Predicting the Distributional Impacts of Climate Change on Agriculture

Nick Hanley, Dugald Tinch
Economics Department, University of Stirling

David Oglethorpe
English Farming and Food Partnership

Kim Swales

Fraser of Allander Research Institute, University of Strathclyde.

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Abstract
In this paper we model the expected impacts of climate change to 2080 on agricultural land-use and farm incomes in Scotland. We compare impacts on four regions of the country (South East, South West, North East and North West), since different farming types dominate in these different regions and since climate change is predicted to vary across these regions. Climate predictions from UK CIP are combined with the weather generator LARS-WG and a crop simulator known as CROPSYST to simulate effects on crop yields (shift in production functions) in each region. These shifts in production functions are then incorporated into optimisation models of farms in each region, to predict the impacts on cropping and land management – although shifts of land out of agriculture are not allowed for. Finally, type-II Input-Output gross value added multipliers are calculated to trace wider effects on regional incomes of predicted changes in farm incomes.

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1. Introduction

Regional predictions of climate change over the next 80 years have become available following work by Hulme and co-authors to spatially disaggregate UK Climate Impacts Programme (UKCIP) forecasts (Hulme et al, 2001). For Scotland, predictions of changes in rainfall, precipitation and other climate variables are now available at a resolution of $50km^2$. Hulme et al predicted wetter winters across Scotland with a tendency towards drier summers. However, these climate change predictions show a marked regional variability across Scotland, predominantly relating to a difference in the magnitude of precipitation change. For some sites on the west coast both wetter summers and winters were predicted, in contrast to the more general trend.

Many studies have suggested that agriculture is a sector which is relatively sensitive to climate change (Scottish Executive, 1999). Climate change can be expected to produce physical effects on yields/potential yields through its influence on: soil moisture levels; temperature and sunlight; and planting and harvesting patterns. Moreover, a direct fertilisation effect from increased CO_2 levels in the atmosphere has been observed (Jones et al, 1996; O'Donnell et al, 2001). A reasonable assumption is that farmers will react to these changes by altering how they allocate and manage land. For instance, farmers could be expected to grow more crops which are favourably impacted by climate change, and less of crops whose yields are expected to fall.

In this paper, we predict changes in the production potential of major agricultural crops in Scotland using a crop growth model known as CROPSYST, for four case study sites located in the South-East, South-West, North-East and North-West of the country. These changes in physical production possibilities are incorporated into optimisation models of farm management, to allow farmers to respond via alterations in land allocation and/or land management, under objectives of both profit and utility maximisation. Predicted changes in farm incomes are then related to expected changes in regional income using simple Type-II mulipliers calculated from regionalised input-output tables. The main objective of the paper is to ascertain whether significant regional variability exists in climate change impacts on agriculture in Scotland, and what changes in land use are predicted by the models.

In what follows, Section 2 describes how physical changes in crop yields were estimated from climate change predictions. Section 3 describes the incorporation of these effects in farm management models. Section 4 then presents results under a number of scenarios relating both to the extent of climate impacts and the nature of the CAP, for land use and farm incomes. Section 5 discusses the derivation of multiplier values, and shows how these multipliers were used to estimate changes in regional incomes. Finally, Section 6 contains discussion and conclusions.

2. Effects of climate change on crop yields

The first stage in identifying the impacts of predicted climate change on Scottish agriculture was to estimate expected changes to yields using a crop yield estimation model. A general model was chosen rather than a series of individual crop-specific models as this meant that results were estimated in a consistent manner. Two such models have been used to predict these changes to yield in other studies, EPIC (e.g. Easterling et al 2001) and CROPSYST (e.g. Tubiello et al 2000). Both operate on a daily time step and require daily weather inputs. A large proportion of the studies carried out using EPIC are North American, whilst CROPSYST has been more widely used in European studies (Tubiello et al 2002).

One of the main reasons that CROPSYST was chosen for this study was that it requires fewer management parameters. The output from whichever model was selected was to become the input to the farm management model. This meant that management decisions were an input to the crop yield model and an output from the management model, so that a crop growth model which operates using straightforward management inputs would significantly simplify this feedback loop. Secondly, work by Rivington which compared EPIC and CROPSYST under Scottish conditions suggested that the latter out-performed the former in terms of predictive accuracy. Finally, as CROPSYST requires less specialist knowledge of crop phenology and is generally less information intensive than EPIC, its use allowed additional runs to be carried out for sensitivity analysis.

In this study Scotland was split into four regions; South East, South West, North East and North West. In order to link model outputs with a biodiversity model (not reported here), case sites were taken from a previous study by Murphy et al (1998). These were East Linton (SE), Auchincruive (SW), Glensaugh (NE) and Skerray (NW) (see map 1), and are taken to be broadly representative of dominant farm types of each region: mixed farming in the SE and in the NE, a greater reliance upon livestock in the SW, with mainly crofting livestock farming in the NW.

UKCIP produces scenarios predicting the future changes to key weather variables in the 2020's, 2050's and 2080's for Low, Medium Low, Medium High and High climate change scenarios (Hulme et al, 2002). In this paper, only Low and High scenarios are used as the volume of data required was considerable: 1176 runs of the crop yield model were required using these two scenarios alone. Estimated changes to climatic variables for our South West and North East sites are presented in Figures 1a-1h as illustrative of the trends embodied in these predictions. As may be seen, rainfall is increasing in winter but declining in the summer, whilst mean temperature is increasing over time.

CROPSYST requires inputs of weather, field, management and crop data. Weather data are required in daily time steps for at least maximum and minimum temperature and precipitation. In this study solar radiation data were also provided. These data were derived for each case-study site from two sources. UKCIP produces scenarios on both a 50km and 5 km square scale, and the 50 km scale was chosen for this analysis as the authors (Hulme et al 2002) suggest that the 5km scale should not be used for predictive purposes**.** Historical weather data over a 30 year period for each site were then extracted from Met office data held by the British Atmospheric Data Centre (BADC). A weather generator, LarsWG (Semenov and Brooks, 1999), was next used to estimate daily weather for each site in each time period, by combining the historical data with the UKCIP predictions.

Field level data required by CROPSYST included altitude and slope of the site and soil data such as soil texte, pH, water content etc. These data for our sites were taken from Murphy et al (1998). Management data required are fertiliser input, irrigation, planting date and criteria for harvest or grass mowing. Fertiliser input data were taken from the Farm Management Handbook (SAC 2001) with an additional treatment of half this level being analysed. After careful analysis of the results of CROPSYST's output directory, it was found that water stress is rarely a limiting factor with regards to the growing of crops in Scotland even given predictions of climatic change. It was therefore assumed that irrigation would not take place. Presently some East Coast farmers irrigate potatoes and the literature suggests that root crops may require irrigation. However, root crops were not included in this analysis. A planting date was chosen for each year group after an analysis of crop yield data for sample crops planted on various days (in a weekly time step). It was thought that this allowed for some adaptation by farmers to changing climatic conditions thus accounting for the "dumb farmer scenario" without assigning farmers precognition of the coming years weather. It was possible, with additional parameterisation, for CROPSYST to automatically compute planting dates. However, the results of this were often counterintuitive in the face of climate change.

