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Assessing the intra-annual variability of agricultural soil losses: a RUSLE application in Nord-Pas-de-Calais, France

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Abstract: The control of water erosion is an important economic and societal challenge. Reduction of the agronomic potential of the parcels, muddy flows, siltation of dams are harmful consequences that mobilize farmers, water managers, local authorities and scientific researchers.

This study focuses on mapping and quantifying seasonal soil losses in the territory of the former Nord-Pas-de-Calais administrative region, using the Revised Universal Soil Loss Equation (RUSLE) which incorporates five factors: rainfall erosivity, soil erodibility, topography, land use and erosion control practices.

The seasonal (3-months) time scale is chosen to better account for the parameters governing the soil water erosion, especially rainfall and vegetation cover, that show great asynchronous intra-annual variability. Also, high resolution data concerning agricultural plots allows to evaluate which type of culture are the more subject to soil losses.

In Nord-Pas-de-Calais, water erosion occurs almost ubiquitously, but the areas characterized by steep slopes are the most at risk (Artois Hills and Flanders), with loss rates up to 54 $t \cdot ha^{-1} \cdot y^{-1}$. The majority of erosion occurs during fall (46% of the computed annual losses of 1.69·Mt), on plots left bare after harvest (especially corn and beets crops).

The study also demonstrates that extending the intercrop technique over the region, and therefore maintaining a fall and winter cover, could reduce the soil losses by 37%.

Keywords: agriculture, Nord-Pas-de-Calais, the Revised Universal Soil Loss Equation, water erosion

INTRODUCTION

Water erosion is one of the major forms of soil degradation. This term refers to all processes of detachment, transport and sedimentation occurring at the surface of the soil at different scales of space and time [Le Bissonnais *et al.* 1998], from sheet erosion to deep gullies that cut through plots of land. The main factors influencing erosion are rainfall, pedology, topography, land use and, in an agricultural context, cultural practices.

Incidentally, the development of intensive farming has contributed significantly to accelerate the degradation of water and soil resources. Every year, large quantities of soil are displaced, particularly in agricultural plots left bare during heavy rainfall. In addition, each successive loss of topsoil increases the soil's sensitivity to erosion: the depletion of organic matter, concentrated in the first few centimetres of the soil, weakens the soil structure, causing it to lose not only its agronomic potential, but also its drainage and infiltration capacities [Boardman, Poesen 2006]. The runoff generated this way can be a source of diffuse pollution, leading to contamination of rivers by pesticides and fertilizers, eutrophication processes or siltation of dams. These environmental issues, combined with agricultural concerns, make erosion a major stake for soil and surface water management authorities worldwide [Duvert *et al.* 2010]. A crucial dimension of erosion lies in the fact that soil is not a renewable resource on a human time scale [Fournier 1960; Le Bissonnais *et al.* 2002; Poulenard *et al.* 2012].

Erosion affects all parts of the globe, including the temperate oceanic and continental plains of developed countries [Mabit *et al.* 2002], even more so since the intensification of farming practices, involving the decline in crop rotation diversity, the shortening of rotations, the increase of the average plot size, the depletion of fallows and the disappearance of groves [Le Bissonnais *et al.* 2002]. In France, this is the case in the Nord-Pas-de-Calais region [Auzet 1987], where industrial crops (wheat, sugar beet, potatoes) predominate, as they constitute major assets for the regional economy. The silty soils of the region, which give it its agricultural potential, are also susceptible to erosion due to surface sealing. This leads to a multiplication of erosion phenomena occurrences in the region, with sometimes catastrophic consequences, such as mudflows affecting villages located downstream of agricultural catchment areas [Auzet 1987; Masson 1980; Wicherek 1993].

This alarming situation drives scientific researchers and decision-makers to focus on the erosion problem. Meanwhile, resources and tools specific to the Nord-Pas-de-Calais are very few or lack spatial resolution, as for instance the risk map drawn at the agricultural region scale with MESALES method [Le Bissonnais *et al.* 2002]. More refined data are available at the national or European scale [Cerdan *et al.* 2010; Panagos *et al.* 2012] and can be extracted for regional purpose. But in these cases, the soil losses are always averaged on a yearly basis, when agriculture and crop development follow a dynamic implying very different soil conditions within a same year, especially in terms of cover. The same appears for the rainfall erosivity, which is not equally distributed during the year.

Therefore, this study aims to quantify the soil losses caused by water erosion over the Nord-Pas-de-Calais region with a seasonal time resolution, in order to assess the periods of greater loss in a year and the influence of simple crop management techniques, namely the implementation of intermediate cultures (intercrops). To do so, the Revised Universal Soil Loss Equation [Wischmeier, Smith 1958; Renard *et al.* 1997] is used, with 3-month rainfall intensity data and precise agricultural information (including the type of culture at the plot scale and, where applicable, the use of intercrops), allowing to modulate for each season the land cover depending on the culture development stage. A scenario extending the use of intercrops is also simulated in order to quantify its potential, giving stakeholders (public administration, farmers) material for discussion.

MATERIAL AND METHODS

STUDY AREA

Nord Pas-de-Calais is a former French region that covers an area of 12,480 km^2 (Fig. 1). The region is bordered to the south by Picardy, to the east by Belgium, to the northwest by the North Sea and to the west by the English Channel (Fig. 1).

Two large geomorphological units with a NW–SE orientation can be distinguished, the High Country and the Lower Country. The 80 m isohypse can be considered as their dividing line. The High Country reaches a height of 270 m, which corresponds to the Artois anticline and the south-eastern end of the Ardennes. In this unit, the most frequent altitudes range from 180 to 220 m and slopes from 2 to 15%. The Lower Country consists of sub-horizontal lowlands and gently rolling plains, with slopes of less than 2%. The altitudes of the low plains are less than 20 m while those of the rolling plains vary between 2 and 50 m, except for the Flanders hills (low inselbergs) whose tops reach from 139 to 176 m.

