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*PRE-PRINT VERSION*

# Farmland Use Transitions After the CAP Greening: a Preliminary Analysis Using Markov Chains Approach


## Abstract

*This paper represents a preliminary attempt to evaluate ex-post impact of the CAP greening payment on farmland use changes, testing by a Markov Chain approach whether farmland use transitions dynamics changed after the introduction of this new policy instrument. Unlike previous contributions, relying on ex-ante simulations, this analysis is based on the actual behaviour of farmers over the period immediately after the last CAP reform. Such ex-post assessment was based on real georeferenced data on farmland allocation, collected in the Lombardy Region, in Northern Italy, over the period 2011-2016. As the current CAP has recently entered in force (in 2015), the present analysis covers the first two years of implementation of the new rules along with the previous four years. Results are in line with previous ex-ante simulations in the same region, detecting a deep discontinuity for those farmland uses characterised by monoculture, before the introduction of the greening. They show a significant discontinuity of farmland use transitions in the reference area after the introduction of greening rules, pointing to a decrease in maize monoculture, in favour of other cereals and legume crops like soybean and alfalfa. Unlike some critical opinions that see current greening rules as a "low profile" compromise, the present analysis points to a strong effect of such rules on regions with high-intensity agriculture.*



Keywords: Common Agricultural Policy, greening, farmland use, Markov chains, crops diversification

JEL Q15, Q18


## 1. INTRODUCTION

Common Agricultural Policy (CAP) is currently structured in two pillars: the first one, that adsorbs the main part of the CAP financial resources, provides direct payments to farmers, while the second one covers rural development policies. The recent last reform has redesigned CAP contents over the programming period 2014-2020, introducing important changes, mainly in the first pillar. In particular, single farm payment (SFP), that represented the main direct payment in the first pillar, has been unpacked in different payments, targeted to different goals and partly tailored to farm specific characteristics. According to European Regulations, Member State are obliged to set some of such payments (base payment, greening payment and payment for young farmers), while setting of other kind of payment (coupled, for less favoured areas, for small farms) is not mandatory for MS.

Among mandatory payments, the so called "greening" represents one of the main novelties of the current CAP programming period, providing an horizontal payment for farmers, conditioned to the compliance with some "agricultural practices beneficial for the climate and the environment (Regulation EU 1307/2013), namely i) arable crops diversification, ii) maintenance of permanent grassland and iii) ecological focus areas (EFA). As a consequence of these rules, such farm practices pertain, and potentially influence, farmland allocation, particularly arable land and grassland.

The introduction of the greening payment within the "package" of direct payments in new CAP 2014-2020 reflects the EU legislators intention to provide a more consistent social and political justification to CAP policy instruments, emphasizing in particular their role in pursuing environmental sustainability (Erjavec and Erjavec, 2015; European Commission, 2010a; European Commission, 2010b). In fact, the implementation of such new instrument aims to plug in Pillar I a reward for the provision of public goods and ecosystem services by agricultural activities (Matthews, 2013a; Cimino *et al.*, 2015). Given the novelty of this political tool, a large debate around greening has arisen after the publication of the initial Commission legislative proposals for the new CAP (Hart and Little, 2012), and even more, after the political agreement among EU Commission, EU Council and EU Parliament (European Commission, 2013), often seen as a watered-down compromise on environmental ambitions (Matthews, 2013b; ). Such a debate mainly focused on some issues related to: *i)* the decision-making process behind greening setting up and the genuineness of its objectives (Erjavec and Erjavec, 2015; Knops *et al.*, 2014; Bureau *et al.*, 2012; Hart and Little, 2012; Mahé, 2012); *ii)* the policy design, particularly referring to their targeting and farm/territorial application level (Buckwel *et al.*, 2012; Hart and Baldock, 2011); *iii)* the weight of technical and economic burdens for farmers and national authorities due to the implementation and monitoring of greening practices (COPA-COGECA, 2012; Roza and Selnes, 2012), *iv*) the degree of substitutability between greening practices and national equivalent practices (Bureau, 2013), and overall, *v)* the potential effectiveness of greening measures in ensuring environmental effects (Hart and Baldock, 2011; Matthews, 2012, 2013a; Westhoek *et al.*, 2013).

The latter point of the debate around greening have been addressed by various analyses and researches. many Authors have attempted to forecast from a quantitative point of view possible effects of greening, mainly recurring to ex-ante simulations. The most popular tool for such kind of simulations is mathematical programming and, in particular, PMP (Van Zeijts *et al.*, 2011; Czekaj *et al.*, 2014; Solazzo *et al.*, 2014; Ahmadi *et al.*, 2015; Cortignani and Dono; 2015; Solazzo *et al.*, 2015; Solazzo *et al.*, 2016; Solazzo and Pierangeli, 2016; Cortignani *et al.*, 2017; Gocht *et al.*, 2017; Louhichi *et al.*, 2017; Cortignani and Dono, 2018). The main output of these simulations pertains the land use change effect induced by the greening. Based on such estimations, some authors have then derived economic and/or environmental impacts of greening (Louchichi *et al.*, 2017; Gocht *et al.*, 2017; Solazzo and Pierangeli, 2016; Cortignani and Dono, 2018). .These simulations have been set to different territorial scale: at European level (Gocht *et al.*, 2017; Louhichi *et al.*, 2017), at country level (Czekaj *et al.*, 2014) or at a regional scale (Solazzo and Pierangeli, 2016; Cortignani and Dono; 2015; Cortignani and Dono, 2018). Some of the analysis covered only some crops or some type of farming (Solazzo *et al.*, 2014, for tomato farms in Italy, Cortignani *et al.*, 2017, for specialized arable farms in Italy).

In these regards the present contribution is framed within the literature aimed at estimating the effect induced by greening rules, firstly in terms of land use change, even if with some differences with respect to previous contributions. First of all, unlike similar studies (all based on ex-ante assessment), the evaluation consists in an ex-post analysis based on actual land allocation choices of farms, after the first two years of greening implementation (2015 and 2016). Furthermore, while previous contributions are grounded on farm-level sample data, this analysis is more detailed (parcel-level) and covers almost the whole universe (from 93% to 96% depending on the year) of regional farmland affected by the CAP. Such level of accuracy confines the analysis to Lombardy region, in Northern Italy. As the greening rules affect farm choices, in order to obtain environmental outcomes at territorial level, the present analysis is particularly appropriate to highlight discontinuities in farmland use registered at territorial scale, after greening introduction.

Given its vocation for high-intensity agricultural production, and in particular for maize monoculture (in some sub-areas), Lombardy region represents an interesting case to examine the interaction between CAP greening and land use transition. As some areas of the Region examined are characterized by monoculture, they may be a target for greening, whose aim is to increase diversity in land use and crop allocation. Maybe for this reason, many earlier analyses on greening covered this Region (Solazzo and Pierangeli, 2016; Solazzo *et al.*; 2016, Cortignani *et al.*, 2017)

For the above mentioned reasons, this paper aims at analysing to a very detailed (parcel) level the temporal and spatial dynamics of farmland use transitions before and after the introduction of greening commitments. Being the first step in a wider research aimed to estimate the net effect of the greening payment on farmland use, the specific contribution aims to highlight whether discontinuities in agricultural land use emerged after the last CAP Reform. To do that a spatial statistical model based on Markov Chains has been developed in order to analyse land use change in the Lombardy Region over the last years.

More specifically, the data in this paper represent the entire population of the region of study, in subsequent years. Thus, for each year, one can explain the past evolution and explore the future developments of farmers' choices of cultivations, to check if and when there has been a significant change. The Markov theory (Norris, 1997) is used to model randomly changing systems, and it is widely assumed in recent studies on land-use changes, (see Brown *et al.*, 2000; Ferreira Filho-Horridge, 2014; Guan *et al.*, 2008; Piet, 2011). In this literature, the Markov theory is often used to model the evolution of a system of parcels. When the emphasis of the evolution is given by the spatial interaction with the neighbourhoods' states, then the system is said to be made by cellular automata (see Ghosh *et al.*, 2017; Fu *et al.*, 2018; Halmy *et al.*, 2015; Palmate *et al.*, 2017; Sang *et al.*, 2011)

A Markov model assumes that future evolutions depend only on the current state of the system, and not on the events that occurred in the past (that is, it assumes the Markov property). Such assumption makes the model computationally tractable, and easy to be interpreted. This aspect is very important due to the big amount of data that are here used and to their spatial geometrical structure (see Aletti, 2018; Aletti-Micheletti, 2017; Micheletti *et al.*, 2016; Micheletti *et al.*, 2010 for examples in other areas of applications).

