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IMPROVING REMOTE SENSING DERIVED DRY MATTER PRODUCTIVITY BY REFORMULATING THE EFFICIENCY FACTORS: CASE STUDIES FOR WHEAT AND MAIZE

Yetkin Özüm Durgun[1,4*], Sven Gilliams[1], Bakary Djaby[2**], Gregory Duveiller[3**], Bernard Tychon[4**]**

[1] Flemish Institute for Technological Research (VITO), Centre for Remote Sensing and Earth Observation Processes, Belgium
[2] MESA, AGRHYMET Regional Centre, Niger
[3] European Commission - Joint Research Centre, Institute for Environment and Sustainability, Italy
[4] University of Liège, Department of Environmental Sciences and Management, Belgium
[*]Corresponding author: ozuem.durgun@vito.be
[**]Thesis supervisors

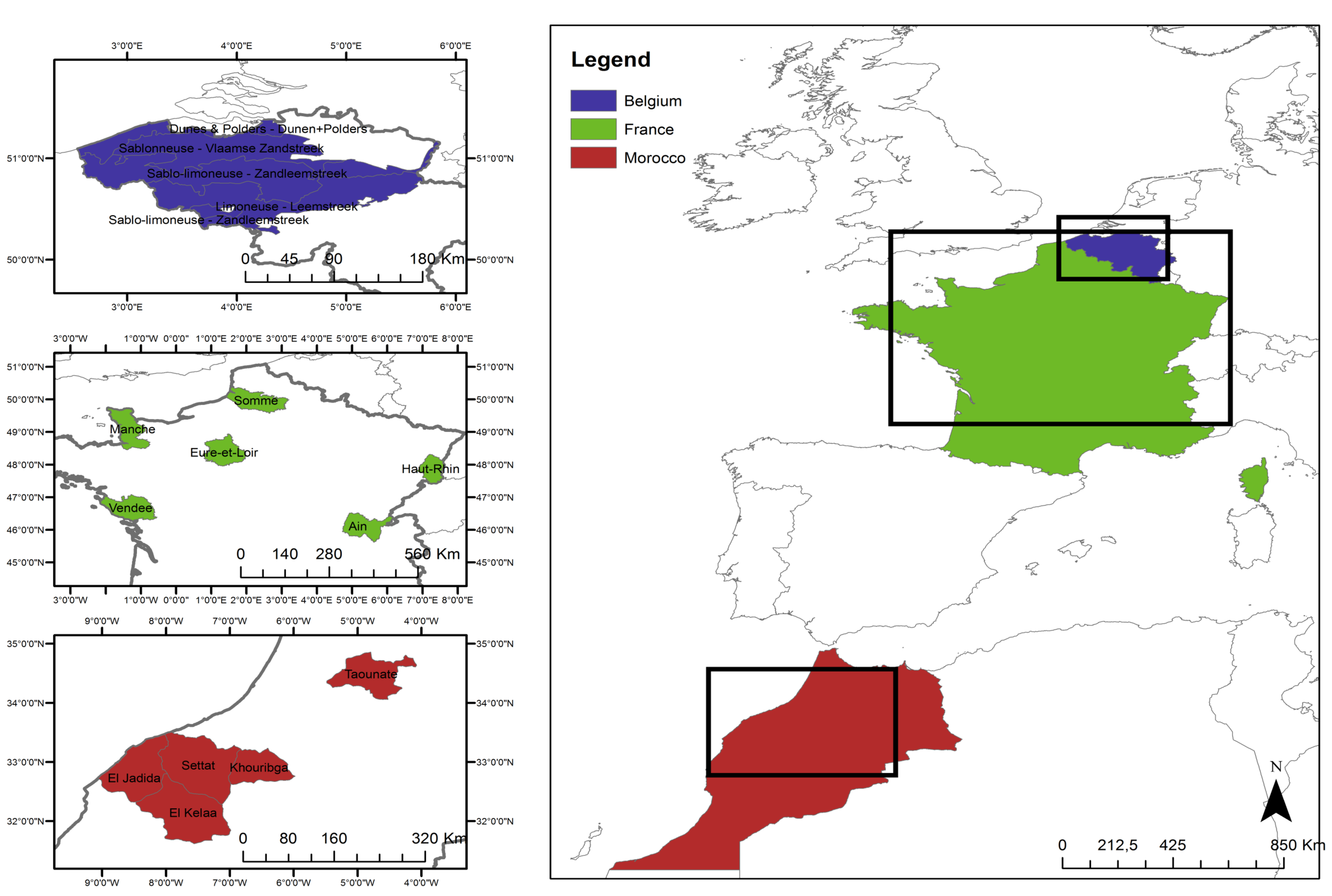
Introduction

The theory of Monteith suggests that growth in biomass is calculated from intercepted solar radiation and the radiation use efficiency (RUE) with which energy is converted into dry matter. RUE is constant for crops unless the growth is limited by water or adverse climatic conditions. Based on the Monteith approach, the Remote Sensing research unit of VITO has started to produce Dry Matter Productivity (DMP) estimates on a regular basis since 2000. The current product does not have a water stress factor. This study presents the improvement of this remote sensing derived product. DMP has been recalculated by different combinations of three stress factors: CO_2 fertilisation effect, temperature and water stress. An empirical model has been applied to evaluate the relation between DMP and crop yield statistics. The model performance is assessed based on several statistical methods.

Data and Methods

Study Sites

The study regions have been selected from different climatic regimes: Belgium, France and Morocco.



Remote Sensing Data

DMP is formulated as

