

Original Research Article

Potential Impact of Climate Change on UK Potato Production

ABSTRACT

This study assessed the potential impact of climate on potato production in the United Kingdom. Climate change actions are becoming a nightmare for growers worldwide, and the British potato industry is not an exception. Extreme weather conditions were experienced in 2006, 2012 and 2018, respectively. Thus, this study identified the future climate risk associated with major potato producing regions in the UK using the recent climate projection weather data (UKCP18) based on RCP 8.5. In total, the study considered seven (7) regions with a minimum average of 3000 hectares of potato planted area in the past five years. Findings showed that drought, high temperatures, and prolonged precipitation caused significant yield and quality loss in the past, with a likelihood of causing a more harmful impact in the future. The analyses revealed a hotter ($T_{\max} \geq 25^{\circ}\text{C}$, $T_{\min} \geq 15^{\circ}\text{C}$) and drier ($1-1.5\text{mm day}^{-1}$) summer most especially in the EE, EM, WM, YH, SW as well as a warmer (T_{\max} & T_{\min} 6-10°C) and wetter winter (5mm day^{-1} on average) in Scotland and North West England. Future climate is predicted to hinder land preparation and harvesting operation in the Northern regions while the EE, EM, SW, WM would be faced with drought, with irrigation and water demands increasing 20-30% as evapotranspiration also increases by 20-30% in 2050-2080. Irrigated potatoes are predicted to double its current spatial coverage in the future. Late blight and potato wart disease are expected to reduce in EE, EW, WM, YH regions. The study identified suitable adaptation measures and strategies required to reduce the impact of climate change on the British potato industry.

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Keywords: Climate change; potato production; extreme weather; climate projections; UK

1. INTRODUCTION

The ~~changing fact that the~~ global climate ~~is changing~~ cannot be overemphasised, as the atmospheric concentration of greenhouse gases have increased by 43% from the pre-industrial era which has been attributed to anthropogenic activities [1]. ~~Whether Although there are people, who feel~~ climate change is politicised or exaggerated. ~~Neverthelessnevertheless~~, irregular precipitation pattern coupled with high temperatures in the summer is gradually becoming a norm [2]. On the other hand, there is also the challenge of meeting the food demand of the current 8 billion ~~world populationpeople~~, coupled with the concern of future food insecurity as the world population is expected to reach 10 billion in the year 2050 [3]. Globally, the agricultural sector is reported to emit ~~g~~Greenhouse gases which drive global warming, at the same time the sector is susceptible to the changing climate and extreme weather events, which is the resultant effect of GHG [2].

In the UK, about 50% of agricultural produce is imported to complement the home-grown. Nonetheless, ~~the United KingdomUK~~ is ranked among the top 20 potato producing countries in the world, found in about 33% of British meal [4]. The UK ~~p~~Potato industry, supermarkets and consumers are gradually feeling the impacts of the changing climate, which has affected

how potato crop is being grown and distributed across Great Britain. Recently consumers have complained about the reduction in the sizes of chips, fries and, number of tubers sold in the supermarkets [5]. Again, the number of growers and the cultivated area is fast decreasing due to the challenge posed by climate change and extreme weather events. Although, other factors such as economies of scale cannot be ignored. The medium-scale farmers were forced to invest in modern irrigation facilities to cope with drought challenges. Presently, over 50% of water abstracted is used for potato production. The year 2018 season saw a reduction in the level of potato production, which was likened to the shortfall recorded in 2012. Frost, drought, and waterlogging affected different growth stages, which reduced potato yield and quality. Fieldwork was hindered at the start of the 2018 season, which was due to extreme cold and wet conditions "Beast from the East" in the spring. This was later followed by a hot and dry spell during the summer months. Tuber development was stalled as a result of the stress. Skin defects such as common scab was reported to be on the rise both in the rainfed and irrigated field. Thus, some pack houses and processors were forced to lower their stands and specifications in order to meet demand. The emerging concern for the impact of drought made some farmers consider delaying desiccation to give more room for tuber bulking. This method worked for some but went wrong for the majority as the tubers initiated secondary growth, which is common in processing and frying varieties. The processing sector fell by 1.1% from 2017, due to limited supplies from the contracted growers; they had to switch into buying packing varieties to complement for the shortage. Of course, this put pressure on free-buy supplies, which increased potato prices. Prepack fell by 6.1%, the area planted for free buy fell by 17%. This harsh condition was last seen in 2006, where Scotland yield was about 25% higher than that of England [6]. Hence, it becomes imperative to prepare for the future and help build resilience to climate change impacts. Climate projections models are, therefore, a valuable tool for predicting future climate to suggest the possible impact on agriculture. Climate change projections prior to the 21st century were primarily based on the scenarios created by the Intergovernmental Panel on Climate Change (IPCC). But the most recent climate change scenarios in the UK have been updated in the UK climate projection (UKCP18), project a revised version of UKCP09. In order to ensure future food security, this study aimed at predicting future climate risks associated with major potato producing regions in the UK and also identify suitable adaptation measures and strategies.