The prediction of land use changes from year t to t+1 is explained by the transition matrix P(t), having elements $p_{ij}(t)$ ,with the following equation

$$S_j(t+1) = \sum_i S_i(t) \cdot p_{ij}(t)\,;$$

where $S_i(t)$ denotes the amount of type-i crops at time t, and the summation is made on all the possible land uses i. Each element $p_{ij}(t)$ is called transition probability, and explains the conditional probability of adopting the cultivation j at time t+1, conditioned on the fact that one has used the type-i crop at time t. A Markov process with transition probabilities that do not depend on t is called stationary, and it models a system whose land-use change does not vary with time. Within this framework, with a suitable model, it is intended to show here that there was a strong discontinuity in the transition matrix just after the introduction of the greening.

## 2. GREENING: NORMATIVE ASPECTS AND PREVIOUS EVIDENCE

### *2.1. Greening legislative framework*

The adoption of environmentally targeted tools is not new in CAP (see Matthews, 2013a and Erjavec and Erjavec, 2015 for a review). Since 2000, an important part of second pillar, has been represented by a set of voluntary measures (agri-environmental measures) intended for farmers willing to uptake environmental friendly practices beyond the baseline established by law. More recently, also payments provided within first pillar have been bonded to environmental contents. An example is represented by cross-compliance, that, since the Mid Term Review of CAP (2003) requires a minimum threshold of environmental friendly behaviours (such as Good Agricultural and Environmental Conditions – GAEC) in order to receive first pillar payments. Such standards are represented by Statutory Management Requirements (SMRs), set by previous EU Regulations and Directives, and by Good Agricultural and Environmental Conditions, established by each Member State. Notably, as both SMGs and a fair part of GAECs are represented by pre-existing compulsory laws, binding the perception of direct payments by farms to their respect, has generated a certain ambiguity. In fact, vesting direct payments as a reward for environmental services, when these are mandatory standards, has become increasingly difficult, in face of societal concerns for public support to European agriculture and increased environmental awareness. (Meyer *et al.*, 2014).

As greening practices represent a step forward with respect to cross-compliance, they are used to justify part of CAP direct payments, bonded to the provision of environmental public goods, climate-friendly practices and to the reduction of environmental impact of agricultural sector.

Such goal is attained by introduction of a “simple, generalised, non-contractual and annual actions that go beyond cross-compliance” (Regulation EU 1307/2013). The fulfilment of such practices represents the necessary condition to receive first pillar direct payments, as laid down by EU Regulation 1307/2013. All Member States are obliged to allocate 30% of their national ceilings for CAP direct payments to greening payments

Even if all farms are eligible to greening payments, only part of them are obliged to comply with greening obligations, that affect only some crop groups (arable land) and farms beyond certain size thresholds. Furthermore greening obligations have many exceptions and exemptions. For instance, organic farms are entitled ipso facto to greening payments, without the obligation to comply to greening commitments.

Those farms that do not comply with one or more greening requirements lose greening payments. From 2017 non complying farms will also lose part of other direct payment, for a share of 20% of greening payments. Such share will increase to 25% from 2018 onward. In those countries where direct payments have been computed on an historical basis, direct payments (and then green payments) are highly variable across farms and consequently are sanctions for non-respecting greening rules. Such differentiation will be partially attenuated by partial convergence of direct payments among farms in the same region/country. Hereafter, main contents of greening rules are presented, while their detailed description and application is reported on Annexes I and II.

One of the three greening commitments is crops diversification; it concerns farms with at least 10 hectares of arable land, and requires that such area is allocated to more than one crop, prohibiting then monoculture. In particular, farms between 10 and 30 hectares of arable land have to allocate at least two crops (with the main crop covering less than 75% of arable land). Farms with more than 30 hectares of arable land have to allocate at least three crops, and the least represented should cover least 5% of arable land. The second greening commitment pertains the maintenance of permanent grassland; such obligation is enforced at national level, rather than to a farm level (at least in Italy). This obligation requires that, over the programming period 2015-2020, the area of permanent grasslands should not decrease more than 5%.

The Ecological Focus Areas (EFA hereafter) commitments applies to farms with more than 15 hectares of arable land. These farms have to allocate at least 5% of arable land to ecological areas (listed in annex II). Different typologies of ecological areas are converted to EFA according to conversion coefficients and weighting factors reported in Annex II.

### *2.2. Previous evidence*

Hereafter results from more recent studies are presented aimed at estimating the effect of greening in terms of land use change, as the contribution of this paper focuses on this phenomenon. It is worth of attention that all these studies represent ex-ante evaluations of greening effects, relying on simulations of the behaviour of farm samples, while this research is based on the detection of farmland use changes after greening introduction, observed for the entire universe of farms in an Italian region.

Gocht *et al.* (2017) simulated the effect of greening (and of each greening practice) at European level, using CAPRI, a partial equilibrium model that is representative both at NUTS2 and at farm type level. Such contribution estimated, at EU-28 level, a small reduction in arable land (-0.3%), an increase in permanent grassland (+2.7%) and in fallow land (+23.3%), within an increase of 0.6 in utilised agricultural area (UAA). Among main crop groups, are estimated a decrease in cereals (-1.7%) and oilseeds (-1%), and an increase in pulses (+4.2%). As pointed out by authors, these are effects estimated at continental level, that allow for different and more pronounced patterns in smaller areas. Louchichi *et al.* (2017) present simulations from an EU-wide farm-level model (IFM-CAP), that simulates behaviour and choices of 83,292 farms belonging to Farm Accountancy Data Network (FADN). According to their results, the share of EU farmland re-allocated as a consequence of greening is only of 4.5%, with a peak among farms specialised in arable crops (6%), that is consistent with estimates of Gocht *et al.* (2018).

The area covered by the present contribution (Lombardy region in Northern Italy) is also examined in previous analyses. As pointed out by some authors (Cimino *et al.*, 2015; Frascarelli, 2014) the Lombardy plain is characterised by a widespread monoculture of maize and therefore it is among the European areas where greening measures may have the strongest impact. Particularly Cimino *et al.* (2015) estimated the share of farms specialised in arable crops, that have to comply with greening measure is higher in Lombardy (35%) with respect to national average (13%). Solazzo and Pierangeli (2016) assess environmental effects of greening adoption in three Northern Italian regions (Emilia-Romagna, Veneto e Lombardy) using a PMP model, that accounts for the penalty for non-complying farms. Such analysis is based on a sample of 2,038 farms of the Italian FADN[1]. The estimated land use impact in Lombardy (the same area of this contribution) forecasts a decrease of 4.6% in maize area (all uses), and at the same time, increases in soybean (+5.8%), alfalfa (+22.8%) and wheat (+2.5%) acreages. Remarkable changes are estimated also for barley, pulses, grassland and fallow land that are limited in absolute terms, given the small area covered by such crops. According to authors, such effects are concentrated in Lombardy plain, where 30% of farms are affected by greening rules. Solazzo *et al.* (2016) examined greening effect both Lombardy and Piedmont regions, using

[1] The Farm Accountancy Data Network is an annual survey gathering structural, productive and economic data from a sample of farms in each country of the European Union. The sample is representative, by type of farming and economic size, of the agricultural region from which it is drawn. For more details see http://ec.europa.eu/agriculture/rica/index.cfm

3000 farms from FADN. In terms of land use, they estimate a drop of 6.6% in maize area (-10% in Lombardy) and growth in other crops like barley (+7.7%), soybean (+9.9%), alfalfa (+5%), pulses (+27.9%) and grassland (+11.6%). Solazzo et al (2015) assess a substitution between maize and nitrogen-fixing crops (especially soybean and alfalfa) in Emilia-Romagna (Northern Italian region). Cortignani *et al.* (2017) focused their attention on cereal crops in Northern Italy (Lombardy) using FADN data from 136 farms. In this sample the estimated effect of greening yields a decrease in 9.1% of maize area, and to increases of 13.8% in other crops, of 19.2% in EFA crops and to growth of 19.2% in permanent grassland. A common element in all mentioned analysis is a drop in maize area (that is dominant in the Lombardy plain), partially compensated by an increase in nitrogen-fixing crops, that fulfils, both diversification and EFA requirements and, at the same time, provide income (Solazzo and Pierangeli, 2016). Furthermore, the main nitrogen-fixing crop (soybean) receives a coupled payment in Northern Italy, where its use is incentivised to comply with greening requirements (Cortignani *et al.*, 2017).

## 3. DATA AND METHODOLOGY

### *3.1. The reference area*

Lombardy is the main Italian region as regard to the value of the agricultural production, with a very intensive farming sector, traditionally characterized by dairy and pigs farms and a widespread maize cultivation (45% of farmland in the entire dataset). However, Lombardy presents also a quite high farmland territorial variability with specialized and spatially concentrated agricultural districts, like that of rice. Such features are useful to highlight how diverse farming systems present in the region reacted to the introduction of greening. The analysis here focuses on plain and hill areas of the Region, excluding mountain areas, that are scarcely affected by greening rules, as they lack of arable land.

