Determining Short Term Responses of Irish Dairy Farms under Climate Change

Bestimmung kurzfristiger Reaktionen irischer Milchviehbetriebe unter Klimawandel

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Abstract

This study aimed to determine short term farm responses of Irish dairy farms under climate change. The Irish National Farm Survey data and Irish weather data were the main datasets used in this study. A set of simulation models were used to determine grass yields and field time under a baseline scenario and a future climate scenario. An optimising farm level model which maximises farm net income under limiting farm resources was then run under these scenarios. Changes in farm net incomes under the climate change scenario compared to the baseline scenario were taken as a measure to determine the effect of climate change on farms. Any changes in farm activities under the climate run compared to the baseline run were considered as farm's responses to maximise farm profits. The results showed that there was a substantial increase in yields of grass (49% to 56%) in all regions. The impact of climate change on farms was different based on the regions. Dairy farms in the Border, Midlands and South East regions suffered whereas dairy farms in other regions generally fared better under the climate change scenario. For a majority of farms, a substitution of concentrate feed with grass based feeds and increasing stocking rate were identified as the most common farm responses. However, farms replaced concentrate feed at varying degree. Dairy farms in the Mid East showed a move towards beef production system where medium dairy farms in the South East regions shifted entire tillage land to grass land. Farms in the South East region also kept animals on grass longer under the climate change scenario compared to the baseline scenario.

Key Words

farm level linear programming model; farm net income; climate change; Irish dairy farms; farm adaptations; Irish regions

Zusammenfassung

Die Studie quantifiziert kurzfristige Reaktionen irischer Milchviehbetriebe auf den Klimawandel. Ergebnisse des Irish National Farm Survey und irische Wetterdaten sind die wichtigsten Datensätze der Studie. Mehrere Simulationsmodelle werden verwendet, um Erträge und Vegetationsdauer von Grünland in einem Basisszenario und einem Klimaszenario in der Zukunft zu untersuchen. Ein Optimierungsmodell bestimmt das maximale Netto-Betriebseinkommen unter Einhaltung von Faktorbegrenzungen für diese Szenarien. Dessen Änderungen im Klimawandelszenario werden dem Basisszenario gegenübergestellt, um die Auswirkungen zu bestimmen. Die durch das Modell angezeigten Änderungen im Vergleich der Szenarien sind eine Folge der unterstellten Gewinnmaximierung. Die Ergebnisse zeigen in allen Regionen eine deutliche Erhöhung der Grünlanderträge (49% bis 56%). Die Auswirkungen des Klimawandels unterscheiden *sich regional. Milchviehbetriebe an der Grenze, im Zentralraum und der Süd-Ost-Region erleiden im Klimawandelszenario Einbußen, während jene in anderen Regionen in der Regel besser abschneiden. In den überwiegenden Fällen reagieren die Betriebe, indem Kraftfutter durch Gras ersetzt wird und die Bestandsdichten erhöht werden. Kraftfutter wird in unterschiedlichem Ausmaß reduziert. Milchviehbetriebe in der Mitte-Ost-Region entwickeln sich in Richtung Rindfleischproduktion, hingegen erfolgt in den Süd-Ost-Regionen eine Umstellung von Acker in Grünland. In der Süd-Ost-Region wird die Dauer der Weidehaltung im Klimawandelszenario gegenüber dem Basisszenario ausgedehnt.*

