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# Estimation of winter soil cover by vegetation before spring-sown crops for mainland France using multispectral satellite imagery

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## Abstract

Winter soil cover by vegetation is associated with multiple benefits. In this study, winter soil cover rate before spring-sown crops was estimated for mainland France from multispectral imagery. For 67% and 84% of the area under spring-sown crops for years 2018 and 2019, soil cover during the previous winter was estimated through the computation of the Normalized Difference Vegetation Index (NDVI), using Sentinel-2 multispectral images. At country scale, winter soil cover rate before spring-sown crops was estimated between 37% and 48 % for 2018 and between 31% and 43% for 2019, depending on the NDVI threshold for a soil to be considered covered by at least 50% of vegetation. Spatial patterns were relatively similar between the two years studied, highlighting strong heterogeneities between French departments. Cropping systems may explain some of these heterogeneities, as it has been shown that there is a large variability in the soil cover rate between spring-sown crops, but also depending on the previous crop. Winter soil cover rate was higher for crops associated with livestock production, such as maize silage (between 59% and 74% of plots covered before this crop). It was also shown that winter soil cover could be ensured by other means than cover crops: temporary grasslands were the previous crop with the highest soil cover, probably due to late ploughing. For these reasons, mixed systems combining livestock and crop productions may be a solution to increase winter soil cover before spring-sown crops.

## Social media abstract (100 characters)

For France, winter soil cover rate before spring crops was estimated between 31% and 48%, with strong spatial heterogeneities.

## Introduction

Bare soils during winter can result in environmental damage while the introduction of cover crops before spring-sown crops has the potential to increase the ecosystem services provided by agricultural systems [1]. Nutrient uptake by plants reduces losses related to leaching during the winter period, when soils are frequently saturated with water [2]. In this regard, winter soil cover is one of the good agricultural practices promoted by the European Nitrate Directive to reduce water pollution by nitrates in sensitive zones [3]. Winter soil cover also slows down surface runoff, thus limiting erosion [4]. Moreover, it provides an opportunity to increase soil carbon storage [5]. Despite these advantages, the adoption of cover crops is commonly considered to be low to moderate [6].

Assessing soil cover by vegetation before spring-sown crops is a necessary step in order to define effective policies to promote the adoption of cover crops. Satellite-based methods offer new possibilities to monitor crop development on a large scale [7], in particular through the computation of the Normalized Difference Vegetation Index (NDVI) from multi-spectral images [8]. This index is especially appropriate for monitoring winter soil cover because, contrary to biomass, soil cover has a linear relationship with NDVI [9]. Several studies have therefore used remote sensing data to evaluate soil cover during winter, as discussed below.

Concerning recent trends, winter soil cover before maize increased between 2009 and 2013 in Pennsylvania (USA), likely associated with increased adoption of cover crops [10]. For the same country, but in the Midwest, an increase in winter soil cover for maize and soybean acreage has also been reported, with more than doubling of cover crop acres planted from 2008–2016 [11]. Despite this increase, winter soil cover remained low in this study (less than 10% of maize and soybean acreage in 2016).

These studies have also highlighted the influence of soil and climatic conditions on the adoption of cover crops by farmers. Cover crop adoption appeared to be more frequent for low-potential soils [11]. In the Netherlands, where cover crops are implemented on nearly all maize fields due to regulatory requirements, a hot and dry summer led to earlier harvest dates, hence earlier sowing dates and greater development of winter cover crops in the eastern part of the country [12]. Regarding the influence of cropping systems, in the USA, it has been shown that cover crops were predominantly grown after silage maize, rather than grain maize, which is harvested later [10]. For the same country, winter soil coverage resulted in a modest yield gain (less than 1%) for the following crop [11].

The objective of this study is to provide an estimate of winter soil cover in a large territory (France) prior to the establishment of a spring-sown crop for two years: 2018 and 2019. For each plot reported as seeded with a spring-sown crop, the soil cover rate during the previous winter was estimated from NDVI. The geographical distribution of winter soil cover, as well as the influence of the previous and following crop, is investigated.

## Methods

### *Spatial plot register pre-processing*

This study focuses on all plots with spring-sown crops in France, declared within the context of the European Common Agricultural Policy. These plots are mapped in a file known as the Registre Parcellaire Graphique (RPG) in France [13], which covers 99% of the French arable crop area [14]. In this file, a plot corresponds to an area cultivated with one main crop (or a crop mixture) in a given year. Two years of cultivation have been taken into account for the study: 2018 and 2019 harvests. For these two years, plots with spring-sown crops were selected from the plot register. In addition, the previous crops for the year 2018 and 2019 were defined with the 2017 and 2018 register, respectively. A 20m negative buffer was applied to the borders of each plot to avoid edge effects due to sensor resolution or ground geolocation uncertainty.