Such zones (the plain and the hill) concentrates 85% of regional UAA, almost 100% of arable crops, 87% of permanent crops and 17% of permanent grassland. In these areas the main part of the UAA is devoted to cereals and forage crops, partly devoted to biogas production (Bartoli *et al.*, 2016, Demartini *et al.*, 2016). It is worth of attention that before 2015 farming practices similar to greening commitments were included among agri-environmental measures in the regional Rural Development Programme, with a fair amount of participation among eligible farmers (Bertoni *et al.*, 2011).

According to an ex-ante evaluation on Lombardy region (Cavicchioli and Bertoni, 2015) using 2011 Agricultural Census microdata as a baseline, among all farms affected by greening, more than 60% were not compliant with requisites of diversification and EFA. The same analysis estimated that the adaptation of non-complying farms would have been required a land use change on farms gathering 367.000 hectares of arable crops.

**Table 1.** Farmland use in the reference area 2011-2016 in hectares (Lombardy Region hills + plain)

| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|
| **1 Arable Crops** | 721,252 | 722,060 | 719,565 | 716,610 | 712,068 | 703,304 |
| 1.1 Cereals | 451,471 | 456,114 | 441,028 | 421,817 | 403,916 | 401,490 |
| 1.2 Dried Pulses and Protein Crops | 832 | 806 | 935 | 894 | 1,288 | 1,622 |
| 1.3 Fresh Vegetables and Flowers | 22,316 | 21,286 | 19,675 | 21,509 | 22,012 | 22,675 |
| 1.4 Industrial Crops | 34,425 | 27,315 | 35,161 | 39,657 | 51,348 | 42,999 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 1.5 Forage Crops | 208,644 | 213,441 | 217,461 | 228,993 | 224,740 | 225,278 |
| 1.6 Fallow Land | 3,564 | 3,099 | 5,306 | 3,741 | 8,765 | 9,240 |
| **2 Permanent Crops** | 26,207 | 26,116 | 25,752 | 25,194 | 25,307 | 25,734 |
| **3 Permanent Grassland** | 26,939 | 27,145 | 26,553 | 26,046 | 26,050 | 26,099 |
| **4= 1+2+3 Utilised Agricultural Area** | 774,399 | 775,321 | 771,870 | 767,851 | 763,425 | 755,138 |
| 5 Landscape Uses | 12 | 47 | 108 | 152 | 1,115 | 2,247 |
| 6 Wooded Areas | 54,008 | 54,333 | 54,988 | 54,682 | 54,866 | 54,387 |
| 7 Other Areas on the Farms | 58,349 | 58,093 | 60,892 | 58,203 | 57,995 | 59,293 |
| **8= 4+5+6+7 Farm Area** | 886,767 | 887,794 | 887,858 | 880,887 | 877,401 | 871,065 |
| Total Efa Utilisation | 93,942 | 86,640 | 93,216 | 98,051 | 123,972 | 117,477 |
| Total Efa Utilisation % | 12.1% | 11.2% | 12.1% | 12.8% | 16.2% | 15.5% |

Source: Own elaboration based on administrative data

### *3.2. Data*

The statistical analysis exploits parcel-level georeferenced data of Lombardy region over the period 2011-2016. In this paper, it is used a dataset of about 2 millions of land parcels in Lombardy, extracted from SISCO, the information system that manages farm demands for CAP payments (first and second pillar) in the Lombardy Region. For each parcel, is registered the barycentre of the parcel shape, in GIS coordinates, its extension in hectares, the farm of membership, and the (main) type of crops over the period 2011-2016. In so doing, two main issues are faced. The first one is the main land use attributed to each parcel each year; in raw data, more crops were associated to the same parcel, due to intra-annual rotation. In such cases, the parcel was attributed to the main crop of the rotation, in line with the greening rules, intended as the crop with the main time coverage in the year. A second issue raised in cases of plots composed by two sub-plots (parcels) having different simultaneous land uses. In this case the parcel was associated to the land use (crop) with the larger area. Such last approximation was necessary as georeferenced data for sub-parcels were not available. Crop typologies have been aggregated into 23 different categories, in order to reduce the complexity of the analysis. As the mountain area of the region is scarcely interested by the implementation of greening, due to its lack of arable crops, this territory was excluded by the analysis. Furthermore, only the parcels recorded in all the years of observation have been considered, building in this way a constant sample 2011-2016 of 638,952 land parcels for a total area of 743,072 hectares[2](table 2). Notably, these parcels represent almost the entire universe of UAA in the reference area, spanning from 93.2% in 2012 to 96.2% in 2016.

Looking at table 2 (constant sample) some patterns in crop allocation emerge clearly, over the period 2011 – 2016. Maize areas show a decreasing trend, especially since 2014. On the other hand, the area used for maize silage is relatively stable over the period, given the long-established tradition in livestock farming of the area. In contrast to maize coverage, land allocated for intra-annual rotation ryegrass-maize for silage increases over time. According to greening rules, even if maize for silage is used for animal feeding (like other fodder crops), it is considered an arable crop, subject to diversification and EFA commitments. On the contrary, when maize for silage is in intra-annual rotation with ryegrass, the latter is considered the first crop for greening rules; as ryegrass is classified as a fodder crops, such intra-annual rotation may contribute to

[2] Parcels non-eligible to CAP payments over the entire period 2011-2016 have been excluded by the constant sample. As a consequence the constant sample includes parcels that have been eligible for CAP payments in at least one year in the reference period 2011-2016.

exemption thresholds with respect to greening rules. All the other cereals (wheat, barley, triticale and others) show a marked increase after 2015, likewise horticultural crops such as potatoes, tomatoes and melons

Among nitrogen-fixing crops there is a remarkable increase in soybean (especially in 2015), alfalfa, legume herbages and, to a smaller extent, in pulses. A fair increase is also observable in rice, that is exempted from greening rules, in those farms where its share is prevalent compared to other arable crops. Fallow land double its areas between 2014 and 2015, while the pattern in wood and natural-like areas is more difficult to track as it is affected by possibility/convenience to use such areas as eligible for CAP payments or as EFA. In particular, it is worth noting that after 2015 in Lombardy, more than 1,000 hectares have been declared as landscape elements for EFA commitments, as well as 400 hectares of wooded areas.

**Table 2.** Farmland use in the constant sample of parcels 2011-2016 (hectares)

| Code | Farm land use | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|
| 10 | Maize | 246,873 | 242,553 | 229,257 | 218,559 | 185,849 | 166,590 |
| 20 | Maize for silage | 57,484 | 60,801 | 67,278 | 73,305 | 66,004 | 68,045 |
| 30 | Rotation ryegrass + maize for silage | 31,728 | 34,025 | 34,907 | 37,141 | 42,943 | 48,003 |
| 40 | Wheat | 45,407 | 56,133 | 63,507 | 57,192 | 66,341 | 79,298 |
| 50 | Barley | 13,715 | 14,966 | 16,139 | 14,065 | 18,892 | 19,536 |
| 60 | Triticale | 5,854 | 9,562 | 9,317 | 11,460 | 10,958 | 9,145 |
| 90 | Other cereals | 4,393 | 3,812 | 5,120 | 4,217 | 3,427 | 3,559 |
| 100 | Rice | 106,059 | 99,175 | 88,319 | 90,850 | 96,894 | 101,648 |
| 160 | Soybean | 22,160 | 15,680 | 24,574 | 27,253 | 39,290 | 32,325 |
| 190 | Pulses | 800 | 751 | 832 | 834 | 1,264 | 1,612 |
| 260 | Horticulture | 16,251 | 15,252 | 14,097 | 15,712 | 16,703 | 17,263 |
| 270 | Flowers | 4,231 | 4,158 | 4,081 | 3,952 | 3,892 | 3,902 |
| 320 | Other arable crops | 9,633 | 9,533 | 8,373 | 9,255 | 7,403 | 7,184 |
| 321 | Ryegrass | 1,514 | 787 | 760 | 898 | 4,024 | 5,315 |
| 322 | Grass herbages | 7,969 | 9,363 | 11,187 | 10,657 | 6,389 | 6,838 |
| 323 | Legume herbages | 238 | 172 | 116 | 142 | 1,214 | 909 |
| 325 | Mixed herbages | 4,458 | 3,928 | 4,892 | 4,629 | 3,674 | 4,435 |
| 330 | Alfalfa | 54,996 | 53,830 | 50,342 | 53,087 | 58,784 | 58,396 |
| 350 | Other temporary grassland | 49,632 | 49,575 | 49,833 | 49,910 | 48,261 | 47,373 |
| 360 | Permanent grassland | 8,831 | 8,979 | 8,797 | 8,700 | 8,871 | 8,941 |
| 414 | Permanent crops | 26,665 | 26,525 | 26,652 | 26,495 | 26,614 | 27,096 |
| 501 | Wood production (Ecological Focus Areas) | - | - | - | - | 317 | 422 |
| 502 | Wood production | 8,386 | 8,409 | 8,218 | 8,113 | 5,074 | 5,478 |
| 503 | Wood (Ecological Focus Area) | 1,996 | 2,530 | 2,910 | 3,243 | 35 | 19 |
| 505 | Landscape elements | 9 | 22 | 42 | 76 | 968 | 957 |
| 961 | Fallow land | 3,484 | 3,241 | 5,304 | 4,520 | 8,158 | 8,927 |
| 990 | Non-eligible surfaces | 10,292 | 9,295 | 8,205 | 8,797 | 10,818 | 9,845 |
| | **TOTAL BALANCED FARMLAND** | **743,072** | **743,072** | **743,072** | **743,072** | **743,072** | **743,072** |
| | - of which UAA (utilised agricultural area) | 722,386 | 722,814 | 723,695 | 722,842 | 725,859 | 726,349 |
| | TOTAL UAA (balanced + unbalanced) | 774,398 | 775,321 | 771,869 | 767,850 | 763,424 | 755,137 |
| | % balanced UAA | 93.3% | 93.2% | 93.8% | 94.1% | 95.1% | 96.2% |

