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CLIMATE CHANGE AND AGRICULTURE RESEARCH PAPER

Irish farms under climate change – is there a regional variation on farm responses?

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SUMMARY

The current paper aims to determine regional impacts of climate change on Irish farms examining the variation in farm responses. A set of crop growth models were used to determine crop and grass yields under a baseline scenario and a future climate scenario. These crop and grass yields were used along with farm-level data taken from the Irish National Farm Survey in an optimizing farm-level (farm-level linear programming) model, which maximizes farm profits under limiting resources. A change in farm net margins under the climate change scenario compared to the baseline scenario was taken as a measure to determine the effect of climate change on farms. The growth models suggested a decrease in cereal crop yields (up to 9%) but substantial increase in yields of forage maize (up to 97%) and grass (up to 56%) in all regions. Farms in the border, midlands and south-east regions suffered, whereas farms in all other regions generally fared better under the climate change scenario used in the current study. The results suggest that there is a regional variability between farms in their responses to the climate change scenario. Although substituting concentrate feed with grass feeds is the main adaptation on all livestock farms, the extent of such substitution differs between farms in different regions. For example, large dairy farms in the south-east region adopted total substitution of concentrate feed while similar dairy farms in the south-west region opted to replace only 0·30 of concentrate feed. Farms in most of the regions benefitted from increasing stocking rate, except for sheep farms in the border and dairy farms in the south-east regions. The tillage farms in the mid-east region responded to the climate change scenario by shifting arable production to beef production on farms.

INTRODUCTION

In the last few decades, extensive research has been conducted to examine the impacts of future climate change on agricultural production, more so recently, with the growing concern over food security (Rötter & Van De Geijn 1999; Chang 2002; Craigon *et al*. 2002; Jones & Thornton 2003; Nelson *et al*. 2009, 2010; Ciscar *et al*. 2013; Shrestha *et al*. 2013; Witzke *et al*. 2014). Many of these studies have concluded that the effects of climate change on crop yields is highly dependent upon the geographical location of crop production, with crops in some regions benefiting (Cuculeanu *et al*. 1999; Ghaffari *et al*. 2002; Witzke *et al*. 2014) while crops in other regions show adverse effects under new climatic conditions (Morison & Lawlor 1999; Jones & Thornton 2003; Parry *et al*. 2004; Witzke *et al*. 2014). In general, higher CO_2 concentration and an increase in spring/summer air temperatures as well as the length of growing season will be beneficial to crop production, especially in northern temperate latitudes (Cannell & Thornley 1998; Campbell & Smith 2000; Donatelli *et al*. 2012). However, an increase in temperature during crop development will depress yields in those regions where summer temperature and water stress are

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Table 1. *Characteristics of representative farms in different regions in Ireland*

Regions	Border	Mideast	Midlands	Midwest	Southeast	Southwest	West
Farm size (ha)	31·2	47·7	39·9	39·3	48·3	40·9	28·4
Total livestock unit (LU)	34·2	63·1	54·2	46·5	66·2	54·6	34·1
Family farm income (€)*	8635	18 296	21 067	21 272	27 876	23 182	10 846
Direct costs (€)	13 745	26 897	20 497	17 271	30 039	26 464	9340
Overhead costs (€)	15 638	29 292	23 106	17 474	28 109	23 334	9250

* Excluding single farm payments.
Source: Connolly *et al.* (2008).

already limiting factors for plant growth (Rosenzweig & Tubiello 1997). Similarly, higher rainfall can enhance grass growth in regions where water is a limiting factor, but it will be detrimental on grazing and grass conservation in areas with poor water drainage due to water logging (Cooper & McGechan 1996). This regional variation of the impact of climate change on agricultural production eventually leads to differences in farms' responses to such change in different regions (Mendelsohn *et al.* 1996; Bryant *et al.* 2000; Tan & Shibasaki 2003; Seo & Mendelsohn 2008; Walker & Schulze 2008; Nelson *et al.* 2009, 2010; Ciscar *et al.* 2013; Shrestha *et al.* 2013; Witzke *et al.* 2014).

Research has also been carried out in recent years to determine the effects of climate change on Irish farms (Brereton & O'Riordan 2001; Holden *et al.* 2004, 2008). Many of these studies included regional variation in farm responses to climate change. For instance, Holden *et al.* (2008) included a number of adaptation measures such as changing stocking rate, N-inputs, silage area and grazing period to examine the impact of climate change on Irish livestock farms in different regions. They concluded that livestock farms in some areas, such as in the southern regions, would not benefit by adopting these changes whereas livestock farms in the eastern regions would improve production by increasing stocking rate or moderately decreasing N-input on farms. These previous Irish studies included farm adaptations as fixed measures implemented on all farms without considering the variability between different farm types. It is argued that use of generalized measures may not be ideal at a farm level without taking account of farm variability (due to socio-economic conditions and farm management), which would have a strong relationship with farm performances and hence influence their responses to future changes (Reidsma *et al.* 2010). This variability can be examined properly by providing modelled farms with more flexibility on selecting management strategies according to their individual needs to adjust under new conditions (Ramsden *et al.* 2000; Gibbons *et al.* 2005).

