European Evaluation Helpdesk

for Rural Development

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Example

'Using Sen4CAP Earth Observation markers for evaluating soil erosion'

WP 2 'Knowledge Transfer'

Thematic Working Group No 9

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European Evaluation Helpdesk for Rural Development

European Network for Rural Development

The Evaluation Helpdesk is responsible for the evaluation function within the European Network for Rural Development (ENRD) by providing guidance on the evaluation of RDPs and policies falling under the remit and guidance of DG AGRI's Unit C.4 'Monitoring and Evaluation' of the European Commission (EC). In order to improve the evaluation of EU rural development policy the Evaluation Helpdesk supports all evaluation stakeholders, in particular DG AGRI, national authorities, RDP managing authorities and evaluators, through the development and dissemination of appropriate methodologies and tools; the collection and exchange of good practices; capacity building, and communicating with network members on evaluation related topics.

Additional information about the activities of European Evaluation Helpdesk for Rural Development is available on the Internet through the Europa server (http://enrd.ec.europa.eu).

CONTENT

Introduction

This document is one of the outcomes of the Working Package 2 'Transferring knowledge for better use of data for evaluating the CAP' which aims to support the transfer of various solutions included in the Evaluation Knowledge Bank to the CAP evaluation context.

This document provides an example of using Earth Observation markers of the project 'Sen4CAP - Sentinels for Common Agriculture Policy' in the evaluation of soil erosion.

This is a **non-binding document**, which serves as a knowledge transfer tool which will facilitate the transfer of the Evaluation Knowledge Bank content into practice.

The drafting of this document has been carried out by evaluation experts in the context of the Evaluation Helpdesk's Thematic Working Group (TWG) on the 'Research projects to support better data for evaluating the CAP'.

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Example 'Using Sen4CAP Earth Observation markers for evaluating soil erosion'

Background

This work aims to demonstrate how Earth Observations (EO) can be used to evaluate Rural Development measures. EO data for agricultural policy has been generated to support monitoring and controlling farmers' compliance with various policy measures, especially greening. In this effort, raw EO data from sentinels undergo treatment and produce biophysical markers such as the Normalised Difference Vegetation Index (NDVI), the Fraction of green Vegetation Cover (FCOVER) and the Leaf Area Index (LAI).

Sentinels for Common Agricultural Policy (Sen4CAP) is a landmark project in EO utilisation in agricultural policy monitoring and control. Sen4CAP has produced a range of EO products and a database of markers suitable to work with the Integrated Administration and Control System (IACS) and the Land Parcel Information System (LPIS). Sen4CAP offers markers data such as the NDVI, FCOVER or LAI biophysical variables averaged at the plot level of the LPIS. An exposition to the Sen4CAP tools that have potential use in evaluation and the description of the markers database are in the newly released Evaluation Knowledge Bank of the European Evaluation Helpdesk for Rural Development.

This work aims to demonstrate using EO data without discussing specific impact indicators' scientific basis and methodologies. The exposition is inclined towards evaluation perspectives and methods and less on remote sensing and soil sciences. Sen4CAP kindly agreed to support the aim of this work and provide a specimen of anonymised data for demonstrating the use of EO data in evaluation. The most convenient sample concerned a small area from a Member State (MS) where Sen4CAP has produced markers at the plot level to check compliance with various greening rules. Thus, the choice of the Ecological Focus Area (EFA) greening measures, especially catch crops, is convenient for demonstration purposes. The soil erosion indicator is an obvious choice as it concerns the impacts of catch crops.

Policy considerations (policy context)

Greening and the Ecological Focus Area context

Greening measures, intended to allow the Common Agricultural Policy (CAP) to deliver environmental and climate change objectives, were introduced by the 2013 CAP reform. The measures are compulsory, account for 30% of the direct payments budget and are deployed in three groups:

- Crop diversification implies cultivating a minimum of two or three crops on arable land above certain size limits, with almost 75% of the arable land being subject to crop diversification;
- Maintenance of permanent grassland aims to keep the ratio of permanent grassland to the total agricultural area above 5%, designate the most environmentally sensitive permanent grasslands (ESPG) and protect them from ploughing. The measures concern almost 50 million hectares;
- Ecological Focus Areas combines farming practices such as catch and cover crops or fallow land and landscape features such as green margins, trees and hedgerows. EFAs manage at least 5% of the arable land of farms with more than 15 hectares and

improve on-farm biodiversity. Almost 70% of arable land is subject to the EFA measure, which translates to 8.5 million ha managed as EFA.

A relatively recent evaluation study of the CAP greening measures found that 'the main types of EFA used by farmers in 2016 were nitrogen-fixing crops (39%), catch and cover crops (34%) and fallow land (24%)'. The same study found that the 'measure has contributed to the expansion of the area under N-fixing crops (alongside voluntary coupled support and the crop diversification measure) and under catch and cover crops (also required under some Nitrate Action Plans). The negative trend in the EU fallow area stabilised in 2015 in many countries where farmers used land lying fallow under the EFA measure'.

Although the effectiveness of EFA measures on biodiversity, habitats and landscapes is relatively low, with the exemption of the fallow land measure, EFAs, especially the use of catch and cover crops, have considerable effects on conservation agriculture (Alliance Environnement, 2019). Conservation agriculture proposes a set of guiding principles based on minimum soil disturbance, permanent plant or crop residue cover and diverse crop rotations to reduce the need for inputs. A catch crop is a fast-growing crop that can be grown between successive main crops, usually for 6 to 10 weeks, to provide soil cover and improve soil properties, including organic matter and rooting structure and to protect soil from water erosion. Catch crops improve bulk density at various depths, increase dry biomass and soil moisture, enhance infiltration and prohibit surface runoff. Multiple experiments have shown that sediment concentration in the runoff is considerably reduced when catch crops or weeds are used (Cerdà et al., 2018).

The evaluation objective

This work aims to evaluate the effects of the EFA measures due to greening in a specific Member State on soil erosion. EFA measures such as the use of catch and cover crops, besides other measures of the greening policy, also can be part of the agri-environment measures of Rural Development Programmes of the Focus Areas 4 or 5, or the eco-schemes and the agri-environment measures of Article 42 of the CAP Strategic Plans. This work will attempt to demonstrate how to combine data from IACS and the LPIS and utilise EO data and other available sources to calculate:

- The results and extent of the intervention – 'How much land is subject to catch crops?' (result indicator).
- The gross impact of the intervention on soil erosion – 'Which is the reduction in soil erosion due to the use of catch crops?' (impact indicator).
- The net impact of the intervention on soil erosion – 'Which is the reduction in soil erosion due to use of catch crops in a counterfactual framework?' (net impact indicator)
- The rate of soil loss by water erosion – 'Which is the erosion estimate before the intervention, i.e., the value of soil erosion before using catch crops under the EFA greening rule?' (context indicator).

Case study and data

Land use (IACS/LPIS)

The case study is a 20 x 25 km rectangle included in a real Sentinel-2 tile located in a Member State. The agricultural area is almost 30 thousand hectares, comprised of arable land (45.2%) and grassland (53.9%). For arable land, the average size per plot is 4.06 hectares and for grassland is 2.48 ha (Table 1). Corn and potatoes occupy almost two-thirds of arable land (Figure 1).

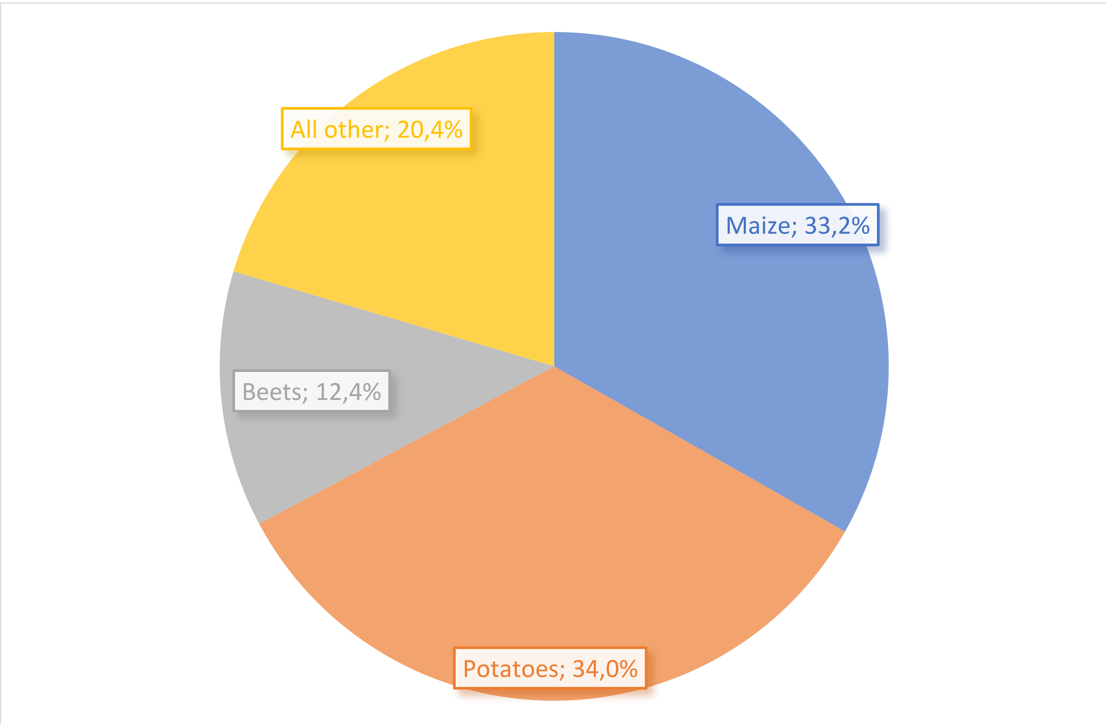
For the EFA areas, the Member State promoted the cultivation of catch crops. Catch crops can be grown either as the main crop or after the main crop. In general, the vegetation period of main non-catch crops is from 1 May to 15 October. For catch crops, farmers have two choices. First, they can be grown as the main crop. In this case, the vegetation period is from 1 May to 15 July. Second, catch crops can be grown as a following up crop. In this case, the vegetation period starts from 15 October. In the case study area, the EFA catch crop eligible area occupies almost 4,000 ha of arable land on 972 plots (Map 1). Out of these 972 plots, 74 plots (7.6%) are cultivated as the main crop and 898 plots (92.4%) as a follow-up crop.

Table 1: Land use allocation, number of plots and average size per plot.

	All land (ha)	Number of plots	Average size per plot (ha)
Semi-natural land	59.93	316	0.19
Arable	13,468.45	3,317	4.06
Permanent plantations	77.61	30	2.59
Grassland	16,065.10	6,475	2.48
Fallow	33.40	63	0.53
Greenhouse or nursery	109.63	99	1.11
Total	**29,814.12**	**10,300**	**2.89**

Source: Data from the MS's IACS/LPIS in 2019. Calculations and analysis by the author.

Figure 1: Major arable land cultivations.



Source: Data from the MS's IACS/LPIS in 2019. Calculations and analysis by the author.

Map 1: The case study area and the spatial disposition of the EFA eligible land.

Source of Data: Declared EFA plots from the MS's IACS/LPIS in 2019. Cartography and spatial analysis by the author.

Soil erosion by water – the baseline (ESDAC/LUCAS Soil)

Water erosion may be estimated either by national simulations based on national soil surveys and experimental methods or by utilising the European estimation of soil erosion data by ESDAC, which are used to calculate the context indicator (Panagos et al., 2015a). The estimated soil erosion is a baseline indicator because all data used in its estimation are before 2013. As indicated in Map 2, water erosion in the case study area is less than moderate and is nowhere higher than 4.2 tonnes per hectare per year (t ha^{-1} y^{-1}).