Schlüsselwörter

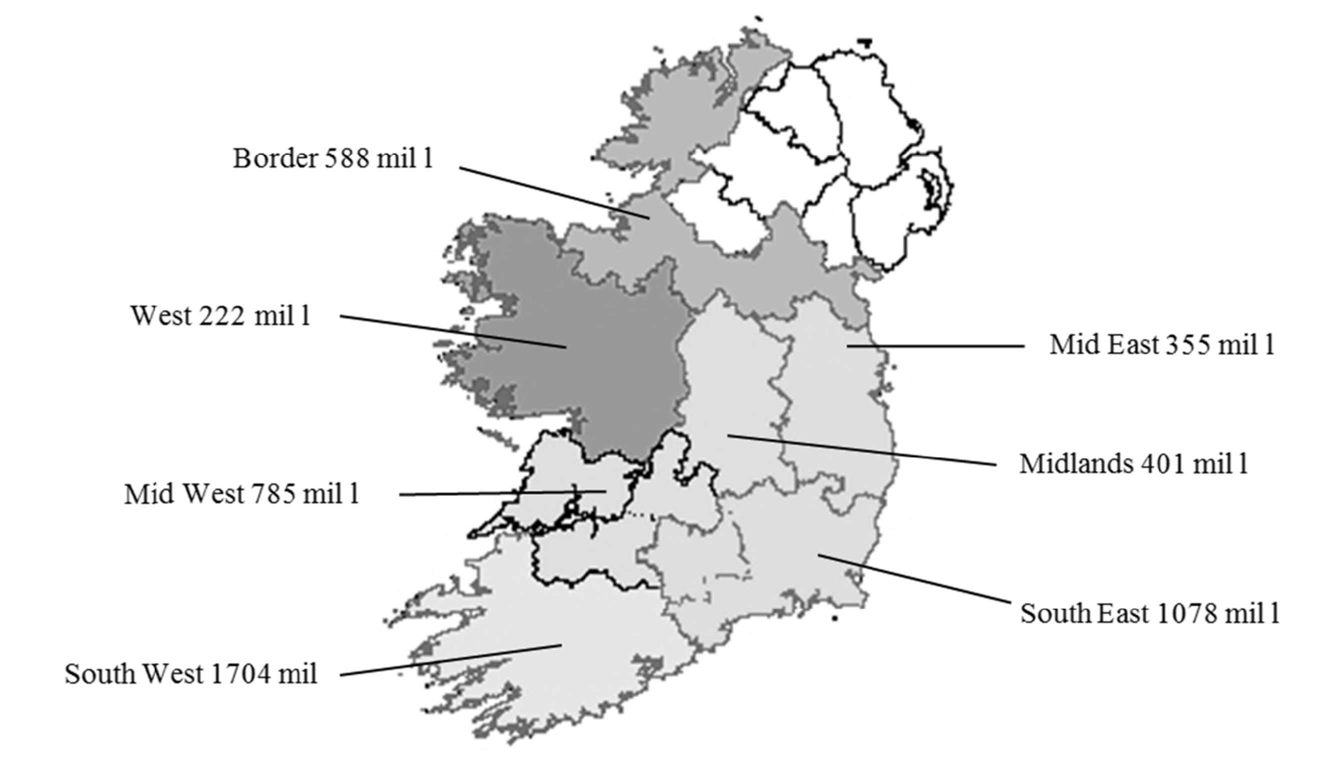
lineare Programmierung; landwirtschaftliches Betriebsmodell; landwirtschaftliches Einkommen; Klimawandel; Milchkuhhaltung; Irland; Betriebsanpassung; Regionen in Irland

1 Introduction

With a growing concern of climate change and food security, extensive researches have been conducted to examine agricultural production under expected future climate conditions (RÖTTER and VAN de GEIJN, 1999; IFPRI, 2009; NELSON et al., 2010; CISCAR et al., 2013; SHRESTHA et al., 2013; WITZKE et al., 2013). These studies suggested some changes in agricultural production based on location and type of sampled farms. Climate change is likely to have a direct impact on livestock production by affecting the health, reproduction and productivity of farm animals. For example, a rise in temperature may induce heat stress in animals which can lower productivity by decreasing appetite and increasing susceptibility to parasitic diseases (ADAMS et al., 1998; SUTHERST et al., 1998; WHITE et al., 2003; THORNTON et al., 2009; NARDONE et al., 2010). However, the major impact of climate changes on livestock production is believed to be through the changes in grass production and conservation under new climate conditions (OLESEN and BINDI, 2002; FITZGERALD et al., 2009). Increased atmospheric CO_2 concentration has been estimated to increase grass yield by 20-30% (CAMPBELL and SMITH, 2000; JONES et al., 1996; CANNELL and THORNLEY, 1998). There is a regional variation of the impact of climate change on grass production. A higher rainfall will be beneficial for grass growth in regions where water is currently a limiting factor, but will have detrimental effects on grazing and grass conservation in areas with poor water drainage (COOPER and MCGEHAN, 1996). Increase in precipitation on farms with poor drainage may also render soil unsuitable for machinery operations such as silage cut as well as grazing. Due to this spatial variation of impact on grass production, farms in different location would respond to climate change differently. The regional variability in farmer's responses to climate change has been well documented by many earlier studies. Using a multinomial choice model, SEO and MENDELSOHN (2008) showed that farmers' choices of particular crops highly depended on the location of the farm in South America. They suggested that farmers in cooler regions are likely to switch to potatoes and wheat productions whereas farmers in warmer regions would opt for fruit and vegetable productions. A regional study carried out on maize farms in three areas of the Highveld region in South Africa concluded that the western drier areas of the region would be more vulnerable under climate change than other regions (WALKER and SCHULZE, 2008). The study showed that for these farms, moving to a minimum tillage method which conserves soil moisture and minimises soil erosion was a better option for their sustainability.

