabilities of grain yield of wheat for Shijiazhuang and Xinxiang stations over two periods

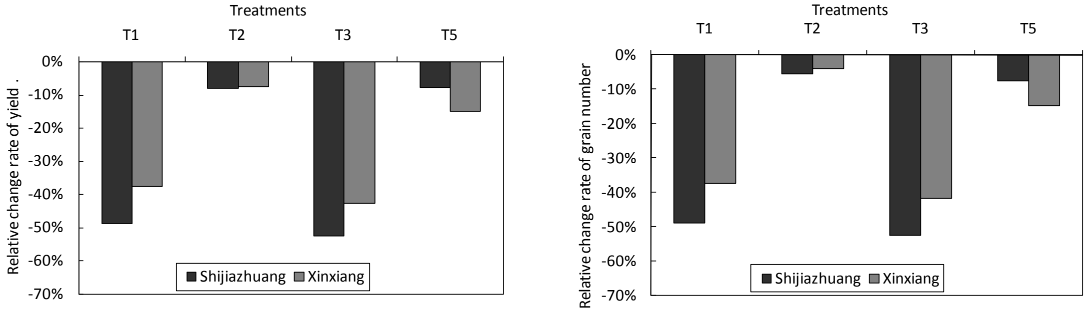


Figure 15. Effects of different irrigation conditions on wheat yield for Shijiazhuang and Xinxiang stations

3.3: India

Groundnut-Sorghum system in Dharwad, Karnataka

Dharwad, in the state of Karnataka in southern India, is in a typical hot semi-arid region. Soils in this region are mostly VERTISOLS with high clay content having water holding capacity of 210 mm. The annual rainfall in this region is about 600-700 mm. Historical climate database of 1975-2009 was used for the study. It is observed that annual maximum temperature significantly increasing during 1975-2009 (Fig 16). No trends were observed in rainfall and minimum temperature.

A Groundnut-Sorghum sequential system was simulated from 1975 to 2009 using the sequential analysis tool in DSSAT. Hagalur series soil which is having 210 mm AWHC was used. The JL 24 cultivar for groundnut and M35-1 of sorghum cultivar were used. This experiment was simulated under rainfed situation with the standard plant populations and fertilizer applications.

The results show that increased temperature by 2 °C has no effect on days taken to groundnut flowering but shortened the flowering to maturity duration by 3 days. Pod yield of groundnut was reduced by 19% with an increase in temperature by 2 °C and further reduced by 31% when coupled with reduced rainfall of 20% (Fig 17). However the yield is substantially improved with increased rainfall. Severe water stress during the crop growing season is main cause of the yield decrease in reduced rainfall scenario. Evapotranspiration is reduced from present 315 mm to 264 mm in the reduced rainfall scenarios (Table 2)

Post-rainy season sorghum was also impacted by climate change. Duration of sowing to flowering is reduced by 7 days and total crop duration is reduced by 11 days with an increase in temperature of 2 °C. Increase in temperature by 2 °C reduced the grain yield by 12% and coupled with reduction in rainfall, grain yield was further reduced by 27% (Table 6.). Evapotranspiration was reduced from present 227 mm to 196 mm.

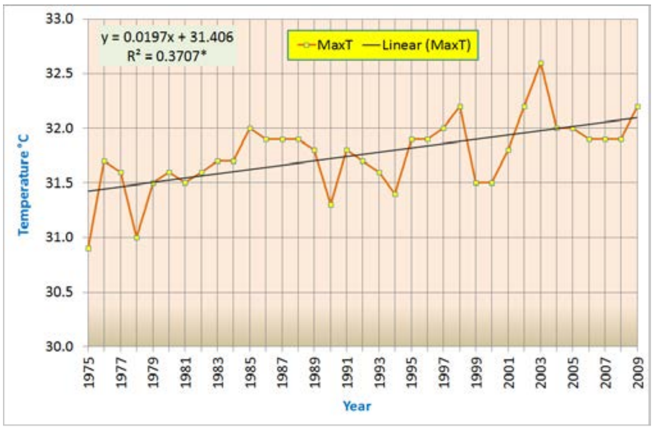


Figure 16. Increasing trend of maximum temperature at Dharwad, India

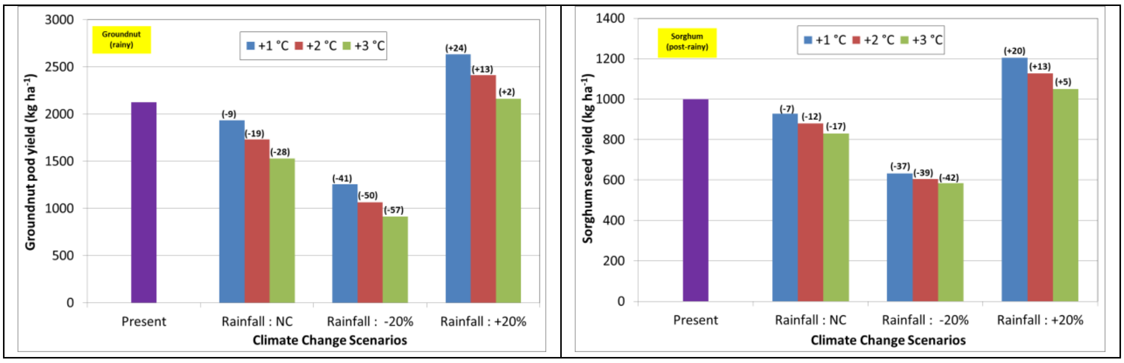


Figure 17. Impact of climate change on yield of groundnut-sorghum system at Dharwad, India

CC Scenario	Groundnut (Rainy) Flowering days	 Maturity days	 TDM (kg/ha)	 ET (mm)	Sorghum (Post-rainy) Flowering days	 Maturity days	 TDM (kg/ha)	 ET (mm)
Present	26	107	5071	315	67	108	5199	227
Rainfall : NC								
+1 °C	25	104	4700	314	64	103	4690	230
+2 °C	26	104	4350	316	60	97	4200	228
+3 °C	26	104	4010	320	57	92	3810	223
Rainfall : -20%								
+1 °C	25	104	3300	264	64	102	3700	199
+2 °C	25	103	3010	264	60	97	3350	199
+3 °C	26	103	2770	266	57	92	3050	196
Rainfall : +20%								
+1 °C	25	105	6080	357	64	102	5490	252
+2 °C	26	105	5660	360	60	97	4920	250
+3 °C	26	105	5310	366	57	92	4390	244

Table 6. Impact of climate change on groundnut-sorghum cropping systems at Dharwad, India

Soybean-Chickpea system in Dharwad, Karnataka

The rainfed soybean-chickpea system was simulated with all standard management practices. The cultivars JS 335 of soybean and JG 118 of chickpea were used. With increase in temperature by 2 °C the crop duration of soybean was shortened by 3 days and yield reduced by 31% (Fig. 18). Reduction in rainfall further reduced yields by 30%. Increase in rainfall substantially compensates the negative effects of temperature improves the crop yields. Evapotranspiration was reduced by 50 mm (Table 7).

The chickpea crop that was grown on stored soil moisture was considerably impacted by climate change. With an increase in temperature by 2 °C, the crop duration was not effected but the grain yield was reduced by 42%. However, a 1 °C increase in temperature with increased rainfall substantially increased yield by 27% compared to present situation.