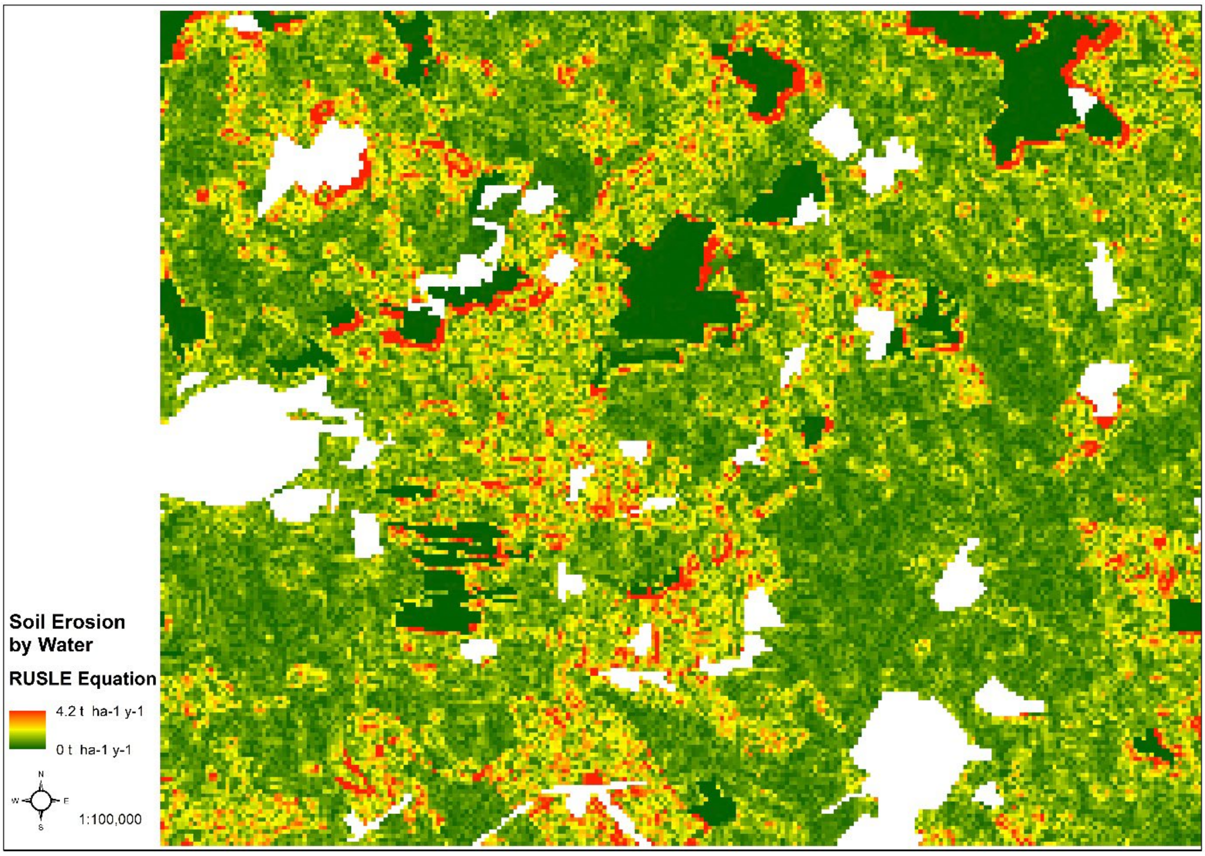
This lower water erosion risk results from the relatively low slopes and favourable soil structure. The average water erosion in the area is 0.153 tonnes per hectare per year for all plots. For arable land, this figure is 0.169 practically without any difference between arable with and without a following up catch crop cultivation (Table 2). This finding is expected since no EFA catch crop measures had been implemented during the baseline period prior to 2014. Fallow land has the highest erosion and semi-natural areas the lowest. Grasslands and arable land contribute almost 2.2 thousand tonnes of eroded soil each. The figures in Table 2 can be produced quickly by raster value statistics of the raster shown in Map 2, combined with data from IACS and LPIS shown in Map 1. From the Eurostat agri-environmental indicators database, one can find out that the respective soil erosion figures for the NUTS3 and the NUTS2 that contains the case study area is 0.2 tonnes per hectare and year and for the country is 0.3 tonnes per hectare and year (Eurostat variable: aei_pr_soiler).

Table 2: Descriptive statistics of baseline erosion in t ha-1 y-1, by land-use.

	Average	Min	Max	Range	St. Dev.	Sum
natural areas	0.110	0.000	1.308	1.307	0.153	79.393
arable	0.169	0.001	2.649	2.648	0.139	2,274.524
of which:						
no-EFA	0.169	0.001	2.649	2.648	0.140	1,604.000
EFA after main crop	0.171	0.001	1.389	1.389	0.135	666.528
annual crops	0.243	0.022	1.168	1.145	0.210	18.928
grassland	0.138	0.000	3.615	3.615	0.123	2,206.401
fallow land	0.191	0.035	0.559	0.523	0.126	5.725
greenhouse or nursery	0.198	0.021	0.796	0.775	0.141	21.935

Source: Data from Panagos et al. (2015a) combined with the MS's IACS/LPIS in 2019. Calculations and analysis by the author.

Map 2: Soil erosion in the case study area.



Source of Data: Panagos et al. (2015a) Soil erosion by water raster at 100m resolution for EU-28 Member states. Note: for areas in white no soil erosion value has been estimated. Cartography by the author.

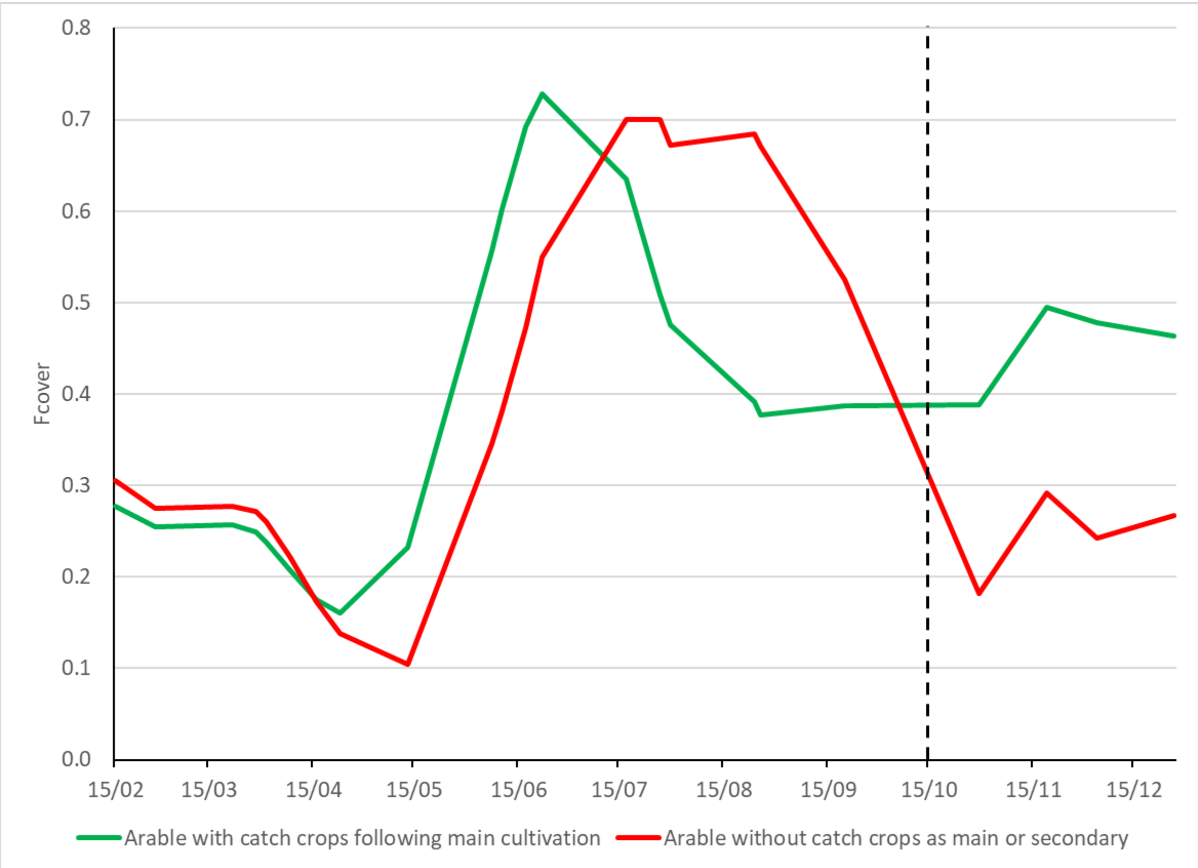
Earth Observations (Sen4CAP)

The Sen4CAP system produces a wide range of EO markers derived from Sentinel-2 and Sentinel-1 over an area of interest defined by the user. This work presents three markers derived from three biophysical markers, namely the FCover, the NDVI and the LAI.

The FCover corresponds to the fraction of ground covered by green vegetation (Copernicus online glossary). FCover quantifies the spatial extent of the vegetation. This marker is independent of the illumination direction, and it is sensitive to the vegetation amount. For this reason, it is a perfect candidate for the replacement of classical vegetation indices for the monitoring of ecosystems. It has been used for estimating the cover management coefficient of soil erosion. NDVI is not a physical property of the vegetation cover, but its very simple formulation makes it widely used for ecosystems monitoring. NDVI is an indicator of the greenness of the biomass (Copernicus online glossary). Finally, LAI is defined as half the total area of green elements of the canopy per unit of horizontal ground area (Copernicus online glossary). Practically, the LAI quantifies the thickness of the vegetation cover and thus is also crucial for soil erosion.

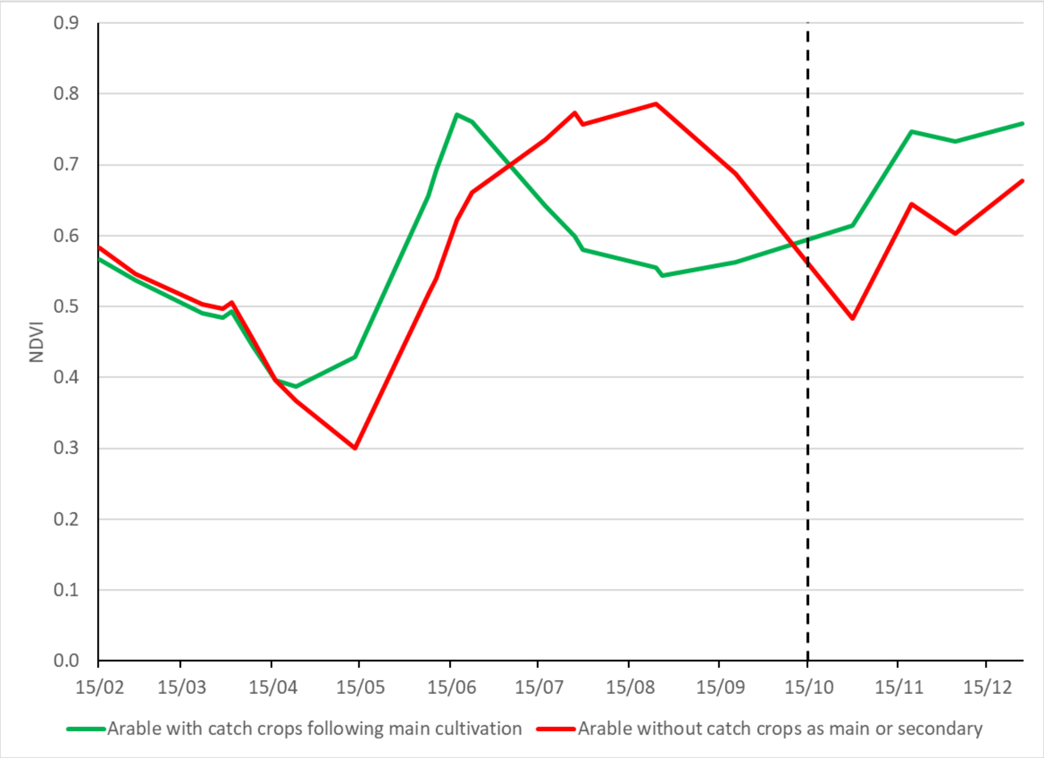
These EO variables, which are based on optical signals, are affected by cloudiness, and thus evaluators should decide how to handle missing data. From the 10,330 parcels of the case study area's LPIS, Sen4CAP provided the average per parcel values of the above-mentioned biophysical markers for 9,962 parcels and each Sentinel-2 acquisition for the whole year of 2019 (up to 99 acquisitions in one year, due to the Sentinel-2 orbits overlapping). Depending on the cloud cover, missing values ranged from 9960 (all plots missing) to 0 (no plots missing). Figures 2, 3 and 4 present the average value of the three markers for selective dates in 2019. These graphics, especially the NDVI, clearly show when the main crop was sown, grown and harvested and when the secondary catch crop cultivation was planted and started to grow.

Figure 2: FCover in the case study area.



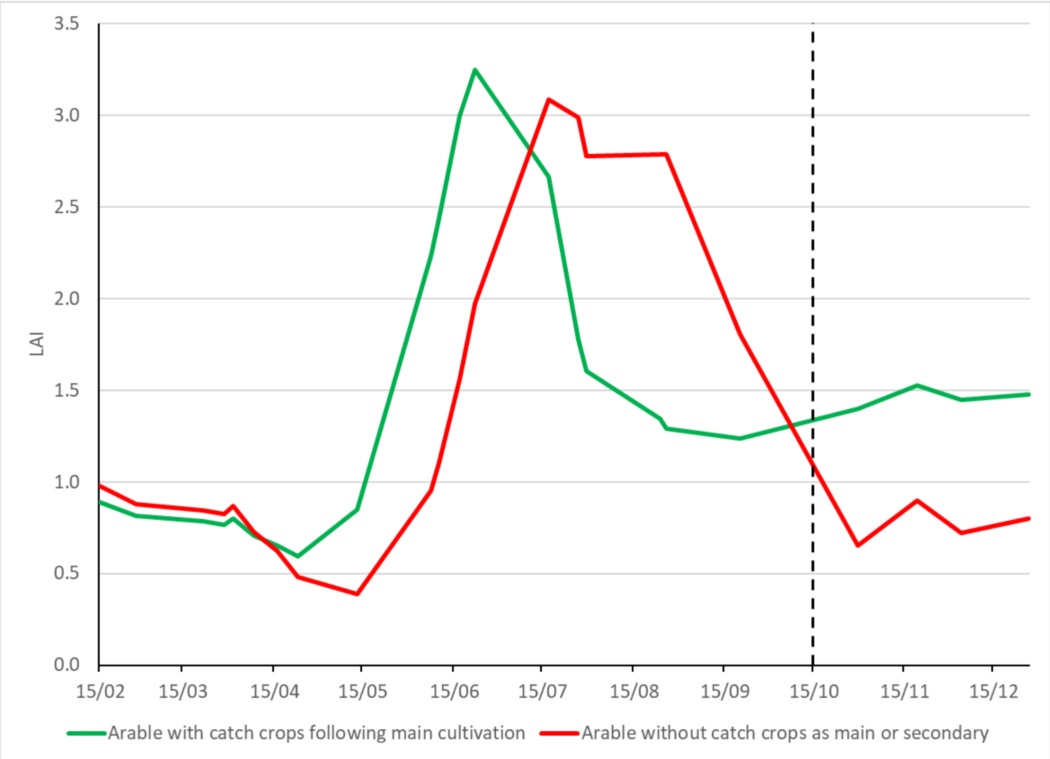
Source of Data: Sen4CAP markers database.

