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Short communication

Modelling *Miscanthus* yields with low resolution input data

Mark Pogson

School of Biological Sciences, University of Aberdeen, 23 St Machar Drive, Aberdeen AB24 3UU, UK

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ABSTRACT

A highly simplified model of crop yield is presented for the bioenergy crop *Miscanthus*, based on annual insolation while accounting for drought and frost kill. The method is intended for use with low resolution input data, particularly monthly meteorological data, which most existing models must interpolate to obtain daily data. The simplicity of the method improves tractability of results, reduces computing time, and makes parameterisation and analysis more straightforward. Comparison of the method with an existing energy use efficiency model demonstrates its effectiveness at predicting both mean yields and annual fluctuations.

1. Introduction

Crop growth models are increasingly used to study a variety of issues, including the use of biomass as an energy source and the effects of climate change on food supply (Lobell et al., 2008; Bringezu et al., 2009). Models vary in the level of detail represented depending on the application, resources and – crucially – available information, where lack of input data is often a greater constraint than physiological understanding (Monteith, 1981; Bouman et al., 1996; Smith and Smith, 2007).

The availability of meteorological data up to the global scale for historical and projected climates (Mitchell and Jones, 2005), combined with a developing interest in crop yields over large areas and time ranges, has tended to shift modelling effort from plot-level studies towards wider ranging predictions, which are often based on lower resolution input data (Challinor et al., 2009). Models originally developed for use with higher resolution data are frequently applied using alternative datasets by estimating or interpolating missing input parameters (van Bussel et al., 2011).

Model sensitivity to input data resolution has been considered both spatially (Challinor et al., 2004) and temporally (Adam et al., 2011; van Bussel et al., 2011), demonstrating the importance of tailoring model detail to the quality of available data (Burie et al., 2010). While existing models vary significantly in complexity, the time step used is generally no longer than one day, with few exceptions (Jame and Cutforth, 1996; Brooks et al., 2001). However, meteorological datasets often provide only monthly values, which is longer than both the duration of many important physiological processes and the time step of even the simplest of models.

The widespread use of datasets based on different forms of interpolation and climate projections (Southworth et al., 2000), in addition to uncertainties in best farming practices for different crops in different regions, makes clear the appeal of a simple method to estimate crop yields commensurate with limited information. This paper presents a 'meta-' or 'surrogate' model to predict the distribution of crop yields from meteorological data while avoiding the use of a time step to model growth. The method is applied to *Miscanthus*, a bioenergy crop, and results are compared against MiscanFor©, an existing energy use efficiency model which uses a daily time step. The simplicity of the model is likely to simplify parameterisation and analysis, and reduce sensitivity to input data. Furthermore, by identifying key parameters, the study helps to highlight major climate effects on *Miscanthus* growth.

2. Method

2.1. Overview

The energy use efficiency method of Monteith (1977) is commonly used to model crop growth, providing accurate predictions for most purposes while avoiding explicit consideration of photosynthesis and respiration (Ewert, 2004). Crop growth is calculated in the method according to the efficiency of conversion into biomass from incident radiation, and a daily time step is generally

E-mail address: m.pogson@abdn.ac.uk

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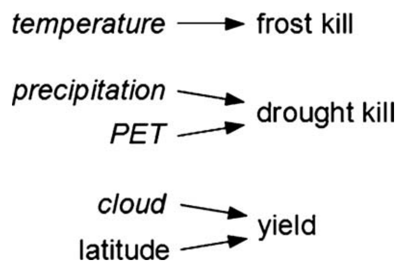

Fig. 1. Diagram of model inputs (meteorological in italics) and their use in the model.

used to estimate leaf formation and hence the fraction of radiation intercepted.

In the present method, leaf formation is not considered explicitly, and annual yields are simply estimated from total insolation. The method is therefore an extreme simplification of the energy use efficiency approach, with leaf area index assumed constant. This approximation is reasonable since light attenuation by the canopy quickly approaches 1 with increasing leaf area index, as described by Beer's Law (Hirose, 2004), and is thus fairly constant for most of the growing season in areas of reasonable yield; the assumption is considered further in Section 4. Such abstraction of detail prevents precise plot-level and intra-annual time-series modelling, but enables a simple estimate of annual yields using comparatively few data inputs.

2.2. Crop calculations

Calculations are performed to estimate annual frost kill, drought kill and yield, as represented in Fig. 1. Meteorological inputs are: fraction cloud cover (C), mean temperature (T), precipitation (P) and potential evapotranspiration (E), which are monthly values obtained from the CRU TS 3.1 dataset (Jones and Harris, 2008). Soil data are not used, and nutrient and water stress are not considered, as discussed in Section 4. Yields are calculated from annual (rather than average) meteorological data, and the yield is set to zero in years where the crop is killed by drought or frost, as with the MiscanFor© model (Hastings et al., 2009a).

