Exploring Stability of Crops in Agricultural Landscape Through GIS Tools and Open Data

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Abstract. Climate change is a well-known issue in both the scientific community and public opinion that, in the long term, could increase frequency and intensity of extreme weather events. Several models have been developed to estimate damages caused to crops by flooding, but most of them assume that crops are stable and unchanged over time.

Conversely, yearly crop rotation is known to be common in agricultural areas making potential flooded areas highly varying along years. In a flood damage estimation context, a proper mapping of actual crops in flooded areas is crucial to make deductions reliable. Open data from institutional players, yearly updated, can be proficiently used for this purpose, providing useful information for a more robust estimate of damages. In this work, with reference to a paradigmatic area located in the western part of the Piemonte Region (NW-Italy), stability and spatial pattern of variability of crops was investigated by coupling spatial information from cadastral maps and crop type information obtained for free from the Regional Geoportal and Agriculture Register service, respectively. Investigation considered the period 2015–2020 and was achieved by comparing crop type maps (generated at parcel level) along time. The proposed methodology is expected to be useful for assessing land use intensity. Results showed a great rate of crop variation in the area, suggesting that, to obtain a robust damage estimation in case of flood, crop type maps have to be yearly updated.

Keywords: Crop rotation · Open data · Flood damage · GIS

1 Introduction

Climate change is a well-known issue in both the scientific community and public opinion. Long term changes have important consequences although the most acute effects could be found in the increased frequency and intensity of extreme weather events (EE) [1–4].

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Extreme floods events are causing important damages all over the world more and more frequently [5–8]. Agricultural areas can be subject to serious damages from flood events [9, 10], therefore an accurate damage assessment is essential for floodplain restoration and prevention actions.

Many economic models have been developed to estimate flood damages caused to cultivated areas [11, 12]. The most of them consider local crops as stable in type and position over the years [9], completely neglecting ordinary agronomic practices related to crop rotation. Consequently, some doubts arise about robustness of estimates of potential EE damage to cultivated areas. It is worth to remind that, crop rotation is an agronomic practice that goes back to antiquity and consist in planting a sequence of different crops on the same field [13, 14]. It is one of the oldest agronomic practices that permits to control environmental stresses and crop performances through the regulation of nutrient, water balances, the control of diseases, insect and weeds infestations [15–18].

Crops have increasingly moved to short rotations and monocultures due to economic market trends, technical advancements, government incentives and customer needs [19]. Intense agriculture is expected to increase in future; unfortunately, evidences indicate that short rotations or monoculture are often related to lower yield with respect to the one obtainable through longer rotations or in first time planting [20, 21].

Tracking crop rotation (CR) is a complex activity [22, 23] that, unfortunately, it is rarely recorded into the farmers' logbook, even though it is a routine activity [13, 24].

In a context where climate change leads to an intensification of EE [1], the analysis and study of the crops present on the area is crucial for an estimation of the potential damage when an event occurs [25, 26]. Consequently, crop stability is a central element in this context, since conditioning reliability of long-term predictions about potential flood damage.

In this work, with reference to the study area, authors give an answer to the above mentioned issues: can the local agricultural landscape be assumed invariant along time? If not, what is the frequency and size of changes? The answer to these questions is expected to provide operational indications to generate proper damage estimates in case of flood. The study was based on a change detection approach based on free data ordinarily obtainable by the Piemonte Region databases, namely (i) farmers' declarations about yearly crop type and (ii) cadastral maps. In particular, with reference to a study area located in the Piemonte Region (NW-Italy), the following analyses were achieved: (i) one concerning yearly crop spatial distribution; (ii) one aiming at mapping and quantifying crop changes along time (2015–2020). Future developments will allow to expand the study area considering the whole Piedmont Region and analyze further aspects related to the CRs and the crops involved in them. All acronyms used in this manuscript were reported in appendix.

2 Material and Methods

2.1 Study Area

An agricultural area located in the Piemonte Region (NW-Italy), sizing about 16079 ha, was selected as area of interest (AOI), including the municipalities of Motta de' Conti, Balzola, Casale Monferrato, Frassineto Po and Villanova Monferrato. This area, majorly

devoted to agriculture that represents one on the most important economic resources, is representative of the local agronomic landscape. It is characterized by the presence of the Po River, the biggest Italian one, that is known to be potentially floodable, therefore determining a high risk for the surrounding crops (Fig. 1).