There have been a number of studies in recent years determining the effects of climate change on Irish farms (BRERETON and O'RIORDAN, 2001; SWEENEY et al., 2003; HOLDEN et al., 2004; HOLDEN and BRERETON, 2006; SWEENEY and FEALY, 2008). HOLDEN et al. (2008) examined a number of adaptations under different stocking rates, reducing N-inputs, changing silage area and the grazing period on dairy production systems across Ireland in response to climate change. They concluded that livestock production in the southern regions would not need to adapt under a climate change scenario whereas livestock farms in the eastern regions could improve production by increasing the stocking rate or moderately decreasing N-input on farms. These studies, however, included adaptations as pre-specified fixed measures for all farms under the study. Farms were only allowed to either adopt or not adopt these measures. There was no flexibility provided on farms to adjust under climate change based on the type of farm introduced. It can be argued that the use of pre-specified measures may not be ideal for all farm types. Farm variability that exists due to socio economic condi-

Figure 1. Regional distribution of milk production in Ireland



Source: calculated from CONNOLLY et al. (2008)

tions and farm managements on different farms could have a strong influence in their responses to future changes (REIDSMA et al., 2010). The view is that farms need to be provided 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). For an individual farm or to some extent a policy maker, it would be more useful to determine the likely impacts of future changes and identify a list of adaptation measures based on types and location of farms rather than having a set of broad scale generalised measures to implement future strategies. Keeping this in mind, this paper assesses the regional effects of climate change in Ireland and aims to examine responses of different dairy farm types using an optimising farm level model. This study focused only on short term farm adaptations which could be adopted by a farmer easily on farm. Long term adaptations which require large investments such as installation of irrigation/drainage facilities on farms were not considered as they were not assumed to be farmers' immediate response to change for this study. This study also did not attempt to examine any effects of external factors such as market prices and agricultural policies on Irish farms.

2 Irish Regional Farm Variability

There are 7 NUTS[1] III agricultural regions in Ireland; Border, Mid East, Midlands, Mid West, South East, South West and West regions. Dairy production system is very diverse in these regions based on the level as well as efficiency of production. For example, the South West region produces more than 33% of total milk production (Figure 1) and is also the most profitable dairy region (HENNESSY et. al., 2009). The western region on the other hand shares only 4% of national milk production and consists of one of the least profitable dairy farms in the country.

In addition to the regional variations, there is also a substantial variation between different farm types within each region based on their production system, management, economic and physical size. A number of studies have examined the variability between Irish farm types and showed that different farms responded differently to changed conditions such as changes

[1] The Nomenclature of Territorial Units for Statistics (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).

in agricultural policies (SHRESTHA and HENNESSY, 2006; SHRESTHA et al., 2007). For example, SHRESTHA et al. (2007) while examining the impacts of decoupling of single farm payments on Irish beef farms in the South West region reported that larger beef farms responded to the change in payment system by decreasing beef numbers by 50% while smaller beef farms entirely de-stocked beef animals.

3 Methodology

The methodology conceived of in this study used two simulation models; a grass growth model and a soil deficit simulator; and an optimising farm level economic model. The first part of the study determined the effects of a climate scenario on grass yields and field time in different Irish regions. The second part of the study then used these model outputs in the farm level economic model to identify possible farm responses in maximising farm profits. Farm family income provided a measure of profitability of each farm group and hence was used as an indicator to determine the economic effects of climate change in this study. A more detailed description of the data input and models are provided below.

3.1 Data Input

The data input for this study was provided by two sources; farm level data from the National Farm Survey, NFS (CONNOLLY et al., 2008) and weather data from the Irish National Meteorological Service (MCGRATH et al., 2008). The NFS consisted of farm level data from 364 dairy farms. This survey collected physical as well as financial information of each of the sampled farms. Farms were well distributed over the 7 regions of the country. Within each of the regions, a cluster analysis was carried out in SPSS[2] to group farms together with similar characteristics. Seven farm variables (production system, farm gross margins, land size, animal number, labour, feed and milk yield) were used to group the farms. These variables were assumed to be the main differences between different farm types. Squared Euclidean Distance Method was used for finding similarities between the farms. This method is commonly used in cluster analysis when there are multi-dimensional variables such as farm variables used in this study (SOLANO et al., 2001). A more detailed description of this methodology is available in SHRESTHA (2004). To preserve the confidentiality of the data, all farm groups with less than 15 farms were removed from the study. The farm level data for each of the remaining farm groups was averaged and used as farm level data for a representative farm type in the model. This averaged farm level data provided physical (such as land size, animal number and family labour units), management (such as feed use, stocking rate and land use) and financial (such as milk prices, beef prices, replacement costs, feed costs, overhead costs and variable costs) information for each of the farm groups. In addition to that, farm management data and other farm variables which were not available in the NFS dataset (such as labour requirements and livestock units) were taken from the Teagasc Management Handbook (TEAGASC, 2009).