Each year, frost kill occurs if the minimum value of T is below a threshold temperature, which is set as $-2\,^{\circ}$C for *Miscanthus*. Drought kill occurs each year if the mean value of P/E is below a threshold ratio, which is set as 1 for *Miscanthus*.

If the crop is not subject to a kill event then the yield is calculated directly from annual insolation. Monthly cloud-free insolation (I_0) is obtained from the latitude and time of year by the method described in the SWAT Theoretical Documentation (Neitsch et al., 2002). Values are rescaled by dividing by the largest annual sum, and monthly insolation (I) adjusted for cloud cover is found as: $I = I_0(1-0.7C)$, thus incident radiation is reduced linearly with cloud cover down to a minimum factor of 0.3. Crop yields are obtained by summing the monthly I values. The maximum possible yield with no cloud would therefore be 1; multiplying the normalised values by the maximum potential yield provides the predicted yields.

2.3. Validation

The present method is tested against the existing model MiscanFor©, which is a development of Miscanmod (Clifton-Brown et al., 2000). Since the purpose of the present method is to simplify estimation of crop yields, it is sufficient to compare it against an existing model rather than field data.

MiscanFor© and Miscanmod have previously been tested in Europe and North America, displaying good agreement with field data (Clifton-Brown et al., 2000, 2004; Khanna et al., 2008; Dondini et al., 2009; Hastings et al., 2009a,b). MiscanFor© uses a daily time step to estimate leaf formation from meteorological and soil conditions; yield mass is estimated by radiation use efficiency, which is adjusted to account for water stress. Drought and frost kill are determined respectively by the number of days with soil water below wilt point and number of days below a set temperature (Hastings et al., 2009a). The CRU TS 3.1 dataset is used to run MiscanFor© for the present comparison, with PET calculated in the model according to the Thornthwaite equation (Thornthwaite, 1948).

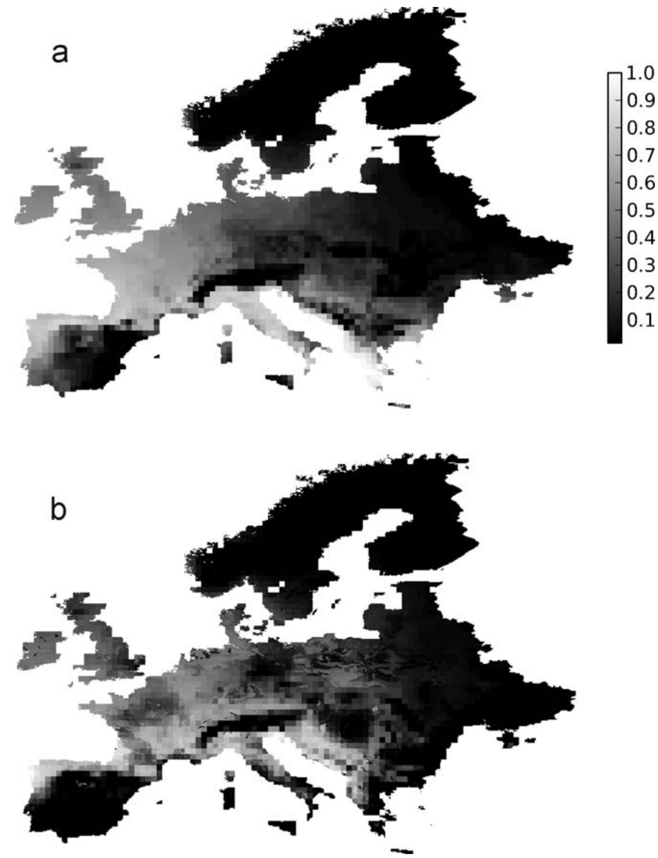

Fig. 2. Normalised yield distribution for the present method (a) and MiscanFor© (b), mean 1960–1990.

Crop yields and annual fluctuations are compared between methods in the present study. Annual fluctuations are represented by the coefficient of variation, which is defined as the standard deviation divided by the magnitude of the mean. Mean crop yields are normalised for both methods to enable straightforward comparison; the present method simply predicts a normalised distribution anyway, which must be multiplied by a maximum expected yield to provide estimates of biomass. Similarity between results is assessed by the correlation coefficient. Results are obtained and analysed for European yields (as presented by Hastings et al. (2009a,b) for MiscanFor© using a previous CRU dataset); correlation between yields in the UK is also considered in order to assess accuracy at different scales.

3. Results

3.1. Mean yield

The distribution of European yields is shown in Fig. 2 for the present method and MiscanFor©, showing normalised mean values in the year range 1960–1990. General agreement between the methods is good, with the effects of frost and drought (in the