Figure 3: NDVI in the case study area.



Source of Data: Sen4CAP markers database.

Figure 4: LAI in the case study area (multiplied by 1000).



Source of Data: Sen4CAP markers database.

The evaluation approach

Soil erosion and the Revised Universal Soil Loss Equation (RUSLE)

Usually, soil erosion is approximated through the Revised Universal Soil Loss Equation (RUSLE) equation which calculates the mean annual soil loss rates by sheet and rill erosion according to the following equation (Panagos et al., 2015a):

$$E = R\ x\ K\ x\ C\ x\ LS\ x\ P \quad (1)$$

where:

E is the annual average soil loss (t ha^{-1} yr^{-1}),

R is the rainfall erosivity factor or the R-factor (MJ mm ha^{-1} h^{-1} yr^{-1}),

K is the soil erodibility factor of K-factor (t ha h ha^{-1} MJ^{-1} mm^{-1}),

C is the cover-management factor or C-factor (dimensionless),

LS is the slope length and slope steepness factor or LS-factor (dimensionless),

P is the support practices factor or P-factor (dimensionless).

All the above factors contribute to the annual average soil loss formulation. However, an agricultural policy can only affect C, cover-management, and P, support practices. For arable land, the C factor is (Panagos et al., 2015b):

$$C_{arable} = C_{crop}\ x\ C_{management} \quad (2)$$

where C_{crop} of equation (2) is the C-factor element based on the crop composition of an agricultural area, defined as:

$$C_{crop} = \sum_{n=1}^{17} C_{cropn}\ x\ [\%\ NUTS2_{cropn}] \quad (3)$$

where C_{cropn} of equation (3) represents the C-factor of the n^{th} crop, and [%] $NUTS2_{cropn}$ represents the share of this crop in the arable land of the given NUTS2 region.

The $C_{management}$ factor of equation (2) quantifies the multiplicative effect of three different management practices, namely reduced tillage, the presence of cover crop and the management of crop residues, on soil erosion reduction. The management factor is:

$$C_{management} = C_{tillage}\ x\ C_{cover}\ x\ C_{residues} \quad (4)$$

Thus, the management factor can reflect the combined effect of conservation agriculture and carbon agriculture measures.

The P-factor accounts for the effect of three support practices, namely contour farming, maintenance of stone walls and presence of grass margins on soil loss. The P-factor is (Panagos et al., 2015c):

$$P = P_c\ x\ P_{sw}\ x\ P_{gm} \quad (5)$$

where P_c is the contouring sub-factor for a given slope of a field, P_{sw} is the stone walls sedimentation sub-factor known as terrace sub-factor, and P_{gm} is the grass margins subfactor, also known as strip cropping sub-factor and buffer strips.

Cover and catch crops affect the C-factor directly by changing the C_{cover} element of the $C_{management}$ sub-factor. Cover and catch crops hold the soil in place, reduce crusting and protect against erosion due to rain, especially during the late autumn and winter months. The above-ground portion of catch crops protects the soil from raindrops and heavy precipitation. The level of protection depends on stalk and leaf growth that prohibit soil loss (SARE, 2007). This is depicted by the levels of the FCover and NDVI biophysical marker. Also, long-term use of cover crops increases water infiltration and reduces runoff that carries away soil. The benefits of catch crops are numerous and well documented and span beyond protection from soil erosion due to water (SARE, 2007).

The evaluation process

Diagram 1 proposes an evaluation process based on EO. Agricultural policy measures attempt to influence the adoption of farm management or support practices that are favourable to resource conservation. In the case of this example, catch crops increase the soil's cover during a period of high risk for erosion by water. The FCover and NDVI markers can measure the increase in soil cover and relate it to changes in the C_{cover} sub-factor. Diagram 2 explains in more detail the last two boxes of this process.

Diagram 1: From Earth Observations to Policy Impacts on Soil Erosion.

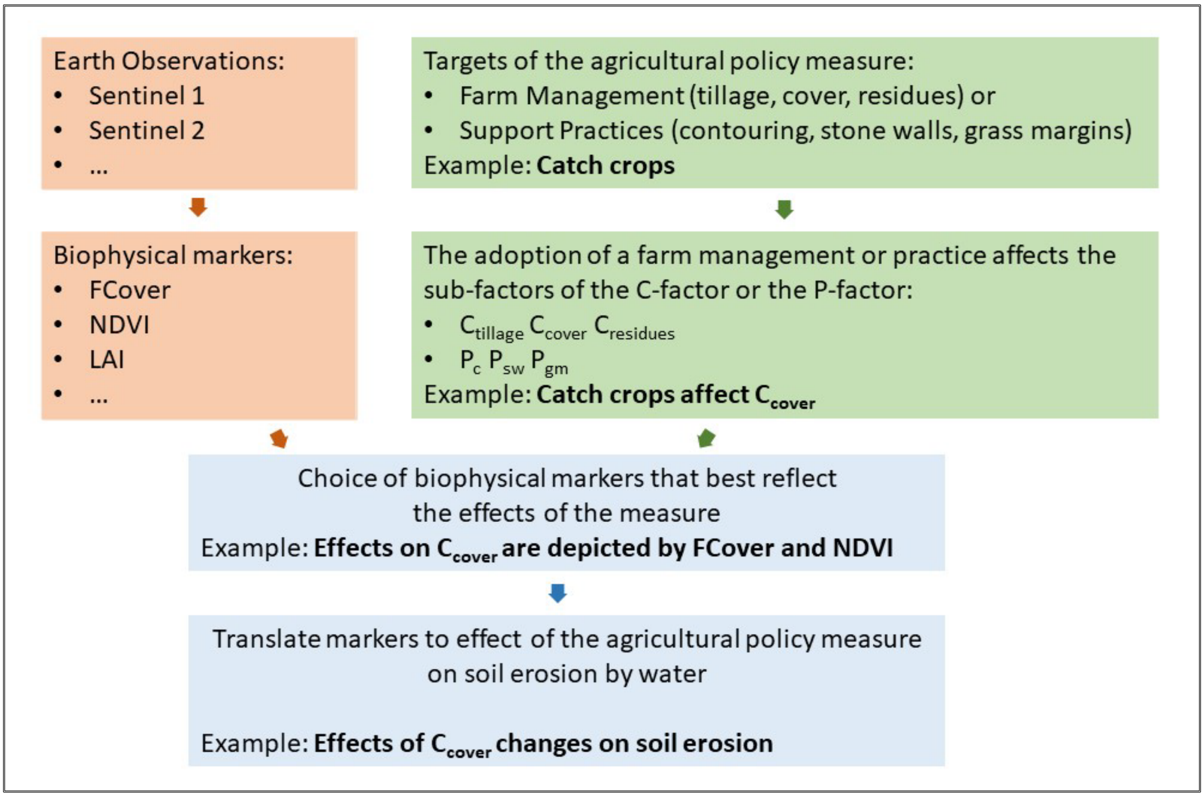
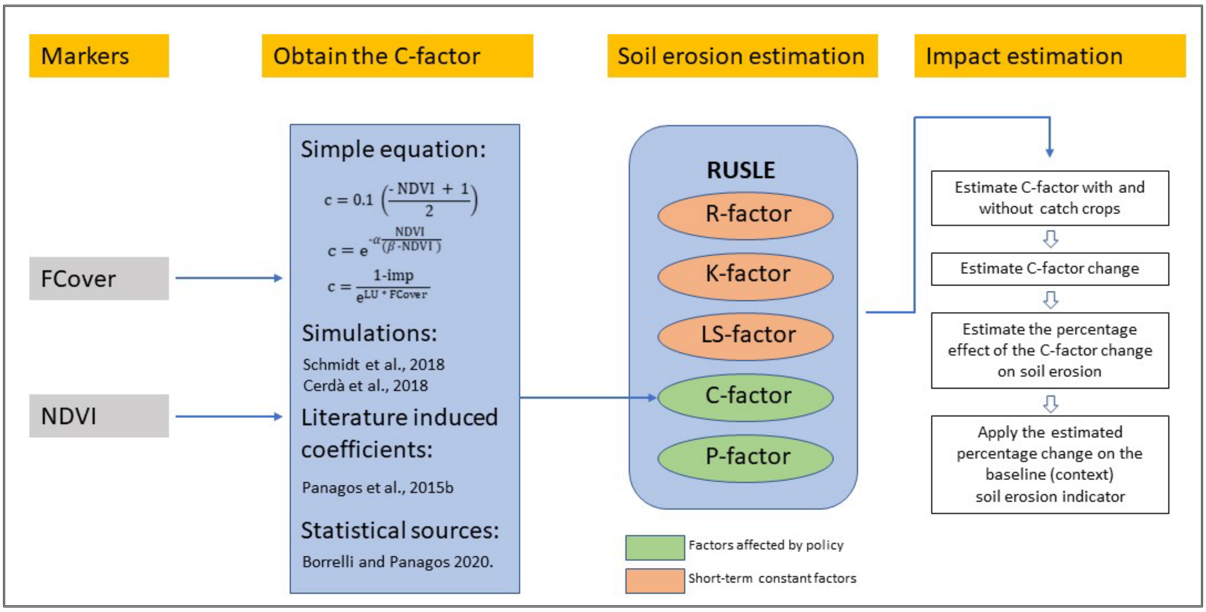


Diagram 2 shows, in detail, the process for 'translating' the chosen markers into soil erosion changes. Markers are related to changes in the C-factor and the P—factor of the RUSLE. In the case of the C-cover factor, FCover and NDVI can be used to derive estimates and changes of the C-cover. For example, in Europe, the FCover marker can be related to the C-factor through the following equation (Karydas and Panagos, 2019):

$$c = \frac{1-imp}{e^{LU * FCover}} \qquad (6)$$

where c is the C-factor for a specific month and land cover/use in the range [0, 1) (dimensionless), imp is the imperviousness degree corresponding to 0–100% of soil sealing, in the range [0,1) (dimensionless) derived from Copernicus services, LU is an empirical parameter for land use, in the range [1,10], with lower values corresponding to intensive management or unprotected land uses and higher values corresponding to better management conditions, and FCover is the Fractional vegetation cover captured by the FCover marker in the range [0,1] (dimensionless). Similar empirical equations relating FCover and the C-factor have been developed for other parts of the world, e.g. Russia (Mukharamova et al., 2021) and various agricultural covers.

Diagram 2: From markers to impacts.



The CAP context indicator for soil erosion adopts literature findings which estimated the reduction of soil loss due to cover crops to be around 23% (Verstraeten et al., 2002) and the C-factor reduction due to cover crops to be approximately 20% (Wall et al., 2002). As such, the context indicator estimates C_{cover} as (Panagos et al., 2015):

$$C_{cover} = 1\,x\,(1 - F_{crop-cover}) + (1 - F_{crop-cover}) \quad (7)$$

where $F_{crop-cover}$ is the fraction of arable land to which cover crops are grown during winter or spring with a range of [0. . .1]. Panagos et al. (2015a) found that cover crops reduced the EU28 C-factor by 1.3% (C_{cover} = 0.987), because 6.5% of the EU28 arable lands are planted with cover crops during winter and spring. They found the highest impact of cover crops (>12.3% C-factor reduction) in three Austrian regions (Vorarlberg, Salzburg and Tirol) due to their high share of cover crops (>61.5%). Cover crops are also common practice in the Netherlands and Belgium. For the 2016 update of the soil erosion context indicator Borrelli and Panagos (2020) estimated the fraction of arable land to which cover crops are grown from the 2016 EU Farm Structure Survey (FSS). For winter cover crops they reduce the management factor by 18% and apply a coefficient of 0.82. For the interested reader, the authors also estimated the C_{crop} values of equation (3) for each of the considered 216 NUTS2 European areas using a weighted C-factor average of 16 different crops plus fallow land present in each NUTS2 region (Table 3).

Other scientists have used the change in cover or tillage in simulations that result in a quantified impact. For example, Schmidt et al., (2018) derived Swiss C-factor maps of grasslands from soil loss ratios weighted with R-factor ratios in using remote sensing products for Switzerland including national orthophoto with spatial resolution of 0.25m and a 10-day time series of fractional green vegetation cover (FGVC, FCover300m). Other scientists measure and simulate the effect of catch crops or, alternatively, of weeds, on soil erosion Cerda et al., 2018).

NDVI also has been used widely to approximate the C-factor of the RUSLE. In Europe, van der Knijff et al. (2000) scaled NDVI-values to approximate C-values for the soil erosion risk assessment of Europe using the following formula:

$$c = e^{-\alpha \frac{NDVI}{(\beta - NDVI)}} \qquad (8)$$

where −α and β are parameters that determine the shape of the NDVI-C curve. The authors argue that an α-value of 2 and a β-value of 1 provide good results for Europe (Van der Knijff et al., 1999). Durigon et al. (2014) proposed the following:

$$c = 0.1 \left(\frac{-NDVI + 1}{2}\right) \qquad (9)$$

Almagro et al. (2019) tested both approaches and suggested the use of equation (9) for tropical environments and of (8) for Europe.

