FINAL REPORT for APN PROJECT
Project Reference: ARCP2010-05CMY-Luck

The Effects of Climate Change on Pests and Diseases of Major Food Crops in the Asia Pacific Region

The following collaborators worked on this project:

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A Bangladesh potato grower sitting in a field of potato affected by late blight, 2010

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OVERVIEW OF PROJECT WORK AND OUTCOMES

Non-technical summary

This project investigated the impact of climate change on an important disease of potato, Late Blight, in the Asia Pacific Region. Potato is increasingly grown in the Asia Pacific as a food staple and cash crop, with India being the third largest producer in the world. Drawing on the project team's agrometeorology and plant pathology skills, an assessment was made on (i) the climate projections for potato growing regions across India, Bangladesh and Australia (ii) the effects of climate change on potato production and (iii) the influence of climate change on potato late blight and subsequently the effects on potato yield under future climates. One major achievement of this project was the new collaboration formed between the three countries on a significant disease issue of potato. This was the first time, crop modellers, agrometerologists and plant pathologists combined their expertise to understand the effects of climate change on this important disease system for the three countries. Over 20 years of disease incidence data was collected from West Bengal and Bangladesh which was critical in predicting future disease incidence. Importantly, we have developed three country policy briefs to deliver the key findings of this project to the Bangladesh and West Bengal Agriculture ministers and to Australian Biosecurity agencies. The project team has formed a new capability to investigate the risk of pests and diseases under future climates and we would now like to extend this capability to other major crops and their pests and diseases within the Asia Pacific.

Objectives

The main objectives of the project were:

1. To share and collate observations and data on any increased risks posed by pests and disease to major food crops of the Asia Pacific under climate change.
2. To form a new collaboration between Australian crop biosecurity scientists and modellers with Indian and Bangladesh pathologists and entomologists with a focus on understanding the effects of Climate Change on crop losses due to pests and diseases.
3. Develop strategies for agriculture and government based on shared knowledge of the project team, to respond to any increased risks posed to food crops (policy briefs)
4. To prepare a scientific paper for submission to an international journal on climate change eg. *Global Change Biology.*

Amount received and number years supported

$ USD 38,720 for Year 1:
$USD 39,520 for Year 2:

Activity undertaken

Workshop 1: Bidhan Chandra Krishi Viswavidyalaya University Kalyani, Kolkata- 15-17 Dec 2009

The first workshop was held at BCKV University, West Bengal State, India. Agrometerologists discussed the climatic variables already affecting Bangladesh, such as severe cyclones in the Bay of Bengal, increasing temperatures increasing precipitation, increasing intensity of floods and droughts and increasing sea levels with rising salinity in soil a major concern for Bangladesh. In India, the rising temperature was considered more limiting and expected to negate the CO_2 fertilisation effect despite the higher transpiration efficiencies. The general approach adopted at the workshop was to identify the climatic risks for each country and then determine how current practices and policies can be adapted to reduce these risks. A session was held to identify which disease could be a common focus for the project, using criteria such as the economic significance, severity of the disease or pest, evidence of changes to distribution or severity, scientific capability and level of background data. After some discussion, a consensus was reached on Potato Late Blight (*Phytophthora infestans*) as the common disease for the network to focus on. A strong case study will be developed over the next 12 months to demonstrate the effects of late blight on a global food staple, potato and how the increasing intensity of droughts and floods may alter the severity and distribution of this disease, in the three member countries.

Image: Workshop 1 delegates, Kalyani 15-17 Dec 2009

Workshop 2 DPI Victoria Melbourne and the University of Western Sydney Oct 17-22, 2010

The second Workshop was held at the Department of Primary Industries (DPI) Victoria, Knoxfield and the University of Western Sydney (UWS), Hawkesbury campus. The workshop focussed on Potato Late Blight in India and Bangladesh. Chilling stories were told of Indian farmers recently suiciding as a result of total crop loss due to PLB, highlighting the seriousness of this disease. India and Bangladesh have the aggressive mating type of *Phytophthora infestans*, whereas Australia is one of the few countries that do not have the aggressive strain of the pathogen. The historical datasets (1972-2010) for planting times, late blight initiation and severity were presented for both countries with climatic data sets associated with late blight establishment presented by project agro meteorologists, for the same period. In addition, downscaled climate projections to 2100 will be used in conjunction with published Late Blight models to determine if there will be increased risk in Late Blight incidence under future climates for India, Bangladesh and Australia. Project members visited Thorpdale and the Hawkesbury potato growing regions in Victoria and NSW to meet Australian growers to learn how late blight is managed in Australia.

Image: Bangladesh team members in potato field, Thorpdale Victoria (L to R), the late Dr Delowar Hossain, Prof G. Miah and Dr M. Assadazzuman

Workshop 3 Writing paper and policy Brief, Kasestart University, Bangkok May 8-13, 2011

The main objective of the third workshop was to prepare a scientific paper and three country policy briefs describing the implications of the project's research. Writing group leaders presented summaries of what they had achieved to date. The team discussed the implications for policy from an industry and government perspective and presented a draft template which was completed at the workshop. The need to document a policy statement was agreed to be a very useful outcome of the project and it was decided to prepare separate documents for each country.

Image: Workshop 3 delegates at Kasestart University, Bangkok (R. Spooner-Hart missing from photo)

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

This project involved the co-ordination of data at the regional and national level for India and Bangladesh. The meteorology expertise (India Meteorology Department, Delhi) was linked to pest and disease data (Bangladesh, India) and used in crop models and Late blight models to provide a multidisciplinary program of Global Change Research. These links will strengthen the research capacity on climate change and food crop pest and diseases. A scientific paper on the research outcomes of this project will formalise the network formed through the APN, increasing the exposure of the APN's global research.

The information generated in this project will be transferred to decision makers through three policy briefs tailored to each member country (Appendix). To respond to future climates, changes to industry practices and government policies may be required. This project identified the potential risks associated with climate change and plant biosecurity and food crop management.

Self evaluation

The three workshops were very productive with the major milestone from the APN-GC project (a co-authored draft manuscript) being successfully completed on "the implication of climate change to potato production and Potato Late Blight disease in Bangladesh, India and Australia" which we have adapted for the technical summary. This paper brings together data from member countries on potato production, historic incidence of the disease together, the climate variables important for establishment of this disease and a review and validation of the models used to analyse potato yield and potato late blight incidence with respect to future climates.

The main achievement of the project was the successful combination of different disciplines eg. agrometeorologists, entomologists, pathologists and crop modellers from the three member countries focused on a common goal. The multi-disciplinary approach resulted in a much more comprehensive analysis of PLB severity under future climates than simply tackling the problem from a pathology and climate perspective only. It was important to understand how the crop itself responded to future climates before understanding how the pathogen behaves.

Potential for further work

A concept proposal "Potato Cultivar and Crop Improvement for South-Southeast Asia and the Pacific Region in the Context of Climate Change" was developed at our final workshop to expand the work done in this project to include adaptation to potato pests and diseases in the Asia Pacific through cultivar improvement. This proposal has been submitted recently to the APN. This project aims at identification of new emerging scenarios of major biotic (diseases and pests) and abiotic (drought, heat, excess humidity and soil salinity) constraints to potato production under the climate change situations in the Asia and Pacific region, and the need of new types of cultivars and production techniques for adaptation.

Acknowledgments

This report and paper that emanates from this project will be dedicated to the late Dr Delowar Hossain, our dear colleague who sadly passed away shortly after our final workshop in Bangkok. He was a dedicated plant pathologist who worked for the Bangladesh Agricultural Research Institute and contributed greatly to the preparation of the historical incidence of potato late blight section in this report. On behalf of the project team it was our pleasure to collaborate with him on this project, we greatly appreciated his efforts and we will remember him fondly.

TECHNICAL REPORT

Preface

The following report is an adaptation of the manuscript we have developed from the research conducted in this project. We present (i) Our findings from modelling the climate projections for the potato production regions in West Bengal, Bangladesh and Australia (ii) the effect climate change will have on potato yield in each of these regions and (iii) how the risks posed by the fungal disease, Potato Late Blight may be altered in future climates.

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1.0 Introduction

The Intergovernmental Panel on Climate Change reported that global surface temperature has increased 0.74 °C during the hundred years ending in 2005 (IPCC, 4th assessment report). Global Climate Models project a rise in global temperature by 1.8 to 4°C by the year 2100 due to the increase in greenhouse gases in the atmosphere. This is expected to have significant consequences for suitability and productivity of current agriculture in specific agro-ecological zones, as well as on the incidence and severity of diseases affecting agricultural crops.

Potato is the world's major non-cereal food crop and the fourth largest crop after maize, rice and wheat, with production reaching a record 325 million tonnes in 2007 (FAO 2008). Potato consumption is growing strongly in the developing countries, which now account for more than half the global harvest. An increasing demand for food from growing populations, together with the impact of a changing climate on weather patterns, is driving a push for greater diversification of agricultural crops to ensure food security in the developing world. The potato is ideally suited to regions where land is limited and labour is abundant, conditions that characterise much of the developing world (FAO 2008). The potato produces more nutritious food more quickly, on less land and in harsher climates than any other crop. Its ease of cultivation and high energy content has made it a valuable cash crop for millions of farmers in the developing countries (FAO 2008).

Asia is second to Europe in annual potato production (FAO 2008) (137 M tonnes and 130 M tonnes in Asia/Oceania and Europe in 2007, respectively), which together account for more than 80% percent of world production. India ranks as the third largest potato producing nation (26 million tonnes in 2007). In Bangladesh, the value of potato production is second only to that of the rice crop. In 2007, 4.3 million tonnes were harvested, placing the country at No. 14 among the world's potato producers and No. 4 in Asia. Australia's annual potato crop of 1.3 million tonnes is small in comparison to world production. However, potatoes rate as the most important horticultural crop in Australia, accounting for more than 40 percent of total vegetable output. Annual per capita consumption in India, Bangladesh and Australia are 17, 24 and 54 kg, respectively (FAO 2008).

Late blight of potato (*Solanum tuberosum*), caused by the oomycete pathogen *Phytophthora infestans*, is considered to be the most economically important disease of potato worldwide. Under favourable climatic conditions, and without intervention (i.e. fungicide sprays), the disease can destroy a potato crop within a few weeks. Late blight is a major disease of potatoes in India (Singh 1996) and Bangladesh. The problem has been exacerbated by the introduction into Asia over the past two decades of new strains of *P. infestans* that are genetically more variable, aggressive, fit and resistant to fungicides than the 'old' strains. In Australia, late blight is only a minor disease of potatoes, occurring sporadically in localised areas when weather conditions are favourable.

Late blight is very much a 'weather-driven' disease, dependent on two major climatic factors: moisture and temperature (Harrison 1992). Late blight epidemics are favoured by still conditions with high moisture and moderate temperatures for periods of several days (Harrison 1992). Typically, late blight will develop when there are waves of warm moist air combined with stagnant or slow-moving weather depressions that give rise to lengthy periods of still, humid, overcast weather that result in a heavy deposition of dew on the leaves (e.g. light rain, fog or mists). These conditions are common in the summer in the temperature regions of Western Europe, for example, or in the tropical highlands of many developing countries.

A key objective of the technical component of this project was to conduct a case study of climate change in India (West Bengal), Bangladesh and Australia and on the impact of the projected climate change on the productivity of the potato crop and on the severity of late blight.

2.0 Methodology

The information presented here was developed through a series of three workshops:

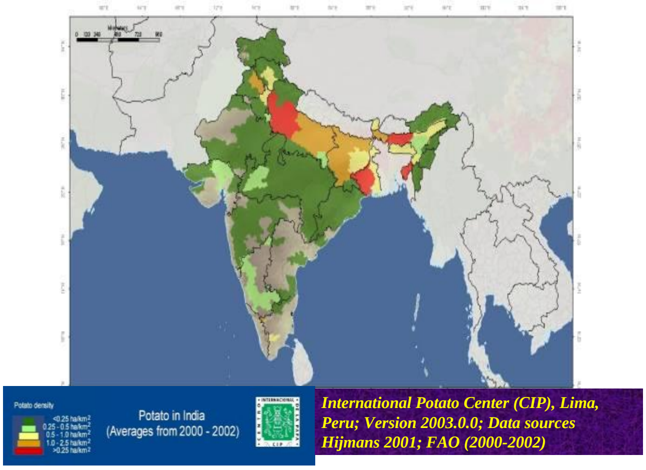
- Workshop 1 – Scoping a case study – understanding crop/pest/pathogen systems in common between West Bengal, Bangladesh and Australia and determining their suitability for a case study on climate change. The potato crop and the late blight disease of potato were selected by the team for further study;
- Workshop 2 – Presentation of data on potato production, late blight disease, climate projections and the impact of a changing climate on potato productivity and the severity of potato late blight disease in West Bengal, Bangladesh and Australia; and
- Workshop 3 – Consolidation of data for the case study and the development of a draft paper for publication in an international journal.

The general approach was to apply realistic climate scenarios as defined by the IPCC applicable to each country. They are well understood throughout the world and provide a known reference for others to compare our results to analyses done in other locations under the same or similar climate scenarios. Downscaled daily data were generated for two representative sites in each country to assess the likely effects of climate change on potato production and late blight disease in West Bengal, Bangladesh and Australia. Specific methodology is described in their respective sections below.

3.0 Results and Discussion

3.1 The importance of potatoes in West Bengal, Bangladesh and Australia

West Bengal



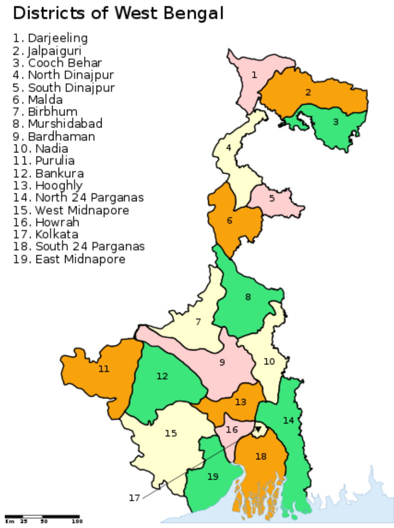


Figure 1 Potato production areas and production intensity in India (red is highest) (source International Potato Centre) and the districts of West Bengal

Based on 2008 figures (FAO 2008), India is the third largest producer of potatoes in the world (26 million tonnes with estimates of possibly 35 million tonnes at present). Figure 1 shows the production areas and production intensity. The potato is primarily a cash crop that provides significant income for farmers. Some potato varieties are grown on the Indo-Gangetic plain during short winter days (October-March), while some are grown year-round in relatively high altitude areas in the south (FAO 2008). The state of West Bengal accounts for more than one quarter of the total crop in India.

Bangladesh

Potato is an important cash crop in Bangladesh, grown as a winter crop from October-March, often after rice. The value of production was around $560 million in 2005, second only to that of paddy rice (FAO 2008). The 2007 harvest was estimated to be 4.3 million tonnes, which placed Bangladesh at No. 14 in the world and No.4 in Asia. Potato production areas of Bangladesh are presented in Figure 2.

Potato will become even more important in Bangladesh with a Government drive to diversify agricultural crops in the country. Bangladesh is one of the most densely populated countries of the world (977 people/km^2) with a population of 147 million and growing, and also one of the most densely farmed countries in the world. Agriculture is the backbone of the economy accounting for 20.6% of GDP and 48.4% of employment. Rice is the dominant grain crop. With population predictions of 173 and 190 million by 2020 and 2030, respectively, Bangladesh will not be able to feed itself in the future. There is no scope for increasing rice production.

Bangladesh faces the problems of a significant lack of arable land, an increasing demand for food, intensification of climate change and natural disasters. A diversification of the production systems, particularly tubers, vegetables, spices and other crops that are expected to improve agricultural output and income, has been given high priority by the government of Bangladesh. The potato crop is ideally suited to this program because it does not complete with rice and because of its ease of cultivation, high productivity per unit areas and diversity of uses. However, a changing climate may potentially have adverse effects on potato productivity into the future.

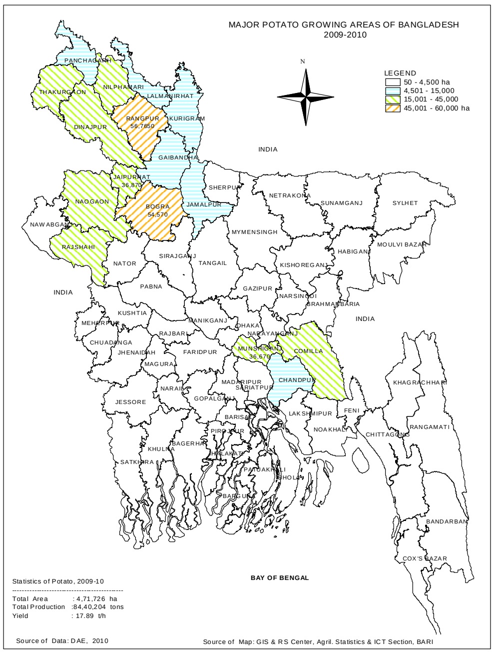


Figure 2. Major potato growing areas of Bangladesh (2009-2010).

