Simulating the growth dynamics of afforestation species under climate change impacts in Northern Benin

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1. Introduction

- The on-going environmental changes (e.g. degradation of forests and croplands, increase in temperature and rainfall variability) in the semi-arid zone of West Africa require adequate mitigation and adaptation measures such as a rehabilitation of degraded farmlands with well-adapted multi-purpose tree species (Fig. 1). This will concurrently enhance agro-ecosystem resilience and improve rural livelihoods.
- As climate change and land degradation can mutually drive or intensify each another, targeted afforestation efforts must account for future changes in climatic conditions, necessitating knowledge on the impacts of climate change on forest/tree growth to support land use planning.

2. Objective

- To predict growth of promising woody species for afforesting degraded croplands (*Jatropha curcas* L. and *Leucaena leucocephala* Lam., Fig. 2) in the Sudano-Sahelian zone of Benin using the Water, Nutrient and Light Capture in Agroforestry Systems (WaNuLCAS) model.

Fig. 1 Transition from a bare, degraded cropland to afforested land in Northern Benin

Fig. 2 The two woody species used in the afforestation trial in Northern Benin

3. Materials and methods

Description of WaNuLCAS model

- WaNuLCAS is a tree-soil-crop interaction model suitable for agroforestry systems and parametrized for a 4-layer soil profile and 4 spatial zones (Fig. 3). The model runs with daily time steps.
- Tree/crop growth is conditioned by light (aboveground resource), as well as water and nutrient (N&P) availability (belowground resources).

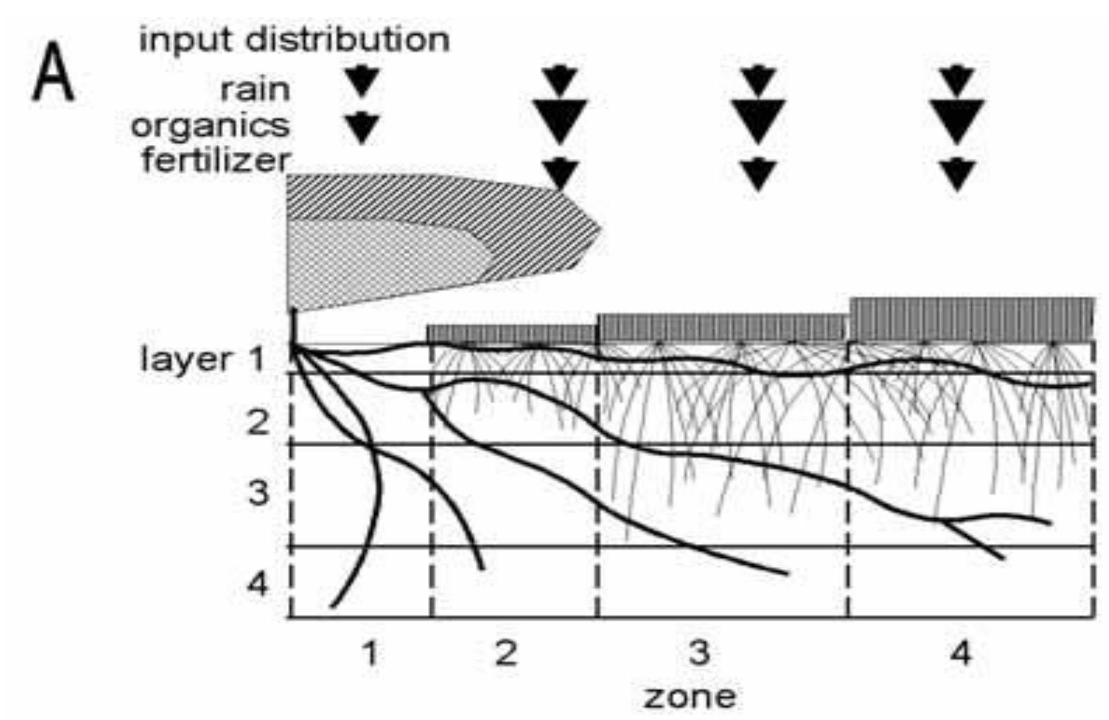

Fig. 3 General layout of zones and layers in the WaNuLCAS model (Source: van Noordwijk et al. 2011)

Input data for WaNuLCAS setup & tree growth simulation

- **Climate data:** daily rainfall, soil temperature and evapotranspiration (for the weather module).
- **Soil data**: a "pedotransfer" function was used to generate soil hydraulic parameters.
- **Tree parameters**: aboveground biomass (AGB), crown width and height, specific leaf area, growth rate etc. were calibrated to match simulated and empirical values.
- **Biophysical data** for simulations stem from a 2-year-old afforestation trial in Dassari basin of Northern Benin. Planted were *J. curcas* and *L. leucocephala* in pure-species plots with an initial density of 5000 trees ha^{-1}.
- Manuring (7.7kg m-2) and supplement irrigation (72.5mm tree^{-1}), with 2 levels each (no application and application), were applied. Tree growth data were collected 3 times (Fig. 4).
- WaNuLCAS was calibrated with trees grown under stress free conditions (Fig. 5). Validation with data from the other treatments.
- Model performance was evaluated based on statistical indicators (Fig. 5, Table 2).

