Supplement to: JULES-BE: representation of bioenergy crops and harvesting in the Joint UK Land Environment Simulator vn5.1

Emma W. Littleton, Anna B. Harper, Naomi E. Vaughan, Rebecca J. Oliver, Maria Carolina Duran-Rojas, Timothy M. Lenton

S1. *Miscanthus* PFT parametrisation

The *Miscanthus* PFT presented here was developed based on a generic C4 grass in the 9 PFT JULES scheme (Harper et al. 2016), with six parameters taken from Hughes et al. (2010), and nine parameters redefined specifically for this study. A full list of PFT and TRIFFID parameters for all bioenergy PFTs used in this study is given in the Supplementary spreadsheet.

Since the periodic harvest mechanism described in this study harvests from above-ground biomass, the chief focus of PFT tuning has been to improve representation of above-ground biomass (AGB).

Five parameters define the allometry of the PFT, i.e. the relationship between height, leaf area index (LAI), and mass of respective portions of the PFT:

- A_{ws}: ratio of total stem biomass to live stem biomass. For all non-woody plants (defined here as grasses), this ratio is equal to 1, meaning that all stem biomass is alive and respiring.
- A_{wl}: wood-to-leaf scaling parameter relating total stem biomass to LAI.
- *LMA*: Leaf mass per area [kg leaf m^{-2} per unit of LAI].
- B_{wl}: allometric exponent relating stem biomass to LAI.
- Eta_{sl}: Ratio of live stem biomass to LAI.

The scaling of the plant is derived iteratively at each TRIFFID call, beginning with L_b (balanced-growth LAI). Absent of deciduous behaviour, L_b is always equal to actual LAI. L_b is bounded by *lai_min* and *lai_max*, which are defined in TRIFFID parameters.

After L_b is determined at each TRIFFID call, the three PFT biomass components are calculated per Equations (56), (57) and (58) in Clark et al. 2011. All units are kg C m^{-2}.

$$Leaf = L_b \times LMA \times 0.4 \tag{S1}$$

$$Root = Leaf \tag{S2}$$

$$Wood = A_{wl} \times {L_b}^{B_{wl}} \tag{S3}$$

$$Cveg = Leaf + Root + Wood \tag{S4}$$

$$AGB = Leaf + Wood \tag{S5}$$

PFT height, *canht*, is related to wood biomass as per Eq. (61) in Clark et al. 2011:

$$canht = \frac{Wood}{A_{ws} \times Eta_{sl}} \times \left(\frac{A_{wl}}{Wood}\right)^{1/B_{wl}} \quad \text{(S6)}$$

Using the equation above for relating *Wood* to *Lb*, this simplifies to:

$$canht = \frac{a_{wl} \times {L_b}^{b_{wl}-1}}{a_{ws} \times \eta_{sl}} \quad \text{(S7)}$$

Above-ground biomass thus relates to L_b:

$$AGB = a_{wl} \times {L_b}^{b_{wl}} + L_b \times LMA \times 0.4 \quad \text{(S8)}$$

In tuning this PFT, *LMA* was fixed at 0.065 kg m^{-2} (Feng et al. 2012), and A_{ws} fixed to 1 in common with other "non-woody" PFTs. The remaining free parameters therefore are A_{wl}, B_{wl}, and Eta_{sl}. The default values for C4 grasses are A_{wl}=0.005, B_{wl}=1.667, and Eta_{sl}=0.01.

Height:AGB, Height:LAI, and Height:(stem proportion of AGB) were calculated using a range of values for A_{wl}, B_{wl}, and Eta_{sl}, a total of 600 parameter combinations.

- A_{wl}: 0.01-0.1 in increments of 0.01
- B_{wl}: 1.333-3 in increments of 0.333
- Eta_{sl}: 0.01-0.1 in increments of 0.01

Observed height:AGB relationships were combined from Cosentino et al. (2007), Jezowski et al. (2011), and Christian et al. 2008 (n=57). Height:LAI relationships were taken from the Lincolnshire site (Fig. 2) (n=15) (Robertson et al, 2016, 2017). Height:stem proportion observations were taken from Cosentino et al. (2007) (n=18). Where two y-values (AGB, LAI or stem%) were given for the same height, the mean of the y-values was taken for that height. The given sample sizes already reflect the mean of repeated x-values. Stem proportion is calculated as (wood)/(AGB) at harvest time.

These relationships (height:AGB, height:LAI, height:stem proportion) were compared against observations, and the root mean square error (RMSE) calculated for each of the parameter combinations for each relationship.