Source: Own elaboration based on administrative data

### *3.3. Methodology*

The system has been modelled as a Markov chain, where each land unit (land parcel) evolves, from one year to the other, into one of the 23 cultivation classes. Denote by $n_{ij}(t)$ the number of land units evolving (i.e. being cultivated) from class $i$ to class $j$, and $p_{ij}(t)$ the probability that a land unit evolves from class $i$ to class $j$, from year $t$ to year $t+1$. The aim here is to check if any statistically significant change in the transition probabilities $p_{ij}(t)$ and/or in the spatial distribution of the 23 cultivation categories, took place after the introduction of greening (that is between 2014 and 2015). A test of stationarity (Anderson and Goodman, 1957) has been performed based on the maximum likelihood ratio, to the transition probabilities $p_{ij}(t)$, for $t$ varying from 2011 to 2014, in order to check if they may be assumed constant in time, before the application of greening. This test is considering all types of cultivation together, being based on the statistics

$$-2\log\Lambda = -\,2\sum_{t=1}^{T}\sum_{i,j=1}^{m} n_{ij}(t)\left[\log(p_{ij}) - \log\left(p_{ij}(t)\right)\right]$$

which is asymptotically distributed as a $\chi^2$ with $m(m-1)(T-1)$ degrees of freedom, where $p_{ij} = \sum_{t=1}^{T} n_{ij}(t) / \sum_{j=1}^{m}\sum_{t=1}^{T} n_{ij}(t)$ is the maximum likelihood estimate of the transition probabilities in the assumption of stationarity, $m=23$ is the number of cultivation classes, and $T$ is the number of considered years. In this first phase the single hectares has been used as statistical units.

This test is first applied to all the $T$=4 years ranging from 2011 to 2014, to test the null hypothesis of stationarity on the overall period preceding greening, i.e. invariance of the transition probabilities with respect to time up to 2014. Unfortunately it was rejected with a *p-value*<0.0001.

The test is then applied to consider only couples of consecutive years (i.e. comparing transition probabilities $p_{ij}(t)$ with $p_{ij}(t+1)$, for $t$=2011, …, 2015), to check if in specific single time steps the stationarity of the process could be assumed. The results are reported in Table 3.

**Table 3.** ML ratio test for $H_0$: transition probabilities are equal in the considered years

| Compared transitions | -2logΛ | P-value | DF |
|---|---|---|---|
| 2011/12 vs. 2012/13 | 14040.14 | <0.0001 | 506 |
| 2012/13 vs. 2013/14 | 17584.59 | <0.0001 | 506 |
| 2013/14 vs. 2014/15 | 39440.43 | <0.0001 | 506 |
| 2014/15 vs. 2015/16 | 21052.54 | <0.0001 | 506 |

Unfortunately also in this case all the hypotheses of stationarity have been rejected with *p-values* <0.0001, but it can be observed an increase in the value of the test statistics -2logΛ after the introduction of greening, that is transition probabilities from 2014 to 2015 are more significantly different from the others.

These results are due to three main causes:

1. The sample size is very high and thus the tests are very sensitive to small variations;
2. The statistical units (hectares) are not independent, since hectares belonging to the same farm, or group of farms with a similar behaviour, will evolve in a correlated way;
3. Every year cultivations are subject to changes, due for example to crop rotation, changes in products prices, etc. Such "physiological" fluctuations in land use must then be filtered out in order to check if the introduction of greening policy had an impact in the cultivation distribution.

### *3.3.1 A weighted $\chi^2$ test for homogeneity*

The starting point to filter out the physiological inhomogeneities was a $\chi^2$ test, applied to the contingency tables of the transition frequencies of each cultivation class $i$ into the others, as the one represented in Table 4.

When the statistical unit is the single hectare or the single parcel, all the null hypotheses are rejected, because of the high sensitivity of the $\chi^2$ test to small deviations in presence of large samples (see e.g. Knoke *et al.*, 2002, Bergh, 2015).

Taking also into account the remark on the possible correlation of groups of hectares (or parcels) showing a geographical proximity, a new parameter *U* has been introduced, representing the number of hectares that should be aggregated to form a statistical unit. This problem of defining the statistical unit in connection with Markov chains has been already studied in Bergh (2015). The methodology given in that paper cannot be applied directly to the data of this paper, and hence a new definition of the statistical unit in this context has been developed. Nevertheless, the ideas at the base of this new definition are comparable with those of Bergh (2015). More precisely, the parameter *U* has been estimated here through a maximum likelihood method (Aletti *et al.*, 2018), in the assumption of time homogeneity of the transition probabilities up to 2014, and it has been used to rescale the transition frequencies of Table 4. In this way the terms $n_{ij}(t)$ actually represent the *number of statistical units* (i.e. groups of *U* hectares) that pass from cultivation *i* to cultivation *j*, from year *t* to year *t+1*. Because of the assumption of stationarity before the application of greening, the resulting $\chi^2$ tests, which are comparing the transition probabilities in subsequent couples of years, bring now to the acceptance of the null hypothesis of time invariance up to 2014, and put in evidence which cultures have experienced a significant change in the transition distribution passing from 2014 to 2015.

**Table 4.** Scheme of the contingency table of transition frequencies from cultivation class i to the other classes during couples of subsequent years

| Transition to-> | **Class 1** | **Class 2** | **…** | **Class 23** |
|---|---|---|---|---|
| **Year 1/Year 2** | $n_{i1}(1)$ | $n_{i2}(1)$ | … | $n_{i23}(1)$ |
| **Year 2/Year 3** | $n_{i1}(2)$ | $n_{i2}(2)$ | … | $n_{i23}(2)$ |

### *3.3.2 The Gini-Simpson index of heterogeneity*

In order to study and visualize the variations in cultivations during the period under study, the normalized Gini-Simpson index is used, whose expression is given by

$$D_i(t) = \frac{m}{m-1}\left(1 - \sum_{j=1}^{m}(p_{ij}(t))^2\right)$$

where *m=23* is still the number of cultivation classes. The quantity $D_i(t)$ represents an index of diversification of the units cultivated with *i* at time *t*. In fact

- $D_i(t)$ is minimum if the cultivation *i* at time *t* is completely transformed into the cultivation *j* at time *t+1* (possibly with *j=i*, which means that the units are not changing cultivation);
- $D_i(t)$ is maximum if $p_{ij}(t)=1/m$, for all *j*, i.e. if passing from time *t* to time *t+1*, the units cultivated with *i* have equal probability to pass into each of the other classes.

The georeferentiation of the data are exploited in this analysis, thus in this phase the statistical unit was the parcel, of which the barycentre has been computationally computed. We then divided the considered area of the Lombardy region into rectangles and in each rectangle the Gini-Simpson index has been computed. Colormaps of the results for the main types of cultivations have thus been produced (see the next section).

## 4. RESULTS

In this section it is highlighted whether any significant discontinuity in farmland use distribution occurred in the Lombardy Region after the introduction of greening in 2015.

Significant changes in the transition probabilities have been tested by applying the weighted $\chi^2$ test to each of the 23 farmland uses. The $\chi^2$ test of homogeneity, or discontinuity, in farmland use transitions has been performed by comparing couples of transitions (for instance transitions occurred between 2011 and 2012 compared to transitions occurred between 2012 and 2013). The interest focuses on detecting discontinuities in farmland uses transitions before (2013/14) and after (2014/15 and 2015/16) the introduction of greening.