With 4·4 million ha of farming land, Irish agriculture covers only a small area of land compared to other EU countries (CSO 2012). However, there is a wide diversity among farms across the country. There are seven nomenclature of territorial units for statistics (NUTS) III agricultural regions in Ireland; border, mideast, midlands, mid-west, south-east, south-west and west regions. The NUTS is a single uniform breakdown of territorial units for the production of regional statistics for the European Union (for details see http://ec.europa.eu/eurostat/ramon/nuts/introduction_regions_en.html). Both of the southern regions are dominated by dairy-production-oriented farms, whereas the north and west regions have smaller extensive farms. Tillage farms are scattered over southern and eastern regions of the country. Table 1 shows the characteristics of average farms in different regions to illustrate the variability between these regions.

In addition to the regional variations, there is also substantial variation between different farm types within each region based on their main production system, management, economics and physical size. A number of studies have examined this variability and showed that in Ireland, different farms responded differently to changed conditions (Shrestha & Hennessy 2006; Shrestha *et al.* 2007). For example, in response to the decoupling of farm payments, within the south-west region larger beef farms responded by reducing beef numbers by 50% whereas smaller beef farms entirely de-stocked beef animals (Shrestha *et al.* 2007).

The current paper examines the regional variation of impacts of climate change on Irish farms. It sets up different farm types in each of the regions in Ireland and aims to capture the variability between farms as mentioned above and explores the differences in farm

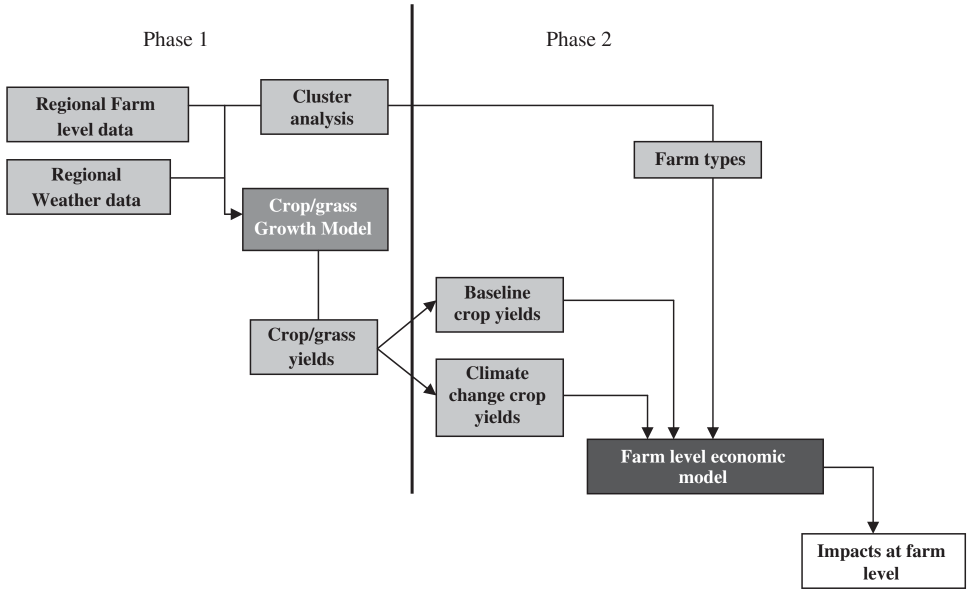

Fig. 1. A schematic diagram of the methodology.

response between those farm types under the changed climate.

MATERIALS AND METHODS

The methodology behind the current study was divided into two phases as shown in Fig. 1. The first phase determined the effects of future climate on yields of crops and grass in Irish regions using bio-physical models. The second phase then used these model outputs in a farm-level economic model to examine farm responses under the changed climate. Family farm income, which represents net margin of a farm, was used as an indicator to determine the effects of climate change. A more detailed description of the data inputs and models is given below.

Data input

The data used in the current paper was provided by two sources; farm-level data from the National Farm Survey (NFS) (Connolly *et al.* 2008) and climate data from the Irish National Meteorological Service (McGrath *et al.* 2008). In addition, farm management data and other farm variables that were not available in the NFS dataset were taken from the Teagasc Management Handbook (Teagasc 2009). The NFS data consisted of farm-level data from 1151 farms, representing 111 913 farms nationally and the NFS survey collects physical as well as financial information from each of the sampled farms. Farms were well distributed over the seven regions of the country and were classified as dairy, beef, sheep and tillage farms, based on the major activity taking place on the farm. Within each of the regions, a cluster analysis was carried out in SPSS (version 16.0.1) to group farms with similar characteristics together. Seven farm variables (production system, farm gross margins, land, animal number, labour, feed and milk yield) were used to group the farms: these variables were assumed to be the main differences between farms. The squared Euclidean distance method was used in finding similarities between the farms: it is commonly used in cluster analysis when there are multi-dimensional variables such as the farm variables used in the current study (Solano *et al.* 2001). A more detailed description of this methodology is available in Shrestha (2004).