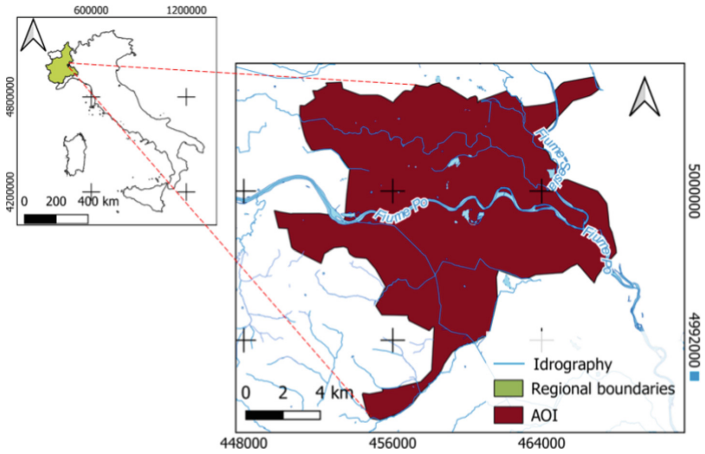

Fig. 1. Study area location – AOI (NW Italy) (Reference frame: WGS84 UTM32N).

2.2 Available Data

Cadastral maps (CM) are made available for free within the BDTRE (Territorial Reference Database for the Regional Institutions of the Piemonte Region). This can be accessed through the Piemonte Region geoportal [27].

For this work, CM was obtained as polygon vector layer (shapefile) covering AOI and including 20416 parcels. CM nominal scale is 1:2000 and was obtained by vectorization and re-projection into the WGS84 UTM32N reference frame of the native hardcopy maps of the Italian National Cadastral Office. CM is updated at 2020 and provide information about parcels geometry with no indication about associated land use.

Consequently, to qualify parcels in terms of crop type, the SIAP (Piemonte Agricultural Information System) database was accessed to obtain crop type information through the so called "Agricultural Register" (AR) service [28].

AR is an open-access system providing agricultural information (concerning crop type, livestock and farm features) at cadastral parcel level in table format (.csv).

AR data is yearly updated (on 11th November) based on declarations that farmers have to yearly provide to the Regional Administration. Typically, this data only report the main crop present in the parcel in the considered year, with no further specification about possible intra-annual rotations [13, 24]. Conversely, AR data can contain, for the same parcel, more than one record if the same parcel was split and cultivated with different crop type in the same year. AR are available for downloading since 2015. In this work, all the available years (2015–2020, hereinafter called reference period, RP) were considered.

Both cadastral map attribute table and the external one from AR contain separated codes about municipality (MC), cadastral sheet (CS) and parcel (PC). Additionally, AR table contain a further field reporting the area size devoted to the declared crop (see Table 1). These common fields made possible to operate related AR with CM, thus providing a map of yearly crop type at parcel level.

Table 1. Common fields to both reference data

Municipality Code (MC)	Cadastral Sheet Code (SC)	Cadastral Parcel Code (PC)	…	…
2082	11	18	…	…
2082	11	19	…	…
2082	15	116	…	…
2082	15	157	…	…
…	…	…	…	…

2.3 Data Processing

Geomatics offers new operative challenges to map and assess crop intensity detecting multiple crop cycles by analyzing multi-temporal spatial data [29, 30]. In this context, AR data represent a new tool, poorly explored in literature [31–33], to assess crop intensity based on farmer declaration data.

In this work, the joint use of CM and AR data were adopted to map and assess crop variability and somehow giving an estimate of crop intensity over AOI. All spatial analyses and related statistics were performed within QGIS vs 3.16.6 [34].

Crop Type Mapping. In order to assign crop type information to the correspondent parcel, a unique identification code (ID) was generated through GIS table field computation, involving strings and numbers. The code was computed for both the external table (foreign key) from AR and the attribute one linked to CM (primary key) using cadastral reference codes (Eq. 1).

$$ID = concat(MC + SC + PC) \tag{1}$$

where MC, CS and PC are respectively municipality code, cadastral sheet code and cadastral parcel code.

Data from AR were preventively filtered to ensure a one-to-one relationship between the CM attribute table and the external one. Filtering was achieved by considering the crop type associated, for the same parcel, to the biggest area as declared by farmer and recorded as additive field in AR.