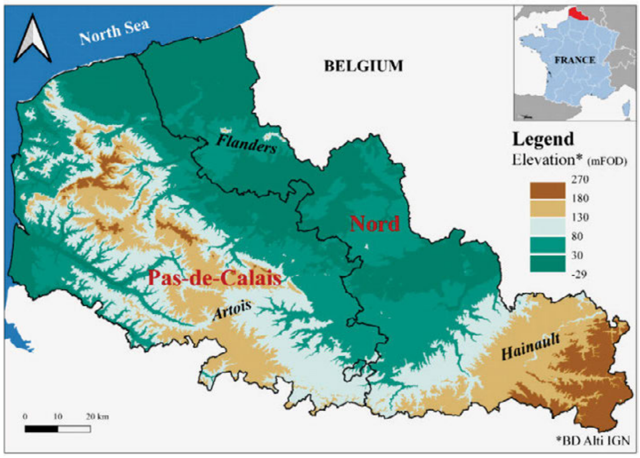

Fig. 1. Location and elevation of the study area; own elaboration based on IGN [2017]

Its coastal location gives it a temperate oceanic climate with a low annual temperature range (mean of 11°C) and moderate annual precipitation (between 600 and 1000 mm·y^{-1} depending on the location).

Geologically, Nord-Pas-de-Calais straddles two major sedimentary basins: the Brussels London basin to the north and the Paris basin to the south. The geological formations of the region are therefore exclusively sedimentary and can be classified into two groups. The first group consists of rocks of marine origin, dating from Primary to Tertiary period. These are hard rocks such as limestone, sandstone or shale, or soft rocks such as chalk and marl chalk. Soft rocks such as clay and sand are also represented in this first group. The second group consists mainly of loessal materials, marine and fluvial sedimentary deposits, and residual flint clay [Sterckeman *et al.* 2007]. The latter is the product of the intense alteration of the chalky formations of the Cretaceous period. This group also includes all remodelling products, often combining wind and colluvial processes.

From a pedological point of view, the soils encountered in the Nord-Pas-de-Calais are predominantly silty, of wind origin, and sometimes more than 10 m thick. They are known for their high fertility, notably because of their large water reserve. However, due to heavy agricultural use, they may be depleted of organic matter and locally susceptible to erosion and soil crusting. Thus, even with a low topographic gradient, runoff and erosion can be significant.

Nearly 70% of the region area are used for agriculture. Apart from Bas-Boulonnais and Thiérache where grasslands occupy more than 50% of the area, agro-systems are of the polyculture type with very varied production [Sterckeman *et al.* 2007]. Cereals, sugar beet, industrial vegetables and potatoes are the main crops. This intensive land use is promoted by a high proportion of soils with good potential, favourable climatic conditions and mild relief. Grassland occupies about 14% of the regional area and the forest cover proportion is particularly low, around 6%.

REVISED UNIVERSAL SOIL LOSS EQUATION RUSLE

The RUSLE (Revised Universal Soil Loss Equation) empirical model is a development by Renard *et al.* [1997] of the USLE (Universal Soil Loss Equation) model of Wischmeier and Smith [1958] which was initially intended for water erosion estimation at the agricultural plot scale. This revision extended the scope of the calculations to large catchment areas, including different types of land use. The spatialized approach of RUSLE is used in many studies to quantify average annual soil losses caused by water erosion [Kouli *et al.* 2009; Lifen *et al.* 2012; Renard, Freimund 1994; Stone, Hilborn 2000].

The equation incorporates five factors, each representing a physical characteristic affecting the potential amount of eroded soil: rain kinetic energy, soil erodibility, topography, vegetation cover and erosion control practices.

$$A = R \cdot K \cdot LS \cdot C \cdot P \tag{1}$$

where: A = average annual soil losses (t·ha^{-1}·y^{-1}), R = rainfall erosivity (MJ·mm·ha^{-1}·h^{-1}·y^{-1}), K = soil erodibility (t·h·MJ^{-1}·mm^{-1}), LS = topographic factor (–), C = land use and vegetation cover factor (–), P = erosion control practices factor (–).

However, RUSLE only considers soil losses resulting from sheet and rill erosion to the exclusion of other forms of erosion (gully, bank undercutting, badland, etc.). This limitation is not critical for our study as the latter forms of erosion very rarely occur in Nord-Pas-de-Calais. In the scope of the study, RUSLE factors are available at a high resolution (between 25 and 500 m), and the land use factor can easily be adapted to represent the evolution of culture growth in each season of a year. Moreover, this study is part of a larger project aiming at assessing the limits and the transferability of the RUSLE method in different climatic conditions. Therefore, it has been chosen over other models that give a more physical representation of the process and a better accountability at high resolution.

RAINFALL EROSIVITY

Precipitation is the main factor of water erosion. Rain erosivity (R) is a measure of the total annual amount of rainfall that can detach soil particles at a given location, considering the distribution of these rains over the year. This parameter is considered to assess the influence of climatic aggressiveness on soil losses. It depends mainly on the rain intensity and the kinetic energy that results directly from it.

The calculation of the R factor according to the formula of Wischmeier and Smith [1978] requires the estimation of kinetic energies (Ec) and the 30-minute average intensity ($I30$) of rain drops from each rainfall over a period of 30 years. The factor distribution in Nord-Pas-de-Calais is extracted from the European dataset proposed by the European Soil Data Centre (ESDAC), at a 500 m resolution, based on 1675 precipitation stations and 26,394 cumulated years of measurements [Panagos *et al.* 2015a]. The conditional data for the interpolation of the factor are well represented in the vicinity of the study area (Fig. 2). The R factor, generally computed for a year-round, is also available for each month, allowing to compute RUSLE at a finer time scale.