### *Sentinel-2 images pre-processing*

Vegetation monitoring was carried out using Sentinel-2 multispectral images at 10m spatial resolution [15], corrected to surface reflectance using Sen2Cor [16]. For each year, winter soil cover monitoring was carried out for two months (December and January) during the winter before sowing the spring-sown crop. December was chosen as the beginning of the study period to limit the risk of detecting unharvested spring-sown crops on the plots, such as grain maize or sugar beet that can be harvested late in the year. January was chosen as the end of the study period because some spring-sown crops, such as peas, can be sown as early as February. Furthermore, if a cover crop was present on the plot, it must have been already detected in December or January.

Two levels of filters were applied to remove invalid observations. First, for the study period, only the least cloudy images (20% threshold) were selected. Then, a second filter at the pixel scale was applied to remove observations identified as clouds, shadows or snow (using the Scene Classification map provided with Sentinel 2 observations).

### *Definition of the occurrence of vegetative cover for each plot*

The spatial average NDVI of each plot that will be sown with a spring-sown crop at the end of the winter was calculated for each satellite acquisition date that was available over the study period. Following this protocol, part of the plots could not be monitored (e.g. 16% of the plots without NDVI extraction in 2019, as shown on **Table 1**) for three main reasons: topological error in the original shapefile delimiting the plots, plot too small after application of the negative buffer or no cloud-free pixel for the period considered. The coverage rate was lower in 2018 than in 2019 because, due to a wetter and cloudier winter [17], fewer satellite images could be exploited. This corresponds to 776,242 plots monitored in 2018, 907,473 plots in 2019. $NDVI_{Max}$ was then defined as the maximum NDVI value among the average NDVI values calculated for each plot for the December-January period. The plot was considered covered if $NDVI_{Max}$ exceeded a given threshold. Soil characteristics, such as colour or moisture, and crop residues influence NDVI measurements, especially in the early stages of crop development, when the soil is still poorly covered [18]. In order to limit these effects, it was therefore considered that soil cover had to exceed 50% for a plot to be considered as covered by vegetation. Based on the literature [19–26], this corresponds to a threshold NDVI value between 0.45 and 0.59 (**Table 2**). These two low and high thresholds were used in this study to assess the uncertainty associated with the threshold selection.

Finally, the plot register from the previous year was used to evaluate the effect of the previous crop. This association could only be carried out for part of the plots because the borders of some of them were modified from one year to the next. Approximately 50% of the plots had both winter NDVI value and previous crop information (**Table 1**).

NDVI calculation was realized through the Google Earth Engine platform [27]. Analysis was conducted in R [28] and figures were produced using the package ggplot2 [29].

## Results

### *Spatial heterogeneities*

For France, global winter soil cover rate before spring-sown crops was estimated between 37% and 48 % for 2018 and between 31% and 43% for 2019, depending on the threshold NDVI value for a soil to be considered covered (**Figure 2**). Spatial patterns are relatively similar between the two years studied. Yet, strong disparities are observed between departments. For instance, soil cover rate exceeds 80% for the department of Loire Atlantique (44), in the west of France, while it is close to 10% for the Bas-Rhin department (67), in the east of France. Overall, based on winter $NDVI_{Max}$ values, soils of the western part of the country are frequently covered whereas, in the East, soils are most often left bare before sowing a spring-sown crop (**Figure 3**). The cereal plain around Paris has relatively low $NDVI_{Max}$ values, also indicating predominantly bare soils. Like those of the West, the soils of the Massif Central, in the center of the country, are estimated as mostly covered, with the exception of the Puy-de-Dôme department (63).

### *Following spring-sown crop*

Cropping systems have an impact on winter soil cover rate. First, the upcoming spring-sown crop has a strong association with winter soil cover. For instance, the results show that plots sown with maize silage are more often covered during the winter than plots sown with sunflowers (**Figure 4**). As shown on this figure, the distribution curve of winter $NDVI_{Max}$ values for maize silage shows a peak close to 0.8 for 2019 and slightly higher for 2018. These spectral signatures correspond to well-developed plant cover. Moreover, depending on the threshold values for a soil to be considered covered, between two-thirds and three-quarters of the plots could be considered covered prior to the seeding of maize silage. Conversely, for both years, the distribution curve of winter $NDVI_{Max}$ values for sunflower shows a single peak at 0.2, a value within the range of spectral signatures of bare soils [30]. About a quarter of the plots could be considered covered before sowing this crop. Finally, the winter $NDVI_{Max}$ distribution curve of some crops, such as grain maize, shows two peaks: one at 0.2 and one at 0.8. Such a distribution illustrates the difference between plots with bare soils during winter and those with covered soils. For the year 2018, it was estimated that between 30% and 43% of the plots were covered before sowing grain maize, depending on the threshold NDVI value selected.