Five "cases" were selected from the 600 parameter combinations, representing the lowest combined RMSE; the lowest combined RMSE of AGB and LAI (prioritised for accuracy over stem proportion); and the lowest RMSE from each of AGB, LAI, and stem proportion independently. Figure S1 shows how height relates to AGB, LAI, and stem proportion under each of these cases. Case 1 was selected as the parametrisation that provides the best fit to AGB while providing reasonable values for LAI and stem proportion.

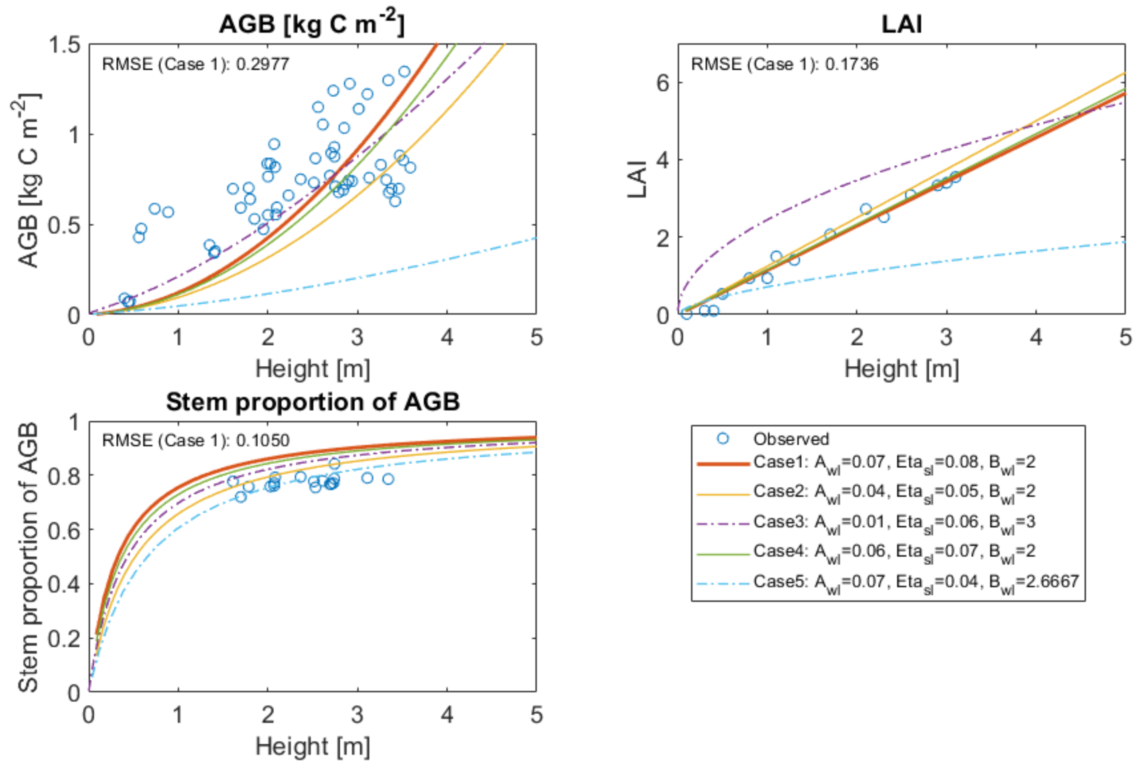

Figure S1. Fitting of allometric parameters A_{wl}, Eta_{sl} and B_{wl} to observations of aboveground biomass (AGB), leaf area index (LAI) and stem proportion of aboveground biomass. AGB observations are combined from Christian et al. (2008); Cosentino et al. (2007); Jezowski et al. (2011). LAI observations are collected from the Lincolnshire site (Robertson et al. 2016/7). Stem proportion observations are from Cosentino et al. (2007).

Gross primary productivity, respiration and litter production

Canopy assimilation depends on three limiting rates of leaf photosynthesis. For C4 plants, these are a light-limited rate, a limitation from PEPCarboxylase, and a Rubisco-limited rate (Collatz et al., 1992;Clark et al., 2011). With adequate light, the maximum rate of carboxylation of Rubisco (V_{cmax}) limits photosynthesis. The V_{cmax} is a bell-shaped function of canopy temperature, dependent on PFT parameters T_{upp} and T_{low}, and the standardised value of V_{cmax} at 25°C ($V_{cmax,25}$), which is modelled as a linear function of leaf N per unit area (N_{area}):

$$V_{cmax,25} = V_{int} + V_{sl} \times N_{area} \qquad \text{(S9)}$$

Where

$$N_{area} = LMA * N_{mass} \qquad \text{(S10)}$$

N_{mass} is the leaf N per unit mass (kg N (kg leaf)$^{-1}$). For C4 grasses, the default values of LMA, N_{mass}, T_{upp} and T_{low} are 0.137, 0.0113, 45 and 13, respectively, which yield an optimal V_{cmax} of 74 µmol CO_2 m^{-2} s^{-1} at 41°C.