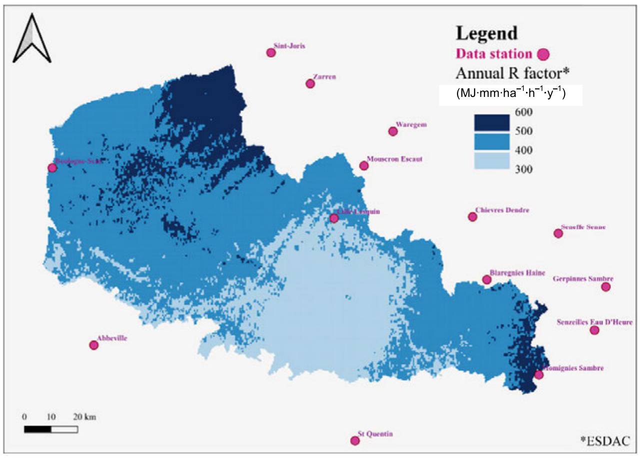

Fig. 2. Annual rainfall erosivity; source: own elaboration based on Panagos *et al.* [2015a]

In the study, monthly erosivity factors are summed to obtain a seasonal R factor (spring: April to June, summer: July to September, fall: October to December, winter: January to March). The total rainfall erosivity on a year is depicted in Figure 2, showing that the distribution of the R factor is controlled by relief, with the highest values near the Flanders hills and the Hainault slopes.

SOIL ERODIBILITY

Soil erodibility (K) is a measure of the vulnerability of soil particles to detachment and transport by rain and runoff. Texture is the main factor influencing the soil erodibility; structure, organic matter content and permeability of the soil are secondary factors [Stone, Hilborn 2000]. Overall, resistance to water erosion is lower for thin soils than for deep ones [Ryan 1982].

The K factor is determined according to the formula of Wischmeier and Smith [1978], based on soil texture, organic matter content, soil structure and permeability according to the following equation:

$$K = 2.8 \cdot 10^{-7} \cdot M^{1.14}(12 - a) + 4.3 \cdot 10^{-3}(b - 2) + 3.3 \cdot 10^{-3}(c - 3) \tag{2}$$

where: M = texture factor calculated as (% silt + % sand)(100 – % clay), a = organic matter content (%), b = soil structure (semi-quantitatively ranked between 1 and 4), and c = permeability (semi-quantitatively ranked between 1 and 6).

The spatialization of the K factor requires distributed database of the information mentioned above. The ESDAC also provides an interpolated grid of K factor at the European scale, with a 500 m resolution and a correction considering the presence of surface stones. This map is based on a 2009 soil survey concatenating 20,000 points of sampling (analysed in terms of organic matter content, soil texture, soil structure and permeability) over Europe [Panagos *et al.* 2014].

TOPOGRAPHIC FACTOR

The topographic factor (LS) represents the combined influence of the slope inclination and length [Hua, Brooks 1992]. By increasing the kinetic energy of the runoff, the inclination is an aggravating factor to the triggering of erosion (i.e. to overcome soil cohesion forces and detach particles). In particular, on the steepest slopes, it becomes predominant over the rainfall own kinetic energy. Wischmeier and Smith [1965] has shown that even on small plots, runoff increases with the slope, but its influence is regulated by soil surface roughness and water-retention capacity (type of crop and saturation level before the rain). However, the longer the slope, the greater the soil losses potential, especially as flow concentration phenomena occur.

The ESDAC topographic factor dataset [Panagos *et al.* 2015b] uses a multiple flow algorithm and specific rules for complex slopes, defined by Desmet and Govers [1996]. It provides a high resolution data grid (25 m).

LAND USE AND VEGETATION COVER

The land use factor (*C*) is a simple relation between erosion on bare soil and erosion observed under an agrarian production system. It is the main anthropogenic factor that can be used to reduce the risk of erosion.

Indeed, vegetation cover protects the soil by intercepting raindrops, dissipating a part of its kinetic energy and therefore reducing the splash effect which causes erosion [Geddes, Dunkerley 1999]. It also helps to slow the rate of formation of a slaking crust, and even more so prevents the formation of a sedimentary crust, the most severe type of agrarian soil degradation. Thus, a high infiltration capacity is maintained, limiting the risk of runoff even during heavy rainfall [Karaoui *et al.* 2018]. And even if runoff is triggered, vegetation's roots, stems and leaves, by increasing the soil surface roughness, limit the magnitude, velocity and mechanical strength of the surface flow.

In addition, vegetation cover helps to maintain soils through root systems: plants improve the cohesion of soils and thus strengthen their mechanical properties [O'Loughlin, Zhang 1986].

The land use distribution in Nord-Pas-de-Calais retained in this study is based on two data sources:
– Corine Land Cover 2018, the last version of the European biophysical land use inventory [EEA 2018];
– RPG 2019 [IGN 2019], the database containing farmers' declarations on the cultivation of their plots, mandatory to obtain Common Agricultural Policy funding.

These data are available in a digitalized GIS format, allowing a very precise spatial distribution (Fig. 3).

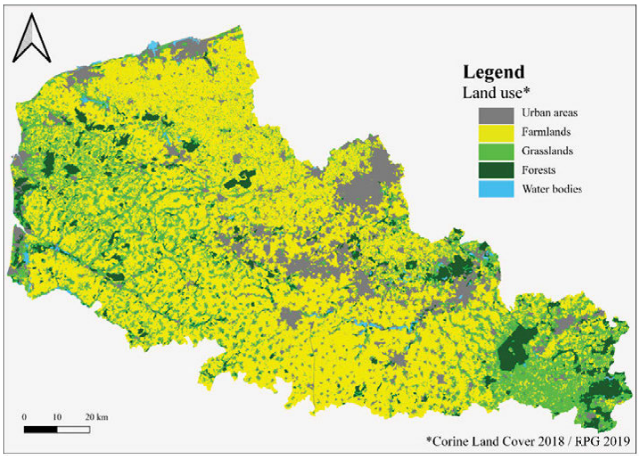

Fig. 3. Land use in Nord-Pas-de-Calais; source: own elaboration based on datasets from EEA [2018] and IGN [2019]

Agricultural plots (excluding arboriculture, indoor farming and grasslands) have been associated with different *C* factor depending on the crop type, the season and their corresponding level of culture growth [Wischmeier, Smith 1965].

