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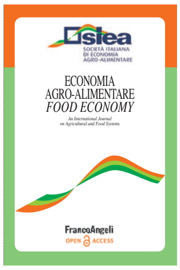

Generating cropping schemes from FADN data at the farm and territorial scale

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Abstract

The paper presents an innovative approach to cropping scheme classification based on FADN data with two main goals. First, the identification at the regional level (NUTS2) of land use patterns common to similar farms defined 'group cropping scheme'. Second, the farm-level construction of farm cropping schemes, which expand the observed crop mix and identify suitable variation ranges considering the farm production context. The schemes are based on the observed behaviour of homogeneous farms and capture their common structural characteristics regarding land use.

The schemes can be used at the territorial scale to analyse land-use trends and patterns over time. At the farm level, the method is designed to analyse short-term adaptations and is suitable to be used, together with other data, in mathematical programming models to run policy analysis exercises. At this latter scale, crop substitution within a scheme allows the set of eligible crops to be expanded while remaining linked to the observed behaviour on a spatial basis.

The paper applies the methodology to identify and quantify the cropping schemes using FADN data on Italian farms specialising in annual field crops. An algorithm implemented in GAMS automates the process. Results confirm the validity of the method and open a field of research for future applications.

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Introduction

Land use is an interesting topic for researchers and institutions, and farmers who must make their choices. Many studies deal with the productivity and economic potential of different cropping systems. However, it is not simple to characterise the crop mix adopted in a given region or country.

This paper is a technical paper proposing a new method to identify and quantify cropping schemes based on FADN data, and the aims are:

- the identification at the territorial scale of land use patterns common to similar farms defined "group cropping scheme";
- the construction at farm level of homonymous cropping schemes, designed to support mathematical programming models, which expand the observed crop mix and identify suitable variation ranges considering the farm production context.

The schemes are based on the observed behaviour in homogeneous groups of farms and capture their common structural characteristics regarding land use. At the farm level, central is the concept of crop substitution within a scheme, which allows the set of eligible crops to be expanded while remaining linked to the observed behaviour on a spatial basis. To clarify, consider a group of farms with similar characteristics in: time, space and agricultural activity; assume that all produce cereals, but only a few in the group a certain cereal; these farms can represent innovators. The methodology allows similar farms to adopt this crop, but with limits on the maximum area, which considers the total cultivated area at the farm and its potential expansion estimated at a territorial scale. In this way, innovation can be spread out. Land use variations can apply only to annual crops; for this reason, farm cropping schemes are designed to analyse short-term adaptations, but they respond to any drivers of change and are therefore suitable to be used in policy analysis studies integrated with other data.

The paper focuses on the description and testing of the method proposed to identify and quantify the cropping schemes at both territorial and farm scales; its application to specific studies shall be done in future studies.

The cropping schemes cannot be identified with crop rotation systems which are the practice of growing different crops on a parcel of land from one year to the next and represent an agronomic tool to maintain soil fertility, affecting the economic performance (Li *et al.*, 2015) and influencing the rural landscape.

Important differences exist between the two approaches:

a) rotations require data for a reasonable number of successive years, while only one year is sufficient for cropping schemes;
b) rotations are farm-specific; cropping schemes are structures that fit all farms in a similar group;

c) rotations include only the observed crops in the farm over the period; cropping schemes, instead, enlarge the set of observed crops at the farm by the crops cultivated in farms with the same characteristics, as detailed below;
d) rotations are rigid in terms of crop areas, the percentage of the crops in each year of the rotation are fixed values; cropping schemes, instead, offer a range of surface for each crop.

Previous analysis at territorial scale exist (Kollas *et al.*, 2015); among them, an interesting approach is proposed by Vitali *et al.* (2012). A central aspect is the availability of adequate data to investigate land use. The FADN database represents an important source of real field data at the national level. An alternative data source could be the census data that counts more farms than FADN and reports information to define farm structures and rotational schemes. However, census data is collected every ten years, whereas FADN data records a high variability among years. For this reason, a time step of 10 years could be too wide to describe the farm dynamics. Therefore, while on the one hand, the census data could be a better source because it provides a complete picture, on the other hand, census data do not have enough repetitions to describe so variable situations among years (Albertazzi, 2014).

The application of the proposed method on FADN data through an ad hoc procedure implemented in GAMS is still FADN, and it is limited to Italian farms specialising in annual open field crops. These farms present a greater variability in land use; for them, there is a need to acquire reliable production patterns and represent a suitable context to test this method.

1. Background

Land use is affected by market rules, administrative policies, farmer knowledge, and climate and slope. Diversification of crop rotations is considered an option to increase the resilience of European crop production under climate change (Kollas *et al.*, 2015). In fact, rotations are often included as an indicator of a degree of compliance with the principles of sustainable agriculture (Bazzani *et al.*, 2021; Kraatz *et al.*, 2019; Di Bene *et al.*, 2016). They are also indicated as sustainable practices in the Common Agricultural Policy. One of the most relevant changes towards sustainability in farm management could be upgrading crop diversification, for instance, requiring specific crop rotation (Cortignani and Dono, 2020). All of these factors define crops available for the farm manager's choice and related practice.

Many studies describe experimental crop rotations to evaluate crop yield, nutrient balance and organic matter level in the soil. Some of these studies are based on the adoption of mathematical models designed with the intent to support farmers in making optimal crop and crop management choices in a complex environment (Pahmeyer *et al*., 2021; Vigneswaran and Selvaganesh, 2020). Peltonen-Sainio *et al.* (2020) developed an interactive, multi-step crop rotation tool, which acknowledges farmer's preferences in land allocation for different crops depending on the farm and field parcel characteristics. Others (Purola and Lehtonen, 2020; Purola *et al*., 2018; Liu *et al*., 2016) applied dynamic optimisation farm models with multiple input-use responses on crop yields. Explicit field parcel-specific crop-rotation constraints are accounted for in solving the farmers' decision problem of soil-renovation investments.

Some studies have demonstrated that farmers' profit also depends on crop rotation scheduling: Li *et al.* (2015) have proposed an operational model that considers crop rotation scheduling to identify the optimal rotation that maximises prices and minimises the profit differences between smallholder farmers. Mohring *et al.* (2010) have applied econometric estimates of production and consumption functions and in this case, rotations are considered a sort of ecological constraint; Pahmeyer *et al.* (2021) have developed a decision support system about alternative cropping and fertilizer management choices where have ranked the desirability of crop rotations, highlighting economic consequences of management choices.