Therefore, in Table 5 are reported the main farmland use which resulted significantly different before and after the introduction of greening (maize, maize for silage, wheat, soybean, alfalfa, horticulture). Given their widespread land coverage, these uses show small proportion of cells of the contingency table with an expected frequency lower than 5, corresponding thus to reliable results. In fact, in cases of cultivations with a limited diffusion the expected frequencies of the resulting $\chi^2$ tests were often lower than 5, causing a limited reliability of the results of the tests.

In Table 5, the first column (*Transitions*) indicates couples of years in which the transition probabilities are compared, particularly highlighted (in bold) are the transitions from the last year before greening introduction and the first two years of new rules application. In columns from the second to the seventh are reported, respectively: *Qt* = value of the $\chi^2$ statistics, *c* = critical value of the test, *DF* = degrees of freedom of *Qt*, *p-value* = p-value of the test, *freq<5* = proportion of cells of the contingency table showing expected frequencies lower than 5, $n_i(t\text{-}1)$=total number of statistical units cultivated with *i* in the first couple of years, $n_i(t)$=total number of statistical units cultivated with *i* in the second couple of years. There is a discontinuity between transitions when the p-value is lower than 0.1, while for p-values bigger than 0.1 there is homogeneity between transitions.

**Table 5.** Results of the weighted $\chi^2$ test for the classes showing a significant change in the transitions before (2013/14) and after (2014/15 and 2015/2016) the greening introduction at level $\alpha$=0.05

*MAIZE*

| *Transitions* | $Q_t$ | *c* | *DF* | *p-value* | *freq<5* | $n_i(t\text{-}1)$ | $n_i(t)$ |
|---|---|---|---|---|---|---|---|
| 11-12/12-13 | 8.052 | 16.919 | 9 | 0.52887 | 0 | 569.9 | 558 |
| 12-13/13-14 | 9.948 | 16.919 | 9 | 0.35475 | 0 | 558 | 528.5 |
| **13-14/14-15** | **11.381** | **16.919** | **9** | **0.25048** | **0** | **528.5** | **503.9** |
| **13-14/15-16** | **14.718** | **16.919** | **9** | **0.09897** | **0** | **528.5** | **428.4** |

*MAIZE FOR SILAGE*

| *Transitions* | $Q_t$ | *c* | *DF* | *p-value* | *freq<5* | $n_i(t\text{-}1)$ | $n_i(t)$ |
|---|---|---|---|---|---|---|---|
| 11-12/12-13 | 4.913 | 15.507 | 8 | 0.76687 | 0.111 | 630.9 | 669.5 |
| 12-13/13-14 | 11.087 | 15.507 | 8 | 0.1968 | 0.056 | 669.5 | 737.3 |
| **13-14/14-15** | **37.151** | **15.507** | **8** | **0.00001** | **0** | **737.3** | **789.6** |
| **13-14/15-16** | **31.102** | **15.507** | **8** | **0.00013** | **0** | **737.3** | **711.6** |

*WHEAT*

| *Transitions* | $Q_t$ | *c* | *DF* | *p-value* | *freq<5* | $n_i(t\text{-}1)$ | $n_i(t)$ |
|---|---|---|---|---|---|---|---|
| 11-12/12-13 | 9.889 | 18.307 | 10 | 0.45031 | 0 | 738.7 | 911 |
| 12-13/13-14 | 10.111 | 18.307 | 10 | 0.43079 | 0 | 911 | 1020.1 |
| **13-14/14-15** | **22.043** | **18.307** | **10** | **0.01489** | **0** | **1020.1** | **914.6** |
| **13-14/15-16** | **42.91** | **18.307** | **10** | **0.00001** | **0** | **1020.1** | **1061.1** |

*SOYBEAN*

| *Transitions* | $Q_t$ | *c* | *DF* | *p-value* | *freq<5* | $n_i(t\text{-}1)$ | $n_i(t)$ |
|---|---|---|---|---|---|---|---|
| 11-12/12-13 | 8.212 | 16.919 | 9 | 0.51292 | 0.25 | 433.2 | 298.9 |
| 12-13/13-14 | 9.788 | 16.919 | 9 | 0.36793 | 0.15 | 298.9 | 476.4 |
| **13-14/14-15** | **17.515** | **16.919** | **9** | **0.04124** | **0.05** | **476.4** | **528.1** |
| **13-14/15-16** | **32.822** | **16.919** | **9** | **0.00014** | **0** | **476.4** | **747.7** |

*ALFALFA*

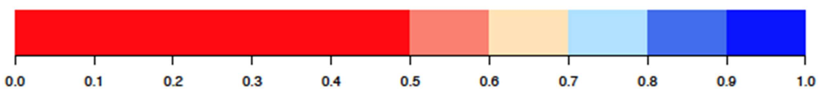
| *Transitions* | $Q_t$ | *c* | *DF* | *p-value* | *freq<5* | $n_i(t\text{-}1)$ | $n_i(t)$ |
|---|---|---|---|---|---|---|---|
| 11-12/12-13 | 1.069 | 14.067 | 7 | 0.99364 | 0 | 921.7 | 901.8 |
| 12-13/13-14 | 12.931 | 14.067 | 7 | 0.07381 | 0 | 901.8 | 837.9 |
| **13-14/14-15** | **19.017** | **14.067** | **7** | **0.00813** | **0** | **837.9** | **878.9** |
| **13-14/15-16** | **21.122** | **14.067** | **7** | **0.00359** | **0** | **837.9** | **962.7** |

*HORTICOLTURE*

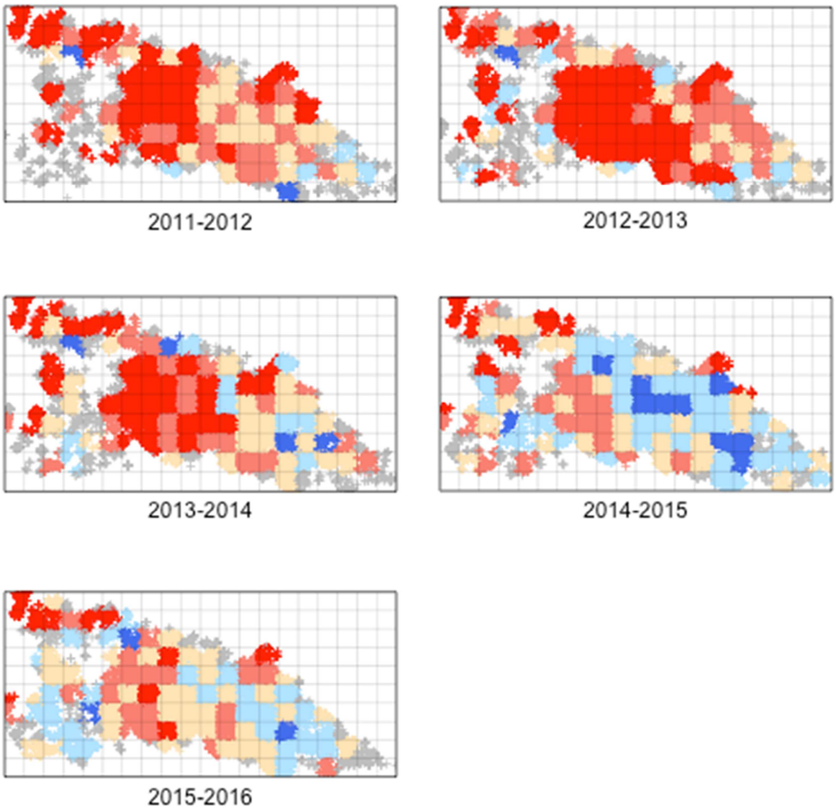
| *Transitions* | $Q_t$ | *c* | *DF* | *p-value* | *freq<5* | $n_i(t\text{-}1)$ | $n_i(t)$ |
|---|---|---|---|---|---|---|---|
| 11-12/12-13 | 6.408 | 12.592 | 6 | 0.37907 | 0 | 716.3 | 678.6 |
| 12-13/13-14 | 5.592 | 12.592 | 6 | 0.47041 | 0 | 678.6 | 621 |
| **13-14/14-15** | **16.181** | **12.592** | **6** | **0.01282** | **0** | **621** | **687** |
| **13-14/15-16** | **19.803** | **12.592** | **6** | **0.003** | **0** | **621** | **739.7** |

The Gini-Simpson index is computed for the main crops of the Region, reporting in Figure 1 some relevant examples.