CROPSYST requires a large number of crop parameters including data on crop growth, morphology, phenology, vernalisation, photo-period, harvest, nitrogen and CO_2 interactions and hardiness. However, CROPSYST provides default information for each of these for the particular crops analysed in this study. Only pasture (rye grass) had to be developed separately although they were based on other crops in the CROPSYST database with adaptation to morphology, phenology and harvest practices. The crops chosen for analysis were Winter and Spring varieties of Wheat, Barley, Oats and Oil Seed Rape and Pasture. However, attempts to develop a model potato which would grow in a way to accurately estimate yields failed. This was especially difficult due to the unique Scottish seed potato agriculture. This modelling problem most likely reflects the difficulties of scaling up from the leaf level to the field level identified by Rotter (1999).

Results for yields under existing climatic conditions are shown in Table 1 and as can be seen, yield estimates are comparable to the yield ranges outlined in SAC (2001). Results with climate change show a distinct change in crop yields, and the patterns vary not only across sites but also across types of crop. A summary of the results is given for each site below and selected graphs are presented in Figure 2. It should be noted that these results are generalised and based upon 10 year averages of yield. Later analysis using the management model requires annual data to allow the risk attached to each crop to be calculated.

Auchincruive

Auchincruive displays an increase in yields over time for all crops for any given climate change scenario with the exception of spring oil seed rape in the 2050 high scenario. In addition, estimates of yield change show a relatively greater increase in the high climate change scenario than the low climate change scenario for all crops with the same exception. The estimates of yield more than double for spring wheat (by a factor of 2.27[1]), spring oil seed rape (2.22) and spring barley (2.02) between the present and 2080 given the estimate for high climate change. A comparison of the same periods for spring oats show an increase of 1.69 times. Winter crops display a similar pattern of increase from

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[1] Figures given throughout this section relate to the magnitude of change from the present period to a future period, the 2080's unless otherwise stated.

1.29 (winter wheat) to 1.73 (winter oats). Pasture yields increase with each incremental step in time and magnitude of predicted change.

East Linton

All crops in East Linton initially display the same pattern of increase as Auchincruive and for the low climate change scenario this pattern continues with increases in the region of 1.8 times for the spring crops and 1.6 times for winter crops. For the high climate change scenario beyond the 2020's this pattern of increase is, however, *reversed,* with falling yields for all crops except spring oil seed rape. Spring wheat and the winter crops all display a fall in yields from the 2020's onwards, although this is more pronounced for the winter crops with winter oil seed rape (0.53) yields almost halving. Pasture yields suffered a fall to the 2050 high scenario similar to those predicted for crops. The 2080's resulted in a failure of CROPSYST to complete the modeling procedure due to water imbalance problems. As this may have been the result of modeling difficulties, an average of other years was used to allow predictions of grazing usage. This fall in yields is not an unexpected result, since the literature suggests that lowland areas with low rainfall are most likely to experience a negative impact (IGER[2]). As East Linton is low lying and located on the east coast, it was the only site to approach this description. Examination of the output from CROPSYST confirmed that the reason for this fall in yields was water stress, which implies that agriculture in this region may become more dependent on irrigation in the future.

Glensaugh

Glensaugh sees an increase in estimated yields in each time period and each climate change scenario for all crops. The high climate change scenario results in higher yield estimates than the low scenario on all occasions. The increase is most pronounced for spring crops with spring wheat yields almost tripling (increase by 2.90 times) between the present and 2080 with high climate change. The increase in predicted yields was large for all crops, the lowest being winter wheat which increased by 1.58 times in the low climate change scenario. Pasture yields also show a marked increase more than doubling for the site (2.29). Estimates show Glensaugh to be the most productive of any of the sample farms for all crops by 2080, although it is the most productive for only three of the determinate crops at the present time.

Skerray

For all crops Skerray is estimated to be able to produce only very low yields in the current time period, which relates to the anticipated levels from this farm type. In the 2020's yields of all crops increase to levels much closer to the other sites considered, although never reaches these levels. There is little difference between estimated yields given high or low climate change in the 2020's. After the 2020's yields fall over time and are larger given low rather than high climate change scenarios. Pasture is the only crop which Skerray can "compete" with the other sites in terms of yields , with the exception of the present period noted below, although a pattern of increase is not seen across all time periods yields remain relatively high.

2.2 The relative importance of CO_2 fertilization effects

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[2] http://www.iger.bbsrc.ac.uk

One interesting question is whether the changes in yields noted above are mainly due to increased CO_2 fertilization (due to increased future levels of CO_2 in the atmosphere) or to climate change itself. To address this, crop yields were calculated given the UKCIP predictions of climate change but without including the impacts of CO_2 enrichment. Barley, and in particular Spring Barley, was especially susceptible to CO_2 enrichment, with yields doubling for some climate change predictions. Another interesting pattern was that CO_2 enrichment had a larger relative yield impact in the South West than the North East, as the "no enrichment" yields are closer to the "enrichment" yields in the North East. The implication is that in the North East, more of the predicted improvement in yield is due to direct climatic variables, in particular solar radiation and temperature, rather than CO_2 enrichment.

3. Modelling Impacts on Farm Decision-Making

Farmers can be expected to respond to changes over time in physical production possibilities brought about by climate change. To represent this, a series of optimization models was constructed for each case study site. These are mathematical programming models based on those developed by Oglethorpe and co-authors (Oglethorpe and Smith, 2002; Oglethorpe and Sanderson, 1999; Hanley and Oglethorpe, 1999; Oglethorpe, 1995). The model incorporates all major cropping and livestock activities. Land use change may be driven by shifts in exogenous factors such as prices, subsidies, climate or technology, but it is best understood by considering land use decisions at the farm level. The models can be run either assuming risk-neutrality (profit maximization), or for expected utility maximization under a range of constant risk aversion parameters.

Elicitation of risk aversion and the likely parameters that describe how much income a farmer might be willing to trade off to achieve particular reductions in income variability (and hence maximize income-risk utility) can be estimated using the Equally-Likely Certainty Equivalent (ELCE) approach. Although fairly well documented for developing agriculture, the only study to do this in recent years for UK farmers was by Oglethorpe (1995). The ELCE approach taken by Oglethorpe allowed farmers to enter a game which offered them to select between farm enterprises that either offered a guaranteed income or offered a variable income that would initially vary equally above and below that guaranteed income. The game involved a bartering procedure where the guaranteed income was continually lowered so that the long run expected income from the variable enterprise become greater than that of the guaranteed enterprise. The end-point of the game would identify the point at which the farmer decided to opt for the risky enterprise rather than accept a lower guaranteed income.