The weather data used were a set of modelled data that were down-scaled from 136 weather stations throughout Ireland and had a horizontal resolution of 25 km (McGrath *et al.* 2008). The data included daily solar radiation, maximum and minimum air temperature, precipitation, dew point and wind speed at a height of 10 m. The weather data were obtained for a baseline scenario (1961–1990) and a climate change scenario (2061–2090). The climate scenario was based on the 'high' emission scenario A1B (IPCC 2000) under a general climate model, HadCM3, which was down-scaled to regional level by using a regional climate model, RCA3 (McGrath *et al.* 2008). A number of emission scenarios based on different extents of GHG emissions were available under these

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models but only the 'high' scenario was chosen for the current study, to determine the largest response of farms under the changed climate.

Simulation models

Three different types of simulation models were used; crop and grass growth models in phase 1 and a linear programming farm-level model in phase 2.

Crop environment resource synthesis model

The crop environment resource synthesis (CERES) model was used to assess the impacts of climate change on winter wheat, spring barley and forage maize yields. The model was originally developed under the auspices of the USDA-ARS Wheat Yield Project and the US government multi-agency AGRISTARS programme, which was later modified into different modules (CERES-Wheat, CERES-Barley and CERES-Maize) to simulate yields for different crops (Ritchie & Otter 1985; Otter-Nacke *et al.* 1991; Ritchie *et al.* 1998). The CERES model has been parameterized worldwide for major crops and has shown reasonable agreement between measured and modelled results in a number of locations (Holden & Brereton 2006; Lizaso *et al.* 2007; Robredo *et al.* 2007; Meza *et al.* 2008).

Johnstown grass model

The Johnstown castle grass model (JGM; Brereton *et al.* 1996) was used in the current study for simulating Irish grass growth. It is a simple empirical pasture model that predicts vegetative growth and development in permanent pastures (Brereton 1995) and was developed for the purpose of understanding the behaviour of grassland systems herbage supply in response to weather variations. This model simulates the production of pasture dominated by perennial ryegrass, which is the common basis of livestock production in Ireland. It has been tested and validated against measured production over a wide geographical range and found suitable for simulating Irish pasture production (Brereton 1995; Holden *et al.* 2008).

Farm-level linear programming model

An optimizing farm-level linear programming (FLLP) model was developed for the current study. The FLLP is based on a farm-level dynamic linear programming model which is described in detail in Shrestha (2004). Modified versions of FLLP have been used in a number of farm-level analyses of Irish Agriculture (Shrestha & Hennessy 2006, 2008; Shrestha *et al.* 2007; Hennessy *et al.* 2008). The FLLP model assumes that all farmers are profit oriented and maximize farm net income within a set of limiting farm resources. For the purpose of the current study, four production systems were considered; dairy, beef, sheep and arable production systems. These systems were constrained by land labour, feed and stock replacement available to a farm. The total land available on a farm was fixed but farms were allowed to transfer land between different production systems. Farms were also allowed to buy in feeds, animal replacements and hire labour if required. The farm net income comprised the accumulated revenues collected from the final product of the farm activities (crops, animals and milk) plus farm payments minus costs incurred for inputs under those activities. The input costs were replacement costs for livestock, variable costs including labour, feed and veterinary costs and overhead costs on farms.

In the crop production system, the model consisted of the three most common crops in Ireland; winter wheat, spring barley and forage maize. The initial land under these crops in each farm was based on the farm-level data; however, as mentioned earlier, the model was allowed to reallocate land under these crops as well as transfer to grass production. The stocking rate on each farm was also fixed to the farm-level data, assuming that all farms were operating under optimum stocking rate. The dairy system had a 4-year replacement structure where dairy animals were culled every 4 years. Similarly, beef and sheep systems followed a 2-year replacement structure. The animals were replaced by on-farm or off-farm replacement stocks. A feed module, based on Alderman & Cottrill (1993), was used in the model to determine feed requirements for each of the animals based on type, age and production level of the animal. Feeds available to the livestock were fresh grass, grass silage, maize silage and concentrate feeds. Concentrate feed included cereal produced on farms as well as those feed bought from outside the farms. Grass silage was produced under one-cut (May) or two-cut (May and June) silage production systems. The quality of the one-cut and two-cut grass silage was assumed to be similar in the current study. The two-cut silage system produces more grass silage annually but has twice the labour costs of the one-cut silage system.

