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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.

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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

Table 1
Area covered by different crop types, and C-factor (C_{cropn}) per crop type based on the literature review.

n	Crop type	Share (%) of the total arable land (EU-28)	C-factor
1	Common wheat and spelt	28.5	0.20
2	Durum wheat	3.2	0.20
3	Rye	3.0	0.20
4	Barley	14.8	0.21
5	Grain maize – corn	12.9	0.38
6	Rice	0.6	0.15
7	Dried pulses (legumes) and protein crop	1.9	0.32
8	Potatoes	2.4	0.34
9	Sugar beet	3.1	0.34
10	Oilseeds	5.8	0.28
11	Rape and turnip rape	8.1	0.30
12	Sunflower seed	4.8	0.32
13	Linseed	0.1	0.25
14	Soya	0.5	0.28
15	Cotton seed	0.4	0.50
16	Tobacco	0.1	0.49
17	Fallow land	9.8	0.50

rare (Gabriels et al., 2003). In the present study, a C-factor has been calculated for the arable lands of each NUTS2 region as follows:

$$C_{arable} = C_{crop} \times C_{management} \quad (1)$$

where C_{crop} is the C-factor based on the crop composition of an agricultural area, and $C_{management}$ quantifies the influence of management practices (reduced tillage, cover crop and crop residues) on soil erosion reduction.

3.1.1. *Crop factor*

The annual soil loss from agricultural lands depends on the crop type. At NUTS2 level, statistical data are available for 16 different crops plus fallow land. A literature review was performed to identify the C_{crop} factor for each of the 16 crops. C-factor values per crop type (Table 1) are based on experimental data from previous studies (Bollinne, 1985; Onchev et al., 1988; NS, 2001; Rousseva, 2004; Biesemans et al., 2000; Wischmeier and Smith, 1978; David, 1988; Cai, 1998; Palmquist and Danielson, 1989; Roose, 1977; Nyakatawa et al., 2001; Gabriels et al., 2003; Boellstorff and Benito, 2005; Antronico et al., 2005; Vezina et al., 2006; Bazzoffi, 2007; Junakova and Balintova, 2012) and applications of the proposed C-factor values (Van Rompaey and Govers, 2002; Wall et al., 2002; Shi et al., 2004; Basic et al., 2004; Morgan, 2005; Bakker et al., 2008; Marker et al., 2008; Terranova et al., 2009; de Vente et al., 2009; Diodato et al., 2011; Borrelli et al., 2014). The criterion for the selection of C-factor values per crop (Table 1) was the most dominant value of the above-mentioned studies.

Eurostat statistics consider three types of land use as fallow land: (a) bare land bearing no crops, (b) land with spontaneous natural growth which may be used as animal feed, and (c) land sown exclusively for the production of green manure. Based on this definition and the C-factor values for fallow land in the literature which is used in crop rotation systems (Nyakatawa et al., 2007; Shi et al., 2004), a C-factor of 0.5 (dimensionless) has been assigned for this land use.

The C_{crop} factor represents the weighted C-factor average of 17 different crops presented in each NUTS2 region.

$$C_{crop} = \sum_{n=1}^{17} C_{cropn} \times \%NUTS2_{cropn} \quad (2)$$

where C_{crop} is the C-factor of the *n*-crop (Table 1) and $\%NUTS2_{crop}$ is the share of this crop in the agricultural land area of a region at NUTS2 level. According to Eq. (2), each NUTS2 region has a different C_{crop} according to its crop composition, and regions with crops susceptible to erosion will have higher C_{crop} factors.

Bakker et al. (2008) adopted a similar approach whereby they introduced an average C-factor value based on the most dominant arable crops grown in four catchment areas.

The F_{cover} is not taken into account in the C-factor estimation of arable lands, as the vegetative growth is volatile during the year. The C-factor per crop (Table 1) is applied to the whole study area. The crop rotation in each agricultural field is an important issue, but the overall share of crops at such a large scale (NUTS2 region) is generally stable in the short term. Crop composition was assessed over a five-year period (2008–2012). The present methodology also allows the C_{crop} factor to be estimated based on past arable statistics. It should also be noted that the C-factor estimation is limited due to a lack of geo-referenced data on crop composition and rotation at the European scale.

3.1.2. *Management factor*

The management factor ($C_{management}$) quantifies the effect of management practices (tillage practices, cover crops, plant residues) on reducing soil loss from agricultural lands. Support practices such as contour farming, terracing and strip cropping are considered in the support practice factor (P-factor) (Panagos et al., 2015). The combined effect of tillage practice ($C_{tillage}$) and plant residues ($C_{residues}$) or cover crops (C_{cover}) is also taken into account for the estimation of management factor:

$$C_{management} = C_{tillage} \times C_{residues} \times C_{cover} \quad (3)$$

Reeves (1994) combined the three practices in various areas of the U.S.A with different crops (cotton, corn, wheat, rye), and estimated that they can reduce soil erosion by 85%.

3.1.2.1. *Reduced and no-till practices.*

The soil erosion by water is affected by tillage, depending on the depth, direction and timing of plowing, the type of tillage equipment used, and the number of passages made. Generally, the less the disturbance of vegetation or residue cover at or near the surface, the more effective is the tillage practice in reducing soil erosion by water. Minimum tillage or no-till practices are effective in reducing soil erosion by water. Reduced tillage systems and cover cropping can reduce soil erosion and the leaching of nutrients into ground water (Nyakatawa et al., 2001).

Tillage practices refer to the tillage operations carried out between the harvesting and the sowing of crops. Conventional tillage is the most wide-spread tillage practice, and is applied in 74.4% of the arable sites in the study area. Conservational tillage is a practice or system of practices applied to arable lands, whereby at least 30% of plant residues are left on the soil surface for erosion control and moisture conservation, normally by not inverting the soil (Eurostat, 2013). Conservation tillage includes the following practices: (a) ridge tillage, (b) tined tillage or vertical tillage, and (c) strip tillage or zonal tillage. Conservation tillage is practiced on around 21.6% of the arable land in the EU-28.