Table 3: Borrelli and Panagos (2020) Table S1 shows the percentage 2016 area covered by different crop types, and C-factor (C_{cropn}) per crop type based on literature review.

n	Crop type	Share (%) of the total arable land (EU-28)	C-factor
1	Common wheat and spelt	28.5	0.2
2	Durum wheat	3.2	0.2
3	Rye	3	0.2
4	Barley	14.8	0.21
5	Grain maize – corn	12.9	0.38
6	Rice	0.6	0.15
7	Dried pulses (legumes), 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	0.3
12	Sunflower seed	4.8	0.32
13	Linseed	0.1	0.25
14	Soya	0.5	0.28
15	Cotton seed	0.4	0.5
16	Tobacco	0.1	0.49
17	Fallow land	9.8	0.5

Source: Exact reproduction of Borreli and Panagos (2020) Table S1 from supplementary material.

The evaluation question

The policy aims to promote catch crops on arable and achieve many environmental benefits. Among them, protection from erosion due to water is the principal target. This protection is achieved mainly when catch crops are used as a secondary crop following the main cultivation. They offer a cover after the 15th of October and throughout the winter when the soil is susceptible to heavy rains. Thus, a farmer who is willing to adopt the measure on a specific parcel should do so before the 15th of October, the ultimate date for the establishment (sowing) of the catch crops as a following up cultivation. The following terminology facilitates the exposition of the evaluation question:

- 'treatment' is the growing of catch crops as a secondary cultivation;
- 'treated subjects' are the parcels of arable land on which catch crops are grown as a secondary cultivation ;
- 'control' is the absence of catch crops as a secondary cultivation;
- 'control subjects' are the parcels of arable land which remain bare or with crop residues after harvesting the main crop;
- 'post-intervention' period is from 15th October when all treated subjects have established catch crops to the end of the year;
- 'pre-intervention' period is from the start of the year to the 15th of October;
- 'counterfactual' is the expected value of a marker if growing of catch crops as secondary cultivation had not been implemented;
- gross impact is the impact of growing catch crops as second cultivation among those parcels on which catch crops are grown only.

The data available to the evaluator dictate the choice of evaluation strategy. In this case, availability refers to the nature of the data and their coverage. Markers data cover a whole year in intervals which can be averaged almost per week, fortnight, even month, and may be provided for a series of consecutive years. This work uses year-round 2019 data for three markers. An evaluator can estimate the effects of the policy by comparing different markers' values. Figure 5 shows the evolution of the FCover marker in 2019 and indicates the pre- and post-intervention periods.

The **gross effect** is estimated by comparing the markers' average value for the treated land parcels only immediately before and after the 15th of October. The immediately before period includes the dates 24/08 and 20/09, i.e. from the last week of August to the last week of September. The after period consists of the dates after the 15th of October up to the year's end. The gross effect is biased because it does not consider the counterfactual.

The **net effect** is estimated by comparing the markers' average value between the treated and control land parcels after the 15th of October. This comparison assumes that the control parcels can serve as counterfactuals. However, for well-documented reasons, this may also be biased. Bias can be reduced (or controlled) if treated and controlled parcels are matched according to some critical characteristics before they are compared.

An agronomist may also argue that farm management practices may change if a parcel is planted with catch crops following the main cultivation. For example, sowing and harvesting of the main crop may be planned slightly earlier than usual to allow time for preparing the land for the catch crop. Control of residues also may be different. These changes can impact the markers' value after the 15th of October and are not accounted for by a mere comparison of matched treated and control parcels in the post-intervention period. Thus, a strategy handling this issue and estimating **net effects** can compare the differences between matched treated and control parcels before and after the intervention.

Evaluation results

Result indicators

In the Focus Area (FA) 4C on ‘Preventing soil erosion and improving soil management’, targets and results measure ‘percentage of agricultural land under management contracts to improve soil management and/or prevent soil erosion’ (R10/T12). In the Performance Monitoring and Evaluation Framework (PMEF), the corresponding result indicator is R.19 on ‘Improving and protecting soils: Share of Utilised Agricultural Area (UAA) under-supported commitments beneficial for soil management to improve soil quality and biota (such as reduce tillage, soil cover with crops, crop rotation included with leguminous crops)’. The data used to depict Map 1 are the IACS data recording payments to different schemes linked to the LPIS, which shows whether a parcel is connected to a policy measure and its corresponding payment. From the data used to depict Map 1, it is easy to calculate that the area under management to improve soil and prevent soil erosion is 3,953.05 ha of arable land, which corresponds to 13.26% of the 29,814.1 ha of total UAA and almost 29.35% of the 13,468.4 ha of total arable land.

The interested reader should be aware that the results can be refined according to information in the IACS or, through the LPIS, to ancillary data. For example, are the results differentiated according to the main cultivation? Are the results related to the spatial occurrence of other physical data? Are the results determined by natural characteristics or constraints? The case study data are used only to demonstrate and provide examples of possible analyses when IACS, LPIS, EO, and other ancillary data are synchronised. Thus, the reader should ignore the interpretations and comments derived from the analyses as these may be imprecise or even erroneous.

The answer to the first question is depicted in Table 4. Catch crops follow barley and potatoes main cultivations and surely do not follow maize. This fact may imply that maize cultivation does not favour catch crops as a following up cultivation. There may be agronomic reasons that prohibit catch crops' growth after maize. A similar finding may indicate that the measure needs adaptation to make the secondary catch crop cultivation on maize growing fields easier.

Table 4: Presence of catch crops by various main crops.

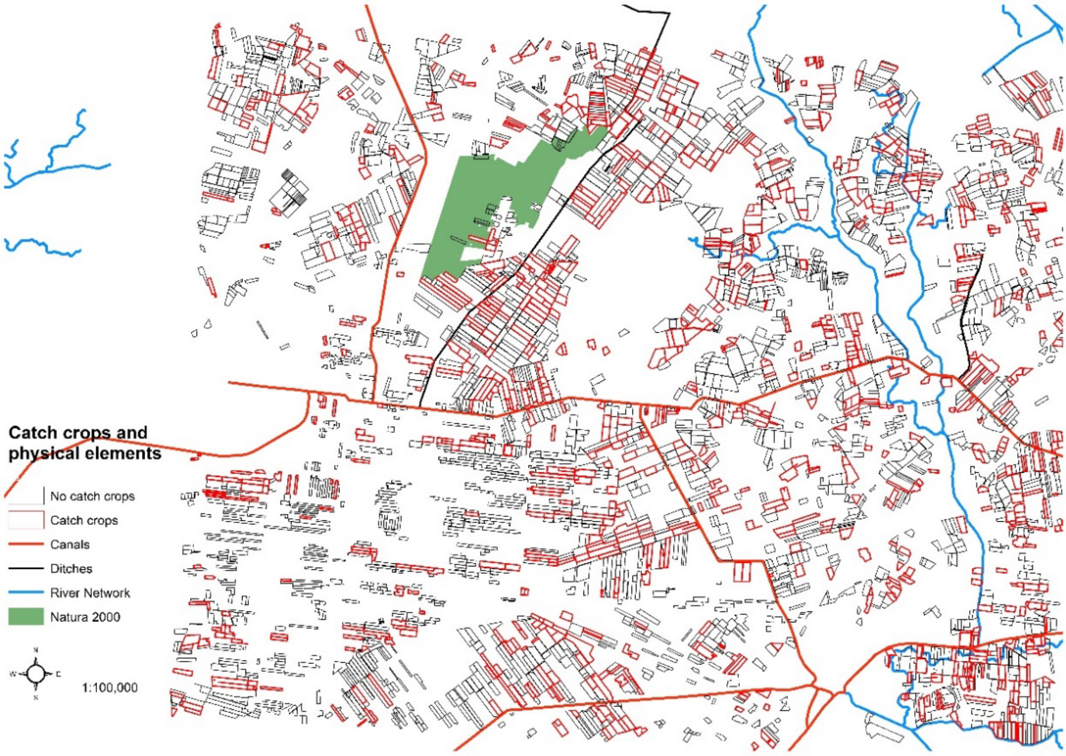
Main cultivation	Number of plots with no catch crops after main crop	Number of plots with catch crops after main crop	Total
Maize	1,209	8	1,217
Potatoes	622	426	1,048
Beets	279	44	323
Barley	54	193	247
All other	255	227	482
Total	2,419	898	3,317

Pearson Chi-Square = 981.65 with 4 degrees of freedom (d.f) significant at 1%.

Source: Author’s analysis.

As an example of analyses related to the simple results indicator, Map 3 shows the spatial disposition of parcels on which catch crops are grown with certain physical elements of the area that may interest the evaluator. Are the catch-crops parcels related to a significant river, canal, or drainage ditch networks that may suffer from transported sediments? Do the catch crop parcels are more concentrated around a Natura 2000 and protect biodiversity areas from soil erosion?

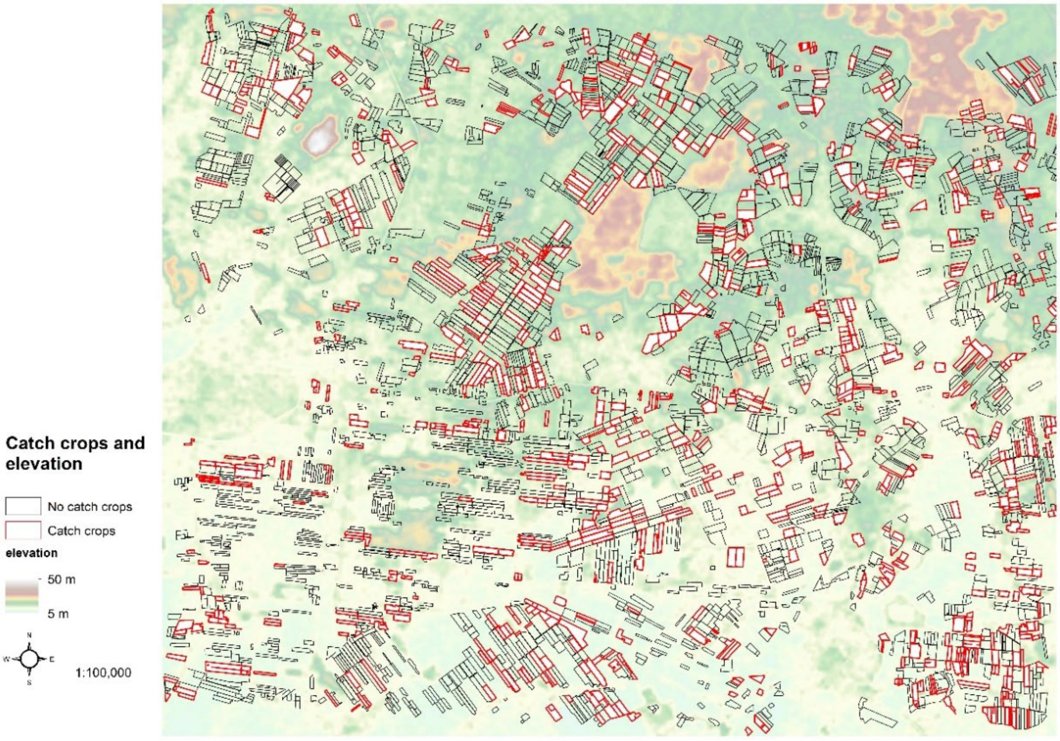
Map 3: Catch-crop eligible parcels and physical elements in the case study area.



Source of Data: Natura 2000 data - the European network of protected sites; EU-Hydro – River Network Database - version 1.3.; IACS/LPIS of the area. Cartography by the author.

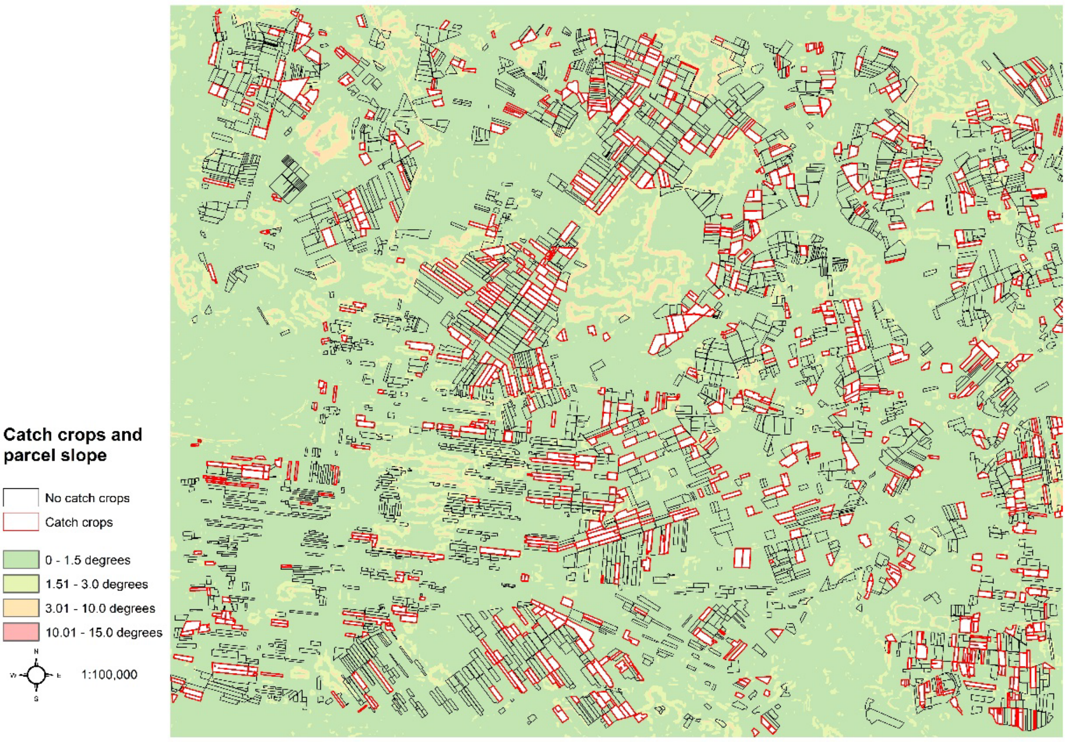
The case study area has low elevations and, by no means any real mountainous areas. However, for the shake of completeness Maps 4 and 5 present the spatial disposition of catch-crops in relation to elevations and slopes constructed from the EU Data Elevation Model (DEM) offered by Copernicus. Both elevations and slopes are important for soil erosion and all MSs have detailed DEMs from which slope and aspect raster maps can be constructed to support the analysis.

