The Farmers Club Charitable Trust
Postgraduate Study Award

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Introduction

The purpose of my study programme was twofold:

i) To develop expertise in using APSIM (Agricultural Production Systems Simulator).
ii) To discuss soil and water conservation methods currently used in Australia, that may be applicable to UK farming systems.

In addition, as a condition of the award, I was asked to write a paper on 'The approach of CSIRO and the way it operates in relationship to the market'. The primary focus of my visit was on part (i) and hence this report focuses on that work, with shorter sections on part (ii) and the report on the way that CSIRO operates.

Funding from the Farmers Club Charitable Trust was granted for a six week study period in Australia. As agreed with the Charitable Trust, the study period was extended using funds from the University of Nottingham, thereby allowing me to be based at CSIRO for a total of seven months.

APSIM

Introduction to APSIM

The Agricultural Production Systems Simulator (APSIM) is a modular modelling framework developed by the Agricultural Production Systems Research Unit (APSRU) in Australia (Keating *et al*., 2003). APSRU is a collaborative group made up of CSIRO and Queensland State Government Agencies. APSIM differs from other well known models such as CERES in that, in addition to predicting crop yield, it also addresses the systems aspects of cropping including rotations, establishment, crop failure, and longer term soil processes such as organic matter content and soil erosion (Keating *et al*., 2003).

APSIM was originally developed for dryland cropping systems in Australia, where water scarcity and soil conservation are major issues. Under climate change, the distribution of rainfall in the UK is likely to change, with increased risk of summer droughts, and more over-winter rainfall. Hence, both water scarcity and soil erosion will be increasingly important issues in the UK, and these have been shown to be well described within the APSIM framework.

APSIM training

A significant amount of work was required to understand the way that the APSIM model operates before it could be used effectively for UK crops. This was done in two ways: (i) one to one training/advice from colleagues in CSIRO, (ii) a formal two day training course on 8-9 March 2011.

Using APSIM for UK cropping

Data from a range of 26 experimental data sets of winter wheat experiments in the UK was used to validate the model for use in UK conditions.

It has been previously reported that, when used in cooler environments, APSIM underestimates the rate of soil N mineralisation (Asseng *et al*., 2000; Lilley *et al*., 2003; Verberg *et al*., 2007). Early results showed that this was also the case with the simulations of UK crops and hence the soil N mineralisation code, developed by Verburg *et al*. (2007) was adopted and found to improve the accuracy with which APSIM was able to predict N uptake, biomass and yield.

Crop biomass was simulated for 16 experimental treatments over two years. Biomass was simulated very well (Figure 1) with R^2 (1:1) of 0.96 indicating very close agreement between observations in UK crops and APSIM predictions.

Crop yield was simulated for all 26 experiments. There was a tendency for APSIM to overpredict yield (Figure 2) which should be expected as APSIM assumes no limiting factors to growth when, in reality, weed competition, pests and diseases are likely to compromise yield to some extent. While most of the experiments were managed with a prophylactic programme of pesticides to minimise weeds, pests and diseases, seven of the crops were managed organically and therefore not treated with any crop protection chemicals, hence yields were often significantly lower than predicted for these crops. The R^2 (1:1) for yield was 0.71 indicating that the agreement between observations and predictions was not as close as for biomass, but still accounted for 71% of the variation in the dataset.

The good agreement between APSIM simulations and observed biomass accumulation and yield in UK wheat crops justifies the use of APSIM to predict the effect of future climate scenarios on UK wheat yield.

APSIM simulations for climate change scenarios

While many authors have concluded that the enhanced atmospheric CO_2 levels will lead to yield increases under climate change, much of this work has been carried out in controlled environments (CE). Long *et al*. (2006) using the FACE system (which operates at the field scale) found that yield response to enhanced CO_2 was much lower than reported in controlled environment studies. When the negative effect of increasing atmospheric ozone concentrations was factored in, the same authors predicted that the yield of C_3 crops would decrease. A recent review by Jaggard *et al*. (2010) concluded that, by 2050, the impact of rising atmospheric ozone concentration is likely to eliminate most of the yield increase due to increased carbon dioxide concentration in C_3 species. Therefore, the analysis in this report focuses on the effect of changes in temperature and rainfall on UK wheat production assuming that the positive effects of CO_2 are cancelled out by the negative effects of atmospheric ozone.

The weather generator created by the UK Climate Projections project (http://ukclimateprojections-ui.defra.gov.uk) was used to generate 30 years of meteorological data for the Sutton Bonington site, both for baseline conditions and post-climate change, centered on 2050. One hundred 30 year runs were generated for baseline, mid-emissions and high-emissions scenarios and these were used to calculate mean monthly met data (Figure 3). The generated baseline data compared well with the 30 year mean measured at the Sutton Bonington met station.