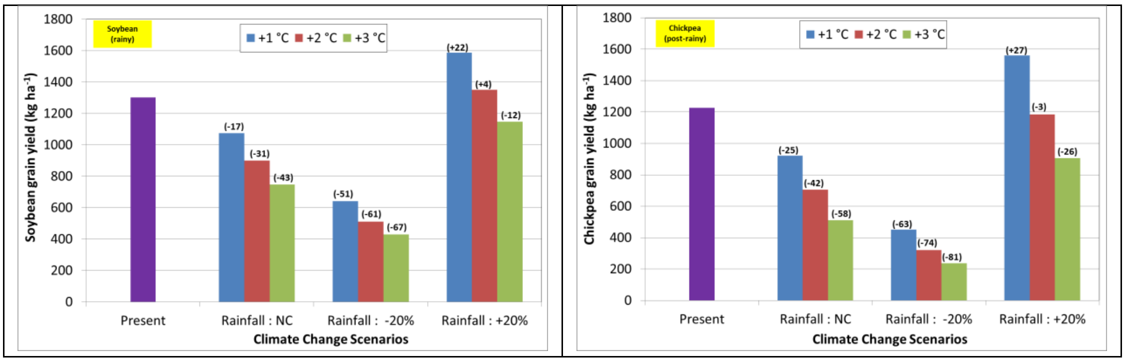


Figure 18. Impact of climate change on yield of soybean-chickpea system at Dharwad, India

CC Scenario	Soybean (Rainy)				Chickpea (Post-rainy)			
	Flowering days	Maturity days	TDM (kg/ha)	ET (mm)	Flowering days	Maturity days	TDM (kg/ha)	ET (mm)
Present	35	92	2450	305	41	80	3176	228
Rainfall : NC								
+1 °C	34	91	2120	305	41	79	2630	231
+2 °C	34	90	1860	305	41	79	2230	233
+3 °C	35	90	1620	307	42	79	1840	232
Rainfall : -20%								
+1 °C	35	90	1350	253	41	78	1680	196
+2 °C	34	89	1140	252	41	78	1390	198
+3 °C	35	89	980	253	42	78	1160	197
Rainfall : +20%								
+1 °C	34	92	2920	346	41	81	3760	260
+2 °C	34	91	2570	347	41	80	3120	265
+3 °C	35	91	2290	351	42	80	2620	265

Table 7. Impact of climate change on soybean-chickpea cropping system at Dharwad, India

Sorghum-Wheat system in Dharwad, Karnataka

Sorghum-wheat is a very important cropping system in the region. The system was simulated with all the standard management practices under rainfed conditions. The cultivar CSV 15 of sorghum and HD2009 of wheat have been used in simulations. Impact of reduced rainfall is much higher compared to increases in temperatures. Grain yield of sorghum in the rainy season is reduced by 17% with a temperature increase of 2 °C and coupled with reduced rainfall decreased by a further 29% (Fig. 19). The crop duration of sorghum was shortened by 8 days with temperature increase of 2 °C. Negative or positive changes in the rainfall by 20% do not significantly affect the crop duration. The increase in rainfall substantially compensates the negative effects of temperature and improves the crop yields. The evapotranspiration was reduced by 65 mm in the increased temperature and reduced rainfall scenario (Table 8).

In wheat, impact of increased temperature is predominant compared to rainfall. Crop duration was not considerably affected by temperature changes. However, Wheat grain yield was reduced by 33% with an increase in temperature of 2 °C and with coupled with reduction in rainfall reduced further by 5%. Increase in rainfall does not help to recover the yield losses due to temperature increase.

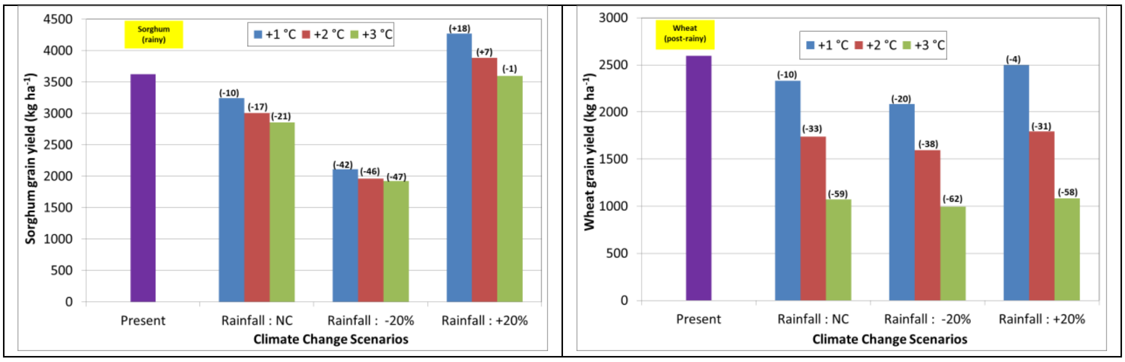


Figure 19. Impact of climate change on yield of sorghum-wheat system at Dharwad, India

CC Scenario	Sorghum (Rainy) Flowering days	 Maturity days	 TDM (kg/ha)	 ET (mm)	wheat (Post-rainy) Flowering days	 Maturity days	 TDM (kg/ha)	 ET (mm)
Present	80	114	9681	355	77	108	4808	227
Rainfall : NC								
+1 °C	76	110	8790	348	76	109	4790	245
+2 °C	72	108	8120	349	74	106	3830	244
+3 °C	69	105	7600	354	74	104	2580	236
Rainfall : -20%								
+1 °C	76	107	6350	292	76	108	4190	228
+2 °C	73	104	5890	289	74	106	3430	231
+3 °C	69	105	5580	297	74	104	2370	219
Rainfall : +20%								
+1 °C	76	113	10770	396	76	109	5200	251
+2 °C	72	110	9870	394	74	106	4090	252
+3 °C	69	106	9170	396	74	104	2650	245

Table 8. Impact of climate change on sorghum-wheat cropping system at Dharwad, India

Soybean-Chickpea system in Guna, Madhya Pradesh

Guna in the state of Madhya Pradesh in central part of India is a hot-dry sub-humid region. Mean annual rainfall in this region ranges between 1000 and 1100 mm. Soils in this region are mostly Vertisols with high clay content having water holding capacity of 200 mm. Crops in this region are soybean, chickpea, wheat sorghum etc. Historical climate database of 1975-2009 was used for the study. Annual maximum and minimum temperatures showed an increasing trend and (Fig 20) and no trend was observed in rainfall.

Soybean-Chickpea sequential system from 1975 to 2009 was simulated. Jamra series soil with an AWHC about 200 mm was used. JS 335 cultivar of soybean and JG 118 of chickpea cultivar were used. This experiment was simulated under rainfed situation with the standard plant populations and fertilizer applications.

Results show that increased temperature does not considerably change the crop duration of soybean. Grain yield of soybean was reduced by 14% with increase in temperature by 2 °C and further reduced by 7% when coupled with reduced rainfall of 20% (Fig 21). Yield was improved with increased rainfall but does not help to recover the total yield losses due to increased temperatures. Water uptake is increased with increased temperatures (Table 9).
Considerable rains during Sep and Oct help the chickpea in post-rainy season to withstand higher temperatures. Total crop duration is reduced by 7 days with increase in temperature of 2 °C. Increase in temperature by 2 °C reduced the grain yield by 3% and coupled with reduction in rainfall further reduced by 15% (Fig 7). Evapotranspiration was reduced from present 145 mm to 106 mm (Table 9).