*Previous crop*

The previous crop also has an influence on the winter soil cover (**Figure 5**). Surface previously established with temporary grassland, which is cultivated for a maximum of five consecutive years with grass or legumes species, pure or mixed, shows higher winter $NDVI_{Max}$ values than other previous crops, and is thus more likely to be covered during the winter period due to late ploughing of grassland. This may partially explain the high soil cover rates shown for maize silage, as it is the crop that most often follows grassland. But there is also an interaction between the previous and the next crop. For example, a plot cultivated with winter soft wheat is more likely to be covered during the winter when it is followed by corn silage as compared to any other spring crop. In particular, the soil is frequently bare during winter for crop rotations of soft winter wheat followed by beet, or soft winter wheat followed by sunflower, which are common patterns in France.

Among cereal crops, winter triticale was the previous crop with the highest winter $NDVI_{Max}$ values. In general, winter soil cover was higher when the previous crop was a winter crop, given that its earlier harvest gave ample time for cover crop growth.

As detailed previously, **Figure 5** confirms that the highest winter $NDVI_{Max}$ values are associated with acreage that will be seeded with maize silage.

*Interactions between cropping system distribution and spatial heterogeneities of winter soil cover*

The distribution of crop rotations across France partially explains the spatial heterogeneities in winter soil cover highlighted in **Figure 3**. Of the four main crop sequences investigated (grain maize followed by grain maize, winter wheat followed by silage maize or grain maize and silage maize followed by silage maize), the period between the harvest of winter wheat and the sowing of maize silage is the one during which the soil is most likely to be covered during winter (**Figure 5**). As this crop sequence is mainly found in the West of France (**Figure 6**), this may explain the patterns previously observed in **Figure 3**. However, crop rotation is not sufficient to explain these spatial heterogeneities as different trends can be observed between departments for the same crop sequence. As shown in **Figure 6**, the median winter NDVI values between two maize grains are higher in western France, indicating that the soil is more frequently covered in this region. Similarly, the soil appears to be more frequently covered in the West between the harvesting of winter wheat and the sowing of grain maize, particularly in comparison with Central France.

## Discussion

### *Evaluation of winter soil cover before spring-sown crops in France*

Areas under spring-sown crops account for slightly more than a quarter of the total arable land in France [31]. It is roughly equivalent to that of winter soft wheat alone,  which is the main cereal crop grown in the country [32]. If it is considered that winter-sown crops are sufficiently developed to ensure soil cover, the winter soil cover rate for the total French agricultural area is therefore higher than the figures presented here. Yet, multiple environmental issues are related to the agricultural practices implemented prior to sowing spring crops. On these areas, winter soil cover can both reduce the negative impacts of agricultural systems, for example by limiting soil erosion [33], and improve the services provided by agriculture, such as soil carbon storage [34].

Several studies have already assessed winter soil cover before spring-sown crop using satellite imagery on a regional scale [10–12], but this study is the first to propose such an assessment on a national scale. Here, it was estimated for France that between one-third and one-half of the acreage could be considered as covered during the winter preceding the sowing of a spring-sown crop, depending on the year and the NDVI threshold used to consider a plot as covered (**Figure 2**). Winter soil cover was slightly lower in 2019 than in 2018, probably due to a drier autumn [17] which hindered the establishment and development of cover crops. Winter soil cover rate estimated in this study is higher than that estimated for Midwestern United States, where cover crops were detected on 9% of maize and soybean acreage in 2016 [11], but lower than that estimated for Pennsylvania, where 52% to 75% of maize acreage was covered in winter, depending on the county [10].

For France, based on a farm structure survey in 2016, it was estimated that before spring-sown crops, about 55% of the soils were covered by cover crops, 21% by crop residues and 24% of the soils were left bare in winter [31]. Crop residues can not be detected with the methodology used in this study, which is based on NDVI monitoring. Furthermore, some plots declared as sown with cover crops may not have sufficient vegetative development to be considered covered with the NDVI thresholds used here, whereas some plots with heavy weed infestation could be considered as covered. Nevertheless, the proportion of cover crops previously reported in the survey mentioned above is relatively similar to the areas estimated to be covered here with reference to the low NDVI threshold (48% in 2018 and 43% in 2019).

The method proposed in this study, with the calculation for each plot of the maximum NDVI during the winter, is relatively simple. Unlike other methods based on the analysis of vegetation index time series, it does not allow a precise analysis of the agricultural practices, such as the estimation of the sowing date [35], crop identification [36], or the determination of the amount of biomass produced [37]. However, these methods may be difficult to apply for monitoring cover crops, which are planted over a short period of time that is generally very cloudy, with few reliable satellite images. Moreover, the method proposed here could easily be applied to other case studies provided that a spatialized plot register is available. Among the potential applications, it could be used to monitor changes in winter soil cover over years or to compare cover crop adoption in different countries for example. Concerning the avenues for improvement, the integration of synthetic aperture radar data such as Sentinel-1 could be relevant for monitoring of winter soil cover, as these data are not sensitive to cloud cover and could be used to identify crops or to monitor agricultural practices [38], especially when combined with multispectral images [39].