Zero tillage refers to arable land on which no tillage is applied between the harvesting and the sowing of crops. Zero tillage is a minimum tillage practice in which the crop is sown directly in soil that has not been tilled since the harvesting of the last crop (Eurostat, 2013). Zero tillage is applied to only 4% of the arable land in the EU-28.

In order to predict the long-term average soil loss from agriculture, Siegerist and Pfister (2013) proposed a C-factor which incorporates a tillage sub-factor. Faist Emmenegger et al. (2009)

and the USLE factsheet (Stone and Hilborn, 2011) propose different values of this $C_{tillage}$ factor, depending on the tillage practice used:

- $C_{tillage}$ = 1 for conventional tillage;
- $C_{tillage}$ = 0.35 for conservation/ridge tillage;
- $C_{tillage}$ = 0.25 for no till practices.

Nyakatawa et al. (2001) also estimated that the no-till practice reduces soil erosion by water by 75% compared to conventional tillage.

The $C_{tillage}$ factor depends on the intensity to which a particular region follows conservation and no-till practices. Where only conventional tillage is applied, $C_{tillage}$ equals 1.

$$C_{tillage} = F_{Conventional} \times 1 + F_{Conservation} \times 0.35 + F_{Notill} \times 0.25 \quad (4a)$$

where:$F_{Conventional}$ is the fraction of arable land with conventional tillage [0...1];$F_{Conservation}$ is the fraction of arable land treated with conservation tillage [0...1];F_{NoTill} is the fraction of arable land where no till practices are applied [0...1];

$$F_{Conventional} + F_{Conservation} + F_{NoTill} = 1 \quad (4b)$$

3.1.2.2. Crop residues practices. In cropland, sheet and rill erosion are reduced by leaving adequate residue on the ground after the harvest (Santhi et al., 2006). However, farmers often plow the land after the harvest, which leads to erosion. Maintaining crop residues on soil surfaces not only protects the soils from splash erosion, but also increases infiltration rates (Unger and Vigil, 1998) and reduces surface runoff (Greenland, 1975), resulting in less soil loss. In their experimental field, Campbell et al. (1979) found that crop residues decrease soil loss by around 12%.

A combined crop management scenario which incorporates cover crops (in order to protect bare soil in winter and spring against storms) and leaving the crop residues on the field resulted in a 35% reduction in soil loss in the Belgian loess belt (Verstraeten et al., 2002). The former contributed to this reduction by 22% (reducing the C-factor from 0.36 to 0.28) while the latter contributed to 13% of the reduction. Another study (Andrews, 2006) found that residue crop cover of around 10-30% may result in reducing soil loss by around 12%. Taking into account the aforementioned literature findings, the proposed $C_{residues}$ value for this study is set at 0.88.

$$C_{residues} = 1 \times (0.88 \times F_{residues}) + (1 - F_{residues}) \quad (5)$$

where:$F_{residues}$ is the fraction of arable land treated with plant residues [0...1].

3.1.2.3. Cover crop practices. Cover crops reduce soil loss by improving soil structure and increasing infiltration, protecting the soil surface, scattering raindrop energy and reducing the velocity of the movement of water over the soil surface (Smith et al., 1987). A management practice that is efficient in reducing soil and nutrient loss is to keep the land covered with crops during the whole year. These crops are not normal winter crops or grassland, but are sown specifically to protect bare soil in winter (and early spring) after the harvesting of summer crops. The economic interest of the cover crops is low – its main goal is to protect soil and nutrients.

Nyakatawa et al. (2001) found that cover crops (e.g. rye) significantly reduce soil erosion by 15% in cotton fields. Verstraeten et al. (2002) estimated the reduction of soil loss due to cover crops to be around 23%. Wall et al. (2002) and Bazzoffi (2007) have estimated the C-factor reduction due to the application of cover crops to be around 20%.

$$C_{cover} = 1 \times (0.80 \times F_{crop\text{-}cover}) + (1 - F_{crop\text{-}cover}) \quad (6)$$

where:$F_{crop\text{-}cover}$ is the fraction of arable land to which cover crops are applied during winter or spring [0...1].

3.2. C-factor estimation for non-arable lands

It is practically and economically feasible to estimate soil erosion at large scales using the latest developments in remote sensing and geographical information system (GIS) techniques (Wang et al., 2003). Landsat images were used to derive C-factor values in the 1990s (De Jong, 1994; Folly et al., 1996). In the early 2000s, remote-sensing data were used to develop the USLE cover-management factor through land-cover classifications (Reusing et al., 2000; Ma et al., 2003). Such approaches assume that the same land-cover types have the same C-factor values throughout the study area. The result greatly depends on the spatial resolution of land-cover maps and their classification accuracy, and the determination of a suitable C-factor value for each land-cover class.

However, the same land-cover class may have different C-factors due to variations in vegetation density (Lu et al., 2004), and different land uses with the same vegetation coverage also result in different C-factors (Panagos et al., 2014b). C-factor estimation should take into account the combined effects of the above- and below-ground biomass, and the different environmental conditions (Smets et al., 2008).

The C-factor was defined for each CORINE Land Cover class according to literature values (Table 2). However, the variety of values found in the literature led to the assignment of a range of values ($C_{landuse}$) to each class. The range of values (Table 2) has been developed based on the most cited studies covering different countries, including Italy, Belgium, Slovakia, Greece, Bulgaria, France, Switzerland, Portugal and Spain (USDA, 1977; Van Rompaey and Govers, 2002; Wall et al., 2002; Arhonditsis et al., 2002; Yang et al., 2003; Angeli, 2004; Santhi et al., 2006; Capolongo et al., 2008; Terranova et al., 2009; de Vente et al., 2009; Pelacani et al., 2008; Bakker et al., 2008; Antronico et al., 2005; Borselli et al., 2008; Konz et al., 2009; Rulli et al., 2013). The range of values for grasslands and pastures have been estimated based on exponential equations (Elwell, 1978). The range of values for Heterogeneous agricultural areas (Codes: 24x) was calculated using values from arable lands, permanent crops, pastures, grasslands and woodlands, and applying the shares (%) of those categories to calculate the worst- and best-case scenarios (higher and lower values, respectively).

