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Integrated Agricultural Systems: Methodologies, Modelling and Measuring

Investigating climate change impacts and adaptation options using integrated assessment methods

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Summary

This paper illustrates the need for a range of methods, operating at different levels of representation and complexity, in order to investigate the impacts of climate change on agriculture and the subsequent development of appropriate adaptation strategies. Three examples are given: 1. agro-meteorological metrics developed through a social co-learning process with stakeholders (simple but easier to communicate); 2. estimates for a spring barley crop using a generic cropping systems model (medium complexity); 3. estimates of grass production under a sheep grazing regime using the same crop model (higher complexity). The metrics and estimates are derived from observed weather data and downscaled future projection data from the HadRM3 Regional Climate Model. Results are shown to illustrate the complementarities between methods and how their combination creates a clearer picture of what conditions may be like in the future. The three levels indicate the need for a step-wise process for engagement with stakeholders.

Key words: Climate change, agro-meteorology, adaptation, mitigation, communication

Introduction

Integrated Assessment to research the impacts of climate change (CC) and to develop viable strategies for adaptation (including mitigation) encompass a wide field of subjects and issues, not least the methods for dealing with uncertainty. Complex issues do not necessarily need complex approaches to study them, or to communicate them to stakeholders. More often, detailed methods are applied to investigate multiple interactions between variable state entities influenced by multiple drivers of change. Acceptability of such study outputs for use by stakeholders may be compromised by the difficulty in establishing credibility due to both issue and representation complexity. This is particularly true when considering multiple conflicting objectives from land use, including emerging ones such as greenhouse gas emissions reduction and carbon sequestration alongside existing food production and the provision of ecosystem services.

There is need for a suite of approaches encompassing simple to complex methods that facilitate the development of appropriate adaptation options with decision makers and other stakeholders. This paper presents two approaches to investigate the impacts of climate change and potential adaptation options that exist at opposing ends of a detail and complexity spectrum. The simple approach consists of using agro-meteorological metrics as a medium for deliberation with stakeholders on impacts and adaptation. The detailed approach uses the CropSyst model (Stöckle *et al*., 2003) to represent cropping systems, given as two examples: a spring barley crop; and a sheep grazing regime with grass production. The two approaches exist within an Integrated Modelling Framework (IMF) (Matthews *et al*., 1999; Rivington *et al*., 2007) where 'soft systems' approaches (Matthews *et al*., 2006) are combined with loosely coupled biophysical modelling with resource and financial accounting frameworks. The IMF serves to integrate across scales (meso- and macro-economics, spatial) and research disciplines, providing support for policy development considering the trade-offs between multiple land use objectives. The focal point is at the farm-scale. We argue that such complimentary approaches are helpful in establishing credibility with stakeholders through a step-wise process of demonstrating relevance of issues, the legitimacy of approaches, and in providing specific details that enable informed decisions to be made. This achieves both more effective communication of the issues to stakeholders and sufficient detail to develop solutions.

The process of engagement with stakeholders using tools functioning at a relatively basic level (i.e. agro-meteorological metrics), where uncertainty issues can be evaluated and presented, compliments the use of sophisticated modelling approaches where detailed estimates can be made but where there may be unquantifiable uncertainty. For example, in climate modelling projections, it is possible to address uncertainty in future social and economic conditions resulting in differing levels of greenhouse gas emissions giving different radiative forcing effects on the climate through the use of scenarios (i.e. Special Report on Emissions Scenarios (SRES) (IPCC, 2000)). However, in modelling the effects of climate change on farm-scale dynamics (interaction between biophysical resources and management driven by climate, economics and policies), it is necessary to consider the details of economics and social responses on local to global scales, through alterations of markets (supply and demand) and policies. There are therefore irreducible uncertainties in making projections into the future, but the physical aspects of the climate may arguably be easier to estimate than the human drivers.