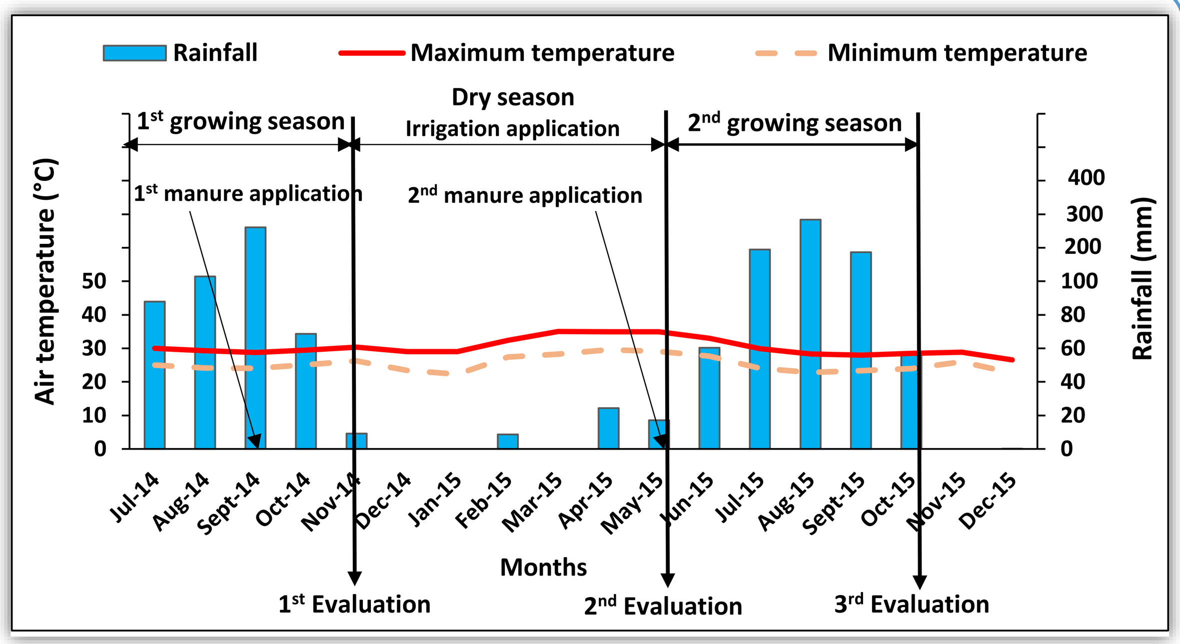

Fig. 4 Seasonal temperatures and rainfall during 2014 and 2015 and timing of manure and irrigation applications and plant trait evaluation (Noulèkoun et al. 2017)

4. Key results

- A significant linear relationship between model estimates and empirical data, but a moderately good fit (Fig. 5). The model still captured well the seasonal dynamics of tree growth.
- The lack of fit was caused by the poor reproducibility of biomass loss due to litterfall and the shrinkage of the diameter (D) in the dry season, resulting in an overestimation of D and aboveground biomass (AGB) (Table 1). Hence, the mechanisms of litterfall in the model needs to be fine-tuned.
- Model validation with independent data-sets (C, F and I treatments , Table 2) allowed for an accurate model calibration.