### *Spatial heterogeneities regarding winter soil cover rate before spring-sown crops*

There was little difference between the two years studied, but strong spatial heterogeneities in winter soil cover were highlighted in **Figure 2** and **Figure 3**. Based on the results obtained in this study, several factors may explain these heterogeneities.

First of all, the results of this study showed that crop rotation has a strong influence on winter soil cover. Previous crops such as winter triticale or winter wheat had a higher winter soil cover than some spring crops such as sugar beet or soybean (**Figure 5**) which, harvested later, leave less time for the establishment of cover crops. Thus the greater occurrence of the crop sequence of winter wheat followed by silage maize in western France partly explains the greater winter soil cover in this region (**Figure 6**). However, as different trends can be observed between departments for the same crop sequence, other factors than crop rotation must therefore be considered to explain the adoption of winter cover crops.

Secondly, the pedoclimatic conditions may influence the development of plant cover. Cover crops are better suited to warm regions with abundant precipitation [4], which is the case of Western France, that is characterized by an oceanic climate, with mild winters and high annual rainfall. This region had indeed the highest soil cover rates of the country (**Figure 3**). In the east of France, the continental climate can hinder the adoption of cover crops, as cooler soil temperature under crop residues may retard the growth of the next crop in a cold climate. In the south of France, with a Mediterranean climate and low rainfall, water used by cover crops can have a negative impact on the yields of the following crops. In addition, under these climates, the droughts which can occur during the sowing of cover crops, is a barrier to the success of these crops. A study based on French case studies has shown that the number of consecutive days without significant water input after sowing is the most significant variable to predict cover crop emergence [40].

Thirdly, the agricultural production of each territory can also influence winter soil cover rate. Here, it has been shown that crops most frequently related to livestock production, such as temporary grassland or maize silage, are more likely to be associated with winter cover soils (**Figure 4**). Potential nutrient excesses resulting from manure application could explain the high winter soil cover in some livestock regions such as western France [3]. Higher winter soil cover in livestock regions may also be partially explained by the use of cover crops to produce additional fodder resources in livestock systems, as previously highlighted in the literature [41]. Here, grasslands alternating with spring-sown crops have also been pointed out as another way to provide winter soil cover in mixed crop-livestock systems, due to their late destruction date. Agricultural systems combining livestock and crop productions may provide multiple benefits, such as improving nutrient cycling [42]. These mixed systems can also provide alternatives to cover crops for winter soil cover, by fostering the integration of grasslands into crop rotations, as a primary crop or as an intermediate crop between two primary crops.

Further work is needed to test the hypotheses formulated here. For example, since the type of agricultural production (i.e. crop or livestock) seems to influence the adoption of cover crops, it would be interesting to allocate each of the plots monitored in this study to the farm to which it belongs in order to study the effect of farm structure on winter soil cover. This could be achieved through the unique identifier that characterizes each plot in the register, provided that confidentiality can be waived for such a study. In addition, the influence of weather data and soil types on winter soil cover has not been fully investigated here but, thanks to the data sets that are now available for France, it could also be possible to characterise the pedoclimatic factors of each plot. The work initiated in this study can therefore be further extended to better understand the drivers of winter soil cover before spring-sown crops.

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## Tables

**Table 1** *Summary of data extraction for the ten main spring-sown crops cultivated in France*

| Crop | Total acreage (kha) | | NDVI extraction (% of total acreage) | | NDVI extraction and information about previous crop (% of total acreage) | |
|---|---|---|---|---|---|---|
| | **2018** | **2019** | **2018** | **2019** | **2018** | **2019** |
| Grain maize | 1536 | 1620 | 67% | 83% | 43% | 54% |
| Silage maize | 1274 | 1286 | 76% | 79% | 47% | 49% |
| Sunflower | 548 | 593 | 60% | 94% | 39% | 65% |
| Sugar beet | 496 | 455 | 70% | 91% | 35% | 46% |
| Spring barley | 481 | 634 | 54% | 80% | 32% | 51% |
| Soybean | 154 | 162 | 62% | 87% | 38% | 55% |
| Spring pea | 103 | 108 | 59% | 91% | 32% | 56% |
| Sorghum | 61 | 83 | 66% | 95% | 39% | 64% |
| Lentil | 37 | 37 | 22% | 100% | 38% | 70% |
| Spring oat | 31 | 37 | 65% | 84% | 39% | 49% |
| **Total** | **4721** | **5015** | **67%** | **84%** | **41%** | **53%** |