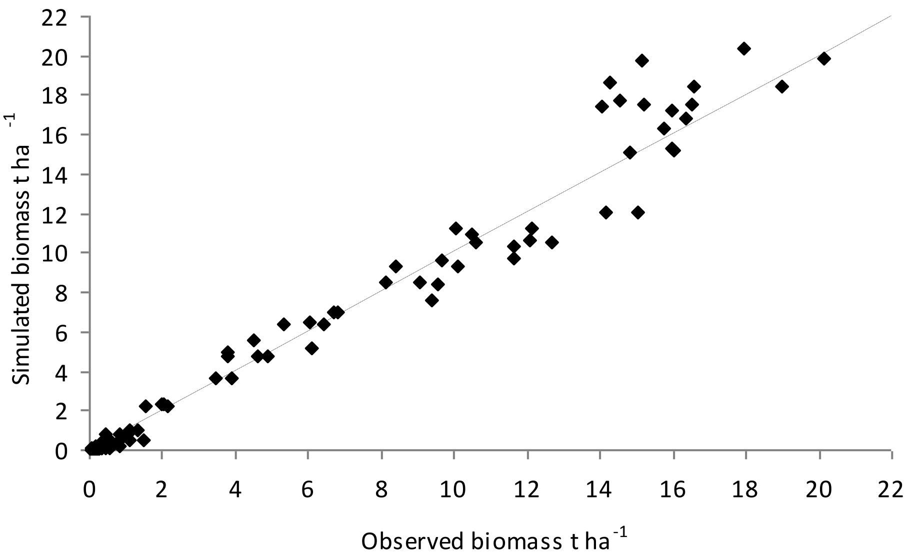


Figure 1. Model performance for total above ground biomass. The dotted line is the 1:1 line.

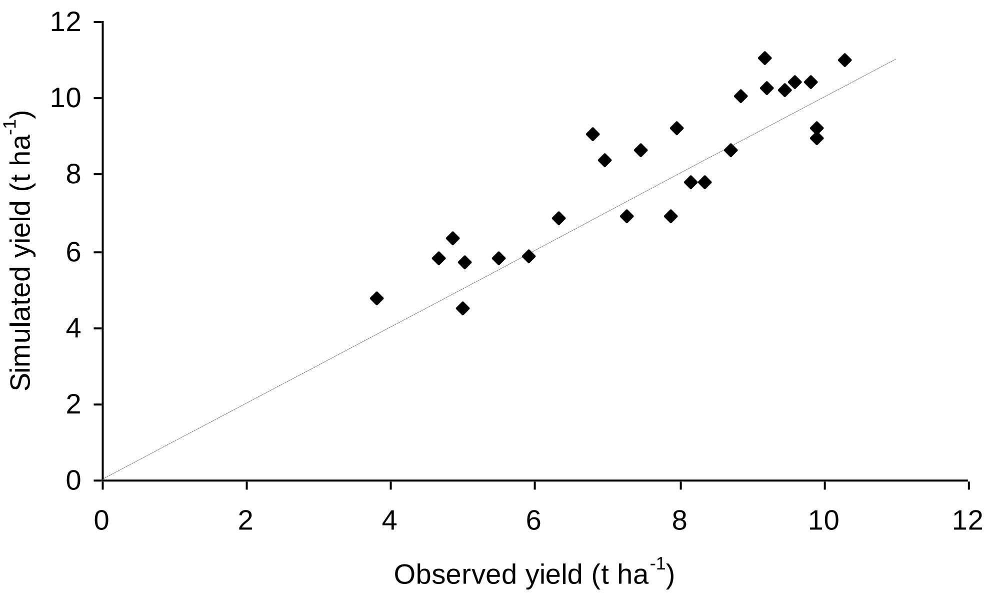


Figure 2. Model performance for yield. The dotted line is the 1:1 line.