The influence of vegetation density can be quantified by the use of biophysical parameters derived from MERIS satellite images (Panagos et al., 2014b). In a similar way, de Asis and Omasa (2007) estimated the C-factor as a function of the fractional abundance of bare soil and ground cover using Landsat imagery. The use of a proxy vegetation layer allows for the quantification of the impact of vegetation cover in the C-factor estimation. F_{cover} is a vegetation layer available in the Copernicus programme and normalised in the range [0–1], which describes the % of soil covered by any type of vegetation.

$$C_{NonArable} = \mathrm{Min}(C_{landuse}) + \mathrm{Range}(C_{landuse}) \times (1 - F_{cover}) \quad (7)$$

Based on this approach, the C-factor reaches its maximum value when the F_{cover} is equal to 0 (no vegetation protection, and high risk of erosion) and its minimum value when the F_{cover} is equal to 1 (soil is fully covered by vegetation). In Eq. (7), the range for each type of land use is the result of maximum–minimum values (Table 2).

4. Results and discussion

4.1. C-factor in arable lands

Given the land management practices of the EU-28, the mean C-factor (C_{arable}) value of arable lands is 0.233. If no conservation

Table 2
C-factor per non-arable land-cover type.

Group	CLC class	Detailed class	Description	C-factor values ($C_{landuse}$)
Permanent crops	221	Vineyards	Areas planted with vines	0.15–0.45
	222	Fruit trees & berry plantations	Parcels planted with fruit trees or shrubs: single/mixed fruit species, fruit trees associated with permanently grassed surfaces.	0.1–0.3
	223	Olive groves	Areas planted with olive trees	0.1–0.3
Pastures	231	Pastures	Dense, predominantly graminoid grass cover, of floral composition, not under a rotation system. Mainly used for grazing.	0.05–0.15
Heterogeneous agricultural areas	241	Annual crops associated with permanent crops	Non-permanent crops (arable land or pasture) associated with permanent crops on the same land parcel (non-associated annual crops represent less than 25%)	0.07–0.35
	242	Complex cultivation patterns	Juxtaposition of small parcels of diverse annual crops, pasture and/or permanent crops (arable land, pasture and orchards each occupy less than 75% of the total surface area of the land unit)	0.07–0.2
	243	Land principally used for agriculture, with significant areas of natural vegetation	Areas principally used for agriculture, interspersed with significant natural areas (agricultural land occupies between 25 and 75% of the total surface of the land unit)	0.05–0.2
	244	Agro-forestry areas	Annual crops or grazing land under the wooded cover of forest species	0.03–0.13
Forests	311	Broad-leaved forest	Vegetation formation composed principally of trees, including shrub and bush understories, where broadleaved species predominate.	0.0001–0.003
	312	Coniferous forest	Vegetation formation composed principally of trees, including shrub and bush understories, where coniferous species predominate	0.0001–0.003
	313	Mixed forest	Vegetation formation composed principally of trees, including shrub and bush understories, where broadleaved and coniferous species co-dominate.	0.0001–0.003
Scrub and/or herbaceous vegetation associations	321	Natural grasslands	Low productivity grassland. Often situated in areas of rough and uneven ground	0.01–0.08
	322	Moors and heathland	Vegetation with low and closed cover, dominated by bushes, shrubs and herbaceous plants (heath, briars, broom, gorse, laburnum)	0.01–0.1
	323	Sclerophyllous vegetation	Bushy sclerophyllous vegetation. Includes maquis (dense vegetation composed of numerous shrubs) and garrige (oak, arbutus, lavender, thyme, cistus)	0.01–0.1
	324	Transitional woodland-shrub	Bushy or herbaceous vegetation with scattered trees. Can represent either woodland degradation or forest Regeneration/colonisation.	0.003–0.05
Open spaces with little or no vegetation	331	Beaches, dunes, sands	Beaches, dunes and expanses of sand or pebbles in coastal or continental areas	0
	332	Bare rocks	Scree, cliffs, rocks and outcrops	0
	333	Sparsely vegetated areas	Includes steppes, tundra and badlands. Scattered high-altitude vegetation	0.1–0.45
	334	Burnt areas	Areas affected by recent fires, still mainly black	0.1–0.55
	335	Glaciers and perpetual snow	Land covered by glaciers or permanent snowfields	0