The FLLP model is pseudo-dynamic in nature, such that it runs for a 10-year time frame but the results from

Table 2. *A list of adaptation measures used in FLLP model*

Adaptation measures	Variable in the model	Description
Land use	Endogenous	The model optimizes land under the most profitable production system
Production system	Endogenous	The model selects the most profitable production system
Number of animals	Endogenous	The model optimizes animal number on farm
Feeding system	Endogenous	The model chooses the most cost effective feeding system
Labour	Endogenous	The model optimizes family and paid labour
Stocking rate	Exogenous	The stocking rate is changed to +0·5 and +1 LU/ha
Miscanthus	Exogenous	Miscanthus is used as an option on arable farms

the first 3 years and the last 3 years were discarded to minimize the starting and terminal effects of linear programming (Ahmad 1997; Shrestha 2004). The model outputs from the middle 4 years were averaged to provide the final results for both the baseline scenario and the climate change scenario runs. Farm activities chosen by the model under the climate change scenario which were different from the baseline scenario were considered as farmers' responses under the changed climate. A list of adaptation variables used in the current study is provided in Table 2. It should be noted here that the study focused only on short-term farm adaptations that could be adopted easily by a farmer on-farm. Long-term adaptations that require large investments, such as installation of irrigation/drainage facilities on farms, were not considered for the current study as they were not assumed to be farmers' immediate response under a changed climate. The adaptation variables considered in the current study can be divided into two types; endogenous farm variables, which were the existing farm management practices and were adjusted by the model during optimization; and exogenous farm variables, which were introduced in the model externally. Two exogenous adaptations were examined in the current paper: stocking rate and introduction of Miscanthus. The stocking rate was increased by +0·5 livestock units (LU)/ha and +1 LU/ha in separate model runs to provide flexibility on farms to increase animal numbers. Miscanthus is provided in the model as an optional crop: it was included as a possible adaptation because of its importance as a biofuel crop and it is considered to be suitable for future growing conditions in Ireland (Breen *et al*. 2009). The gross margin for Miscanthus was set at €30·7 per tonne (Clancy *et al.* 2009).

The current study only considered the changes on crops and grass yields under a climate change scenario. Direct effects of climate change on grazing animals were not covered in detail because, in a temperate climate like Ireland, animals are expected to be capable of tolerating heat stress for the next 50 years (Parsons *et al*. 2001). However, a 10% increase in livestock variable costs (especially increases in veterinary costs) was included in the study to enable livestock farms to undertake any preventive measures against the possibility of parasitic infestation. It should also be noted here that the current study focused entirely on the impacts of climate change and all other external factors such as market prices, technological progress and agricultural policies were kept unchanged.

RESULTS

Model validation

Crop environment resource synthesis model

The CERES crop model results for winter wheat and spring barley were validated using field data. As shown in Table 3, the model baseline average yields fall within the range of field data and RMSE value for winter wheat and spring barley are both 0·5 t/ha. The model, however, underestimated the biomass of forage maize with an RMSE value of 1·5 t/ha.

Farm-level linear programming model

The baseline farm net incomes provided by the FLLP model were compared with the farm family net income of all farm types in each of the region. Figure 2 presents a snapshot comparison of farm types in two regions; southwest (one of the most efficient production regions) and border (one of the least efficient production regions). The comparison for other regions is similar to these two regions. The FLLP is robust for large and efficient farms but it overestimated the farm income for some of the small and less efficient farms. This is

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Table 3. *A comparison of CERES baseline yields against field data for three crops*

Crops	Baseline	Field data*	RMSE
Winter wheat (t/ha)	9·1–10·2	8·9–11·4 (9·5)	0·50
Spring barley (t/ha)	6–6·4	4·4–9·3 (6·5)	0·54
Forage maize (t/ha)	9·7–14·5	8·8–15·9 (6·0–19·0)	1·50

* Winter wheat and spring barley field data (1998–2006) taken from Forristal (2007) and Forage maize field data (1992–1998) taken from Holden & Brereton (2003*a*, *b*).

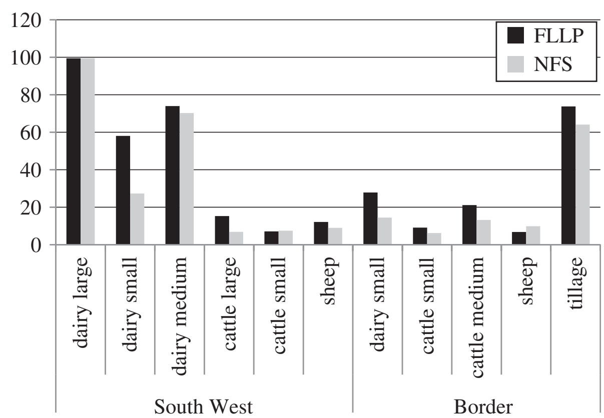

Fig. 2. Comparison of farm net incomes between FLLP baseline and NFS farm-level data for southwest and border regions.

understandable as FLLP is an optimizing model, hence tries to maximize utilization of farm resources on those small and less efficient farms. The model is not adjusted in the current study for these small farms since the focus was to examine counterfactual scenarios and compare them with a baseline scenario.