2. MATERIAL AND METHODS

2.1 Study Area

The study focused on the administrative regions in the United Kingdom, jointly referred to as Great Britain. The UK is a sovereign country which is among the Western European countries. Great Britain ceases to be a member of European Union after exiting on the 31st of January 2020. The UK is made up of four (4) nations namely: England, Scotland, Northern Ireland, and Wales. It is reported to occupy an area of about 242,495 km² [7] with a population of about 67,000,000 [8]. The country is surrounded by the Atlantic Ocean and located in the temperate climate region of the world with four (4) seasons all year round (summer, autumn, winter, and spring). The UK agriculture takes up practically 75% of the whole land area, producing about 50% of the food consumed and non-food products, coupled with natural landscaping, which enhances various environmental services [9].

2.2 Data Sources and Framework

In this study, climate model was integrated with relevant information derived from literature regarding potato production and other horticultural crops to make future predictions. This

approach was used in making predictions about the impact of climate change on horticulture by Collier & Thomas, [10]. This study used global climate simulation because the global model projection provides better climate variability and spatial coherence. The weather data used for this study was collected from the UK Met Office in 2019, basically using the recent UK climate projection model UKCP18 which is an improvement on the previous UKCP09 model to generate the required dataset [11].

2.3 Data Collection and Sampling Technique

Quantitative regional weather data were sourced from the recent UK climate projection model (UKCP18), which formed the basis of the analysis. The data collected were based on the highest emission scenario and Representative Concentration Pathway (RCP 8.5), which presents the worst-case GHG emission scenario and the possible risk associated with different regions in the UK. Firstly, the major potato producing region in the UK with a minimum average of 3000 hectares of potato planted area in the past five years, as indicated by Agriculture and Horticulture Development Board were selected (Appendix 1 & 2). They include East Midlands (EM), East of England (EE), North West England (NW), Scotland (SCT), South West England (SW), West Midlands (WM), and Yorkshire & Humber (YH). In addition, an absolute weather dataset (precipitation, maximum and minimum temperature) were obtained from the Global Land Projection (60km downscale) over the selected region in the UK.

2.4 Data Variables

Weather factors:

- *Precipitation:* Precipitation rate per day (mm day^{-1}) was selected for the study.
- *Temperature:* Maximum and minimum air temperature at 1.5m ($^{\circ}\text{C}$) was selected for the study.

Spatial Representation: UK administrative region was selected for the study.

Temporal average type: Monthly (ALL) average time interval was selected for the study.

Start and end of time series:

- *Baseline:* 30 years trend (1990-2020) was selected for the study.
- *Future Scenario:* 30 years trend (2050-2080) was selected for the study.

Projection Subset: Regional 12km spatial resolution over the UK, which includes 12-member sets, was selected for the study.

Comment [JM3]: Why not 2020-2050? It is also a 30-year period?

2.5 Data Analysis

The weather data was analysed using Microsoft Excel 2016 and the embedded statistical tools such as averages and frequency count, while pivot table was used in summarizing the data. ~~30 years~~ Thirty years average monthly temperature and precipitation of the baseline (1990-2020) and the future scenario (2050-2080) were calculated. The analysed data for both the baseline and future scenario were plotted together on the same graph using Origin Lab 2016 software. This allows for comparison of mean values and standard deviation.

3. RESULTS AND DISCUSSION

In predicting where future problems may occur in the major regions producing potato in the UK, the study considered ~~Precipitation~~ precipitation, ~~Maximum~~ maximum and ~~Minimum~~ minimum temperature as the climate factors to be used in the predictions. In most cases, the results of the UKCP18 projections will be discussed with regards to the "maincrop"

potatoes, which are widely grown in the UK. East Midlands and East of England ~~are~~ expected to experience an increase of T_{max} 3.4-3.5°C, T_{min} 2.6-2.7°C in average monthly temperature all the year-round, in the future from the baseline. However, in the future scenario precipitation slightly increases in the winter (2.7-2.9mm day⁻¹) from baseline (2.4-2.5mm day⁻¹). North West England and Scotland ~~are~~ foreseen to further increase by T_{max} 2.7-3.0°C, T_{min} 2.6°C all the year-round in the future from the baseline (Figure 1). However, precipitation in winter is almost two times higher (5.2-5.8mm day⁻¹) in future winter months compared to other regions in the UK. West Midlands, Yorkshire and Humber ~~are~~ expected to experience an all-time increase in average monthly temperature by T_{max} 3.2-3.4°C, T_{min} 2.6°C all the year-round in the future from the baseline. In the future scenario precipitation slightly increases in the winter month (3.4-3.6mm day⁻¹) from baseline (3mm day⁻¹). South West England is expected to experience an all-time increase in average monthly temperature by T_{max} 3.4°C, T_{min} 2.6°C all the year-round, in the future from the baseline (Figure 2). However, in the future scenario precipitation slightly increases in the winter month (4mm day⁻¹) from baseline (3.6mm day⁻¹). In all the regions, August (future) replaced July (baseline) as the month with the highest temperature. Scotland is the region with the lowest temperature and highest precipitation in the future when compared to other regions while East England is the region with the highest temperature in the future and lowest precipitation when compared to other regions. (So, what does it mean by this change?)