Australia

Australia produces about 1.3 million tonnes of potatoes on 38,000 hectares (average 35 t/ha) on a wide range of soil types, climatic conditions and varying day lengths (Figure 3). Crops are generally grown over the Spring-Summer, although in some regions, two plantings are possible, a mid-summer planting and a mid winter planting. Annual farm gate value is estimated to be around $500 million annually. Production is highly mechanised with a continuing trend over the past few decades of fewer farmers working larger acreages. Crop yields are managed with a high input of fertiliser and irrigation. About 70% of production is processed for French fries and crisps, with the remainder used for the fresh market (table and seed potatoes). Only about 5% of the crop is exported. Because of the heavy reliance on irrigation to produce current yields, any trends in warming and drying of the climate could be expected to reduce productivity.

Figure 3.Potato production areas in Australia

3.2 Climate change predictions for West Bengal, Bangladesh and Australia

We were not able to use identical IPCC scenarios across all countries because some Global and Regional Climate Models do not provide all the IPCC scenarios (e.g. A1Fi). We chose the A1B scenario for India and Bangladesh using two global climate models (EH5OM and HadCM3Q) downscaled respectively, by the RegCM3 and PRECIS regional models. For Australia we chose the A1Fi scenario using CSIRO's global atmosphere model (CCAM-Mark 3.5). The A1B scenario describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and rapid introduction of new and more efficient technologies and balanced across energy sources. For Australia we chose the A1Fi scenario that represents a greater reliance on fossil fuel whereby emissions continue to accelerate through to mid century but the scenarios do not differ greatly until after 2050.

3.2.1 West Bengal and Bangladesh

Potato is a major horticultural crop grown in West Bengal and Bangladesh and yield of which is likely to be influenced by the future climate. To understand the future trend of climate and to study its impact on yield of potato two regional climate models (RegCM3 and PRECIS) were run over for selected locations in Australia, Bangladesh and West Bengal (India). This Regional Climate Models (RCM) are run at 25km resolution and driven with the Global Circulation Model (GCM) outputs as initial condition and boundaries. We have used EH5OM GCMs output in RegCM3 and HadCM3Q output in PRECIS. Both models used A1B scenario, which describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and rapid introduction of new and more efficient technologies and balanced across energy sources. The RegCM3 is being developed by International Centre for Theoretical Physics, Italy while the PRECIS (Providing Regional Climate for Impact Studies) is being developed at Hadley Centre, UK Met Office, United Kingdom (http://www.metoffice.gov.uk/precis).

The post processed outputs from the model runs were utilised for working out decadal mean for the ensuing four decades starting from 2011-2050. Both models showed an increasing and significant linear trend (0.2 to 0.6 C per decade) for the maximum temperature and minimum temperature (Table 1 and Figures 4 and 5), as indicated by IPCC (2007). Though both the models showed increasing trend for rainfall outputs from PRECIS are higher than those from RegCM3. No difference in solar radiation is predicted.

Table 1. Decade-wise mean projections for Bangladesh and West Bengal for minimum and maximum temperature, solar radiation and rainfall determined from the downscaled RCMs.

Decade	RegCM3				PRECIS			
	TMIN (°C)	TMAX (°C)	SRAD MJ/m^2	RAIN (mm)	TMIN (°C)	TMAX (°C)	SRAD MJ/m^2	RAIN (mm)
2011-2020	18.8	29.4	18.2	2004	20.1	28.9	16.7	2203
2021-2030	19.0	29.6	18.1	2021	20.5	29.0	16.4	2432
2031-2040	19.5	30.1	18.2	2058	20.9	29.6	16.7	2371
2041-2050	19.9	30.4	18.2	2021	21.4	30.2	16.8	2505

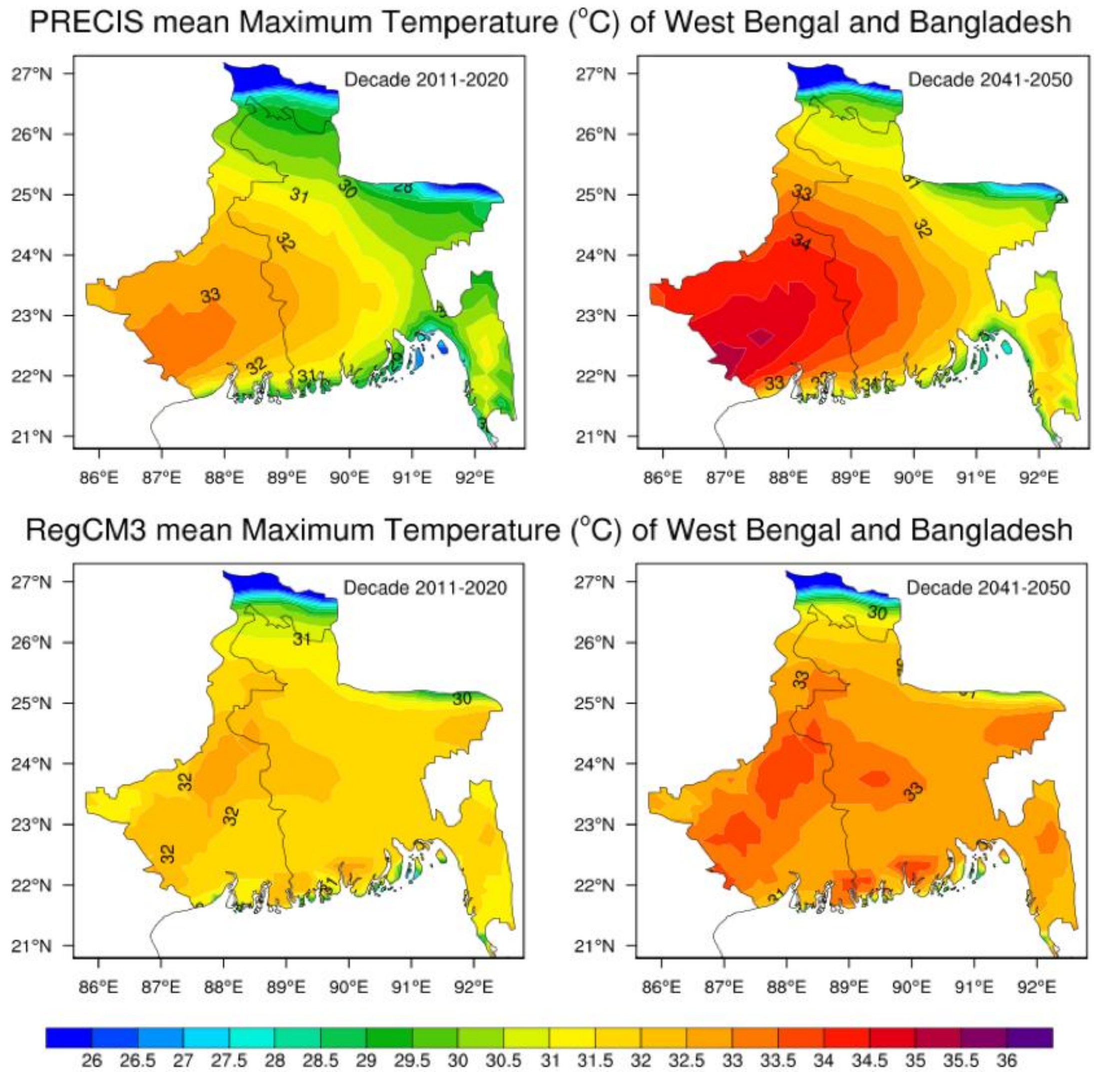


Figure 4. Maximum temperature projections for decades 2011-2020 and 2041-2050.

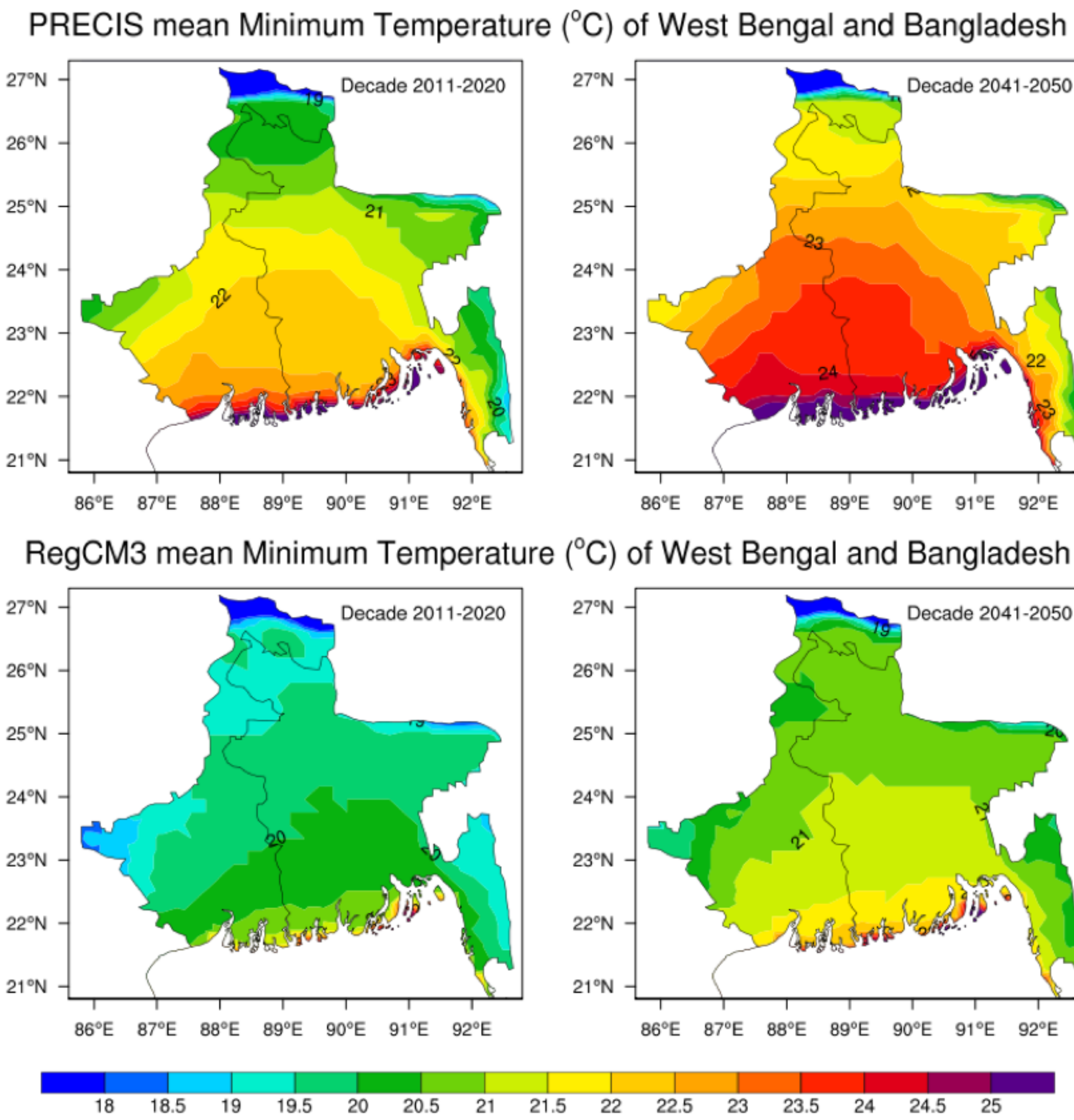


Figure 5. Minimum temperature projections for decades 2011-2020 and 2041-2050.

Representative locations were selected within West Bengal and Bangladesh to generate local daily data to run the potato and late blight disease models. These locations were selected because of important climatic differences. There is a greater temperature range at Krishnanagar than at Bagati. The minimum temp during the growing season (Nov to Feb) at Krishnanagar is slightly cooler (12 to 17°C) than at Bagati (15-18°C) but the maximum temperature at Krishnangar is warmer (29-32 °C) than Bagati (22 to 28 °C). Monthly rainfall at both locations is rather low because it is the dry season ranging from 9 to 24 mm at Krishnanagar and 6 to 38 mm at Bagati.

3.2.2 Australia

We selected a tropical and temperate location in Australia to compare the expected effects of climate change on potato production by 2050. The locations were Kairi Research Station, Queensland (Australian Bureau of Meteorology Station #031034, lat. 17.22°S Long. 145.57°E, elev. 697m) and Thorpdale State School, Victoria (Station #085081 Lat. 38.30°S, Long. 146.20°E, elev. 243m). The weather patterns during the growing seasons for these localities are different. At the tropical location potato is grown during the dry season from the end of summer (March to May) and at the temperate location it is grown in the Spring-Summer (October to December) period. The seasonality of climate change is, therefore, crucial to understanding its effects on potential potato production and on the incidence and severity of potato late blight.

Climate Projections for Australia

The International Panel on Climate Change (IPCC) scenarios were used to define likely climatic changes that are well understood throughout the world (IPCC, 2007). This was to provide a known reference for others to compare our results to analyses done in other locations under the same or similar climate scenario. We chose the IPCC scenarios A1Fi based on CSIRO's global atmosphere model (CCAM-Mark 3.5) to reflect a realistic possible future climate because it was clear that world-wide mitigation effects expressed in A2 and B1 were not likely. Indeed, the present day (2011) actual atmospheric CO_2 concentrations at Horsham in Victoria Australia are 386 ppm that is very close to the A1FI scenario (391 ppm). We think that the future in Australia might be much more pessimistic than A1FI.

The predicted change in winter (May to October) climate in Australia by 2050 shows significant warming and drying in much of the country (Figure 6). For the two contrasting temperate and tropical areas of interest for potato growing (Gippsland, Victoria and the Atherton Tablelands, Queensland) the general trend of warming and drying applies with increases in daily minimum and maximum temperatures of around 2-3°C and declines in seasonal rainfall expected to be about 30-40% in both locations. However, significant differences in solar radiation and humidity between these locations are evident. In the tropical north solar radiation is expected to increase by around 0- 2% whilst in the southern location a greater increase of around 2 to 3% in radiation is expected. The relative humidity is expected to decrease by about 2 to 3% and greater than 4% in the north and south, respectively.

The predicted change in summer (November to April) climate in Australia by 2050 shows a similar warming and drying across country (Figure 7) compared to the winter predictions. The warming is less in the tropics (1 to 2°C) compared to the temperate south (2 to 3°C).

Parts of Australia are predicted to have significant increases in summer rainfall (mid-Queensland coast and North-western New South Wales) but near our tropical experimental site the rainfall is expected to decrease by a smaller amount (5-10%) compared to the winter rainfall (40%). Solar radiation is expected to increase over much of Australia, including the Atherton tablelands areas, over summer between 2 and 3%. Relative humidity is expected to decrease over summer from 4 to 8 % as both locations.

Downscaling from global to Thorpdale, Victoria and Kairi, Queensland Australia

Global and regional climatic effects need to be applied at the local scale to be of practical use. Whilst dynamic downscaling methods are the most desirable, the more common statistical methods are readily available. We have found a useful downscaling method involving scaling historic daily climate sequences by a derived mean-monthly spatial pattern of climate change per degree of global warming (Suppiah et al. 2001, Anwar et al. 2007, Weeks et al. 2010). The historical sequence weather data can provide a useful base line for current, non-climate changed environment comparisons to some future environment.

We used patterns of climate change per degree of global warming on a monthly basis for four climate variables (rainfall, maximum and minimum temperature, and solar radiation) at Thorpdale and Kairi (Hennessy et al., 2006). The pattern was applied to 68 years of historical data from these sites (1935-2004) (obtained from SILO patch-point, http://www.longpaddock.qld.gov.au/silo/), which was then used to create a 68-year future scenario for 2050 (Method B, Weeks et al. 2010). This implies that for each future year we have a sequence of weather data with the same number of years as the historical data. This method allows the climate change effect to be analysed without confounding from atypical individual years. This statistical method assumes that the autocorrelation that exists between years in the historical data is applied to all sequences applied to any future years. However, this method does not address extreme events that are believed to increase in intensity and frequency due to progressive climate change.

Overall, the effects of climate change are subtly different between our example locations. To compare the agronomic response between the sites, the changes in the summer climate at Kairi need to be compared to the changes in the spring-summer climate at Thorpdale (Tables 2 and 3). In the downscaled weather data we see large differences in temperature, rainfall and radiation that are expected to have important implications for potato production and its associated likelihood for Potato Late Blight infection and its management.

Historical climatic differences between Kairi and Thorpdale, Australia

Both the minimum and maximum temperatures during the growing season (Mar to Oct) are much warmer at Kairi (Min 11 to 19°C, max 21 to 27°C) than Thorpdale (Oct-May) (min 7 to 12 °C, max 16 to 24 °C), respectively (Tables 2 and 3). The length of the growing season is therefore expected to be significantly shorter at Kairi than Thorpdale with the same cultivar. Large differences in rainfall patterns exist between the sites with Kairi having the largest range and highest monthly totals (20 to 263 mm) compared to Thorpdale with a monthly range from 56 to 98 mm (Tables 2 and 3). The daily solar radiation at Kairi is similar (15 to 24 MJ/m2/d) to Thorpdale (17 to 22 MJ/m2/d) but differences reflect cloudiness and latitude.