Farm types

The cluster analysis resulted in different farm groups in each of the seven regions. The number of farm types in each of the regions is shown in Table 4. All of the regions contained both dairy and beef farm groups, whereas sheep farm groups are identified only in the border, mid-east, south-west and west regions and tillage farm groups are concentrated only in border, mid-east and south-east regions (it should be noted that all regions actually contain some sheep and tillage farms, but in order to preserve confidentiality those groups with fewer than 15 farms were not considered in the current study).

Based on their characteristics, the farm groups were arbitrarily designated as small-, medium- and large-sized farms to differentiate them from each other. Some major characteristics of the farm groups in each of the regions are provided in Table 5, showing the size of farm, available family labour, farm gross margins and livestock units. The results showed that the northern regions have smaller, extensive livestock farms whereas southern regions consisted of more intensive livestock farms. It also showed that most of the Irish tillage farms had beef or sheep activities on farms.

Table 4. *Number of farm types in each of the regions*

	Farm types			
Regions	Dairy	Beef	Sheep	Tillage
Border	1	2	1	1
Mideast	2	1	1	1
Midlands	2	1	0	0
Midwest	2	2	0	0
Southeast	2	2	0	1
Southwest	3	2	1	0
West	1	2	2	0

Crop yields

Both of the cereal crops used in the current study, winter wheat and spring barley, showed a decrease in yields on farms under climate change in all three tillage regions (Table 6). The extents of impact on yields were different in each of the regions. The most severe impact for both winter wheat and spring barley crops was observed on farms in the south-east region compared to farms in the mid-east and border regions. In contrast to the cereal crops, forage maize production in the three regions investigated was increased substantially under the climate change scenario compared to the baseline scenario, with yields ranging from 19·1 to 21·3 t/ha which represented increase of 43–97%.

Grass yield

Under the climate change scenario, grass growth was substantially increased in all regions compared to the baseline scenario with yields ranging from 10·0 to 16·8 t/ha (Table 7). The south-west region had the highest grass yield in the baseline scenario but had the lowest increment (49%) of yield under the climate change scenario. In contrast, the border region had the lowest grass yield in the baseline scenario but the

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Table 5. *Characteristics of farm groups in different regions*

Regions	Farm size (ha)	Family labour (MWU)	Farm gross margins (€)	Dairy (LU)	Cattle (LU)	Sheep (LU)
Border						
Dairy small	31	1·1	29 013	13	15	7
Cattle small	25	0·9	14 210	0	24	3
Cattle medium	46	1·2	34 533	0	41	7
Sheep	53	1·0	19 591	0	9	21
Tillage	88	1·1	112 297	1	46	10
Mideast						
Dairy large	100	1·3	210 262	120	79	0
Dairy medium	53	1·2	86 844	48	40	7
Cattle	40	0·9	27 252	0	45	4
Sheep	51	1·3	52 084	0	29	43
Tillage	80	1·2	113 153	0	43	7
Midlands						
Dairy large	84	1·7	190 787	93	74	0
Dairy medium	56	1·4	93 043	44	52	3
Cattle large	91	1·4	93 757	0	137	12
Midwest						
Dairy large	72	1·3	126 655	65	56	1
Dairy medium	45	1·4	54 534	32	38	1
Cattle medium	37	1·1	19 444	0	31	1
Cattle large	55	1·3	49 072	0	66	3
Southeast						
Dairy large	68	1·3	123 413	59	57	1
Dairy medium	53	1·3	66 474	24	44	14
Cattle large	85	1·2	73 755	0	122	12
Cattle medium	32	0·9	20 985	0	34	4
Tillage	55	0·9	69 705	0	24	11
Southwest						
Dairy large	95	1·7	186 313	103	70	1
Dairy small	39	1·4	47 109	29	22	2
Dairy medium	57	1·5	112 365	59	41	3
Cattle large	50	1·1	35 559	0	56	2
Cattle small	26	1·0	14 680	0	26	1
Sheep	82	0·9	22 137	0	13	34
West						
Dairy	40	1·6	71 802	36	24	4
Cattle medium	39	1·2	35 097	0	47	8
Cattle small	22	0·8	13 585	0	23	1
Sheep small	21	0·9	15 828	0	13	18
Sheep medium	48	1·2	39 388	0	28	45

MWU: man work unit; LU: livestock unit

increase under the climate change was the highest at 56%.

