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Estimating the soil erosion cover-management factor at the European scale

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ABSTRACT

Land use and management influence the magnitude of soil loss. Among the different soil erosion risk factors, the cover-management factor (C-factor) is the one that policy makers and farmers can most readily influence in order to help reduce soil loss rates. The present study proposes a methodology for estimating the C-factor in the European Union (EU), using pan-European datasets (such as CORINE Land Cover), biophysical attributes derived from remote sensing, and statistical data on agricultural crops and practices. In arable lands, the C-factor was estimated using crop statistics (% of land per crop) and data on management practices such as conservation tillage, plant residues and winter crop cover. The C-factor in non-arable lands was estimated by weighting the range of literature values found according to fractional vegetation cover, which was estimated based on the remote sensing dataset F_{cover}. The mean C-factor in the EU is estimated to be 0.1043, with an extremely high variability; forests have the lowest mean C-factor (0.00116), and arable lands and sparsely vegetated areas the highest (0.233 and 0.2651, respectively). Conservation management practices (reduced/no tillage, use of cover crops and plant residues) reduce the C-factor by on average 19.1% in arable lands.

The methodology is designed to be a tool for policy makers to assess the effect of future land use and crop rotation scenarios on soil erosion by water. The impact of land use changes (deforestation, arable land expansion) and the effect of policies (such as the Common Agricultural Policy and the push to grow more renewable energy crops) can potentially be quantified with the proposed model. The C-factor data and the statistical input data used are available from the European Soil Data Centre.

1. Introduction

Agricultural and management practices play an important role in controlling soil erosion. For instance, soil loss rates decrease exponentially as vegetation cover increases (Gyssels et al., 2005). Besides vegetation cover, several other land use and management factors affect soil loss, such as type of crop, tillage practice, etc. The influence of land use and management is often parameterised in the cover-management factor (C-factor). The C-factor is among the five factors that are used to estimate the risk of soil erosion within the Universal Soil Loss Equation (USLE) and its revised version, the RUSLE. The C-factor is perhaps the most important factor with regard to policy and land use decisions, as it represents conditions that can be most easily managed to reduce erosion (Renard et al., 1991). In RUSLE, the C-factor accounts for how land cover, crops and crop management cause soil loss to vary from those losses occurring in bare fallow areas (Kinnell, 2010). The bare plot (no vegetation) with till up and down the slope is taken as a reference condition, with a C-factor value of 1. The soil loss from different land-cover types is compared to the loss from the reference plot and the results are given as a ratio. The C-factor value for a particular land-cover type is the weighted average of those soil loss ratios (SLRs), and ranges between 0 and 1. Following the RUSLE handbook (Renard et al., 1997), SLRs are computed as a product of five sub-factors: prior land use, canopy cover, surface cover, surface roughness and soil moisture. These sub-factors include variables, such as residue cover, canopy cover, canopy height, below-ground biomass (root mass plus incorporated residue) and time. The SLR's are calculated for several time intervals during a year and multiplied by the corresponding percentage of annual rainfall erosivity to estimate the C-factor. This approach is feasible on plot- to field scales.

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Simplified approaches are adopted for larger spatial scales: (i) assigning uniform C-factor values found in the literature to a land-cover map (de Vente et al., 2009; Borrelli et al., 2014), and (ii) mapping vegetation parameters using techniques such as image classification (Karydas et al., 2008) and normalized difference vegetation index (NDVI) (Alexandridis et al., in press). NDVI was not considered in the present study as this is proved to correlate poorly with vegetation attributes due to the effect of soil reflectance and vitality of vegetation (Vrieling, 2006; de Asis and Omasa, 2007). A hybrid C-factor land use and management (LANDUM) model has been developed for this European-scale study, which covers an area of 4,381,376 km^2 of the 28 Member States of the European Union (EU-28). The LANDUM model is based on a literature review, remote sensing data at high spatial resolution, and statistical data on agricultural and management practices.

The main objective of this study is to estimate the cover-management factor (C-factor) based on the best available data, in combination with a literature review at European scale (EU-28). The proposed C-factor incorporates management practices such as reduced or no tillage, cover crops and plant residues (Reeves, 1994; Wall et al., 2002). Other management-related practices such as contour farming, terracing, strip cropping and hedge rows are, by definition, considered in the support practice factor (P-factor). The P-factor includes the control practices that reduce the erosion potential of runoff by their influence on drainage patterns, runoff concentration, runoff velocity and hydraulic forces (Renard et al., 1997). More specifically, this study aims to:

a) propose weighted average C-factor values for arable lands based on the crop composition of an area;
b) calibrate the C-factors found in the literature for non-arable lands based on biophysical attributes derived from remote sensing data;
c) estimate the effect of management practices such as reduced tillage, cover crops and plant residues to reduce soil loss rates;
d) quantify the impact of land use and conservation management scenarios.