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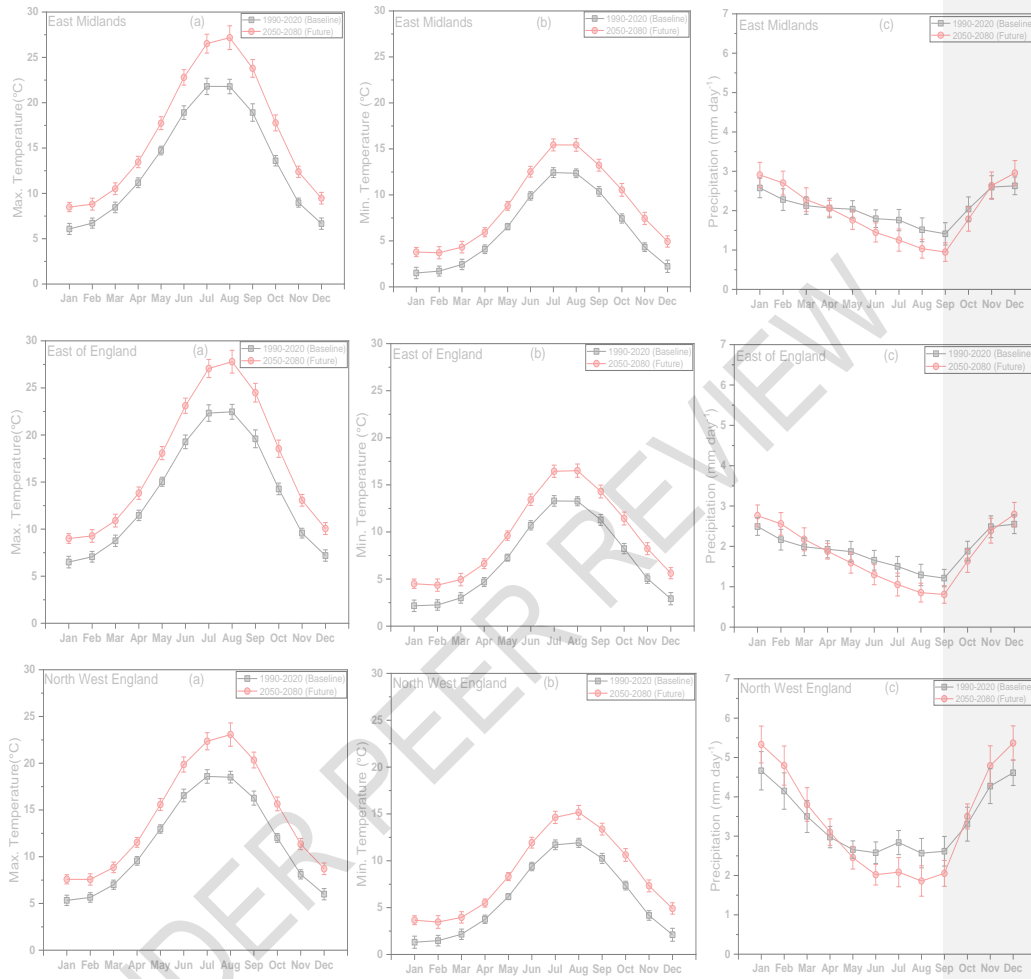


Figure 1: East Midlands, East of England, and North West England changes in 30 years monthly average. (a) Maximum temperature (T_{max}). (b) Minimum temperature (T_{min}). (c) Precipitation (mm day^{-1}) in the future scenario, represented with the red line (2050-2080) compare to the baseline, represented with the black line (1990-2020). Standard deviation bars indicating the extent of variation in the mean values. The vertical axis shows the temperature while the horizontal axis represents the month.