The studies highlight the need for access to the most complete and consistent data with the research aims. The farm accountancy data network (FADN) mainly provides extensive information on the economic performance of farms (European Commission - EU FADN, 2018; Finger and El Benni, 2014) and can be used to highlight the relationships between the adoption of European policies and producer's investment (Klepacka *et al*., 2019; Purola *et al*., 2018; Bezat-Jarzębowska *et al*., 2014; Arfini and Donati, 2013). FADN data are used as a source of information in estimation methodologies to assess the effects of agricultural policies (Cagliero *et al*., 2018). The use of data from the FADN is widespread, and there is a large number of papers based on this information and research groups dealing with it (PACIOLI workshop[1], several years). In recent years, an increasing number of studies have used FADN data both as a statistical source and as a fundamental way of collecting a range of information needed to analyse the business effects of complex processes in several farming contexts (Forleo *et al*., 2021; Cristiano *et al*., 2020). FADN data are also used to draw on unique multicriteria assessments to compare economic and environmental objectives and assess their compatibility (Špička *et al*., 2020).

1. "Every year Wageningen Economic Research (formerly known as LEI) organises the Pacioli workshop on the collection and use of farm level data for policy analysis, research and extension. An example of such a farm level data system is the European Farm Accountancy Network (FADN)", www.pacioli.org.Fad.

Several works have been indicating rotations as elements to be considered in the analysis and have used FADN data, among them: simulation models for the study of relationships between the policy and economic rent (Offermann and Margarian, 2014; Dell'Aquila and Cimino, 2012; Poppe *et al*., 1999); management of agronomic practices related to climate change, in particular, CO_2 abatement (Bazzani *et al*., 2021); the definition of a farm sustainability index as a support tool to policies (Sulewski and Kłoczko-Gajewska, 2018); compliance with agri-environmental regulations (Jensen and Ørum, 2014); to check the suitability of the most popular biodiversity indices for measuring the level of diversification of cropping structure for assessing the fulfilment of CAP greening criteria (Was and Kobus, 2014).

2. Data and methods

Data

The Italian section of FADN, RICA (Rete di Informazione Contabile Agricola), is the data source. FADN collects accountancy information from a representative sample of EU farms. In Italy, data collection and maintenance are carried out by CREA-MIPAAF (National Council for Agriculture Research and Agricultural Economics, of the Ministry of Agricultural, Food and Forest Policies). The collected information includes structural aspects (e.g., cropped surface, workforce) and economical information (e.g., producing value, goods and services purchased and sold, subsidies).

Since 2003, the principle that the farm sample should represent a country farm universe has been introduced. Farm selection is in agreement with the results of the investigation of economic performances of farm holdings (REA) managed by the Italian National Institute for Statistics (Istat). This approach allowed to give each farm a weight estimating its representation on a national basis, which is obtained from three data; location (NUTS2)[2], economic size (since 2009 expressed in Euro) and type of farming.

The 2012-2016 databases have been used, considering the Emilia-Romagna region only; since in 2016 the composition of the database has been drastically changed, only 6 farms are present over all the period. Cropping schemes have been estimated for all the five years. Results show variation in land use which are captured by the FADN database. In the context of this paper, which is a technical one, the focus is not on the application of cropping schemes to any specific study but rather on the methodology itself, thus result only refers to 2016, the most recent year.