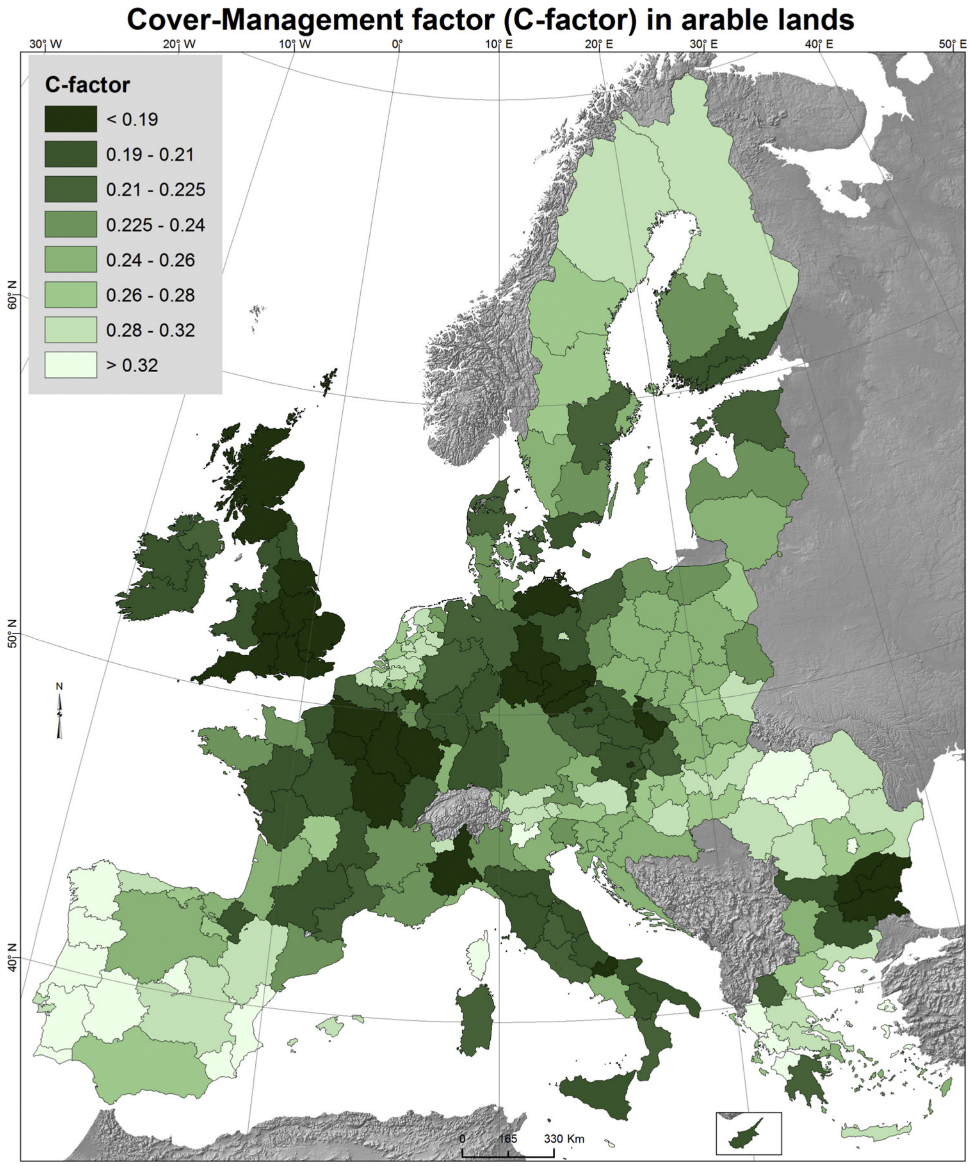

Fig. 1. Cover-management factor (C-factor) in arable lands of the European Union.

management practices are used, the mean C_{crop}-factor increases to 0.287. The mean $C_{management}$ factor is 0.809, which means that the average C-factor is reduced by 19.1% as a result of the combined management techniques (reduced tillage, crop residues, cover crop) practiced in the arable lands of the EU-28. The lowest C-factor values in croplands (<0.17) were identified in Germany (Thüringen, Sachsen-Anhalt and Sachsen), the United Kingdom (South East, East Midlands) and Bulgaria (Yugoiztochen, Severoiztochen), which score high in conservation tillage practices. The highest C-factor values in croplands (>0.39) were found in Portugal (Algarve), Malta, France (Corse) and Spain (Región de Murcia, Comunidad Valenciana) (Fig. 1), due to a predominance of fallow land and lack of conservation practices. Romania, Hungary, Malta, Greece and the Iberian Peninsula (Spain, Portugal) have the highest mean values at the national scale, at >0.27. The lowest mean values at the national scale are found in the United Kingdom, Bulgaria, Cyprus, the Czech Republic and Germany (<0.20).

The practice of conservation tillage reduces the C-factor by 17% ($C_{tillage}$ = 0.83), mainly due to reduced tillage, as no-till practices are carried out in a very small share (4%) of the EU-28 arable lands. Conservation tillage practices are found to be predominant in regions with the lowest C-factor values (Fig. 2a).

The application of crop residues, which is applied in 10.6% of the arable lands of the EU-28, reduced the C-factor by 1.2% ($C_{residues}$ = 0.988). The greatest impact of plant residues (>6%) is noticed in two regions of Ireland (Border, Midland and Western – Southern and Eastern) and in two regions of Finland (Etelä-Suomi, Helsinki-Uusimaa), given the high share of arable lands dedicated to this management practice in these regions (>53%) (Fig. 2b).

Cover crops reduced the EU-28C-factor by another 1.3% (C_{cover} = 0.987), as 6.5% of the EU-28 arable lands are planted with cover crops during winter and spring. The highest impact of cover crops (>12.3% C-factor reduction) is found in three Austrian regions (Vorarlberg, Salzburg and Tirol) due to their high share of cover crops (>61.5%). The use of cover crops is also common practice in the Netherlands and Belgium, while it is hardly applied at all in Mediterranean regions (Fig. 2c).