$$DMP = (R * \varepsilon_p * fAPAR) \times (\varepsilon_{RUE} * \varepsilon_T * \varepsilon_{CO2} * \varepsilon_{AR} * \varepsilon_{H2O})$$

TERM		MEANING	VALUE	UNIT	SENSOR
DMP		Dry Matter Productivity	0-320	kgDM/ha/day	SPOT VGT
R		Total shortwave incoming radiation (0.2 – 3.0µm)	0-320	GJ/ha/day	ALTERRA
ε_p		Fraction of PAR (0.4 – 0.7µm) in total shortwave	0.48	J/J	-
fAPAR	smoothed fAPAR	PAR-fraction absorbed by green vegetation	0-1	J/J	SPOT VGT
ε_{RUE}	$\varepsilon_{RUE\,C3}$	Radiation use efficiency for C3 crops at optimum	3.11	kgC/GJ	-
	$\varepsilon_{RUE\,C4}$	Radiation use efficiency for C4 crops at optimum	4.44		
ε_T		Normalized temperature effect	0-1	-	ALTERRA
ε_{CO2}		Normalized CO2 fertilization effect	0-1	-	ALTERRA
ε_{AR}		Fraction kept after autotrophic respiration	0-1	-	ALTERRA
ε_{H2O}		Water stress factor (WSF)	0-1	-	METEO

Changes in the new formula:

- **C_3** and **C_4** specific maximum RUE values have been used.
- **Yearly variable CO_2** value has been used for the CO_2 fertilisation effect.
- **Water stress factor** (ε_{H2O}) has been added as
  $0.5 + 0.5 * ET_{ACT} / ET_C$ (described as in CASA model)
  where ET_{ACT} is actual evapotranspiration calculated in AgroMetShell (FAO Water Balance Model), and ET_C is crop evapotranspiration and calculated as
  $ET_C = K_C \times ET_{POT}$
  where K_c is crop coefficient and ET_{POT} is the evapotranspiration rate from a hypothetical grass reference crop.

Yield Statistics

Official yield statistics of forage maize and winter wheat were collected from national statistical service at regional level.

Linear Regression

A single linear regression between different versions of DMP cumulated over an optimal temporal window and actual yield statistics has been calculated for the 1999-2012 period. Temporal window was defined by an initial and final dekad within the growing season of winter wheat and fodder maize.