383 **Table 2** *Estimation of soil cover rate from NDVI*

| Authors | Year | Crop | Country | NDVI value for 50% soil cover with vegetation | Date source for NDVI calculation |
|---|---|---|---|---|---|
| de la Casa et al. | 2018 | Soybean | Argentina | 0.45 | Landsat satellite images |
| Er-Raki et al. | 2007 | Wheat | Morocco | 0.54 | CROPSCAN field sensor |
| Imukova et al. | 2015 | Multiple crops | Germany | 0.57 | RapidEye satellite images |
| Jimenez-Munoz et al. | 2009 | Multiple crops | Spain | 0.53 | PROBA/CHRIS satellite images |
| Johnson and Trout | 2012 | Multiple crops | USA | 0.54 | Landsat satellite images |
| Lopez-Urrea et al. | 2009 | Wheat | Spain | 0.55 | GER3700 field sensor |
| Prabhakara et al. | 2015 | Multiple crops | USA | 0.56 | CROPSCAN field sensor |
| Trout et al. | 2008 | Multiple crops | USA | 0.59 | TetraCam field sensor |

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## Figures

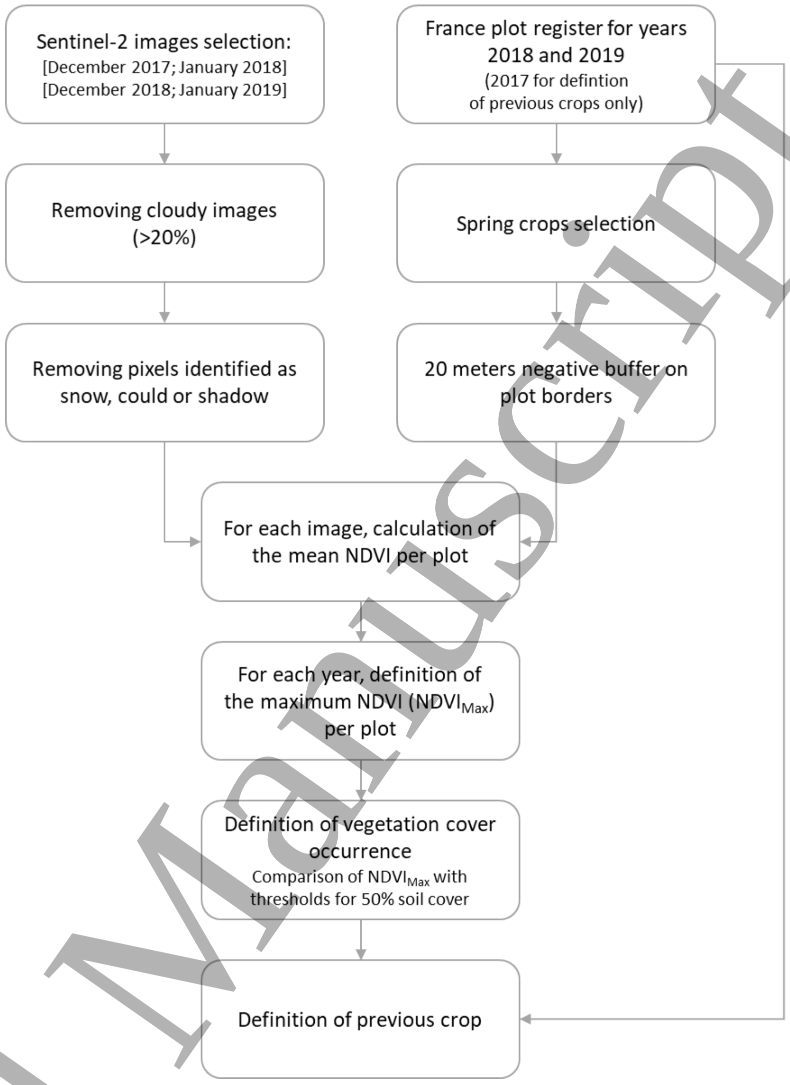

**Figure 1** *Workflow to set the maximum value of NDVI (NDVI$_{Max}$) for each plot*

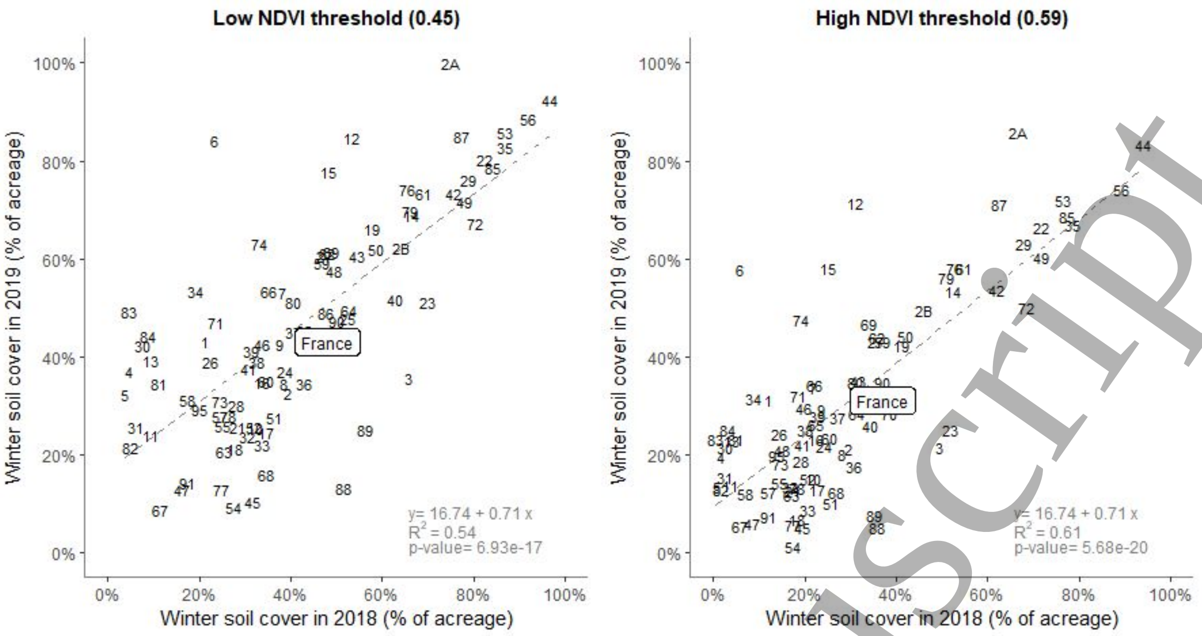

**Figure 2** *Estimation of the winter land cover rate by French department for the years 2018 and 2019, according to the NDVI threshold chosen to consider a soil as covered. Numbers represent the codes of the different departments. "France" label represents the estimate for mainland France.*

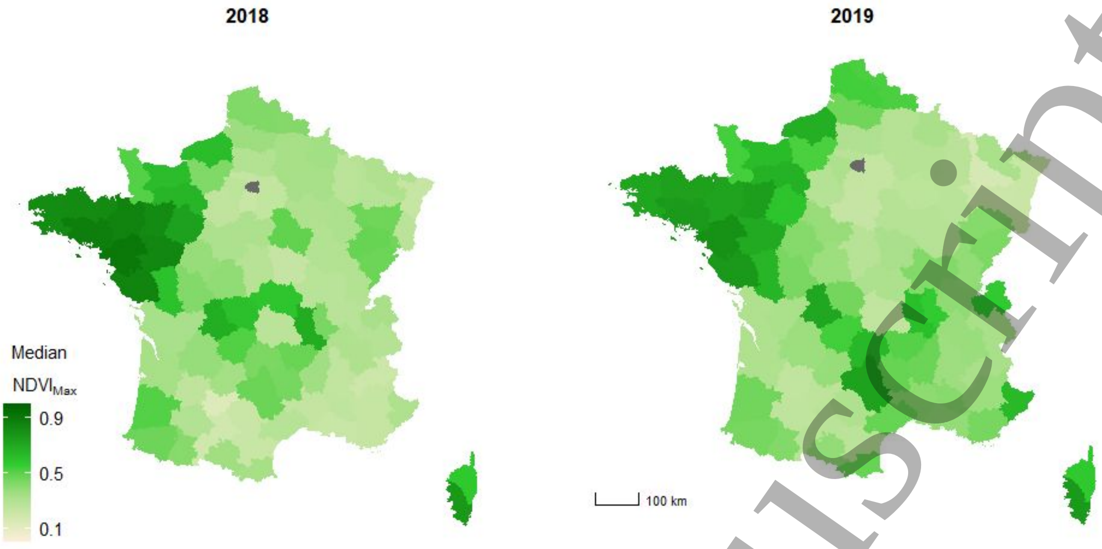

**Figure 3** *Map of median winter NDVI$_{Max}$ preceding spring-sown crops by French department (all spring-sown crops combined). The department in grey corresponds to the Paris area, where no crops are grown.*