From this study, a range of risk-aversion parameters were produced that describe the position where a sample of farmers switched between the guaranteed and the risky enterprises. Effectively, these parameters tell us the proportion of the maximum income that is possibly attainable (the profit maximizing position) that the farmer is willing to give up to achieve less risky options. On overage, across the sample in Oglethorpe (1995), this proportionate trade-off in income was approximately 5% (rising to 10% for the more risk averse farmers).

Before giving results, it is useful to present some validation information. To do this, the model was calibrated (in terms of resource endowments) to represent the average position for the major farm types found in Scotland as reported in the latest published edition of Farm Incomes in the UK. These farm types are:

- Cattle & Sheep (LFA) farms;
- Dairy farms;

- General Cropping farms;
- Cereal farms;
- Mixed farms.

The calibration procedure involves identifying: the amount of available land of different grades; the policy related constraints, such as livestock quotas; and the other infrastructural constraints, such as the amount of available housing for livestock. Once calibrated to represent each of the farm types, SW Dairy (for Auchincruive), NW Cattle and Sheep LFA (for Skerray) and NE (for Glensaugh) and SE (for East Linton) General Cropping, the models were then run in Microsoft Excel Solver and the output of the models compared to the reported figures for each farm type, in terms of financial return and structure of the business.

Since the model is to be used to assess changes in the relative balance and intensity of different enterprises and associated changes in resource use, the key parameters of interest in this validation process are:

- the proportions of total revenue gained from different activities, in particular the percentage of output from crops (for Cereals, General Cropping and Mixed farms) or livestock (LFA Cattle & Sheep and Dairy farms);
- the proportion of total variable costs the main cost items account for (feed, seed, fertiliser, machinery running, hired labour);
- the total net farm income.

If the model creates accurate simulations of all three items, then the combination of enterprise selection, output and farm cost is deemed validated. Table 2 provides a summary for these items for each farm type, for both the model and the observed data. It is clear from Table 2 that although there are inherent weaknesses in this type of farm modelling such as assumed maximising behaviour and the explicitly linear technology (constant input-output coefficients) and associated corner point solutions, the model provides a reasonably accurate simulation of both farm enterprise selection and cost structure[3]. For the purposes of this study, Gross Margin (NFI before fixed costs are deducted) is used as a measure of performance, since risk-income trade-offs were to be evaluated and internal (manageable) farm risks are predominantly related to output and variable costs.

Following this validation procedure, the models were calibrated for each of the case study areas used for this analysis. Again, this calibration procedure involved an identification of the resource endowments of each of four "example farms", one for each case study site. Although initial model runs required the model to be calibrated according to current subsidy entitlements as well as basic resource endowments, the climate change analysis was also undertaken assuming a completely decoupled CAP regime. The key farm resource endowments used to calibrate the model for each farm were as shown in Table 3. The decoupled payment was calculated by summing the total direct subsidy payments following an initial run of the models under a current (2003/4) CAP regime. Following calibration with these basic resource endowments, the model was run for each farm situation under all the climate change scenarios.

4. Results of climate change on land use and farm incomes

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[3] Attaching importance to percentage differences in NFI levels is not particularly useful (since zero does not represent its lowest possible level) and, as can be seen, absolute NFI levels compare well.

The representative farm models were run under assumptions of both profit maximization and expected utility maximization , using the 5% income-risk trade-off ratio as discussed above. In all three cases, eight simulations were undertaken: present climate with present CAP measures; present climate with complete de-linking of production and support payments (reformed CAP), and six climate change scenarios, for 2020, 2050 and 2080 under “low” and “high” climate change, as defined in UKCIP (2002), under reformed CAP conditions. The main results of interest are changes in land use, and effects on farm income. We initially focus solely on profit maximization, then discuss any changes brought about by alternative behavioral assumptions. Main results are summarized in Table 4. Crops have been grouped by season and input levels in order to simplify the presentation.

Auchincruive (SW)

Under current conditions, this farm is predicted to have most of its land in grass, mainly for dairy. Moving from present CAP to a decoupled version produces a switch from store cattle to breeding ewes, and reduces the average stocking density from 2.03 to 1.89 glu/ha. Climate change produces a significant further shift in dairy, a move out of breeding ewes, and in some cases a move from winter wheat to spring wheat. Nitrogen applications to oil seed rape fall under climate change. Farm incomes rise, by 60% by 2020 and by 100% by 2080; rises in income are higher the greater is the extent of climate change. Stocking rates increase as warming intensifies. Risk aversion at the 5% level reduces farm income in all periods (definitionally) simply because of the trade-off of less income for a less variable (and less risky) income., and results in more diversification in land use, but breeding ewe numbers still go to zero under climate change.

East Linton (SE)

Under current conditions, land use is split between winter barley and wheat, winter oil seed rape and store cattle. Decoupling of CAP support produces a change from store cattle to breeding ewes, and a rise in income. Progressive climate change brings similar switches in production as at Auchincruive, from winter to spring wheat and barley, reductions in fertiliser use, and increasing farm income. Risk aversion again produces a more diverse pattern of land use, but with spring-sown crops coming to dominate arable production. Greater climate change produces bigger reductions in fertilizer rates applied to pasture. Stocking densities fall under the “high” climate change scenario, but farm incomes still rise. This is due to increases in grass productivity from climate change meaning that a particular parcel of grassland is capable of carrying more animals. In turn, this means that each animal needs less absolute area to graze and total stocking density can fall whilst similar (or greater) margins are made.

Glensaugh (NE)

Glensaugh differs from the two southern sites described above in that there is no predicted move to spring-sown crops. The initial land allocation is mainly winter wheat, winter barley, winter oil seed rape, and store cattle. Climate change brings about an increase in fertilizer use on winter wheat and on winter barley, with store cattle being replaced by breeding ewes. Farm incomes rise by the greatest amounts (by 128% by 2080 under the “high” scenario), and the mean stocking density increases. The picture is thus one of a more-intensive agricultural system emerging. Under risk aversion, there is much less of an increase in fertiliser use, and a lower increase in income, but cattle are still replaced by sheep production – although this latter outcome is more related to the change in the CAP.

Skerray (NW)

Skerray is almost entirely dedicated to store lamb production under all scenarios, except under current climate conditions with elements of production-related support still in place. In this case, suckler cows, store cattle and breeding ewes are raised instead. Only two percent of the area is given over to arable crops, wheat and barley, and the same pattern of a move to spring crops as witnessed in East Linton and Auchincruive is seen as a result of climate change. Progessive climate change reduces nitrogen applications to grassland, and incomes rise, although by the smallest proportion across all 4 case-study sites. Risk aversion produces more diversity in the intensity of pasture management, but production remains focused on store lambs.