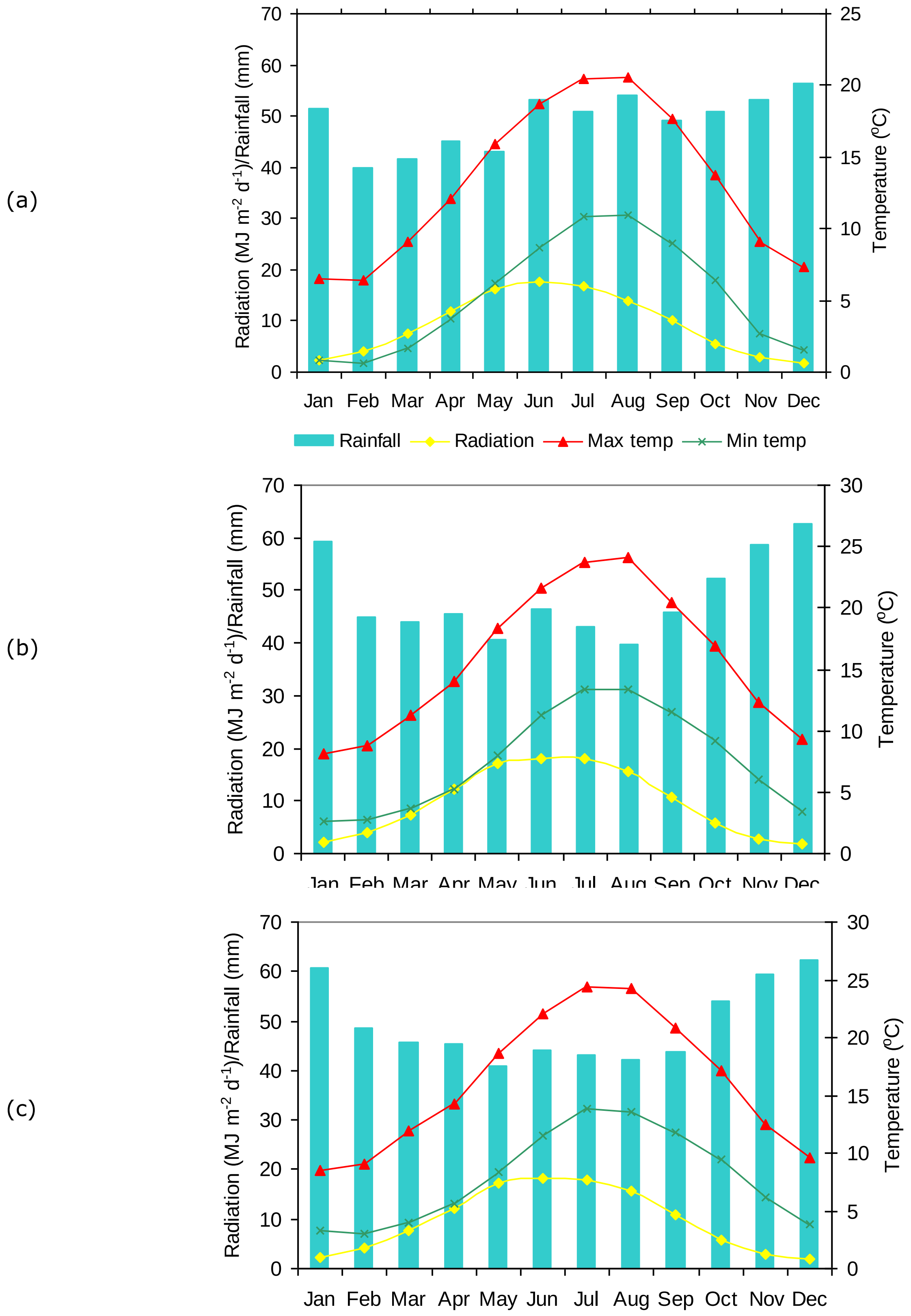


Figure 3. Monthly met data generated by UKCP for (a) baseline, (b) mid emissions and (c) high emissions scenarios in 2050.

Under the mid-emissions scenario for 2050, there was no significant change in annual rainfall but the distribution changed with more winter rainfall (especially November to January) and lower monthly rainfall from May to September. The mean daily maximum temperature increased from 13.1 to 15.7^{o}C and the mean daily minimum temperature from 5.3 to 7.5^{o}C. The mid and high emissions scenarios were rather similar, but this was not surprising as it is expected that these scenarios will not differ significantly before the 2080s. Due to the similarity in met data between the mid and high emissions scenarios, crop simulations focussed on comparing baseline (current conditions) with the mid-emissions scenario for 2050.

<u>APSIM simulation results</u>

Initially, the simulations were carried out for a clay loam soil with a plant available water capacity of 222mm. These results were then compared with a sandy soil with 92mm plant available water capacity. Plant available water capacity is the difference between upper water storage limit of the soil and the lower extraction limit of a crop over the depth of rooting.

A preliminary APSIM run was carried out to calculate the effect of these changes in climate on starting soil moisture for the UK wheat crop. The average extractable soil water at sowing was found to be 178mm for the baseline and 142mm for the mid-emissions scenario. These values were then used for the main simulation runs.