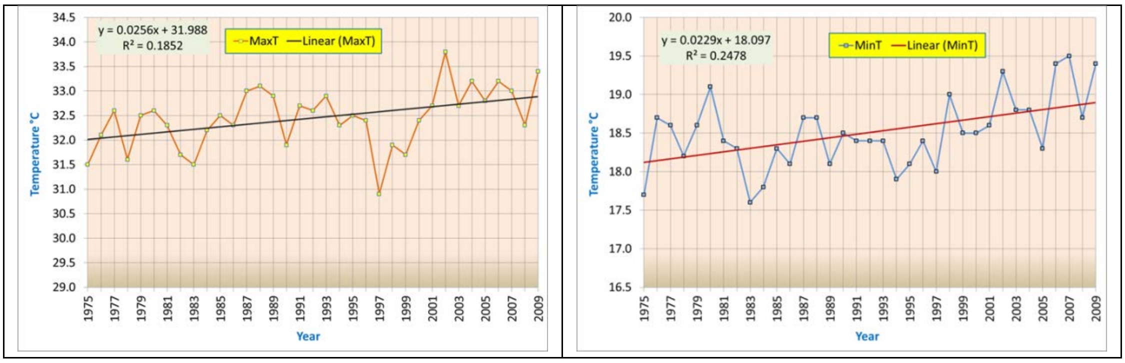


Figure 20. Increased maximum and minimum temperatures at Guna, India

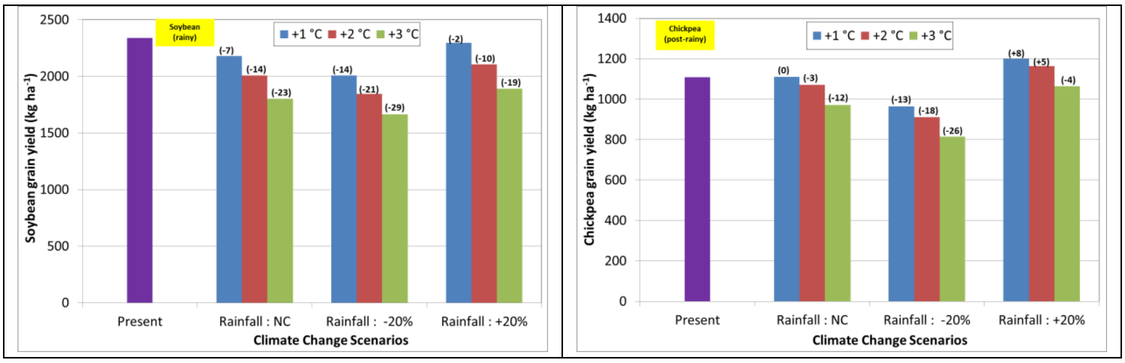


Figure 21. Impact of climate change on yield of soybean-chickpea system at Guna, India

CC Scenario	Soybean (Rainy)				Chickpea (Post-rainy)			
	Flowering days	Maturity days	TDM (kg/ha)	ET (mm)	Flowering days	Maturity days	TDM (kg/ha)	ET (mm)
Present	40	95	4370	46	107	2030	145	46
Rainfall : NC								
+1 °C	41	94	4170	45	103	1950	137	45
+2 °C	42	95	3970	45	100	1830	130	45
+3 °C	43	95	3730	45	98	1610	119	45
Rainfall : -20%								
+1 °C	40	92	3860	46	103	1680	125	46
+2 °C	41	93	3660	45	99	1540	116	45
+3 °C	42	93	3440	45	98	1340	106	45
Rainfall : +20%								
+1 °C	42	96	4390	45	102	2140	145	45
+2 °C	42	96	4150	45	100	2010	138	45
+3 °C	43	96	3910	45	98	1790	127	45

Table 9. Impact of climate change on soybean-chickpea cropping systems at Guna, India

Soybean-wheat system in Guna, Madhya Pradesh

The soybean-wheat system was simulated with standard crop management practices under rainfed conditions. Results show that increased temperature does not considerably change the crop duration of soybean at Guna. Grain yield of soybean was reduced by 14% with increase in temperature by 2°C and further reduced by 5% when coupled with reduced rainfall of 20% (Fig

22). Water uptake is increased with increased temperature (Table 6). Total dry matter was reduced from 4.6 t ha^{-1} in the present to 3.7 t ha^{-1} with increased temperature and decreased rainfall climate scenario.

Wheat crop duration is reduced by 10 days with increase in temperature of 2°C. Increase in temperature by 2°C reduced the grain yield by 29% and coupled with reduction in rainfall further reduced by 2% (Fig 22). Evapotranspiration was reduced from present 162 mm to 127 mm (Table 10).

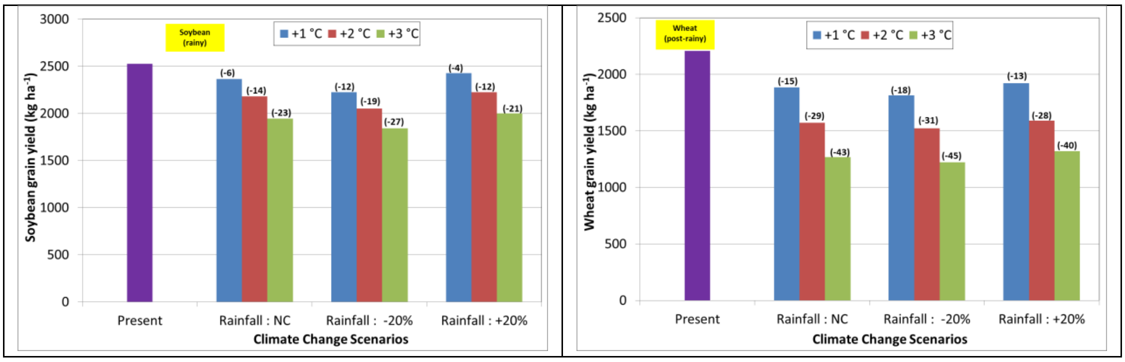


Figure 22. Impact of climate change on yield of soybean-wheat system at Guna, India

CC Scenario	Soybean (Rainy)				Wheat (Post-rainy)			
	Flowering days	Maturity days	TDM (kg/ha)	ET (mm)	Flowering days	Maturity days	TDM (kg/ha)	ET (mm)
Present	42	99	4630	390	98	136	3950	162
Rainfall : NC								
+1 ^{o}C	43	99	4430	405	93	131	3350	152
+2 ^{o}C	43	97	4210	418	89	126	2760	141
+3 ^{o}C	44	98	3960	435	86	121	2210	130
Rainfall : -20%								
+1 ^{o}C	41	96	4160	387	93	131	3250	148
+2 ^{o}C	42	96	3950	401	89	126	2710	138
+3 ^{o}C	43	96	3700	415	86	121	2160	127
Rainfall : +20%								
+1 ^{o}C	43	99	4570	415	93	130	3400	154
+2 ^{o}C	43	98	4320	431	89	126	2810	144
+3 ^{o}C	45	100	4080	448	86	121	2300	134

Table 10. Impact of climate change on soybean-wheat cropping systems at Guna, India

Groundnut-fallow system in Anantapur, Andhra Pradesh

Anantapur in Andhra Pradesh is a typical arid location which receives a low rainfall of about 450 mm in the crop-growing season (Jun-Nov) and groundnut is the major crop. Because of low rainfall farmers grow only one crop of groundnut in the rainy season and keep the field fallow in the post-rainy season. The groundnut-fallow system was simulated following the standard crop management practices under rainfed conditions. Prominent variety TMV-2 was used in this study. Groundnut pod yields would reduce by 20% with an increase in temperature of 2 °C and when coupled with decreased rainfall conditions, groundnut yields would reduce up to 32%. However in the increased rainfall scenarios the pod yield reductions were restricted to 10% (Fig 23). An increase in temperature by 3 °C extends mean days to flower and physiological maturity by 2 and 4 days respectively. Water use efficiency (productivity for each mm of water) was reduced by 24 and 38% with increases in temperature by 2 and 3 °C respectively (Table 11).