The most represented crop type of the region is winter cereals (mainly wheat). They are sown during fall, shortly after their harvest, ensuring a soil cover during the winter season and an already advanced level of development in spring. Most of the other crops (corn, vegetables etc.) are sown in spring, months after their harvest, also occurring in late summer or in fall. For these types of culture, the soil cover during winter is very poor and their development peaks later (during summer) than the winter crops. Therefore, winter crops have been associated with lower *C* factor than other crops for winter (0.3 max while bare fields are associated with *C* ranging from 0.6 to 0.8) and spring (to address their more advanced development stage).

In parallel, intercrops protect the soils during fall and winter, and also improve the soil structure for the rest of the year. When applied on a plot, this farming strategy is represented by a *C* factor of 0.3 during fall and winter, and a reduction of one-third of the initial *C* value for spring and summer (to take into account the influence on the soil structure). This parametrization is inspired by the values used in studies considering crop rotations [Bielders *et al.* 2012; Wall *et al.* 2002].

Farmlands that are not covered by the RPG declarations are set by default to a spring crop *C* factor pattern, without intermediate culture. More static land use categories are associated with constant *C* values over the year (Tab. 1).

Table 1. Land use and corresponding *C* factors

Land use (%)	*C* factors (*C* factors with intermediate crops)			
	spring	summer	fall	winter
Urban areas – 10%	0			
Grasslands – 15%	0.001–0.005			
Forest – 6%	0.001			
Wetlands – 1%	0.002–0.007			
Farmlands[1)] – 68%				
– winter cereals – 51% (40%)	0.1 (0.07)		0.7 (0.3)	0.3 (0.2)
– corn – 12% (1%)	0.4 (0.3)	0.2 (0.13)	0.8 (0.3)	
– beets – 10% (<1%)	0.5 (0.35)	0.4 (0.3)	0.8 (0.3)	
– potatoes – 10% (<1%)	0.5 (0.35)	0.4 (0.3)	0.8 (0.3)	
– other vegetables – 6% (5%)	0.35 (0.25)	0.2 (0.13)	0.7 (0.3)	
– oilseeds – 4% (1%)	0.3 (0.2)	0.1 (0.07)	0.7 (0.3)	

1) Main crops % of farmlands (of which, % of intermediate crops).
Source: land use sources: EEA [2018] and IGN [2019]; *C* factors references: Wall *et al.* [2002]; Lastoria *et al.* [2008]; Bielders *et al.* [2012].

Winter cereals are already quite commonly associated with intermediate culture (40%). For the others industrial crops, this practice is very marginal. The highest *C* factors have been associated with potatoes and beets, in view of the limited leaf cover they develop. In addition, their harvesting methods (cutting leaves and mechanical removal of massive roots) make the soil more vulnerable to erosion.

Overall, the best coverage is ensured during summer, when all crops are the top of their growth. In fall, the process of harvesting leaves the soil unprotected from rainfall, which is depicted by the highest *C* factor values. For most of the crops, this high *C* remains during winter, and then decrease during spring. For winter crops, the growth is early, so the *C* factor is less degraded in winter than in fall, and the coverage during spring is reputed similar to the one in summer.

In order to assess the potential of the intermediate crop as a reduction technique of soil loss in Nord-Pas-de-Calais, a secondary computation is led with the appropriate *C* factor extended to all plots that are not yet subject to it, according to the 2019 RPG data.

ANTI-EROSION PRACTICES

The anti-erosion practices are integrated to RUSLE as corrective factor (*P*) depicting conservation cultivation techniques, other than cover techniques, already taken into account by the land cover factor. These cultural techniques reduce the quantity and speed of runoff and subsequently the erosive potential. The most common conservation practices are counter-slope tillage, contour tillage or ridging, and strip cropping. The factor is ranked from 1 (no erosion control measures) to about 0.1 when partitioned ridging is used on a gentle slope [Masson 1980; Roose 1975; Roose, Bertrand 1971; Wischmeier, Smith 1958].

In this study, *P* factor was not used because no data is available for the desired resolution. ESDAC provides a large-scale estimation that would only skew the study focus, that considers the land cover and practices (intermediate crops) at the plot scale.

METHOD FLOWCHART

Data sources and RUSLE methodology at an intra-annual seasonal time scale are summed up in Figure 4.

The soil loss maps are generated at a 25 m resolution.

RESULTS AND DISCUSSION

TOPOGRAPHIC FACTOR *LS*

The Figure 5 shows the *LS* factor extracted from the ESDAC dataset. This factor is derived from the topography, therefore, relief areas are associated with high values. The highest values are located alongside the rivers, their banks constituting the steepest slopes.

Most of the study area is characterized by very low relief and then very low topographic factors.

SOIL ERODIBILITY FACTOR *K*

The *K* factor extracted from the ESDAC dataset is compared, in Figure 6, to a simplified soil map, based on the Regional Soil Reference data [Masson 2010].

The highest *K* factors (>0.05 $t \cdot h \cdot MJ^{-1} \cdot mm^{-1}$) correspond to the leached calcic soils found in Artois and in the Flanders, and cover 29% of the region area. Silty brown soils categories show intermediate erodibility (0.03 to 0.05 $t \cdot h \cdot MJ^{-1} \cdot mm^{-1}$) while the alluvial and hydromorphic categories (7% of the area) are the least erodible.