Map 4: Catch-crop eligible parcels and elevation in the case study area.



Source of Data: EU-DEM (raster) - version 1.1, Apr. 2016; IACS/LPIS for the area. Cartography by the author.

Map 5: Catch-crop eligible parcels and their slope in the case study area.



Source of Data: EU-DEM (raster) - version 1.1, Apr. 2016; Slope map produced by the slope spatial analyst tool of ArcMap 10.8 for demonstration purposes. Cartography and spatial analysis by the author.

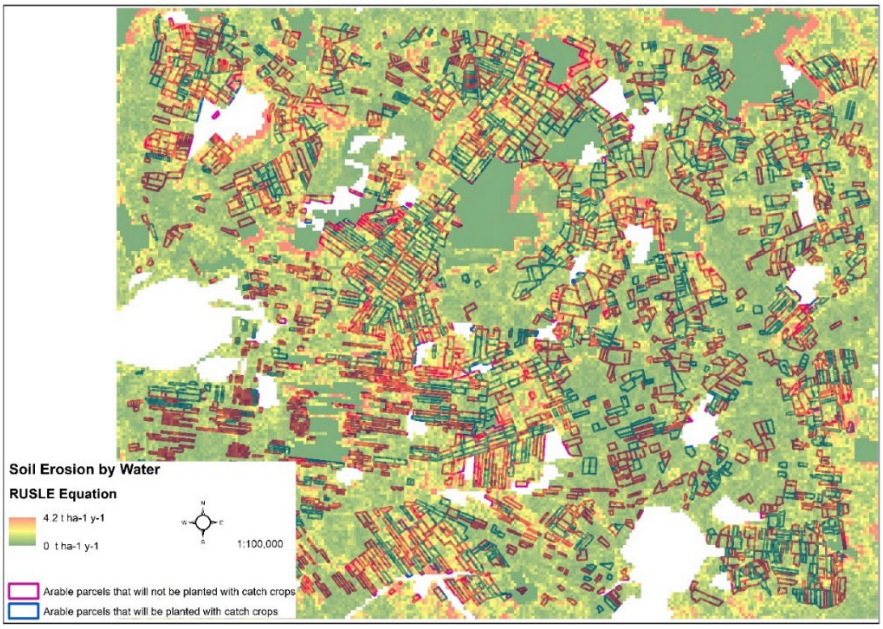
The context indicator of soil erosion by water

The Common Monitoring and Evaluation Framework (CMEF) context indicator ‘Soil erosion by water’ (C.42) consists of 2 sub-indicators:

- rate of soil loss by water erosion;
- the agricultural area affected by a specific rate of soil erosion by water. (The estimated size is also expressed as a share of the total agricultural area).

The PMEF context indicator C.41 is, practically, the same. The context indicator for the case study area is calculated from the European context indicator estimated by JRC/ISPRA and provided as a comprehensive European raster for 2013, i.e., before 2014-2020 and the application of the EFA catch-crops policy. Map 2 and Table 2 present the value of soil erosion by water for the whole area and each land use category. For arable land, the average soil erosion value in 2013 is not different between (a) parcels which in 2019 were sown with catch crops as secondary cultivation and (b) parcels which in 2019 were not planted with catch crops (Map 6)[1]. This indicates that, possibly, there is no self-selection in the choice of parcels to be sown with catch crops as secondary cultivation. In other words, the criterion to choose which parcel should be eligible for the measure is not the parcel’s soil erosion value at the baseline. The value of the first context sub-indicator for the whole case study area is 6,830.72 tonnes per year (Table 2). Since the area's highest value of soil erosion is less than 5 tonnes per hectare per year, no agricultural land can be classified as having even modest soil erosion (Map 2). Thus, the value of the second context sub-indicator is 0%.

Map 6: Soil erosion in arable land parcels in 2013, before the application of the EFA-catch crops policy.



Source of Data: Panagos et al. (2015a) Soil erosion by water raster at 100m resolution for EU-28 Member states. Note: No soil erosion value has been estimated for areas in white. Cartography by the author.

[1] A t-test of the soil erosion value in 2013 between parcels that in 2019 were (0.171 t ha-1 y-1) or were not (0.169 t ha-1 y-1) sown with catch crops as a secondary cultivation concluded that the null hypothesis of the equality of means cannot be rejected. There are slight differences in average erosion depending on whether the average is estimated from the 2013 erosion raster as an average for all EFA catch crops dissolved into one parcel or as an average of the individual parcels’ averages.

The evaluation approach adopted in this work will derive the policy's impacts on soil erosion through changes in the cover factor (C-factor) since the C-factor can change in the short term under agricultural policy measures. Thus, it is also essential to examine the C-factor at the 2013 baseline period, i.e., before applying the EFA policy greening measures. Table 5 shows the C-factor across all land uses of the case study area.

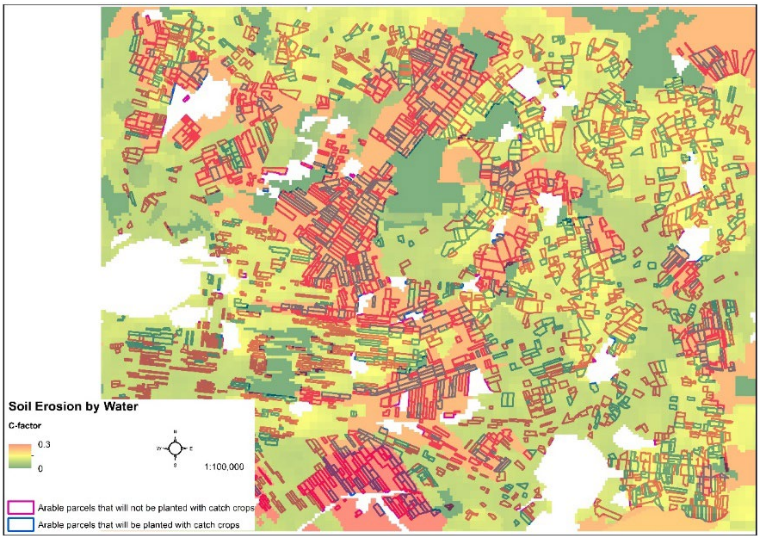
Table 5: Descriptive statistics of the C-factor (dimensionless) at baseline by land-use.

	Average	Min	Max	Range	St. Dev.
natural areas	0.089	0.001	0.298	0.297	0.087
arable	0.156	0.000	0.298	0.298	0.078
of which:					
No catch crops	0.154	0.000	0.298	0.298	0.079
Catch crop after main crop	0.162	0.000	0.298	0.298	0.075
annual crops	0.203	0.123	0.244	0.121	0.053
grassland	0.131	0.001	0.298	0.297	0.061
fallow land	0.189	0.082	0.298	0.216	0.065
greenhouse or nursery	0.190	0.082	0.298	0.216	0.087

Source: Data from Panagos et al. (2015a) combined with the MS's IACS/LPIS in 2019. Calculations and analysis by the author.

Map 7 shows the average C-factor values in 2013 for (a) parcels which in 2019 were sown with catch crops as secondary cultivation and (b) parcels which in 2019 were not planted with catch crops (Map 6)[2].

Map 7: The C-factor among arable land parcels in 2013, before applying the EFA-catch crops policy.

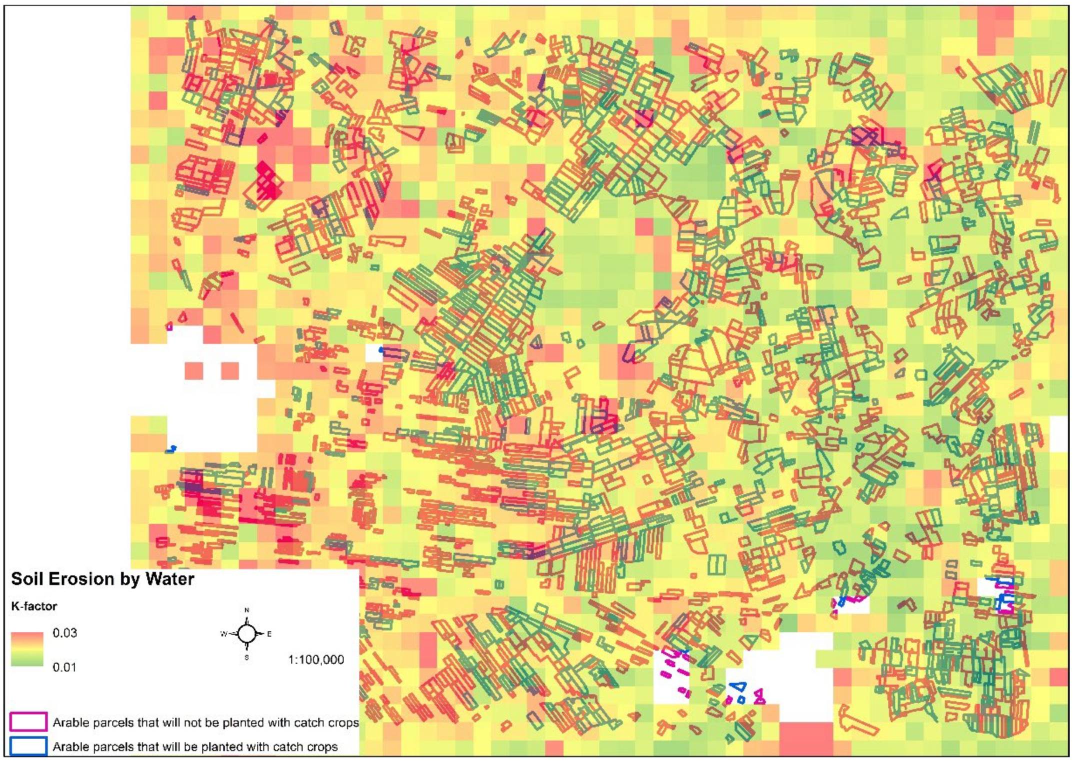


Source of Data: Panagos et al. (2015b) Soil erosion by water raster at 100m resolution for EU-28 Member states. Note: No C-factor value has been estimated for areas in white. Cartography by the author.

[2] A t-test of the C-factor value in 2013 between parcels that in 2019 were or were not sown with catch crops as a secondary cultivation concluded that the null hypothesis of the equality of means cannot be accepted. For very small differences in the 2013 C-factor estimates see Footnote 1.

A final key parameter for modelling soil erosion is the soil erodibility, the K-factor of the RUSLE equation, which expresses the susceptibility of a soil to erode concerning soil properties such as organic matter content, soil texture, soil structure and permeability. Renard's et al. (1997) define that "the K-factor is a lumped parameter that represents an integrated annual value of the soil profile reaction to the process of soil detachment and transport by raindrops and surface flow. Panagos et al. (20140 estimated the mean K-factor for Europe at 0.032 t ha h ha−1 MJ−1 mm−1 with a standard deviation of 0.009 t ha h ha−1 MJ−1 mm−1. The average K-factor for the MS where the case study area is located is 0.025 t ha h ha−1 MJ−1 mm−1. Map 8 shows the K-factor of the case study area at baseline, i.e., in 2013 estimated with soil parameters from the 2009 Land Use and Cover Area frame Survey (LUCAS). The average K-factor for arable land in the case study area is 0.0165 t ha h ha−1 MJ−1 mm−1 without any statistically significant difference between parcels which in 2019 (a) were sown with catch crops as secondary cultivation and (b) were not planted with catch crops (Map 8).