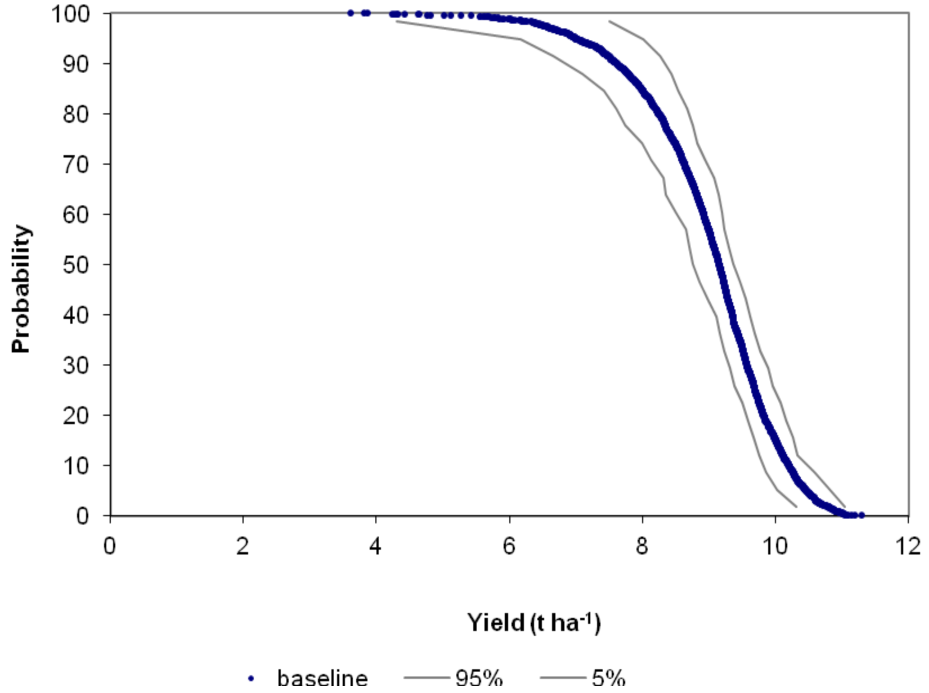
Figure 4 describes the probability of achieving a particular yield on the clay loam soil under (a) baseline and (b) the mid-emissions scenario for 2050. For example, in 90% of years, a yield of 7.8 t ha^{-1} or greater would be expected under baseline conditions, but under climate change this is reduced to 6.2 t ha^{-1} or greater. The median yield (the yield that could be expected in 50% of years) was 9.15 t ha^{-1} under baseline conditions reducing to 8.27 t ha^{-1} under the mid-emissions scenario for 2050. However, this 10% reduction in yield masks the dramatic increase in variation expected under climate change. This is described by the narrow lines on Figure 4, which indicate the 95% confidence limits. Figure 4(a) shows much narrower confidence limits than Figure 4(b) highlighting the greater expected variability in yield under climate change.

The impact of the changes in rainfall distribution would be expected to be greater on a soil with lower water holding capacity and this was confirmed by simulations using a sandy soil with a plant available water capacity of 92mm. On this light textured soil the median wheat yield would reduce by 24% from 5.42 t ha^{-1} to 4.13 t ha^{-1}, but once again the increase in variability is more dramatic than the average results (Figure 5).

APSIM allows the mechanisms by which yield is reduced under climate change to be explored. This is discussed in detail here for the clay loam soil, which was the main soil investigated. The 10% reduction in yield was associated with a 5% reduction in biomass, indicating that harvest index (the proportion of biomass converted to grain) was also reduced (4%). Median grain number per m^2 was reduced by 3% and median grain size by 6%. The larger impact on grain size indicates that the grain filling period was adversely affected by the changes in climate. There are two possible mechanisms for this: a reduction in the duration of grain filling caused by increased temperatures and increased water stress during grain filling. Both mechanisms were in evidence with mean temperature during grain filling increased by 2.1^{o}C which reduced the grain filling duration by 4 days. In addition, rainfall during the same period decreased by 26%, on average, resulting in significant water stress in most years.

Extractable soil water at harvest reduced from 126mm in the baseline scenario to 96mm under climate change (26%). However, by the start of the sowing window, the differences were shown to have little impact on sowing opportunity and the profile was usually recharged over the winter period.

