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Application note

A multi-approach software library for estimating crop suitability to environment

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ABSTRACT

The assessment of crop biophysical suitability to agro-environmental conditions is a valuable component of crop production studies, especially when evaluating productivity potential of new crops and areas, or for the assessment of potential cultivation shifts and crop adaptation needs under climate change scenarios. The software component Suitability presented herein implements several published approaches for computing crop suitability, based on available climate, soil and crop information. Users can access the *Suitability* software component via two application programming interfaces for single- and multi-cell estimations, the latter based on multiple regression methods. The component, extensible by third parties, is released as .NET 3.5 DLL, thus targeting the development of .NET clients. A case study on wheat suitability in Morocco is also presented.

1. Introduction

Evaluating crop suitability – i.e., how agro-environmental conditions control establishment and growth of specific crop species and their cultivars – is a valuable component of agro-ecological assessment studies (e.g., Ceballos-Silva and López-Blanco, 2003), allowing for the assessment of potential productivity of crops under a variety of current or future conditions, including changes to crops geographic distribution under climate change (Hood et al., 2006). Soil type and climatology, in particular local thermo-pluviometric regimes (Jing-Song et al., 2012), determine overall crop productivity; suitability assessments thus help identify production potential under specific conditions, including those associated with different management choices – such as fertilization and irrigation amounts or with a range of projected climate scenarios – which may drive crop cultivation towards higher latitudes (e.g., Jarvis et al., 2008). In this context, different criteria have been proposed for evaluating crop suitability to environmental conditions, ranging from simple approaches based on temperature and precipitation during the growing season (e.g., Woodward, 1987) to complex criteria requiring a variety of information on climate, soil chemistry, soil physics, etc. (e.g., Eliasson et al., 2010).

In particular for climate change applications, most of the available agro-environmental modelling platforms assume a fixed crop mask, i.e., they tend to ignore a basic form of adaptation: under changed conditions, farmers will switch, where possible, to cultivars and crop species that become more suitable under changed conditions.

Importantly from a modelling platform perspective, the few crop suitability tools that are currently available are platform-specific and cannot be easily re-used in custom-developed applications. This implies that users interested in suitability modelling solutions must currently also adopt pre-determined crop growth platforms. The *Suitability* software proposed here allows to overcome this barrier. It was developed for maximum flexibility of use, as a framework-independent .NET 3.5 component, implementing a library of approaches for evaluating crop suitability to environment.

2. The software component

2.1. Implemented approaches

The approaches implemented in the component are taken from the literature, with specific additional options implemented for increased flexibility of use (Table 1).

Two main categories of approaches are available in the software component, providing for single- and multi-cell criteria. Single-cell criteria include (i) the FAO Ecocrop approach, based on crop-specific response functions to temperature and rainfall calculated on a monthly basis (Ecocrop, 2012); (ii) the Less Favoured Areas (LFA) approach, based on thresholds on climatic data, a simplified

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Table 1
Factors, inputs and description of suitability criteria implemented in the *Suitability* component.