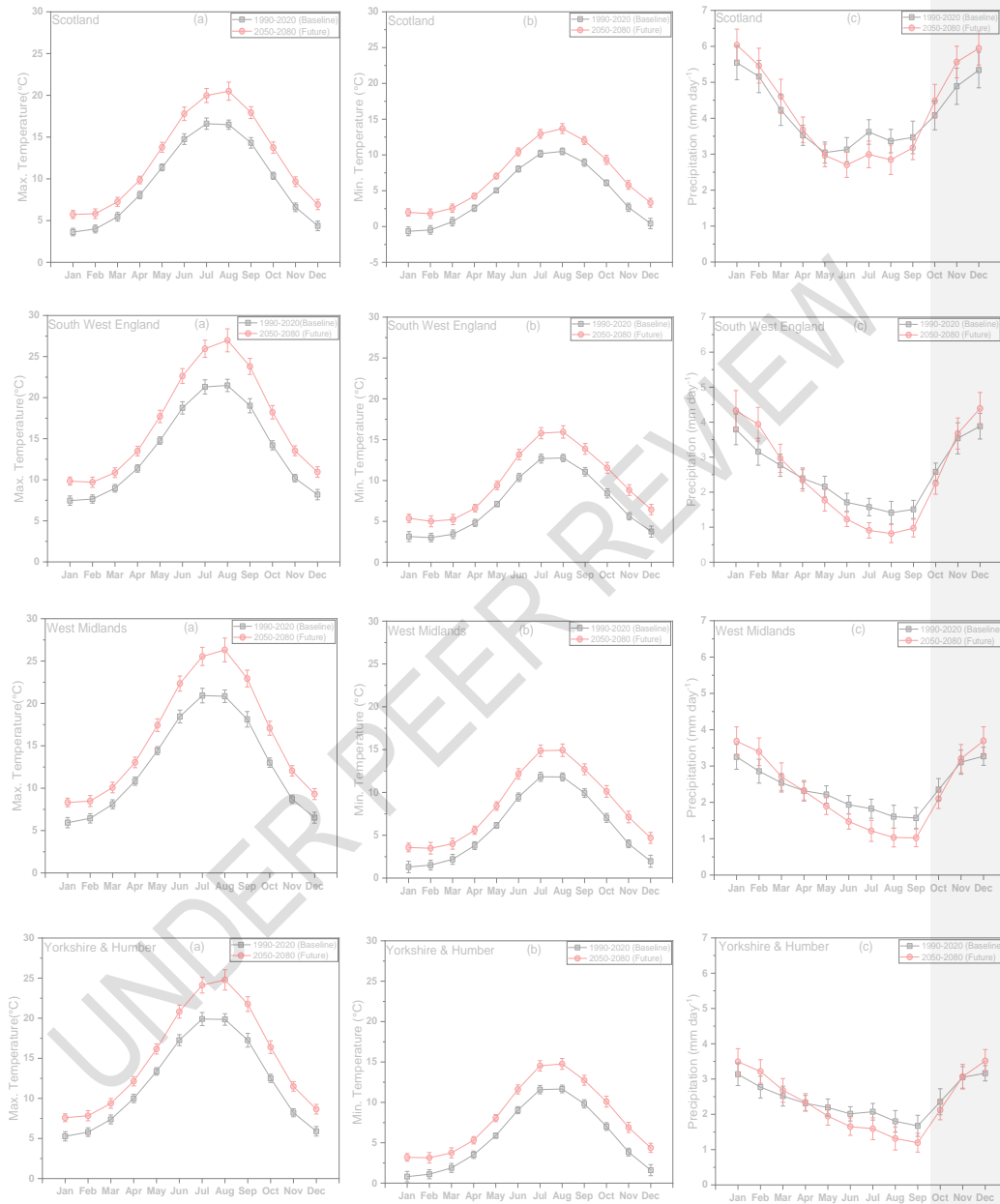


Figure 2: Scotland, South West England, West Midlands, Yorkshire and Humber changes in 30 years monthly average. (a) Maximum temperature (T_{max}). (b) Minimum temperature (T_{min}). (c) Precipitation (mm day^{-1}) in the future scenario, represented with the red line (2050-2080) compare to the baseline, represented with the black line (1990-2020). Standard deviation bars indicating the extent of variation in the mean values. The vertical axis shows the temperature while the horizontal axis represents the month.

4.1 Land Suitability and Crop Establishment

Comment [JM5]: What is this heading?

Studies have shown that agro climate, water, and soil type, influence land suitability, which is a major determinant of a viable potato production system. However, the result presented in this study shows that drought is expected to reduce the area of land in the UK currently suitable for rainfed potato production in the future. This study agrees with Daccache *et al.*, [12] who suggested that about 80% reduction of land currently suitable for potato production by 2050 under a high emission scenario. Suitable land for potato production in some part of Eastern England, East Midlands, and West Midlands could be more at risk due to an average monthly temperature exceeding 25°C in the summer month coupled with about 20-30% reduction in the future precipitation across the UK. For instance, drought in 2012 and 2018 affected land suitability and reduced potato production from about 6000Kt to 4500Kt with the yield dropping from 52t/ha to 40t/ha [5]. Noteworthy, about 50% of the potato grown in the UK are irrigated [13]. Nevertheless, a large area of lands in the East of England, East and West Midlands will still be suitable for production under irrigation.

Comment [JM6]: How does drought affect irrigation? What's the connect?

Moreover, the delay in planting due to frozen soil ~~as which was~~ experienced in ~~the month of~~ March, 2018 ~~which span~~ for about 10 days long [14] ~~will not~~ be a serious problem for potato growers in the future as the likelihood of late frost spanning from late March to April is very minimal resulting from the projected increase in winter temperatures across the UK towards the end of the century. According to ~~the result from the~~ UKCP18 ~~projection~~, only Scotland is expected to experience a monthly average temperature below 0°C in winter at T_{min} . This implies that early planting in Scotland is vulnerable to delayed sprouting, or even seed rotting underground. ~~Please note, t~~ This does not mean there will not be days when temperatures go below 0°C in other regions because the spell of freezing days in the future winter month cannot be derived from this monthly average output, which limits the projection. Besides the indoor growers will not be affected as such, although the number of indoor growers is few and domiciliary in the South East region.

Furthermore, increased winter and spring precipitation could affect land preparation activities, particularly in Scotland and North West regions in January and February, where future winter precipitation exceeds 5mm day⁻¹. A prolonged wet spell of such amount of precipitation will make the soil unsuitable to work on, which could result in late planting. ~~At that~~ Thus, farmers could damage their tractors and also compact the topsoil if they forcefully initiate land preparation.