(a)



(b)

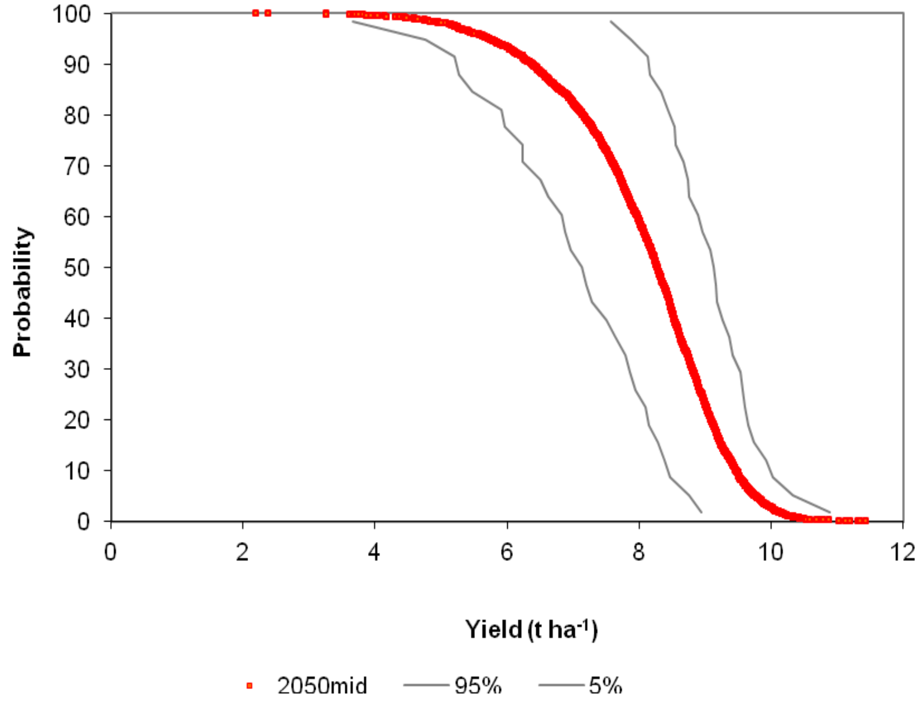
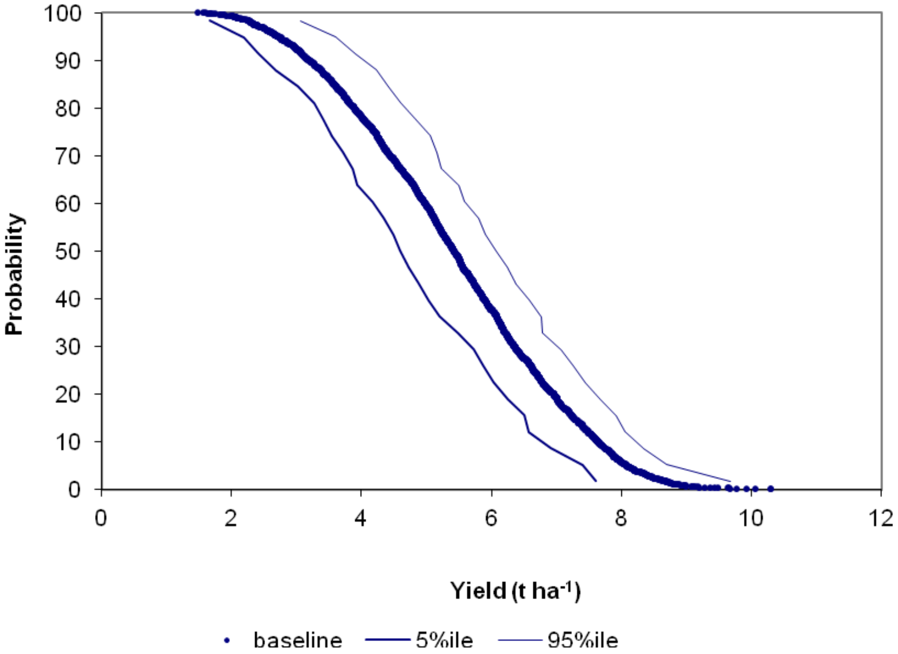


Figure 4. Probability of achieving a given yield of wheat on a clay loam soil under (a) baseline conditions and (b) the mid-emissions scenario for 2050. The narrow lines indicate 95% confidence limits.

(a)



(b)