The weather data was drawn from a set of modelled data that was downscaled from 136 weather stations throughout Ireland and had a horizontal resolution of 25 km grids (MCGRATH et al., 2008). The weather data used in the simulation models (described below) included daily solar radiation, maximum and minimum air temperature and precipitation. The weather data was obtained for a baseline scenario and a climate change scenario. The 'baseline scenario' consisted of a 30 years averaged weather data from 1961 till 1990 while the 'climate scenario' contained a 30 years average weather data from 2061 to 2090. The 'climate scenario' selected for this study was based on the 'high' emission scenario A1B as described by IPCC (2000). The 'high' scenario was chosen in this study to determine the largest response of farms under the changed climate.

3.2 Models

For this study the two types of simulation models and an optimisation model were used which are listed as follows;

3.2.1 Johnstown Grass Model (JGM)

The first simulation model used in this study was the Johnstown Castle Grass Model (JGM). This model was used to simulate Irish grass growth in different Irish regions under both baseline and climate change scenarios. JGM is an empirical pasture model that predicts vegetative growth and development in permanent pastures (BRERETON, 1995). It was developed for the purpose of understanding the behaviours of grassland systems herbage supply in response to weather variations. The model has been tested and validated against measured production over a wide

[2] SPSS is a statistical software. More details are available @ http://www-01.ibm.com/software/analytics/spss/.

geographical range and found suitable for simulating Irish pasture production (BRERETON et al., 1996; HOLDEN et al., 2008).

Perennial ryegrass was selected for simulation of grass production as this is the dominant species of agricultural grass in Ireland. A list of grassland management activities used for the model simulation is shown in Table 1. This list represents the most common practices in grassland management on Irish livestock farms and was prepared by consulting a number of Irish livestock and grass experts. A digital soil classification was used in this study in which the area of Ireland was divided into grey brown podzolic, brown earth, acid brown earth, podzol and gley (SWEENEY et al., 2003). Weather grids falling in each region were isolated and the models were run for each grid as a separate calculation, then the average yield for the whole region was calculated by aggregating grid results.

Table 1. Management input data used in the grass model

Grass type	Permanent pasture (Perennial Ryegrass)
Growing cycle	Simulation started January 01
Fertilizer application	250 kg N/ha
Harvesting date	Cutting each 28 days interval subsequently

Source: personal communication with livestock and grass experts

3.2.2 Johnstown Soil Moisture Deficit Simulator (JSMD)

The second simulation model used in this study was the Johnstown Soil Moisture Deficit simulator, (JSMD) which was developed to determine soil moisture deficit measurements from the soil (SCHULTE et al., 2005). Field time is a parameter to measure the suitability of soil on a farm for field activities such as planting and harvesting crops. Soil moisture deficit (SMD) is considered as a reliable measure in representing field time (KEANE, 2001). The simulator was set up with the weather data for the baseline scenario as well as climate change scenario. A weather grid from a number of weather grids in each of the 7 regions was selected randomly to run the simulator. Each of the regions had a designated water drainage system (well drained, moderately drained and poorly drained) based on the soil type of the region. The model provided a simulation of daily SMD values for 30 years under both of the scenarios in all 7 regions. A representative year was then determined for each of the scenario by using a median SMD value for each of the days within those 30 years. A threshold of 10mm SMD was set up where, soil was assumed to be suitable for tractors and other machinery operations on field when the SMD value was greater than 10mm (EARL, 1996, in FITZGERALD et al., 2008). Soil was assumed to be suitable only for grazing when the SMD value was less than 10mm but greater than 0mm. Finally, when the SMD value was below 0mm, the soil was assumed not to be suitable for any field activity without causing some damage to top soil.

3.2.3 Farm Level Linear Programming (FLLP) Model

An optimising Farm Level Linear Programming (FLLP) model was developed for this study. The FLLP is based on a farm level dynamic linear programming model (FDLP) which is described in detail in SHRESTHA (2004). Modified versions of farm level linear programming models have been used in a number of farm level analyses of Irish Agriculture (SHRESTHA and HENNESSY, 2006, 2008; SHRESTHA et al., 2007; HENNESSY et al., 2008). The main assumption behind the FLLP model was that all farmers were profit oriented. Under this assumption, the model maximised farm net income within a set of limiting farm resources, land, feed, replacement stock and labour. The total land available to a farm was fixed, however, 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 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.