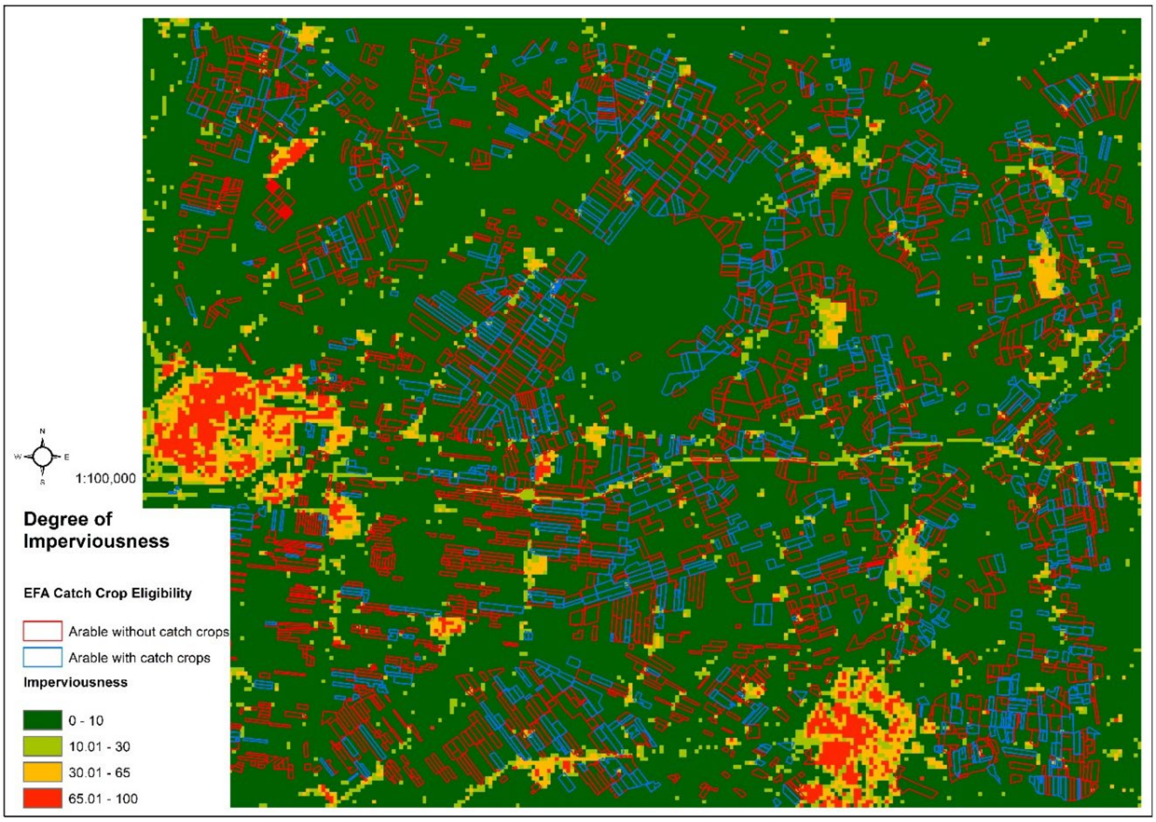
Map 8: The K-factor among arable land parcels in 2013, before applying the EFA-catch crops policy.



Source of Data: Panagos et al. (2014) Soil erosion by water raster at 100m resolution for EU-28 Member states. Note: No soil erosion value has been estimated for areas in white. Cartography by the author.

Soil permeability, i.e., the easiness with which water flows through soils, is closely related to soil sealing and imperviousness. Imperviousness is the degree to which land is impervious, i.e, from completely sealed to completely pervious. Copernicus provides the level of sealed soil (imperviousness degree from 1% to 100%) using an automatic algorithm based on calibrated NDVI. The degree of imperviousness is also used in the equation estimating the C-factor from the FCover (equation 6). Map 9 shows the degree of imperviousness for the case study area. The average imperviousness degree for arable land in the case study area is 32.5% without any statistically significant difference between parcels which in 2019 (a) were sown with catch crops as secondary cultivation and (b) were not planted with catch crops (Map 9).

Map 9: Imperviousness among arable land parcels in 2018.



Source of Data: Degree of Imperviousness, 2018, Copernicus; Cartography and spatial analysis by the author.

Gross and net policy impacts

Gross impact

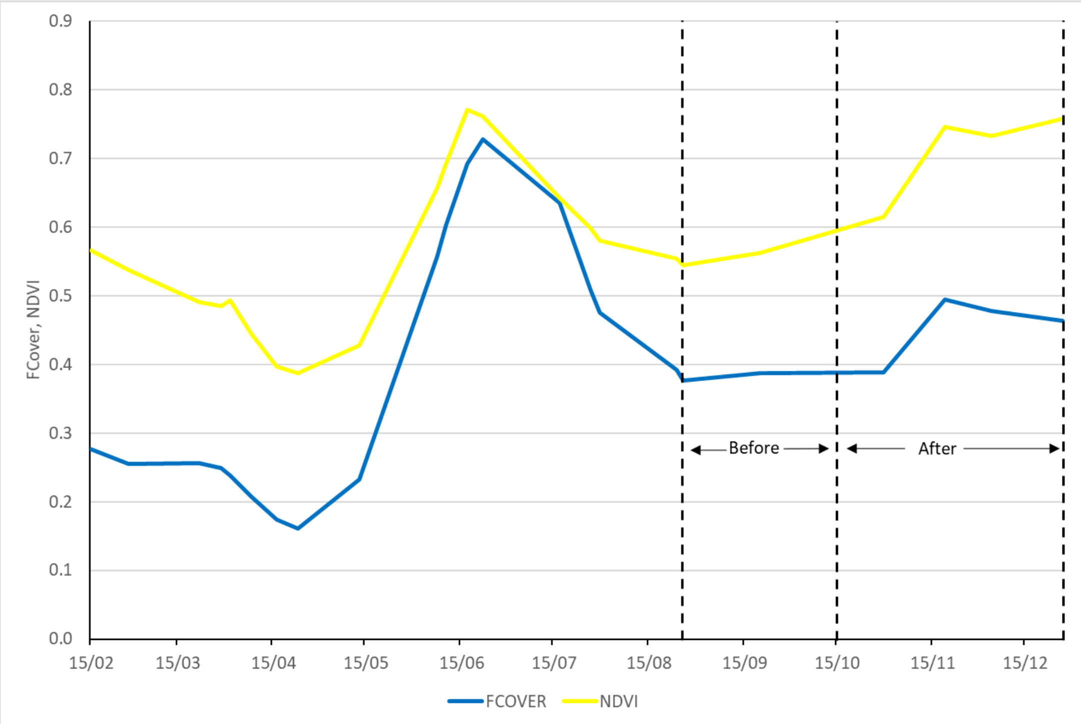
The gross impacts of catch crops as second cultivation on EO are estimated by comparing the treated parcels only before and after the intervention. This is a typical gross impact evaluation because it assumes that the 'before' is the counterfactual. In other words, the estimation assumes that the EO on the treated parcels 'before' are the EO expected if the catch crops are not grown on the same parcels. Figure 5 shows how the 'before' and 'after' are defined. Table 6 depicts the gross change in EO estimates, i.e., the change in the EO before and after catch crops are grown, on the treated parcels.

Table 6: Matched pairs tests of FCover, NDVI and LAI markers before and after the growth of catch crops for treated parcels only.

			Paired Differences				
Earth Observation	Mean	N	Mean before-after	Confidence interval low	Confidence interval high	t-test	Signif.
FCover before	0.317	528					
FCover after	0.523	528	-0.206	-0.230	-0.181	-16.518	<.001
NDVI before	0.499	527					
NDVI after	0.761	527	-0.261	-0.278	-0.245	-16.518	<.001
LAI before	1.033	528					
LAI after	1.683	528	-0.650	-0.743	-0.557	-13.703	<.001

Source: EO data analysis.

Figure 5: Gross impacts: Treated parcels of arable land only, and the definition of 'before' and 'after' periods.



Source of Data: Sen4CAP markers database. The before period is the average of the values of the markers on 24/08 and 20/09 capturing August and September. The after period is the average of the values of the markers on 30/10, 19/11, 04/12 and 27/12 capturing October, November and December.

Table 7 'translates' the EO changes into C-factor changes and, consequently, into soil erosion changes as regards the RUSLE and under the assumption that all other factors of the RUSLE remain constant at the baseline estimate. The way EO changes are translated into soil erosion changes is chosen by the evaluator depending on what models or suggested equations are available by the scientific community. Even if such models are not available, the evaluator can choose one of the equations suggested in the literature. Table 7 shows estimates with three equations which make use of the FCover and NDVI markers. All equations approximate the c-factor without catch crops in the range 0.125 to 0.142 when the baseline estimate for the same parcels in 2013 was 0.162 (Table 5). These three equations estimate differently the change in the C-factor because of their construction (Figure 6). The exponential equation using NDVI, minimises the C-factor for NDVI measurements of more than 0.6 while the linear NDVI is flatter and smoother. This has implications in the estimation of the C-factor change. For example, since catch crops achieve NDVIs of more than 0.6 the C-factor approaches zero and the change is very large. So, such an equation may be good to estimate the C-factor on arable land but not the change in the C-factor when this is reduced to almost zero because of the presence of the catch crops.

Table 7: Estimated C-factor before and after applying the catch crops on treated parcels only.

Estimation method	EO parameter	C-factor	C-factor change	% Change
$c = \frac{1 - imp}{e^{LU * FCover}}$	FCover before	0.142		
	FCover after	0.051	-0.092	-64.30%
$c = e^{-\alpha\frac{NDVI}{(\beta - NDVI)}}$	NDVI before	0.136		
	NDVI after	0.002	-0.135	-98.74%
$c = 0.5\frac{-NDVI + 1}{2}$	NDVI before	0.125		
	NDVI after	0.060	-0.066	-52.30%

Source: EO data analysis. Note imperviousness factor set at 0.31 which is the average of the treated plots in the case study area. The LU factor is set to 5. The α and β parameters of the exponential c-factor equation are set to -2 and 1.

Figure 6: C-factor estimation using the FCover marker.

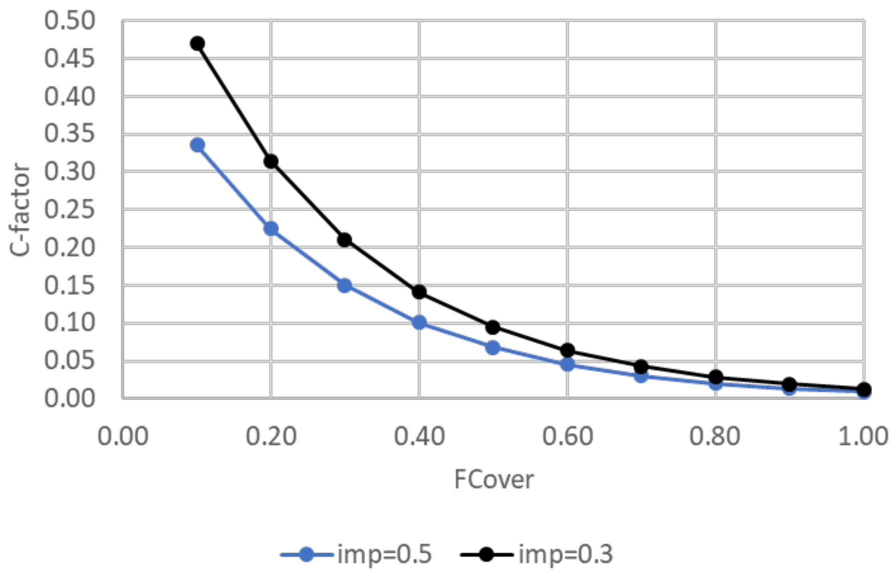
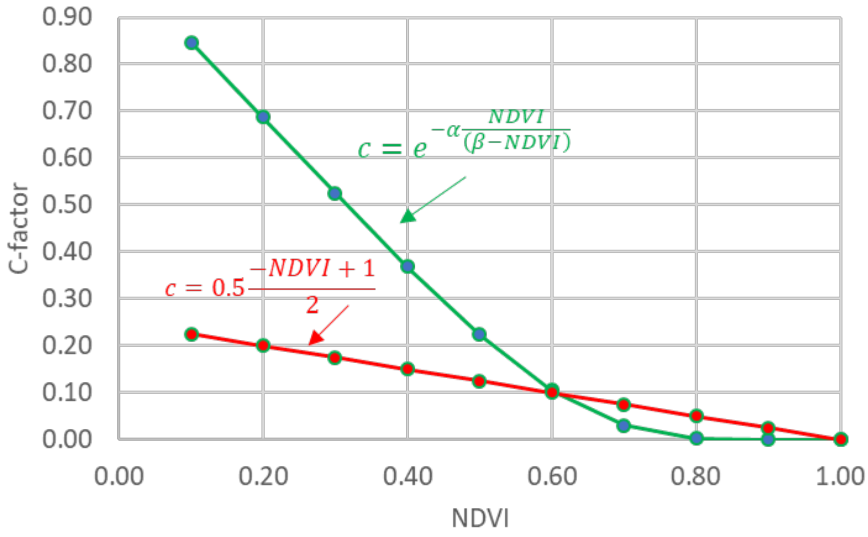


Figure 7. C-factor estimation using the NDVI marker.



Net impact

The net impacts of catch crops as second cultivation on EO are estimated by comparing the treated and control parcels only after the intervention. This is a typical net impact evaluation because it assumes that the control is the counterfactual. In other words, it is assumed that the estimation of the marker on the control parcels 'after', is the expected marker if the catch crops are not grown on the treatment parcels. In other words, the control group is the counterfactual. Figure 8 shows how the comparison between the 'treatment' and 'control' is defined. Table 8 depicts the gross change in markers' estimates, i.e., the change in the markers between treated and control parcels after catch crops are grown on the treated parcels.

Table 8: Independent samples test of FCover, NDVI and LAI markers between treated and control parcels, after the growth of catch crops.