4.2 Water Demand and Irrigation

Potato is known to be a water-thirsty crop, which is widely planted in the Eastern part of the UK, which is drier and requires irrigation to survive. The results from the UKCP18 model depicts a widespread reduction of about 20-30% in the amount of precipitation recorded all through the potato growing months (March-September) in the future compared to baseline. In addition to the reduction in precipitation during the growing month, the temperatures increased significantly all through the growing month. Hence, this is expected to increase the rate of evapotranspiration by 20-30%, thereby causing a drastic reduction in the amount of water available for the growth and development of potatoes specifically in the East of England, South West, East and West Midlands [15]. This study suggests that Irrigation demand for potato production is expected to rise by 20-30% in the **EE, EM, WM, SW regions** by 2050-2080. This will lead to a future reduction in the area of land cultivated and the number of current growers, most notably the small-scale growers who cannot afford modern irrigation facilities. ~~E.g.~~ For example in 2018, the UK experienced a reduction of about 600 registered growers from the numbers recorded in 2017.

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In the future, Scotland and North West region will experience a considerable amount of precipitation. Thus, both regions will not suffer from the increasing demand for water. Increases in potato production in both regions are somewhat high. Based on the UKCP18 results, rainfed potatoes will flourish in both regions with a marginal increase in future temperature. No doubt, potatoes grown in the EE, EM, WM, SW, YH regions will require irrigation to survive the summer, which implies that in the future, potatoes will continue to be the most irrigated crop in Britain, and this is in agreement with [13]. However, growers who want to adopt the irrigation system in East of England and some part of the Midlands might not have access as it is becoming much more challenging to obtain abstraction licenses in the region especially in the summer month as the region is currently over licensed [16]. Noteworthy, an increase in water required to grow potatoes will impact the cost of production resulting from water and energy consumption. However, the current irrigation specification and design will not meet the grower's requirement in the future which could affect the ability of farmers to meet the demand of supermarkets and industry [17].

Comment [JM7]: Not mentioned above

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4.3 Crop Development, Yield, and Quality

Literature review revealed that vegetative growth, potato yield and quality are sensitive to environmental conditions. According to the projected outcomes of this study, an increase in future temperature should facilitate the rate of sprouting which occurs basically between March-April (see stage 1 in Figure 3) particularly in Scotland (T_{max} 6°C in winter) and North West England (T_{max} 8°C in winter) with lower temperatures in the future scenario. Based on previous studies temperature between 5-20°C is suitable for potato emergence [18]. Nevertheless, a monthly average of 30 years interval used in this study will not show daily exceptions where temperatures go below optimum conditions. From planting to sprouting, little water is consumed daily (averagely 0.5-3.0mm day⁻¹). Therefore, in the first phase of emergence, most of the regions might not be affected as such, as the seed (mother) potatoes would also complement the external moisture content. The stems and leaves start growing rapidly 20-25 days after emergence around May (See stage 3 in Figure 3). This is when the plant consumes an average of 2.0-3.5mm day⁻¹. The EE, EM, SW regions are expected to be slightly at risk of water shortage in this stage as precipitation rate falls, while other regions are not affected. At the tuber initiation and development stage which is between June and July (see stages 3-4 in Figure 3) when root stops growing, plant blossoms and reaches the maximum height, leaf area. Then, the potato crop will consume between 3.0-5.0mm day⁻¹ on an average. At this phase, the UKCP18 results predict that the EM, EE, SW, WM, YH regions will be at a high risk of water deficits, thus affecting the number of tubers formed and development [15]. The risk of common scab resulting from the shortage of water supply cannot be ruled out from regions such as East of England, East Midlands, and West Midlands where the combined effect of high temperatures which exceeds T_{max} 25°C and lower precipitation (1-1.5mm day⁻¹) in the growing season increases evapotranspiration by 20-30% from baseline. According to literature review, temperatures above 28°C within a couple of days limits tuber bulking and development yield and also affecting the quality of potato produced in the aforementioned regions.

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Noteworthy, potato varieties such as Maris Peer, Melody, Estima and Maris Piper market values could be more affected as they are mostly sold as prepacks. Furthermore, determinate cultivars producing few leaves which flowers in a short period are more sensitive to water stress during the mid-late canopy expansion stage. Example of such potato varieties includes Lady Rosetta and Estima. Lack of frequent irrigation or rainfall during the mid-late canopy expansion stage could result in pre-mature senescence, coupled with significant yield loss [12]. This implies that a region such as the South West known for growing Estima and Lady Rosetta, where irrigation is currently lesser could face a decline in

the growth of such cultivar since rainfall is expected to reduce significantly below the baseline under the UKCP18 projection in the region.

Between July and August, the potato tubers are expected to develop rapidly as the plant comes closer to the end of the maturation stage (see stage 4-5 in Figure 3). This is the most important and critical stage for potato tuber yield and weight accumulation. At optimum conditions, tubers could increase between 600-1200 kg/ha/day [19]. At this stage, the water consumed ranges between 5.0-7.0mm day⁻¹. Hence, potato grown without irrigation will degenerate at this stage in EM, EE, SW, WM, YH regions where drought and high temperatures are forecasted. An example is the summer of 2006, where growers' productivity was affected by the hot weather and bone-dry soil, particularly in Eastern England and East Midlands under r_f water availability was limited even under irrigated conditions. Between August and September when the physiological maturation is reached, getting ready for harvest, the aerial part of the plant diebacks, tubers stop growing and enter dormancy, it ripens and thickens the skin. At this stage, the water requirement decreases to 2.0-3.0mm day⁻¹. Based on the UKCP18 projection, rainfed potato production may decrease by 20% if harvesting is delayed in EM, EE, SW, WM, YH regions due to dehydration. Weeds growth will also compete for water at this stage.

