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Modelling the production impacts of a widespread conversion to organic agriculture in England and Wales

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ABSTRACT

We assess the production impacts of a 100% conversion to organic agriculture in England and Wales using a large-scale linear programming model. The model includes a range of typical farm structures, scaled up across the available land area, with the objective of maximising food production. The effects of soil and rainfall, nitrogen (N) supply/offtake and livestock feed demand are accounted for. Results reveal major reductions in wheat and barley production, whilst the production of minor cereals such as oats and rye increase. Monogastric livestock and milk production also decreased considerably, whilst beef and sheep numbers increased. Vegetable production was generally comparable to that under conventional farming. Minimising the area of fertility building leys and/or improving rates of N fixation increased the food supply from organic agriculture at the national level. The total food output, in terms of metabolisable energy, was 64% of that under conventional farming. This would necessitate substantial increases in food imports, with corresponding expansion of cultivated agricultural land overseas. Significant changes in diet and reductions in food waste would be required to offset the production impacts of a 100% conversion to organic farming.

1. Introduction

The continuing expansion and intensification of global agriculture presents a clear need to develop modes of production that can supply sufficient amounts of food for growing populations with more efficient use of resources (Godfray et al., 2010). At the same time there is a pressing need to move populations of western countries towards more balanced diets to promote public health, with particular regard to increasing the share of fresh fruit and vegetables in the diet (Macdiarmid et al., 2011; Wellesley et al., 2015). Organic farming has the potential to contribute to developments in the first of these areas through a focus on reduced input intensity and the maintenance or enhancement of ecosystem functions and various studies have identified and quantified the benefits of organic production, in areas such as fossil-energy use, biodiversity and on-farm employment (Lampkin et al., 2015). The significantly higher soil carbon sequestration rates observed in organically managed soils have also led to suggestions that wider use of this production system could help to delay the onset of damaging climate change (Gattinger et al., 2012) although others have noted that these benefits would be offset by the requirement to increase the area of land in agricultural production to meet food demand (Leifeld et al., 2013). The benefits provided by organic agriculture in areas such as soil protection and rural development also align with the dimensions of sustainability proposed by the United Nations following Rio + 20 through the Sustainable Development Goals (SDGs) and EU action plans such as the Biodiversity Strategy (European Commission, 2010) and Soil Thematic Strategy (European Commission, 2006).

While acknowledging these sustainability benefits and the potential for further growth in the market for organic products (Willer and Lernoud, 2016) some commentators (for example Connor, 2008) have suggested that the lower yields observed in organic agriculture would mean that widespread conversion to organic production could be detrimental to food security. Because the land area devoted to organic farming globally currently remains very small (i.e. organic farmland constitutes approximately 1% of the total global agricultural area, Willer and Lernoud, 2016), it is also difficult to extrapolate from this low baseline to assess the impacts of much larger scale adoption.

Despite this limitation, a few studies have attempted to explore the production and food security impacts of a widespread conversion to organic farming, the most recent of which, with a focus on the UK, was undertaken in 2009 by Jones and Crane. In this study, two different approaches were used to estimate how much food might be produced

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under an assumed 100% organic conversion of agriculture in England and Wales. The results indicated that full organic conversion would lead to major reductions in wheat, barley, and oilseed rape production. Pig and poultry numbers would also fall markedly, while there would be significant increases in the production of minor-cereals (e.g. oats, rye) and ruminant livestock. Although the Jones and Crane (2009) study projected credible trends, levels of production were not adjusted in line with N availability (i.e. the nitrogen availability constraints that impact organic farming, Berry et al., 2002). Feed availability and the nutritional requirements of livestock were also not assessed in detail. Prior to this 2009 study, Badgley et al. (2007) assessed the implications of a 100% conversion to organic production at the global level using FAO-derived data. Organic yield adjustment coefficients (i.e. organic versus conventional) were estimated for 10 groups of crops and livestock products, based on a review of 293 studies drawn from the peer-reviewed literature. Badgley et al. (2007) estimated the average organic yield ratio for all crop types at the global level as 1.32 (i.e. organic would produce 132% of the conventional yield). In the Badgley et al. (2007) study the total N supplied by leguminous cover crops in organic systems was estimated to be 140 million Mg which, according to the study authors "is 58 million Mg greater than the amount of synthetic N currently in use". The authors therefore suggest that the rates of biologically fixed N under widespread organic conversion could support yields equivalent to high-yielding conventional agriculture. Although the Badgley et al. (2007) study included estimates of N availability, the authors base these on the erroneous assumption that 100% of arable land could accept an additional legume crop, following the main crop in the same year. In making this assumption, the authors failed to account for the fact that much of the world's most productive land is already required to carry multiple food crops in a single year to meet food demand. Additionally, no account was taken of areas where climatic conditions and water supplies limit the possibility of a second crop in the same year (Connor, 2008). In consequence of the methodological limitations of recent studies, there is still an absence of reliable data on the food security implications of upscaled organic agriculture.