2. In Italy corresponds to administrative Regions.

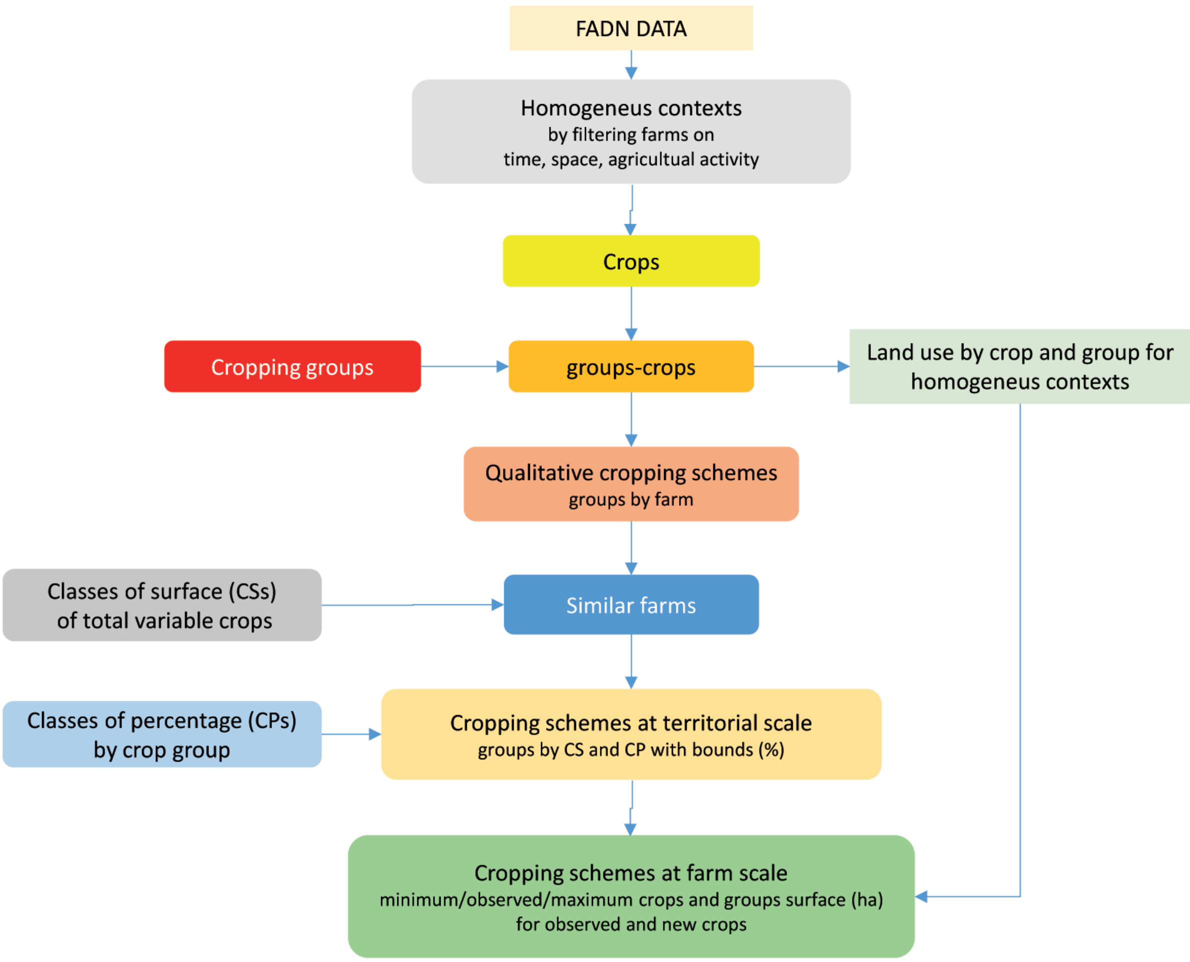
Methods

The method is graphically described in Figure 1. In the first phase, starting from the FADN data, a filtering procedure identifies homogenous context considering three dimensions: time, space and agricultural activity. The linking of predefined crops groups with the observed farms crops leads to the creation of qualitative cropping schemes at group level and to describe land use by the context in terms of covered surface. In the second phase, the introduction of surface classes "CSa", based on the total variable area at the farm, identifies similar farms. The additional component of the group percentage class "CP" allows estimating group cropping schemes at a territorial scale. Finally, cropping schemes are defined at the farm level and are expressed in hectares providing the variation range both for groups and crops, expanding the crop mix to all the crops observed in similar farms.

The procedure is implemented in GAMS and requires only few seconds to run.

It is explained in detail in the next section.

Figure 1 - Flow diagram of the method



Cropping schemes at territorial scale

The first phase involves a filtering procedure of the FADN database to identify a set of farms with the same technical orientation and active in a homogeneous context from a climatic and territorial point of view in a certain year. This approach makes it possible to reduce the universe to subsets of similar farms, on which subsequent processing is easy, and representative situations can be derived.

Three main dimensions have been identified to identify the context: time, space and agricultural activity, articulated into one or more criteria as outlined below.

1. time: one or multiple years, referred to the years of the farms in the FADN sample
2. space:
   2.1. macro area
   2.2. administrative region
   2.3. climatic zone
   2.4. altimetric zone
   2.5. slope
3. agricultural activity:
   3.1. conventional or organic
   3.2. type of farming[3], identifying the main products such as annual crops, horticultural, perennial cultivation
   3.3. legal form
   3.4. type of occupation, based on employment and external services
   3.5. disadvantaged area
   3.6. livestock, describing the existing animals if any

Most of the previous data are collected from the “FARM” table in the FADN database. Other criteria may be introduced if requested, and FADN or other available source provides the necessary data.

The method in the next phases is applied separately by context.

The table “crops” in the FADN database contains the land use area data of the farms selected, identifying the crops and their surface; this is the main data source for the procedure.

The method requires the prior association of crops in crop groups; the latter are defined based on agronomic, productive and commercial criteria.

The cropping schemes are designed to analyse short-term adaptations; for this, the distinction of groups and crops into fix and variable is requested. Most of the annual crops which can change every year are considered variable. Fixed groups include perennial crops or crops with multiple year

3. OTE in the Italian FADN database.

cycles, such as orchards, vineyards, rice fields, but also some annual crops such as flower plants, nursery and ornamental plants are considered fixed due to the infrastructures required and the complexity of the production process, which block short term adaptation.

The identification of the groups and the relation with crops is done by hand. The crop-group relation must capture the local agricultural productive context and should be implemented by experts knowing the specificities of the analysed systems. Cluster analysis is not recommended, it has been tested but the result have not been satisfactory. There is not a unique way to identify and create groups. The central concept that must be preserved is crops substitution within a group; in fact a group should include crops that can be interchangeable at farm level, due to not to different productive requirements in term of farmers knowledge and equipment in a homogeneous context.

For example, in a plain area of Emilia-Romagna, with irrigation available, distinct groups include cereals, vegetables, legumes, oilseeds, industrial crops, fodder crops, meadowland, textiles, seeds, rice, tobacco, aromatic and officinal, flower plants, nursery and ornamental plants, pasture and meadows, orchards, uncultivated area.

In the same region in 2016, the cereals group based on FADN data comprises the following crops: durum wheat, tender wheat, hybrid corn, native corn, barley, sorghum, triticale, cereals other from grain. In other years and/or regions the crops included in the cereals group may be different.

Fixed and variables groups may be both included in a cropping scheme, but only the latter are relevant to analyse land-use change in the short term (Table 1).

Different groupings are possible; for instance, the group of industrial crops that may comprehend potato, tomato, and sugar beet could be split by creating separate groups for the three previous crops. The split would prevent a farm growing tomato from switching to potato or sugar beet, which could happen if they are all included in the same "industrial crops" group. The choice to keep crops in a common group or separate them in distinct ones should always be based on the local conditions and existing agriculture practices.

If new crops are added to the FADN database over time, they must also be added to the previous table. Even if the crops-groups relation is fixed, the crops included in a group may vary by the context and over time in accordance with the FADN data.

The procedure assigns to each observed crop the related group and creates the qualitative cropping scheme, which is the set of the groups at the farm level. For example, if three farms cultivate processing tomato (classified as an industrial crop) associated with durum wheat, tender wheat, or hybrid corn, only one cropping scheme, including cereals and industrial crops, will be considered.

Table 1 - Cropping groups classified by permanence

Groups	**Fixed**	**Variable**
Plantations	X	
Aromatic and officinal	X	
Flower plants	X	
Nursery and ornamental plants	X	
Pasture and meadows	X	
Orchards	X	
Rice	X	
Cereals		X
Legumes		X
Oilseeds		X
Industrial crops		X
Tobacco		X
Textiles		X
Seeds		X
Vegetables		X
Meadowland		X
Fodder crops		X
Uncultivated area		X

The qualitative cropping scheme does not provide any quantitative information; it simply identifies the crops groups of the farm based on the observed crops.

In this stage, crop surfaces, observed in the table 'crop', are used to describe land use by the context in terms of covered area. The information expressed in percentage allows to capture the relative importance of crops and groups. This information will be used in the final stage of the procedure at the farm level to enlarge the crop mix.

In the next step, the procedure uses the data of crop areas at the farm to create a quantitative cropping scheme at the group level. Only the variable crops are considered since they can change the cultivated surface in the short term, the reference period for the methodology.

