PhD Research Proposal

1 Proposal Title

The impacts of climate change and land degradation on global food production.

2 Background and research questions

In 2014, 50% of global cereal production came from just four countries: China, USA, India and Russia (The World Bank, 2016). By 2050, an increased population and changes to diets mean that food production is likely to have to increase by 60% to meet demand (Bruinsma, 2009). A recent OECD/FAO study projected cereal production to increase by 14% in the next decade, principally through yield increases (Table 1).

Yet food production both now and in the future is likely to be adversely affected by two interacting processes that are already established and ongoing. One of these processes is land degradation, which is already having a severe impact on food production in some parts of the world and impeding necessary efforts to close the 'food yield gap' between highly productive agriculture in some countries and much less productive agriculture, on land of similar basic productive land potential, elsewhere. The other is climate change, the effects of which are already beginning to bring about the social and economic instability and damage which climate scientists have been warning of for some years. Further climate change is likely to change crop yields in the future.

Numerous studies have examined the potential impact of climate change on food production. Some are experimental studies, such as the Free Air Concentration Enrichment (FACE) studies that examine the impacts of increased CO_2 and ozone on crop yields within fields. These experiments provide useful data for a range of crop modelling studies. In the IPCC fifth assessment report (AR5), 66 yield impact studies are compared for wheat, maize and rice in temperate and tropical regions (Porter *et al.*, 2014). These studies commonly examine the impacts of drought, temperature changes, and sometimes CO_2 fertilisation. The impact of pests, weeds and disease is not normally considered, despite global yield losses from these, in the absence of crop protection, being estimated at 18%, 34% and 16% (Oerke, 2006). However, a lack of experimental data makes credible modelling in this area very difficult.

Cereal	Yield (t/ha)		Area (Mha)		Production (Mt)	
	Now	2024	Now	2024	Now	2024
Wheat	3.16	3.5	222	226	700	787
Whole grains	3.73	4.1	337	354	1255	1449
Rice	3.04	3.5	162	161	494	564

Table 1. World cereal projections. "Now" is the average 2012–14 and projection for 2024. Source: OECD and FAO (2015, p132).

Despite the number of studies in this area, there are substantial and important gaps in the literature. Many studies consider only a single or a small range of crops, or examine only a single region. Studies tend to examine long-term average yield changes, without considering the impacts on interannual yield variability, which is so important for farmer livelihoods (Dodds, 2010). Adaptation is generally only considered to a limited extent and uncertainties are not normally considered.

Land degradation through loss of top-soil reduces crop water availability and increases nutrient requirements, and leads to increased eutrophication and N_2O emissions. It is not considered in the IPCC AR5, except as a note in a case study of the African Sahel. It was discussed in some detail in an IPCC special report on land use, land use change and forestry in 2000 (Noble *et al.*, 2000), and a new special report on land degradation has recently been announced. In contrast to climate change, there are few assessments of the impact of land degradation outside of Mid-West USA and Sub-Saharan Africa.

The impacts of climate change and the rate and impacts of land degradation could be reduced by adapting existing farming practices. The IPCC defines adaptation as reductions in risk and vulnerability through the actions of adjusting practices, processes, and capital in response to the actuality or threat of climate change (Porter *et al.*, 2014). Actions include changes in the decision environment, such as social and institutional structures, and altered technical options that can affect the potential or capacity for these actions to be realised. Adaptation options that have co-benefits for both land degradation and climate change would be particularly useful.

Adaptation options for land degradation include changing tilling and other crop management practices to conserve topsoil. Adaptation options for climate change could include changing planting dates coupled with optimisation of crop varieties, expansion of cropping activities polewards in regions where low temperature has been a past limitation, improving cultivar tolerance to high temperature, breeding additional drought-tolerant crop varieties, more efficient water delivery systems, improved irrigation technologies such as deficit irrigation, more effective water harvesting, agronomy that increases soil water retention through practices such as minimum tillage and canopy management, agroforestry, increase in soil carbon, and more effective decision support. Diversification of activities is another climate

adaptation option for cropping systems – but while reducing the risk to rural livelihoods, it will reduce overall food production. On average, agronomic adaptation improves yields by the equivalent of ~15-18% of current yields, but the effectiveness of adaptation is highly variable (Porter *et al.*, 2014).

A major Grantham Foundation-funded project, led by Prof Paul Ekins at the UCL Institute of Sustainable Resources and including the US Department of Agriculture (USDA), is examining the impacts of climate change and land degradation on global food production and food security. This PhD research will be integrated into and will contribute to this wider project. A collaboration between the Grantham consortium, the International Institute for Applied Systems Analysis (IIASA) and the Universität für Bodenkultur (BOKU) has been negotiated to support this work, as both organisations have a substantial track record of research in this field. Both organisations are based in Vienna and they have worked closely together in the past.