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Studies have indicated the possibility of growing season extension due to a warmer climate is high in the future as late spring frost could come earlier while autumn frost coming in a later date, favouring potato growers in Scotland, North and South West. This implies that crops could grow much longer than the present date, with a potential increase in yield, which will also reduce the area of land planted. This study suggests a month extension in growing season across the across the UK based on the results of UKCP18 projection as the month with the highest temperature shifts from July in the baseline to August in the future scenario. However, crops could stop growing if the daylight is not sufficient enough particularly in the Northern region (Scotland and North West) while early planting could be hindered by saturated soil resulting from increase rainfall in the winters which impedes workability as it is currently experienced in February and March. High temperatures and lower rainfall could degrade soil causing soil compaction, which limits plant emergence and root length. Hence, negatively affecting the potato yield in Scotland and North West England.

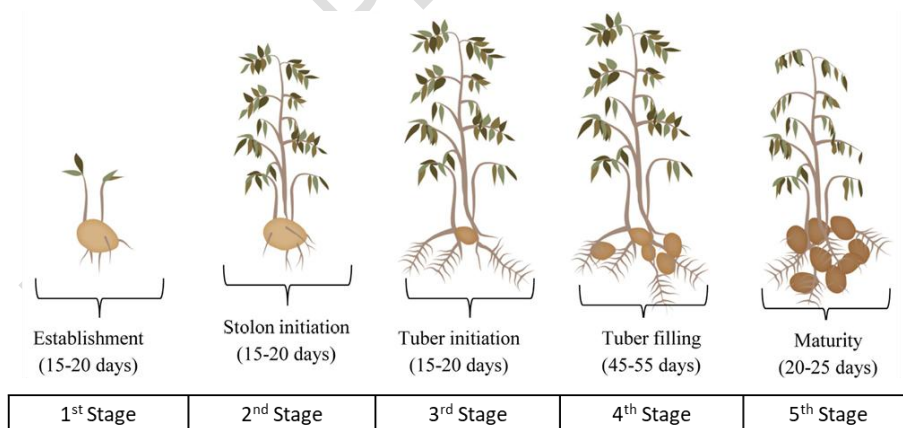


Figure 3: Stages in the potato life cycle affected by environmental conditions

Overall, it appears there will be a marginal increase in yield, depending on region and adaptation technique adopted by British potato growers, coupled with the potential increase in radiation and higher temperature in the future compared to the baseline. Although the unit of irrigation water required in producing the current yield will not be enough in the future. A

moderate increase in temperature would have a positive impact on yield, most especially in Scotland and North West resulting in a rapid crop emergence and a longer growing season, resulting from accumulated average temperature. However, temperatures higher than optimum could affect the root growth, vine and perhaps cause a setback for tuber initiation, which in turns reduce yield. Literature has suggested an increase in atmospheric CO₂ concentration over time [20]. Thus, irrigation intervals in irrigated potato could be extended due to improving root growth, which is enhanced by CO₂ concentration and photosynthesis rate, as plants are able to access water from a great depth. Yields could increase by 10-15% with nitrogen fertilizer where water availability is not limited [12], but then environmental regulations are coming against intensive use of fertilizers in the UK, which is another factor to consider.

4.4 Autumn Rainfall and Harvesting Operations

Literature review shows that potatoes are vulnerable to waterlogging and flooding. Whenever the heaps are flooded, tubers get exposed to sunlight, which causes a greening problem. Therefore, tubers become poisonous when consumed [16]. The results from the UKCP18 projection depict that the autumn rainfall is expected to decline below 2.5mm day⁻¹ in EM, EE, SW, WM, YH in the future except Scotland and North West England. This implies that the delay in potato lifting which was experienced in the year 2000 and 2018 due to high autumn precipitation and waterlogging hindering machinery operation is expected to reduce in EM, EE, SW, WM, YH regions. However, an increase in autumn precipitation is foreseen in Scotland going beyond 4mm day⁻¹ between September and October and reaching 6mm day⁻¹ by November. Hence, there is every possibility of soil saturation. Although this will depend on the frequency of wet spell and intensity, literature revealed that accumulation of 10mm or more rainfall within a week hinders lifting [21]. Also, there is a high possibility of outdoor growers facing the challenge of waterlogged soil impeding potato lifting in the North West region if harvesting is delayed until October in the future compared to other regions. An example of the impact of increase autumn precipitation was seen in 2000, where about 20% (25000 hectares) of potato tubers were still buried in the ground at Christmas [21]. A similar situation was experienced in 2007, where about 2000 hectares of crops were damaged by flooding, and also exposing the tubers to sunlight, which causes greening problems [16]. Moreover, harvesting potatoes in such wet conditions lead to wastage and soil compaction, thereby degrading the topsoil quality [22].