Two distinct types of classes are requested for this purpose:

- the first one considers the total area of variable crops; four surface classes have been defined, indicated with CS1-CS4, with ranges expressed in

hectares, respectively: <5, 5-15, 15-40, >40; the procedure assigns each farm to one of the previous classes summing the surface of the observed variable crops, on the basis of the previously defined membership relation;
- the second one considers the incidence of a group on the total variable farm area; four percentage classes (CP1-CP4) have been defined with intervals equal to: <10%, 10%-25%, 25%-50%, >50%. The area of the group, equal to the sum of the areas of the included crops, divided by the total variable farm areas, allows the group's assignment to one of the previous classes.

The CSs replace the group surface, an exact value equal to the sum of the observed crops in a farm included in the group, with a range. Farms of a context assigned to the same CS are defined as 'similar'.

The joint consideration of the two classes allows to build a table in which the rows report the qualitative schemes, the groups present on the farms, each identified by the identification number in position one and the farm surface class (CS) in position two; the columns (CPs) provide quantitative information on the incidence of the groups on the total of variable crops of each farm.

Table 2 shows an example with three farms, having respectively 4, 2 and 3 groups; these are, therefore, three different schemes. The cereals group is always present in class CP4, which means that covers more than 50% of the total variable crop surface of the tree farms, which in the first case is in the range 15-40 ha (CS3), in the second case is in the range >40 ha (CS4), in the third case is in the range 5-15 ha (CS2). The fodder crops group appears in two farms ID[4] 26020160159090000001 and ID 26020140150010000001 with different total variable crop surface, respectively CS3 and CS2, once in CP1 (<10%), and once in CP3 (25%-50%).

As illustrated in the next section, the complete analysis of the schemes shows that they are recurrent, albeit in different ways. As expected, few schemes collect the vast majority of farms, while a larger number of schemes are observed only a few times.

The analysis so far allows an aggregated and synthetic representation of land use in a homogenous area by identifying prevailing/ordinary and extraordinary behaviours. The group schemes do not consider crops but identify crop groups and the related percentage on the total variable area.

The method, in the next step, set lower and upper extremes to the groups by scheme, keeping separate the CSs, which means by similar farms.
- If a scheme in a certain CS is present only once, the minimum and maximum values coincide with those of the observed CP for all the included groups.

4. ID is the farm identification code.

Table 2 - Cropping schemes by total variable surface and group percentage classes

	CP1	CP2	CP3	CP4
2602016015909000001.CS3.fodder crops	X			
2602016015909000001.CS3.cereals				X
2602016015909000001.CS3.legumes		X		
2602016015909000001.CS3.industrial crops			X	
2602016015467000001.CS4.cereals				X
2602016015467000001.CS4.legumes		X		
2602014015001000001.CS2.uncultivated area			X	
2602014015001000001.CS2.fodder crops			X	
2602014015001000001.CS2.cereals				X

- When a scheme appears in more than one farm with the same CS, two situations are possible:
  - all farms have the same CP for all groups; this is like the previous case;
  - the CPs in one or more groups are different among the farms; in this case the extreme limits of the CPs concerned are taken.

To clarify the latter situation consider the following example. Scheme 28 comprehends two groups, cereals and industrial crops and is observed in two farms in CS3. Groups surface by farm are reported in Table 3.

Table 3 - Surface by group for farms with cropping scheme 28

	Tot.	Cereals		Industrial crops	
Farm ID.Class of surface.Scheme	**ha**	**ha**	**%**	**ha**	**%**
2602008010991000001.CS3.sch28	14.98	12.57	83.91	2.41	16.09
2602016015902000001.CS3.sch28	14.97	9.72	64.93	5.25	35.07

The first group, cereals, covers 83.91% and 64.93% of the total farm variable area, and in both cases, is assigned to CP4. Industrial crops cover 16.09% in the first farm and 35.07% in the second farm, corresponding to CP2 and CP3, respectively.

When this information is aggregated over the farms, CP4 is the only class for the cereals group; instead, the industrial crops group appears in two classes CP2 and CP3, as shown in Table 4, where farm IDs do not appear anymore.

Table 4 - Group percentage classes in cropping scheme 28

Class of surface.Scheme.Group	CP2	CP3	CP4
CS3.sch28.cereals			X
CS3.sch28. industrial crops	X	X	

The extreme of the observed CPs gives the range of variation of each group. The range of CP4 gives the bounds for the cereals group (50%-100%). For industrial crops, since two classes CP2 and CP3 exist, the lower bound of CP2 (10%), which is the minimum value, represents the lower limit, while the upper bound of CP3 (50%), which is the maximum value, represents the upper limit, as shown in Table 5.

Table 5 - Group ranges in scheme 28 for surface class CS3

Class of surface.Scheme.Group	CP2.mi	CP3.ma	CP4.mi	CP4.ma
CS3.sch28.cereals			50	100
CS3.sch28.industrial crops	10	50		

The upper and lower limits thus constructed may require corrections to meet the following requirements:

- minimum and maximum bounds within a group must be compatible with the scheme;
- for each group the bounds must be compatible with the values observed in the other groups of the scheme.

If a scheme comprises only one group, the minimum and maximum are set equal to 100 so that the whole arable land is used, to respond to the former requirement.

If more groups exist, which is the common situation, for each group the following rule must hold: the value of the group maximum plus the sum of the minimum of all the other groups belonging to the scheme must be equal or lower than 100.

When this rule does not hold some values must change. The choice is to keep unchanged the minima (mi), the lower bound, and reduce the upper bounds (ma) of the group. This restricts the range of variation for the group. The correction is done applying the following formula:

$$\widetilde{ma}_i = 100 - \sum_j mi_j \quad \vee \ i \neq j \qquad \textit{Eq. 1}$$

Where 'i' and 'j' identify different groups within the same scheme.

In the previous scheme 28 in Tab. 4 cereals have a maximum of 100% which is not compatible with the minimum of 10% for industrial crops, in fact the sum is 110%. Applying *Eq.* 1 the value of 100 is lowered to 90.

Another example refers to scheme 7. A large farm in CS4 comprehends three groups: cereals, legumes, industrial crops, respectively in CP4, CP1 CP2, as showed in Table 6 where the class percentages are reported.