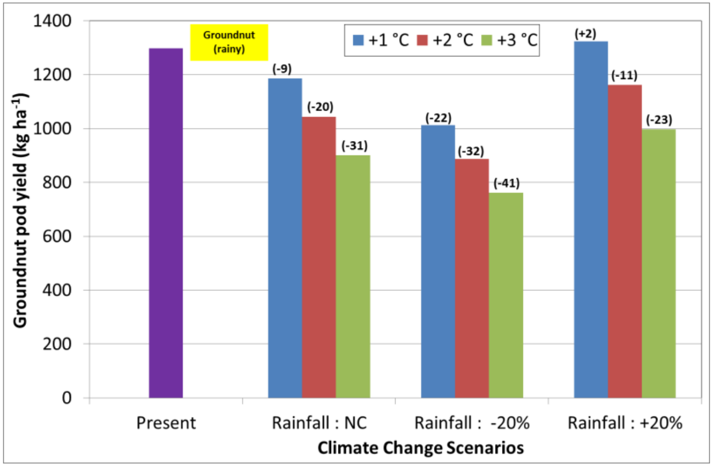


Figure 23. Impact of climate change on yield of groundnut at Anantapur, India

CC Scenario	Flowering days	Maturity days	TDM (kg ha^{-1})	Evapotranspiration (mm)
Control (Present)	30	95	3530	245
Rainfall : NC				
+1 °C	30	96	3440	251
+2 °C	31	97	3360	256
+3 °C	32	99	3350	268
Rainfall : -20%				
+1 °C	30	95	2990	228
+2 °C	31	97	2900	233
+3 °C	32	99	2890	242
Rainfall : +20%				
+1 °C	30	96	3760	267
+2 °C	31	98	3690	273
+3 °C	32	100	3640	283

Table 11. Impact of climate change on groundnut at Anantapur, India

Groundnut-Chickpea sequential system in Kurnool, Andhra Pradesh

Kurnool in Andhra Pradesh receives an annual rainfall of 700 mm. The prevailing soils are clay loam soils with AWHC of 200 mm. Groundnut-Chickpea is the predominant cropping system in this region. This system was simulated with standard crop management conditions under rainfed conditions. The cultivars TMV-2 of groundnut and ICCC-37 of chickpea were used in this study. Groundnut yields in the rainy season would reduce by 23% with an increase in temperature of 2 °C and when coupled with reduced rainfall, yields would reduce up to 46% (Fig

24). In the increased rainfall scenarios, the pod yield reduction was restricted only 7%. With increase in temperature by 3°C, days to flowering were extended by two days and physiological maturity was extended by four days. Due to the negligible rainfall in the post-rainy season, increased temperature drastically reduced the chickpea yield. Increase in temperature of 2 °C would reduce chickpea yield by 42% and coupled with reduced rainfall, chickpea yield would reduce up to 58%. Duration for flowering is extended by two days but the overall crop duration is not changed. The evapotranspiration of groundnut was not considerably changed while it is reduced for chickpea crop (Table 12).

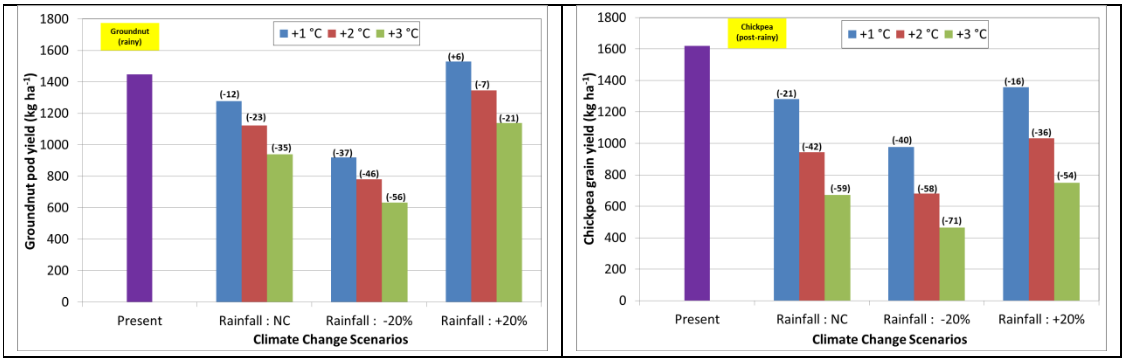


Figure 24. Impact of climate change on yield of groundnut-chickpea system at Kurnool, India

	Groundnut (Rainy)				Chickpea (Post-rainy)			
CC Scenario	**Flowering days**	**Maturity days**	**TDM (kg/ha)**	**ET (mm)**	**Flowering days**	**Maturity days**	**TDM (kg/ha)**	**ET (mm)**
Present	30	96	5380	277	37	79	3880	219
Rainfall : NC								
+1 °C	30	96	5140	285	37	79	3340	218
+2 °C	31	98	4940	296	38	79	2780	215
+3 °C	32	100	4740	307	39	80	2300	210
Rainfall : -20%								
+1 °C	30	96	4170	259	37	78	2770	198
+2 °C	30	97	3990	267	38	79	2260	195
+3 °C	31	100	3840	278	39	80	1870	189
Rainfall : +20%								
+1 °C	30	97	5840	304	37	79	3550	232
+2 °C	31	98	5660	317	38	79	3010	229
+3 °C	32	101	5430	330	39	80	2530	223

Table 12. Impact of climate change on groundnut-chickpea cropping systems at Kurnool, India

Post-rainy season Sorghum in Bijapur, Karnataka

Bijapur in Karnataka is a dry region, which receives 460 mm rainfall during June-September and 130 mm during October-December. Here, farmers generally grow sorghum during the post-rainy season. Soils are Vertisols with medium water holding capacity of 200 mm. The variety M35-1, which is extensively adopted during the post-rainy season, was used in this study. Since sorghum is grown on stored soil moisture, the impact of increased temperature is less compared to other locations. Increase in temperature reduced the grain yield of sorghum by 11% and when coupled with reduced rainfall the yield reduction was 14%. Increase in rainfall by 20% restricted the yield reduction only to 10% (Fig 25). Phenology of post-rainy season sorghum was considerably impacted with increasing temperatures. Days to flowering and physiological maturity were reduced by nine and 19 days respectively with increase in temperature by 3 °C (Table 13).