4.5 Suitable Adaptation Measures and Strategies

Uncertainty in future precipitation patterns necessitates both short term and long-term adaptation strategies to help strengthen grower's resilience to climate change. The present study suggests that rainfed potatoes will decrease by 20-30% under the RCP 8.5 emission scenario across the UK due to climate change. Moreover, irrigated potatoes are expected to dominate the South and East region. This implies that small scale farmers will be the most vulnerable to climate change actions, and they will continue to decrease with time due to limited production capacity. But then, larger capacity growers might not be able to obtain abstraction licenses in East of England, Yorkshire and Humber and part of Midlands in future as the region is currently over licensed or abstracted [23] (Appendix 1). Nevertheless, there is every possibility that some unused licenses exist in these regions. Thus, growers could consider transferring or trading abstract licenses. However, there is a rising concern that re-activating unused licenses in the over abstracted region will further deplete water resources available in the summer month (Appendix 1). Responding to the challenge of groundwater reduction in the summer month, growers can also exploit the off-season licenses, which is still much available as it allows for abstraction during the winter (high-flow). But this requires investing in reservoirs to help store water on the farm which would be used for irrigation

purposes during the summer period. Moreover, rainwater harvesting is already becoming popular worldwide and can be adopted to help strengthen resilience against climate change actions [13]. It can be used to refill underground water or surface water for local abstraction. Besides, improve water efficiency technology is another way of managing water on the farm. This includes precision irrigation, which allows for uniformity water dispensation, and water recycling techniques, which allows the re-use of water used for other purposes on the farm. Although, ~~studies~~ have argued the suitability of wastewater for irrigation purposes due to contamination, which limits its usage. ~~However~~, less expensive purification strategies could be adopted. Irrigation scheduling methods could also be cost-effective, although it requires adequate monitoring with an in-depth knowledge of cultivar, soil type and water holding capacity, as well as the understanding of water requirement of the crop, suitable management practice and weather forecast. Increase growers adoption of modern irrigation facilities such as boom sprayers or sprinklers, drips will help increase efficiency. In an attempt to proffer a sustainable solution to the challenge posed by climate change, some authors have also suggest that irrigated potato be moved to the North and West [24], due to water shortage in the South and East region, to regions with considerable water levels and suitable for potato growth. But then, the process of moving from one region to another might not be feasible for established growers. Better still, potential growers can consider the option of moving north and westwards where water will not be a significant problem in the future [16].

Comment [JM13]: What studies?

Early planting of potato cultivar has also been suggested as a means of adapting to the challenge posed by climate change. According to Wolf, [25] simulation, earlier planting date resulted in higher potato yield both in rainfed and irrigated fields. Advancing planting date is also expected to reduce irrigation requirement for crop development, due to wetter and warmer winter. Although this will vary across the regions, as such the crops can be seen to survive the summer drought. However, ~~e~~ Early planting in Scotland and North West would be difficult to practice as the land will still be saturated and waterlogged due to increasing winter rainfall, hence hindering land preparation. Nonetheless, early planting in the South West is suggested to be more feasible [26]. Since drought posed the biggest challenge, it is essential to invest in research and breeding of improved cultivars of potato breeds that use available water efficiently, which are drought-tolerant and resists pest and diseases attack [27, 28]. Breeders could also consider breeding potato cultivars suited to a specific region and its environmental conditions. Meanwhile, high-level traits heritability is low, which is a major limiting factor [28]. However, water efficiency mechanisms are expected to help utilize limited water effectively to achieve a considerable high yield. Understanding the relationships and interactions between different molecular, physiological and biochemical mechanism is essential in identifying the best trait suitable for potato production in a particular area or region.

As the climate changes, ~~so also is~~ crop, water and soil management practices ~~are~~ also expected to change, and develop into adapting to heat stress, drought and threats from pest and disease invasion. While improved infrastructural facilities such as drainage, bridges and roads will help growers cope with the expected increase in wet conditions during the winter months. Agroforestry and diversity of cropland are capable of improving resilience to extreme wind events. As it stands today, there are several ethical issues linked to ~~g~~ Genetically ~~m~~ Modified ~~t~~ Technology. This study suggests a change in the perception of genetically modified crops, as it can be a significant tool for reducing the impact of climate change. ~~Haven~~ outlined and discussed essential adaptation strategies.

Comment [JM14]: Is this a source?

4. CONCLUSION

Comment [JM15]: Why 4 comes after 4.1-4.5?