The main activity in the FLLP model was dairy production. However, it also included beef, sheep and tillage production activities to represent activities on mixed dairy farms. The dairy system had a four year lactation cycle where lactating dairy animals were culled after every four year. The animals were replaced by on-farm or off-farm replacement stocks. A feed module, based on ALDERMAN and COTTRILL (1993) was used to determine feed requirements for each of the animals on a farm based on type, age and production level of the animal. Feeds, available to the livestock on farm, were fresh grass, grass silage, maize silage and concentrate feeds. Concentrate feeds included cereal produced on farm (on farms with arable land only) as well as those feeds bought from outside the farms. Grass silage was produced under one-cut or two-cut silage production systems. The quality of the one-cut and two-cut grass silage is assumed to be similar in this study. The two-cut silage systems produce more grass silage annually than the one-cut silage system but doubles the labour costs for silage production. The choice of silage production system was based on suitability of soil, availability of field time (especially in case of two-cut silage production) and the amount of grass silage required to feed animals. A shortened in-house period would require less grass silage so a lower cost silage production like one-cut silage production system could be an optimal system for a farm. A grazing constraint was added to the FLLP model so that animals were turn out for grazing only if the grass yield on field was greater than 0.9 t/ha (TOPP and DOYLE, 1996) and if the soil had a SMD greater than 0 mm.

The FLLP model was pseudo-dynamic in nature with a 10-year time frame. A farm activity in a particular year was based on the farm activity in the previous year. For example, number of dairy animals in year '*t*' for each of the farm type '*f*' was based on the number of dairy animals and heifers in year '*t-1*' as well as number of replacements and culled animals in year 't' as shown in Equation 1;

$$\text{dairy}_t = \text{dairy}_{t-1} + \text{heifer}_{t-1} + \text{replacement}_t - \text{cull}_t \quad \forall f \qquad (1)$$

The model results from first three years and last four years were discarded to minimise the starting and terminal effects of linear programming (SHRESTHA, 2004; AHMAD, 1997). 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.

The farm activities chosen by the model under the climate change scenario which were different from the baseline scenario were considered as the farm's responses to maximise farm profits. A selective list of adaptation variables focused in this study is provided in Table 2. The endogenous adaptation variables were the existing farm practices that could be adjusted by the model. The model was run under a 'Core' climate change scenario under which only endogenous variables were considered. Stocking rate was fixed under the baseline and 'Core' climate change scenarios. However, it was increased by +0.5 LU/ha and +1LU/ha in additional climate runs (called as stocking rate adaptation scenarios hereafter) to provide flexibility on farms to increase animal numbers.

Table 2. A selection of adaptation measures used in the FLLP model

Adaptation measures	Variable in the model	Description
Land use	Endogenous	The model optimises land use under the most profitable production system.
Production system	Endogenous	The model selects the most profitable production system.
Number of animals	Endogenous	The model optimises animal number on farm.
Feeding system	Endogenous	The model chooses the most cost efficient feeding system.
Labour	Endogenous	The model optimises the input of family and paid labour.
Stocking rate	Exogenous	The stocking rate is changed to +0.5lu/ha and +1lu/ha.

Source: authors' own derivation

As stated earlier, the FLLP model used the farm level data for representative farms derived from the NFS dataset and the grass yields and field time data taken from JGM and JSMD simulator, respectively. This study only considered the changes on grass yields and field time availability under a climate change scenario. The effects of climate change on grazing animals were not covered in detail in this study as in a temperate climate like in Ireland animals were expected to be capable of tolerating expected change in temperature for the next fifty years (PARSONS et al., 2001). However, a 10% increase in livestock variable costs (especially increase in veterinary costs) was included in the study to enable livestock farms undertake any preventive measures against a possibility of parasitic infestation.

4 Results

4.1 Farm Types

The cluster analysis resulted in different dairy farm groups in each of the 7 regions. Based on their characteristics, the farm groups were arbitrarily designated as small sized (<40 ha), medium sized (41 ha – 65 ha) and large sized (>66 ha) farms to differentiate them from each other. Some major characteristics of these farm groups in each of the regions are provided in Table 3, showing the size of farm, available family labour, farm gross margins and livestock units.