An ordinary GIS join procedure was therefore applied to transfer AR information concerning crop type into the CM attribute table, thus permitting of generating 6 different yearly crop type maps.

In this work, authors focused on 8 crop types that were coded according to Table 2.

Table 2. Selected reference crops.

Reference classes	Main crop type
0	Other (vegetables, horticulture, greenhouses, minor crops)
1	Rise
2	Soya
3	Corn
4	Meadow
5	Wheet
6	Barley
7	Arboriculture (ochards, vineyards, poplar)

Temporal Crop Variability in AOI. To assess the temporal crop variability in AOI, the following conditions were tested at parcel level two years in two years: (i) parcels maintaining the same crop type for two consecutive years were coded as "unchanged" (UC); (ii) parcels where crop type changed between two consecutive years were coded as "changed" (CC) (Table 3). The areal size of CC and UC was therefore computed making possible to get an estimate of yearly changes affecting the considered crop types, namely the ones 2015–2016, 2016–2017, 2017–2018, 2018–2019 and 2019–2020. Additionally, CC was used to compute the total area that moved from one class to another assuming G = gained for increasing values and L = lost for decreasing values.

Table 3. Temporal crop variability.

ID	…	Area	2015 - 2016	2016–2017	2017–2018	2018–2019	2019–2020
20821118	…	0.37	UC	UC	UC	UC	CC
20821119	…	0.31	CC	CC	CC	CC	CC
208215116	…	0.62	CC	UC	UC	CC	CC
2082115157	…	0.07	UC	UC	UC	CC	CC
…	…	…	…	…	…	…	…

Mapping Spatial Crop Variability in AOI. Once parcels were characterized in terms of crop variation through the above mentioned UC/CC coding, CC occurrences were

counted at parcel level making possible to summarize the local degree of variability (Eq. 2).

$$CV = \sum_{i=2016}^{2020} CC_i \tag{2}$$

Resulting values (CV) were recorded as a new attribute in the CM table. This permitted to map crop variability assuming CV as driver for graduation. The resulting map, hereinafter called crop variability map (CVM) was generated and the correspondent cumulative frequency distribution (CFD) explored.

3 Results and Discussions

3.1 Temporal Crop Variability in AOI

To analyze the temporal variability of crops in AOI, the total area for each crop for each year of RP was calculated (Fig. 2). Rice and corn resulted to be the most cultivated crops in AOI during RP (more than 4500 ha and 2000 ha respectively) while soya and barley the least ones (less than 500 ha). Crops extension presented very different trends in RP: arboriculture, meadows and barley showed a constant increasing trend, wheat a decreasing one, soya and rice fluctuated, corn and other crops remained slightly stable.