Impacts on farms

The model results for farm net income under the climate change scenario are shown in Table 8. In the table, the first column represents the region and farm types within each region. The second column provides farm income data under the baseline scenario. The third column, which is the climate scenario column, is further divided into four columns; the first column, 'Basic', is the climate change scenario where only endogenous adaptations were considered in the model. The remaining columns in the table provide the results with exogenously introduced adaptation measures as indicated by corresponding column titles. The results are discussed in more detail for each region below.

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Table 6. *Effects of baseline and climate change scenario on crop yields (t/ha) and % change in yields on a regional basis*

Crops/region	Baseline scenario	Climate scenario	% Change
Winter wheat			
Border	9·1	8·8	−3
Mideast	9·7	9·3	−4
Southeast	10·2	9·3	−9
Spring barley			
Border	6·0	5·8	−3
Mideast	6·3	5·8	−8
Southeast	6·4	5·9	−8
Forage maize			
Border	9·7	19·1	+97
Mideast	13·0	21·3	+64
Southeast	14·5	20·8	+43

Table 7. *Effects of baseline and climate change scenario on the grass biomass production (t/ha)*

Region	Baseline scenario	Climate change scenario	% Increase
Border	6·4	10·0	56
Mideast	9·5	14·6	54
Midlands	9·2	14·0	52
Midwest	10·3	15·6	51
Southeast	10·4	16·2	56
Southwest	11·3	16·8	49
West	7·3	11·0	51

In the border region there was a negative impact on all farm types under the climate change scenario. The impact was small in the case of dairy farms and beef farms but the sheep and tillage farms showed relatively larger negative impacts (*c.* −10%). There was a very small replacement of concentrate feed by grass and grass silage on dairy farms, but for beef and sheep farms there was no change in feeding system as these farms already had a system based completely on grass. There was no change for animal number but most of the farms benefitted when stocking rate was increased. Sheep farms, however, did not improve for farm income since the productivity of these farms decreased when the number of animals on farms increased.

In the mid-east region, dairy farms showed mixed responses with larger farms losing out but medium-sized farms benefitting under the 'Basic' climate change scenario. Sheep and tillage farms had higher gains under the climate change scenario compared to the beef farms. The medium dairy farms replaced only 0·40 of the concentrate feed by grass feeds, whereas the beef farms replaced concentrate feed by up to 0·84. All other farms replaced concentrate completely with grass and grass silage feeds. The tillage farms removed all land under crop production and moved to grass production. These tillage farms increased beef numbers by 0·30. Increased stocking rate on farms substantially improved the family income in all farm types, especially in the sheep farms where there was over 100% increase in farm incomes.

In the midlands region, all farm types showed a decrease in their farm incomes. The only adjustment on these farms was to replace the entire use of concentrate feed by grass and grass silage feeds. Dairy farms in the mid-west region, however, showed only a negligible impact from climate change. However, all beef farms in this region benefitted substantially. These farms replaced all concentrate feed used on farms with grass and grass silage feeds.

Of all farm types in all regions, the large-sized dairy farms in the south-east region had the highest loss (−24%) in farm income under the 'Basic' climate change scenario. These farms are the milk producers with highest costs of production (€928/dairy LU). The 10% increase in variable costs under climate change affected these farms more than any other farms. These farms opted to reduce dairy animals on farm by 2%. These farms were affected more when the number of animals was increased under the higher stocking rate scenarios. The small dairy farm as well as all types of beef and tillage farms had comparatively a smaller reduction in farm income. However, these farms show an improvement on farm income under the higher stocking rate scenarios. The tillage farms benefitted by increasing 0·5 LU of animals on farms but further increase in stocking rate had a negative impact on incomes of these farms. The medium dairy farms showed a very small improvement in farm income when Miscanthus was allowed on farm. These farms had a small piece of arable land (*c.* 4 ha) used for cereal production to feed animals. Miscanthus as a cash crop was slightly more profitable alternative for these farms, as the farms could sell it to the market.

In the south-west region, the large dairy farms had an increase in farm income under the 'Basic' climate change scenario. These farms replaced *c.* 0·30 of concentrate feed with grass, grass silage and maize silage in animal feed and also put the animals on grass 1 month earlier in the 'Basic' climate

Table 8. *Percentage change in farm net incomes under climate change scenarios in different regions*