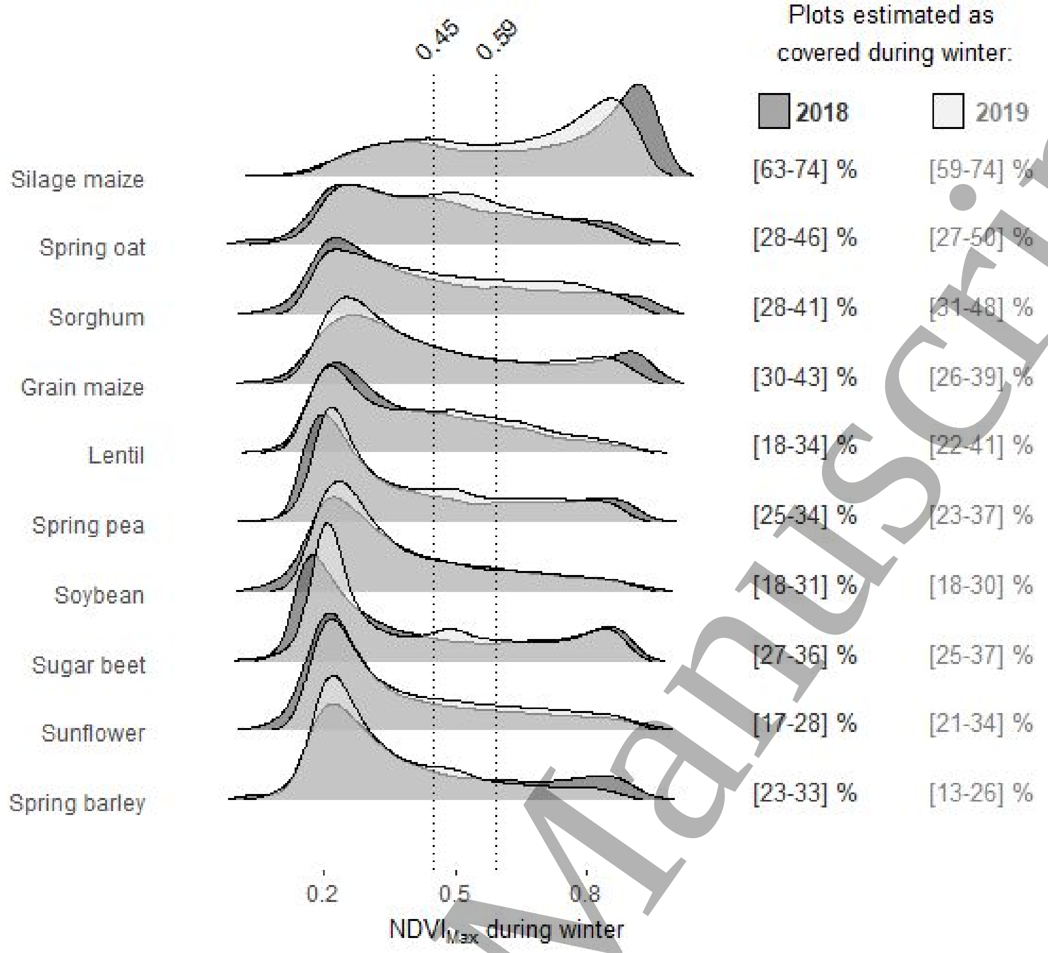

**Figure 4** *Distribution curves of winter* $NDVI_{Max}$ *by plot depending on the crops sown the following spring for years 2018 (dark colored) and 2019 (light colored). The estimate of the percentage of plots with winter soil coverage is given according to two NDVI thresholds for a plot to be considered covered (0.45 and 0.59).*