Plant nitrogen content affects the gross primary productivity (GPP), plant respiration, and therefore total biomass (C_{veg}). Values for N_{mass} (kg N (kg leaf)$^{-1}$), N_r (N:C ratio of roots) and N_{sw} (N:C ratio of stem wood) were determined for *Miscanthus* using values from BETYdb (LeBauer et al., 2018), and assuming carbon concentration of dry biomass of 40 % for leaves and roots (hardcoded in JULES for all PFTs) and 48 % for stems (after Baxter et al., 2014). The value of T_{low} was tested iteratively against GPP measurements at the Lincolnshire site from 2008-2012 until further iterations failed to reduce the root mean square error. New values of *LMA*, N_{mass}, and T_{low} (0.065 kg m^{-2}, 0.0217 kg kg^{-1} and 12.8 °C, respectively) resulted in a lower optimal V_{cmax} of 67 µmol CO_2 m^{-2} s^{-1} at 41°C.

N_r and N_{sw} were changed from 0.0084 and 0.0202, respectively, (default values for C4 grasses) to 0.0228 and 0.0101. These changes (along with the increased Eta_{sl}) result in slightly higher root N and stem N that is four times higher than for C4 grasses. In other words, the larger woody content of *Miscanthus* comes at a cost in terms of the maintenance respiration, since in JULES maintenance respiration is a function of plant N content (Harper et al., 2018b).

The leaf turnover rate, *gleaf_0*, represents mean lifetime in years of a leaf absent of any climate-deciduous behaviour. Observations from Amougou et al. (2012) revealed cumulative leaf litter of 13–15 % as much as above-ground biomass at harvest time. Absent deciduous behaviour, leaf litter production is linearly correlated to LAI, but *gleaf* is only one of the factors; the equation is:

$$leaf_{litc} = gleaf \ \times LMA \times LAI \times 0.4 \tag{S10}$$

$$LAI = \frac{leaf_{litc}}{gleaf \times LMA \times 0.4} \tag{S11}$$

$$AGB = a_{wl} \times \left(\frac{leaf_{litc} \times 0.4 \times LMA}{gleaf}\right)^{b_{wl}} + \frac{leaf\_litc}{gleaf} \tag{S12}$$

Given the values above for a_{wl}, LMA, b_{wl}, Eq. (S12) simplifies to:

$$AGB = 0.07 \ \times \left(\frac{leaf_{litc} \times 0.026}{gleaf}\right)^{2} + \frac{leaf_{litc}}{gleaf} \tag{S13}$$

gleaf was adjusted iteratively until annual *leaf_litc* at the Lincolnshire site reached 15 % of AGB at harvest, at *gleaf* = 2.

S2. Response of *Miscanthus* yield to climatic variables in model and observations