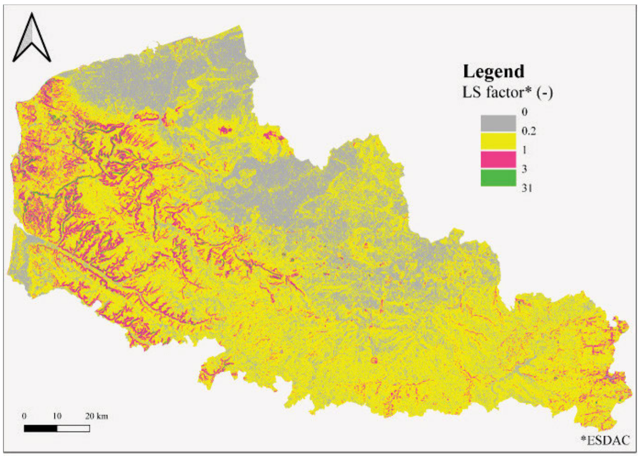

Fig. 5. Topography factor in Nord-Pas-de-Calais; source: own elaboration based on Panagos *et al.* [2015b]

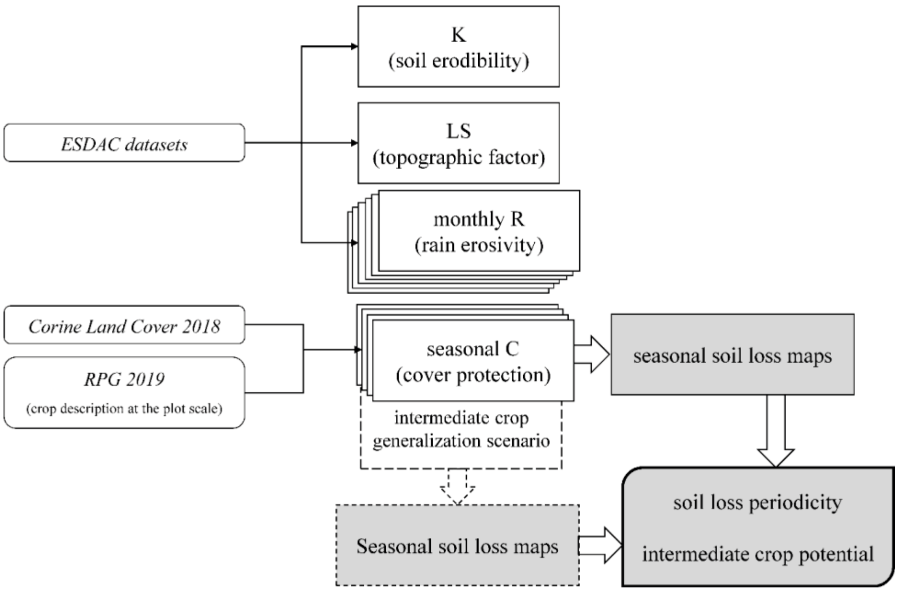

Fig. 4. Methodology flowchart; source: own elaboration

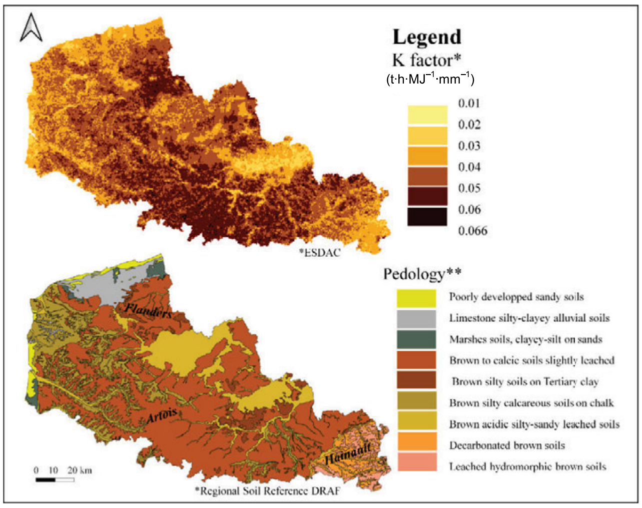

Fig. 6. Soil erodibility compared to pedology; source: own elaboration based on Panagos *et al*. [2014] (top) and Masson [2010] (bottom)

RAINFALL EROSIVITY FACTOR *R*

While the previous parameters are considered static, the *R* factor shows a significant intra-annual disparity (Fig. 7). Half of the annual erosivity occurs during summer (storm events) and very few during winter (drizzle), depicting an inverse pattern to that of the *C* factor. The rest of the erosivity is almost equally distributed between spring and fall (22.6% and 20.5% respectively).

Spatially, the values are less dispersed, with relative standard deviation (*RSD*) ranging between 9.7% (winter) and 14.1% (fall) (Tab. 2). Nonetheless, the most erosive rainfalls, as already shown in Figure 2, are located near the Flanders hills and the Hainault reliefs (Foehn effect).

LAND USE FACTOR *C*

By combining the land use layout (Fig. 3) and the crop cover seasonality (Tab. 1), the *C* factor spatial and temporal distributions are shown in Figure 8.