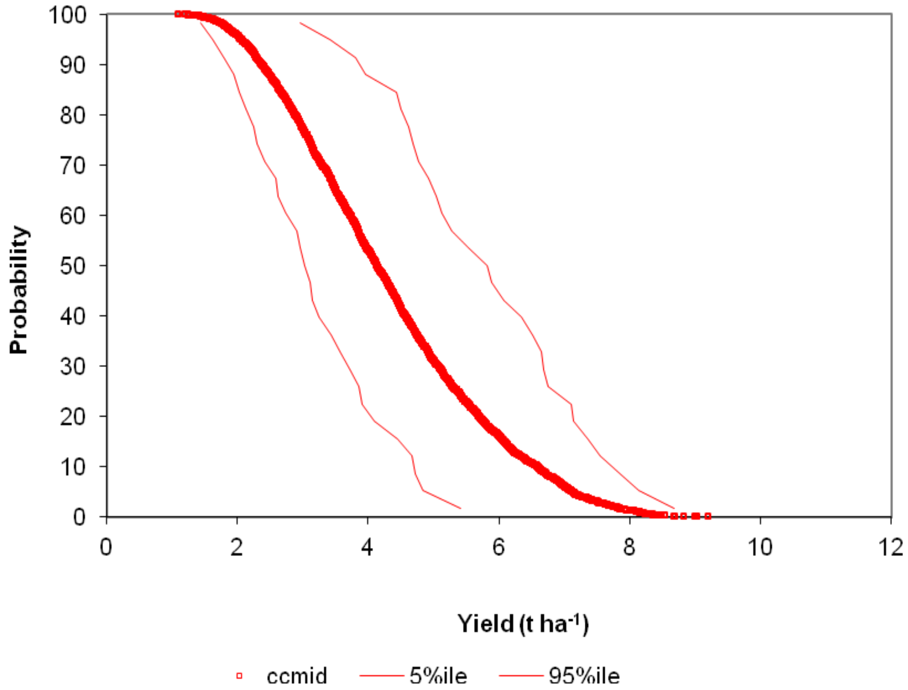


Figure 5. Probability of achieving a given yield of wheat on a sandy loam soil under (a) baseline conditions and (b) the mid-emissions scenario for 2050. The narrow lines indicate 95% confidence limits.

Summary

APSIM was successfully validated for UK wheat crops using data from 26 experimental data sets over a 10 year period. Agreement between the APSIM simulations and experimental observations was shown to be 96% for biomass and 71% for grain yield. To further improve the predictive ability of APSIM, full soil characterisation is required, in particular, direct measurements of plant available water capacity througout the soil profile.

Median wheat yield on a moisture retentive clay loam soil was predicted to decline by 10% by 2050 under the mid emissions scenario. The mechanism was mainly through reduction in grain size, rather than grain number with increased temperature reducing the duration of the grain filling period alongside greater water stress between anthesis and maturity.

Although predicted yield reductions on a moisture retentive soil are moderate, variability between years increases dramatically, increasing uncertainty for growers. This increased variability could have potentially big impacts on the farm business in terms of planning, marketing etc.

Although the study focussed on retentive soils, simulations on sandy soils, with poor moisture retention were also carried out. These predicted a 24% reduction in wheat yield on a sandy soil.

Questions to be considered:

- Can plant breeders produce varieties that are better adapted to conditions under climate change?
- How will growers cope with increased uncertainty under climate change?

Additional outcomes

- APSIM will be used as both a teaching and research tool at the University of Nottingham.
- In collaboration with colleagues at CSIRO, a paper will be submitted to the European Journal of Agronomy which will summarise the results of this work.
- Continued collaboration with CSIRO is planned by way of a jointly supervised PhD student to continue the work on APSIM (as detailed under Future Work).

Future work

- Extend analysis across main arable areas of the UK (climate change scenarios vary across regions).
- Validation of APSIM for other UK crops such as oilseed rape and barley to allow rotational studies. This was not possible during the study period due to the lack of data on these crops.
- Full characterisation of a range of UK soils to improve model performance (see next section of report).

Soil and water conservation in Australia.

Due to the highly diverse environments within Australia, this part of the report will focus on the environment of South East Queensland, where my study period was based, and will consider the soil and water conservation methods used in this region.

South East Queensland is classified as having a sub-tropical climate with mild, dry winters and hot summers. The majority of the rainfall occurs during summer, which is the main cropping period. Cotton and maize are the favoured summer crops, with winter crops, such as wheat, being grown if there is sufficient soil water available (or irrigation capacity). Many practices have been adopted by growers to conserve both soil and water.

Opportunity cropping

Knowledge of the amount of water stored in the soil profile, together with the seasonal weather forecast, is used to determine whether to sow a crop, or leave the land fallow. Researchers, in particular at CSIRO, have been promoting the concept of the soil as a 'bucket' that can hold a certain volume of water. By understanding the storage capacity of their soil, and how full the 'bucket' is, growers can make informed decisions as to whether to sow a crop. A user-friendly version of the model APSIM can be used by growers or agronomists to inform decision making; whether to sow, what sowing density to use, and the level of N fertiliser to be applied.

Soil characterisation

To enable growers to make informed decisions regarding choice of crop, and whether to sow in a particular year, detailed soil characterisation is required to determine the plant available water capacity and to identify any limitations to root growth (such as salinity and sodicity). CSIRO have run a number of workshops for growers and agronomists to provide training in the characterisation of soils – particularly for plant available water capacity.