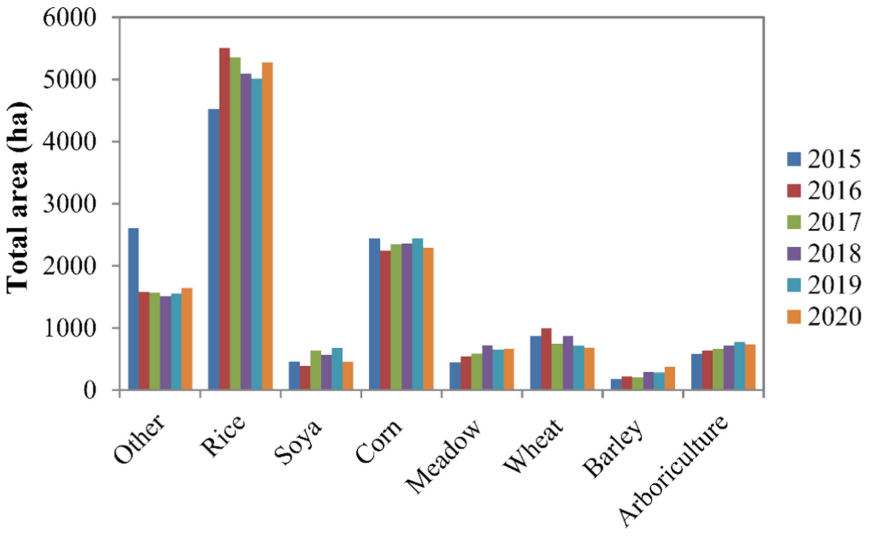

Fig. 2. Total area (ha) of crops in AOI

Yearly UC area was computed for all crops (Fig. 3). Results show that rice and corn, other crops, arboriculture and meadows were the most stable over time. For example, rice capitalized more than 4000 unchanged hectares in RP, followed by corn (>1300 ha), other crops (>1100 ha), arboriculture and meadows (~500 ha). Conversely, soybean, barley and wheat resulted the most varying one, showing a UC area of about 100 ha/y. These results are coherent to the local agricultural context. It is well known that rice tends to be cultivated on the same field for many years [35, 36]. A similarly behavior affects arboriculture class, where new plantations (e.g. orchards, vineyard and poplar stands) are expected to be maintained for 10–20 years. Barley, wheat and soya show low UC areas. In fact, they are the main rotating crops in the Piemonte region, since the firsts two (winter cereals) are frequently alternated with soya, a major soil-enriching crop [37–39].

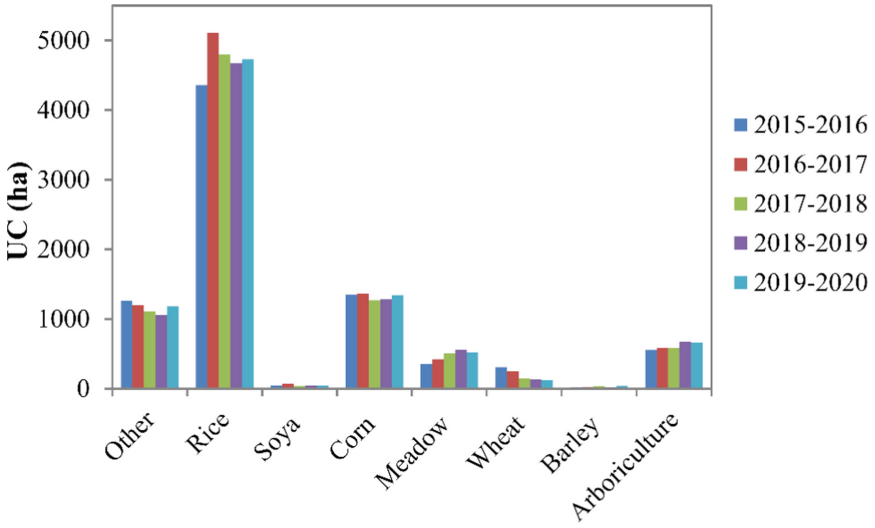

Fig. 3. Annual UC class.

Yearly CC values are reported in Fig. 4.

According to Fig. 4, CC proved to be averagely about 260 ha. The notable increase in rice in 2016 is symmetrical to the decrease in "other". Authors hypothesize that this outcome is due to the early transitional phase of the AR system. The first year of AR data availability is 2015 and is reasonable to consider that, in the first year, many rice CMs were not correctly coded in the system and consequently excluded from computation. In fact, from the following year, an increase in information and data is evident, consequently determining a migration of parcels from the "other" class to a specific crop.

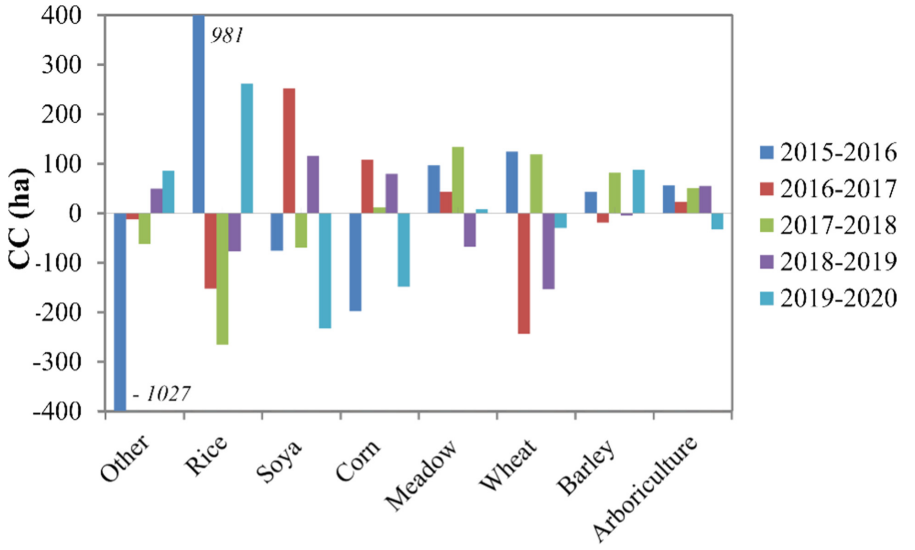

Fig. 4. Annual CC class.