Table 6 - Cropping scheme 7 initial bounds in per cent of total variable area

CS.scheme.group	**mi %**	**ma %**
CS4.sch7.cereals	50	100
CS4.sch7.legumes		10
CS4.sch7.industrial crops	10	25

Consider the cereals group, the maximum equal 100, plus the minimum of the other groups (0 and 10) sum 110. The maximum is reduced to 90, subtracting from 100 the sum of the minimum of the other groups (0+10). The sum of the three percentage (90+0+10) is now 100, which is correct (Table 7).

Table 7 - Cropping scheme 7 final bounds in per cent of total variable area

CS.scheme.group	**$\widetilde{mi}$ %**	**$\widetilde{ma}$ %**
CS4.sch7.cereals	50	90
CS4.sch7.legumes		10
CS4.sch7.industrial crops	10	25

In cropping scheme 3 two groups require correction, as shown in Table 8, cereals and fodder crops have two high values (50+10+50=110) and (100+10+25=135), respectively.

Table 8 - Cropping scheme 3 initial bounds in per cent of total variable area

CS.scheme.group	**mi %**	**ma %**
CS4.sch3.uncoltivated area	10	25
CS4.sch3.cereals	25	50
CS4.sch3.fodder crops	50	100

The maximum value (ma) have been reduced to $\widetilde{ma}$ in Table 9, with the formula in Eq. 1. Cereals 100 – (10 + 50) = 40 and fodder crops 100 – (10 + 25) = 65.

Table 9 - Cropping scheme 3 final bounds in percentage of total variable area

CS.scheme.group	$\widetilde{mi}$ **%**	$\widetilde{ma}$ **%**
CS4.sch3.uncoltivated area	10	25
CS4.sch3.cereals	25	40
CS4.sch3.fodder crops	50	65

The method so far leads to the identification of 'group cropping schemes' that quantify the minimum and the maximum percentages of the total variable area by group and can be applied to similar farms, considering the context and the farm CS.

The following aspects of the schemes at territorial scale should be highlighted:
- they apply to similar farms;
- groups and not crops are considered;
- values are percentages and not areas.

Cropping schemes at farm scale

The next step applies to the cropping schemes to the original farms, and moves from percentages to surfaces.

The farm's total variable surface, related with the CS, multiplied by the group percentage, quantifies the range of variation in hectares for the groups.

Crops can now be introduced into the schemes.

For each farm, the crops observed (obs) in the table crop of the FADN are first included. A test verifies that the minima and maxima calculated for the groups to which the crop belong are compatible with the observed crop values; in fact, the method preserves the observed farm production mix. The minimum area is quantified first, multiplying the observed surface by the minimum percentage of the group. The maximum area for each observed crop is set equal to the surface of the group to which it belongs minus the sum of other crops included in the group.

The introduction of new crops now expands the crop mix. This process broadly reflects the production behaviour adopted by similar farms based on the criteria set out above, which ensure similarity of climatic and territorial conditions and farm, structural and management conditions. Therefore, the cultivation of the new crops should be compatible with the farmer's skills and aptitudes and the existing machinery and equipment without the need for new investment. This approach makes it possible to identify common situations among farms and enlarge the farm cropping mix based on the behaviour of similar ones.

For example, if durum wheat and barley, which are cereals, are present in a homogeneous context, these crops can be introduced on farms that do not grow if they are similar to those where these crops are observed and already grow cereals. In the same way, new vegetable crops, such as industrial crops, can only be introduced on farms where those groups are already grown and if similar farms grow them.

The range of variation for the new crops has a minimum of zero, the only value which does not force cultivation and is therefore compatible with the observed situation in which these crops are not present. The crop upper bound is, instead, always defined and is positive; it is quantified considering the territorial coverage of the crop in similar farms and it is expressed as percentage on the group to which the crop belongs. This percentage multiplied by the area of the group on the farm quantifies the crop upper bound as showed in the next section.

Crops with a maximum surface lower than 0.1 hectares are eliminated, as this value is set as the lower limit for the cultivated area.

The cropping schemes refer now to farms and quantify surface values expressed in hectares.

3. Proof of concept

The method was automated through a code written in GAMS (Bussieck and Meeraus, 2004) and applied experimentally to several Italian production sites. One is illustrated here in detail to allow full understanding.

The Emilia-Romagna case study

The first part of the procedure aims to identify the "context" which is a homogeneous sample from the Italian FADN database. The following criteria have been defined to the purpose:

1. time: 2016
2. space:
   2.1. macro area: Nord Italy

   2.2. administrative Region, Emilia-Romagna
   2.3. climatic zone: castanetum[5]
   2.4. altimetric zone: plain
   2.5. slope: < 5%
3. agricultural activity:
   3.1. conventional
   3.2. pool type of farming: 1 field cropping
   3.3. type of farming: 1510, 1520, 1530, 1610, 1620, 1630, 1660
   3.4. legal form: simple company, sole proprietorship
   3.5. type of occupation: direct
   3.6. disadvantaged area: no
   3.7. livestock: not present.

A subsample with 119 farms was extracted, with a total area of 8284.53 hectares, of which 7708.21 are allocated on variable crops. Almost all of them are medium-large farms, the average area of variable crops being about 65 hectares.

The distribution of farms between variable surface size classes (CSs) shows that the two largest classes account for 79% of the sample, with only one holding in the smallest class (Table 10).

Table 10 - Farms by variable surface size class

CS1	**CS2**	**CS3**	**CS4**	**Total**
1	24	49	45	119

Based on the annual field crops observed in the sample, nine crop groups have been defined: uncultivated area, meadowland, fodder crops, cereals, legumes, oilseeds, industrial crops, seeds, vegetables.

The crops have been associated with the groups, as illustrated in Table 11.

5. Classification has been done using a national phyto-climatic mapping developed by Tomaselli *et al.* (1973) and Pedrotti (2013), defining five classes: Z1-Lauretum, Z2-Quercetum, Z3-Castanetum, Z4-Fagetum and Z5-Picetum; the choice revealed to be a good compromise in terms of resolution and complexity.