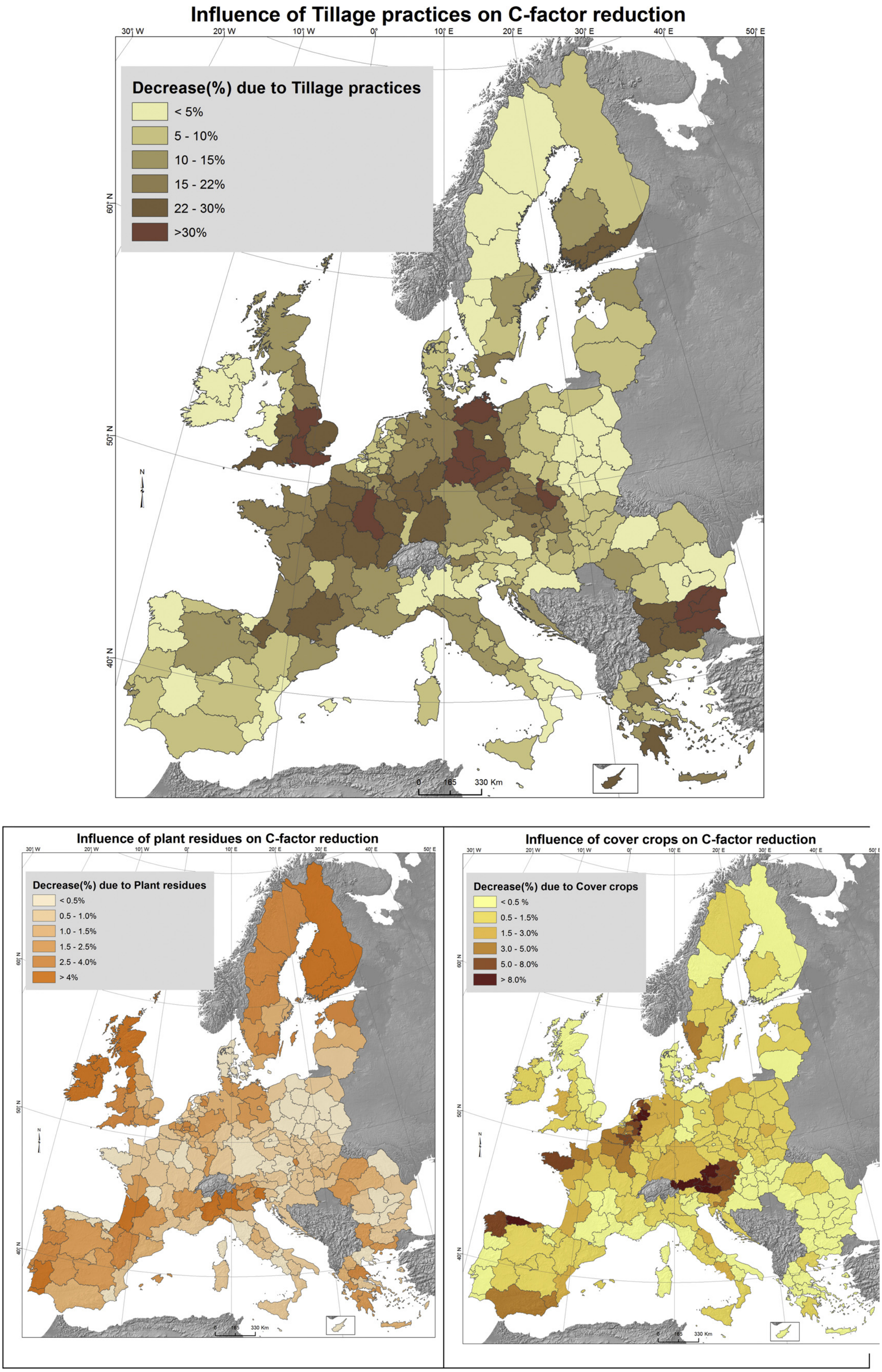

Fig. 2. C-factor reduction due to (a) tillage practices (upper frame), (b) plant residues (lower left), (c) cover crops (lower right).

Table 3
Mean C-factor per land-cover type, using remotely-sensed data.

Group	CLC class	Description	% of the area	C-factor values
Permanent crops	221	Vineyards	1.3%	0.3527
	222	Fruit trees & berry plantations	0.9%	0.2188
	223	Olive groves	1.4%	0.2273
Pastures	231	Pastures	12.9%	0.0903
Heterogeneous agricultural areas	241	Annual crops associated with permanent crops	0.3%	0.2323
	242	Complex cultivation patterns	8.2%	0.1384
	243	Land principally used for agriculture, with significant areas of natural vegetation	6.7%	0.1232
	244	Agro-forestry areas	1.2%	0.0881
Forests	311	Broad-leaved forest	14.7%	0.0013
	312	Coniferous forest	22.1%	0.0011
	313	Mixed forest	10.3%	0.0011
Scrub and/or herbaceous vegetation associations	321	Natural grasslands	3.9%	0.0435
	322	Moors and heathland	2.8%	0.0420
	323	Sclerophyllous vegetation	3.2%	0.0623
	324	Transitional woodland-shrub	8.7%	0.0219
Open spaces with little or no vegetation	333	Sparsely vegetated areas	1.3%	0.2652
	334	Burnt areas	0.04%	0.3427
TOTAL (Non-arable)			100%	0.0539

4.2. C-factor in non-arable lands

The mean C-factor value in the non-arable lands of the EU-28 is 0.0539, with a high standard deviation of 0.073 due to the large range of assigned values in the different land-cover classes. The mean C-factor values per land-cover type at the European scale (Table 3) were calculated by applying the Eq. (7) at pixel level and then aggregating by land cover. These mean C-factor values demonstrate the influence of vegetation density on the C-factor estimation.

However, the mean C-factor value per land-cover type can also be estimated at national (Table 4) or even at NUTS2 levels, using information on different management practices or the influence of climate. For instance, vineyards (class 221) have the highest mean C-factor value in Spain (0.396), followed by Bulgaria (0.375) and Hungary (0.36). On the other hand, the lowest mean C-factor values of vineyards are found in Luxembourg (0.29) followed by Slovenia (0.299) and Germany (0.311). The soil is bare in major parts of vineyards in Spain, while there is herbaceous protective coverage in Luxembourg and Slovenia.

The influence of climate can be observed in the fact that the pastures in Ireland are less susceptible to erosion (C-factor = 0.077) than are those in Cyprus (C-factor = 0.125), as they have denser vegetation coverage. Similarly, the forests in Finland and Sweden are twice as dense (C-factor = 0.0009) as those in Cyprus (C-factor = 0.0018).

4.3. C-factor map

The cover-management factor, known as C-factor in RUSLE, was mapped at 100-m resolution. The LANDUM model used data from the CORINE Land Cover map at 100-m resolution, the MERIS remote sensing dataset F_{cover} at 300-m resolution, statistical data on crops and management practices, plus literature references to the C-factor. Given the use of CORINE Land Cover as the main input and the fact that vegetation density is a proxy dataset, the final C-factor map has a fine resolution. The C-factor is estimated in agricultural (arable and permanent crops) land, grasslands, pastures, forests and semi-natural areas (Fig. 3). This area, which is potentially erodible, accounts for 90.3% of the total EU-28 surface. The mean C-factor in the EU-28 is 0.1043, with a standard deviation of 0.1046 and values ranging from 0.0001 to 0.526.

At country level, the highest mean C-factors (>0.15) are found in Hungary, Denmark, Malta and Romania (Table 5) for different reasons. Denmark and Hungary have the highest shares (%) of arable lands, and Romania has the second highest C_{arable} factor due to its crop composition and minimum application of conservation practices. In Malta, the $C_{non\text{-}Arable}$ is high due to a predominance of land that is principally used for agriculture, with significant areas of natural vegetation (class 243). The lowest C-factor values (<0.075) were identified in Finland and Sweden, followed by Slovenia, Estonia, Latvia and Austria, where forest is the dominant land use.