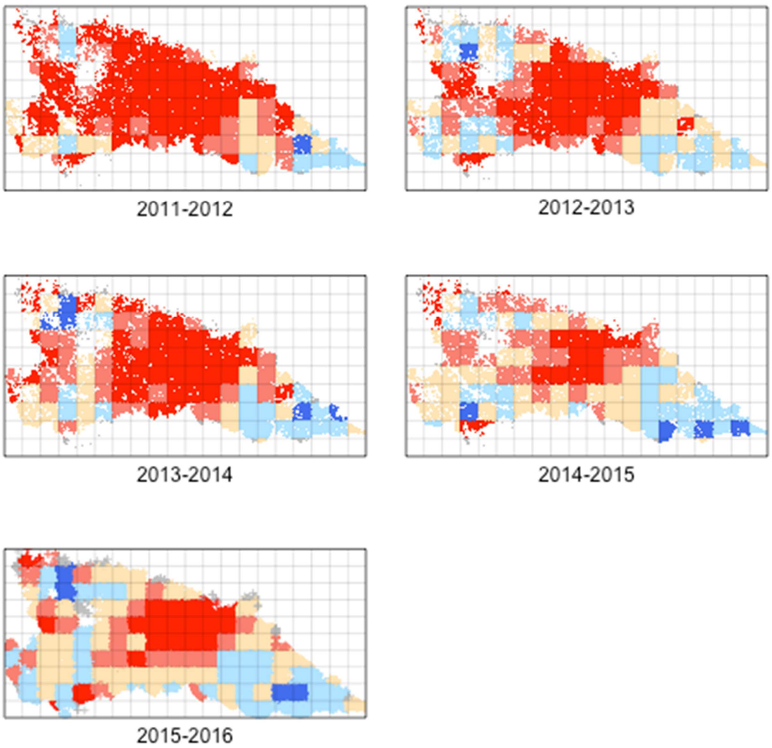
**Figure 1.** Gini-Simpson index. The colormap has been settled according to the following coding for the index value: red indicates a low level of transition toward other crops, while blue denotes high rates of transition to other crops; grey dots correspond to regions with a low frequency of the considered farmland use. A change in colour from grey to red/blue indicates an increase in that particular farmland use. See online version for colours.



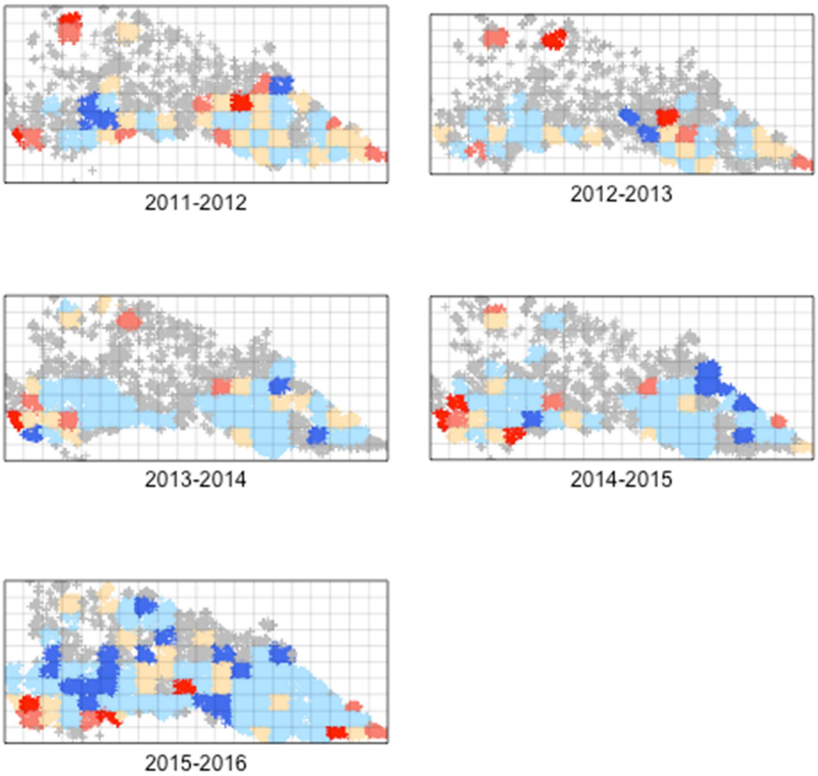
*MAIZE FOR SILAGE*



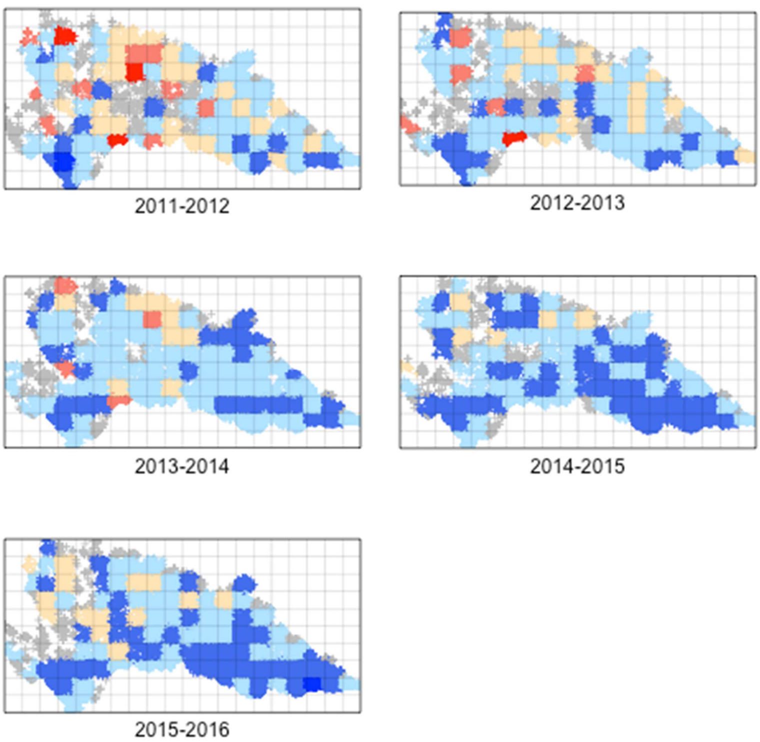

*MAIZE*



*SOYBEAN*




*WHEAT*



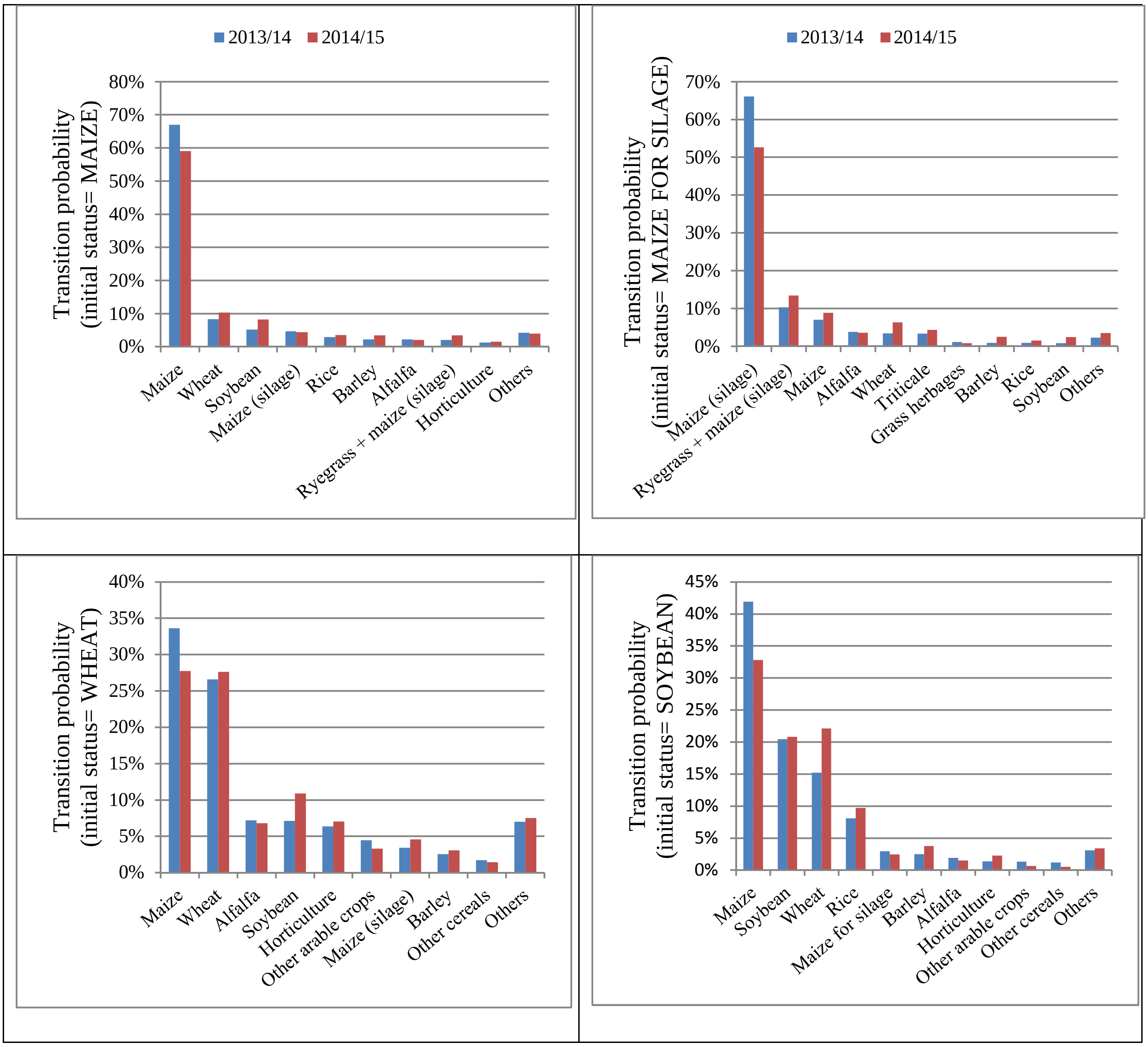
In spite of the fact that the weighted $\chi^2$ test did not reveal a significant change in the overall transition probabilities in Lombardy, it can be observed a bigger differentiation in the crop turnover starting from the transition 2014-2015, but mainly in the central part of Lombardy, which has a major livestock tradition, characterized by dairy farms based on on-farm feed production (particularly maize). Therefore, the weighted $\chi^2$ test was applied only to the data located in the provinces of Bergamo, Brescia, Lodi, Cremona, representing the core of the livestock district. The results of the test are reported in Table 6. The small *p-value* in the comparisons 13/14-14/15 and 13/14-14/15 shows a significant change in the transition probabilities when greening was introduced, confirming that in this part of Lombardy a significant change in maize diffusion and in alternation with other crops occurred.