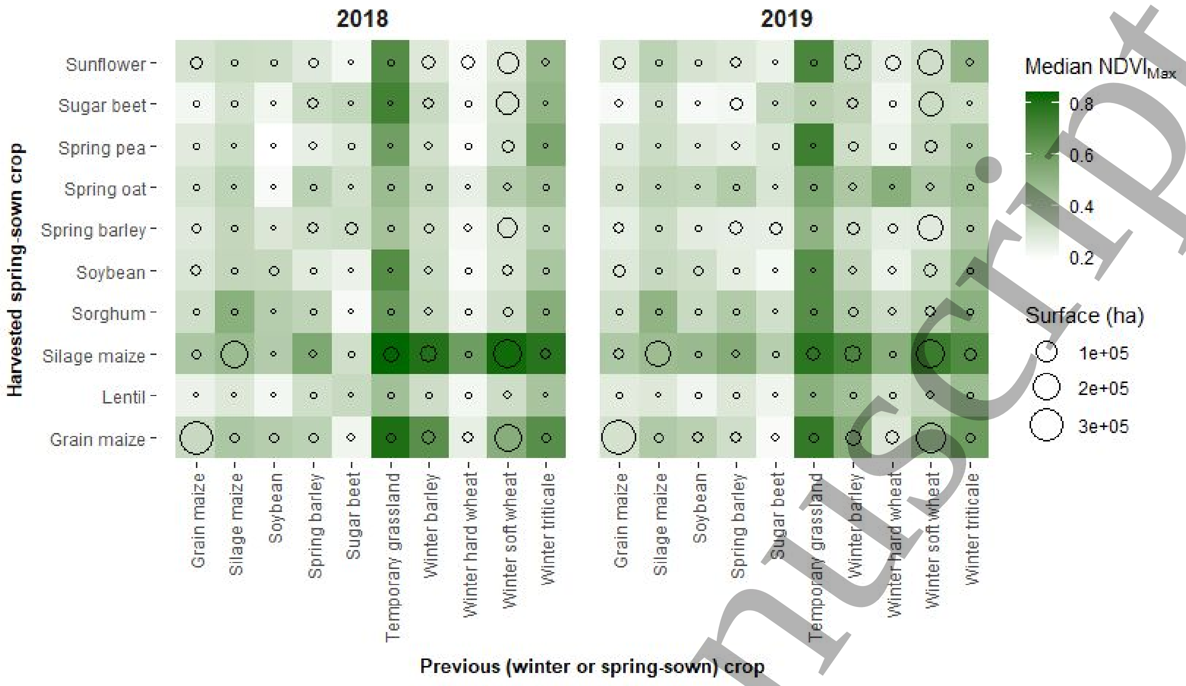

**Figure 5** *Median winter NDVI$_{Max}$ by previously harvested crop (in column) and next spring seeded crop (in row) for the years 2018 and 2019. The color intensity represents the NDVI$_{Max}$ value, the shape size represents the scale of each crop succession (in hectares).*

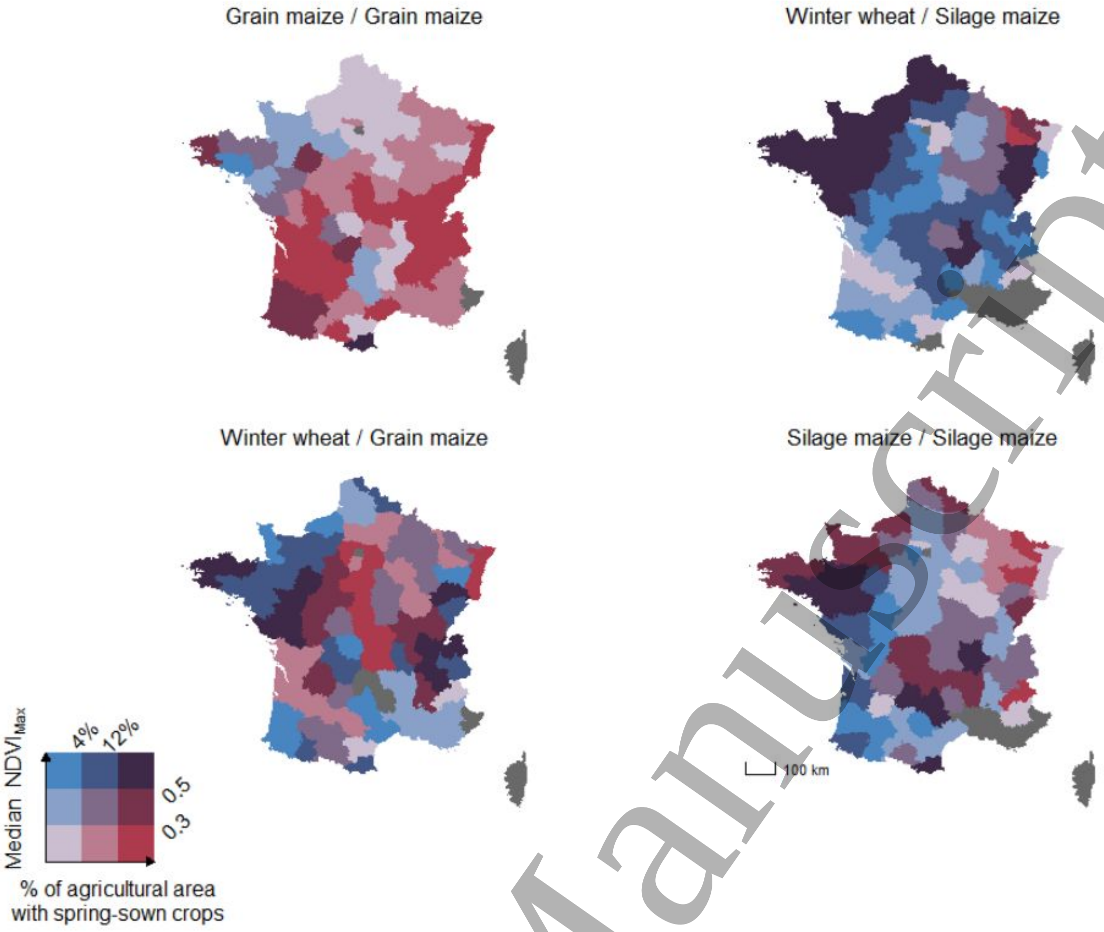

**Figure 6** *Maps of median winter NDVI$_{Max}$ values and percentage of area occupied by each crop rotation for the four main crop sequences ending with a spring-sown crops (Grain maize followed by grain maize, winter wheat followed by silage maize or grain maize and silage maize followed by silage maize). Percentage of area occupied by each sequence is calculated from the total area of spring-sown crops with information about preceding crop (Table 1). Classes in the legend correspond to the one-third and two-third quantiles of the variables. Values are calculated for both study years (2018 and 2019) together. For the departments coloured in grey, the corresponding crop sequence was not present in the dataset*