Table 11 - Crop-group associations for field cropping

Crop	Group	Crop	Group
Supported set-aside	Uncultivated area	Sweet corn	Industrial crops
Unsupported set-aside	Uncultivated area	Potato	Industrial crops
Durum wheat	Cereals	Other industrial crops	Industrial crops
Tender wheat	Cereals	Soybean	Legumes
Hybrid corn	Cereals	Broad bean	Legumes
Native corn	Cereals	Chickpea	Legumes
Barley	Cereals	Seed fodder crops	Seeds
Sorghum	Cereals	Seed vegetables	Seeds
Triticale	Cereals	Garlic	Vegetables
Cereals other from grain	Cereals	Table tomato	Vegetables
Grass meadowland	Meadowland	Watermelon	Vegetables
Legumes meadowland	Meadowland	Melon	Vegetables
Alfalfa	Fodder crops	Peas	Vegetables
Ryegrass	Fodder crops	Green beans	Vegetables
Other fodder crops	Fodder crops	Onion	Vegetables
Silo corn	Fodder crops	Endive	Vegetables
Sunflower	Oilseeds	Chard	Vegetables
Rapeseed	Oilseeds	Shallot	Vegetables
Other oilseeds	Oilseeds	Spinach	Vegetables
Industrial tomato	Industrial crops	Pumpkin	Vegetables
Sugar beet	Industrial crops	Other vegetables	Vegetables

The distribution of the groups in the 119 farms is very different: cereals are present in 33 farms, 27,73% of the total; followed by: fodder crops 18.49%, industrial crops 14.29%, legumes and vegetables 11.76%, as reported in the first two columns in Table 12.

Cereals cover over 57% of the cultivated area at variable crops, fodder crops (15.11%), industrial crops (12.97%) and legumes (8.30%) are the only groups over 5% of the total.

Table 12 - Farms and surface by groups

Group	Farms		Surface	
	n	%	ha	%
Uncultivated area	5	4.20	22.87	0.30
Meadowland	4	3.36	126.36	1.64
Fodder crops	22	18.49	1165.09	15.11
Cereals	33	27.73	4424.16	57.40
Legumes	14	11.76	640.11	8.30
Oilseeds	7	5.88	158.94	2.06
Industrial crops	17	14.29	999.52	12.97
Seeds	3	2.52	67.30	0.87
Vegetables	14	11.76	103.86	1.35
Total	**119**	**100.00**	**7708.21**	**100.00**

Cropping scheme at territorial scale

The algorithm, on the basis of the associations defined in Table 11, identified 37 different patterns in the 119 farms, defined “qualitative cropping schemes”. Table 13 lists the schemes on the rows and the groups on the columns. The presence of an ‘x’ in the box indicates that the group is part of the scheme.

The number of groups present in the schemes ranges from 1 to 5. Schemes with three and four groups are the most frequent (30% each); only three schemes include only one group; 7 schemes have two groups; 5 schemes include 5 groups (Table 14).

The number of schemes observed vary by the number of groups, as reported in Table 15. Schemes with two and three groups are the most frequent, with 45 and 36 cases, respectively. Schemes with only one group are observed in 14 farms; the presence of 5 groups is observed only six times.

Sixty-two farms are concentrated in 4 schemes: 19 in scheme 8; 16 in schemes 2 and 7; 11 in scheme 16.

The land size class is considered to calculate the percentages of the crop groups within the schemes. For example, scheme 9 includes three groups: fodder crops, cereals, legumes, and is present in farms belonging to classes CS3 and CS4 (Table 16).

Comparing the two CSs, it can be observed that while cereals are always present with the same percentage of the total that goes from 25% to 100% of the total area under variable crops; the situation is different for fodder crops

Table 13 - Qualitative cropping schemes

Scheme	Uncultivated area	Meadowland	Fodder crops	Cereals	Legumes	Oilseeds	Industrial crops	Seeds	Vegetables
1			X	X	X		X		
2				X	X				
3	X		X	X					
4	X		X	X			X		X
5				X	X	X	X		
6			X	X	X	X			
7				X	X		X		
8			X	X					
9			X	X	X				
10			X	X			X		
11				X		X			X
12			X						
13			X	X			X		X
14			X	X					X
15				X		X	X		X
16				X					
17		X	X	X					
18			X	X	X	X			X
19			X	X	X		X		X
20	X			X	X				X
21		X	X	X			X		
22		X	X						
23				X					X
24		X	X	X	X		X		
25							X		X
26				X	X		X		X
27	X		X	X	X				
28				X			X		
29							X		
30			X	X				X	
31			X	X		X			
32	X			X					
33			X	X	X			X	
34			X	X			X	X	X
35				X	X				X
36			X	X		X	X		
37				X			X		X

Table 14 - Count of schemes by the number of groups

N. of groups in the scheme					
1	**2**	**3**	**4**	**5**	**Total**
3	7	11	11	5	37

Table 15 - Count of farms by group of crops

N. of groups in the scheme					
1	**2**	**3**	**4**	**5**	**Total**
14	45	36	18	6	119

Table 16 - Percentages of groups in the scheme 9, by land size class

	Scheme	**Group**	**mi %**	**ma %**
CS3	sch9	Fodder crops	25	50
CS3	sch9	Cereals	25	100
CS3	sch9	Legumes		10
CS4	sch9	Fodder crops		25
CS4	sch9	Cereals	25	100
CS4	sch9	Legumes	10	50

Legend: mi=minimum, ma=maximum.

that range from 25% to 50%, in CS3 and are less than 25% in CS4; also, legumes show different percentages: less than 10% in CS3, between 10% and 50% in CS4.

As shown in Table 16, the percentages assigned to the minima and maxima within a scheme are not always compatible.

If the scheme includes only one group, cases 12, 16 and 29 in Table 13, all the area must be allocated to that group, so the minima (mi) equal to 50 is set to 100 ($\widetilde{mi}$), as reported in Table 17 in the first row for schemes 12 and 29.

If a scheme includes more than one group, when the sum of the maximum of a group, plus the minima of the other groups is higher than 100, the maximum (ma) is lowered with Eq. 1 to make it compatible with the minima; the new values are in column in Table 17, which shows initial and correct percentages of groups in 10 schemes.