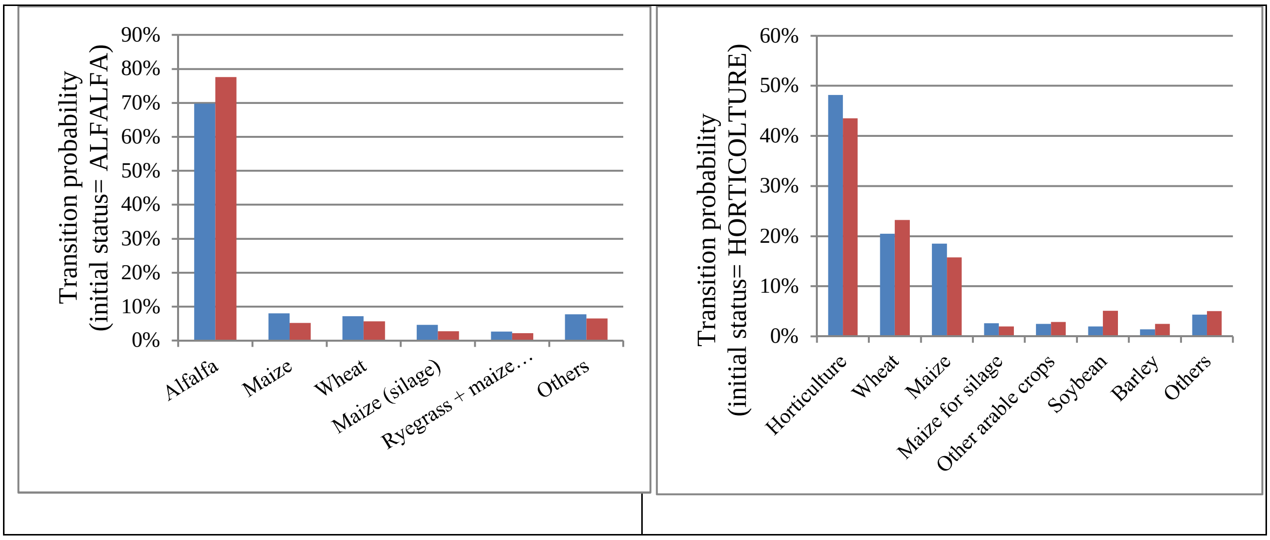
**Table 6.** Weighted $\chi^2$ test for maize in the livestock district.

| *Transitions* | $Q_t$ | *c* | *DF* | *p-value* | *freq<5* | $n_i(t-1)$ | $n_i(t)$ |
|---|---|---|---|---|---|---|---|
| 11-12/12-13 | 5.536 | 15.507 | 8 | 0.69908 | 0.22 | 578.9 | 558.3 |
| 12-13/13-14 | 10.464 | 15.507 | 8 | 0.23394 | 0.11 | 558.3 | 524.2 |
| **13-14/14-15** | **21.421** | **15.507** | **8** | **0.00611** | **0** | **524.2** | **504.1** |
| **13-14/15-16** | **24.109** | **15.507** | **8** | **0.00219** | **0.05** | **524.2** | **431.1** |

In order to examine in depth land use changes among main crops within Lombardy Region, transition matrices for years 2013/14 e al 2014/15 have been set. Such computation allowed to isolate to what extent land use flows have caused increases and decreases in each crop, in the first year of greening implementation. Transition matrices are reported, in graphical form, in Figure 2.

**Figure 2**. Transition probability matrices 2013/14-2014/15 for the main farmland uses. The histograms indicate, for two couple of transitions (2013/14 in blue colour and 2014/15 in red colour) and for each crop, the share of the area in the first year that flows into each farmland use in the second year of the transition. The first bars indicates the percentage of self-rotation. The transition 2013/14 is the last before greening introduction, while 2014/15 is the first after greening introduction. Making reference to the initial status 'MAIZE', it can be observed that the self-rotation rate of maize diminishes after greening introduction, while at the same time transition rates toward wheat and soybean increase. See online version for colours.






## 5. DISCUSSION

The main goal of the analysis was to test for the presence of significant discontinuities in transition probabilities before and after the implementation of greening payments (2015). Such analysis has been carried out using a large dataset, containing almost the entire population of farmland parcels in plain and hills areas of Lombardy Region (Northern Italy). Land use transitions among 23 crop groups have been studied over the period 2011-2016. In this paper, it was used a new methodology that allows to assume stationarity conditions in land use transitions, over the period before the adoption of greening rules, in order to put in evidence any discontinuities over the subsequent period.

In discussing the results, it should be reaffirmed the preliminary nature of this analysis, that at moment does not aspire to demonstrate a strict causality between greening and land use transitions. In fact farmland allocation choice may be affected by different exogenous variables (such as selling price of agricultural products and coupled payments) that are not controlled for in the present analysis. On the other hand, many other variables that may influence farmland allocation are structural in nature (soil characteristics, field of specialisation of each farm) and it is unlikely they can change in the relatively short time span examined. Furthermore, the introduction of greening rules has disposed a sudden bound to farmland use choices since its first year of adoption. Such norms have represented a strong discontinuity element, especially in an area like Lombardy Region, where the share of farms potentially affected by this policy is more relevant than in other territories (Cavicchioli and Bertoni, 2015; Cimino *et al.*, 2015).

Given the above mentioned considerations, even if present results should be interpreted with caution, the estimated discontinuities in farmland uses may be viewed as the consequence of greening rules; furthermore they would be consistent with previous ex-ante evaluations on the same area (Cortignani *et al.*, 2017; Solazzo and Pierangeli, 2016; Solazzo *et al.*, 2016).

In the present analysis it was found, for some crops, a significant discontinuity in land use transition probabilities after 2015, compared to previous period. For those crops in which discontinuities have been found, in-flows and out-flows have been examined through transition matrices 2013/2014-2014/2015. Among cereal crops, discontinuities in land use transition probabilities have been found for maize for silage and wheat. In particular, after 2015, maize for silage decrease significantly its monoculture (intended as “self rotation” rate), in favour of other crops such as: infra-annual rotation ryegrass-maize for silage, wheat, barley and soybean. Farmland devoted to wheat increases slightly its monoculture rate, diminishes its transition toward maize and increase the transition in soybean and to a smaller extent, to horticultural crops. It is worth remembering that even if maize for silage is used for livestock feeding, it is classified as maize (arable crop) for greening commitments (crops diversification and EFA). Nevertheless, such crop is among the most important sources of self-produced feed for dairy farms and represent the main staple feed crop in the region. For this reason, allocation of land for maize silage is often necessary for livestock farms. Territorial concentration of such crop (see Figure 1) overlaps exactly to the areas where dairy farms are concentrated (provinces of Cremona and Lodi and plane portions of Bergamo and Brescia). A possible solution for livestock farms (that relies on maize for feeding) to comply with greening commitments is to switch to the intra-annual rotation ryegrass-maize for silage, as in such a case ryegrass is considered the main crop in the year considered. Being ryegrass a fodder crop, such intra-annual rotation contributes to reach thresholds to be exempted by greening commitments.