Regions	Baseline farm incomes(€)	% Change in incomes under climate change scenario			
		Basic	Stocking rate +0·5 LU/ha	Stocking rate +1 LU/ha	Miscanthus
Border					
Dairy small	27 850	−3	37	69	−3
Cattle small	9153	−2	74	150	−2
Cattle medium	21 138	−1	76	156	−1
Sheep	6816	−11	−59	−78	−11
Tillage	73 786	−9	7	3	−9
Mideast					
Dairy large	74 132	−7	33	56	−7
Dairy medium	60 153	8	22	30	8
Cattle	25 266	4	29	40	4
Sheep	26 243	32	67	103	32
Tillage	61 052	14	23	37	14
Midlands					
Dairy large	109 860	−6	11	28	–
Dairy medium	95 279	−3	24	51	–
Cattle large	99 356	−6	24	53	–
Midwest					
Dairy large	99 400	1	23	45	–
Dairy medium	73 185	0	25	49	–
Cattle medium	12 192	26	115	205	–
Cattle large	42 854	17	667	110	–
Southeast					
Dairy large	68 858	−4	11	34	−4
Dairy medium	63 827	−24	−25	−30	−23
Cattle large	60 979	−3	14	32	−3
Cattle medium	16 975	−6	27	58	−6
Tillage	28 712	−5	2	−12	−5
Southwest					
Dairy large	99 430	11	31	50	–
Dairy small	58 036	0	24	48	–
Dairy medium	73 992	0	24	49	–
Cattle large	6893	99	332	510	–
Cattle small	7520	33	129	222	–
Sheep	9003	15	169	307	–
West					
Dairy	55 121	0	17	34	–
Cattle medium	22 083	20	70	117	–
Cattle small	7016	33	118	202	–
Sheep small	7702	16	103	180	–
Sheep medium	21 498	12	70	128	–

LU: livestock unit

change scenario compared to the baseline scenario. However, for smaller dairy farms in this region there were no impacts of climate change on farm incomes. The beef and sheep farms, however, had substantial increases in farm income under the climate change scenario. This was entirely due to replacing concentrate feed by grass feeds and hence lowering expenses. Increasing animals on farms benefitted all farms in this region.

In the west region, there was no impact of the 'Basic' climate change scenario on dairy farms but the cattle and sheep farms had a larger beneficial effect of climate change. These farms also exploited increase in grass yield by replacing the concentrate feed

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completely with grass feed. These farms also improved their incomes substantially when more animals were allowed on farms.

Farms in all regions also opted for one-cut grass silage production system to minimize production costs. As the quality of grass silage was assumed to be the same in all types of grass conservation method, the results suggested that the higher production costs for two-cut silage systems outweighs the benefits of an increase in grass silage compared to one-cut silage system.

DISCUSSION

Previous studies have shown that the growth models used in the current study (CERES and JGM) can predict crop production in Ireland reliably (Holden & Brereton 2002, 2003*a*, *b*, 2006). The future crop yields projected under the climate change scenario were lower compared to the baseline scenario for both winter wheat and spring barley crops in all three regions. This result contrasts with the results of some earlier studies (Holden & Brereton 2003*a*, *b*; Holden *et al.* 2004, 2008), where positive yield for cereal crops was provided. The difference, however, lies in the climatic scenario used. Owing to the uncertainty of future climate change, a number of climatic scenarios are available ranging from low- to high-temperature change. For the current study, a 'high' A1B climate scenario was used to determine the farm responses under extreme conditions. Although a mild increase in temperature would benefit crops in temperate regions such as Ireland, as indicated in earlier studies, a higher temperature would cause crop stress and shortening of the grain filling period (Midmore *et al.* 1982; Blum *et al.* 1994; Wolfe 1994; Luo & Mooney 1999; Anwar *et al.* 2007), therefore reducing grain yields. This difference in the use of climate change scenario has also been illustrated by Donatelli *et al.* (2012), who showed that for the northern European regions, cereal production would increase by up to 20% under a 'mild' climate scenario but decrease by −20% under a 'warm' climate scenario. The 'warm' scenario used in the Donatelli study is similar to the 'high' climate scenario used in the current study.

The effect of climate change on forage maize and grass yields is generally positive in all regions in Ireland. Warmer conditions are more favourable for maize production and recent projections show a projected substantial increase (up to 200%) in maize yield in all Irish regions with climate warming (Holden & Brereton 2003*a*, *b*). It has also been suggested that the predicted future dry summers (McGrath *et al.* 2008) may affect biomass production of forage maize negatively, as higher precipitation is important for higher crop yield (Mera *et al.* 2006; Kovacevic *et al.* 2009*a*, *b*). However, the model results suggest that future warmer temperatures will increase forage maize biomass production sufficiently to compensate yield reduction due to expected reduced precipitation. Increases in grass yields were due to the combined effects of increasing winter rainfall, temperature and CO_2 concentration (McGrath *et al.* 2008). There have been several studies suggesting that increases in precipitation (Rosenzweig & Tubiello 1997; Izaurralde *et al.* 2003; Mearns 2003), temperature (Fiscus *et al.* 1997) and carbon dioxide concentrations (Mitchell *et al.* 1993; Anwar *et al.* 2007) have a positive effect on grass productivity. Increase in future grass biomass production in Ireland due to climate change has been suggested by Holden & Brereton (2002) and Fitzgerald *et al.* (2009) using the Dairy_Sim model, and Abdalla *et al.* (2010) using the DeNitrification–DeComposition (DNDC) and DayCent models.