Table 3. Characteristics of farm groups in different regions

Regions	Farm size (ha)	Family labour (MWU)	Farm gross margins (€)	Dairy cows LU	Beef cattle LU	Sheep LU
Border						
Dairy small	31	1.1	29,013	13	15	7
Mid East						
Dairy large	100	1.3	210,262	120	79	0
Dairy medium	53	1.2	86,844	48	40	7
Midlands						
Dairy large	84	1.7	190,787	93	74	0
Dairy medium	56	1.4	93,043	44	52	3
Mid West						
Dairy large	72	1.3	126,655	65	56	1
Dairy medium	45	1.4	54,534	32	38	1
South East						
Dairy large	68	1.3	123,413	59	57	1
Dairy medium	53	1.3	66,474	24	44	14
South West						
Dairy large	95	1.7	186,313	103	70	1
Dairy medium	57	1.5	112,365	59	41	3
Dairy small	39	1.4	47,109	29	22	2
West						
Dairy	40	1.6	71,802	36	24	4

MWU = man work units; LU = livestock units
Source: authors' own calculations

4.2 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 to 16.8 t ha^{-1} as shown in Table 4. 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 increase under the climate change was the highest at 56%.

Table 4. 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	56
Mid East	9.5	14.6	54
Midlands	9.2	14	52
Mid West	10.3	15.6	51
South East	10.4	16.2	56
South West	11.3	16.8	49
West	7.3	11	51

Source: authors' own calculations

4.3 Field Time

The JSMD simulation showed an increase in field time under the climate change scenario in most regions as presented in Table 5. The table indicates different levels of soil suitability for field operations in each month based on the SMD values. Months with less than 0 mm SMD were designated as '0' level for no grazing conditions, months with more than 0 mm SMD and less than 10 mm SMD were indicated as '1' level suitable for grazing only and months with more than 10 mm SMD were designated as '2' level suitable for grazing as well as field operating machines on field. The results show that the grazing period was lengthened by at least one month in the Mid East, Midlands, Mid West, South West and West regions as these regions moved from '0' level to '1' or '2' level in March and October. Farms in all regions moved to '2' level between May and September. This was important especially for grass conservation, as farms had an opportunity to opt for two-cut silage production.

4.4 Impacts on Farms

The FLLP model results showed that the impact of climate change and farms' responses to climate change was different in different types of dairy farms. Figure 2

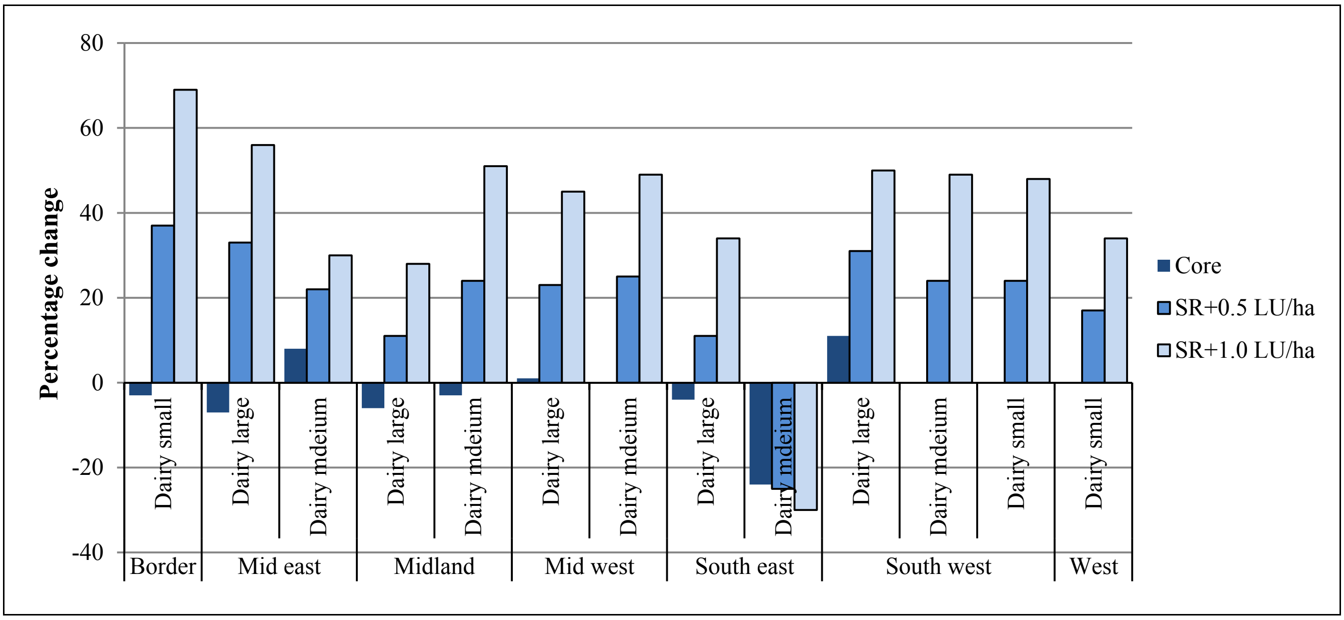
Table 5. Monthly field time levels on farms in each of the 7 regions in baseline (Base) and climate change (CC)conditions