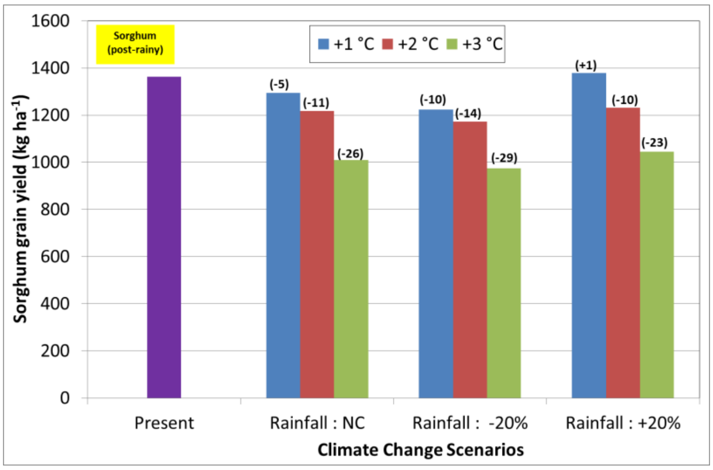


Figure 25. Impact of climate change on yield of post-rainy sorghum at Bijapur, India

CC Scenario	Flowering days	Maturity days	TDM (kg ha^{-1})	Evapotranspiration (mm)
Control (Present)	65	109	5180	217
Rainfall : NC				
+1 °C	62	103	4670	216
+2 °C	59	97	4050	212
+3 °C	56	90	3330	205
Rainfall : -20%				
+1 °C	62	103	4440	206
+2 °C	59	97	3900	203
+3 °C	56	90	3240	196
Rainfall : +20%				
+1 °C	62	103	4870	226
+2 °C	59	95	4110	219
+3 °C	56	90	3420	213

Table 13. Impact of climate change on post-rainy sorghum at Bijapur, India

Conclusions

The simulation results have shown that the selected temperature and rainfall change scenarios could reduce yields of major crops and cropping systems across locations. In most of the cases, crop durations are being shortened. In the increased rainfall climate scenario, additional rainfall could help to recoup the yield losses in the low rainfall years. Results of study indicated that, better water and nutrient management approach is the key and Integrated Watershed Management plays a major role in sustaining productivity of cropping systems productivity under future climate scenarios. Adoption of varieties tolerant to high temperature could also play a major role in sustainable yields. Water stress during the end of season could be avoided by sowing the short duration varieties. Breeding of varieties which produce extra root mass is required for sustainable production of cropping systems in the future.

Groundnut-fallow system in Anantapur, Andhra Pradesh

Anantapur in Andhra Pradesh is a typical arid location which receives a low rainfall of about 450 mm in the crop-growing season (Jun-Nov) and groundnut is the major crop. Groundnut pod yields would reduce by 20% with an increase in temperature of 2 °C and when coupled with decreased rainfall conditions, groundnut yields would reduce up to 32%. However in the increased rainfall scenarios the reduction in the pod yields were restricted to 10%. An increase in temperature by 3 °C extends mean days to flower and physiological maturity by 2 and 4 days respectively. The water use efficiency was reduced by 24 and 38% with increases in temperature by 2 and 3 °C respectively.

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4.0 Conclusions

The major technical aims of our Studies of the effects of realized Climate Change/Global Warming on crop production in three countries were:

a. To determine expected temporal shifts in crop phenology under realized climate change and future climates
b. To assess likely shifts in the pattern of rain and water availability
c. To estimate elements of climate change that will contribute to any mismatch between crop phenology and water availability, and
~~d.~~ To evaluate expected consequences of this mismatch and other shifts associated with climate change for food security

The APN Project has provided some valuable lessons, and led to some important conclusions. They include:

1. In assessing Global Warming effects, it is important to assess the effect on the crop production cycle, and not just on individual crops. For example, negative effects on one crop may be overridden by positive effects on another in the cycle
2. Mismatches were identified in both water availability and extreme temperatures during critical growth phases
3. In some cases, the effect of regional warming can be positive, for example in northern China where the extended growing season leads to increased productivity in the winter wheat-maize system
4. Use of historical field monitoring data may not be useful in assessing the effects of realized climate change on crop production, particularly if initial yields are low. Effects of Climate Change may be swamped by yield increases due to improved crop management and adaptation to changing climate. This was the case particularly in India. The effect of Climate Change in this case can be separated only by simulation.
5. Historical data is more useful in Australia because crop management practices are more sophisticated, and the main limitation to yield is water
6. Simulation of future Climates in Australia suggests that serious adverse effects on yields will not be evident till about 2050. This will allow researchers and farmers to develop adaptation strategies. In fact farming is a continual response to changing conditions (market, climate variability, climate change). Examples of adaptation are supplementary irrigation if feasible, breeding new varieties with better phenology adaption, or concentrating agriculture in areas more suited following Climate Change. In China, wheat-maize systems in the north are favored and rice-based systems in the south disadvantaged by increasing temperatures.
7. In India, the simulation results have shown that the selected temperature and rainfall change scenarios could reduce yields of major crops and cropping systems across locations. In most of the cases, crop durations are being shortened. In the increased rainfall climate

scenario, the additional rainfall could help to recoup the yield losses in the low rainfall years. Results of study indicated that, better water and nutrient management approach is the key and Integrated Watershed Management plays a major role in sustaining productivity of cropping systems productivity under future climate scenarios. Adoption of varieties tolerant to high temperature could also play a major role in sustainable yields. Water stress during the end of season could be avoided by sowing the short duration varieties. Breeding of varieties which produce extra root mass is required for sustainable production of cropping systems in the future.

8. Anantapur in Andhra Pradesh is a typical arid location which receives a low rainfall of about 450 mm in the crop-growing season (Jun-Nov) and groundnut is the major crop. Groundnut pod yields would reduce by 20% with an increase in temperature of 2 °C and when coupled with decreased rainfall conditions, groundnut yields would reduce up to 32%. However in the increased rainfall scenarios the reduction in the pod yields were restricted to 10%. An increase in temperature by 3 °C extends mean days to flower and physiological maturity by 2 and 4 days respectively. The water use efficiency was reduced by 24 and 38% with increases in temperature by 2 and 3 °C respectively.

Our project has had three important types of outcomes- technical results, capacity building through our Early Researchers Program (see Appendix 3) and communication to a wider audience. A strategy for communication to users (farmer organizations) and to policy makers is being developed for each country (see appendix 2).

5.0 Future Directions

Thanks to APN for their support in funding this current research project. Our work on food security and better crop management in a variable climate will continue through the following project funds:

- US $ 1.028 million over the period of 2013-2016 for a related research project “Improving Food Security in Qatar: Assessing Alternative Cropping Systems Feasibility and Productivity in Variable Climates, Soil and Marketing Environments”. Assoc. Prof. Samsul Huda is leading this project in collaboration with Qatar University, Al-Sulaiteen Agricultural and Industrial Complex, Doha, Qatar; and Trent University, Canada. Funding Source: Qatar National Research Fund (QNRF), National Priority Research Program (NPRP).

- $ 149, 057 over the period of 2013-2014 for a related research project **“**Better understanding constraints to smallholder adoption of agricultural technologies from the perspective of knowledge providers in Cambodia. Assoc. Prof. Samsul Huda is leading this project in collaboration with Cambodian Agricultural Research and Development Institute-CARDI), Funding Source: the Australian Centre for International Agricultural Research (ACIAR).

- US $500,000 over period of 2012-2016 for a related research project “The 12th five-year plan of the National Key Technologies R&D Program (No. 2012BAD09B01)”. Prof. Changrong Yan is leading this project in collaboration with Qingdao Agricultural University, Liaoning Academy of Agricultural Sciences, Funding source: Ministry of Science and Technology of the People’s Republic of China.