The study presented here builds on these earlier studies to make a significant contribution to these data needs, through estimating the production and food security impacts of a 100% conversion to organic farming in England and Wales. A modelling approach was adopted that was able to account for yield differences between conventional and organic production, as well as yield variation due to local environmental conditions, plus supply constraints imposed by the availability of N, the need to maintain agronomically rational crop rotations, and the availability of livestock feeds. A multi-scenario approach was adopted to explore the impact of variation in the assumptions underpinning these constraints. In addition, a healthy eating framework developed in the UK was used to assess the ability of a fully organic domestic agriculture to supply optimal human nutritional requirements (i.e. the Eatwell Plate, Macdiarmid et al., 2011)

2. Materials and methods

2.1. The OLUM model

A linear programming model was developed – the Optimal Land Use Model (OLUM) – in the GAMS programming language (GAMS Development Corporation, http://www.gams.com/), to explore the impacts of 100% conversion to organic farming in England and Wales. Fig. 1 summarises the model. At its core is an objective function, Z, to maximise the output of food (expressed as metabolisable energy – ME), defined as:

$$Z = \sum_{ij=0}^{n} \boldsymbol{C_{ij}} \cdot \boldsymbol{x_{ij}} \quad \text{subject to} \quad \boldsymbol{Rx_{ij}} \leq \mathbf{b},\ \boldsymbol{x_{ij}} \geq 0 \tag{1}$$

where C_{ij} is ME output per unit of agricultural products i (i.e. tonnes of crop or livestock product) on soil × rainfall class j, *while* x_{ij} is a scalar, i.e. areas of crops in hectares and numbers of livestock on each soil x rainfall class.Rx_{ij} is the resource (R) requirement for producing enterprises (x_{ij}) and b is the resource endowment and input availability vector. Constraints are specified as linear inequalities and equalities and employed to determine the following:

1. Availability of land by farm type and soil × rainfall class.
2. Maximum and minimum stocking densities (livestock units per ha).
3. Annual feed requirements of different livestock, expressed as metabolisable energy (ME) and crude protein (CP) requirements.
4. Maximum/minimum crop areas by crop groups (i.e. rotation constraints).
5. Soil N availability reflecting cycling of nutrients, plus N inputs and outputs through crop and livestock offtake, atmospheric deposition and biological N fixation.
6. Upper limits on the total permissible production volumes of individual crop and livestock products set at 150% of the current supply, on the assumption that increases beyond this volume could not be absorbed by the market. Evidence suggests that most consumers are unwilling to make major changes to diet (Traill et al., 2008) and this constraint ensured that national levels of production would remain broadly in-line with current dietary choices at a national level, preventing the model from returning unrealistic solutions (e.g. with regard to the over-production of oats and other minor cereals commonly found in organic rotations). Geographical constraints on sugar-beet production were also imposed to restrict the expansion of this crop away from major processing centres in eastern regions.

The components of the model are as follows.

2.1.1. Farm Types

The model's functional units are farms, i.e. production systems consuming various inputs, including land and other resources, to produce multiple crop and livestock outputs. Nine farm types are defined based on the Defra Robust Farm Types (Fig. 2). The mix of enterprises available to each farm type was fixed, although the model was permitted to vary the relative scale of these. This constraint was based on the observation that the dominant enterprises on farms under conventional agriculture is usually maintained post-conversion, because these are the activities that suit existing farm infrastructure and local conditions (Howlett et al., 2002; Langer, 2002).

2.1.2. The land base

Land availability was fixed, at the national level, within NUTS1 region and within farm type. Within each farm type, the allocated land area was fixed at the area observed under each Robust Farm Type in the 2010 Defra June Survey of Agriculture. It was assumed that the total land area under each robust farm type would not change following organic conversion. The land base was disaggregated into 16 classes based on soil type and rainfall (next section). Yield potential was determined for each of these classes. Within each farm type and NUTS1 region, the areas of these 16 land classes were fixed according to their observed spatial distribution.

2.1.3. Land classes

Heavy, medium and light soil classes were specified, each with estimated organic matter content and pH values based on data from long-term organic cropping trials (Smith et al., 2016). A fourth soil class was specified for 'humose', i.e. cultivated soils with an organic matter content and pH typical of the Downholland soil series of the Soil Survey of England and Wales (www.LandIS.org.uk). The spatial distribution of each soil class in 5 km × 5 km grid squares across England and Wales was obtained from the National Soil Inventory (www.LandIS.org.uk). Four rainfall classes were specified, based on 30-year Meteorological