Materials and Methods

The examples given are the use of agro-meteorological metrics (Ag-metrics) to communicate the impacts of climate change to stakeholders (see Matthews *et al*., 2008, Rivington *et al*., 2008*c* for details), and on-going research using the CropSyst cropping systems simulation model to study the responses of crops to an altered climate.

Underpinning these approaches is the evaluation of the quality of projected climate data used as input to derive Ag-metrics and CropSyst estimates. The IMF approach first used and evaluated the Hadley Centre's HadRM3 Regional Climate Model's estimates of the past climate at specific locations (Rivington *et al.,* 2008*a*). Subsequently downscaling using bias correction (Rivington *et al.,* 2008*b*) was used in order to increase confidence in the utility of projection data (SRES A2 medium-high emissions scenario). Following this:

1. Ag-metrics and simple meteorological summaries were developed and refined through stakeholder group interviews and workshops in a process of social co-learning (between stakeholders and researchers) (Matthews *et al*., 2008) and applied at eight sites in Scotland (Rivington *et al*., 2008*c*) using both observed and downscaled future projection weather data. During the group interviews and workshops the climate model evaluation and downscaling process was described, helping to establish a level of credibility that enabled subsequent deliberation on the utility of the Ag-metrics and discussion on the potential adaptation requirements implied by the CC impacts.
2. Parallel to this within the IMF, the CropSyst model was used to simulate crop production under observed and a downscaled future climate. A spring barley simulation was used to illustrate potential changes in crop phenology and yield. A theoretical cultivar was also created that represented anticipated physiological adaptation requirements to take advantage of possible benefits of a future climate.
3. Also, grass production was estimated under an observed and downscaled future climate using

CropSyst. A simulation was created to represent a sheep grazing regime that maintained a uniform off-take between 1 April and 30 October. However, the grass crop within CropSyst continues to have substantial limitations concerning the calibration and validation of grass growth. This partly due to both structural and parameterisation issues. Hence estimates are provided for illustrative purposes, and for comparison with results from the Ag-metrics, to demonstrate the value in using alternative approaches to investigate the same subject.

Results

Results for the Agro-metrics can be found in Matthews *et al.* (2008), Rivington *et al.* (2008*c*) and at: http://www.macaulay.ac.uk/LADSS/comm_cc_consequences.html. Fig. 1 shows the Ag-metrics as cumulative distribution function (CDF) plots for the date (Day of year) of a phenomenon at a single site (Aberdeen). These differ from the form of representation used at the workshops, where simple line and bar charts were used (given to participants in A3 paper format). The advantage of the CDF plots is that they show the temporal distribution in a similar way to a probability plot, but with a linear axis. They are also more explicit in the variation of a phenomenon that simple line or bar plots. However, they are less easily explained to a lay audience.

1. Ag-metrics: The CDF plots indicate the growing season will start earlier, the last spring air frost and the thermal time accumulation to 200 degree days (Tsum 200, sometimes used as an indication of the start of field operations) will occur earlier in the year. However, the date at which the end of field capacity is reached remains approximately the same, as does the shape of the distribution curve, indicating similar ranges of variation. The soil moisture deficit was seen in Matthews *et al.* (2008) to increase in the summer and the number of days when plants could experience heat stress is expected to rise by 14–15 days per year. Fig. 1 shows that date at which maximum soil moisture deficit is reached occurs approximately 20 days later in the future scenario, but the variability is similar to the observed data. The date of the return to field capacity is projected to be later in the year, on average by 22 days and the end of the growing season will be later by on average 19 days. Presentation of the Ag-metrics (in their simple form) estimated for each location in stakeholder workshops resulted in positive feedback on their utility and meaningful discussion on impacts and adaptation potential (Matthews *et al.,* 2008).

2. For the spring barley modelling, there is a reduction in the time taken for the crop to reach physiological maturity (Fig. 2) due to higher temperatures. The modelled theoretical cultivar included adjustments to the phenological parameters to slow the rate of development, hence it matures at a similar time to that derived from the observed weather data. Fig. 3 shows a reduction in yield under the future scenario (both using the raw data from the HadRM3 and the downscaled data). This may be attributed primarily to the reduction in the time taken to reach physiological maturity and therefore less time to accumulate biomass. The theoretical cultivar achieves a higher yield as it was able to continue accumulating biomass for longer.