- US $42,857 over period 2014-2016 for a related research project “Modeling studies on soil water carbon quantitative relationship and crop water productivity in the Black soil in Songnen plain, China”. Mr. Qin Liu is co-leading this project in collaboration with Jilin Academy of Agricultural Sciences, Funding source: Ministry of Agriculture (MOA).

Other planned research in China includes:

1. To compare the responses of crop productivity to climate change with and without CO2 fertilization effects and between winter wheat and summer maize based on a crop model.
2. To access the impact of climatic trends and variability in crop system productivity using DSSAT

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Appendices

Appendix 1 a: The China Workshop-July 2013

Report on Final Workshop-APN funded research project "Food Security and Climate Change",

7-13 July 2013, China

Introduction:

The major aim of this workshop was to bring Project Leaders from China, India and Australia together to provide an update on progress at the finalization of the project, and to plan final reporting and future collaboration. The Agenda for the meeting is given below, and incorporated four major activities:

1. *Visit to Zhejiang University Tuesday 9th July:*

A familiarization trip to Zhejiang University was undertaken by Assoc. Prof. Samsul Huda along with local researchers to the library, information technology centre and the science precinct.

2. *Visit to China National Rice Research Institute Wednesday 10 July:*

The Field Trip on this day involved a visit to CNRRI and an overview of agriculture in Zhejiang province. Following formal discussions at CNRRI, we visited field plots. Of particular interest were experiments involving growth chambers exposing rice to varying periods at different phenological stages above an average temperature of 35 degrees Celsius. These experiments will be used to develop adaptation strategies and new cultivars.

3. *Project Planning Meeting, Hangzhou Thursday 11 July:*

The workshop was divided into two sections:

- Presentations by Prof. Huda, Prof. Mei and Dr. Wani updating technical results in Australia, China and India. Copies of these presentations are available on the Compact Disc accompanying this report

- Development of a plan for preparation of a Progress report and a Final Report for the project, and technical and policy documents.

4. *Meeting with Stakeholders, Beijing 13 July*

On the morning of 13th July the Project team met with Stakeholders from the Chinese Government at the CAAS building in Beijing to examine the significance of our project outcomes to Government policy and decision-making. The Stakeholders were:

- Xu Fahui, Division Head, Department of Crop Production, Ministry of Agriculture
- Ning Minghui, Division Head, Department of Crop Production, MOA,
- Li Bo, Division Head, Department of Science, Technology and Education, MOA, and
- Guo Jianping, Professor, China Meteorological Administration

Dr. Coughlan acted as Chairman for the meeting, and after a brief welcome from Prof. Huda he outlined the purpose of the meeting, in particular pointing out that the results of agricultural research were only of significant value when they were used for decision-making by policy makers, industry and farmers.

Program for Final Workshop-APN funded research project "Food Security and Climate Change",

7-13 July 2013, China

Date	Location	Activities
7 Jul Sun	Shanghai	Participants arrive
8 Jul Mon	Shanghai	Meeting with local researchers
9 Jul Tue	Travel to Hangzhou	Travel to Hangzhou Visit to Zhejiang University Revisiting project objectives and expected outcomes
10 Jul Wed	Hangzhou	Field trip (Rice)- visit China National Rice Research institute
11 Jul Thu	Hangzhou	Project Team Meeting Discussion for selected locations in Australia, China and India on: Historical climate data Effect of realised climate change on phenology, crop water availability and yield Effect of climate change scenarios on crop performance Implications of climate change, adaptation and policy Contrast and similarities across case studies Discussion on preparation of: Workshop proceedings 2013 Project final report
12 July Fri	Travel to Beijing	Travel to Beijing Interactions among national research leaders
13 Jul Sat	Beijing –Policy makers meeting	Involvement of policy makers to obtain feedback and develop policy briefs as appropriate Discussion on finalization of the work plan to complete the project

Appendix 1 b: The Sydney Workshop, March 2013

University of Western Sydney, Hawkesbury, Richmond, NSW

11-14 March 2013

The major aims of this workshop were to:

- Revisit the Project Objectives and expected outcomes, and ensure planning for achievement of all Objectives.
- Report on an update of data analysis for climatic data and Case Studies for India, China and Australia
- Group discussion of the content of reports and papers to ensure consistency
- Prepare rough drafts of papers. This activity occupied about 50% of the workshop time, and consisted of periods of writing by the three country groups, followed by plenary feedback over a two-day period.
- Planning for any further data analysis
- Planning of China final Workshop program. Originally planned for October 2013

A Program for the workshop is shown below

Program for University of Western Sydney, Hawkesbury, Richmond, Australia, 11-14 March 2013

Monday 11 March 2013

Time	
0830-0900	Revisit project objectives and expected outcomes
0900-0945	Analysis Summary –Australian locations
0945-1030	Analysis Summary – China locations
1030-1100	Tea
1100-1145	Analysis Summary – India locations
1145-1230	General discussion
1230-1330	Lunch
1330-1415	Plan for paper and report preparation-Australia
1415-1500	Plan for paper and report preparation-China
1500-1530	Tea
1530-1600	Plan for paper and report preparation-India
1600-1700	General discussion

Tuesday 12 March 2013

Time	
0830-0900	Summary of Monday's results
0900-0945	Preparation for paper and report -Australia,
0945-1030	Preparation for paper and report - China
1030-1100	Tea
1100-1145	Preparation for paper and report - India
1145-1230	General discussion
1230-1330	Lunch
1330-1415	Preparation for paper and report - India

1415-1300	Preparation for paper and report - China
1500-1530	Tea
1530-1600	Preparation for paper and report -Australia
1600-1700	General discussion

Wednesday 13 March 2013

Time	
0830-0900	Summary of Tuesday's results
0900-0945	Scientific paper writing : Australia, China, India
0945-1030	
1030-1100	Tea
1100-1145	
1145-1230	General discussion
1230-1330	Lunch
1330-1415	Future planning: Plan for project workshop in China
1415-1300	Further Analysis and data needs
1500-1530	Tea
1530-1600	Chinese team departs
1600-1700	General discussion

Thursday 14 March 2013

Time	
0830-0900	Summary of Workshop outputs
0900-0945	Field visit to University of Western Sydney facilities and local agricultural areas
0945-1030	
1030-1100	
1100-1145	
1145-1230	General discussion and concluding remarks
1230-1330	Lunch

Papers for different countries presented comparative case studies built on the analysis done so far including the contribution resulting from the Early Career Researchers' visit to Australia during August-September 2012.

The presentations addressed the following questions:

In the past,

- What are the realized long term climate trends (particularly rainfall and temperature?)
- What observed and simulated effects (using actual climate data and cropping systems simulation models) have these trends had on crop phenology and productivity?

And in the future,

- What models/scenarios are being used to predict future climates?
- Using these predictions, what are the expected temporal shifts in crop phenology under future climates?
- 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 crop yields and food security?
- What adaptation strategies and policies can be developed to build the resilience of

communities and the 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.

Copies of these presentations are available on request, and will be supplied in Compact Disc form with the Final Report.