Months	Border		Mid East		Midlands		Mid West		South East		South West		West	
	Scenarios		Scenarios		Scenarios		Scenarios		Scenarios		Scenarios		Scenarios	
	Base	CC	Base	CC	Base	CC	Base	CC	Base	CC	Base	CC	Base	CC
Jan	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0	0	1	1	0	0	0	0
March	1	1	0	1	0	1	0	1	1	1	0	1	0	0
April	1	1	1	1	1	1	1	1	1	1	1	1	1	1
May	2	2	2	2	2	2	2	2	2	2	2	2	2	2
June	1	2	1	2	1	2	1	2	2	2	1	2	1	2
July	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Aug	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Sep	2	2	1	2	1	2	1	2	2	2	1	2	1	2
Oct	1	1	0	2	0	1	0	1	1	2	0	1	0	1
Nov	0	0	0	0	0	0	0	0	1	1	0	0	0	0
Dec	0	0	0	0	0	0	0	0	0	0	0	0	0	0

0 = level suitable for no field work (<0 mm SMD), 1 = level suitable for grazing only (0-10 mm SMD), 2 = level suitable for grazing and machine operation (>10 mm SMD)
Source: authors' own calculations

presents a percentage change in farm net margins under the 'Core' and two stocking rate adaptation scenarios compared to the baseline scenario. All of the dairy farms in the Border, Midlands and South East and large dairy farms in the Mid East regions showed a negative effect on farm margins under the 'Core' climate scenario. However, large dairy farms in the South West and Mid West regions had positive effects on their farm margins. Dairy farms in all of the regions except for the South East region showed positive response to climate change scenario when stocking rate was relaxed by 0.5 LU/ha and 1.0 LU/ha. Among the high dairy production southern regions, medium sized dairy farms in the South East region had the highest loss (-24%) in farm income under the 'Core' climate change scenario. These farms were the milk producers with highest costs of production (€928/dairyLU). The 10% increase in variable costs under climate change affected these farms more than any other farms. These farms lose out more under the higher stocking rate scenarios. The small dairy farms in the West and South West regions showed no impact

Figure 2. Percentage change in farm incomes under climate change scenarios in different regions



Source: authors' own calculations

of climate change but had a small reduction in farm incomes in the Border region. However, all of these farms show an improvement on farm income under the higher stocking rate scenarios.

The responses of farms under the climate scenario are presented in Table 6. There was a substantial decrease in dairy animal numbers on farms in the Mid East region. These animals were replaced by beef animals indicating a shift from dairy towards beef production on these farms. All of the dairy farm groups in the South West and West regions and large dairy farms in the South East region had a small decrease in dairy animal numbers. The farms in the Southern regions had substituted dairy animals with beef animals. All of the dairy farms regardless to regions had a change in feeding system on farms. Most of the farms had a replacement of entire concentrate feed by grass feed. Some farms such as farms in Mid East region had only a portion of concentrate feed replaced by grass feed. Farms in the Southern regions and West region also show a change in the use of maize silage in their feeding system. Medium sized dairy farms in the South East region, which had a small tillage land producing maize silage (≈4 ha), shifted that land entirely to grass land and substituted maize silage by grass feeds.

All of the dairy farms opted for one-cut silage production system in all 7 regions even if suitability of soil for machinery operation increased under climate change scenario. This suggests that with the increased grass yield under the climate change scenario, silage production on farm was sufficient enough with only one-cut silage system and hence reduce production costs by not opting for a two-cut silage system. Only the farms in the Mid East region responded to increased field time by keeping the animals on grazing two months longer under the climate change scenario compared to the baseline scenario.