Unlike maize for silage, maize for other purposes (mainly grain maize) shows homogeneity in farmland transition over the period 2013/14 and 2014/15 and a weak inhomogeneity in the comparison 2013/14-2015/16 (p-value = 0.10). Such pattern is congruent with two possible explanations. The first one is a decreasing trend in area devoted to such crop, due probably to a decline in selling prices, in place both before and after the adoption of greening. In this sense, the reduction trend of maize area would be homogeneous before and after greening introduction. The second one is related to different uses of maize in each area within the region. In those areas where livestock production is the core farming activity, maize represents the main (and less expensive) source of in-farm feed; for this reason, and for the recent expansion of biogas plants (Bartoli *et al.*, 2016, Demartini *et al.*, 2016), the demand for maize has locally increased, and it is therefore difficult to replace such crop with others. While in other areas of the region, where animal productions are not prevalent, maize monoculture is less frequent and it may enter more frequently in rotation with other crops, making its producers more compliant to crops diversification commitment from the start. Nevertheless, Figure 1 shows that after 2015 maize monoculture has decreased in livestock-dense areas of the region, where it was initially predominant. In face of this fact, transition trends in areas where maize monoculture was predominant (table 6) have been tested, finding a significant discontinuity. Interestingly, in livestock-dense areas, maize monoculture decreases in favour of a bigger frequency of land devoted to soybean, that enters in crop rotation more frequently. Looking at land use dynamics of soybean and alfalfa, such crops increase their area considerably after the introduction of the greening, as predicted by simulations of Cortignani *et al.* (2017) and Solazzo *et al.* (2016). For soybean this is due to a certain discontinuity in its transition probabilities, that resulted on the one hand in a slight increase in its monoculture (intended ad higher frequency in “self-succession) and, on the other hand, in higher transition probabilities from other crops (maize, other cereals, and horticultural crops) toward soybean. Area allocated to alfalfa increases, as a consequence of a bigger share of monoculture in such crop. In the light of greening rules, increases in nitrogen-fixing crops may be explained by the fulfilment of both arable crops diversification and EFA commitments, even if for the latter obligation their conversion coefficient is only 0.7. Furthermore soybean enjoys a coupled payment that provides a further incentive for its cultivation. Among the other more representative land uses, it is observed an increase in transition dynamics in horticultural crops, mainly for potato, tomato and melon. They reduce transition probabilities toward their self and toward maize, in favour to increased transitions toward wheat and soybean.

Even if the main part of present results are consistent with previous ex-ante analyses carried out in Lombardy region, some findings are not in line with part of the literature. The main example is represented by permanent grassland areas that do not show significant changes, while Cortignani *et al.*, 2017 forecasted their increase. Further analyses are needed to explore transition dynamics toward landscape elements and wooded areas, acknowledged to fulfil EFA requirements, even if such land uses are quite limited in the area examined.

## 6. CONCLUSIONS

The aim of this paper has been that of assessing transition dynamics among different crops and land uses over the period before the introduction of greening (2011-2014) and over the two subsequent years (2015-2016) of adoption of such new toll of the CAP. To carry out such analysis it has been exploited a large georeferenced dataset of about 700.000 farmland parcels localized in Lombardy Region, in Northern Italy. Land uses of each parcel have been registered each year between 2011 and 2016. Transition probability matrices for each crop/land use toward each other land use have been computed. Such computations have been made for each couple of year from 2011 to 2016 and for each of 23 land use categories (that are crops or crops groups). Then, using stationarity tests for each crop, possible inhomogeneities in land use transition after the introduction of greening have been tested, compared to the previous period. Results show a significant discontinuity in land use transitions, pointing to a decrease in maize areas, in favour of other cereals and legume crops like soybean.

Reaffirming the preliminary nature of this analysis, that does not pretend to provide a direct quantification or to isolate the "pure" effect of greening, nevertheless it is detected a deep discontinuity in land use dynamics after greening introduction, in an area with strong diffusion of maize monoculture and an high share of farms potentially affected by such obligations. For the above mentioned reasons, It can be stated with a fair degree of confidence, that land use discontinuities observed in the presence analysis are mainly caused by the introduction of greening.

Some limitations of the present analysis should be taken into account. First of all, the lack of control for some factors that may affect farmland use change, such as farm size and other farm characteristics, selling price of farm products, the presence of coupled payments and the penalities for non-complying greening rules. In particular, farmland discontuities detected may be stronger if the analysis would be limited to bigger farms, as they are subject to greening rules. Furthermore, there are some issues in land use attribution. In building up the dataset, when a parcel showed multiple land uses at the same time, it was attributed the main land use (in terms of area covered). Such choice may have led to an under-representation of marginal land uses, such as fallow land, landcape elements and wooded areas

The next step and natural evolution of the present analysis is to isolate and quantify the "pure" effect of greening in terms of land use change, taking into account all those observable elements that may have affected cropland allocation choices before and after the adoption of greening rules.

Finally, it is worthily to be mentioned the positive properties of the adopted methodology to diagnostic farmland transitions discontinuities, considering both spatial and temporal dimension. Indeed, such kind of analysis may represent a useful tool for public administrations (national, regional and EU authorities) to assess the degree of farmland diversification and distribution in a given region. This is particularly important when considering the current greening rules will be probably included (under another guise) in the post-2020 CAP Reform, within the "new enhanced conditionality" (European Commission, 2018). Finally, the results of the present analysis highlight that the introduction of greening in a region with high density of monoculture has led to strong discontinuities in farmland allocation; such result is relevant, if compared to a certain widespread opinion that considered greening rules quite ineffective at EU level (European Court of Auditors, 2017).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**Annex I** – Greening rules[1,] applied in Italy (following EU Regulations No1307/2013, 639/2014 and 1001/2014)

| Greening Practice | Affected farms | Constraints | Exemptions |
|---|---|---|---|
| *Arable crops diversification* | Farms with 10-30 hectares of arable land | At least two arable crops; the main crop<=75% of the arable land | 1. arable land entirely cultivated with crops under water (rice);<br>2. at least 75% of farm eligible agricultural area is represented by grassland, forage crops or crops under water and the remaining arable land is <= 30 hectares;<br>3. at least 75% of farm arable land is represented by forage crops or fallow land and the remaining arable land is <= 30 hectares. |
| | Farms with more than 30 hectares of arable land | At least three arable crops; the main crop<=75% of the arable land; the two main crops <=95% of the arable land | |
| *Permanent grassland maintenance* | Farms with permanent grassland | The share of permanent grassland on the total agricultural area has not to decrease by more 5% at the national level | |
| *Ecological Focus Areas (EFA)* | Farms with more than 15 hectares of arable land | 5% of arable land has to be devoted to ecological focus areas | 1. at least 75% of farm eligible agricultural area is represented by grassland, forage crops or crops under water and the remaining arable land is <= 30 hectares;<br>2. at least 75% of farm arable land is represented by forage crops or fallow land and the remaining arable land is <= 30 hectares. |

[1] These rules covers the period 2015-2016; Regulation (EU) No 1155/2017 has subsequently made further changes to the greening

**Annex II** – EFA conversion and weighting factors[1] applied in Italy (following EU Regulations No 639/2014 and 1001/2014)

| **Features** | **Unit of measurement (UM)** | **Conversion factor (sqm/UM)** | **Weighting factor** | **Ecological focus area (sqm/UM)** |
|---|---|---|---|---|
| Land lying fallow | Sqm | na | 1 | 1 |
| Terraces | Sqm | 2 | 1 | 2 |
| Landscape features | | | | |
| - Hedgerows, tree rows | m | 5 | 2 | 10 |
| - Groves | Sqm | na | 1.5 | 1.5 |
| - Isolated trees | Unit | 20 | 1.5 | 30 |
| - Ponds | Sqm | na | 1.5 | 1.5 |
| - Ditches | m | 3 | 2 | 6 |
| - Dry stone walls | m | 1 | 1 | 1 |
| Buffer strips | m | 6 | 1.5 | 9 |
| Hectares of agro-forestry | Sqm | na | 1 | 1 |
| Strips of eligible hectares along forest edges (without production) | m | 6 | 1.5 | 9 |
| Strips of eligible hectares along forest edges (with production) | m | 6 | 0.3 | 1.8 |
| Areas with short rotation coppice | Sqm | na | 0.3 | 0.3 |
| Afforested areas (by 2nd pillar measures) | Sqm | na | 1 | 1 |
| Areas with catch crops or green cover | Not applied in Italy | | | |
| Areas with nitrogen-fixing crops | Sqm | na | 0.7 | 0.7 |

[1] These rules covers the period 2015-2016; Regulation (EU) No 1155/2017 has subsequently made further changes to the coefficients