Results

Several versions of DMP have been computed and compared taking into account CO_2 fertilisation effect, temperature and water stress factors. The model performance is assessed based on the coefficient of determination (R^2), the root mean square error (RMSE), the relative RMSE (RRMSE) and the index of agreement of Willmott (*d*). Additionally *p-value* is given to assess whether the results are significant. The results are presented for both modified and original DMP (Table 1).

Table 1

			R^2		RMSE (kg/ha)		RRMSE (%)		*d*		*p*	
			DMP(Mod)	DMP(Ori)	DMP(Mod)	DMP(Ori)	DMP(Mod)	DMP(Ori)	DMP(Mod)	DMP(Ori)	DMP(Mod)	DMP(Ori)
Wheat	BE	Dunes-Polders	0.72	0.61	372.07	790.27	4.22	8.97	0.91	0.77	<0.01	<0.01
		Loamy	0.56	0.47	2395.80	2589.56	27.14	29.34	0.20	0.19	<0.01	<0.01
		Sandy	0.70	0.45	3094.16	1408.97	39.39	17.94	0.22	0.41	<0.01	<0.01
		Sandy-loamy	0.74	0.60	2587.18	2880.47	30.37	33.82	0.27	0.25	<0.01	<0.01
	FR	Eure-et-Loir	0.57	0.30	820.29	6576.19	10.55	84.54	0.63	0.13	<0.01	0.04
		Somme	0.58	0.40	1828.33	930.75	21.22	10.80	0.35	0.59	<0.01	0.01
	MAR	El-Jadida	0.78	0.56	295.47	462.01	16.94	26.48	0.91	0.72	<0.01	<0.01
		El-Kelaa	0.89	0.58	291.39	431.73	30.07	44.56	0.92	0.76	<0.01	<0.01
		Khouribga	0.79	0.63	330.44	380.91	44.91	51.77	0.86	0.77	<0.01	<0.01
		Settat	0.83	0.76	346.18	505.74	31.22	45.60	0.90	0.71	<0.01	<0.01
		Taounate	0.71	0.75	473.17	495.62	33.64	35.23	0.81	0.76	<0.01	<0.01
Maize	FR	Ain	0.62	0.34	3425.57	11135.28	26.42	85.89	0.49	0.17	<0.01	0.03
		Haut-Rhin	0.53	0.51	7306.70	8753.56	45.69	54.73	0.28	0.24	<0.01	<0.01
		Manche	0.56	0.36	4416.29	827.60	31.71	5.94	0.24	0.63	<0.01	0.02
		Vendee	0.63	0.46	4746.09	1814.51	40.33	15.42	0.34	0.59	<0.01	<0.01

Table 2

			Stress Factor		
			CO_2	Temp	H_2O
Wheat	BE	Dunes-Polders	-	-	-
		Loamy	✓	-	✓
		Sandy	✓	-	-
		Sandy-loamy	✓	-	-
	FR	Eure-et-Loir	✓	-	✓
		Somme	✓	✓	–
	MAR	El Jadida	-	✓	✓
		El Kelaa des Sraghna	-	✓	✓
		Khouribga	-	✓	✓
		Settat	-	✓	✓
		Taounate	-	✓	✓
Maize	FR	Ain	✓	✓	✓
		Haut-Rhin	✓	✓	✓
		Manche	✓	-	-
		Vendee	✓	-	✓

For all study sites on average there is an improvement of 37 % in R^2 and 35% in *d , and* decrease of 30 % in (R)RMSE. Based on the results of these several statistical methods one DMP version has been selected per study region (Table 2). Each study region is sensitive to different stress factors except Morocco where the best results have been obtained always with temperature and water stress factors.

Conclusions and Limitations

- Using combination of different stress factors in DMP model has a strong potential to improve the DMP product itself and as a result it can be used in the crop yield estimates.
- Water stress factor has been introduced to DMP in this study. In general it improves the correlation between DMP and crop yield.
- The inter-annual variability of the official yield is low in Belgium and France.
- Crop specific map was not available.

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