Tab. 17 - Initial and final percentages of groups in some schemes

	mi	**ma**	**$\widetilde{mi}$ %**	**$\widetilde{ma}$ %**
CS1.sch29.industrial crops	50.00	100.00	100.00	100.00
CS2.sch2.cereals	50.00	100.00	50.00	90.00
CS2.sch2.legumes	10.00	25.00	10.00	25.00
CS2.sch3.uncultivated area	10.00	25.00	10.00	25.00
CS2.sch3.fodder crops	25.00	50.00	25.00	40.00
CS2.sch3.cereals	50.00	100.00	50.00	65.00
CS2.sch8.fodder crops		100.00		75.00
CS2.sch8.cereals	25.00	100.00	25.00	100.00
CS2.sch11.cereals	25.00	50.00	25.00	50.00
CS2.sch11.oilseeds	50.00	100.00	50.00	75.00
CS2.sch11.vegetables		10.00		10.00
CS2.sch12.fodder crops	50.00	100.00	100.00	50.00
CS2.sch16.cereals	50.00	100.00	100.00	50.00
CS2.sch17.meadowland	10.00	25.00	10.00	25.00
CS2.sch17.fodder crops	50.00	100.00	50.00	65.00
CS2.sch17.cereals	25.00	50.00	25.00	40.00
CS2.sch23.cereals	50.00	100.00	50.00	100.00
CS2.sch23.vegetables		10.00		10.00
CS2.sch28.cereals	50.00	100.00	50.00	90.00
CS2.sch28.industrial crops	10.00	50.00	10.00	50.00
CS2.sch32.uncultivated area		10.00		10.00
CS2.sch32.cereals	50.00	100.00	50.00	100.00

Cropping scheme at farm scale

At this stage the schemes are applied to the original farms and integrated with the crops and the surfaces.

Table 18 illustrates one of the farm schemes; each row identifies a group and a crop. The farm ID 2602016015909000001 includes four groups of crops: fodder crops, cereals, legumes and industrial crops and is associated with the cropping scheme 1 and is in CS3.

The farm crop mix observed in the FADN database is reported in column 'obs' expressed in hectares.

Table 18 - Farm ID 2602016015909000001 scheme with only the observed crops

		mi		obs	ma	
Group	Crop	ha	%	ha	ha	%
fodder crops	Tot			0.84	2.67	10.00
fodder crops	alfalfa			0.84	2.67	
cereals	Tot	13.33	50.00	16.96	21.34	80.00
cereals	durum wheat	4.34		8.68	17.20	
cereals	hybrid corn	4.14		8.28	17.00	
legumes	Tot	2.67	10.00	2.78	6.67	25.00
legumes	soybean	0.28		2.78	6.67	
industrial crops	Tot	2.67	10.00	6.09	6.67	25.00
industrial crops	industrial tomato	0.61		6.09	6.67	
variable crops	Tot			26.67		

The columns ‘mi %’ and ‘ma %’ report the adjusted group percentages calculated in the previous stage. These values multiplied for the total variable crop surface of 26.67 hectares, quantify lower and upper bounds in hectare for the groups ‘mi ha’ and ‘ma ha’.

The lower bound for the observed crops, column ‘mi’, is calculated, multiplying the crop observed area by the group minimum percentage. In Table 18 durum wheat has an observed surface of 8.68 ha, which multiplied by the cereals group minimum percentage (50%) quantifies in 4.34 ha the crop lower bound; in the same way hybrid corn, which also belongs to cereals, reduces the observed surface to a minimum of 4.14 ha. Soybean drops from 2.78 to 0.28 due to the lower group minimum percentage of 10%; the same happens to industrial tomato. Alfalfa has a minimum area of zero due to the group percentage value.

The upper bound, columns ‘ma’, for the observed crops is quantified in hectares adding to the previous calculus the minima of the other crops present in the group. If a group includes only a crop, the maximum is set equal to the group surface. This is the case for alfalfa in fodder crops and soybean and industrial tomato in their respective groups. The cereals group, instead, includes two crops. In this case, durum wheat maximum equal to 17.20 ha is quantified subtracting to the maximum surface for the group (21.34 ha) the hybrid corn minimum surface (4.14 ha). For hybrid corn holds 21.34 – 4.34 = 17.00 hectares.

As expected, the crop observed surface is always interior to the calculated range of variation.

The consideration of similar farms provides information to expand the crop mix; in fact, all the crops cultivated by those farms represent a set that is available to each of them. As an example, the crop territorial coverage for this farm is reported in Table 19. On the rows the crops, on the columns the groups. The crop percentages are quantified from the FADN data.

Table 19 - Land use in the territorial context of farm ID 2602016015909000001 (%)

	Groups			
Crops	fodder crops	cereals	legumes	industrial crops
durum wheat		23.10		
tender wheat		37.56		
hybrid corn		23.24		
native corn		2.08		
barley		2.38		
sorghum		11.65		
alfalfa	87.53			
ryegrass	1.65			
silo corn	10.71			
other fodder crops	0.11			
sugarbeet				52.02
potato				15.53
industrial tomato				24.06
other industrial crops				8.29
sweet corn				0.08
chickpea			7.21	
broad bean			0.15	
bean			3.48	
soybean			89.16	
Total	100.00	100.00	100.00	100.00

The previous values, applied to farm ID 2602016015909000001, are reported in the column 'ma %' in Table 20. Multiplying these values by the upper bound of the cereals group, equal 21.34 ha, quantify the maximum crop area in hectares, column 'ma'. The same procedure is applied to all groups in the scheme. Finally, all new crops with a maximum area lower than 0.1 hectares are dropped; this explains why other fodder crops, sweet corn, broad bean are in Table 19 but do not appear in Table 20.

The farm scheme allows reproducing the observed land use and introducing variations matching the farm and the production context.

Table 20 - Cropping scheme for the farm ID 26020160159090000001.CS3.sch1

		mi		obs	ma	
Group	Crop	ha	%	ha	ha	%
fodder crops	Tot			0.84	2.67	10.00
fodder crops	alfalfa			0.84	2.67	
fodder crops	silo corn				0.29	10.71
cereals	Tot	13.33	50.00	16.96	21.34	80.00
cereals	durum wheat	4.34		8.68	17.20	
cereals	tender wheat				8.01	37.56
cereals	hybrid corn	4.14		8.28	17.00	
cereals	native corn				0.44	2.08
cereals	barley				0.51	2.38
cereals	sorghum				2.49	11.65
legumes	Tot	2.67	10.00	2.78	6.67	25.00
legumes	chickpea				0.48	7.21
legumes	broad bean				0.23	3.48
legumes	soybean	0.28		2.78	6.67	
industrial crops	Tot	2.67	10.00	6.09	6.67	25.00
industrial crops	sugarbeet				3.47	52.02
industrial crops	potato				1.04	15.53
industrial crops	industrial tomato	0.61		6.09	6.67	
industrial crops	other industrial crops				0.55	8.29
variable crops	Tot			26.67		

Another example considers the farm ID 26020160155440000000. It is associated with scheme 11, and a total variable crops area of 10.9 hectares puts it in CS2 and (Table 21).