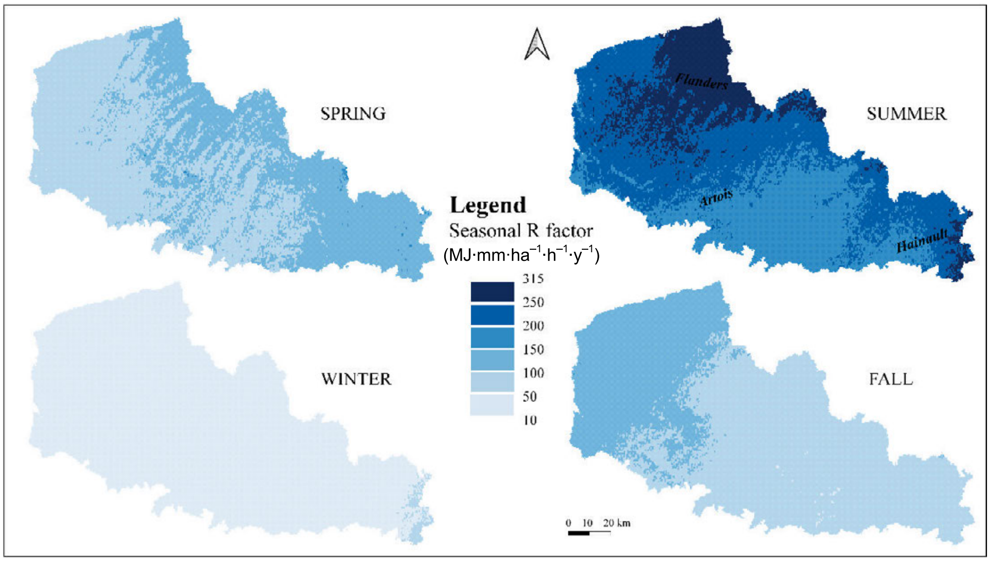

Fig. 7. Seasonal rainfall erosivity in Nord-Pas-de-Calais; source: own study

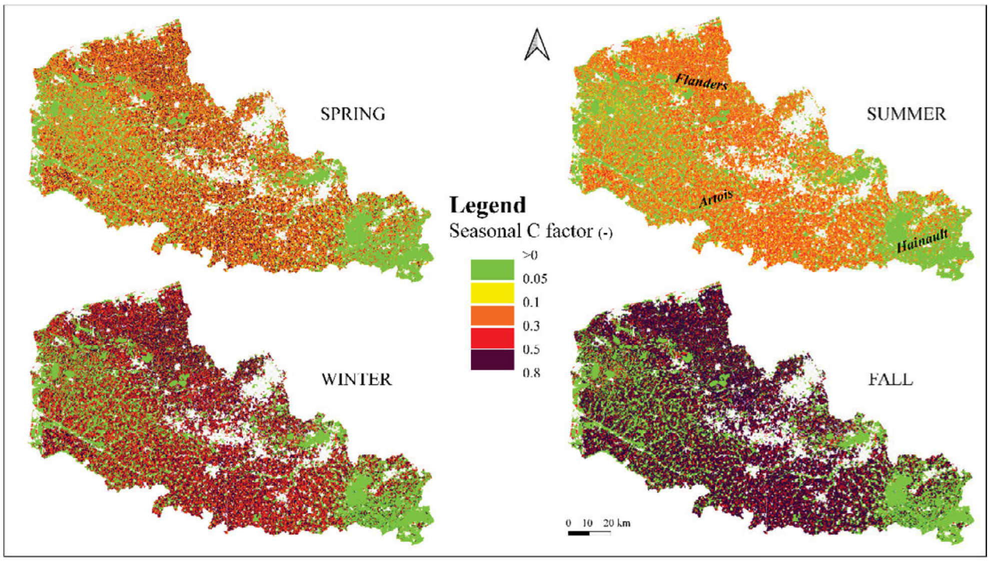

Fig. 8. Land cover factor seasonality; source: own study

Table 2. *R* factors characteristics per seasons and annually

Period	*R* factor ($MJ·mm·ha^{-1}·h^{-1}·y^{-1}$)			*RSD* (%)	Contribution (%)
	min	max	mean		
Spring	48.6	174.9	98.7	10.9	22.6
Summer	153.1	315.9	219.9	10.3	50.4
Fall	45.7	164.3	89.6	14.1	20.5
Winter	14.4	68.9	27.9	9.7	6.3
Yearly total	305.6	597.4	436.2	9.2	100.0

Source: own study.

Nord-Pas-de-Calais being mainly covered by industrial crops, high *C* factors are widely distributed over the region. The Hainaut sub-region (S–W), dominated by pastures and grasslands, but also the coastal fringes and the vicinity of rivers, constitute the areas of low *C* factors.

The times cycle of this factor is opposite to the rainfall erosivity: summer is associated with the lowest values (mean: 0.095). Due to a high proportion of early sown crops (winter wheat), winter season is characterized by a lower *C* factor (0.293) than fall (0.377), the least protective season in terms of plant cover. Meanwhile, the spring average value (0.145) is mid-way between winter and summer, in line with the growth pattern of the crops.

SEASONALITY AND MAGNITUDE OF WATER EROSION IN NORD-PAS-DE-CALAIS

The main outputs of the modelling process are seasonal soil loss maps with a 25 m spatial resolution (Fig. 9).

Although the rain erosivity is concentrated in summer, the high level of crop development ensures a moderate soil loss during this season (accounting for 26% of the total annual loss). In contrast, during winter, rainfall delivers very low kinetic energy and soil losses are minimal (11% of the total), even if the *C* factors are quite high. The desynchronization of the *C* and *R* factor cycles (Fig. 10) also results in a low contribution of spring (17%) and a maximal ratio for autumn (46%), with loss peaking, for the most degraded location (pixel), at 36 $t·ha^{-1}·y^{-1}$ (this value corresponding to the soil loss occurring in one season of the year).

An annual soil loss map, resulting from the addition of the seasonal rates, is put in comparison with the 2016 ESDAC RUSLE results in Figure 11. When cumulated over the year, the erosion rates range between 0 and 54 $t·ha^{-1}$, for a total of 1.69 Mt of losses over the Nord-Pas-de-Calais region. ESDAC estimates ratio up to 23 $t·ha^{-1}$ and a total loss of 1.32 Mt. This discrepancy is mainly due to a different *C* parametrization: the ESDAC mean *C* value is 0.157 while this study considers a mean *C* of 0.228 over the year. In particular, the ESDAC *C* values never exceed 0.26, even for industrial crops, while, in this study, the mean annual *C* for corn, beets and wheat are 0.5, 0.63 and 0.3 respectively. These values are more consistent with the literature [Bielders *et al.* 2012; Lastoria *et al.* 2008; Wall *et al.* 2002]. In addition, the ESDAC calculation incorporates an anti-erosion practice ratio (*P* factor ranging from 0.75 to 1) that has not been retained in this study, in the absence of data at the plot scale.