3. The simulated grass production within an artificial sheep grazing regime derived using observed weather data and downscaled future projection data (Fig. 4) shows a similar pattern of growth, but growth starts earlier in the year and continues until later into the winter. The dip in production during the summer can be attributed to water limited growth, but this appears over-represented in the simulation using the observed weather data.

However, due to the limitations in the current grass modelling capabilities, there are issues of credibility in the use of model estimates. Where a models' ability to represent past events cannot be appropriately demonstrated, then there is a limit to there credibility. Such a situation arises more frequently when more complex environmental systems (greater interaction between components) are modelled (Bellocchi *et al*., 2009). With the grass – sheep system there are addition levels of feedback that become harder to both represent within the model and explain to stakeholders. Conversely, there are benefits to the more complex representations as they also include greater ranges of estimates. For example from the grass simulations CropSyst also estimates the soil water and nitrogen balances, changes in organic matter content etc. Whilst there may be issues of credibility in the quality of the estimates, the range of outputs do serve to add detail to areas of discussion and deliberation that the more simple, i.e. Ag-metrics, cannot cover.

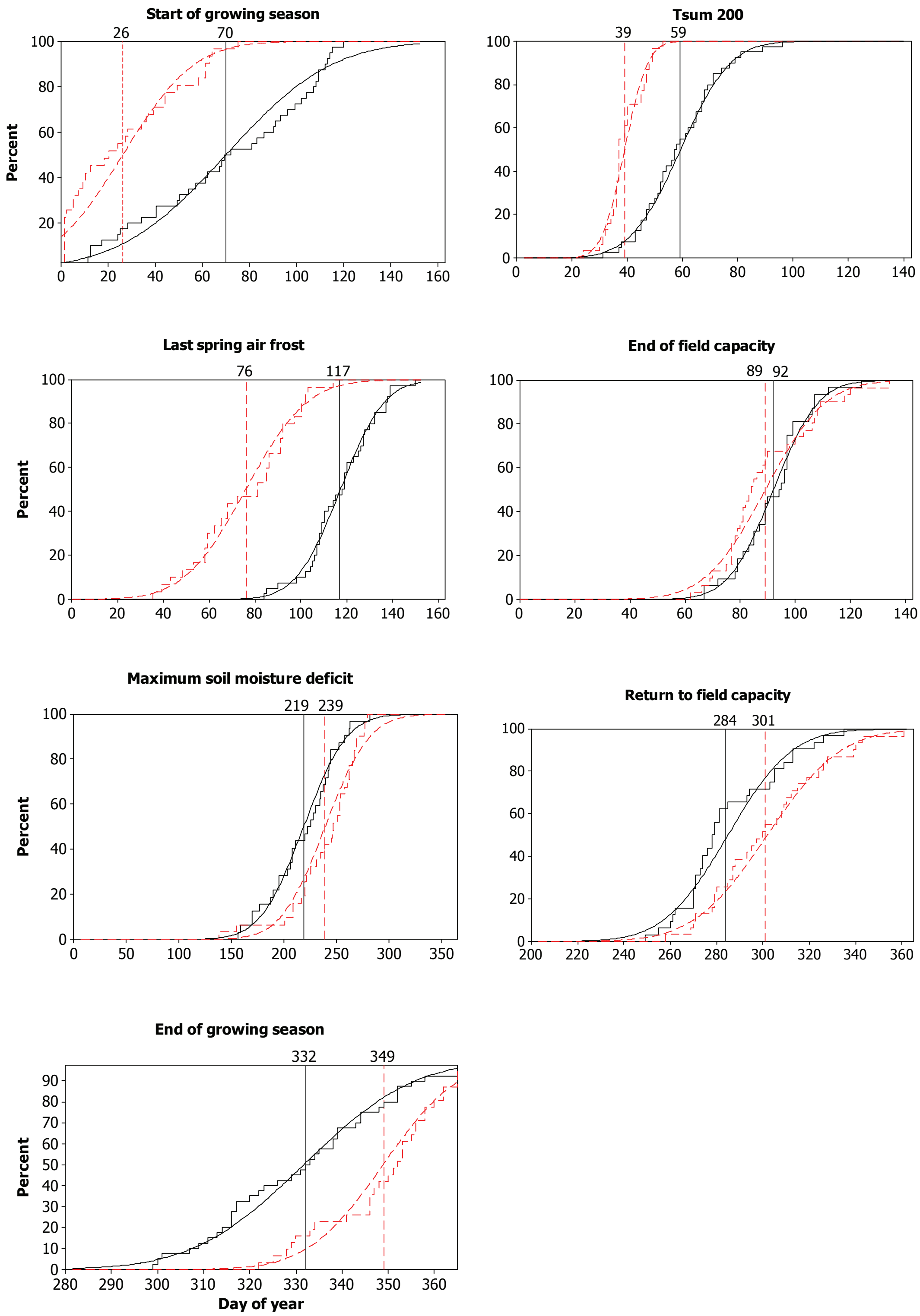

Fig. 1. Day of year occurrence of phenomenon at Aberdeen for observed climate (solid line) and downscaled future projection (dashed line) (A2 medium high emissions scenario). Values on the top axis are the estimated means.

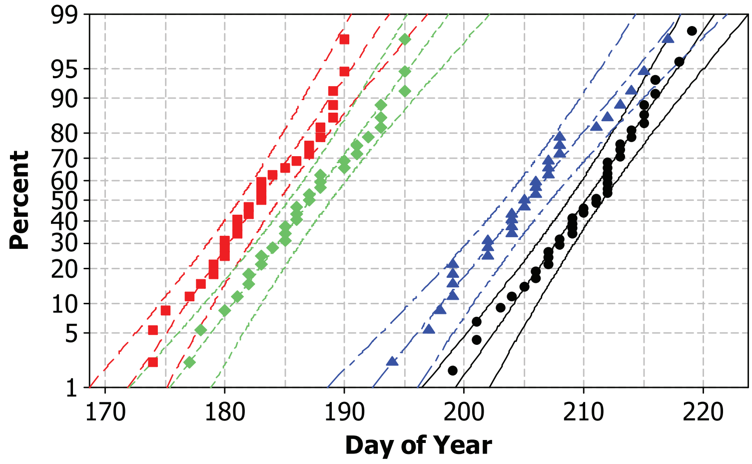

Fig. 2 Probability distribution of estimated Spring barley day of year for reaching physiological maturity from four weather data sources: Observed (•), HadRM3 original future projection (■), downscaled future projection (♦) and the anticipated future cultivar using the downscaled future projection (▲). Dashed lines mark 95% confidence intervals.

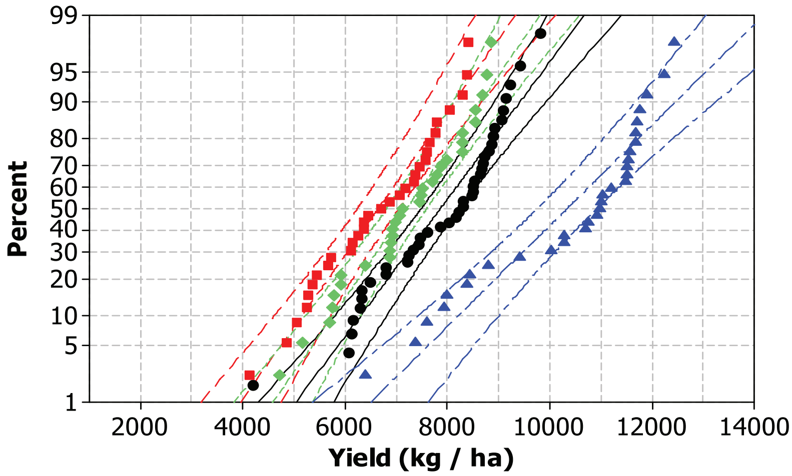

Fig. 3. Probability distribution of estimated Spring barley yield from four weather data sources: Observed (•), HadRM3 original future projection (■), downscaled future projection (♦) and the anticipated future cultivar using the downscaled future projection (▲). Dashed lines mark 95% confidence intervals.