Farm ID 26020160155440000000 has three crop groups: cereals, oilseeds and vegetables. Given the limited surface of vegetable crops in this farm and the percentage with which other crops of this group are observed in the context, only garlic can be introduced in this group, due to the minimum surface requirement set to 0.1 hectare; for the same reason, only a few crops enter in the cereal group.

The procedure on a PC with an Intel(R) Core(TM) i7-4770K CPU @ 3.50GHz, 32.0 GB of RAM, a 64-bit operating system takes less than 3 seconds to generate the cropping schemes and save them in an Excel spreadsheet.

Table 21 - Cropping scheme for the farm ID 2602016015544000001.CS2.sch11

		mi		obs	ma	
Group	Crop	ha	%	ha	ha	%
cereals	Tot	2.72	25.00	4.05	5.45	50.00
cereals	durum wheat				1.19	21.82
cereals	tender wheat	Crop		4.05	5.45	
cereals	hybrid corn				1.09	20.03
cereals	sorghum				0.43	7.94
oilseeds	Tot	5.45	50.00	6.73	8.18	75.00
oilseeds	sunflower	3.36		6.73	8.18	
vegetables	Tot			0.12	1.09	10.00
vegetables	garlic				0.87	79.66
vegetables	other vegetables			0.12	1.09	
variable crops	Tot			10.90		

4. Conclusions

The use of FADN data to identify land use on territorial and farm-scale has so far been a fruitful line of research that we believe deserves further investigation. The use of surface data, together with technical and economic data, opens the way to important operational outlets to analyse policies and intervention measures.

The proposed method is directly applicable across EU member states, where FADN data is a requirement, or in other countries where other data sources on land use by crop at farm scale are available. FADN is recommended for two other main reasons: first, it provides economic data on the same farms, the integrated use of the information available makes economic analyses in agriculture possible; second, FADN identifies crops in much higher details than other EU land use sources, such as the Integrated Administration and Control System (IACS) which since 2018 uses satellites and other Earth observation data and do not include any economic information (Inan *et al.*, 2010; Tomlinson *et al.*, 2018).

The method differs from other approaches such as CropRot (Schönhart *et al.*, 2011), which uses economic information to derives the relative shares of crop rotations with a maximisation process, primarily because only information on the observed land use is requested, and second because the output is not rotation but cropping schemes, flexible structures characterised by ranges of variation and not fixed surfaces.

The method uses in an original way the tables "farms" and "crops", which provide information on the farms and describe land use at farm level for individual crops, to generate cropping schemes for similar farms in a homogeneous production context, identified based on a plurality of criteria, temporal, spatial and productive. Spatial aspects such as regional location, climatic conditions, and location are taken into account, along with specific factors of agricultural activity such as the type of farming practised, the technical-economic orientation, the legal form, the form of management, whether or not the farm is in a disadvantaged area, and the presence of livestock. Only crops which can vary their coverage every year are considered due to the short time horizon adopted.

The method collects the observed crop surfaces at the farms in groups, identified on agronomic and economic criteria; in this way, general land use patterns, called "qualitative cropping scheme", can be identified, which entail the identification of ordinary and extraordinary situations based on their number. The more refined bounded group schemes at the territorial scale, integrated with the land-use coverage generated, can be used in different studies where the aggregate scale is requested. A series of this data over time can describe land use patter over time for homogenous production systems.

A separate output is offered at farm level, where the method quantify cropping schemes that capture possible land-use adaptations. The central hypothesis is that similar farms, the ones located in the same context and with a not too different total variable crops area, can be assimilated to representative farms, can behave similarly, that is, grow the same crops. At this scale, cropping schemes represent a menu of crops, organised into groups, with ranges of variation compatible with the farm surface. This feature makes the schemes suitable for use in mathematical programming models having as independent variables the crop surface area measured in hectares. It should be noted that while all crops in a scheme have an upper bound value, necessary for the model not to be 'unbound'; lower bounds are only present for some of the observed crops; this allows models to reproduce the FADN land use. An important characteristic of the schemes is the consideration of two complementary levels, groups and crops each with own bounds; the former level force the included crops to respect the aggregate value and this acts a strong constrain on the crop mix.

The use of FADN data also provides a plurality of technical-economic information on production processes linked to land use. This feature makes it possible to derive a set of parameters that is homogeneous with the cropping patterns. Their joint application in mathematical programming models makes it possible to assess the adaptation processes that occur in the presence of measures implementing different policies, making explicit the diversity in production systems at the farm level. Initial applications have demonstrated the validity and potential of the method (Bazzani *et al*., 2021). It should be noted that such model integrates more contexts and many representative farms, in this way, complex territorial analysis can be carried out considering in the same time local specificities, which is necessary to capture how different farms respond to external drivers and how cost and benefit are distributed among them.

This method is currently being integrated into a web-based support system that allows the selection of homogeneous production contexts and subsequently the creation of cropping patterns and their use.

Since cropping schemes bounds depend on the observed values in the FADN database, the method provides the possibility to explore expansion or contraction of the crop surface. This can be done by a scenario analysis where variable crops surface may be increased or decreased by a variation coefficient, quantified on available information to simulate realistic changes in production, markets and regulatory framework. This option is suitable to run policy exercises to analyse policies, markets, climate and any drivers of change.

The field of application is wide. Hydrologic models (Gao *et al*., 2017) would benefit from the high level of detail offered, which could entail quantitative evaluation of land-use change effects on hydrologic outcomes, lost when few crops are considered. Carbon footprint, life cycle assessment and environmental studies could benefit from this information source (Bontinck *et al*., 2020); in fact, cropping schemes could be used at more scales by different scientific disciplines with specific research purposes to describe agro-ecosystem in an integrated land-use modelling framework.

Author Contributions

Conceptualisation, G.M.B., R.S.; methodology, G.M.B.; GAMS coding, G.M.B.; writing – original draft preparation, G.M.B., R.S.; writing – review and editing, R.S., G.M.B. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

Restrictions apply to the availability of these data. The data were obtained from the Council for Agricultural Research and Economics (CREA) and are accessible at the URL https://bancadatirica.crea.gov.it/Account/Login.aspx with the permission of CREA.

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Conflicts of Interest
The authors declare no conflict of interest.

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