Nonetheless, all crops showed alternate counts over the years, except for grassland and arboriculture that appeared to almost constantly increase in RP. Another interesting aspect is the alternating trend of soya and wheat crops over the years, probably due to the fact that both are often used in crop rotation.

Concerning crop type transition between two consecutive years, G and L can further improve the AOI crop variability assessment. G and L area values are reported in Fig. 5.

Figure 5 shows that corn was the most variable class, showing about 1000 ha exchanged in terms of G and L area. This result is coherent with local agronomic management as corn is well known to be one of the main crops subjected to CR.

For the same reason, in the wheat and soybean classes, high values of G and L area were observed, resulting in about 600 ha and 650 ha for the wheat class and 520 ha and 490 ha for the soya one respectively.

Conversely, meadows and arboriculture classes showed the smallest transition in RP, resulting in a G value of about 160 ha and 95 ha respectively, and in a L value of about 120 ha and 65 ha respectively. Additionally, it should be noted that the values of L area tend to be lower than the ones of G in RP, suggesting an increasing in terms of area for these two classes over time (Fig. 4). This result is coherent with the growing area trend previously observed in Fig. 2. Since these two classes are ordinary stable crops they are expected to remaining unchanged for many years as supported by Fig. 3 and therefore characterized by low variability and a potential increase in terms of area (Fig. 5).

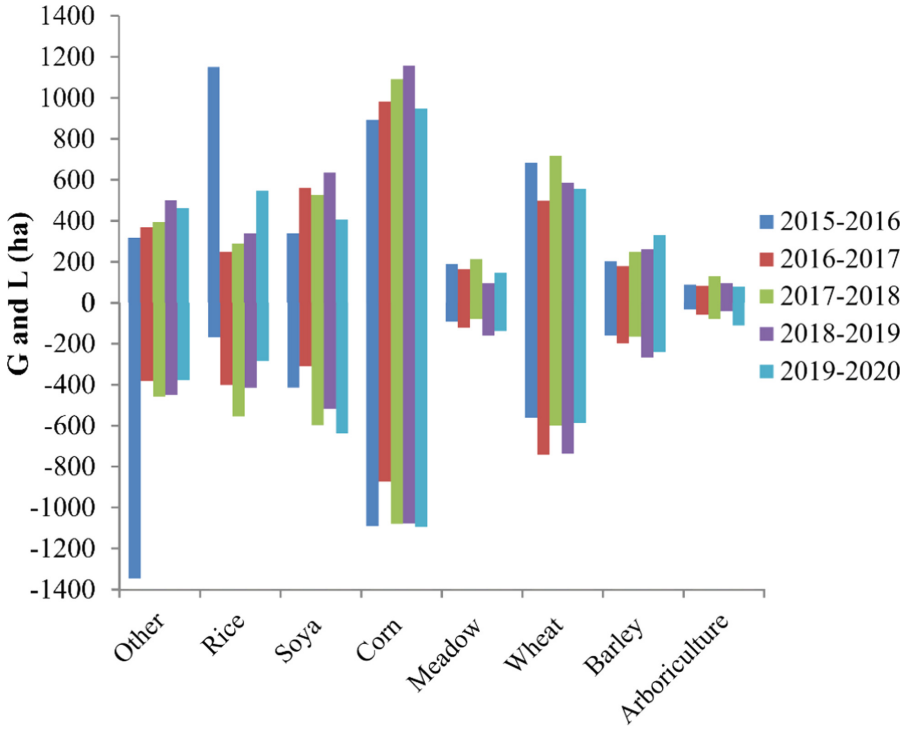

Fig. 5. G and L variability.

Regarding the rice class, both G and L values resulted to be about 350 ha. Among these results it is worth to note the high value of G (1100 ha) occurred between 2015 and 2016 (Fig. 4). However, rice remains a permanent crop with low variability in terms of G and L area. Moreover, it is worth to remind that CM size can differ considerably depending on crop. Rice extension was found to be significantly larger than other crops. Therefore, a variation of G and L of 350 ha in rice class can certainly be considered as a poorly significant.