5. Regional spill-overs of farm income changes

Farming is linked to regional economic activity not only by the direct farm-generated income. There is an additional demand injections through the expenditure of this income on local consumption, and through farm purchases of locally-supplied goods and services as intermediate inputs to production. Changes in agricultural activity due to exogenous factors, such as climate change, can thus be expected to have wider implications for the regional economy than just the change in on-farm income. To calculate these wider impacts, and in particular how they vary regionally, regional Input-Output (IO) Type II gross value added (GVA) multipliers have been estimated. Type II multipliers include the impact of increased expenditure on local linkages and consumption. these are known as the indirect and induced effects (Miller and Blair, 1985). Impacts on both the relevant regional and national (Scottish) economies are calculated. Multiplier values will vary regionally due to differences in the structure of regional economies, and differences in the profile of farming activities in each region.

In calculating the multiplier values a number of implicit assumptions are made. The most important is that there are taken to be no economic supply-side constraints. That is to say, the supply-side is modelled as totally passive, with no price or wage changes accompanying the changes in the activity. Output in any one sector changes linearly in response to any change in demand. This implies that industries are operating under constant returns to scale and that consumption income elasticities are unity. Input-Output multipliers are therefore often thought to apply to short-run situations in regions with underutilised labour and excess capacity. However, Input-Output results also apply as long-run outcomes in more restricted economies where the short-run labour market and capacity constraints can be ultimately eased through migration and investment (McGregor *et al*, 1996).

For the purposes of this aspect of the analysis, Scotland was again divided into four regions, South East, South West, North East and North West. These correspond to the SEERAD (REFS) administrative areas of NE Scotland and Tayside (NE), Shetland, Orkney, Highland and Western Isles (NW), Fife, Lothian, Scottish Borders and East Central (SE) and Argyll and Bute, Clyde Valley, Ayrshire and Dumfries and Galloway (SW). The multiplier values were calculated using the 1999 Input-Output Tables for Scotland (Scottish Executive, 2002), with additional disaggregation of the agricultural sector into seven representative farm types (Fraser of Allander Institute, 2003). Using the distribution of farm types within each of the four regions, this disaggregation allowed calculation of national value multipliers for each region.

Regional value multipliers were estimated by, firstly, breaking down direct, indirect and induced impacts into 128 input-output sectors. Direct impacts are allocated to the region in which they occur.

For indirect and induced effects, sectors were identified as being national or local in orientation.[4] For an increase in demand for national sectors, the spatial distribution of impacts is taken to equal the spatial distribution of employment, available through NOMIS. The geographical distribution of the additional direct activity and the indirect and induced activity in the national sectors then determines the geographical distribution of activity in the local sectors.

The resultant multiplier values are shown in Table 5. The national multiplier values are relatively close: a £1 million increase in farm income in any of the 4 Scottish regions generates a further increase in Scottish GDP of between £1.2 – £1.3 million, driven by additional consumption and intermediate demand. The variation in the multiplier values from differences in the composition of farm activity between the regions is small. The variation in regional Type II multipliers is bigger and is highest for the South-West and lowest for the North East. Clearly the nature of the regional economies plays a bigger role in determining the size of the local multiplier.

These multipliers were then used to estimate the total (direct + indirect + induced) effects of changes in regional farm income, as estimated in the previous section. Again, Table 5 gives illustrative results on a per hectare basis. We predicted that the impacts of climate change upon Scottish agriculture will have a largely positive impact upon farm incomes, and this translates obviously into largely positive effects on the Scottish national and regional economies.

5. Discussion and Conclusions

Climate change would appear to bring about increased incomes for Scottish farmers, mainly due to increases in predicted yields. However, we also found that predicted changes in climate and corresponding changes in yields vary across Scotland, although broad trends are still identifiable. The South-West and North-East regions are predicted to enjoy the biggest increases in potential yields, and, given farmer optimization in the face of these changes, the biggest rise in farm income. The income gap between the most spatially-disadvantaged site (in the North-West) and the others is indeed set to increase in relative terms. However, not all yield changes were positive: we predict possible falls in yields in the South-East due to water stress in drier summers. Once regional knock-on effects are taken into account, differences in the changes in farm income in per hectare terms are further accentuated, from £1416 per ha. in the SW, to £102 per ha. in the NW by 2020 under the “low” scenario.

We also find switches in land use, in terms of the intensity of grassland and arable cultivation and changes from winter to spring-sown crops. These changes will have environmental implications (for example, in terms of nitrate pollution and on-farm biodiversity) which it has not been possible to take into account in this paper.

In terms of the determinants of changes in potential yields, CO_2 enrichment of the atmosphere was found to be relatively important compared to direct climatic impacts, but this depended on which site was being studied, and on which UKCIP scenario was used.

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[4] National sectors were ones where over 25% of their gross output generated in Scotland iis sold outwith Scotland.

Finally, it is important to be aware of the considerable limitations of the modeling system used here. Although regional climate change was simulated using both a weather generator based on past weather patterns (LARS-WG) and on the widely-accepted UKCIP scenarios, the effects of these on crop yields was estimated using a model which is calibrated on current climatic conditions. In particular, the carbon enrichment effect found here might be mitigated by higher O_3 levels produced by climate change or other limiting factors (Olesen and Bindi 2002). Also, the way in which CROPSYST was calibrated here was rather simplistic, for example in terms of using only one (dominant) soil type for each site. Moreover, some crops which might be especially impacted by climate change (such a potatoes) and novel crops were not included.

These results have distinct regional policy implications and in particular those which identify distinct geographical areas as having ‘Less Favoured’ status. Even in the medium term, climate change may require new boundaries to be drawn or different categories to be identified to enable effective allocation of policy payments. Given the results of the multiplier analysis, this clearly also has implications for regional economic policy and in particular the growing number of CAP ‘Pillar 2’ Rural Development initiatives where agriculture is used as a means of delivering social benefit to rural communities. Although the techniques used may have limitations, the study provides a valuable insight into the possible structural and institutional changes that may be required to manage future agricultural, environmental and rural policy.