2. Data

2.1. CORINE Land Cover

The CORINE Land Cover map was developed by image analysis and land use/cover digitalisation of Landsat photos in a GIS environment. CORINE Land Cover datasets are available for 1990, 2000, and 2006, and have been used to calculate the C-factor at the European level (Bosco and de Rigo, 2013; Panagos et al., 2014a). The datasets contain homogeneous data on land-cover areas, which are provided in vector format (as polygons). All CORINE Land Cover datasets (CLC, 2014) were established following harmonised procedures based on a common classification system, and can therefore be easily compared. Data are classified into 44 land-cover classes, which are grouped under three hierarchical levels. Their nominal scale is 1:100,000 with a minimum mapping unit (MMU) of 25 ha and a change detection threshold of 5 ha. The data are also available in a raster format at a pixel resolution of 100 m, and refer to the year 2006. European validation studies such as the LUCAS survey have shown that the accuracy achieved is above the minimum specified by CLC (85%) (Buttner, 2014).

2.2. Biophysical attributes derived from remote sensing data

Under the Copernicus programme (Copernicus, 2012), the MERIS (MEdium Resolution Imaging Spectrometer) Environmental Satellite sensor produced regular standardised biophysical parameter layers over Europe at 300-m resolution covering the period 2011–2012, and at 1-km resolution for about 10 continuous years (2002–2012). The biophysical attributes named 'BioPar' are derived from MERIS using the 'SAIL/PROSPECT' baseline vegetation model (Verhoef, 1985). Among the nine biophysical parameters available in the Geoland2 portal, the current C-factor development considers that F_{cover} is the most appropriate layer as it represents the percentage(fraction) of the surface covered by any kind of vegetation. The F_{cover} dataset is used to weight C-factors of a specific land-use type, depending on the fractional vegetation cover.

2.3. Agricultural statistical data from Eurostat

NUTS (Nomenclature of Territorial Units for Statistics) is a system used by the administrative authorities and Member States of the European Union (EU) for classifying the European territory into hierarchical levels according to population size. The NUTS2 level represents regions of 0.8–3 million people for which regional policies are implemented and agricultural data are available. Among the statistics that the European Commission's statistical service (Eurostat) provides to the public, three datasets were used in this study at the NUTS2 level: (a) regional agricultural statistics and land use (named agr_r_landuse), (b) tillage methods (named ef_pmtilaa), and (c) soil conservation (named ef_pmsoilaa). The first dataset includes annual crop statistics on the area (hectares) of a given crop during the crop year at regional (NUTS2) level. The mean values for each crop category for the period 2008–2012 have been taken in order to incorporate the crop variation (rotation) during this period.

The dataset of tillage methods includes statistics on tillage practices, and the soil conservation dataset provides statistics on cover crops and plant residues; both are results of the Farm Structure Survey (FSS). Eurostat collected data from the Farm Structure Survey on Agricultural Production Methods (SAPM, 2010), a once-off survey carried out in 2010 to collect data at farm level on agro-environmental measures. The EU Member States collected information from individual agricultural holdings and, following rules of confidentiality, these data were transmitted to Eurostat and aggregated at the NUTS2 regional level.

In this study, the statistical data of tillage practices, cover crops and plant residues are used as input for estimating the C-factor. Data on tillage practices are defined as the share (%) of arable areas under conventional, conservation and zero tillage at the NUTS2 level.

3. Methods

The LANDUM model for C-factor estimation is differentiated between (a) arable lands and (b) all other land uses (non-arable). Artificial areas, wetlands, water bodies, bare rocks, beaches and glaciers are not considered in the C-factor evaluation. Finally, a mosaic layer of the C-factor for arable lands and C-factor for non-arable lands is proposed as the annual C-factor in Europe.

3.1. C-factor estimation for arable lands

Arable lands (CORINE Land Cover classes 21x) cover around 25.2% of the total European land area. Arable lands are strongly affected by policy decisions (e.g. the Common Agricultural Policy). In the past, published studies (de Vente et al., 2009; Borrelli et al., 2014) assigned constant C-factor values to all agricultural lands without considering the type of crop and management. The C-factor values for croplands are assigned based on field experiments which are very time consuming and expensive, and therefore