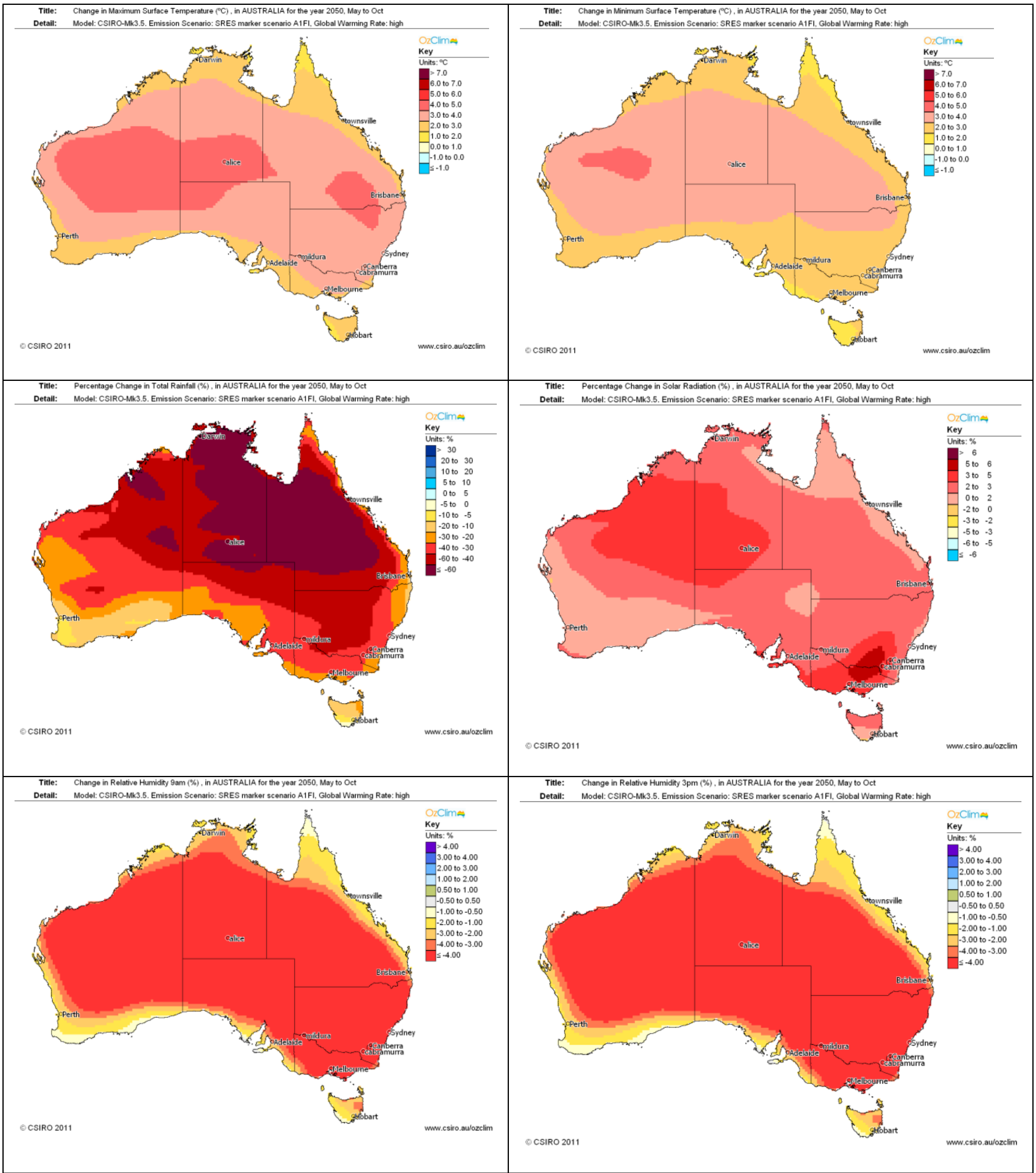


Figure 6. Predicted Australian winter seasonal change (May to October for 2050) in (a) minimum surface temperature (°C), (b) maximum surface temperature (°C), (c) rainfall (%), (d) solar radiation (%), (e) relative humidity (%) at 0900 h and (f) relative humidity (%) at 1500 h. Model: CSIRO-Mk3.5. Emission Scenario: SRES marker scenario A1Fi, Global Warming Rate: high. Source: http://www.csiro.au/ozclim/.

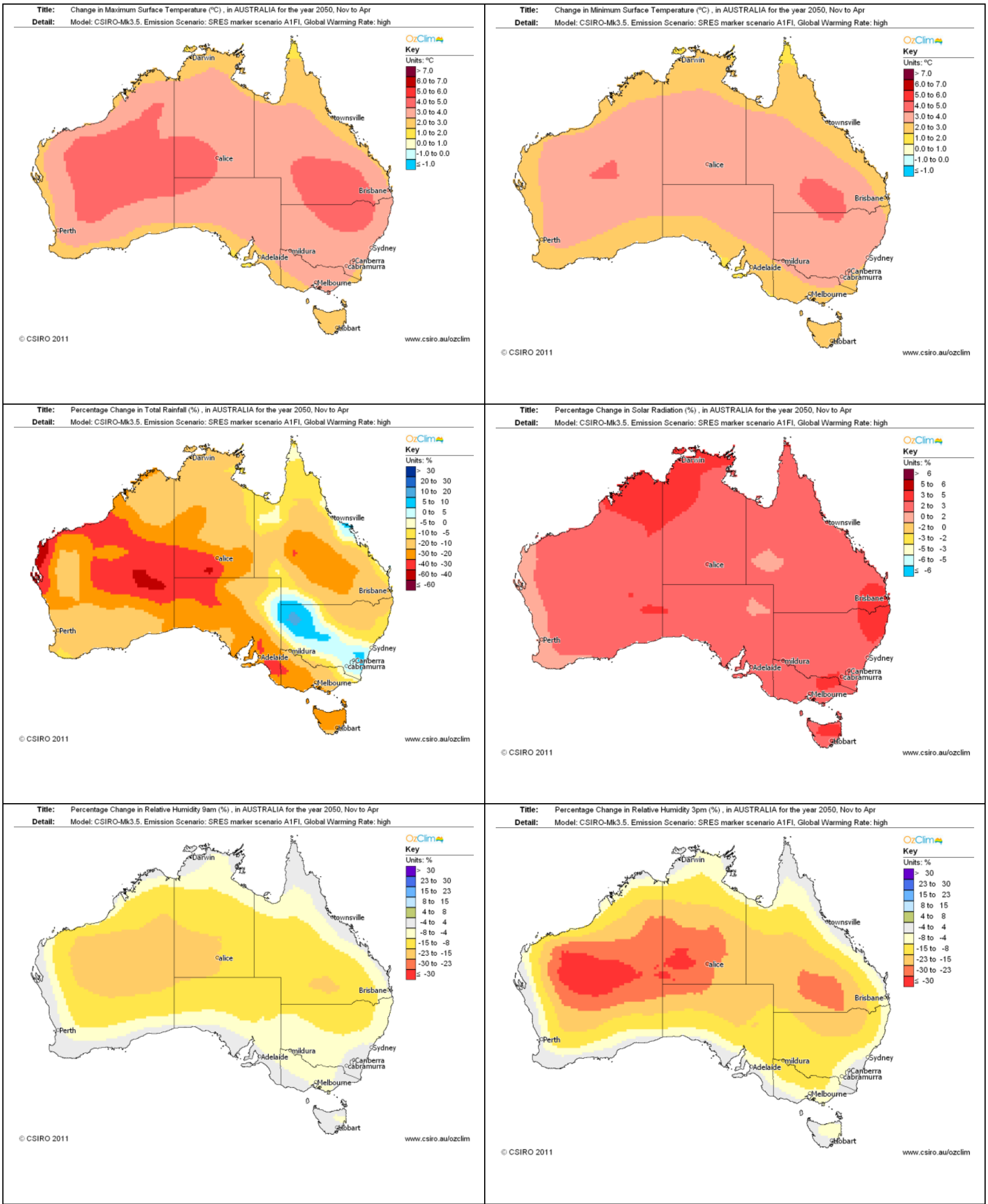


Figure 7 Predicted Australian summer seasonal change (November to April for 2050) in (a) minimum surface temperature (°C), (b) maximum surface temperature (°C), (c) rainfall (%), (d) solar radiation (%), (e) relative humidity (%) at 0900 h and (f) relative humidity (%) at 1500 h. Model: CSIRO-Mk3.5. Emission Scenario: SRES marker scenario A1Fi, Global Warming Rate: high. Source: http://www.csiro.au/ozclim/.

Table 2. Summary of mean historical (1935-2002) meteorological observations and future expectations for the year 2050 (CSIRO CCAM A1Fi High rate of warming) at Kairi, Queensland Australia.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Daily minimum temperature (^oC)												
Historical	19.1	19.4	18.5	16.7	14.6	12.1	11.2	11.5	12.9	15.0	17.1	18.4
2050 mk3	21.0	21.1	20.0	18.2	16.2	13.3	12.4	12.8	14.1	16.1	18.4	19.9
2050 mk3.5	21.1	21.7	20.4	18.6	16.4	14.1	13.0	13.2	14.5	16.8	18.9	20.3
Daily maximum temperature (^oC)												
Historical	28.3	27.7	26.5	24.8	23.1	21.5	21.3	22.6	24.8	27.1	28.5	28.9
2050 mk3	30.6	29.8	28.5	27.2	25.5	23.2	22.8	24.2	26.5	28.8	30.7	31.7
2050 mk3.5	30.5	30.2	28.8	26.9	25.5	23.7	23.3	24.6	26.6	29.1	30.7	31.2
Monthly rainfall (mm)												
Historical	223	305	263	95	54	40	25	23	20	28	72	126
2050 mk3	229	286	198	25	39	25	20	17	15	3	37	2
2050 mk3.5	217	374	213	68	35	30	15	12	19	10	47	93
Daily solar radiation (MJ/m^2)												
Historical	20.5	18.5	18.0	17.0	15.5	14.9	15.9	18.4	21.3	23.6	23.6	22.4
2050 mk3	22.7	19.8	19.9	18.7	16.1	14.8	16.2	18.4	21.9	25.1	26.1	24.1
2050 mk3.5	21.1	19.2	18.6	17.5	16.1	15.1	16.1	18.6	21.6	24.0	24.0	23.1

Table 3. Summary of mean historical (1935-2002) meteorological observations and future expectations for the year 2050 (CSIRO CCAM A1Fi High rate of warming) at Thorpdale, Victoria Australia.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Daily minimum temperature (^oC)												
Historical	11.5	11.9	10.8	8.5	6.7	5.0	4.0	4.5	5.6	7.1	8.5	10.0
2050 mk3	13.0	13.7	12.9	9.9	8.2	6.7	5.7	6.0	6.7	8.5	10.1	12.1
2050 mk3.5	13.9	14.4	13.4	10.9	8.6	6.8	6.3	6.5	7.4	9.6	11.0	12.6
Daily maximum temperature (^oC)												
Historical	23.1	23.5	21.0	17.3	13.9	11.4	10.8	12.0	14.1	16.4	18.4	20.9
2050 mk3	25.6	26.0	23.7	19.5	15.6	13.1	12.6	13.9	16.6	19.6	21.9	24.1
2050 mk3.5	25.8	26.4	23.9	20.4	16.9	13.8	13.3	14.8	17.3	19.9	21.6	24.1
Monthly rainfall (mm)												
Historical	56	60	69	82	93	104	94	109	109	98	92	76
2050 mk3	39	63	54	62	92	106	90	103	63	50	56	42
2050 mk3.5	55	49	59	72	79	86	69	63	62	67	58	56
Daily solar radiation (MJ/m^2)												
Historical	22.1	19.8	15.5	11.5	8.0	6.7	7.3	9.9	13.5	17.1	19.9	21.7
2050 mk3	23.6	20.4	15.9	11.6	7.9	6.7	7.2	10.1	13.6	17.6	20.6	23.3
2050 mk3.5	22.6	20.1	16.1	12.2	8.4	7.0	7.7	10.4	14.1	17.8	20.5	22.4

3.3 Effects of climate change on potato production

Downscaled daily data were generated for two representative sites in each country to assess the likely effects of A1B and A1Fi climate change scenarios on potato production and late blight disease in West Bengal, Bangladesh and Australia.

3.3.1 West Bengal and Bangladesh

The effect of climate change on potato production in India has previously been studied by Singh et al. (2009). This study showed that potato productivity is expected to decline in all potato growing districts of India (Table 4). For West Bengal by 2050 a 16% decline in tuber yield is expected without any special adaptation strategies. However, if planting time is adjusted significant reductions in the yield decline may be achieved (Table 5). Indeed, some increase in yield is possible in the Punjab and Haryana, but in West Bengal the yield loss is expected to be less at about 8% if crops were planted at a new optimal date of mid November.

Table 4: Impact of climate change on tuber productivity in major potato growing states of India without adaptations under optimal management (2020: 1ºC, 393 ppm; 2050:3ºC, 543 ppm)

States	Change (%) from current productivity	
	Future climate (year)	
	2020	2050
Uttar Pradesh (UP)	-1.61	-9.08
West Bengal (WB)	-4.86	-16.11
Bihar	-3.01	-11.50
Punjab & Haryana	-7.31	-3.66
Madhya Pradesh	-6.64	-20.63
Gujrat	-16.75	-55.10
Maharashtra	-8.82	-35.29
Karnataka	-18.68	-45.73

Ref.: Singh *et al.*, 2009

Table 5: Effect of adaptation through change of planting date on potato production in India from Singh *et al.* 2009

Location: Indo-Gangetic Plains	DOP	Change (%) in yield		
		Current	2020	2050
Jalandhar (Punjab)	-5	-5.6	6.7	-3.4
	OPT (Nov 1st)	0.0	7.3	3.7
	+5	15.1*	18.1	13.8
	+10	19.4*	21.7	18.9
Burdwan (West Bengal)	-5	-1.4	-7.5	-19.8
	OPT (Mid Nov)	0.0	-3.9	-7.7
	+5	-8.6	-9.4	-15.5
	+10	-15.0	-19.6	-24.1

*In the current climate during frost free years delayed planting was found beneficial but is not recommended due to enhanced risk of frost damage

Our analyses in West Bengal and Bangladesh concur with Singh et al. (2009) for the propensity for yield decline by 2050 but ranging from a 23 - 32% loss. Our more pessimistic results probably reflect the more pessimistic A1B scenario than the generic 3^{o}C mean temperature rise and elevated CO_2 of 543 ppm. Some differences between the regional climate models were notable highlighting the variance between the regional models, but overall the same conclusions of yield decline would be drawn from both models (Table 6).

At Bogra in Bangladesh the PRECIS model indicated a much lower yield loss (7.2%) compared to the RegCM3 RCM analysis of -26% and this location had an overall lower yield loss than at Munshiganj. Crop management strategies therefore might need to be regionally adapted.

Table 6 : Summary of expected mean potato tuber yield (dry weight t/ha) for 2011-2020 and 2040-2049 and percentage change between the decades using the DSSAT-Potato crop model and downscaled daily data generated by the PRECIS and RegCM3regional climate models (see text for details).

	2011-2020			2040-2049			Difference	
RCM	PRECIS	RegCM3		PRECIS	RegCM3		PRECIS	RegCM3
Nadia,	18.3	18.4		14.2	12.9		-23%	-30%

West Bengal India								
Hoogly, West Bengal India	16.4	17.5		11.7	11.9		-28%	-32%
Bogra, Bangladesh	21.3	19.2		19.8	14.2		-7.2%	-26%
Munshiganj, Bangladesh	20.3	17.6		16.6	12.2		-18%	-31%

3.3.2 Australia – Thorpdale and Kairi

The potato crop simulation model

We simulated potato tuber yield with the APSIM-Potato model Version 7 for cultivar Russet Burbank. This is a daily time step model that simulates water balance for a crop, including crop transpiration and deep drainage. It comprises sub-models that simulate crop phenology, above-ground biomass with partitioning to tubers. The model requires significant soil parameters such as lower and upper extractable water limits, bulk density, pH and initial soil water and mineral and organic carbon and nitrogen. It is responsive to elevated CO_2 by amending the growth parameters of radiation use efficiency and transpiration efficiency. The model has not been formally tested in these localities but has performed very well in New Zealand but its performance statistics are not currently available (Brown et al. 2011).

Simulation analyses

We applied the models to a single agronomic regime at each location over three levels of climate. At Kairi planting of potato was set to occur within a window defined by accumulated rainfall (10 mm over any two days and soil water content of at least 10 mm) between 15 March and 15 July each year a period coinciding with the end of the wet season. At Thorpdale the planting window was 1 October to 31 December reflecting the summer dominant conditions at the southern location, but with the same rainfall and soil water criteria as at Kairi.

At planting we assumed a seed density of 15/m2 to 30 mm depth and row spacing of 350 mm. Crop were fertilised with an initial large dose of mineral N to remove any deficiency issues (500 kg N/ha at both sites). Soil water was set at full profile (347 mm) for the first year and was simulated for subsequent years based on seasonal conditions but with supplemental irrigation to maintain water stress conditions such that the relative available water is above 0.5 in the top 30 cm of the soil profile. Surface organic matter was set at 1000 kg/ha with a C:N ratio of 80.