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Table 1 A comparison of Estimated Yield with Yields from SAC (2001)

Crop	**SAC (2001) Range tones/ha**	**Estimated Yields Range tonnes/ha**
Winter Wheat	6 to 10	8.1 to 9.5
Winter Barley	6 to 9	6.9 to 8.6
Winter Oats	6 to 9	6.2 to 8.5
Winter OSR	3 to 4	3.3 to 3.4
Spring Wheat	4.5 to 8.5	4.4 to 5.7
Spring Barley	4 to 7	5.3 to 6.4
Spring Oats	3.5 to 6.5	5.4 to 6
Spring OSR	1.6 to 2.6	1.6 to 1.7
Pasture*	6.7 to 11.8	8.6 to 9.2

Notes: Skerray data has not been included in this analysis
* 120 kg Nitrogen application assumed

Table 2: Model Verification

Farm Type	**% C or %L**		**% VC**		**NFI**	
	Model	Observed	Model	Observed	Model	Observed
Cattle & Sheep (LFA)	76%	76%	39%	45%	5508	5600
Dairy	94%	91%	51%	60%	10182	12600
General Cropping	81%	81%	39%	46%	10251	8800
Cereals	77%	79%	33%	43%	-860	-500
Mixed	35%	37%	56%	53%	8011	6100

Key:

%C = percentage of output from crops (for Cereals, General Cropping and Mixed farms) % L = percentage of output from livestock (LFA Cattle & Sheep and Dairy farms)
% VC = percentage of variable costs of total costs; and,
NFI = net farm income

Table 3: Resource Endowments for case study representative farm types

	Auchincruive	**Glensaugh**	**East Linton**	**Skerray**
Decoupled Payment (£)	13110	28616	35729	20171
Cow Shed (head)	No upper limit	No upper limit	No upper limit	60
Sheep Shed (head)	No upper limit	No upper limit	No upper limit	475
Arable Land (ha)	12	121	102	8
Grass land (ha)	83	26	23	371
Dairy Capacity (head)	95	0	0	0

Table 4: Summary of landuse and farm income effects

Auchincruive Profit Maximiser

Hectares of	Present Climate, Present CAP	Present Climate, Decoupled CAP	2020 Low Climate	2020 High Climate	2050 Low Climate	2050 High Climate	2080 Low Climate	2080 High Climate
Winter Crops High Input	10	10	7	7	7	7	7	2
Winter Crops Low Input	2	2	0	0	0	0	0	0
Spring Crops High Input	0	0	5	5	5	5	5	10
Spring Crops Low Input	0	0	0	0	0	0	0	0
Pasture High Input	83	83	83	83	83	83	83	83
Pasture Low Input	0	0	0	0	0	0	0	0
Average Grazing Density	2.03	1.89	2.03	2.23	2.21	2.27	2.27	2.59
% Change in Income from Present	-	28%	60%	75%	74%	79%	79%	104%

Auchincruive Risk Minimiser

Hectares of	Present Climate, Present CAP	Present Climate, Decoupled CAP	2020 Low Climate	2020 High Climate	2050 Low Climate	2050 High Climate	2080 Low Climate	2080 High Climate
Winter Crops High Input	12	12	12	12	12	7	12	8
Winter Crops Low Input	0	0	0	0	0	0	0	0
Spring Crops High Input	0	0	0	0	0	5	0	4
Spring Crops Low Input	0	0	0	0	0	0	0	0
Pasture High Input	45	65	64	82	39	83	83	74
Pasture Low Input	38	18	19	0	44	0	0	0
Average Grazing Density	1.68	1.75	1.92	2.15	2.08	2.14	2.15	2.59

East Linton Profit Maximiser

Hectares of	Present Climate, Present CAP	Present Climate, Decoupled CAP	2020 Low Climate	2020 High Climate	2050 Low Climate	2050 High Climate	2080 Low Climate	2080 High Climate
Winter Crops High Input	82	82	61	61	61	61	61	20
Winter Crops Low Input	20	20	0	0	0	0	0	0
Spring Crops High Input	0	0	41	41	41	41	41	82
Spring Crops Low Input	0	1	2	3	4	5	6	7
Pasture High Input	2	23	23	23	23	23	23	23
Pasture Low Input	21	0	0	0	0	0	0	0
Average Grazing Density	0.47	0.60	0.64	0.68	0.66	0.48	0.70	0.49
% Change in Income from Present	-	32%	56%	61%	68%	73%	78%	93%

East Linton Risk Minimiser

Hectares of	Present Climate, Present CAP	Present Climate, Decoupled CAP	2020 Low Climate	2020 High Climate	2050 Low Climate	2050 High Climate	2080 Low Climate	2080 High Climate
Winter Crops High Input	82	47	24	10	73	42	78	20
Winter Crops Low Input	6	9	18	20	29	0	20	20
Spring Crops High Input	14	36	50	70	0	60	0	62
Spring Crops Low Input	0	0	0	0	0	0	4	0
Pasture High Input	0	23	23	23	22	0	22	0
Pasture Low Input	23	0	0	0	1	23	1	23

Setaside	0	10	10	1	0	0	0	0
Average Grazing Density	0.45	0.60	0.60	0.67	0.65	0.27	0.69	0.39

Glensaugh Profit Maximiser								
Hectares of	Present Climate, Present CAP	Present Climate, Decoupled CAP	2020 Low Climate	2020 High Climate	2050 Low Climate	2050 High Climate	2080 Low Climate	2080 High Climate
Winter Crops High Input	0	0	48	48	97	121	121	121
Winter Crops Low Input	121	121	73	73	24	0	0	0
Spring Crops High Input	0	0	0	0	0	0	0	0
Spring Crops Low Input	0	0	0	0	0	0	0	0
Pasture High Input	26	26	26	26	0	26	26	26
Pasture Low Input	0	0	0	0	26	0	0	0
Average Grazing Density	1.77	1.49	2.38	1.75	2.25	2.28	2.68	3.44
% Change in Income from Present	-	19%	64%	55%	76%	91%	97%	128%
Glensaugh Risk Minimiser								
Hectares of	Present Climate, Present CAP	Present Climate, Decoupled CAP	2020 Low Climate	2020 High Climate	2050 Low Climate	2050 High Climate	2080 Low Climate	2080 High Climate
Winter Crops High Input	0	0	4	0	4	16	24	31
Winter Crops Low Input	111	119	102	121	117	105	97	68
Spring Crops High Input	10	2	3	0	0	0	0	22
Spring Crops Low Input	0	0	13	0	0	0	0	0
Pasture High Input	1	14	26	16	12	23	26	26
Pasture Low Input	25	12	0	10	14	3	0	0
Average Grazing Density	1.07	1.22	2.37	1.59	2.17	2.20	2.67	3.40