Table 6. Farm responses under climate change scenarios

Regions	**Farm responses under climate change scenario**				
	‘Core’				Stocking rate
	Land use	Production system	Number of dairy animals	Feeding system	
Border					
Dairy small	No change	No change	0%	100% concentrate replaced by grass feeds	√
Mid East					
Dairy large	No change	315% increase in beef	-28%	27% concentrate replaced by grass feeds	√
Dairy medium	No change	93% increase in beef	-30%	40% concentrate replaced by grass feeds	√
Midlands					
Dairy large	No change	20% increase in beef	-5%	100% concentrate replaced by grass feeds	√
Dairy medium	No change	No change	0	100% concentrate replaced by grass feeds	√
Mid West					
Dairy large	No change	No change	0	100% concentrate replaced by grass feeds	√
Dairy medium	No change	No change	0	100% concentrate replaced by grass feeds	√
South East					
Dairy large	No change	No change	0	100% concentrate replaced by grass feeds	√
Dairy medium	100% tillage area reduction	Tillage production reduced to zero	-2	100% concentrate and 100% maize silage feeds replaced by grass feeds	x
South West					
Dairy large	No change	87% beef	-7%	100 concentrate and 30% maize silage replaced by grass feeds	√
Dairy medium	No change	10% beef	-1%	100 concentrate replaced by grass feeds and maize silage	√
Dairy small	No change	No change	0	100 concentrate replaced by grass feeds and maize silage	√
West					
Dairy	No change	No change	-5%	100 concentrate and 14% maize silage replaced by grass feeds	√

Source: authors’ own calculations

5 Discussion

The effect of climate change on grass yields is expected to be positive in all regions in Ireland. Increases in grass yields in the model results 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 and TUBIELLO, 1997; IZAURRALDE et al., 2003; MEARNS, 2003), temperature (FISCUS et al., 1997) and carbon dioxide concentrations (MITCHELL et al., 1993) have a positive effect on grass productivity. Increases in future grass biomass production in Ireland due to climate change have been predicted by HOLDEN and BRERETON (2002) and FITZGERALD et al. (2009) using Dairy_Sim model and ABDALLA et al. (2010) using DNDC and DayCent models. HOLDEN and BRERETON (2002) projected an increase in future grass biomass production in the West region but a decrease in the eastern regions of the country. The authors suggested this decrease due to summer drought stress in the east of Ireland. This difference between the studies could be due to the differences in climate scenarios, the input weather and management data used as well as assumptions behind each of the models.

The FLLP model results suggested that there is some variation expected in impacts of climate change on Irish farms based on types and location of the farms. The dairy farms in the Border and Midlands regions seem to experience negative impacts of climate change on their farm margins. Most of these farms are extensive grass based farms. Due to a fixed stocking rate under 'Core' climate change scenario, these farms could not exploit the increase in grass production and could only benefit under the higher stocking rate scenarios. This is true for other farm types in these regions as well.

The FLLP results also showed that there were small differences between the responses of farms to the climate change in farms in different regions. Large dairy farms in the Mid East and South West regions show an improvement on their income under the 'Core' climate change and they do so by increasing in beef numbers on farms. These farms already have a capacity in beef production. Beef production in this region is more commercialised and has a tendency to increase the number of animals when possible (SHRESTHA et al., 2007). A change in feeding pattern was the main adaptation on all farms. Increase in grass yield and field time means these farms could use more grass feed and decrease the costs of buying concentrates. This adaptation was similar in all farm types in all regions.

Farms in all regions opted for only one-cut grass silage production system even though an increase in field time provided an opportunity to select two-cut silage production systems. A higher production costs for two-cut silage systems outweighs the benefits of an increase in grass silage for all dairy farm groups in this study. RAMSDEN et al. (1999) also suggested in their study that cost saving strategies such as lowering labour costs would be preferred by farmers in England. The benefit of longer grazing period was exploited only by the large dairy farms in the South East region. This suggests that other regions did not have sufficiently large enough increase in grass yield on field for animals to be turned out early.

The model results also suggested that a majority of Irish dairy farms benefit from relaxing stocking rate constraint to exploit the increased grass yield under the climate scenarios used in this study. PARSONS et al. (1997; 2001) also suggested that farmers benefit from increased grass yield under climate change when the stocking rate constraint was relaxed. However, it should be noted that there would be a limit on stocking rate where no more animals could be put on grass without damaging soil or without spending on additional feed. 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 the northern regions of Ireland. Another aspect of a higher stocking rate is a possibility of a higher emission of methane per unit of land. Methane is one of the major green house gas (GHG) and ruminants are estimated to produce more than 90% of the total methane emissions (OPIO et al., 2013). Increasing stocking rate and hence leading to higher GHG emissions would be a major obstacle on a farm especially if there is a limit imposed on farms on total GHG emissions. However, some researchers argue that increase in stocking rate (without damaging soil) especially in waste lands would lower another major GHG, nitrous oxide emissions and conserve ecosystem (WOLF et al., 2010).

Finally, this study shows that a farm level approach is a useful tool to examine the economic impact of climate change on different dairy farm types in different regions. However, this type of study is highly dependent on the estimates provided by the growth models, climate scenarios used as well as assumptions made in the LP model itself. Further research would be beneficial under a number of possible climate change scenarios to identify a wider range of potential strategies under different climate conditions.

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