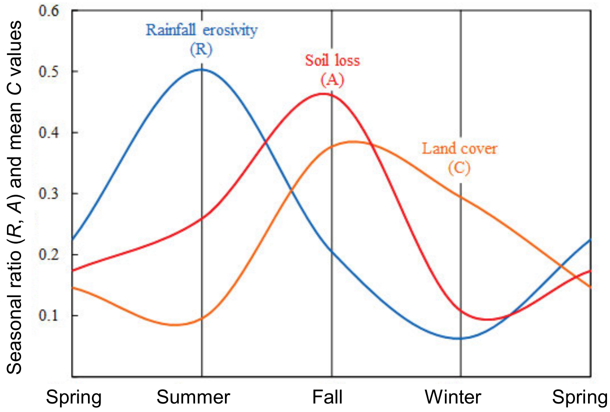

Fig. 10. RUSLE parameter and output annual cycles; source: own elaboration

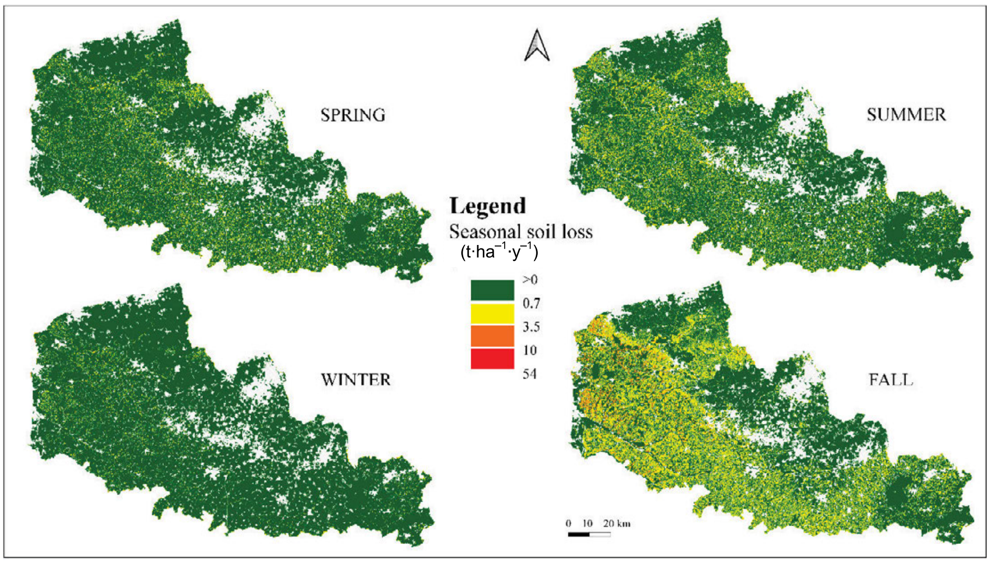

Fig. 9. Seasonal soil losses in Nord-Pas-de-Calais; source: own study

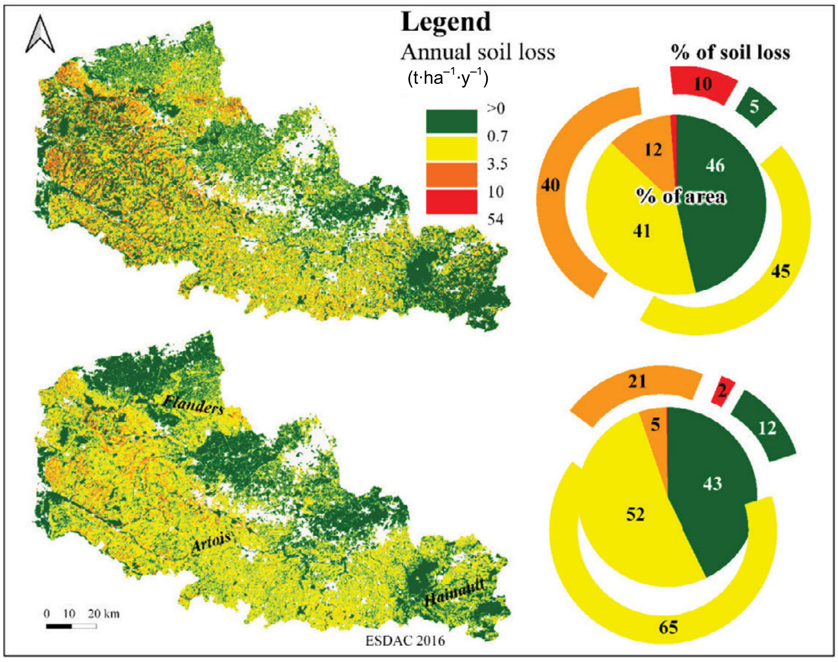

Fig. 11. Annual water erosion comparison; source: own study (top) and PANAGOS *et al.* [2012] dataset revised in 2016 (bottom)

On the other hand, by better representing the time cycle of crop growth and climate intra-annual heterogeneity, the seasonal approach tends to reduce the calculated losses in Nord-Pas-de-Calais, when compared to the values that would be obtained with averaged C factors from our study. Indeed, in these conditions, RUSLE estimates a total annual soil loss of 1.83 Mt.

SPATIAL DISTRIBUTION AND CLASSIFICATION OF THE WATER EROSION

The classification chosen to represent the different degrees of soil loss (Fig. 9 and 11) is based on an irregular scale with a strong refinement at the location of low erosion rates, in order not to assess their contribution to the global loss (see diagrams on Fig. 11). The lowest rates (<0.7 $t{\cdot}ha^{-1}{\cdot}y^{-1}$) are located in the grasslands (including buffer strips near the cultivated plots) and where the topographic factor is very low (<0.2). Encompassing most of the Lower Country, but also the Hainault sub-region, this class represents 46% of the region area but accounts only for 5% of the total loss (Fig. 11). The second contributing class is of intermediate rates (from 0.7 to 3.5 $t{\cdot}ha^{-1}{\cdot}y^{-1}$) and generates losses in proportion to its surface area (45% of the losses for 41% of the area). This can be analysed as the background soil loss occurring almost ubiquitously on plots in Nord-Pas-de-Calais, in its current agricultural structuration. The most contributing classes (>3.5 $t{\cdot}ha^{-1}{\cdot}y^{-1}$) are located on the steepest slope of the region (Artois and Flanders sub-regions). Therefore, their extent is very limited (13%) but their contribution is major (50%). The same agricultural sub-regions (Flanders and Artois) are associated with a strong to a very strong erosion hazard by the MESALES regional risk map. The spatial distribution of the ESDAC computation is also very comparable to the study one.