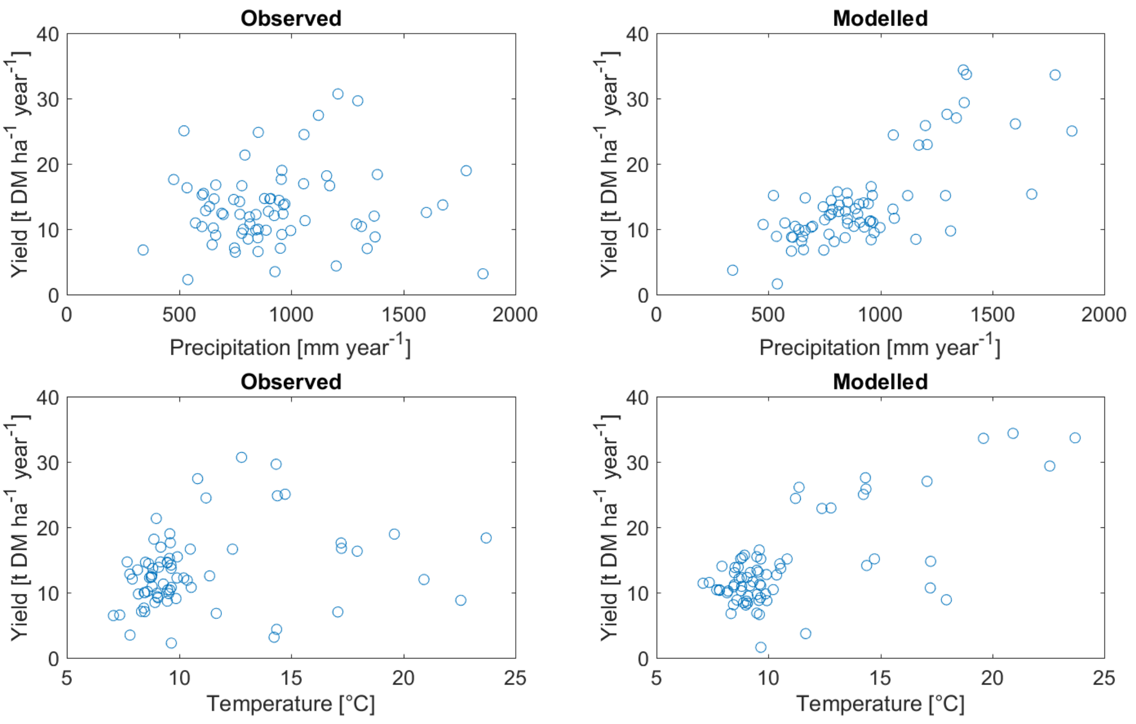

Figure S2. Relationship of observed (left) and modelled (right) *Miscanthus* yields to mean annual precipitation (top) and mean annual temperature (bottom). Precipitation and temperature were both derived from WATCH meteorological forcing data over the model simulation period (1980–1999).

S3. Growth characteristics for *Miscanthus* and C4 grass

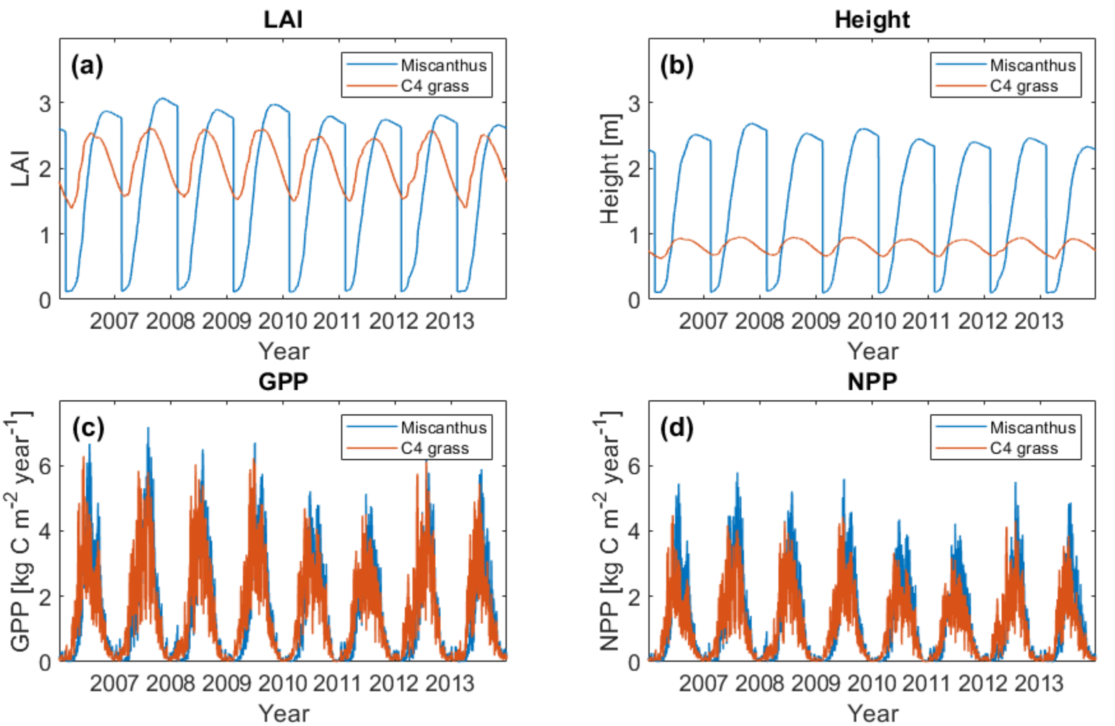

Figure S3: Modelled leaf area index (LAI), height, gross primary productivity (GPP) and net primary productivity (NPP) for the Miscanthus PFT compared to the generic C4 grass PFT, over the period 2006-2013 at the Lincolnshire site.

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