The LANDUM model uses the best available pan-European input datasets (CORINE Land Cover, official agricultural statistical data from Eurostat, MERIS Remote sensing) and the literature values given to land uses and management practices.

4.4. Drivers and policies that influence the C-factor

The C-factor and its associated soil loss rates can potentially be influenced by land-use changes, crop rotation and management practices. Land-use change has the highest impact on the C-factor, especially deforestation due to cropland expansion. In the past century, demographic, cultural and political changes have had a strong impact on deforestation, replacing forests with croplands, which led to increased soil erosion (Begueria et al., 2006). This land use change may have resulted in a significant increase in the C-factor, and consequently in an increase in soil loss. Other important drivers that influence land-cover change are the expansion of agricultural areas (for wheat production) to replace shrub land areas. The latter is possible mainly due to technologically advanced irrigation systems and the technical developments (machinery) which facilitate the cultivation of land in hilly areas.

In the early 1980s, the Common Agricultural Policy (CAP) subsidised cereal and traditional permanent crops, which were then extended at the expense of shrublands, leading ultimately to higher soil erosion risk (Onate and Peco, 2005). The mean C-factor of cereal crops is at least five times that of shrublands (Table 3). The financial incentives of the CAP to farmers and market prices for commodities led to changes in land use and crop rotation. For example, in Mediterranean countries, the CAP subsidies for olive and almond trees led to the transformation of some semi-natural areas (mainly on hilly slopes) to permanent crops (Garcia-Ruiz, 2010), increasing soil erosion risk. Another example of the effect of CAP incentives was the four-fold increase in cotton cultivation (which is highly erosive) in Greece during the period 1980–1996 (Tzouvelekas et al., 2001).

On the other hand, the CAP reform in the 2000s included some agro-environmental measures, which had positive effects on runoff

Table 4
C-factor per land-cover type and country.

Cover Type (class) Country	Vineyards 221	Olives 223	Pastures 231	Complex cultivation 242	Agriculture & natural areas 243	Forests 31X	Grasslands 321	Transitional woodland & Shrub 324	Sparse vegetation 333
AT	0.3403		0.0853	0.1300	0.1211	0.0012	0.0345	0.0215	0.2308
BE			0.0893	0.1286	0.1153	0.0011	0.0372	0.0216	
BG	0.3750		0.1185	0.1517	0.1449	0.0016	0.0498	0.0302	0.2889
CY		0.2524	0.1256	0.1659	0.1595	0.0019	0.0639	0.0359	0.3780
CZ	0.3546		0.0927	0.1506	0.1253	0.0014	0.0391	0.0235	0.2865
DE	0.3111		0.0920	0.1282	0.1219	0.0012	0.0421	0.0235	0.2810
DK			0.0905	0.1250	0.1152	0.0012	0.0424	0.0216	0.2648
EE			0.0829	0.1171	0.0997	0.0009	0.0342	0.0171	0.2794
ES	0.3963	0.2413	0.0901	0.1585	0.1457	0.0015	0.0516	0.0296	0.3517
FI			0.0971	0.1102	0.0981	0.0009	0.0273	0.0161	0.2052
FR	0.3363	0.2145	0.0906	0.1302	0.1195	0.0012	0.0403	0.0229	0.2581
GR	0.3269	0.2094	0.1132	0.1476	0.1307	0.0014	0.0522	0.0260	0.3062
HR	0.3254	0.1981	0.0975	0.1461	0.1193	0.0011	0.0440	0.0228	0.2752
HU	0.3605		0.1167	0.1583	0.1491	0.0017	0.0564	0.0306	0.3564
IE			0.0770	0.1087	0.0902	0.0010	0.0294	0.0165	0.2171
IT	0.3454	0.2163	0.0988	0.1478	0.1245	0.0013	0.0416	0.0242	0.2509
LT			0.0873	0.1224	0.1021	0.0011	0.0389	0.0190	0.2822
LU	0.2905		0.0907	0.1254	0.1107	0.0011		0.0231	
LV			0.0819	0.1169	0.0944	0.0010	0.0331	0.0171	0.2671
MT					0.1483				
NL			0.0900	0.1317	0.1126	0.0013	0.0489	0.0251	
PL			0.0933	0.1358	0.1214	0.0012	0.0432	0.0231	0.3115
PT	0.3313	0.2216	0.1030	0.1432	0.1342	0.0015	0.0491	0.0270	0.2858
RO	0.3460		0.1026	0.1398	0.1313	0.0013	0.0419	0.0242	0.2449
SE			0.0833	0.1082	0.0947	0.0009	0.0317	0.0162	0.2301
SI	0.2993		0.0965	0.1359	0.1185	0.0013	0.0447	0.0244	0.2864
SK	0.3433		0.0922	0.1465	0.1212	0.0013	0.0395	0.0228	0.2254
UK			0.0867	0.1201	0.1068	0.0011	0.0319	0.0183	0.1825
EU-28	0.3527	0.2273	0.0903	0.1384	0.1232	0.0012	0.0435	0.0219	0.2652

and soil erosion by water. For instance, the creation of buffer strips, the maintenance of terraces, the promotion of hedge planting and the measures to convert arable land into extensively managed grassland are some of the agro-environmental measures of the CAP. Pastures have a protective effect against erosion, as the C-factor is around 2.5 times lower than that of arable lands. An additional benefit of the conversion to grasslands or their preservation is the resulting high soil organic carbon accumulation (Lugato et al., 2014), which in turn promotes soil aggregation and prevents erosion. Germany is an illustrative example of the effectiveness of government subsidies for reduced tillage in areas at risk of soil erosion (Lahmar, 2010). As a result of the subsidies, reduced tillage

Table 5
C-factor per country.