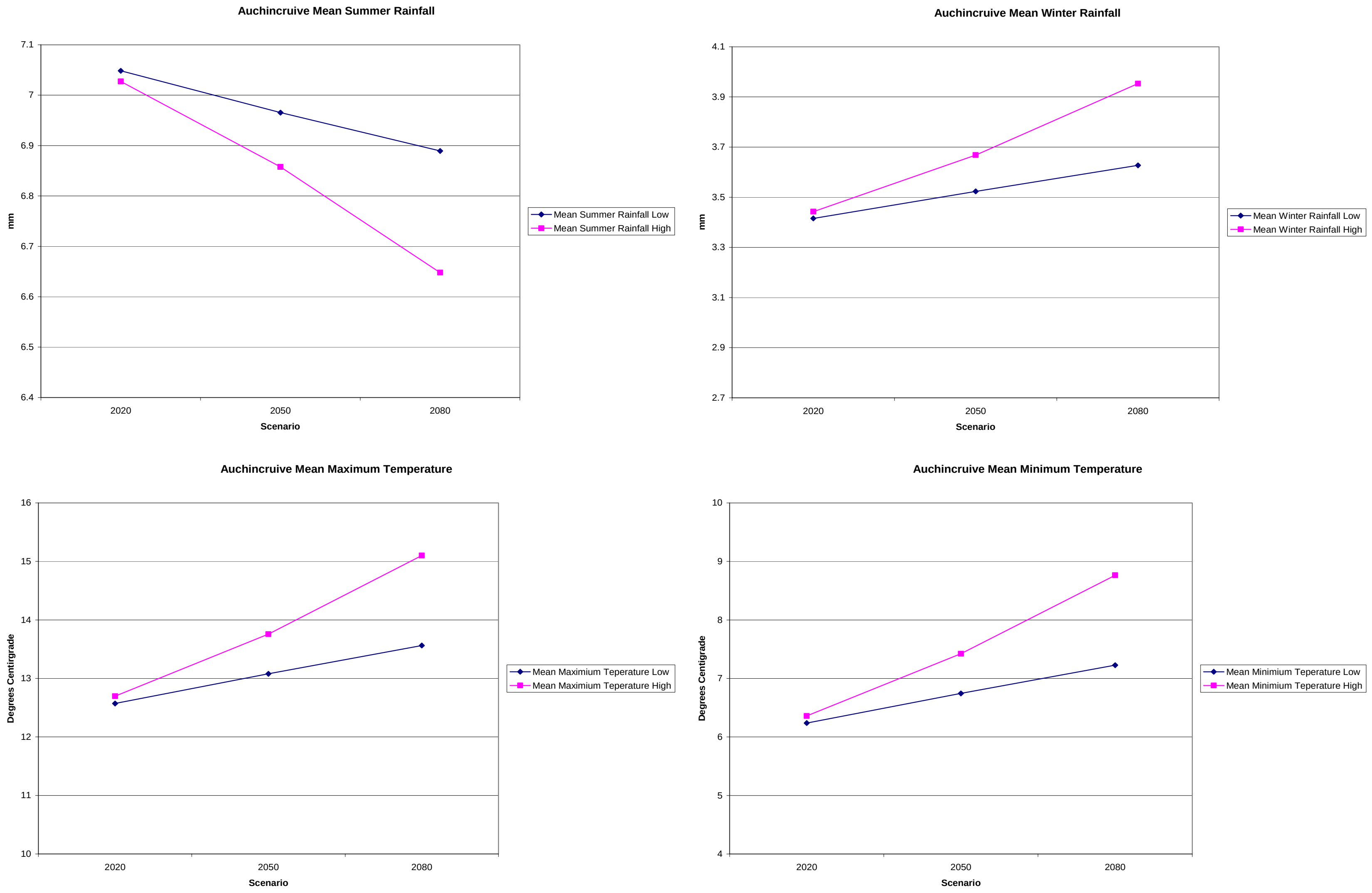
Skerray Profit Maximiser								
Hectares of	Present Climate, Present CAP	Present Climate, Decoupled CAP	2020 Low Climate	2020 High Climate	2050 Low Climate	2050 High Climate	2080 Low Climate	2080 High Climate
Winter Crops High Input	8	8	4	4	4	4	4	0
Winter Crops Low Input	0	1	2	3	4	5	6	7
Spring Crops High Input	0	0	4	4	4	4	4	8
Spring Crops Low Input	0	1	2	3	4	5	6	7
Pasture High Input	371	371	371	371	371	0	0	0
Pasture Low Input	0	0	0	0	0	371	371	371
Average Grazing Density	0.78	0.99	0.96	0.97	0.87	0.74	0.75	0.96
% Change in Income from Present	-	52%	50%	53%	32%	63%	64%	74%
Skerray Risk Minimiser								
Hectares of	Present Climate, Present CAP	Present Climate, Decoupled CAP	2020 Low Climate	2020 High Climate	2050 Low Climate	2050 High Climate	2080 Low Climate	2080 High Climate
Winter Crops High Input	8	8	8	1	8	4	4	4
Winter Crops Low Input	0	1	2	3	4	5	6	7
Spring Crops High Input	0	0	0	6	0	4	4	4
Spring Crops Low Input	0	1	2	3	4	5	6	7
Pasture High Input	337	337	341	314	302	237	79	97

Pasture Low Input	34	34	9	49	62	134	292	259
Average Grazing Density	0.72	0.94	0.97	0.94	0.86	0.92	0.84	0.95

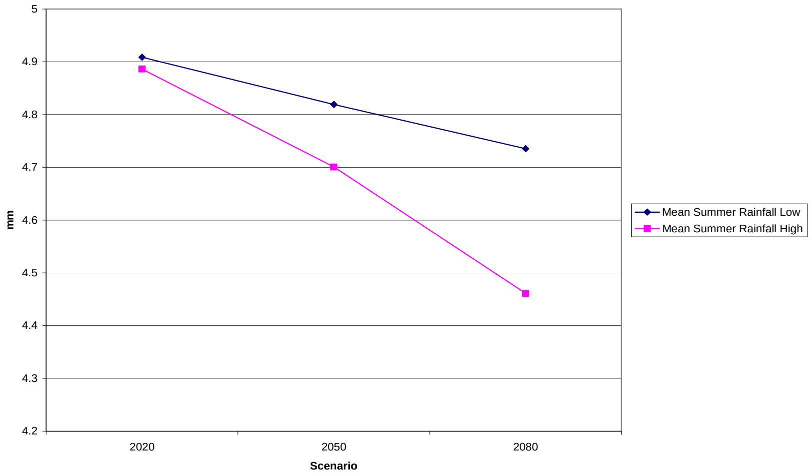
Table 5: Regional and National economic impact of increased farm revenues.