The FLLP model results suggested that there is a regional variation in the impacts of the climate change scenario on farms and the response of farms are different between farms in all regions. Livestock farms in the border region had reductions in farm net margins under the climate change scenario. The increase in grass yield under the climate change scenario did not make any difference to their farm management as these farms were already using grass-based systems. These farms, however, had an increase of 10% in livestock variable costs under the climate change scenario, which reduced their net margins. The farms in the west region, which are assumed to be very similar to farms in the border region, have higher costs of production and used more concentrate feed compared to their counterparts from the border region (Connolly *et al.* 2008). Moving to a complete grass-based system decreased the costs of production on these farms, hence improving the farm margins. Similarly, in the dairy producing southern regions, dairy farms in the south-west region improved their farm net margin under climate change by replacing 0·30 of concentrate feed with grass-based feed. However, dairy farms in the south-east region replaced the entire concentrate feed used on farm with grass feeds to minimize production costs. The livestock farms in all regions also opted for one-cut silage production on farms. It has been suggested that cost-saving strategies such as lowering labour costs would be preferred by farmers in the future (Ramsden *et al.* 1999). Rötter & Van De Geijn (1999) also pointed out that the impact of climate change would be more favourable to a grass-based livestock production system as they could lower the costs of production further.

For a majority of farm groups, a restriction on stocking rate seemed to be a major constraint as their farm incomes improved when stocking rate was increased. This shows that these farms could exploit an increase in grass yield under climate change by simply increasing the number of animals. Parsons *et al.* (2001) also suggested that farmers benefit from increased grass yield under climate change when stocking rate was relaxed. However, increasing stocking rate has its own consequences and may not be applicable because of policy restrictions, the possibility of damaging soil and an increase in variable costs. Some farms are not profitable enough to increase animal numbers, such as sheep farms in the border and medium dairy farms/tillage farms in the south-east regions. The productivity of animals could also be affected adversely by increasing stocking rate, as reported by Gordon (1986) who found a decrease of 4% in milk yield per cow when stocking rate was increased from 2·5 to 3 cows/ha in northern Ireland. Ruminants are also considered to produce 17% of the total global methane emission (Benchaar *et al.* 1998) so any activity leading to further increases in the methane emissions should be considered carefully, especially if there is a limit imposed on farms on total GHG emissions.

For tillage farms, lower crop yields under the climate change scenario had a negative impact on farms. However, tillage farms in the mid-east region showed an improvement in their incomes under climate change by moving from tillage to beef farming. Beef production in this region is more commercialized with higher beef price and has a tendency to increase the number of animals when possible (Shrestha *et al.* 2007). The tillage farms in this region already have a capacity in beef production and hence can expand beef production without incurring a large investment. In the current study, Miscanthus, as an alternative crop, could not compete with other arable crops and hence most of the farms did not choose it as an adaptation. The only farms that chose Miscanthus were the medium-sized dairy farms in the south-east region, which had a small piece of land under cereal production to feed their animals. These farms moved completely to the grass-based feed system and opted for Miscanthus on arable land to sell it in the market. The prices of Miscanthus in the current study were fixed to the 2004 level but under future price projections, Miscanthus could be more competitive and considered as an adaptation measure to improve farm margins (Styles *et al.* 2008).

There are some limitations in the current study. The responses examined were based on the assumption that all farmers were profit oriented: farmers are known to take up new technologies and change their management practices to improve their profits (Kaiser & Crosson 1995). However, the current study did not cover those farmers whose responses were not always aimed at maximizing farm profits, such as hobby farmers. The study also only focused on farm adaptations and did not include long-term adaptations which would incur large investments. Another limitation of the current study is that the results are highly dependent on the outcomes of the crop growth models and climate change scenarios. Different sets of crop growth model or climate change scenarios could provide entirely different sets of crop yield results. Since only one climate change scenario was included, the sensitivity of the growth models to temperature and rainfall suggests that further research would be beneficial under a range of climate change scenarios to identify the full scale of possible strategies under different climatic conditions. It should also be noted that prices for the future were fixed at the current level and the study did not consider any price or market effects on farm responses to the future climate.

CONCLUSIONS

Most of the farms in the border, midlands and south regions suffered while farms in rest of the regions benefitted under the climate change scenario used in the current study. A majority of livestock farms replaced all concentrate feed with grass feeds, but a number of farms opted for only a fraction of such replacement. Dairy farms in south-east regions responded to climate change by decreasing dairy animals on farms whereas dairy farms in other regions benefitted when stocking rate was increased on farms. Tillage farms in the mid-east region were able to compensate for a loss in crop yield under climate change by shifting from crop production to beef production. The current paper shows that there exists a regional variability in farm responses to the impacts of climate change on Irish farms.

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