Country	C-factor	Arable lands		Non arable lands	
		C-factor	% Share	C-factor	% Share
AT	0.071	0.218	15.3%	0.045	84.7%
BE	0.121	0.245	27.9%	0.073	72.1%
BG	0.105	0.188	37.5%	0.055	62.5%
CY	0.129	0.193	30.8%	0.100	69.2%
CZ	0.107	0.199	41.1%	0.042	58.9%
DE	0.112	0.200	42.1%	0.048	57.9%
DK	0.178	0.222	72.4%	0.061	27.6%
EE	0.059	0.217	16.7%	0.027	83.3%
ES	0.140	0.289	24.9%	0.090	75.1%
FI	0.023	0.231	6.2%	0.010	93.8%
FR	0.108	0.202	30.3%	0.068	69.7%
GR	0.111	0.280	17.5%	0.075	82.5%
HR	0.075	0.255	7.5%	0.061	92.5%
HU	0.188	0.275	58.3%	0.066	41.7%
IE	0.082	0.202	9.6%	0.069	90.4%
IT	0.119	0.211	30.4%	0.078	69.6%
LT	0.121	0.242	36.5%	0.051	63.5%
LU	0.082	0.215	13.4%	0.061	86.6%
LV	0.070	0.237	16.4%	0.037	83.6%
MT	0.151	0.434	1.7%	0.148	98.3%
NL	0.133	0.260	26.4%	0.088	73.6%
PL	0.140	0.247	47.3%	0.043	52.7%
PT	0.123	0.352	14.8%	0.083	85.2%
RO	0.150	0.296	38.5%	0.058	61.5%
SE	0.032	0.237	8.1%	0.014	91.9%
SI	0.057	0.248	5.8%	0.046	94.2%
SK	0.106	0.235	36.5%	0.032	63.5%
UK	0.099	0.177	32.2%	0.062	67.8%

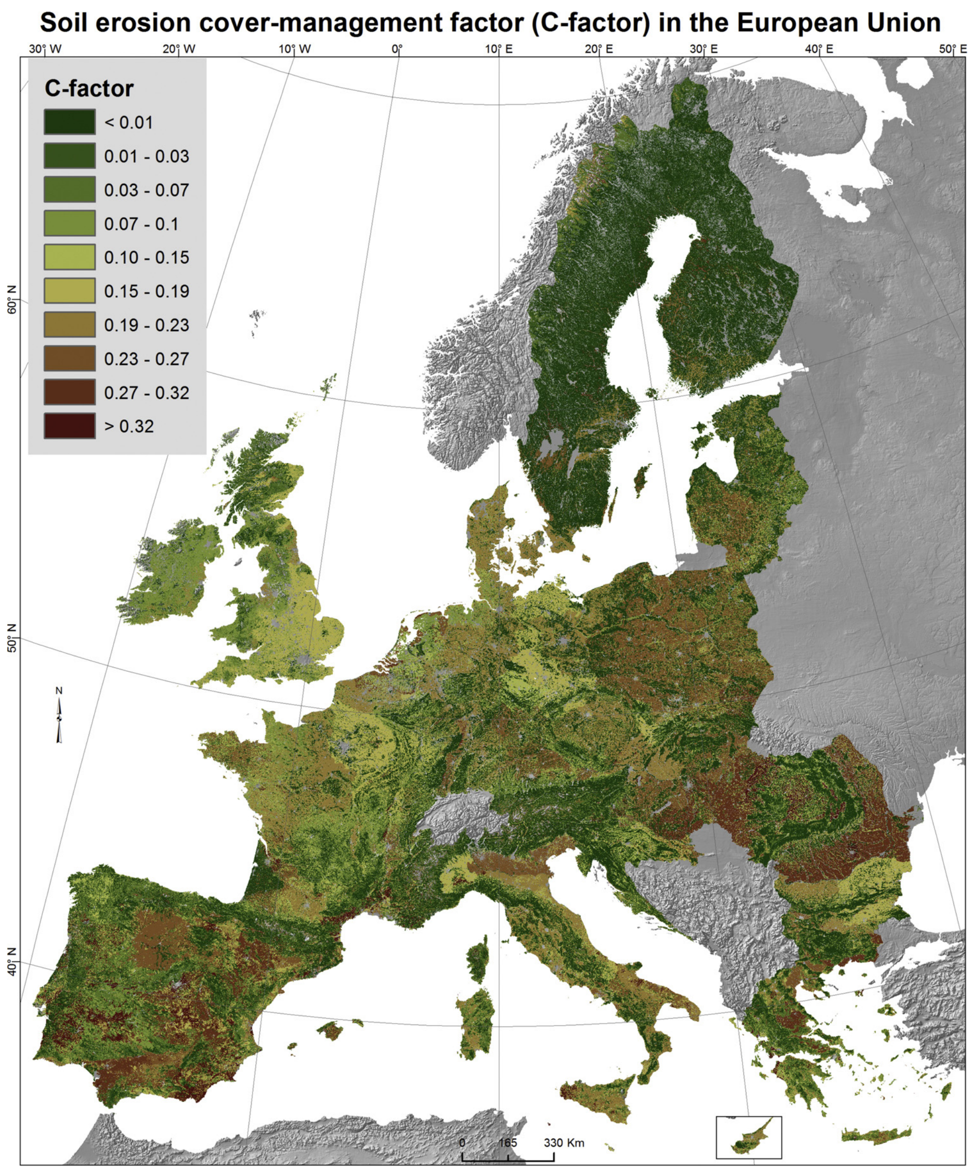

Fig. 3. C-factor map of the European Union.

is now applied to almost 40% of arable lands in Germany. At the EU policy level, the Sustainable Agriculture and Soil Conservation (SoCo) project identified the importance of plant residues as a protective measure against soil erosion (Louwagie et al., 2010).

In the context of energy policy, the EU has set a target of obtaining 10% of transport fuel from biofuels by 2020. This target will increase the demand for energy crops such as sugar beets, sunflowers, maize and oil seeds at the expense of wheat, which is a less soil-erosive crop. Moreover, this will lead to a reduction in plant residue coverage, which will have an overall negative impact on soil conservation, including the potential loss of soil organic carbon (Lugato et al., 2014). In a scenario whereby 10% of arable land is transformed from cereal to energy crop production, and plant residues are reduced to 5%, the mean C-factor in arable lands will increase by 3.8% to 0.242, resulting in an overall increase in soil erosion risk of 2.2%.