The three climate regimes were: (1) 68 years of historical weather data, (2) 68 years of historical weather data with elevated atmospheric CO2 at 550 ppm and (3) 68 years of representative 2050 weather data after A1Fi IPCC CSIRO Mark 3.5 projection.

Table 7. Mean potato (*cv* Russet Burbank) tuber dry weight (t/ha) under historical and future (2050) climatic scenarios for 68 year of simulation (APSIM 7) at Kairi, Queensland and Thorpdale, Victoria. Simulated treatments are for historical climate (aCO2 386 ppm), historical climate with elevated CO_2 (e $CO_2$550 ppm) and the full Mark 3.5 2050 future climatic that includes changes to temperature, rainfall, radiation and CO_2.

	Historical (1935-2003)	**Historical + eCO_2**	**A1Fi 2050**
Kairi, Queensland	**15.1**	**15.3**	**14.6**
Thorpdale, Victoria	**13.0**	**13.4**	**12.9**

The effects of likely climate change on potato tuber yields in both locations in Australia show similar behaviour. There is a very slight increase in mean yield from the fertilisation effect of elevated CO_2 under a present climate scenario (Table 7). However, adding the full effect of the A1Fi climate change scenario (increased temperatures and reduced rainfall) caused a small reduction in mean yield (3%) at the tropical location with virtually no change at the temperate location(<1%).

These responses were further explored by examining the variance of yield over the years expressed as the probability of exceedence of any particular yield. At Thorpdale the climate change effect appears to be distributed evenly about the mean response with about half the time yields being less (and higher) than the present climate (Figure 8). However, at the tropical site (Kairi, Queensland) yields by 2050 are not expected to be not much greater than the present climate in any cases.

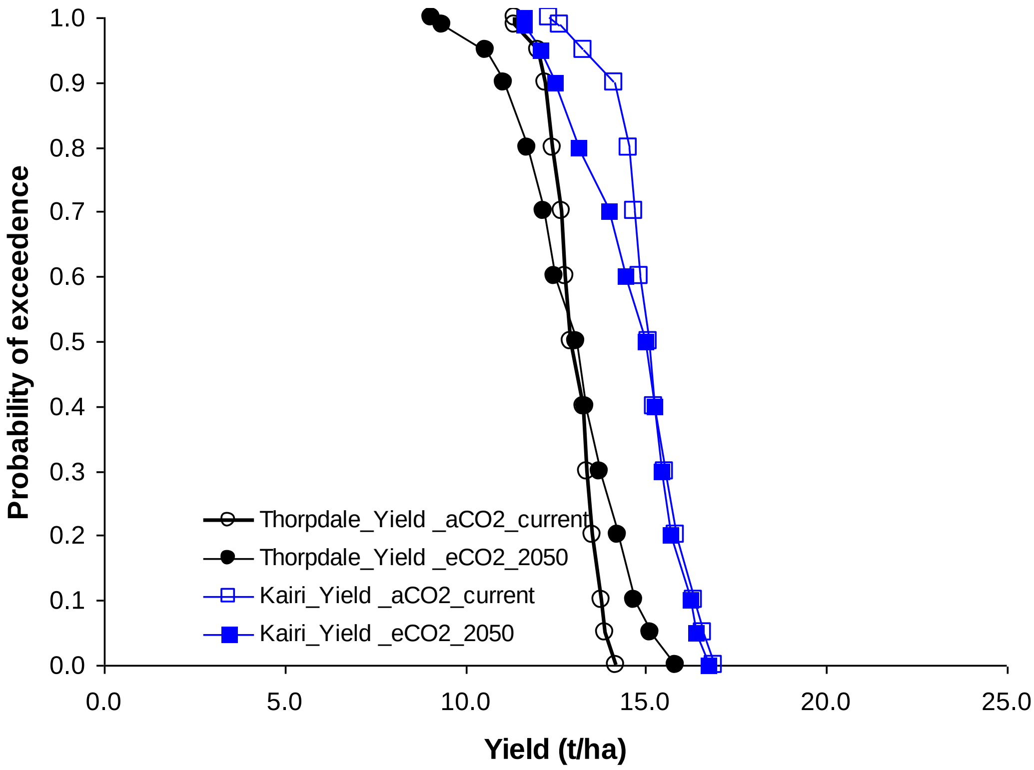


Figure 8 Probability of exceedence for potato (*cv* Russet Burbank) tuber dry weight (t/ha) for 68 year of simulation (APSIM 7) at Thorpdale, Victoria and Kairi, Queensland. Simulated treatments are for historical climate (aCO_2 386 ppm) and the full Mark 3.5 2050 future climatic that includes changes to temperature, rainfall, radiation and eCO_2.

The differences between the present climate and a future climate in terms of yield expectation is shown in Figure 9 with the tropical site showing a greater tendency for lower yields than the southerly site. Future potato production is likely to be more reliable in the southern regions of Australian than in its tropical counterparts.

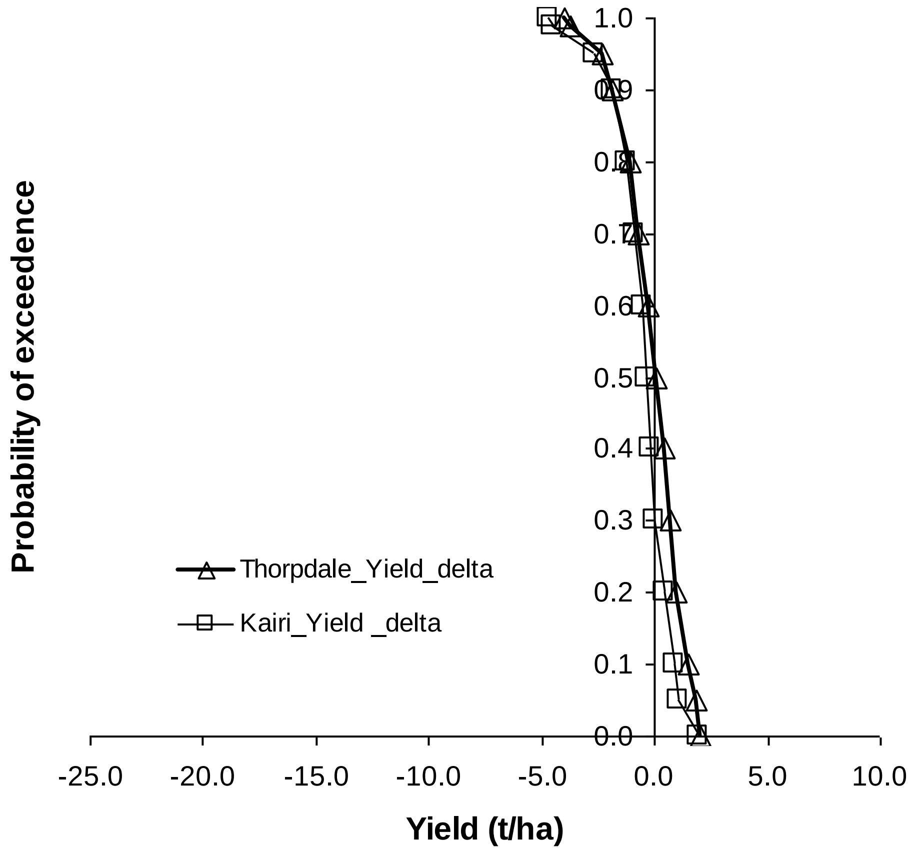


Figure 9 Probability of exceedence for potato (*cv* Russet Burbank) tuber dry weight (t/ha) response difference between future (2050) and current climatic scenarios for 68 year of simulation (APSIM 7) at Thorpdale, Victoria and Kairi, Queensland. Simulated treatments are for historical climate (aCO_2 386 ppm) and the full Mark 3.5 2050 future climatic that includes changes to temperature, rainfall, radiation and eCO_2.

3.4 Effects of climate change of late blight disease

3.4.1 Historic and current incidence of potato late blight in West Bengal, Bangladesh and Australia

An historical perspective of late blight in West Bengal and Bangladesh

Potato is a valuable food crop in India, Bangladesh, Indonesia and elsewhere in Asia cultivated primarily by resource-poor farmers. In these regions, potatoes are an excellent supplement to rice-heavy diets providing vitamins, nutrients, minerals and supplemental calories.

Late blight is considered to be the most destructive disease of potatoes in India and Bangladesh. Under favourable climatic condition, the disease can destroy potato crops in an area within two to three weeks. Estimates of losses to late blight in developing countries vary between $3 and $10 billion each year, and about $750 million of which is spent on pesticides alone. In the temperate Indian hills (20% acreage), a severe epiphytotic (epidemic) of late blight recurs every year resulting in 40-85% yield losses. In the subtropical Indo-Gangetic plains (80% acreage), late blight infection is mild to moderate. However, once in every 2 to 3 years it becomes epiphytotic resulting in 15-75% losses. In Bangladesh, potato is grown on 245,000 hectares and annual crop losses from late blight are 20-30% (*http://www.usaid.gov/our_work/agriculture/biotechnology*) and in some situations, losses of 30-40% have been recorded.

Like any high epidemic disease, potato late blight is the outcome of a complex interaction between a pathogen, its host and the environment. In north-western plains of India, the late blight disease of potato used to occur in mild to moderate form and epiphytotic (epidemic proportions) only once in 4 to 5 years, but more recently is steadily assuming epiphytotic proportions almost every alternate year. It appeared in the epiphytotic form in 3 out of 4 years from 2003 to 2006. The disease now appears earlier in northern part (November) and later in eastern part (February) and within a wider temperature range of 14.0-27.5°C than at 10-25°C recorded in earlier years. There is evidence of significant changes in the genetic make-up of populations of *Phytophthora infestans* in India and Bangladesh over the past two decades, including the appearance of A2 mating types. This is not doubt one of the reasons for the increasing frequency of late blight epidemics in India over the past 15 years.

Historic incidence and severity of late blight of potato in West Bengal and Bangladesh

Figure 10 shows the seasonal severity of late blight in West Bengal from 1991-2011. The late blight disease intensity was found to be less than 20 % in 1990-91 to 1999-2000, except in the 1994-95 seasons. More frequent late blight epidemics have been reported throughout West Bengal in the last 5 years. The late blight epidemics were observed during the year 2006-07 and 2008-09. The efficacy of metalaxyl fungicide treatments for late blight control appear to be significantly reduced in the last few years suggesting the possible development of metalaxyl resistant strains in West Bengal.

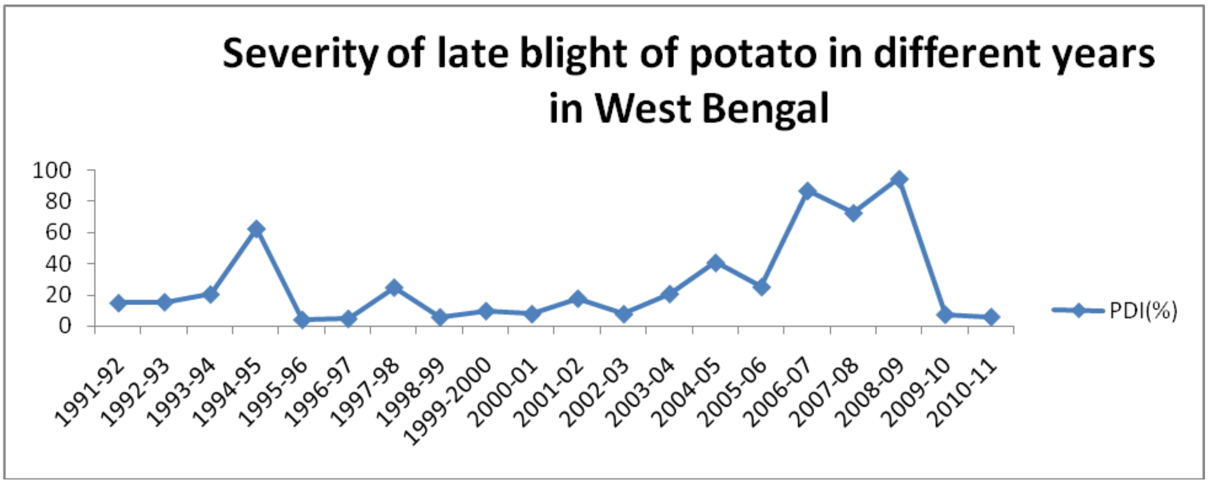


Figure 10. Severity of late blight (Percent Disease Index (PDI) on potato in West Bengal in different seasons.

Weather factors associated with development of potato late blight epidemics in West Bengal

Temperature and humidity are two critical factors for the development of late blight. Table 8 shows the date of initiation of late blight infection in potato crops in West Bengal over the past decade. Minimum temperature (>10°C) and average Relative Humidity (>70%) were found to be the most critical weather parameters associated with the days on which late blight was initiated (Figures RX and RY). The occurrence of morning fog was found to be a critical factor in disease initiation. Based on the data collected, foggy days with minimum temperatures greater than 10.0 °C were designated as late blight trigger days. The late blight percentage disease index (PDI) each season over the past decade was found to be strongly correlated (90%) with the total number of trigger days each year (data not shown).

Table 8. Potato late blight initiation dates in West Bengal in last decade (1999 – 2010).

Year	Date of initiation of late blight outbreaks
1999-2000	15 January
2000-2001	06 January
2001-2002	13 January
2002-2003	20 January
2003-2004	16 January
2004-2005	13 January
2005-2006	15 January
2006-2007	14 January
2007-2008	14 January
2008-2009	15 January
2009-2010	29 January

3.4.2 Reviewing late blight prediction models and forecasting the effects of climate change on potato late blight in West Bengal and Bangladesh

West Bengal growers experienced a huge economic loss during the recent late blight epidemic years (2006/07 and 2008/09) in West Bengal resulting in potato prices 3-4 times higher than the normal price. The disease spreads rapidly, is difficult to manage and can cause massive losses in yields, both in the field and in storage. Forecasting models that predict the likelihood of late blight outbreaks may provide important information for potato producers in Gangetic alluvial region of West Bengal, enabling farmers to implement a timely disease management plan. Practical benefits include an advanced warning system for Gangetic alluvial region of West Bengal potato farmers. In late-blight-favourable years, fungicide use may increase due to the added control gained by early forecasts. However, when weather is not favourable for late blight, growers could use the forecasts to reduce unnecessary fungicide applications, thereby reducing the monetary and environmental costs associated with traditional calendar-based spray pro-grams. Several models have been developed to predict the initiation of a late blight epidemic.

There are many systems some simple, some sophisticated, for predicting the initial occurrence of blight in a crop and for scheduling subsequent control treatments, all of which are based on an assumed response of the pathogen to various parameters of the aerial environment. The main features of some of the better known systems for predicting blight illustrate their diversity and are presented in Table 9. Some methods, such as that of Beaumont (1947), have been designed solely to indicate the start of fungicide treatments, while others, such as BLITECAST schedule both first and subsequent applications of fungicide and, depending on the weather, can save one or more fungicide sprays. The different systems vary widely in their complexity, from the relatively simple, such as that of Smith (1956), to the highly complex, such as that devised by Schrodter & Ullrich (1966, 1967). Linear discriminant and logistic regression analyses have also been used for predicting potato late blight (1S). It is now well established that different methods and weather criteria are required for forecasting potato late blight in different regions. West Bengal has six different agro-climatic zones and, therefore, weather during the crop season varies greatly from region to region. The Gangetic alluvial region of West Bengal in India represents diverse agro-ecological zones where the major proportion of India's potatoes is grown. Since no late blight forecasting system has been developed for this region so far, present studies were aimed at validation of available late blight prediction models from historical data to develop a suitable late blight prediction system(s) for the Gangetic alluvial region of West Bengal, one of the most important potato growing regions in the country.

Methodology

Late blight trap nurseries were raised with susceptible cultivars Kufri Chandramukhi at Adisaptagram Block Seed Farm, Hooghly, West Bengal, under AICRP on Potato crops, BCKV, since 1999 to 2009. The disease intensity data were recorded as per Malcomson, 1976. Appearance of first late blight symptom was recorded in the trap nursery and in other fields at the farm and adjoining farmer's fields. The last ten year disease initiation and intensity data were obtained from AICRP on Potato crops, Bidhan Chandra Krishi Viswavidyalaya (BCKV), Kalyani and the last ten years daily and hourly weather parameters viz., temperatures (max. and min.), RH (max. and min.), fog, sunshine hours and rainfall were obtained from AICRP on Agro-Meteorology, BCKV.

The temperature and relative humidity data was computed on hourly basis and rainfall, leaf wetness and sunshine hours were computed on daily basis. The temperature, RH and rainfall data were interpolated with the actual date of disease appearance using Fox-Pro based computer programmes Castor-2. The nine forecasting systems tested are listed in table 9.

Table 9. A summary of critical weather combinations and decisions used different models to predict the onset and severity of potato late blight

New Models for late blight prediction:

The weather data was updated daily by entering it manually or by an automatic weather station INTERFACE' programme and the models are executed for knowing the status of late blight. Depending on the weather conditions, any of the following two late blight status will be displayed.