Appendix 2: Research Implications for Policy Making and Agro-meteorology Advisory Services

A group meeting with Stakeholders was held in Beijing in July 2013 to discuss the relevance of our APN project to management and policy making in the areas of climate change and climate variability. Major feedback and conclusions are listed below:

1. Policy making on future food security cannot ignore Climate Change
2. In Agriculture, the Chinese Government is concentrating more on Adaptation than on Mitigation. Researchers have to develop integrated adaptation technologies including new cultivars and more efficient water use, and generally improved agronomic practices to overcome threats from Climate Change. One issue is that farmers in Developing Countries do not have significant education or awareness about Climate Change.
3. Mitigation strategies (reductions in Greenhouse Gas Emissions) in China will concentrate on industry and power production.
4. The Chinese Government has established a Disaster Fund to deal with extreme weather events as part of an Adaptation strategy
5. Climate Change has driven the development of new crop varieties for future climates. For example, maize varieties with a longer growing season (now available in northern China due to increasing temperatures) are less frost tolerant, and breeding is required to overcome this deficiency.
6. Greenhouse Gas Emissions from agriculture will also be addressed. In recent years there has been a decrease in soya bean production and an increase in rice production. Therefore research must concentrate on practices to reduce Greenhouse Gas Emissions and water use by rice, and to replace biological nitrogen fixation from soya bean crops.
7. The area of cotton production in China has also increased significantly, with plastic mulching being used as an adaptation strategy to reduce water use
8. Food security is of prime concern for the Government of China, and policy changes in northeast China have resulted in increased rice area. In China's northern plains this has increased the area planted to rice to 50 million Mu.
9. One major policy consideration in China is the move in concentration of cropping from south to north China. This is associated with two major developments over recent years:
    - Increased population density and industrialization in southern China has alienated considerable areas of agricultural land, and

- Increasing temperatures are reducing rice yields in the south, but having favorable effects on cropping systems in the north

In India the Challenge of achieving food security and sustainable development particularly in the semi-arid tropics with limited water availability and increasing land degradation is a daunting task. The challenge is further aggravated because of vulnerability of the semi-arid tropics to the adverse impacts of climate change in terms of decreased length of growing period, growing water scarcity, prolonged dry spells and increased occurrence of high intensity rainfall events.

In order to bridge the existing yield gaps, ICRISAT has proposed the “Hypothesis of Hope” as framework for minimizing the impacts of the climate change on the small and marginal farm holders in the semi-arid tropics. The existing yield gaps can be bridged through empowerment of the farmers by increasing adoption of improved management practices. In the “Hypothesis of Hope”, it is anticipated that by bridging the yield gaps with improved management practices, which can serve as the adaptation strategies in short-term for minimizing the impacts of the climate change, with the development of climate resilient crops/cultivars along with adaptation strategy in long-term, the farmers can benefit immensely with minimal impact of climate change.

In order to empower the farmers and cope with the uncertainty in the weather, ICRISAT and its Government partners have developed a strategy using the participatory watershed management as the framework for increased adoption of sustainability and eco-friendly options to unlock the potential of rainfed agriculture for meeting the goal of food security and sustainable development.

Integrated Watershed Management Programmes will benefit farmers through increased productivity and incomes by addressing issues of water use efficiency, drought management, soil erosion, soil nutritional deficiency and integrated pest management. Day-to-day agricultural operations are weather sensitive and weather-based agricultural advisories or Agromet Advisories at watershed level will help farmers to follow good agricultural practices to bring resilience in agriculture.

ICRISAT has installed automatic weather stations and raingauges in all watersheds. Climate and weather awareness among the rural community has been enhanced through trainings of high school students and farmers. Students are encouraged to write the daily weather data on notice boards in the school as well as on the school boundary walls in the local language to enhance the usage of weather information by the community. Agro-climatic information with respect to seasonal rainfall, start and end of crop-growing period with possible dry and wet spells is displayed as wall-writings in the watershed villages for climate awareness. Using the medium range (7-10 days) weather forecasts and NOAA satellite multispectral images, Agromet Advisories were provided to the watershed managers for taking appropriate crop management activities as part of a Pilot Study. Environmental Clubs also played a major role in building weather awareness among the community.

Public extension system requires a paradigm shift from top-down, blanket dissemination of technological packages, towards providing producers with the knowledge and understanding with which they solve their own location - specific problems. Continuous two-way interaction among the farmers and agricultural scientists is the most critical component of Agricultural Extension. In a new extension system, trained farmers are working as Farmer Facilitators and serving as link between the farmers and the Department of Agriculture staff.

ICRISAT has launched innovative extension systems namely ***KrishiGyanSagar*** (KGS) and ***Krishi Vani*** to benefit the Farmer facilitators and farmers in Karnataka to help transform target villages into model villages through capacity building of farmers and science-led interventions. These initiatives will use Information and Communication Technology (ICT)-based tools and means to provide up-to-date information on soil nutrient status, packages of practices, pests and diseases, taluk-wise nutrient recommendations, and crop related information in both Kannada and English. In addition to tablet-based delivery of information, farmer-to-farmer short videos will be made to be shown by Farmer Facilitators using battery-operated Pico Projectors. This will also enable the facilitators to track the adoption of the new technologies and obtain farmers' feedback.

In Australia, results from this APN Project will be communicated via the recently established Australian Society for Agricultural Meteorology (ASAM). One aim of this society is to provide opportunities for international collaboration, where resources and knowledge can be shared and reciprocal growth be facilitated. Since the push towards global food security is set to create a massive demand on developing sustainable agriculture in Australia, the Society is created to play an important role in particular to address climate-related factors for improving Australian agricultural production to meet future demands. ASAM aims to create a community of leading practitioners from both research (e.g. Universities, Departments, and the Bureau of Meteorology) and agricultural industries to improve the capacity of agriculture in Australia to meet these challenges. ASAM's linkage with the Europe-based International Society for Agricultural Meteorology (INSAM) will facilitate communication between users in Australia and overseas. It is creating opportunities to reinforce national skills through the Global Federation of Agro-meteorological Societies (GFAMS) facilitated by the Commission for Agricultural Meteorology (CAgM) of the World Meteorological Organization (WMO). It will provide opportunities to discuss common perspectives and motivations to work towards a successful societal networking to enhance research capability and performance in the areas of agriculture and the environment. As a founding member (and an additional Vice President) of the International Society for Agricultural Meteorology (INSAM) which has now operated for a decade, Assoc. Prof. Samsul Huda is in an excellent position to provide linkages between INSAM, the Australian Bureau of Meteorology, and the recently established the Australian Society for Agricultural Meteorology (ASAM).

Appendix 3: List of Early Career Researchers

Include brief detail (full name, involvement in the project activity) and contact detail (name of institution/country and email address) of your scientists involved in the project. Also include short message from the young scientists about his/her involvement in the project and how it helps develop/build his capacity and the knowledge he gained.

An Early Career researchers program: Realizing the significant input to the project that would be made by early career researchers in China and India, Mr Liu from IEDA, China and Mr Srinivas from ICRISAT, India were invited to spend six weeks in Australia in 2012. Strategies were developed to enhance capacity-building of these researchers during the project, including training in Australia and their involvement in the final international project workshop.

The early researchers program provided:

- Capacity-building from senior researchers in their own country and in Australia
- Their visit to Australia for training and mentoring, and research on the Australian program

A brief report from these early career researchers is given below:

Report from Mr Qin Liu, IEDA, China

My name is Qin Liu and I am from Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences located in Beijing. It is my great honor to attend the Young Researchers Program during 1 Aug to 15 September 2012 at University of Western Sydney and South Australia Research and Development Institute, Australia funded by the APN project.