The proportions of losses attributable to each of the main crop types are reported in the Table 3. When normalized by the proportion of the agrarian area occupied, this value gives an indication of the soil loss productivity for each crop type. Due to the predominance of early sown cultures and the association with intermediate crops, cereals are the least productive in terms of erosion (ratio of 0.7). On the opposite, corn and beets are superproductive of soil losses, with a 1.6 ratio. Potatoes crops are located in areas where erosion sensibility is less thanks to the other factors, resulting to a lower ratio (1.3) despite the fact it shares the same C values than beets.

Table 3. Crop contribution to erosion

Crops	% of area	% of soil loss	loss/area ratio
Cereals	53	38	0.7
Corn	12	19	1.6
Beets	10	16	1.6
Potatoes	10	13	1.3
Oilseeds	4	4	1.0
Other crops	11	10	0.9

Source: own study.

Other land covers (urban, grasslands, forest) generate less than 1% of the total loss.

ESTIMATION OF THE INTERMEDIATE CROP TECHNIQUE POTENTIAL

As introduced in the methodology section, the intermediate crop technique is represented in the RUSLE model thanks to lower C values, especially during fall and winter. The generalization of these minored C values in Nord-Pas-de-Calais gives a quantification of the intermediate crop technique potential in reducing the soil erosion process.

The output of this prospective model is presented in Table 4.

Table 4. Intermediate crops extension scenario output

	Spring	Summer	Fall	Winter	Total
Soil loss (Mt) with extended intercrops	0.22	0.32	0.42	0.11	1.07
Reduction compared to the current situation (%)	26	27	46	40	37
Seasonal contribution to the total reduction (%)	12	19	58	11	100

Source: own study.

The seasonal reduction during spring and summer is roughly equal to the *C* factor modification, imposed at 2/3 of its value without intermediate crop (to take into account the improvement of the soil structure). The percentage of reduction is slightly lower because of the plots (mainly wheat) already involved in this technique. The greatest seasonal reductions occur in fall and winter, the *C* values being capped at 0.3 during these seasons.

Overall, the model predicts a decrease of the yearly losses above 1/3, with more than half of the gain occurring during fall.

BENEFITS AND LIMITATIONS OF THE STUDY

Compared to yearly averaged RUSLE applications, the seasonal approach of the study better represents the plant cover cycle and its protective role against rainfall erosivity, also varying depending on the time of the year. These two factors cycles being out of phase, the time discretization effort appears very appropriate.

In parallel, the implementation of high resolution crop data, both in terms of categorization (precise crop type) and of localisation (plot scale), gives to the output (soil loss maps) great operability. Indeed, these maps can be used by stakeholders, at various sub-region scales (given the resolution), to locate and prioritize the actions and parties involved. Thanks to figures aggregated for a specific crop type, action groups can be constituted by the farmers at stake.

The intra-annual time discretization has been used to assess the input of the intermediate crop technique. But this time scale is not the only one appropriate to assess farming influence on the water erosion phenomenon. In particular, the soil structuration takes place over several years, and is highly influenced by the crop rotations. Extending the seasonal methodology to multiple years (RPG survey data being published every year), with a crop rotation modulated *C* factor, is perceived as a logical follow-up of the current study.

Finally, if large scale mapping can be downscaled for local purposes, it should be controlled by gauging field data, in order to check its consistency at the given scale and location.

CONCLUSIONS

The Revised Universal Soil Loss Equation (RUSLE) has been used to assess the extent and the dynamic of soil water erosion in the Nord-Pas-de Calais region (France), with a seasonal time discretization and accurate farming data (both in terms of classification and localization).

Due to a time lag between the intra-annual cycles of the parameter accounting for the culture growth on one part, and the rainfall erosivity on the other part, fall has been found as the most contributing season of the year in terms of soil losses (46% of the annual total of 1.69 Mt). In this season, most of the plots are left bare after harvest, making the soils very vulnerable to rainfall. In winter, the vegetation cover is also fairly low (apart from plots growing winter cereals), but the rain erosivity is not high enough to trigger significant amount of erosion (only 11% of the total). The most aggressive rainfall events occur during summer, but the crops development is at its maximum, ensuring moderate losses (26%).

The winter cereal crops, especially when associated with intercrops, are the less subject to water erosion, while the corn and beet cultures (almost never integrating intercrops) are the most productive of soil losses in Nord-Pas-de-Calais. The computation of the model with a scenario of extension of the intercrop technique has shown a loss reduction potential of 37% over a year.

Soils water erosion is almost ubiquitous in the region. The most protected areas are the grasslands (Hainault). The sub-region at risk are the Artois Hills and the Flanders, characterized by the steepest slopes, and therefore, the highest losses (up to 54 $t \cdot ha^{-1} \cdot y^{-1}$).

The seasonal approach of the study gives a better picture of the parameters influencing water erosion (plant cover, rainfall distribution) while being consistent with the ESDAC own calculations. The high resolution crop data gives also great operability to the maps and rates generated, making it possible to aim at specific groups of farmers as well as prioritize and build appropriate actions depending on the type of culture. However, the time range of the study (computing RUSLE over a sole year) can be seen somehow problematic, a great part of the soil structuration (or weakening) taking place over the years and the rotations of cultures.

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