1) Fog Based Rules: consecutive 2 days with morning fog; minimum temperature more than 10°C; potato late blight initiation 7-14 days after this threshold condition is attained

2) Minimum Temperature and Avg. RH based rules:

Model	Critical weather combination	Decisions
Dutch Rules	Rainfall,Dew at night, Night-time temperature and Mean cloudiness	Late blight was predicted within 14 days of favourable condition
Beaumont Rules	Tmin not less than 10ºC and RH not less than 75%	Late blight is predicted 2 days after such condition.
Cooks model	Temperature and rainfall (7-day moving average and total respectively)	Initiation of disease when rainfall crosses critical line and 7-day mean T> 75 Degree F
Hyre model	Mean T of the previous 5 days < 25.5ºC and accumulated rainfall for previous 10 days = 30mm	Late blight predicted: 2 weeks after accumulation of 10 favourable days
Smith model	Two consecutive days with Tmin.10ºC and >=11 hours with RH>90%	Initiate Treatments
Wallin model	Severity values assigned based on hours of different range of temperature at RH >90%	Prediction of PLB 7-14 days after accumulation of 18-20 severity values
Blitecast	Hourly readings of mean temperature, RH and rainfall. Also consider minimum night temperature and rainfall accumulated over the last 10 days	Disease initiation based on either Hyre or Wallin Model. Subsequent spraying based on accumulated rain favourable days and Blite Unit
Fry Model	Establishment of Blite Unit based on hourly temperature and hours of RH>90%) and fungicide unit based on daily rainfall	Fungicide application based on cumulative blight unit or fungicide unit since last spray
Hartill & Young model	Hourly temperature above a base of 7.2ºC are summed for hours with leaf wetness>50%. A sum of 80 degree hours denotes one IP	Outbreak of disease after accumulated threshold IPs are reached
Ullrich and Schrodter	Daily severity figures based on hourly temperature, RH>90 and rainfall are summed to a threshold value	Disease is expected when accumulated risk value exceeds 150
Jhulsacast	Hourly temperature and RH	Initiation of PLB when 7-day moving >= 85% RH (>= 50 hours) and congenial temperature (7.2-26.6oC) periods (>= 105 hours)

Model -2

Avg RH	Minimum Temperature			
	8.5 – 10	10.1 - 12	12.1 - 14	14.1 - 18
70 - 75 %	0.5	1.0	1	0.5
75 - 80 %	1.0	2.0	1.5	1
80 - 85 %	1.5	3.0	2	1.5
> 85%	2.0	4.0	2.5	2.0

Table 11. 15th Day onward DSV will be calculated and the disease will be initiated within 14 days after DSV attaining 12.

Results and Discussion

Validation of some of the most popular late blight forecasting systems used the world over was tested on the basis of the last ten years for predicting late blight in Gangetic alluvial region of West Bengal. Their performance is discussed below:

Table 12: Performance of Existing Potato Late Blight Prediction Models in the Gangetic Plains of West Bengal, India (Hourly Data) (Figures in parenthesis indicate difference in days between forecast and disease initiation)

Date of Planting	Disease initiation	NegFry Predicted	Smith Predicted	Winstel Predicted
15 Dec 06	14 Jan 07	11 Jan 07 (-3)	1 Jan 07 (-13)	1 Jan 07 (-13)
21 Nov 07	14 Jan 08	14 Dec 07 (-31)	8 Dec 07 (-37)	8 Dec 07 (-37)
1 Dec 07	16 Jan 08	25 Dec 07 (-22)	18 Dec 07 (-29)	18 Dec 07 ((29)
11 Dec 07	19 Jan 08	4 Jan 08 (-15)	23 Dec 07 (-27)	28 Dec 07 (-22)
14 Nov 08	7 Jan 09	6 Dec 08 (-32)	2 Dec 08 (-36)	15 Dec 08 (-23)
24 Nov 08	12 Jan 09	15 Dec 08 (-28)	11 Dec 08 (-32)	15 Dec 08 (-28)
4 Dec 08	15 Jan 09	23 Dec 08 (-23)	21 Dec 08 (-25)	21 Dec 08 (-25)

15 Dec 09	29 Jan 10	9 Jan 10 (-20)	1 Jan 10 (-28)	2 Jan 10 (-27)
Percentage Success		0	0	0

Table: 13 Performance of Existing Potato Late Blight Prediction Models in the Gangetic Plains of West Bengal, India (Daily Data) (Figures in parenthesis indicate difference in days between forecast and disease initiation)

Date of Planting	Disease initiation	Hyre Predicted	Forsund Predicted
9 Dec 99	10 Jan 00	No Warning	9 Feb 00 (30)
19 Dec 99	15 Jan 00	No Warning	9 Feb 00 (25)
10 Dec 00	6 Jan 01	No Warning	No Warning
10 Dec 01	14 Jan 02	No Warning	25 Jan 02 (11)
15 Dec 02	20 Jan 03	No Warning	No Warning
15 Dec 03	16 Jan 04	No Warning	No Warning
15 Dec 04	13 Jan 05	No Warning	13 Jan 05
15 Dec 05	15 Jan 06	No Warning	No Warning
15 Dec 06	14 Jan 07	23-29 Feb 07 (40-46)	14 Dec 07 (-31)
21 Nov 07	14 Jan 08	11-18 Feb 08 (28-35)	26 Jan 08 (12)
1 Dec 07	16 Jan 08	11-18 Feb 08 (26-33)	26 Jan 08 (10)
15 Dec 07	19 Jan 08	11-18 Feb 08 (23-30)	26 Jan 08 (7)
14 Nov 08	7 Jan 09	No Warning	No Warning
24 Nov 08	12 Jan 09	No Warning	No Warning
4 Dec 08	15 Jan 09	No Warning	No Warning
15 Dec 09	29 Jan 10	No Warning	No Warning
Percentage Success		0	6.25

Performance of Existing Potato Late Blight Prediction Models in the Gangetic Plains of West Bengal, India (Daily Data)

The weather data collected at AWS, BCKV, Mohanpur, did not fit well with both the Hyre and Forsund Model. The Hyre model found to be unsuccessful in forecasting late blight. The Forsund model was successful in forecasting late blight of potato only in 2003/04 potato season.

Performance of Existing Potato Late Blight Prediction Models in the Gangetic Plains of West Bengal, India (hourly Data)

Seven late blight prediction models (Blitecaste, Walin, Ulrich, Fry, NegFry, Smith and Winstel) were evaluated for predicting the late blight under Gangetic alluvial region of West Bengal based on last few years hourly data of temperature, RH and daily rainfall data for this region. None of the models, except the Walin Model, was found to be successful in predicting late blight of potato in each year of evaluation. The Walin model was found to be successful in forecasting late blight only in 2006/07 and 2009/10 potato seasons. In these years blight appeared after 7-14 days of fulfilment of Walin periods. The overall success rate of Walin Model was only 25%.

Evaluation of nine well established models, based on temperature and rainfall and temperature and relative humidity using 10 years disease data from AICRP on Potato, Kalyani Centre and data from Governmental organisation and whether data from AICRP on Agro-Meteorology, Bidhan Chandra Krishi Viswavidyalaya, Kalyani, revealed that none of these models worked well under Gangetic alluvial region of West Bengal conditions. Out of all of the models, the Walin Model was the best but even their accuracy was only 25%. It was also observed that no rainfall was recorded even during late blight epidemic year (2006-07). Rainfall is sporadic during potato growing seasons in the plains. The results showed that rain is not a pre-requisite for outbreak of late blight in Gangetic alluvial region of West Bengal and, therefore, any criterion/model which has a component of rainfall will not be suitable for predicting late blight in this region. Hence, the majority of popular late blight popular models were not to be useful in this region.

Therefore, an alternative approach based on morning fog and minimum temperature was developed for predicting late blight of potato under Gangetic alluvial region of West Bengal (see previous discussion).

Disease initiation was simulated using the model for the Chinsurah area for the period 1980 to 2040. Yearly data on average 5-day temperature preceding disease initiation summarised in decadal interval from 1981-1990 to 2031-2040 were plotted against the decadal average disease initiation dates. Figure 14 shows that decadal average of 5-day Tmin preceding PLB initiation increased from 7°C (1981-90) to 12.8°C (2031-2040). It showed a clear direct relationship between enhanced thermal regime for the future decades and earliness of PLB initiation. This indicates that increasing temperature regime in future years during potato season will help in attaining the critical Disease Severity Values (DSV) of 12 earlier than at the present time.

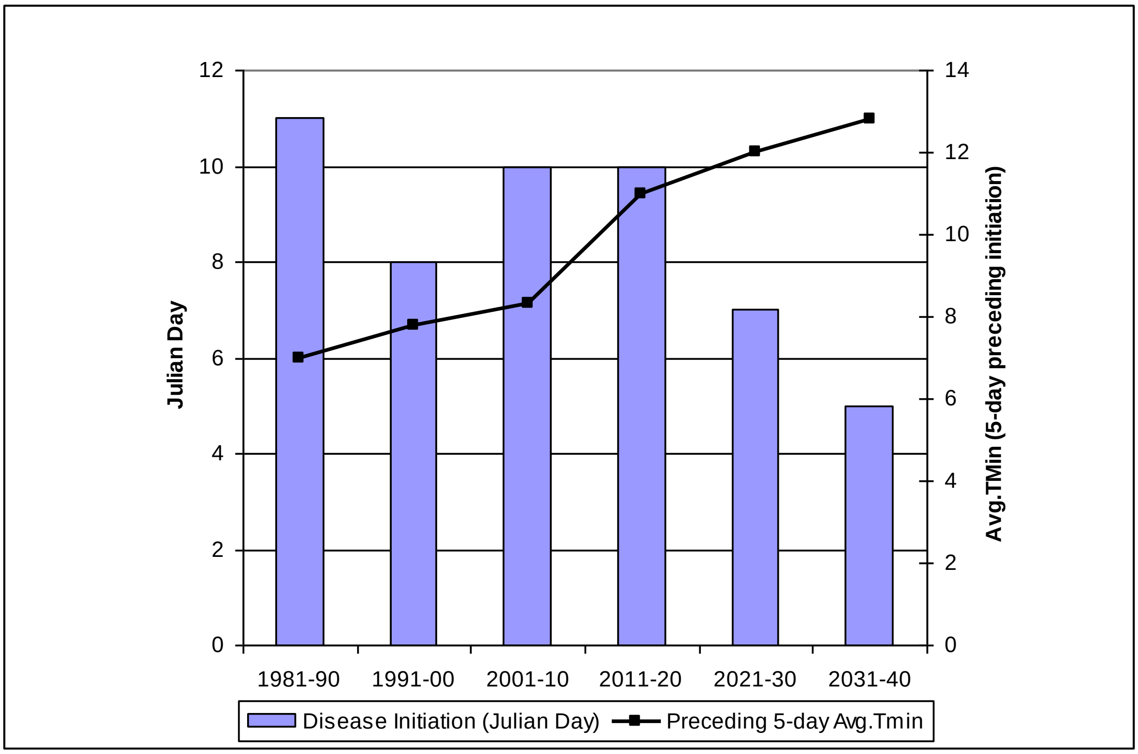


Figure 14. Relationship between 5-day preceding temperature and PLB initiation (Chinsurah, West Bengal).

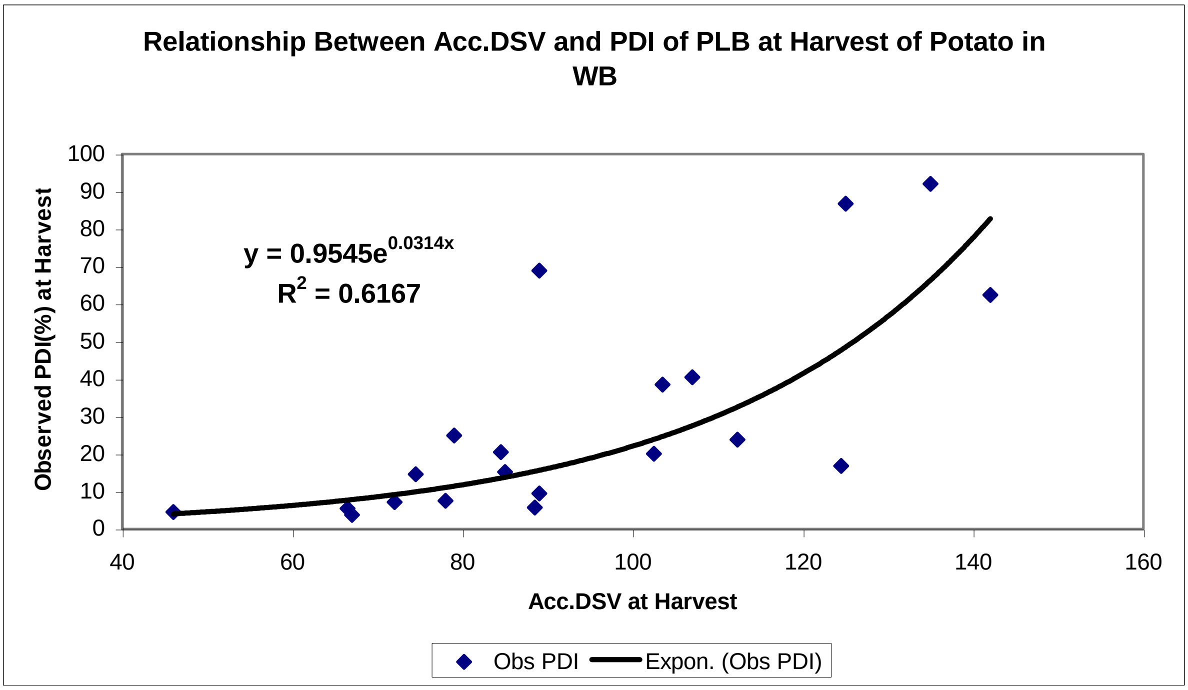


Figure 15. Relationship between Acc.DSV and PDI of PLB at harvest of potato in West Bengal.

In order to estimate PDI of PLB from accumulated DSV at harvest, generated from weather data, for the purpose of past and future disease trend analysis, an experimental dataset were considered for Nadia district of West Bengal for the period of 1999-2000 to 2009-10. An exponential relationship between these two parameters can explain around 62% variance of observed PDI (Figure 15). We used this statistical relationship to estimate intensity of PLB from 1981-2040 to compare its past and future trend (Figure 16).

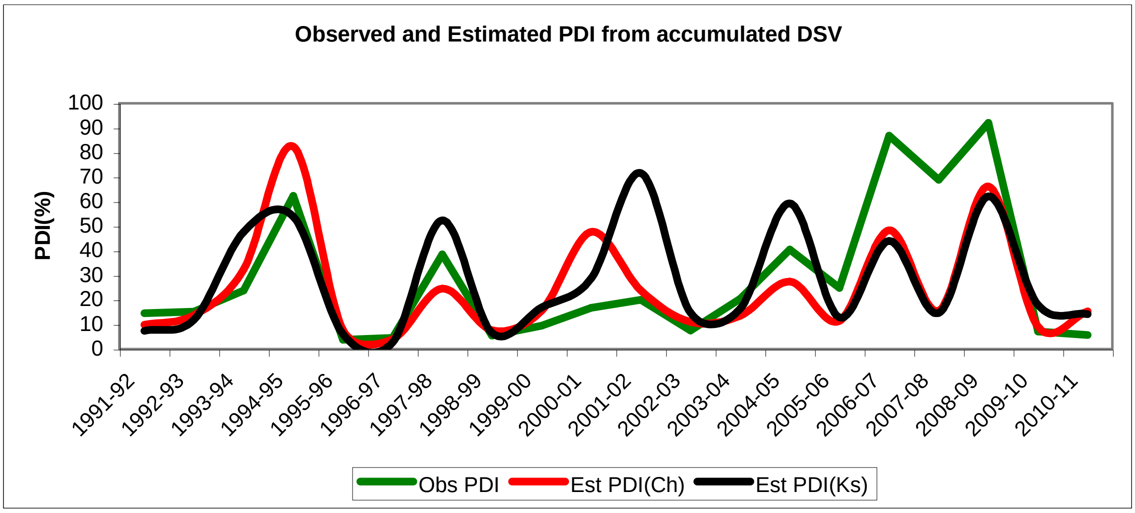


Figure 16. Comparison of the observed and estimated PDI of PLB over time in two locations of West Bengal, Krishnanagar (Ks) and Chinsurah (Ch).

Trends of the values of yearly PDI of PLB estimated from the model closely followed the observed PDI from 1991-92 to 2010-2011 as observed in the experimental field. While exploring values of PDI for individual years, it was observed that the model could not explain well very high values of PDI during 2007-08 to 2009-10 which might be due to the fact that in the year 2009-10 there was significant amount of unusual rainfall during the potato growing season and during other two years, there were very high number of unusual fog days during the crop growing season as compared to other database years. Deviation of the estimated value from the observed one is primarily because of the fact that these two variables (fog and rain) have not been included as the model parameters. It is also evident from the 1:1 graph that, the model has a limitation in simulating very high disease intensity values more than 40% (data not shown).