			Paired Differences				
Earth Observation	Mean	N	Mean control-treatment	Confidence interval low	Confidence interval high	t-test	Signif.
FCover control	0.269	899					
FCover treatment	0.521	541	-0.253	-0.273	-0.232	-24.361	0.000
NDVI control	0.632	892					
NDVI treatment	0.760	540	-0.128	-0.139	-0.117	-22.896	0.000
LAI control	0.800	900					
LAI treatment	1.675	541	-0.875	-0.953	-0.797	-22.012	0.000

Source: EO data analysis.

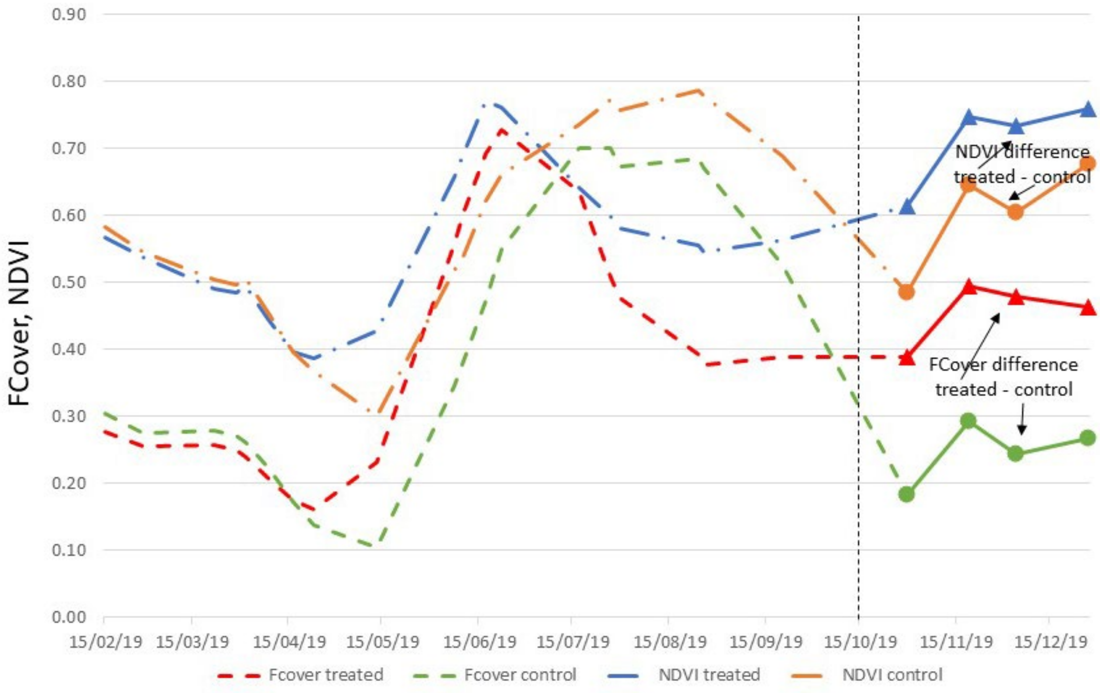
Table 9 'translates' the markers changes into C-factor estimates and changes using the three equations as before. The markers are the average of 4 observations after the 15th of October. Thus, it is not meaningful to compare them with the baseline c-factor. It is important to examine the percentage difference between control and treated parcels because this is also the percentage difference in soil erosion due to the growth of catch crops. The exponential equation using NDVI, again results to a very high percentage change.

Table 9: Estimated C-factor and C-factor change from treatment-control comparisons.

Estimation method	EO parameter	C-factor	C-factor change	% Change
$c = \frac{1 - imp}{e^{LU * FCover}}$	FCover control	0.228		
	FCover treatment	0.086	-0.142	-62.14%
$c = e^{-\alpha \frac{NDVI}{(\beta - NDVI)}}$	NDVI control	0.032		
	NDVI treatment	0.002	-0.030	-94.58%
$c = 0.5 \frac{-NDVI + 1}{2}$	NDVI control	0.092		
	NDVI treatment	0.060	-0.032	-34.91%

Source: EO data analysis. Note: imperviousness factor set at 0.31 for the treated and 0.33 for the control which are the corresponding averages of the treated and control parcels in the case study area. The LU factor is set to 5. The α and β parameters of the exponential c-factor equation are set to -2 and 1.

Figure 8: Net impact: Treated and control parcels of arable land only and the definition of treatment-control comparisons.



Source of Data: Sen4CAP markers database. The comparison between treatment and control parcels is restricted to the period after the catch crops are sown. The value of the markers is the average of the values of the markers on 30/10, 19/11, 04/12 and 27/12 capturing October, November and December.

A further refinement can be achieved if the treatment and control parcels are matched with a matching algorithm on certain variables which are a-priori known to be different between the two groups. For example, control parcels have an average size of 8.2 ha and treatment parcels 4.4 ha. Other differences may be specific to the baseline coefficients of the RUSLE equation, i.e., the baseline C-factor or K-factor, the soil, e.g. imperviousness, the elevation and slope, the main crop, etc. For demonstration purposes, control and treatment parcels are matched according to their size from the LPIS and their baseline C-factor as this was estimated by Panagos et al. (2015b). Results for the FCover and NDVI markers are shown in Tables 10 and 11. The results from matching are very similar to those reported in Table 8. For example, the difference between matched pairs, is 0.261 as opposed to 0.253 for unmatched pairs. This means that the Average Treatment Effect on the Treated (ATT), which shows what is the expected causal effect of the treatment (catch crops) for individual parcels in the treatment group for the FCover marker, is 0.261. In other words, the ATET of 0.261 means that the FCover is 0.261 units (26.1%) over the baseline wage of 0.260 units, which is the average FCover marker that would be observed if those parcels which got the treatment had not gotten it. The Average Treatment Effect (ATE), which shows the expected effect of the treatment (catch crops) if all individual parcels had been treated, is 0.238. For the purpose of this evaluation the ATT will be used to aggregate the effects of catch crops on soil erosion by water for the whole case study area.

Table 10: Matching treatment and control parcels for FCover using the psmatch2 command.

Treatment	**Coefficient**	**Std. error**	**z**	**P>|z|**	**95% C.I (Confidence intervals)**	
Parcel size	0.072	0.013	5.700	0.000	0.047	0.097
C-factor in 2013	1.781	0.463	3.840	0.000	0.872	2.689
Constant	-0.851	0.082	-10.360	0.000	-1.012	-0.690
Variable	**Sample**	**Treated**	**Controls**	**Difference**	**S.E.**	**T-stat**
FCover	Unmatched	0.521	0.269	0.253	0.009	28.210
	Matched (ATT)	0.521	0.260	0.261	0.012	22.300
	Matched (ATE)			0.238		

Source: Estimations from the psmatch2 routine of Stata.

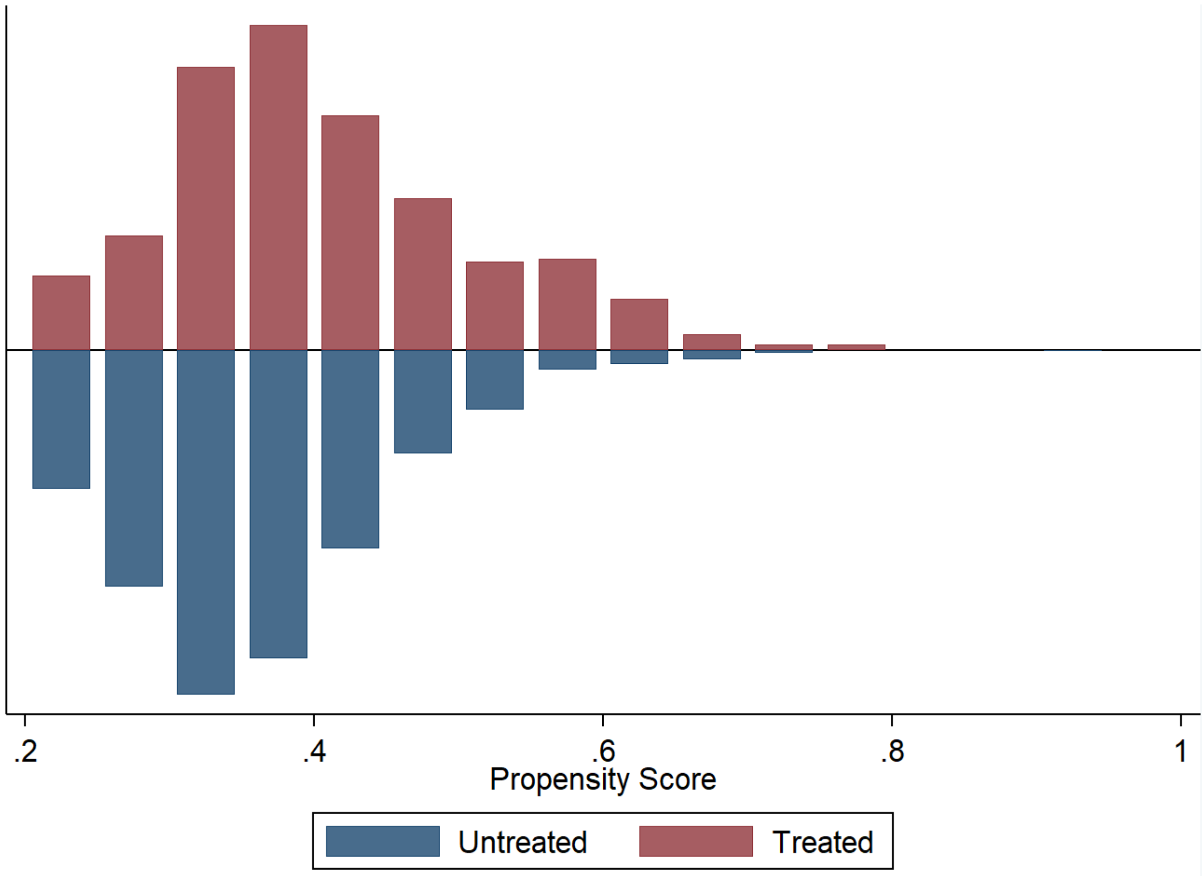
Table 11: Matching treatment and control parcels for NDVI using the psmatch2 command.

Treatment	**Coefficient**	**Std. error**	**z**	**P>|z|**	**95% C.I (Confidence intervals)**	
Parcel size	0.072	0.013	5.680	0.000	0.047	0.097
C-factor in 2013	1.767	0.463	3.810	0.000	0.859	2.676
Constant	-0.845	0.082	-10.280	0.000	-1.007	-0.684
Variable	**Sample**	**Treated**	**Controls**	**Difference**	**S.E.**	**T-stat**
NDVI	Unmatched	0.760	0.632	0.128	0.005	24.290
	Matched (ATT)	0.760	0.637	0.124	0.007	17.260
	Matched (ATE)			0.124		

Source: Estimations from the psmatch2 routine of Stata.

Once matching has finished it is advisable that the evaluator examines whether matching has been successful and achieved its aim of bias reduction. First, it is important to know that all treated observations have been matched (supported, in the matching terminology) by a control observation. In the case of the FCover all treated observations have been matched by control observations and figure 9 shows that the support was very good in all propensity score classes up to 0.7 and just adequate after that. After matching, the average of the variables used for matching should not be statistically different between control and treatment groups. Table 12 shows a typical test for the equality of the variables used for matching after matching. It is evident that there is no statistically significant difference, i.e., matched control and treatment parcels are very much alike as regards the matching variables. As said elsewhere, if the farmer knows that, on a specific parcel, catch crops will follow the main cultivation, then the farm practice behaviour may be affected, in anticipation of the catch crops. For example, the farmer may sow and harvest the main cultivation earlier, may sow the catch crops without very careful land preparation, etc. In order to capture these possible effects of changing farm practice behaviour because of expected catch crop as a second cultivation, the average FCover and NDVI values before the 15th of October can be included among the matching variables. This will assure that matched and compared treatment-control parcels had the same agronomic treatment before establishing the catch crop.

Figure 9: Matched treated and support observations for the FCover marker.



Source: Graphic of the psgraph command of Stata.

Table 12: A test of equality of means between treated and control subjects for the variables used for matching.

Variable	Mean		%bias	t-test	t p>t	V(T)/V(C)
	Treated	Control				
Parcel size	4.240	4.189	1.900	0.280	0.780	0.960
C-factor in 2013	0.164	0.166	-2.800	-0.450	0.651	0.990

Source: Estimations from the pstest command of Stata.

Table 13 'translates' the matched markers changes into C-factor estimates and C-factor changes using the three equations as before. The matched estimates do not differ from the unmatched but this may not be always the case and matching is a strongly suggested action. The markers are the average of 4 observations after the 15th of October. The percentage differences between control and treated parcels do not differ very much from the unmatched case presented in Table 9. Again, the exponential equation using NDVI, results to an unrealistically high percentage change.

Table 13: Estimated C-factor and C-factor change from matched treatment-control comparisons.

Estimation method	EO parameter	C-factor	C-factor change	% change
$c = \frac{1 - imp}{e^{LU * FCover}}$	FCover control	0.236		
	FCover treatment	0.086	-0.150	-63.49%
$c = e^{-\alpha \frac{NDVI}{(\beta - NDVI)}}$	NDVI control	0.030		
	NDVI treatment	0.002	-0.028	-94.18%
$c = 0.5 \frac{-NDVI + 1}{2}$	NDVI control	0.091		
	NDVI treatment	0.060	-0.031	-34.05%

Source: EO data analysis. Note: imperviousness factor set at 0.31 for the treated and 0.33 for the control which are the corresponding averages of the treated and control parcels in the case study area. The LU factor is set to 5. The α and β parameters of the exponential c-factor equation are set to -2 and 1.