As defined earlier in this report, plant available water capacity (PAWC) is the difference between upper water storage limit of the soil and the lower extraction limit of a crop over the depth of rooting. Theoretical upper and lower limits can be measured in the laboratory but, in practice, crops vary in their ability to extract water (particularly at depth) and thus the crop lower limit may vary markedly from the laboratory value. For this reason, the drained upper limit and crop lower limit are measured in the field. This contrasts with current practice in the UK where laboratory methods are utilised. As water becomes more limiting for crop growth under climate change (as indicated by the APSIM simulations detailed earlier in this report) better understanding of the water available for crop growth will be required, hence the adoption of field based measurements would be advantageous.

The main disadvantage of field based measurements of PAWC is that they are time consuming and labour intensive. To address this, a database of soils in Australia, that have previously been characterised, is available. Growers can access the database, and where their own soil types match those previously characterised, can use this information directly. In a similar way, if detailed soil characterisation were adopted in the UK, a representative range of soils could be identified for analysis. These could then be used to form a database for UK growers.

No-till

The majority of Australian growers (70-80%) have adopted no-till which has a role to play in both soil and water conservation. Crop residues are left on the soil surface to protect the soil from raindrop impact, which can lead to soil erosion. This then extends the protection of the soil surface into the next crop – until the crop's own canopy is able to protect the soil. The residues break down over time and contribute to soil organic matter, with benefits for soil structure and water holding capacity.

In many areas, the no-till practices have been incorporated in a system known as 'Controlled Traffic Farming' or CTF. In this system, tractor wheelings are confined to permanent wheelways such that the majority of the soil surface does not receive any surface compaction. The combination of no tillage and reduced compaction allows the soil structure to develop and results in increased water infiltration, hence greater water available for crop growth leading to improved yields. Other reported benefits include: increased soil physical and biological health; improved access and 'trafficability' after rainfall resulting in improved timeliness; reduced energy requirements of CTF allowing a reduction in fuel use, tractor size and production costs resulting from higher work rates.

The implementation of CTF in the UK therefore has the potential to reduce combinable crop production costs. However, there are many differences between arable production systems in the UK and Australia (e.g. soil type, climate, topography, agronomic practices) and these differences must be quantified before a recommendation can be made about the viability of CTF in the UK. There are existing groups who are currently evaluating controlled traffic farming in the UK (e.g. www.controlledtrafficfarming.co.uk). It will be interesting to see the outcome of this work, in particular in relation to soil health and water available for crop growth.

The approach of CSIRO and how it operates in relationship to the market.

Background to CSIRO

CSIRO is Australia's national science organisation and is one of the largest and most diverse scientific research organisations in the world. Originally established as the Council for Scientific and Industrial Research (CSIR), the purpose was to carry out scientific research to assist primary and secondary industries in Australia – farming, mining and manufacturing. CSIR was renamed in 1949 to the Commonwealth Scientific and Industrial Research Organisation (CSIRO), and now has more than 6,500 staff operating at 55 sites in Australia and around the world.

CSIRO carries out scientific research to assist Australian industry, to further the interests of the Australian community, and contribute to the achievement of national and international objectives (CSIRO, 2010).

CSIRO's primary functions, are to:

• carry out scientific research to:
  - assist Australian industry and further the interests of the Australian community
  - contribute to national and international objectives and responsibilities of the Australian Government.

• encourage or facilitate the application and use of the results of CSIRO scientific research.

Secondary functions include international scientific liaison, training research workers, publishing research results, and disseminating information about science and technology.

CSIRO is organised into thirteen business units. Of these, five are directly related to agriculture:

Ecosystem Sciences applies multidisciplinary science to the sustainability of Australia's agriculture and forestry, built environments, biodiversity, communities, and industries.

Food and Nutritional Sciences conducts food and nutrition research to support the health and wellbeing of the Australian community and the sustainability and viability of the Australian food industry.

Land and Water undertakes research focusing on the measurement and prediction of the availability and condition of Australia's land and water resources.

Livestock Industries provides research solutions to enable Australia's livestock and allied industries to be globally competitive.

Plant Industry is promoting profitable and sustainable agri-food, fibre and horticultural industries, developing new plant products and improving natural resource management. Research focuses on cereals, oilseeds, legumes, cotton, sugar cane, grapes and native species.

CSIRO has formed ten multidisciplinary Flagship programmes which work across business units. These are:

- Climate Adaptation
- Energy Transformed
- Food Futures
- Future Manufacturing
- Light Metals
- Minerals Down Under
- Preventative Health
- Sustainable Agriculture

- Water for a Healthy Country
- Wealth from Oceans

How CSIRO operates in relation to the agricultural market.