3.3.3 Effect of climate change on late blight at two locations in Australia

Potato late blight in Australia

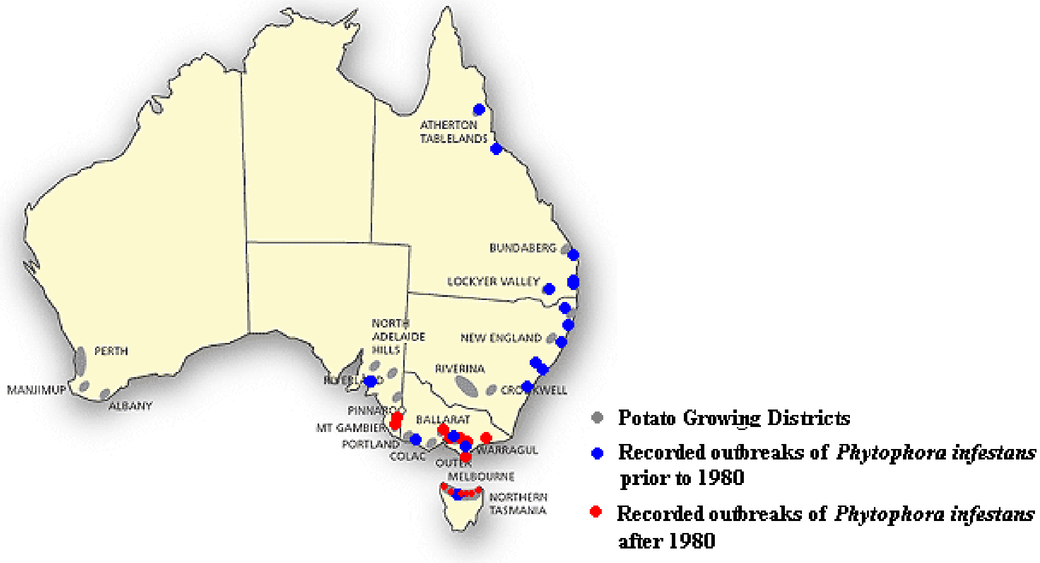


Figure 17. The location of potato growing areas and recorded outbreaks of potato late blight in Australia

Late blight is a relatively minor disease of potatoes in Australia. Figure 17 shows the locations of recorded outbreaks of late blight in potato production regions. The disease was reported to cause significant damage to crops in the early 1900s (McAlpine 1911). In the past three decades, however, the disease has occurred only sporadically at a few locations in Tasmania, South Australia, Victoria and New South Wales. Disease severity is generally low.

Australian summers are generally too hot and dry for late blight. The pathogen requires several days of relatively warm, still and humid weather conditions that are conducive to formation of dew on the potato leaflets. Under average summer conditions in the temperate production areas, irrigation and rainfall are not conducive to the development of late blight. The still and humid conditions occur most often on the north coast of Tasmania where the disease generally occurs every year but at a relative low incidence and severity. Some farmers in Northern New South Wales will find late blight in most years but only in a few crops of the most susceptible varieties. The common practice of protecting mature crops with fungicides for early blight disease *(Alternaria solani)* will also reduce the risk of late blight when weather conditions are conducive to the disease.

Australia is one of only a few countries in the world that do not have the new strains of *P. infestans*. The new populations affecting potato production worldwide are genetically more variable, aggressive, fit and resistant to fungicides than the 'old' strains and are able to cause disease under much wider environmental parameters of temperature and moisture. There is a risk that late blight could become more common if these new strains were to be become established in country. Figure 18 shows Climex model projections of potential late blight severity in Australia based on climate matching. Although the modelling includes rainfall and irrigation, it does not take into account other agronomic and genetic (crop and pathogen) and specific soil water/nutrient and atmospheric conditions that cause late blight outbreaks. This model, therefore, may exaggerate the potential problem.

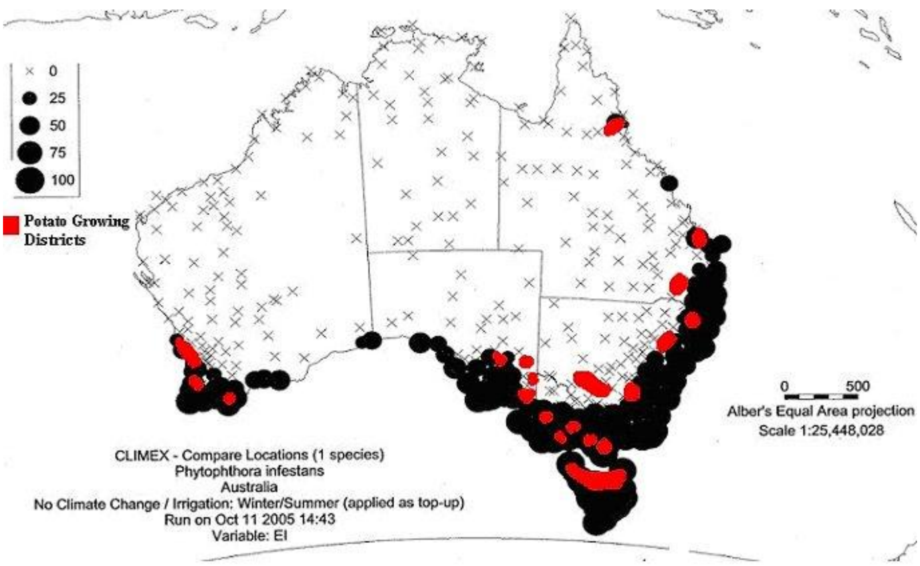


Figure 18. Regions of Australia identified by Climex v2 to have climates that match the climatic conditions of regions in the world where the new strains of *P. infestans* have established. The figures in the legend indicate the closeness of the match eg 100 = 100% match, 50 = 50% match. The areas coloured red represent Australia's potato growing districts. (Source: Pest Risk Analysis for exotic strains of the potato late blight pathogen, Plant Health Australia).

Future climates and potato late blight

The Jhulsacast PLB model (Singh et al. 2000) was applied to the Australian climatic data sets to assess the likely response of the disease under Australian conditions (historical and a projected future climate).

We selected a tropical and temperate location in Australia to compare the expected effects of climate change on potato production and late blight by 2050. The locations were Kairi Research Station, Queensland (Australian Bureau of Meteorology Station #031034, lat. 17.22^{o}S Long. 145.57^{o}E, elev. 697m) and Thorpdale State School, Victoria (Station #085081 Lat. 38.30^{o}S, Long. 146.20^{o}E, elev. 243m). The weather patterns during the growing seasons for these localities are different. At the tropical location potato is grown during the dry season from the end of summer (March to May) and at the temperate location it is grown in the spring and summer period. The seasonality of climate change is therefore crucial to understanding its effects on potential potato production and its likely response to potato late blight.

A potato crop sowing window was defined for the historical climate to assess the likely changes to planting times which influence disease onset. This was applied using the APSIM-Potato simulation model. At Kairi planting of potato was set to occur within a window defined by accumulated rainfall (10 mm over any two days and soil water content of at least 10 mm) between 15 March and 15 July each year a period coinciding with the end of the wet season. At Thorpdale the planting window was 1 October to 31 December reflecting the summer dominant conditions at the southern location, but with the same rainfall and soil water criteria as at Kairi.

To discriminate between sources of variance (climate or management) the historical sowing dates were applied to the future climate well as new sowing dates that would be expected under the new climate.

Results

Table 14 shows the mean number of days from sowing to the forecast alert (PLB12), the differences between the simulations and the mean severity index (total accumulated PLB index) and its difference between the simulations (%) for each site. Figures 19 and 20 show the variance over time of these variables. At Kairi, the tropical site, under the A1Fi climate scenario the time of sowing would be delayed from a historical mean sowing time from 29 April to 10 May. However, this will have a negligible effect on PLB disease onset or severity (Table 14). A delay in the onset of infection (12 days) with a corresponding decrease in severity of around 18% is expected with the sowing date change. Very little change is seen if the sowing date remained identical to historical dates.

In contrast, at Thorpdale, the temperate site, the onset of PLB is predicted to be 15 days earlier with a very slight increase in severity with a 5 day mean delay in sowing due to the altered climate. However, if the sowing time was identical to the historical pattern then the onset changes by one day with a significant increase in severity likely (26% increase). A delay in sowing is a strategy to minimise PLB infection in Victoria.

Table 14. Mean days to the forecast alert (PLB12) and severity of PLB infection at two locations under historical and future climate scenario A1Fi 2050. A sowing window for the historic and A1Fi 2050 scenario were used to simulate realistic growing seasons. For comparison the identical sowing dates were also used against the climate changed data.

	Kairi				Thorpdale			
	PLB12 (days)	Delay Difference (days)	Severity Index	Difference (%)	PLB12 (days)	Delay Difference (days)	Severity Index	Difference (%)
Historical Climate with **TOS window**	14	0	192	0	159	0	52	0

A1Fi 2050 With future **TOS window**	26	+12	158	-18	144	-15	53	+2
A1Fi 2050 with Identical **TOS date as** Historical	23	+9	163	-15	160	+1	65	+26

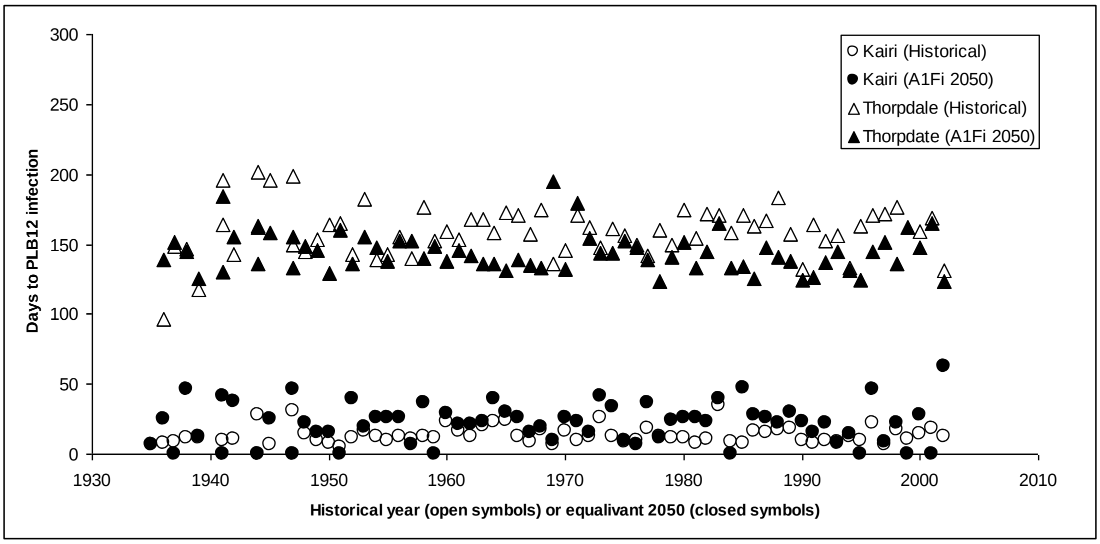


Figure 19. The day of year when the potato late blight warning (PLB12 index) is reached at Kairri and Thorpdale under historical (open symbols) and equivalent but future scenario (A1Fi) for the year 2050 (closed symbols).

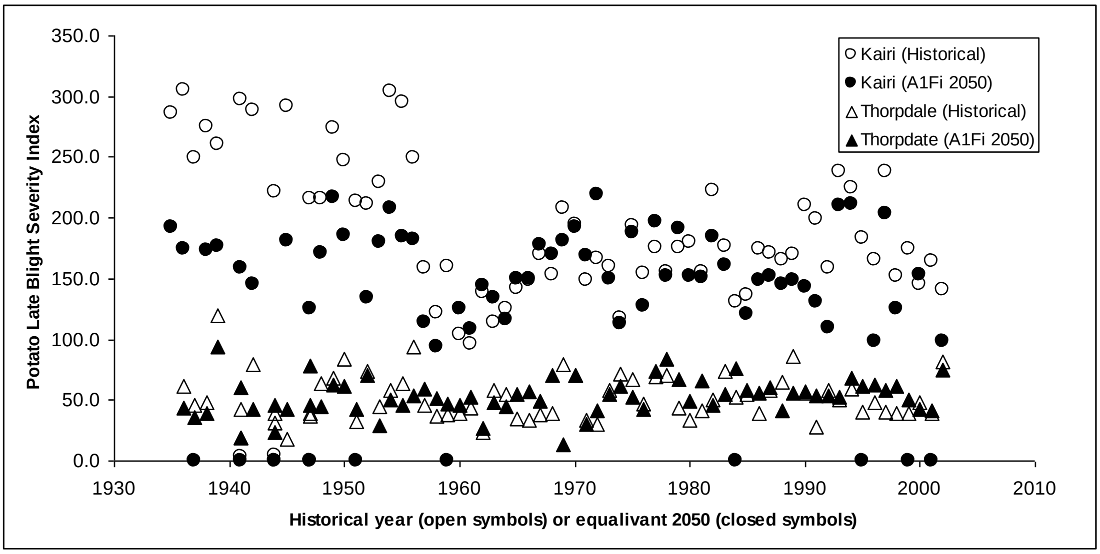


Figure 20. The potato late blight severity index at Kairri and Thorpdale under historical (open symbols) and equivalent but future scenario (A1Fi) for the year 2050 (closed symbols).

Discussion

In any individual year there is large variance in the onset and severity of PLB (Figures 19 and 20). This strengthens the case to maintain forecasting capability where the disease is likely to be a problem in the future (e.g. Queensland).

This model does not consider evolution of pathogen virulence or changes in host genetics through breeding. The cultivar Russet Burbank was used in this study because it has a long growing season and might be most affected by a warming climate. It is possible to experiment with likely alternative degrees of virulence and the next stage of research would be to explore the virulence parameters for the new A2 mating type now identified in Europe.

Our analyses are intriguing because of the very large differences between the locations and the observed non linear behaviour. Because the PLB model was calibrated against Indian observed data its applicability to the Australian climate will always be doubtful without local calibration. Indeed, the time to infection seems overly long at Thorpdale (144-160 days) compared to Kairi (14-26 days) and the crop at Thorpdale would be expected to be harvested by this time. It is uncertain if this very long time to infection at Thorpdale is a calibration problem or indicative of the real situation. Applications of more generic PLB models that can be applied without calibration are in their infancy and may generate high levels of uncertainty. It is critical that some validation is undertaken at selected locations.

In conclusion, the application of the Jhulsacast PLB model to Australian production areas and associated climate data sets has provided the first objective analysis of the likely effects of climate change on PLB in Australia.

Despite shortcomings, PLB is expected to be less of a problem in the tropical north than in the southern regions as the climate tracks with the projected A1Fi 2050 pattern. In the southern production regions there is little change in PLB risk but a later planting time will be the direction to move if the current strains become more virulent.

Potato tuber yields will also change as the climate changes but as the climate dries irrigation water will become scarce and expensive leading to a propensity for lower yields. This will be true in India, Bangladesh and Australia.

4.0 Conclusions

West Bengal and Bangladesh

Key Findings

1. In these regions the maximum temperature will increase by 0.2 - 0.6 ºC and minimum temperature increase will be 0.2 - 0.5 ºC per decade up until 2050.
2. In 2025, the average potential potato yield reduction in West Bengal will be around 3.3 t/ha and in 2050, it will be around 5.08 t/ha and the best yield can be obtained if the crop is sown on (or around) 6th Nov, whereas in 2050 the mid November sown crops will give the best output.
3. The late blight disease intensity was found to be less than 20% in 1990-91 to 1999-2000, except in the 1994-95 seasons. More frequent late blight epidemics have been reported throughout West Bengal in the last 5 years. The late blight epidemics were observed during the year 2006-07 and 2008-09. The efficacy of metalaxyl fungicide treatments for late blight control appear to be significantly reduced in the last few years suggesting the possible development of metalaxyl resistant strains in West Bengal.
4. Onset of PLB is likely to be earlier in the growing season in the future decades as compared to the present decades (2011-20).
5. The future trend for PLB is that the disease severity is likely to reduce by 5-7% from 1981-2010 period to 2031-40 period in the intensive potato growing areas of West Bengal, India. However, in similar intensive growing areas of Bangladesh, disease severity can shift to either direction. It can increase up to 12% in intensively potato cultivated areas of northern Bangladesh and can reduce to around 7% in similar intensive growing areas of central Bangladesh.

Australia

Key Findings

1. Climate change projection for the two production regions
    a. A warming of 2°C-3°C mean temperature is expected by 2050 across both contrasting temperate and tropical potato growing areas of Australia.
    b. Rainfall is expected to decline by about 30-40% by 2050 across both regions.
    c. In the tropical north solar radiation is expected to increase by around 0 to 2% whilst in the temperate south a greater increase of around 2 to 3% in radiation is expected.
    d. The relative humidity is expected to decrease by about 2 to 3% and greater than 4% in the tropical and temperate regions, respectively.

2. Expected potato yield changes due to climate change
    a. Temperate Australia: Increased yield variance from -6 to +5 t/ha by 2050. Propensity for higher yields with median yield gain of +3 t/ha.
    b. Tropical Australia: Smaller yield variance from -1 to +4 t/ha by 2050. Propensity for higher yields with median yield gain of +1 t/ha

c. The length of the growing season is expected to be shortened by about 30 days in temperate Australia if cultivars are not changed. No change is expected in the duration to harvest in the tropical regions.