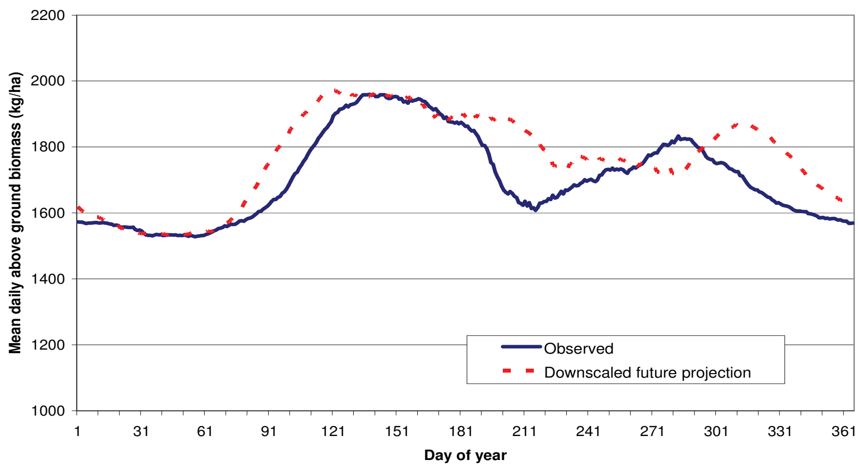

Fig. 4. Simulated grass above ground biomass in a sheep grazing system using observed weather data (solid line) and the downscaled future projection (dashed line) for Aberdeen.

Discussion

The aim of this paper was to illustrate that there is utility in using a suite of methods to connect between how land is currently managed and what management changes may be required due to alterations to the biophysical conditions in the future. Simple approaches such as the use of agro-meteorological metrics serve to illustrate the general future conditions and help identify potential thresholds and altered constraints. However, they do not provide sufficient detail to enable evaluation of individual crop responses and the mixes of land uses within a farm. Whilst land management stakeholders were able to envisage the potential necessity to change land uses and management practises from the Ag-metrics, they could only speculate on the changes to productivity and soil processes. Hence the estimates from the crop model provide supplementary detail to enable a clearer picture to be created on the particularities of how climate change impacts will manifest themselves. It is through the combination of methods (simple but easier to communicate through to complex but more informative) and through evaluation of the sources of uncertainty, i.e. climate model assessment, that it will be possible to both maintain credibility with stakeholders and investigate options for adaptation with sufficient detail to make informed decisions. This can also be combined with studies functioning at larger spatial scales (i.e. Brown *et al*., 2008).

However, whilst the estimates from the approaches operating at differing levels of complexity are useful, there is a risk that there may be a conflict with the agency of the stakeholders if the models are seen to be too prescriptive, i.e. telling them what to do. Achieving a balance in information provision should therefore be an aim of stakeholder engagement. The outputs from whatever approaches are used needs to be communicated in ways that promote discussion and deliberation, enabling stakeholders to draw their own conclusions.

The combination of methods also serves as a form of regulation, in that it becomes possible to identify when contradictory results are produced. The results shown here show sufficient similarity in responses, i.e. the Ag-metrics and grass modelling both indicate increases in the growing season length, to allow some confidence in their utility (accepting the wide range on uncertainty associated with economics and policies). Expert review of these multiple approaches also serves as a 'safety net' in the event of complex model shortcomings. Fundamentally this research has shown the value in taking a step-wise approach utilising multiple methods functioning at differing levels of complexity to investigate the same issue. This builds credibility and salience by employing a legitimate process.

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