This study assessed the potential impact of climate change on UK potato production. It sourced weather data from the recent UKCP18 based on the highest representative concentration pathway (RCP 8.5). The results from the weather model showed a

pronounced change in the UK future climate (2050-2080) from the baseline (1990-2020). In the future, potato growers' productivity, land suitability, yield and quality will be affected by climate change, ~~no doubt~~. At that, not all impact of climate change would be disastrous for UK potato production. However, the negative impact outweighs the benefits. In the future, part of East and West Midlands, as well as East of England, will experience an increased rate of evapotranspiration due to the combined effect of drought spell and increase temperature beyond 25°C in the summer months, intensifying the occurrence of common scab, causing yield and quality loss. Thus, irrigation demand is expected to triple the current requirement in the EE, EM, WM, and SW regions in the future. Besides the impact on crop growth, climate change is also expected to affect other farm operations and management practices such as land preparation and harvesting operation. The precipitation pattern varied more than the temperature pattern across all regions. There is a likelihood of the current growing period extending due to warmer temperatures in SCT and NW with higher productivity. The study predicts a further reduction in the current number of smallholder potato growers and area cultivated in the future due to challenges of climate change, with the yield dropping below 4000Kt a year if adaptation measures and strategies are not adopted in the future (2050-2080). In general, the level of future climate change impact will depend on the rate of GHG emissions in the future. Thus, potato growers are expected to adopt and utilize both short and long term adaptation measures compatible with their agro-climatic conditions in order to cope with the negative impact of climate change and at the same time, maximise the opportunities associated with warmer temperatures. Also, the urge to increase crop yield and profits should not come at the expense of the environment. With the support of the government, GHG emission from the agricultural sector could be reduced with several emerging green technology, e.g. solar-powered pumps for irrigation, and anaerobic digesters for generating energy. It is essential to re-consider the possible changes in UK agricultural and environmental policies should in case the UK decides to let go of European Union Laws. Besides, future research could consider other climate factors such as wind and radiation with respect to potato production in the UK. Furthermore, Pest and disease model could be added to the climate model if the daily time series is later updated on the UKCP18 website in order to improve the quality of the projected outcome.

Comment [JM16]: How about YH?

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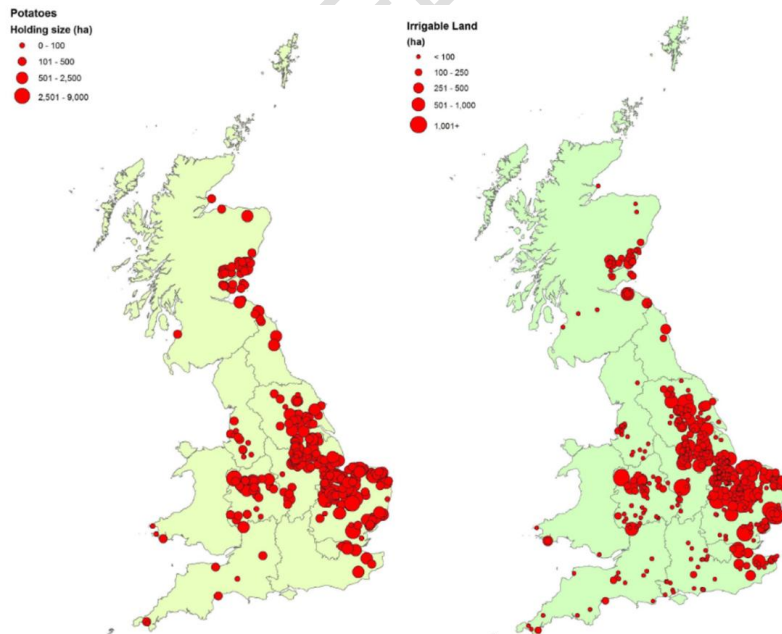
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DEFINITIONS, ACRONYMS, ABBREVIATIONS

AHDB	Agriculture and Horticulture Development Board
CO ₂	Carbon dioxide
Defra	Department for Environment, Food and Rural Affairs
EE	East of England
SW	South West England
NW	North West England
WM	West Midlands
EW	East Midlands
YH	Yorkshire & Humber
SCT	Scotland
GCM	Global Climate Model
GHG	Greenhouse Gas
Ha	Hectares
IPCC	Intergovernmental Panel on Climate Change
TMAX	Maximum Monthly Temperature
TMIN	Minimum Monthly Temperature
UK	United Kingdom
UKCIP	United Kingdom Climate Impacts Programme 2002
UKCP09	UK Climate Projections 2009
UKCP18	UK Climate Projections 2018

APPENDIX



Appendix 1

*(a) Location and size of Potato Holdings**(b) Location of irrigated land***Source:** AHDB, (2016).

GB region	2013	2014	2015	2016	2017*	2017 % of total area
North East	900	1,000	800	900	900	1
North West	5,800	5,800	5,600	6,100	5,800	5
Yorks & Humber	13,900	14,400	13,600	13,800	15,400	13
East Midlands	16,500	16,800	16,200	15,900	16,600	14
West Midlands	14,700	13,900	12,800	13,500	13,800	11
East of England	32,800	32,300	30,300	31,300	32,300	27
South East	3,200	3,000	2,600	2,800	2,800	2
South West	6,000	5,800	4,900	5,500	5,800	5
Scotland	26,900	26,400	23,600	24,800	25,800	21
Wales	1,600	1,700	1,700	1,700	1,800	1
Grand Total	122,400	121,100	112,000	116,200	120,900	

Source: AHDB. Notes: *2017 provisional data as at November 2017. Please note that totals may not exactly tally due to rounding. Data for 2016 and 2017 has been restated due to improved data availability for the period

Appendix 2: Potato planted area by region (UK) in hectares
Source: AHDB

UNDER REVIEW