3. Expected PLB changes due to climate change
   a. The likely warmer but drier conditions expected in the tropical and temperate regions of Australia is expected to result in reduced incidence and severity of PLB at all locations despite a general increase in productivity.
   b. At Kairi, the tropical site, under the A1Fi climate scenario the time of sowing would be delayed from a historical mean sowing time from 29 April to 10 May. However, this will have a negligible effect on PLB disease onset or severity. A delay in the onset of infection (12 days) with a corresponding decrease in severity of around 18% is expected with the sowing date change. Very little change is seen if the sowing date remained identical to historical dates.
   c. In contrast, at Thorpdale, the temperate site, the onset of PLB is predicted to be 15 days earlier with a very slight increase in severity with a 5 day mean delay in sowing due to the altered climate. However, if the sowing time was identical to the historical pattern then the onset changes by one day with a significant increase in severity likely (26% increase). A delay in sowing is a strategy to minimise PLB infection in Victoria.
   d. It appears that the risk for PLB damage under future climates will decrease in the two Australian growing regions. It is recommended however, that vigilance is maintained through high plant health and quarantine practices to prevent the virulent strain of *P. infestans* entering the country.

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5.0 Future Directions

An interesting gap highlighted in this project was that fog data, which is critical to the development of potato late blight, is not routinely collected by the meteorological agencies in all three countries. The collection of this data by the respective bureaus will provide the resources to establish a fog-warning system for growers.

The development of a fully integrated model which incorporates a potato crop model with the PLB model needs to be further refined in a full research project. This model will provide a more comprehensive assessment of how late blight will affect potato crops under future climates.

To progress this area of work, a concept proposal “Potato Cultivar and Crop Improvement for South-Southeast Asia and the Pacific Region in the Context of Climate Change” was developed by Dr Tung (Vietnam) at our final workshop to include adaptation to potato pests and diseases in the Asia Pacific through cultivar improvement. This project aims at identification of new emerging scenarios of major biotic (diseases and pests) and abiotic (drought, heat, excess humidity and soil salinity) constraints to potato production under the climate change situations in the Asia and Pacific region, and the need of new types of cultivars and production techniques for adaptation.

Appendix 1: Workshop 1 Program

Asia Pacific Networks for Global Change

The effects of climate change on pests and diseases of key crops in India, Bangladesh and Australia

Workshop 1

Bidhan Chandra Krishi Viswavidyalaya

Kalyani Farmers Training Centre

15 & 16 December 2009

Date	Time	Workshop Activity
Tuesday 15 December 2009	10.00	Registration of Participants
	10.30	Presidential Address by **Prof. S. K. Sanyal**, Director of Research
	10.45	Introduction and Purpose of the Workshop, by **Dr. Jo Luck**, Cooperative Research Centre for National Plant Biosecurity (CRC NPB), Australia
	10.55	Vote of Thanks by **Dr. I. Bhattacharya**
	11.00	**Tea break**
	11.30	**Session 1. General Climate change projections for India, Bangladesh and Australia** *Chair Dr S. Huda* *Points to cover in each presentations (15mins + 5 mins questions)* • *The main climate change projections for crop growing regions 2030, 2050 and 2070* • *What are the gaps in knowledge?* • *What data/resources can be contributed to the objectives of this project?*
	11.30	**Dr Giashuddin Miah** (Department of Agroforestry and Environment Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur). Climate Change and anthropogenic activities: Impact on natural resources and food security particularly in the coastal regions of Bangladesh
	11.50	**Dr Rathore** (Additional Director General, India

		Meteorology Department) Projected climate change for India
	12.10	**Dr Jo Luck** Projected climate change for Australia
	12.30-1.30	*Lunch Break*
	1.30	**Session 2. major The effects of climate change on cropping systems for Bangladesh, India and Australia** *Chair Dr Miah* *Points to cover in each presentations (15 mins + 5 mins questions)* • *Major crops that are a priority for this study* • *What is the most important climate change projections for these crops in future scenarios* • *Changes in distribution of cropping?* • *New varieties, new practices required?* • *Adapting to climate change?*
	1.30	**Dr. Sanjeeb Chopra I.A.S** Principal Agriculture Secretary Govt. of West Bengal Effect of climate change on productivity of major crops in Indo Gangetic plains of West Bengal bordering Bangladesh.
	1.50	**Dr GGSN Rao**, All India Coordinated Projects of Agrometeorology *to be confirmed*
	2.10	**Dr. Prof S.A. Khan** An overview of agrometeorological research in West Bengal
	2.30	**Professor R. Jagannathan** Climate change projections for Tamilnadu and possible impacts on crop yield.
	2.50	**Dr Garry O'Leary** (DPI Victoria) The effects of climate change on wheat production in Australia.
	3.10-3.30	**Tea break**
	3.30	**Dhananjoy Mandal and M K Dasgupta:** Has the weather gone erratic locally at Red and lateritic region of West Bengal?: Elementary risk analysis from the farmers' perspective.
	3.50	**Dr S. Huda** Linking achievements from recently completed APN project "Climate and crop disease risk management" to this present project with emphasis on climate change and crop-pest/disease modeling
	4.15	Questions/Discussion
	5.00	Aquaintance with activities of Research scholars/ Fellows
	7.00	Dinner at Hotel Aquatic Palace, Kalyani
Wednesday 15 December 2009	**10.00**	**Session 3. The interaction of climate change on pests and diseases of crops in India, Bangladesh and Australia** *Chair Dr Khan* *Points to cover in each presentations (15 mins + 5 mins questions)* • Crop protection specialists to identify main constraints of pests and diseases of major crops

		• Collection and reviewing of historical data on biology of the pathogens and pests. • Disease and pests. • What are the gaps in data collection • What management practices may need to change
	10.20	**Dr. Indrabrata Bhattacharya** (Kalyani Nadia west Bengal) Recent trends on pest and pathogen infestation in major crops of West Bengal
	10.50	**Dr. Suseelendra Desai** (CRIDA) Effects of Climate change on groundnut/pigeon-pea pathogens *to be confirmed*.
	11.10-11.30	**Tea break**
	11.30	**Dr. Chirantan Chattopadhyay** (Indian Institute of Pulses Research, Kanpur) will climate change influence on Pigeonpea pathology in the northern regions.
	11.50	**Dr. M. Srinivasa Rao**, (CRIDA, Santoshnagar) The effects of climate change on pests of XXX *to be confirmed*
	12.10	**Dr. R. Spooner Hart (UWS, Sydney)** Influence of elevated CO_2 on phytophagus arthropod species resulting from changes in the host plant.
	12.30	**Dr. Md. Delowar Hossain (BARI Bangladesh)** The effects of climate change on plant pathogens
	12.30-1.30	**Lunch**
	1.30	**Dr Maddi Vanaja** (CRIDA) The effects of climate change on pest and diseases -elevated CO_2 research *to be confirmed*
	1.50	**Dr Jo Luck** The effects of climate change on Wheat and Citrus diseases - Modelling and elevated CO_2 research in Australia
	2.10	**Planning and Implementation of project work in India, Bangladesh and Australia. (Working Group Mode)** • *What data/resources can be contributed to the objectives of this project?* • *Work plan, new proposals* • *Milestones* • *Roles and responsibilities (who will do what)* • *Next workshop* • *Paper –review* • *Policy Paper* *Recommendations from this workshop*
	2.10	Discussion with the policy makers and participating scientists for improving linkages in the program
	5.00	Finalization of Program
	5.05	Vote of Thanks
	6.00	Cultural function - Rabindranath Tagore's Dance Drama Chandalika by the tribal girls at Vidyasagar Mancha, Kalyani.

	8.00	Dinner

Appendix 2: Workshop 2 Program

APN Workshop 2, Australia

18-22 October 2010

WORKSHOP PROGRAM

Monday 18 October – APN Workshop Day 1		
		Venue: DPI Theatre
9:00am	**APN Workshop Welcome and Opening Introduction and Acknowledgements**	Dr Jo Luck, DPI Vic
9:10am	**Welcome to Country**	Mr Ian Hunter, Wurundjeri Elder
9:25am	**Welcome on behalf of DPI Victoria**	Dr Martin Barlass Deputy Executive Director
9:40am	**Welcome on behalf of APN for Global Change**	Dr Md Giashuddin Miah
9:50am	**Brief Summary from APN Workshop 1 (Kalyani) and Purpose and Objectives of Workshop 2**	Dr Jo Luck, DPI Vic
10:00am	*Group photo and morning tea*	
10:30am	**Potato Late Blight –A Global Perspective**	Dr Dolf De Boer, DPI Vic Dr
11:00am	**Climate Change and Plant Diseases**	Dr Sukumar Chakraborty CSIRO
11:30am	**Regionalised climate change projections for potato growing areas in India, Bangladesh and Australia**	**Venue: Syndicate Room 1/2** Prof. Jagannathan, Tamil Nadu

	Present status and future climate change scenarios over potato growing districts of West Bengal	University, Prof Samsul Huda, University of Western Sydney, Dr Garry O'Leary, DPI Dr Debnath
12:00 nn	**Review of the Effects of Climate Change on Potato Production**	Dr Saon Banerjee and S.A Khan BCKV
12:30pm	**Review of *P. infestans* data for India, Bangladesh and Australia**	Dr S.Dutta and Dr.A.Saha Dr Delowar Hossain and Dr Dolf de Boer (15 +5 mins each)
1:00pm	*Lunch*	***Venue: Syndicate Room 3/4***
1:30pm	**Review of Aphid/Potato Virus data for India, Bangladesh and Australia**	**Venue: Syndicate Room 1/2** Dr Dutta/ I.Bhattacharya BCKV, Prof Robert Spooner-Hart University Western Sydney, Dr Brendan Rodoni DPI Vic (10? +5 mins each)
2:30pm		
3:30pm	*Afternoon Tea*	
4:00pm		Dr Wendy Griffiths, DPI Vic
4:20pm	General Discussion and next steps	
5:00pm	Close	
Tuesday, 19 October – APN Workshop Day 2		
9:30am		Dr Miah, Dr Kep Coughlan, Dr Indra Bhatacharya
10:00am	*Morning Tea*	
10:30am	Field Trip: Potato production areas in Thorpdale, Koo-Wee-Rup Swamp	
12:30pm	*Lunch in Trafalgar*	
1:30-6.00pm	Field Trip: Potato production areas in Thorpdale, Koo-Wee-Rup Swamp. Returning through vegetable production area, Cranbourne	Dr Dolf deBoer

Wednesday, 20 October – APN Workshop Day 3		
8:30 – 10:30am	**Research and Policy Gaps based on presentations from Day 1** **Writing Workshop - Suggested Writing Groups** **- Structure and process** **1. Climate Projections for potato growing areas in India, Bangladesh and Australia-climate change effects on production** **2. Historic incidence of Late Blight in India, Bangladesh and Australia relation to climate change Incidence of other pests and diseases including PVY** **3. Late Blight Management practices in each country current versus future** **4. Late Blight Modelling tools and experimental studies used to analyse the effects of climate change on *P.infestans* incidence**	**Prof Miah** 1. Jagannathan, Debnath, Miah, Huda, Khan, Banerjee and O'Leary, DeBoer 2. Indra, Asad, Saha, Dutta, Hossain, DeBoer, Spooner-Hart (Rodoni) 3. Hossain,Dutta, Bhattacharya, De Boer, 4.Wendy Griffiths, Dolf DeBoer, Garry O'Leary, Dutta, Saha, Huda,
10:30am	*Morning Tea*	
11:00am	**Writing Workshop continues**	All
12:00nn	*Lunch*	
12:30pm	Depart for airport via MCG.	

Thursday, 21 October – APN Workshop Day 3		
8.30am	**Feedback - Writing working groups, finalise activities and procedures.**	All (Robert S-H, chair)
9.30am	**Discussion. Future project activities. Planning Dhaka workshop.**	All (Jo Luck, chair)
10.30am	*Morning tea*	
11.00am	Tour of UWS, especially Climate Change Facilities and research activities.	Robert S-H, Samsul Huda, David Tissue, Markus Riegler (UWS)

12.30pm	*Lunch*	
1:30pm-5:00pm	Visit Hawkesbury farming area, and potato farm. Visit Featherdale Farm Wildlife Park, Blacktown (if time permits)	Including NSW DPI staff (Leigh James)
Friday, 22 October – APN Workshop Day 5		
8.30-9.30am	Workshop Wrap-up	Jo Luck to Chair
9.45am	Depart for Sydney airport and hotel.	

1. Workshop 3 Program

APN Workshop 3, Bangkok

9-13 May 2011

Kasetsart University
"KU Home"
50 Moo 3 Kasetsart University
Ngamwongwan Road. Ladyao, Chatuchak, Bangkok 10900

WORKSHOP PROGRAM

Monday 9 May, 2011 – APN Workshop Day 1		
10.00am	**Welcome on behalf of Thai Hosts**	Dr Sirachi Kamlayanarat (Head of Post-Harvest technology Program King Moncutt's University of Technology, Bangkok)
10.10 am	Morning tea and group photo	"KU Home" and Meeting Rooms
10.15 am	**APN Workshop Welcome and Opening**	Dr Jo Luck
10.20 am	**Welcome on behalf of APN for Global Change**	Dr Md Giashuddin Miah
10.30 am	**Potato production and late blight in Vietnam**	Dr Pham Xuan Tung CIP Coordinator for SE Asia
11.00 pm	**Summary from APN Workshop 2 and Purpose and Objectives of Workshop 3 Reiteration of milestones to achieve for APN project**	Jo Luck
11.30	**Structure of Workshop 3**	Jo Luck
12.30 pm	*Lunch*	"KU Home" and Meeting Rooms

1.30 pm	**Climate data and projections (1971-2050) for potato growing areas in India, Bangladesh and Australia-climate change effects on production**	Jagannathan, O'Leary (Presentation)
2.00 pm	**Late blight modeling tools and assessment of the effect of climate change on PLB in India, Bangladesh and Australia**	Dr Saha, Debnath, Hossain (Presentation)
2.30 pm	**Potential adjustment of Management for PLB with changing climate- We may not have advanced the work enough for this?**	Indra, Hossain, Dutta? (presentation)
3.00 pm	**Implications for policy, growers, Government**	Kep/Miah/Jo
3.30 pm	*Afternoon tea*	*"KU Home" and Meeting Rooms*
4.00 pm	**Discussion and next steps**	Jo Luck to lead
5.30 pm	*Close*	
7.00 pm	*Dinner*	*Local restaurants*

Tuesday 10 May, 2011 – APN Workshop Day 2

9:00am	**Writing Group 1** **Climate data and projections (1971-2050) for potato growing areas in India, Bangladesh and Australia-climate change effects on production** **Leader: Jagannathan**	**Writing Group 2** **Late blight modeling tools and assessment of the effect of climate change on PLB in India, Bangladesh and Australia** **Leader: Saha**	**Writing Group 3** **Management of PLB current and with changing climate** **Leader: Indra**	**Writing Group 4** **Implications for policy, growers, Government** **Leader: Kep**
9.00-10.30am	Assemble teams, determine writing roles for team members, identify gaps Resources required: power points for multiple laptops team to bring own lap tops, rooms or space for four groups to assemble separately, internet access to search for papers?			
10:30am	*Morning tea*			
10:30-12.30 pm	Writing Group 1 Climate data and projections (1971-2050) for potato growing areas in India, Bangladesh and Australia-climate	Writing Group 2 Late blight modeling tools and assessment of the effect of climate change on PLB in India, Bangladesh	Writing Group 3 Management of PLB current and with changing climate	Writing Group 4 Implications for policy, growers, Government Leader: Kep

	change effects on production Leader: Jagannathan	and Australia Leader: Saha	Leader: Indra	
12:30pm	*Lunch*			
1:30pm	Writing Group 1 Climate data and projections (1971-2050) for potato growing areas in India, Bangladesh and Australia-climate change effects on production Leader: Jagannathan	Writing Group 2 Late blight modeling tools and assessment of the effect of climate change on PLB in India, Bangladesh and Australia Leader: Saha	Writing Group 3 Management of PLB current and with changing climate Leader: Indra	Writing Group 4 Implications for policy, growers, Government Leader Kep
3:30pm	*Afternoon tea*			
	Writing Group 1 Climate data and projections (1971-2050) for potato growing areas in India, Bangladesh and Australia-climate change effects on production Leader: Jagannathan	Writing Group 2 Late blight modeling tools and assessment of the effect of climate change on PLB in India, Bangladesh and Australia Leader:Saha	Writing Group 3 Management of PLB current and with changing climate Leader: Indra	Writing Group 4 Implications for policy, growers, Government Leader Kep
5.00pm	*Close*			
7.00pm	*Dinner*			

Wednesday 11 May, 2011 – APN Workshop Day 3

9:00am	**Report Back Writing Group 1** **Climate data and projections (1971-2050) for potato growing areas in India, Bangladesh and Australia-climate change effects on production** Leader: Jagannathan	**Report Back Writing Group 2** **Late blight modeling tools and assessment of the effect of climate change on PLB in India, Bangladesh and Australia** Leader:Saha	**Report Back Writing Group 3** **Management of PLB current and with changing climate** Leader: Indra	**Report Back Writing Group 4** **Implications for policy, growers, Government** Leader Kep