Criteria	Factors	Inputs	Description
Single-cell suitability approaches			
Less favoured areas[a,d]	Climate	Temperature	Number of days with average daily temp. above a threshold (days)
			Growing degree days accumulated above a threshold (°C)
		Heat stress	Number of periods of consecutive days with average daily temperature above a threshold (unitless)
	Water balance	Rainfall, soil moisture, evapotranspiration	Number of days within growing period with amount of rainfall and soil moisture exceeding half of potential evapotranspiration (days)
	Chemical soil properties	Salinity	Soil electric conductivity above a threshold (dS m^{-1})
		Sodicity	Soil exchangeable sodium percentage above a threshold (%)
		Gypsum	Soil gypsum content above a threshold (%)
	Physical soil properties	Drainage	Daily drainage below a threshold (mm day^{-1})
		Texture	Sand content above a threshold (weight%)
			Clay content above a threshold (weight%)
			Organic matter content above a threshold (weight%)
		Coarse material	Coarse material above a threshold (volume%)
		Rooting depth	Maximum rooting depth (cm)
		Slope	Change of elevation with respect to the planimetric distance (%)
FAO EcoCrop[b]	Climate	Temperature	Response function considering cardinal minimum, optimum and maximum temperatures (%)
		Rainfall	Response function considering minimum, optimum and maximum rainfall amount (%)
Direct crop suitability discriminant[c]	Production	Yield	Yield of the crop (t ha^{-1})
	Crop success	Maximum development stage	Maximum development stage of the crop computed by a crop model (unitless)
	Abiotic suitability	Yield gap frost	Percentage of yield gap due to frost damages (%)
		Yield gap sterility (cold and/or heat)	Percentage of yield gap due to pre-flowering heat and/or cold sterility (%)
		Stem lodging	Stem lodging affecting the crop, which can or cannot still survive (yes/no)
	Diseases suitability	Yield gap diseases	Percentage of yield gap due to disease intensity (%)
		Potential infection events	Number of potential infection events in a specific crop stage (unitless)
	Water stress suitability	Yield gap due to water stress	Percentage of yield gap due to water limitation (%)
Multi-cell suitability approaches			
Less favoured areas[a,d]	The ones indicated in single cell approach	The same factors considered in single cell computations are used as multiple regressors and related to the percentage of crop presence in a specific area, which represents the dependent variable. The regressor coefficients are then used to predict the percentage of crop presence in the same area under different climatic conditions.	
Direct crop suitability discriminant[c]	The ones indicated in single cell approach		

[a] Eliasson et al. (2010).
[b] Ecocrop (2012).
[c] Modified from Schaldach et al.(2011).
[d] Default thresholds available.

water balance, and soil physical and chemical properties (Eliasson et al., 2010); (iii) the Direct Crop Suitability Discriminant (DCSD), based on data simulated by a dynamic cropping system model (e.g., Schaldach et al., 2011).

Multi-cell approaches are based on the use of multiple regressions, used to relate current crop geographic distribution in a given area – constituted by single spatial units (i.e., the grid cells) – to climate, soil or simulated crop data (e.g., Moriondo et al., 2010). The derived regression models are then used to predict the percentage of crop presence in each cell under, e.g., a different climate. In this case, the component implements two regression-based methods, each using as regressors the information used by two of the single-cell approaches described above (LFA and DCSD). Specific options are available in case of data unavailability, e.g., lack of soil physical or chemical properties.

In addition, a District criterion can be coupled as an option to either single- or multi-cell estimations. This criterion allows to mimic farmers' behaviour in tending to aggregate crops in production districts (Kurosaki, 2003), and is based on the following rules: if the percentage of neighbouring cells where the same crop is computed as present by the suitability model is higher than a user's specified threshold (high threshold), the district criterion increases the percentage of crop presence of the cell by a user specified percentage value; the opposite is done in case of percentage presence in the cell lower than another user's specified threshold (low threshold); otherwise (percentage value between high and low thresholds), it does not modify the percentage of crop presence for the cell.

Detailed description of all the suitability criteria implemented is provided in the component help file.

Finally, the *Suitability* component can be run by directly selecting a specific approach, or alternatively by an automatic procedure, whereby the software selects the most appropriate suitability method based on the information available. An example flow chart describing the implementation of the Less Favoured Areas criterion is presented in Fig. 1, showing the possibility to compute partial suitability outputs and to activate/deactivate categories of biophysical factors according to user needs or inputs availability.

2.2. Software design

The *Suitability* component implements the Strategy pattern (Gamma et al., 1995), with each strategy encapsulating the algorithm, the parameters' ontology, and pre- and post-conditions tests, according to the design-by-contract approach (Meyer, 1997). The strategy diagram of the *Suitability* component is shown in Fig. 2.

The software design, which allows for extending data-types, as well as adding new suitability criteria without the need of recompilation (Donatelli and Rizzoli, 2008), promotes reusability by limiting dependencies (limited to Extreme.Numerics and CRA.Core.Preconditions in this case) and by providing two