2020 low	Regional Multiplier	National Multiplier	Income change over base per Ha	Regional GDP change per Ha	Scottish GDP change per Ha
South West	1.68	2.22	+843	1416	1872
South East	1.6	2.3	+241	385	553
North West	1.85	2.31	+44	82	102
North East	1.78	2.24	+398	709	892
2080 high					
South West	1.68	2.22	+1472	2473	3268
South East	1.6	2.3	+400	641	921
North West	1.85	2.31	+65	120	150
North East	1.78	2.24	+799	1422	1790

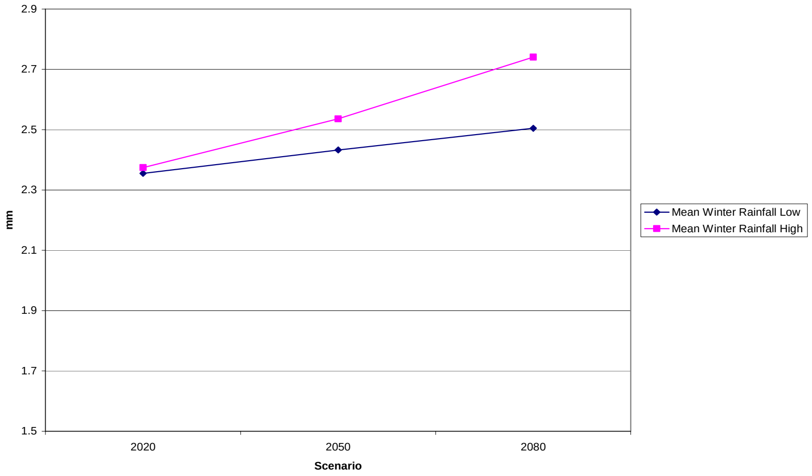
Figure 1: UKCIP Scenarios for two of the case study sites



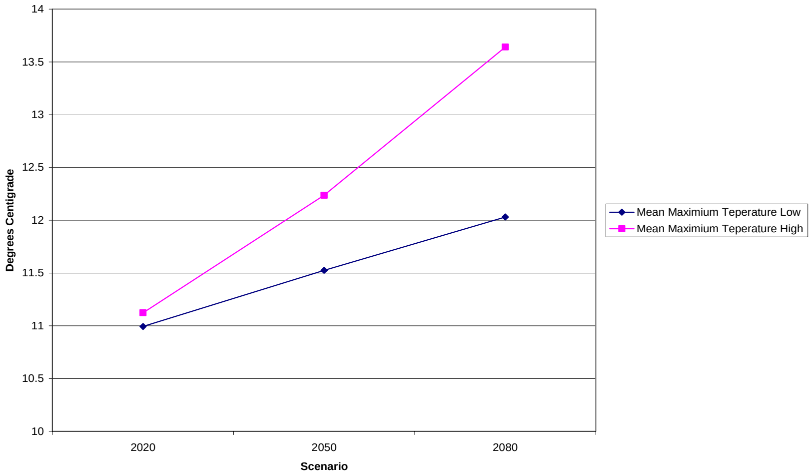
Glensaugh Mean Summer Rainfall



Glensaugh Mean Winter Precipitaion



Glensaugh Mean Maximum Temperature



Glensaugh Mean Minimum Temperature

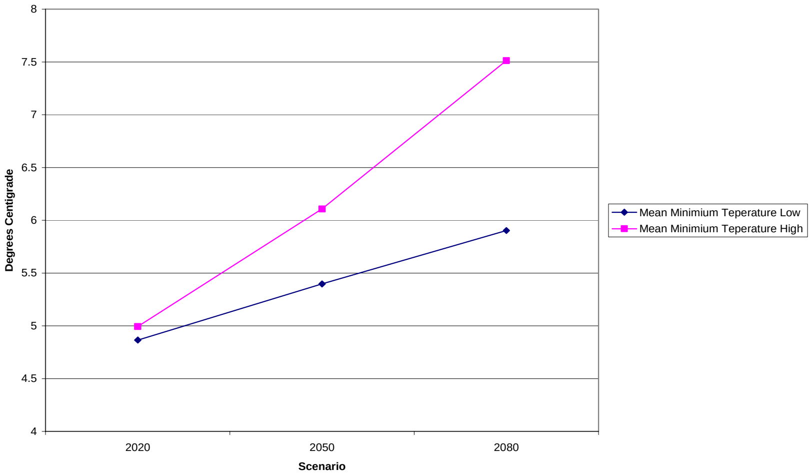
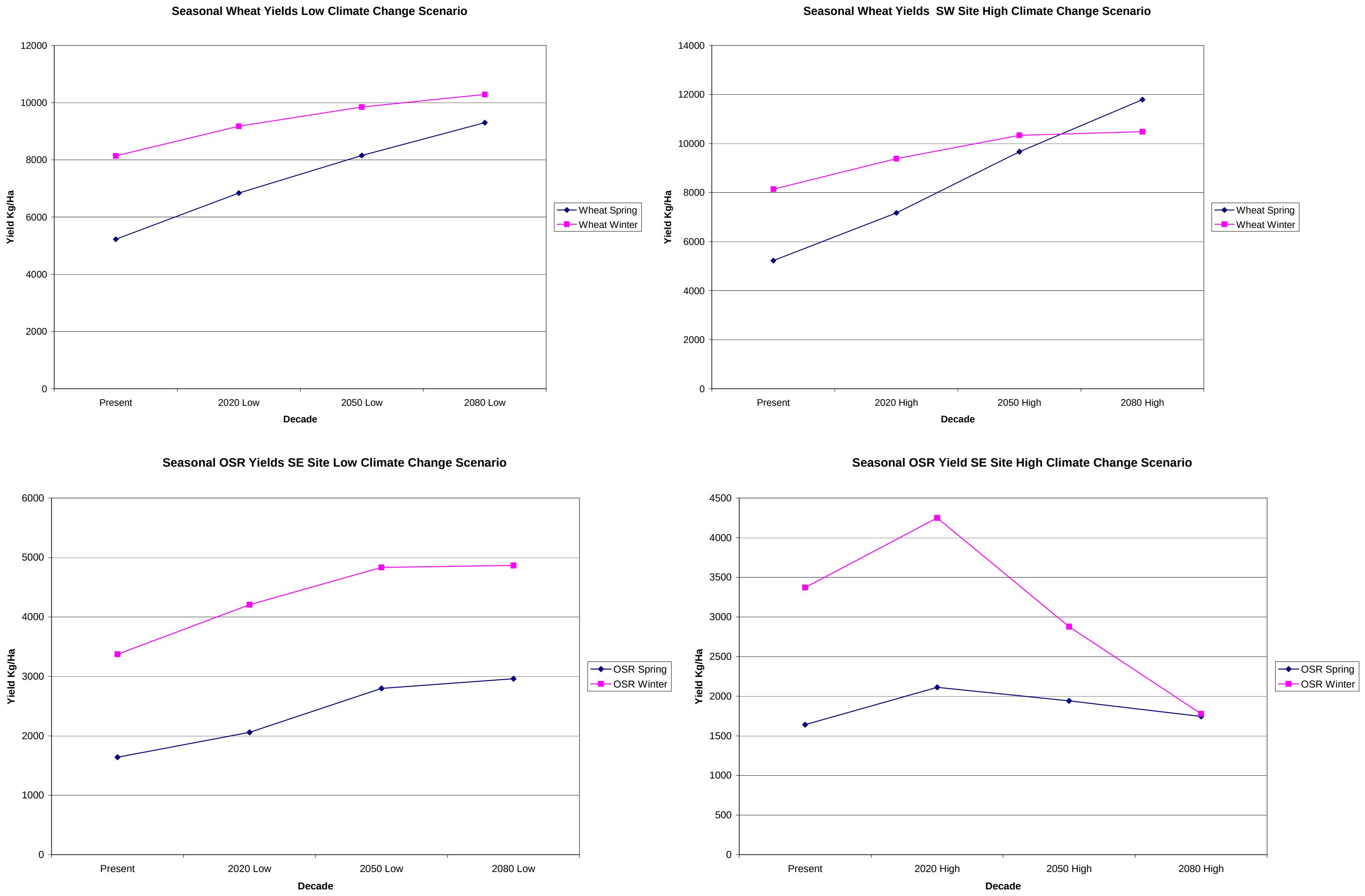
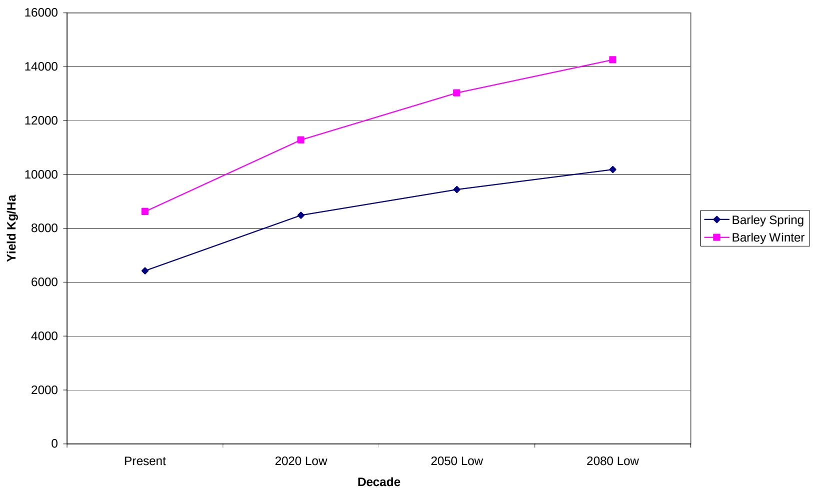
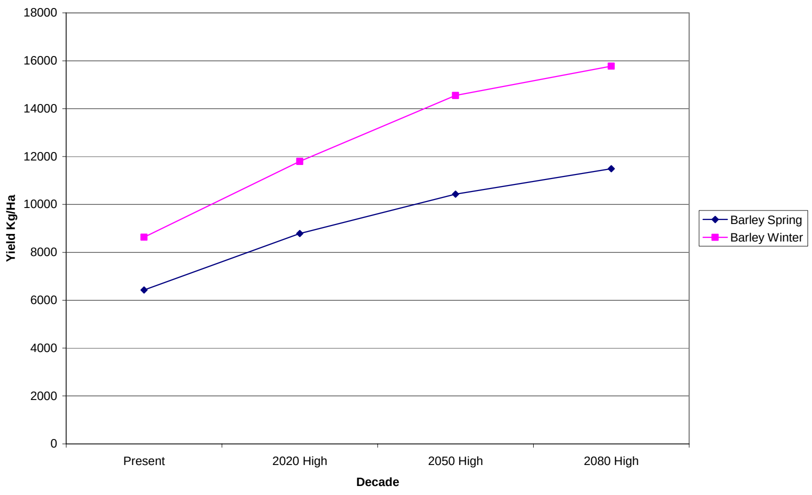