10:30am				
	Writing Group 1 Climate data and projections (1971-2050) for potato growing areas in India, Bangladesh and Australia-climate change effects on production Leader: Jagannathan	Writing Group 2 Late blight modeling tools and assessment of the effect of climate change on PLB in India, Bangladesh and Australia Leader:Saha	Writing Group 3 Management of PLB current and with changing climate Leader: Indra	Writing Group 4 Implications for policy, growers, Government Leader: Kep
12:30pm				
	Bangkok Tour			
3:30pm				
5.00pm	*Close*			

Thursday 12 May, 2011 – APN Workshop Day 4

9:00am	**Report Back Writing Group 1** **Climate data and projections (1971-2050) for potato growing areas in India, Bangladesh and Australia-climate change effects on production** **Leader: Jagannathan**	**Report Back Writing** **Group 2** **Late blight modeling tools and assessment of the effect of climate change on PLB in India, Bangladesh and Australia** **Leader:Saha**	**Report Back Writing Group 3** **Management of PLB current and with changing climate** **Leader: Indra**	**Report Back Writing Group 4** **Implications for policy, growers, Government** **Leader Kep**
10:30am	*Morning tea*			
10:30am	1. Reporting against milestones 2. Further responsibilities of team 3. Gaps and next steps with paper 4. Gaps and next steps on policy document 5. Critical policy/government contacts for each country		Kep Coughlan	

	6. New directions for APN project or similar	
12:30pm	*Lunch*	
1:30pm	1. New project ideas, 2. Funding opportunities 3. Potential Project leaders	Led by Robert Spooner Hart
3:30pm	*Afternoon tea*	
	1. New project concepts	Led by Robert Spooner Hart
7.00 pm	*Dinner*	

Friday 13 May, 2011 – APN Workshop Day 5

9.00-1200	New Project groups and nominated leads	Robert
	Regional Policy Report Back	Kep
	Update on integrated paper	Jo
	Roles and Responsibilities-Next steps	Jo
	APN Final Report	Jo
	Feedback	All
	Closing Words	Jo
12.00 pm	*Lunch*	
2.30 pm	Free Program	

Appendix 4: Participants List

1) Dr. Jo Luck, DPI Victoria, Cooperative Research Centre for National Plant Biosecurity (CRC NPB), Australia jo.luck@dpi.vic.gov.au
2) Assoc Prof Samsul Huda, Crop Modelling, University of Western Sydney, Australia s.huda@uws.edu.au,
3) Professor R. Jagannathan, Tamil Nadu Agricultural University, Coimbatore, Agronomist, jagan@tnau.ac.in, Professor and Head of Agro Climate Research Centre.
4) Prof S.A. Khan Bidhan Chandra Krishi Viswavidyalaya (BCKV), India, sakhan_bckv@sify.com,
5) Dr. Indrabrata Bhattacharya Kalyani Nadia West Bengal indrabratabhattacharya@gmail.com,
6) Dr Mohammad Asaduzzaman, Bangladesh Science Foundation (BSF), Bangladesh masad@agni.com
7) Dr Kep Coughlan UWS Visiting Fellow kepcoughlan@optusnet.com.au
8) Prof Robert Spooner-Hart, University of Western Sydney (UWS), Australia, r.spooner-hart@uws.edu.au
9) Dr. Md. Delowar Hossain, Chief Scientific Officer, Plant Pathology Division BARI, Gazipur.Bangladesh, csopath@bari.gov.bd
10) Giashuddin Miah (Agricultural Policy Bangladesh) giash1960@gmail.com
11) Dr.Subrata Dutta <subrata_mithu@yahoo.co.in>, Plant Pathologist working on rice and vegetable Pathology
12) Dr.A.Saha asaha_bckv@yahoo.co.in, Agrometeoreolgy,BCKV,Mohanpur specialization on Crop growth modelling and Climate change.
13) Dr Garry O'Leary DPI Victoria, Crop Modeller garryo'leary@dpi.vic.gov.au
14) Dr Saon Banerjee. (BCKV University) sbaner2000@yahoo.com
15) Dr Gakul Debnath, (BCKV University) gcdebnath11@yahoo.com

5. Policy Brief West Bengal

Climate change implications for Potato Late Blight and its effect on potato production in West Bengal

Policy Brief prepared for the Direct Agriculture West Bengal

Climate change is presenting new threats and opportunities for the management of an important fungal disease Potato Late Blight. Potato is the third largest food crop globally, and Late Blight has historically has led to serious crop losses, resulting in one extreme case in famine and the emigration of many people from Ireland in the mid nineteenth century.

In West Bengal, India potatoes are mainly grown in the Gangetic alluvium region and contribute an annual value of INR 80 million to the economy. Serious epidemics of Potato Late Blight (PLB) have occurred in 2006-07 and 2008-09 and have caused around 40% yield losses. PLB affects the potato plant late in its growth cycle, initially infesting the leaves and stems and later resulting in devastating damage to tubers. PLB is basically a soil-borne disease, including carryover in unharvested tubers, but can also be spread through crop residues, and aerially by wind and insect vectors.

In West Bengal, the maximum temperature will increase by 0.2 - 0.6 ° C and minimum temperature increase will be 0.2 - 0.5 °C per decade up until 2050.

In 2025, the average potential potato yield reduction in West Bengal will be around 3.3 t/ha and in 2050, it will be around 5.08 t/ha and the best yield can be obtained if the crop is sown on (or around) 6th Nov, whereas in 2050 the mid November sown crops will give the best output.

The late blight disease intensity was found to be less than 20% in 1990-91 to 1999-2000, except in the 1994-95 seasons. More frequent late blight epidemics have been reported throughout West Bengal in the last 5 years. The late blight epidemics were observed during the year 2006-07 and 2008-09. The efficacy of metalaxyl fungicide treatments for late blight control appear to be significantly reduced in the last few years suggesting the possible development of metalaxyl resistant strains in West Bengal.

Onset of PLB is likely to be earlier in the growing season in the future decades as compared to the present decades (2011-20).

The future trend for PLB is that the disease severity is likely to reduce by 5-7% from 1981-2010 period to 2031-40 period in the intensive potato growing areas of West Bengal, India.

PLB responds to cloudy days, humidity, fog and rain, and rules-based early warning systems have been developed. However, fog data is not routinely collected for West Bengal.

In the past fungicide spraying has been the only effective control for PLB, but their over-use has led to human health problems. Farmers and technical experts need to use a range of agronomic and biological methods to reduce the use of fungicides and to develop an Integrated Disease Management (IDM) system.

These should include:

1. Strategic use of fungicide sprays based on an early warning system
2. Use wherever possible of varieties with some resistance to PLB and increased temperature
3. Production of high quality certified Potato seed, locally in villages.
4. Development of fungal and bacterial bio-control agents to attack PLB
5. Removal of the above ground vegetative part of the plant (Dehaulming) should be practised at 10-15 days before harvesting
6. Furrow irrigation should be limited to half of the height of the ridges, and Irrigation should be completed before 12 noon. These strategies reduce subsequent high humidity overnight in the potato canopy
7. Avoid potato cultivation in low lying rice areas
8. Soil test based nutrient application, particularly with respect to Nitrogen, should be followed to avoid excess vegetative growth, which is more susceptible to infestation by PLB
9. More cold storage facilities should be developed to enable farmers to store surplus production, providing suitable storage temperature and chemical treatments to sustain quality.
10. Farmers training in farmer's field schools (FFS) to generate awareness among the farmers to monitor disease regularly and select proper strategies of disease management in a participatory mode

Appendix 6. Policy Brief Bangladesh

Climate Change Implications for Potato Late Blight and its effect on potato production in Bangladesh

Policy Brief prepared for the Ministry of Agriculture, Government of Bangladesh

Climate Change is presenting new threats and opportunities for the management of an important fungal disease Potato Late Blight. Potatoes are ranked the fourth most important food crop in the world with PLB estimated to cause losses of up to 15% of annual global production (CIP, 1996). Potato is the third largest food crop globally, and Late Blight historically has led to serious crop losses, resulting in one extreme case in famine and the emigration of many people from Ireland in the mid nineteenth century.

In Bangladesh, potato is the third largest food crop and it is extensively grown in the Rangpur, Bogra, Dhaka and Comilla regions. It contributes an annual value of US$ 1189.48 (value of Tk. 10/kg) to the economy. Infestations of Potato Late Blight (PLB) have occurred in most years and have usually caused losses of about 20-30 percent and estimated losses at US$ 238-357. However, in one recent severe outbreak in 2005-06 crop losses were about 38%. PLB affects the potato plant late in its growth cycle, initially infesting the leaves and stems and later resulting in devastating damage to tubers. PLB is basically a soil-borne disease, including carryover in unharvested tubers, but can also be spread through crop residues, and aerially by wind and insect vectors.

In Bangladesh, the maximum temperature will increase by 0.2 - 0.6 ° C and minimum temperature increase will be 0.2 - 0.5 °C per decade up until 2050.

The future trend for PLB in intensive growings areas of Bangladesh, will be disease severity increasing up to 12% in intensively potato cultivated areas of northern Bangladesh and reducing to around 7% in similar intensive growing areas of central Bangladesh.

PLB responds to cloudy days, humidity, fog and rain, and rules-based early warning systems have been developed. However, fog data is not routinely collected for Bangladesh.

In the past, fungicide spraying has been the only effective control for PLB, but their over-use has led to human health problems. Farmers and technical experts need to use a range of agronomic and biological methods to reduce the use of fungicides and to develop an Integrated Disease Management (IDM) system. These should include:

1. Strategic use of fungicide sprays based on an early warning system for PLB
2. Use of varieties with resistance/tolerance to PLB and heat wherever possible
3. Use of good quality pre- treated seed
4. Development of bacterial bio-control agents to control attack of PLB
5. Provide improved sanitation facilities to avoid excessive moisture/water regimes
6. Promote micro irrigation system (drip irrigation) replacing macro irrigation system (flood irrigation)

7. Judicious use of fertilisers based on soil testing; over-use makes tissues soft and susceptible to infection by PLB

8. Avoid growing potatoes in the same areas and at the same time as irrigated rice as this increases fog occurrence which is a major environmental precursor of PLB infestation

9. Earlier planting of potatoes where temperature regimes allow, as this has positive effect of reducing exposure to early frosts as well, another environmental precursor of PLB infestation

10. Adaptation to climate change by growing potatoes in areas where the temperature profiles for different crop development phases are ideal. This may involve moving from existing production areas.

11. Form a joint team consisting of scientists and policy makers of Bangladesh and India (West Bengal) to monitor disease infestation, management strategy and recommend action to minimize yield gap.

Appendix 7 Policy Brief Australia

Climate Change Implications for Potato Late Blight and its effect on potato production in Australia

Policy Brief prepared for the Chief Plant Protection Officer Lois Ransom, Mickael Hirsch and the CEO of Plant Health Australia Dr Greg Fraser

Introduction

Climate Change is presenting new threats and opportunities for the management of an important fungal disease, Potato Late Blight (PLB). Potatoes are ranked the fourth most important food crop in the world with PLB estimated to cause losses of up to 15% of annual global production (CIP, 1996). Although *P.infestans* (mating type A1) has been present in Australia since the early 1900s, it is one of the few countries in the world that remains free of the virulent mating type (A2). Disease outbreaks are sporadic and mainly confined to Victoria and Tasmania but still can be effectively controlled with metalaxyl based fungicide (Edwards et al, 2006).

Late blight is dependent on two main climatic variables: moisture and temperature, specifically warm moist air coupled with stagnant or slow moving depressions. The projected climates for two potato production areas in Australia, Thorpdale, Victoria and Kairi, Queensland were identified and based on these projections, the effect on future yield was modelled. A series of late blight models were assessed for their use in determining the influence of projected climates on late blight severity for two potato production regions in West Bengal, India and Australia.

Key Findings

4. Climate change projection for the two production regions
   a. A warming of 2^{o}C-3^{o}C mean temperature is expected by 2050 across both contrasting temperate and tropical potato growing areas of Australia.
   b. Rainfall is expected to decline by about 30-40% by 2050 across both regions.
   c. In the tropical north solar radiation is expected to increase by around 0 to 2% whilst in the temperate south a greater increase of around 2 to 3% in radiation is expected.
   d. The relative humidity is expected to decrease by about 2 to 3% and greater than 4% in the tropical and temperate regions, respectively.

5. Expected potato yield changes due to climate change
   a. Temperate Australia: Increased yield variance from -6 to +5 t/ha by 2050. Propensity for higher yields with median yield gain of +3 t/ha.
   b. Tropical Australia: Smaller yield variance from -1 to +4 t/ha by 2050. Propensity for higher yields with median yield gain of +1 t/ha
   c. The length of the growing season is expected to be shortened by about 30 days in temperate Australia if cultivars are not changed. No change is expected in the duration to harvest in the tropical regions.

6. Expected PLB changes due to climate change

a. The likely warmer but drier conditions expected in the tropical and temperate regions of Australia is expected to result in reduced incidence and severity of PLB at all locations despite a general increase in productivity.
b. At Kairi, the tropical site, under the A1Fi climate scenario the time of sowing would be delayed from a historical mean sowing time from 29 April to 10 May. However, this will have a negligible effect on PLB disease onset or severity. A delay in the onset of infection (12 days) with a corresponding decrease in severity of around 18% is expected with the sowing date change. Very little change is seen if the sowing date remained identical to historical dates.
c. In contrast, at Thorpdale, the temperate site, the onset of PLB is predicted to be 15 days earlier with a very slight increase in severity with a 5 day mean delay in sowing due to the altered climate. However, if the sowing time was identical to the historical pattern then the onset changes by one day with a significant increase in severity likely (26% increase). A delay in sowing is a strategy to minimise PLB infection in Victoria.

Recommendations

- While the risk for PLB damage under future climates will decrease in the two Australian growing regions, it is recommended that vigilance is maintained through planting high health material and quarantine practices are kept in place to prevent the virulent strain of *P. infestans* entering the country.
- Early detection of *P. infestans* strains and a close monitoring of the genetic mutations of the new strains overseas will be important in preventing establishment of the aggressive PLB.
- A regular revision of the PLB contingency plan is suggested with special attention given to the status of PLB management in near neighbouring countries in the Asia Pacific Region.
- Revision of the contingency plan is also recommended as each Intergovernmental Panel for Climate Change (IPCC) Assessment report is released (the 5th Assessment Report is due for release in 2014) to determine how climatic conditions may alter the risks posed by PLB.
- For endemic infections of PLB, earlier planting of potatoes (where temperature regimes allow) will reduce the crop's exposure to early frosts, another environmental precursor of PLB infestation. In the medium to long term climate projections the reduction in frost events will likely reduce the risk of PLB infection further.

Funding sources outside the APN

Estimate of in-kind/cash contributions $USD

Agency	***2010***	***2011***
DPI Vic	10% Luck $25,000	10% Luck $25,000
Cooperative Research Centre National Plant Biosecurity	10% De Boer$25,000 10% O'Leary $25,000 5% Hossein $10,000	10% De Boer$25,000 10% O'Leary $25,000
University of Western Sydney	10% Spooner-Hart $25,000 10% Coughlan $25,000 10% Huda $25,000	10% Spooner-Hart $25,000 10% Coughlan $25,000 10% Huda $25,000
BCKV	10% Indrabrata Bhattachaya 10% Subrata Dutta 10% Saon Banerjee 10% Debnath 10% Safi Khan	10% Indrabrata Bhattachaya 10% Subrata Dutta 10% Saon Banerjee 10% Debnath 10% Safi Khan
Bangladesh Science Foundation	10% Mohammed Asaduzzaman	10% Mohammed Asaduzzaman
Bangladesh	10% D. Hossain	10% D. Hossain
Tamil Nadu University, Coimbature	10% R. Jagannathan	10% R. Jagannathan
Bangabandhu Sheikh Mujibur Rahman Agricultural University	10% Giashuddin Miah	10% Giashuddin Miah
Total in-kind	>$160,000	>$150,000

List of Young Scientists

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.

1. Dr. Subrata Dutta, M.Sc. (IARI), Ph.D. (IARI)
Department of Plant Pathology
BCKV, Kalyani, Nadia
West Bengal- 741235
phone: 09476272646
subrata_mithu@yahoo.co.in

Short message from Dr Dutta: *"It is great exposure for me in strengthening my knowledge in the field of disease forewarning system by interacting with experts from different disciplines and countries especially in data interpretation and analytical studies. I gathered a lot in field experience of potato farming related progress and problems in different countries. It is really a great learning process on how an interdisciplinary project works in solving the future threats of potato crops in three different countries. "*

2. Dr Saon Banerjee
Associate Professor (Agricultural Meteorology),
AICRP on Agro-meteorology, Research Complex building,
BCKV, P.O.-Kalyani, PIN – 741235.
West Bengal. India.
E-mail: saonbanerjee@gmail.com

Short message from Dr Banerjee: "*It is a great exposure for me to strengthen my interpretation and analytical ability and a learning process on how an interdisciplinary project works."*

Glossary of Terms

PRECIS: Providing Regional Climates for Impacts Studies

RegCM: Regional Climate Model

CSIRO: Commonwealth Scientific and Industrial Research Organisation

TOS: Time of Sowing