Table 14 shows the average estimates of the effects of catch crops on soil erosion from various estimation methodologies and using the FCover and NDVI marks. As is usual when alternative methods and markers are used, the result is estimated from their average. The exponential method based on the NDVI is excluded because of unrealistically high percentage changes. The method estimating the gross effects (before-after, treated subjects only) seems to overestimate erosion decrease due to catch crops in comparison to the method estimating net effects (treatment-control). The equation based on the NDVI marker provides conservative estimates comparative to the equation based on the FCover. Table 15 calculates the impact indicator, i.e., re-calculates the baseline by changing only the part of arable land that was eligible for catch crops. The baseline estimate of the indicator in 2013 is 4,554.55 t per year. The gross estimate is 4,161.64 tonnes per year with a reduction of 392.91 tonnes per year due to the growth of catch crops as secondary cultivation. The corresponding net estimate is 4,228.44 tonnes per year with a reduction of 326.11 tonnes per year. The difference between gross and net estimates is only 66.8 tonnes per year. Of course, one should not forget that all this reduction is due to the application of catch crops as second cultivation on only 3,929 ha of the 13,468 ha of arable land on a UAA of 29,814 ha. Finally, although there is no difference between unmatched and matched net estimates, evaluators should not be prevented from applying a matching procedure when comparing treatment and control subjects.

Table 14: The effects of catch crops on erosion in the case study area.

Estimation methods with 2 different markers	Erosion among treated in 2013 in t ha-1 y-1 (Table 2)	Gross effects (Table 7)		Net effects unmatched (Table 9)		Net effects matched (Table 13)	
		% change	Erosion t ha-1 y-1	% change	Erosion t ha-1 y-1	% change	Erosion t ha-1 y-1
$c = \frac{1 - imp}{e^{LU * FCover}}$	0.171	-64.30%	0.061	-62.14%	0.065	-63.49%	0.062
$c = 0.5 \frac{-NDVI + 1}{2}$	0.171	-52.30%	0.082	-34.91%	0.111	-34.05%	0.113
Average of the 2 methods	0.171	-58.30%	0.071	-48.52%	0.088	48.77%	0.088

Source: Own analysis.

Table 15: Estimation of aggregate soil erosion in the case study area.

	Area in ha	Average erosion in t ha-1 y-1 in 2013	Total erosion in t y-1			
	(1)	(2)	(3)			
			Before (in 2013)	After the adoption of catch crops		
			(3)=(1)x(2)	Gross (1) x 0.071	Net unmatched (1) x 0.088	Net matched (1) x 0.088
natural areas	59.93	0.110	6.59	6.5923	6.592	6.592
arable	13,468.45	0.169	2,276.17	1,891.12	2,276.168	2,276.168
of which:						
no-EFA catch crops	9,539.42	0.169	1,612.16	1,612.16	1,612.162	1,612.162
EFA catch crops	3,929.03	0.171	671.86	278.96	345.755	345.755
annual crops	77.61	0.243	18.86	18.86	18.859	18.859
grassland	16,065.10	0.138	2,216.98	2,216.98	2,216.984	2,216.984
fallow land	33.40	0.191	6.38	6.38	6.379	6.379
greenhouse or nursery	109.63	0.198	21.71	21.71	21.707	21.707
Total (Impact Indicator)	29,814.12		4,554.55	4,161.64	4,228.44	4,228.44

Source: Data analysis based on LPIS. Arable land which was grown with catch crops as main cultivation is considered part of the arable no-EFA catch crops.

Conclusions

The evaluation process

EO data greatly assists the evaluation of the impacts of agricultural policies on soil erosion. In the way produced, stored and retrieved by Sen4CAP, EO can provide a series of biophysical markers at the parcel level. These parcel specific markers can be combined with information from IACS/LPIS to connect parcels with beneficiaries and non-beneficiaries of agricultural policy measures. Beneficiaries make up the group of treated parcels that may be recipients of subsidies or other types of benefits or are liable and obliged to adopt or follow a measure or farm practice. Also, they can connect with other ancillary sources of information, such as the ESDAC raster maps of soil erosion and all RUSLE factor estimates. This connection is possible using geospatial analyses capable of producing parcel specific values out of rasters.

Biophysical markers can be linked to impact indicators and combined to estimate agricultural practices. For example, FCover and LAI can be linked to the 'Soil erosion' context and impact indicators. NDVI can be linked, among many other things, to Soil Carbon (C) and Nitrogen (N) distributions and supply estimates for the new PMEF indicator on 'Soil organic carbon in agricultural land'. Thus, at the end of this data preparation process, the evaluator can access parcel specific values of (a) the indicator under consideration from Sen4CAP, (b) the treatment indicator of beneficiary or non-beneficiary from IACS/LPIS, and (c) ancillary data such as soil properties from a soil survey or soil erosion factors from a soil erosion simulation model that can be used to estimate the baseline or can be used as control or matching variables in netting out the effects of the treatment.

The bulk of EO-derived information provided by Sen4CAP act beneficially on two issues. First, they provide extensive spatial coverage, ensuring that the majority of the parcels in the LPIS will be in the sample, thus resulting in a large sample of beneficiaries and non-beneficiaries. Second, they provide extensive temporal coverage, and so the biophysical marker (e.g., FCover or NDVI) affected by a farm practice (e.g., cover and catch crops), which in turn is linked to an impact indicator (e.g., soil erosion or soil organic carbon) is observed before and after the farm practice takes place, for beneficiaries and non-beneficiaries alike. The same is true for a farm practice 'yes-no' indicator (e.g., tillage or mowing). In this data formulation, EO s can achieve two methodological targets. First, it allows the application of DiD methods because of observations on before and after for treatment and control groups (beneficiaries and non-beneficiaries). Second, it makes the use of matching algorithms easier because of the large sample and the links with other databases.

Issues and constraints

The most crucial issue related to the use of EOs is their availability to the evaluator as markers in the form provided by Sen4CAP. The production of markers implies that raw sentinel or Landsat data are converted to biophysical markers and are averaged at the parcel level. For 'yes-no' farm practice markers such as tillage or mowing, EOs may have to undergo treatment with Artificial Intelligence and Machine Learning methods combined with field visits to calibrate the process. Such an effort may be difficult and expensive to undertake unless an evaluator is equipped with skills and specialised equipment. Thus, the work of Sen4CAP to provide evaluators with ready to 're-use' markers is invaluable.

The second issue is related to the missing observations due to cloudiness. Sometimes this may be an issue, especially if persistently cloudy weather coincides with the application of the 'treatment'. Missing values can reduce the sample considerably. The evaluator should adopt a strategy to deal with missing values. One way is to use one of the many algorithms to impute missing data and fill in the data gaps. The choice of algorithm depends on the numerical nature of the biophysical marker and any patterns in missing data. Another way is to find relevant alternatives in the Synthetic Aperture Radar (SAR) domain since SAR data are not sensitive to cloud cover.

The third issue is related to the agronomic knowledge required in using the biophysical markers. For example, the evaluator should know that FCover is a suitable physical marker for approaching a soil erosion evaluation question. At the same time, NDVI is more appropriate to a soil carbon evaluation exercise. Agronomic and EO related questions should be addressed. When are catch crops sown to frame the pre-treatment period? When are catch crops harvested (or mowed) to frame the post-treatment period? For various countries, efforts have been undertaken to provide evidence on these questions. Vogt et al. (undated) in the Netherlands have used EO data to study (1) the presence of the catch crop, (2) sowing dates (before 1 October), (3) retention time of the catch crop (8-10 weeks), (4) estimate the area, (5) estimate the sowing density and (6) the seed mixture. The variability in catch crops is considerable as they found English ryegrass following maise cultivation and sown in late September, and radish sown in September or radish following onions sown in mid-July. Other questions relate EO data s to the subject matter of evaluation, such as How is FCover related to the C-Factor of the RUSLE15? and How to translate FCover to erosion reduction coefficients? How to use FCover in a soil erosion simulation model?

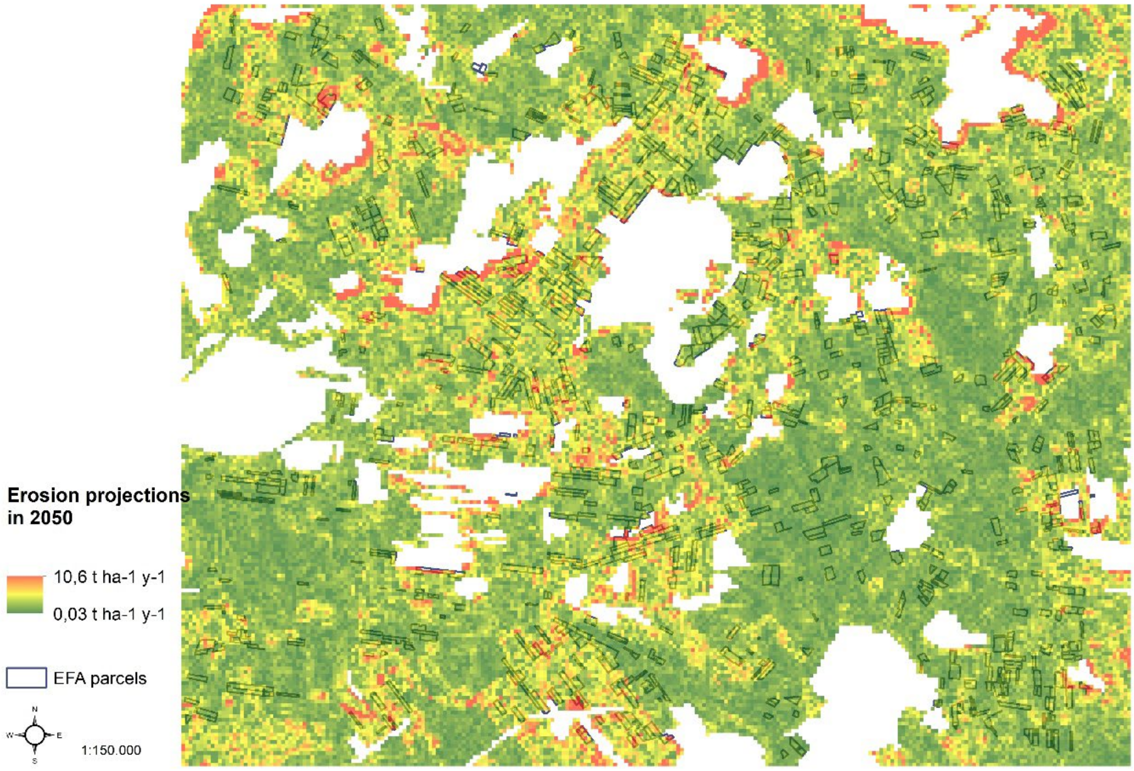
Extensions to the evaluation

The analysis presented in this work aims to demonstrate the potential use of EO data in evaluation. The parcel-level was chosen as the level of analysis. Alternatively, one could have chosen the household level since IACS/LPIS offers this possibility. The household level may be preferred when the ‘treatment’ can be optimised at the household level, i.e., the treatment takes account of the resources at the household level. For example, if there is a choice of which parcel to submit to the greening measure, decision-makers may choose the less productive land. This decision introduces a bias between treatment and control parcels that should be considered.

The bulk of EO data and their spatio-temporal nature may require the introduction of more suitable evaluation techniques or algorithms. For example, techniques allowing panel data evaluation may become more common. Or algorithms that approach matching through Machine Learning instead of the more traditional statistical matching. Artificial Intelligence and Machine Learning techniques may be considered in complex evaluations where various farm practices operate simultaneously at the same parcel. For example, on a parcel, a farmer may have adopted carbon agricultural practices implying low or no-tillage and use of catch and cover crops (many practices on the same plot), while other farmers in the area may have adopted mowing restrictions on the grassland (many practices in the same area).

Finally, the use of EO data can extend the evaluation well beyond the estimation of the gross and net impact indicator to address broader issues. For example, by overlaying the baseline raster of erosion values, an inference was made about the successful targeting of the policy (Map 1). In other words, the parcels included in the measure had higher erosion values. Another interesting evaluation question could address whether the policy is climate change proofed. Recently, Panagos et al. (2021) produced projections of soil erosion under three alternative climate change scenarios to 2050. Map 3 shows projections for the RCP 8.5 (worst-case scenario) for the case study area and the currently included EFA parcels. Projected soil erosion under this scenario is well above current levels and includes many moderate (>5 t ha^{-1} year^{-1}) and high (>10 t ha^{-1} year^{-1}) areas. The map also shows an overlay of current EFA treatment parcels with projected erosion levels that may allow policy designers to examine whether the extent and intensity of measures needs to be re-considered. One could further pursue this analysis by isolating 'hot' and 'cold' erosion spots under climate change. Depending on what data are available, the extensions in using EO and geospatial analysis are numerous and significant.

Map 3: Soil erosion projections for the case study area under the RCP 8.5 worst-case scenario to 2050.



Source of Data: Panagos et al. (2021) Soil erosion rasters for all three scenarios, the projected C-Factor and R-Factor are available by ESDAC upon request. Cartography and spatial analysis by the author.

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