3.2 Crop Variability Map

Crop type variability (CV) along the considered period was finally mapped in CVM (Fig. 6a). To quantitatively summarize CVM content the correspondent CFD was computed (Fig. 6b).

CFD (Fig. 6b) highlights that about 45% of the parcels did not change in RP. These areas are mainly located in the northern part of AOI where rice is the dominant crop (Fig. 6a). In fact, rice cultivation requires many irrigation infrastructures and a yearly terrain leveling to guarantee plant submersion [40]. Conversely, only less than 10% of CMs continuously changed yearly (CV = 5).

Moreover, they showed a clustered pattern suggesting that highly variable crops (e.g. wheat and soya) are rotating to each other persisting always over the same area.

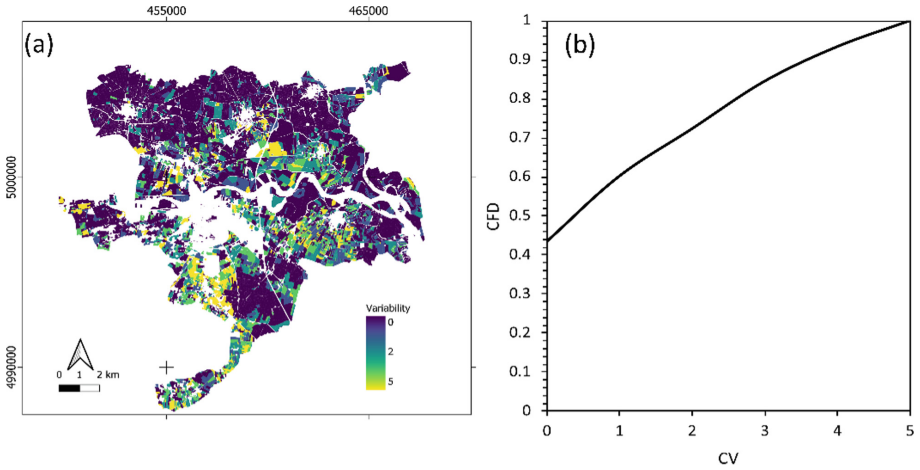

Fig. 6. CVM (a) and CFD (b) computing.

Results proved that, depending on crops, and, possibly, on the area of interest, crop distribution and consistency is, averagely, not stable in time. This suggests that, while longing for reliable estimates of crop-related losses by floods, an updated map of crops is required. If one considers that AR of the current year is, in general, made available in autumn, he has to admit that an alternative method to map actual crops has to be found. In this context, satellite-based classification can probably play an important role that has to be fostered in the next years.

4 Conclusions

In this work, crop variability in a representative agricultural area in Piemonte (NW-Italy) was explored based on free data and GIS tools.

Using AR and CM data, AOI agricultural dynamics (6 years) concerning crop type rotation was analyzed to determine if, a sort of time horizon could be eventually defined for programming crop type mapping depending on stability of crops.

To achieve this task, with reference to the main local crops and working at cadastral parcel level, authors operated a change detection analysis involving 6 years (2015–2020). Maps of transition were generated and some statistics computed. In AOI rice and arboriculture plants proved to be the most stable crops in RP. Nevertheless, in general, a high degree of variability was found; specifically soybean and wheat showed an alternating trend over the years, confirming their primary role in in crop rotation. They also showed an increasing trend in RP, demonstrated by analyzing the correspondent G and L values.

To summarize and mapping crop variability, a counter, namely CV, was mapped at parcel level. Resulting map (CVM) is expected to be used to assess land use intensity by farmers and to address the estimation process of flooded crops, suggesting, if no updated map is available, where estimates can be retained majorly reliable (Table 4.).

5 Appendix

Table 4. Acronyms used in the paper

Acronyms	Extended acronyms
EE	Extreme Events
CR	Crop Rotation
AOI	Area Of Interest
CM	Cadastral Maps
BDTRE	Territorial Reference Database for the Regional Institutions of the Piemonte Region
SIAP	Piemonte Agricultural Information System
AR	Agricultural Register
RP	Reference Period
MC	Municipality Code
CS	Cadastral Sheet Code
PC	Cadastral Parcel Code
ID	Identification Code
UC	Unchanged Crop
CC	Changed Crop
G	Gained area
L	Lost area
CV	Crop Variability
CVM	Crop Variability Map
CFD	Cumulative Frequency Distribution

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