Historically, CSIRO set its own research priorities, with central funds available for a large proportion of the work. However, now researchers are expected to have more than 50% of their time funded from external sources. In the areas of crop science and agronomy, the majority of this funding comes from the Grains Research and Development Corporation (GRDC). GRDC itself is funded by a grower levy (0.99% value of grain sold) which is matched by the Australian Government. The GRDC spends c.AUD$100m per annum on research, development and extension. This contrasts with the £9.8 million total levy received each year by HGCA (at current exchange rates £9.8 million equates to AUD$14.7million).

CSIRO is represented on the GRDC committees that identify research priorities to be funded. Growers are also well represented on these committees (similar to HGCA).

CSIRO has a strong tradition of working closely with the farming industry. Much of their research is carried out on-farm, with various levels of participation by farmers, from hosting trials through to direct involvement in the design of experiments and interpretation of results. There is a strong focus within CSIRO on farm systems research, something that is rarely funded in the UK.

An example of how CSIRO operates in relation to the agricultural industry is the National Water Use Efficiency Initiative. The aim of this AUD$12million project, funded by the GRDC, is to increase water use efficiency (WUE) by 10% over 5 years. Grower groups, ranging in size from 2-300 growers, are involved at the local scale. Each group puts forward ideas as to how WUE can be increased and these are evaluated by local research groups. CSIRO scientists are involved using the APSIM model, discussed in the first part of this report, to identify the likely benefit of changing agronomic practice on water use efficiency. CSIRO also has a coordination role, providing a framework for the research and linkages between groups.

Another example of how CSIRO operates in relation to the agricultural industry is the GISERA project. Australia has recently identified 26,000 petajoules of coal seam gas reserves, 90% of which is in Queensland – and much of this underlies farmland. Extraction of the gas requires a large number of wells due to the impermeability of the gas seams. The wells are located at 100-300m apart, with each one occupying an area the size of a basketball court. Once in place, the wells are likely to be active for 10 years. Hence the impact on the landscape, and on agricultural activity, is considerable.

Extraction of coal seam gas is extremely controversial due to the potential impact on the agricultural community and on agricultural output. The Gas Industry Social and Environmental Alliance (GISERA) has been established to research environmental, social and economic impacts and opportunities associated with the coal seam gas industry. CSIRO are one of the founding members of the Alliance. Their status within the industry as a trusted research provider allows CSIRO to provide impartial, integrated research to industry, the regulators and the wider community. Research results will help to inform government policy in relation to the development of the natural gas industry and provide guidance for growers who are directly affected. GISERA has an initial budget of AUS$15M over five years and incorporates the following areas: Terrestrial Biodiversity, Agriculture and Land Management, Surface and Groundwater, Marine Environment and Socioeconomic Impacts.

In summary, CSIRO is a well respected and trusted research provider within the agricultural industry. In addition to providing research on agricultural production that informs the farming industry, they also have a role in coordinating larger farmer-led research programmes, and work closely with the GRDC in this capacity. Due to the wide nature of CSIRO's remit, they are able to offer support in programmes such as GISERA that involve environmental and socioeconomic aspects, alongside agricultural production. The systems approach, whether at the farm scale, or regional level, is effective and something that would, in my opinion, be of great benefit in the UK.

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Summary of visits, training courses and seminars.

24-25 February:	Visited University of Adelaide which hosts the Australian Plant Phenomics Centre and large group of scientists working on breeding for drought tolerance. Presented seminar: 'Ancient wheat species as a source of genetic improvement for wheat'.
2-3 March:	Attended GRDC Grains Research Update, Goondiwindi.
8-9 March:	Participated in APSIM training course, Toowoomba.
22-23 March:	Participated in CSIRO soil measurement workshop, Adelaide
6-7 April:	Grower meetings on high yielding wheat: avoiding lodging. Gave presentations on UK experience. Goondiwindi and Brookstead.
12 May:	Visited Dr Jack Christopher, Leslie Research Institute, Toowoomba.
19 May:	Visted CSIRO Plant Industry in Canberra: Dr Kirsten Verburg, Dr Julianne Lilley, Dr John Kirkegaard and Dr Enli Wang.
20 May:	Visited GRDC, Canberra to discuss interactions between GRDC and CSIRO.
9 June:	Presented seminar at the Leslie Research Centre, Toowoomba: 'Separating the effects of light quality and quantity on growth and development of wheat'.
16 June:	Visited University of New England in Armidale including on-farm field trials.
17 June:	Visited Douglas McMaster Research Station, Warialda.
20 June:	Meeting with Dr Bob McGowan to discuss relationship between CSIRO and industry.
11-13 July:	Emerald: field trials for high input wheat crops.
22 July:	Visited Dr Fernanda Dreccer, CSIRO Plant Industry at Gatton.
27 July:	Presented seminar at CSIRO, Toowoomba: 'Using APSIM to predict the effect of climate change on UK wheat production'.