The aims of this PhD are to:

1. Understand the potential impacts of climate change on interannual cereal yield variability. A dataset of crop yield projections for climate change scenarios has been jointly produced by IIASA and BOKU. The projections cover a long time period for a range of crops. The database has been made available for this project.
2. Examine the potential impacts of land degradation on interannual crop yields in the principal global crop-growing regions, which have been identified by the Grantham project.
3. Identify how the impacts of both climate change and land degradation together compare to the individual impacts of each process, to understand the nature of the interactions between the two processes in the principal global crop-growing regions.
4. Characterise the relative impacts of adaptation options on climate change and land degradation, with a particular focus on identifying options that could substantially reduce the impacts of both climate change and land degradation and climate change.

The focus on interannual yield variability, land degradation and adaptation are all novel aspects of this project that will complement the existing literature.

3 Methodology

Crop models are generally used to examine the impacts of climate change. These complex biophysical models have hundreds of parameters and hence studies tend to only consider a small subset of future scenarios. The EPIC crop model is able to

simulate the growth of a wide range of crops, and has a sophisticated representation of land degradation that has been developed over several decades by the USDA and Texas A&M university (Sharpley and Williams, 1990). This model will be the foundation of this PhD.

IIASA and BOKU have carried out a gridded assessment of the impacts of climate change on several crops for 100,000 global locations using EPIC. This assessment examines the impacts of several adaptation options. They have also carried out some separate runs for Europe that consider the impacts of dynamic land degradation (i.e. where land degradation at the end of each year is used as the starting point for the following year, rather than being reset).

IIASA and BOKU have made the results database available to the project team. Interannual yield variability has not previously been examined using this database. The potential impacts of climate change on yield variability will be examined through statistical analyses. This will require the development of some sophisticated analysis routes using software such as Python or R. This work will initially be carried out at IIASA, in order to understand the structure of the database and the underlying decisions in the modelling runs.

A similar analysis will be carried out on the dataset for land degradation impacts. It is likely that additional crop model runs will be required to fully investigate this research question. IIASA and BOKU have indicated that the underlying EPIC modelling system and climate data will be made available as part of the collaboration; if not, then they could be obtained from Texas A&M University. In either case, the representation of land degradation will be further developed by a PDRA at the USDA who is employed by the wider Grantham project. Downscaled climate and weather data for the modelling will similarly be produced by the wider Grantham project, where necessary.

The relative impacts of land degradation and climate change can be examined using the same crop modelling system. The analysis will use dynamic land degradation modelling. Crop yields across the principal regions will be aggregated to produce regional production projections in the major global cropping areas. This information will be given to the econometric and macro-economic modelling teams of the Grantham project for further analyses. The PhD student will therefore experience a much wider research project.

Adaptation options will be initially assessed from the database that has already been created, and further model runs will be performed to assess other adaptation options that are considered potentially important. These will be identified once the initial database analyses have been carried out.

This research will build on and complement my Masters research project, based at the University of Nebraska, where I examined historic interannual yield variability of corn across the State using a crop model.

4 Supervisory team

The principal supervisor will be XXXX of the UCL Institute of Sustainable Resources, who's PhD examined interannual yield variability as a function of weather and climate change in West Africa.

The secondary supervisor will be XXXX of the UCL Energy Institute, who is an expert in climate change models and data.

XXXX of the US Department of Agriculture has also agreed to supervise the PhD in an honorary capacity, and it is likely that a fourth advisor will be appointed from IIASA or BOKU as appropriate.

5 Potential publications

During the course of the studies, there is scope for papers on at least: (i) the impact of climate change on regional interannual crop yields and global food production; (ii) the impact of land degradation on regional interannual crop yields and production; (iii) the relative importance of and interactions between climate change and land degradation for regional food production; (iv) adaptation options with co-benefits for land degradation and climate change.

6 Proposed Timetable

Proposals for the key dates are:

- Start – August 2016
- Upgrade report – July 2017
- Second year report – July 2018
- Paper submission – May 2017 (initial database analysis) and February 2019
- Thesis submission – July 2019

A Gantt chart of the expected activities is shown below.

	Year one						Year two						Year Three					
Literature review																		
1. Database analysis: climate change																		
2. Database analysis: land degradation																		
3. EPIC model system development																		
4. Land degradation and climate change																		
5. Adaptation options analysis																		
Conference and paper writing																		
Write up thesis																		

7 REFERENCES

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