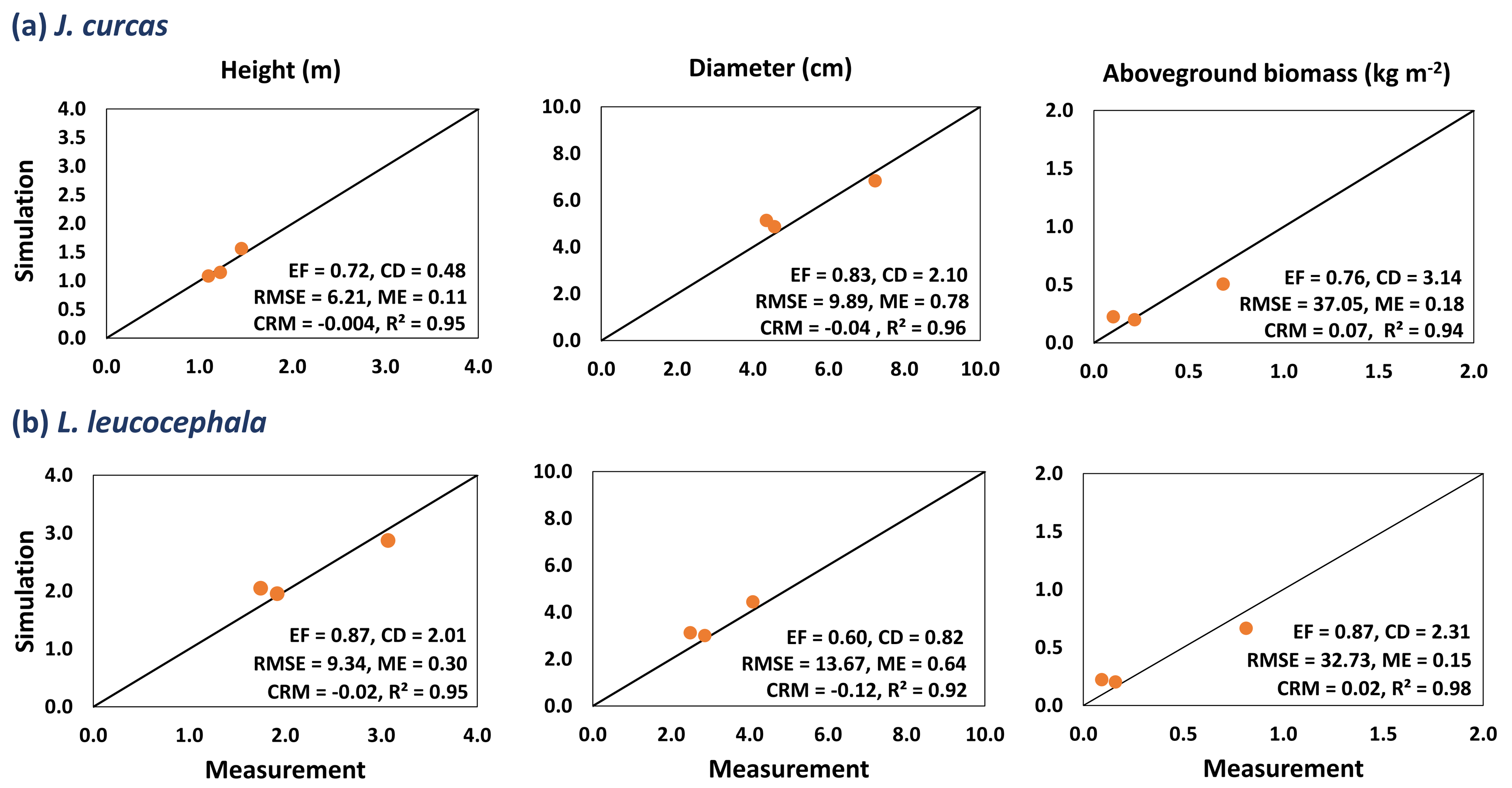

Fig. 5 Relationships between simulated and observed values of height, stem diameter and aboveground biomass for *J. curcas* and *L. leucocephala* during calibration along with the evaluation criteria. The data from irrigation plus fertilization (IF) treatment were used. The lines are the 1:1 lines.

Table 1 Increment in stem diameter (D, m) and aboveground biomass (AGB, kg m^{-2}) during the dry season for the control (C), fertilization (F), irrigation (I) and fertilization + irrigation (IF) treatments. Both measured (M) and simulated (S) values are presented.

Parameters	Treatments	*J. curcas*		*L. leucocephala*	
		M	S	M	S
D	C	0.13	0.18	0.47	0.08
	F	-0.24	0.21	-0.01	0.10
	I	0.06	0.18	-0.15	0.08
	IF	-0.22	0.29	-0.37	0.13
AGB	C	-0.09	-0.02	0.01	0.00
	F	-0.13	-0.01	-0.04	0.01
	I	-0.08	0.01	-0.04	0.01
	IF	-0.11	0.03	-0.07	0.03

5. Conclusion and outlook

- All assessment criteria used (R^2>0.5, CD between 1.2-4.6, EF close to 1, CRM close to 0) point at a successful calibration rendering the model suitable for simulating climate change scenarios.
- Further simulations will thus include (i) predicting climate change impacts on early growth and development of trees, (ii) identifying growth-limiting factors under future climatic conditions and (iii) exploring management options for an improved and sustainable (re)afforestation

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Table 2 Results of the models validation with the dataset from the control (C), fertilization (F) and irrigation (I) treatments based on the criteria suggested by Loague and Green (1991).

Species	Parameters (Optimum value)	EF (1)	CD (1)	RMSE (0)	CRM (0)	ME (0)	R^2 (1)
J. curcas	Height (m)	**0.91**	**1.37**	**3.93**	**-0.01**	**0.10**	**0.93**
	Diameter (cm)	**0.71**	3.17	10.51	**-0.04**	0.78	**0.95**
	Aboveground biomass (kg m^{-2})	**0.74**	3.70	32.93	**-0.01**	**0.14**	**0.94**
L. leucocephala	Height (m)	**0.71**	3.42	13.20	**0.02**	0.64	**0.89**
	Diameter (cm)	**0.69**	3.27	15.61	**-0.03**	0.86	**0.84**
	Aboveground biomass (kg m^{-2})	**0.71**	2.98	49.76	**0.07**	0.34	**0.83**

EF: model efficiency; CD: coefficient of determination; RMSE root mean square error; CRM coefficient of residual mass; ME: maximum error; R^2: coefficient of determination of linear regression between observed and simulated values.