Scenarios of different crop rotation and management practices can be applied using the proposed LANDUM model. For example, if conservation tillage were applied to 50% (compared to the existing 25%) of European arable lands, and cover crops were increased to 35% (compared to the current 10.6%) and crop residues to 25% (compared to 6.5%), the C-factor of arable lands would decrease by a remarkable 40%, to 0.172, due to conservation management practices. This would result in a reduction of 16.5% in the overall C-factor and, consequently, the soil erosion risk. In another scenario, increasing pastures by 15% to replace arable lands would result in a reduction in soil loss of 2%.

4.5. LANDUM evaluation and related uncertainties

The LANDUM model has introduced certain improvements over previous European-scale C-factor studies (Bosco and de Rigo, 2013; Panagos et al., 2014a). As vegetation coverage differs from country to country, the incorporation of vegetation coverage density from remotely sensed data (F_{cover}) in the C-factor estimation is a major improvement compared to assigning constant values to 14 generic CORINE classes. For example, the new C-factor map (Fig. 3) reflects the fact that pastures in Ireland have a much higher density and protective function than those in Cyprus and Bulgaria. In a similar way, the C-factor in vineyards incorporates the herbaceous protection applied in certain regions of northern countries compared to the bare land in Spain. In conclusion, the LANDUM model pro-

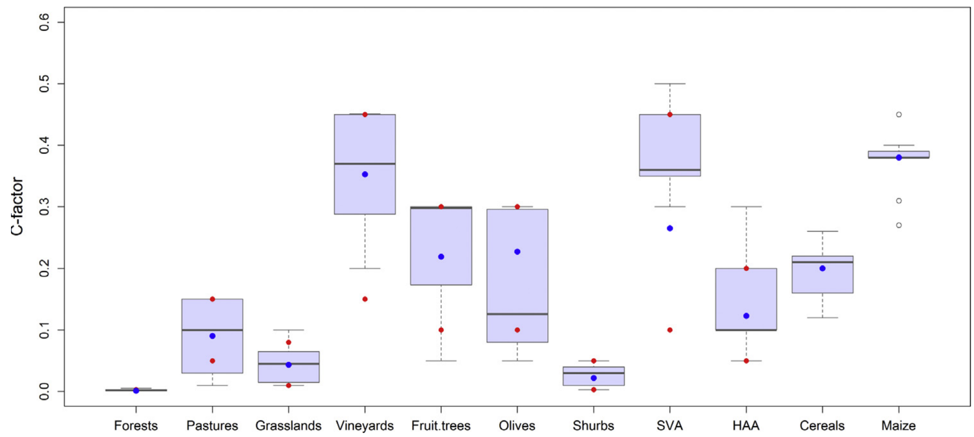

Fig. 4. Comparison of LANDUM model C-factor values (mean values in blue dots; minimum and maximum values in red dots) with literature findings (box plots). SVA stands for sparsely vegetated areas; HAA stands for heterogeneous (agricultural – natural vegetation) areas.

poses aggregated C-factor values per land cover type and country (Table 4), which can also be estimated at regional levels.

The proposed C-factor values by LANDUM model fit well compared to the literature findings (Fig. 4). The values of major categories (forests, pastures, grasslands, shrubs and croplands) match very well with the literature ones while the sparsely vegetation areas literature values are higher than the LANDUM ones.

Special focus was given to arable lands. LANDUM is the first model to incorporate crop composition and conservation management practices in C-factor estimation at the European scale. Compared to assigning a single C-factor value (0.335 or 0.2) to all European arable lands, LANDUM focuses on the regional level and assigns C-factors based on the crop composition. The conservation management practices (reduced/zero tillage, cover crops and plant residues) reduced the C-factor in arable lands by an average of 19.1%. Conservation tillage has the greatest impact of all the management practices reviewed.

LANDUM uses pan-European harmonised datasets (CORINE Land Cover, Copernicus Remote Sensing, Statistical data) and C-factor values assigned in a large pool of acknowledged literature studies. CORINE data have also been validated with LUCAS earth observations. The coarser resolution (300 m) of vegetation density and the lack of validation in Copernicus F_{cover} is a source of uncertainty. LANDUM C-factor values have not yet been validated at the plot or field scale, but the model assigned C-factor values to each crop type based on the results of experiments that were mainly carried out in European countries (indirect validation).

The accuracy of the model may be further increased if statistical data (on crop composition, tillage practices, cover crops and plant residues) are available at finer (province or district) scales. Taking into account its uncertainties, the LANDUM model can be used by policy makers at the European level to run scenarios on crop rotation, land use and conservation practices.

5. Conclusions

The LANDUM model has been developed at the European scale in order to estimate the C-factor for all land uses. The C-factor map has improved the data quality in terms of resolution, data input, parameterisation and inclusion of management practices. The transparency of the LANDUM model ensures comparability with other regional/national studies, replicability of the results with future CORINE Land Cover and vegetation density databases, and usability by policy makers and scientists.

The soil erosion risk factors such as rainfall erosivity, soil erodibility, slope length and steepness (R, K, LS) depend mainly on nature and cannot be easily altered. Support practices (P-factor) such as contour farming and terracing can reduce soil erosion by water, but they require considerable financial investment. Currently, the only soil erosion risk factor that can be modified by policy makers and farmers at reasonable costs is the cover and management factor (C-factor), which reduces soil erosion by water in arable lands, hence preventing the loss of nutrients and preserving soil organic carbon.

The C-factor dataset and its derived products provide the most up-to-date general picture of land cover and management practices at the European Union scale today. It is not intended to be a substitute for regional or local maps that are based on spatial crop statistics or higher resolution remote sensing data. However, the proposed C-factor dataset provides information to soil erosion modellers where detailed C-factor datasets do not exist. The maps and tools (tables of crop composition and management practices) produced in this study are freely available for download from the European Soil Data Centre (Panagos et al., 2012).

Conflict of interest

The authors confirm that there is no conflict of interest with the networks, organisations, and data centres referred to in the paper.

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