I looked forward to this training when I stayed in China and I wanted to get to know different people, different country and different culture. I met a new friend, K. Srinivas who is from India, when I arrived at my residence. We talked about what we would learn and how we finish our job in UWS. With Dr. AKS Huda's cordial help and support we had a very comfortable and fruitful stay in Sydney as well as at Adelaide. We all were very much satisfied with this training. During this training we learnt many new tools for studying the trends of climate change and their impact. As for me, I learned how to conduct climate trend based on typical locations in detail and carry out APSIM and DSSAT model simulation especially parameter calibration.

We had the opportunity to work with climate datasets of three countries, viz. Australia, India and China. In China, significant increasing trend was detected for both minimum and maximum temperatures in annual and the winter season in all the six selected locations. Dr. Huda's excellent knowledge and vast experience in climate analysis is invaluable and with his help Srinivas developed a software tool based on programming language to estimate the starting and ending of the crop growing season and crop duration based on the user specified criteria of rainfall.

When we arrived at South Australia Research and Development Institute in Adelaide, it is another important experience for me to work with Dr. Victor Sadras along with Dr. Samsul Huda and Dr. Kep Coughlan about the impact of observed (real) climate change on the phenology and productivity of the wheat crop in transect locations of Australia using APSIM crop simulation model. In addition, Prof. Huda is so kind that he helped me modify two manuscripts titled by "Spatiotemporal characteristics of reference evapotranspiration and its sensitivity coefficients to climate factors in Huang-Huai-Hai plain, China" and "Spatial variations in phenological phases of winter wheat and its precipitation deficit in Huang-Huai-Hai Plain, China".

I am much thankful to my colleague from India, Mr. K. Srinivas. He generously taught me how to conduct model simulation research including how to get such important different parameters. Mr. K. Srinivas and I became good friends and we kept close touch by Email after this training.

I am very thankful to Prof. Xurong Mei, our Program Leader, for giving me this chance to attend this unforgettable training and to Prof. Huda for giving me this opportunity and the APN project.

Thanks and best regards,

Qin Liu
Assistant Professor

Key Laboratory of Dryland Agriculture, Ministry of Agriculture,
IEDA, CAAS

Report from Mr K. Srinivas, ICRISAT, India

"I have attended the Young Researchers Program from 1 Aug to 15 September 2012 at University of Western Sydney and South Australia Research and Development Institute, Australia under the APN project ARCP2011-08CMY-Huda. This was a wonderful experience for me to learn new tools to study the real and future climates and their impacts on agriculture in Australia, India and China.

This was my first international experience and when we landed in Sydney we were not sure what we learn and how we apply our existing knowledge to Australian climates. With Dr. AKS Huda's cordial help and support we had a very comfortable and fruitful stay at Sydney as well as at Adelaide. At the end of this career development program, we were very much satisfied with training provided. During this training we learnt many new tools for studying the trends of climate change and their impact. The readymade climate datasets of transect locations in south and southeast Australia eased our job to start the analysis right in the first day itself.

We had the opportunity to work with climate datasets of three countries, viz. Australia, India and China. Initially we have done trend analysis of monthly, seasonal and annual temperatures and rainfall. Even though there were no trends identified in the amounts of rainfall, there were some interesting results found in temperatures. There were significant increasing trends in minimum temperatures especially in winter season in Australia which could impact the wheat crop. In China, all the 6 locations having significant increasing trend in both minimum and maximum temperatures in the winter season and annual. Dr. Huda's excellent knowledge and vast experience in climate analysis is invaluable and with his help we could develop a software tool to estimate the starting and ending of the crop growing season and crop duration based on the user specified criteria of rainfall. With Dr. Huda's help we also established procedures in Microsoft excel to study the patterns of extreme rainfall and temperature events.

At South Australia Research and Development Institute, Adelaide, it was wonderful experience to work with Dr. Victor Sadras, Dr. Samsul Huda and Dr. Kep Coughlan. We were exposed to using APSIM crop simulation model to study the impact of observed (real) climate change on the phenology and productivity of the wheat crop in transect locations of Australia. During this training we had a good grasp over the soils of south and southeast Australia and rainfall patterns in these regions. We identified the water availability and water deficit patterns during the critical stage of wheat crop. We identified the probability of increased water stress during the critical phase of wheat in recent years (1984-2011) compared to previous period (1957-1983) at few locations. The increase temperatures in winter caused to shortening the flowering and crop duration of the wheat and resulted into probability of getting lesser yields.

During this training, we had an excellent opportunity to interact with eminent professors in School of Natural sciences, UWS. Apart from climate analysis and impacts of climate change on crops, we also had exposure to field visits near UWS and attend to some important lectures on carbon assessment and environmental issues in Australia. These visits were useful to understand the measures being taken in Australia to deal with Carbon issues.

My colleague from China, Mr. Quin Liu was very friendly and we used to exchange the cultural and life style information of both the countries of India and China.

I am very thankful to Dr. Wani, our Program Leader, for choosing me for this training and Dr. Huda for giving me this opportunity and the APN project ARCP2011-08CMY-Huda. I hope the results of this training could be useful for the project and could be explored further.

Thank you and warm regards,

K.Srinivas
Lead Scientific Officer
RP1-Resilient Dryland Systems
ICRISAT, Patancheru"

In addition, a number of young researchers particularly in China and India were formally involved in the project through formal studies in their home countries. These researchers are listed in the Table below.

The list of students involved in APN Project in China and India

Name	Major	Dissertation	Supervisor	Years
CHINA				
Zhai Zhifen	Agronomy (PhD)	Assessment of agricultural adaption techniques against climate Change	Yan Changrong	2009 - 2012
Yang Jianying	Ecology (PhD)	Study on the water productivity of winter wheat-maize in 3H Plain, China	Mei Xurong	2011 - 2014
Hu Wei	Ecology (Master)	The effect of drought on winter wheat in 3H Plain, China	Yan Changrong	2011 - 2014
Xu Jianwen	Agro-Meteorology (Master)	Assessment of drought risk for winter wheat in 3H plain, China	Ju Hui & Liu Qin	2011 - 2014
INDIA				
Alisaheb A Nadaf	Agronomy (Master)	Performance of pigeonpea varieties under broadbed and furrow cultivation of model watershed of Dharwad	SP Wani	2011 -12
A C Gnanesha	Agronomy (PhD)	Integrated Nutrient Management in maize, chickpea sequence cropping under broadbed and furrow land management systems in model watershed of Dharwad	SP Wani	2011 -14

Appendix 4. Glossary of Term

ACIAR	Australian Centre for International Agricultural Research
APSIM	Agricultural Production Simulator
CAAS	Chinese Academy of Agricultural Sciences
CARDI	Cambodian Agricultural Research and Development Institute
CCAM	CSIRO Cubic Conformal Model
CNRRI	Chinese National Rice Research Institute
DSSAT	Decision Support System for Agrotechnology Transfer
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IEDA	Institute of Environment and Sustainable Development in Agriculture
NBSS&LUP	National Bureau of Soil Survey and Land Use Planning
NOAA	National Oceanic and Atmospheric Administration
QNRF	Qatar National Research Foundation
SARDI	South Australian Research and Development Institute
UWS	University of Western Sydney
3-H	The Huang-Huai-Hai Plain in China

Appendix 5. Separate CD with Photos, PowerPoint Presentations, Copies of Papers