Figure 2: illustrative predicted changes in potential yields for case study sites

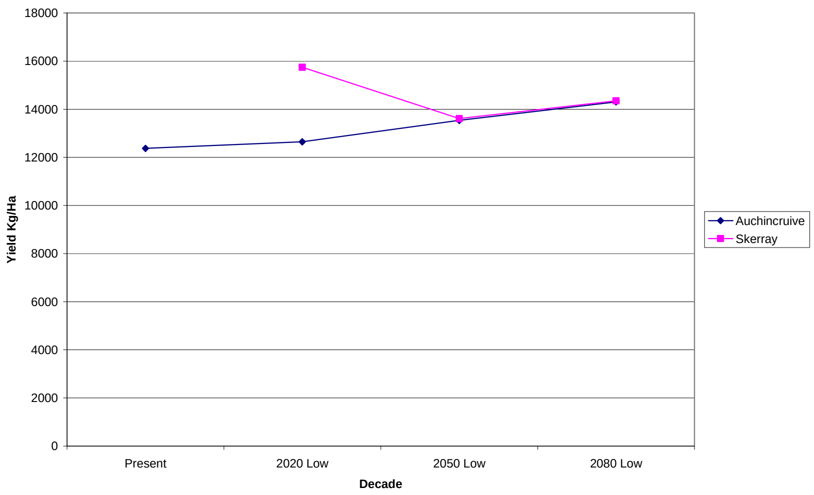




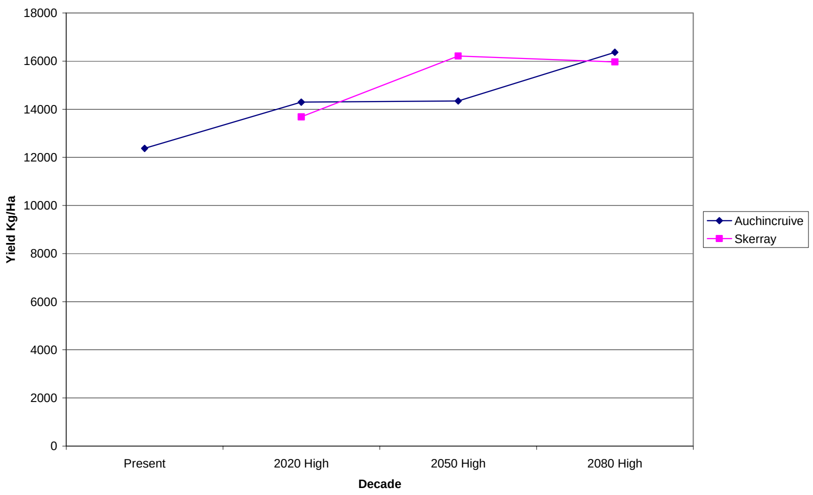
Seasonal Barley Yields NE Site Low Climate Change Scenario



Seasonal Barley Yields NE Site High Climate Change Scenario



Pasture Yields SW and NW Sites Low Climate Change Scenario



Pasture Yields SW and NW Sites High Climate Change Scenario