

Multi-stage linear programming model for optimizing cropping plan decisions under the new Common Agricultural Policy

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HIGHLIGHTS

A mathematical programming model to support cropping plan decisions is developed.

The model supports farmer's decisions facing the Common Agricultural Policy reform.

An optimal cropping plan in each Spanish agricultural region is provided.

The model supports government proposing a subsidy to encourage sustainable practices.

1 **ABSTRACT**

2 The new European Union's Common Agricultural Policy will cover the period from
3 2015 to 2020. Significant novelties in the payment scheme have been introduced which
4 may potentially encourage farmers to implement changes at the farm level by meeting
5 certain environmental requirements in return for support payments. The mandatory
6 requirements, commonly known as 'greening rules', consist of crop diversification,
7 maintenance of permanent grassland and establishment of an ecological focus area.
8 This paper presents a decision-support tool based on a multi-stage linear programming
9 model that identifies optimal cropping plan decisions under the new Common
10 Agricultural Policy. The capabilities of our tool are illustrated through its application to
11 the Spanish agricultural regions. Our method identifies the optimal cropping plan (i.e.
12 crops to be grown and their acreage each year during the reform horizon) that
13 maximizes the farmer's net return in each region. Furthermore, the model can also be
14 used to calculate the minimum subsidy value that would make the implementation of
15 greening rules economically appealing, thereby promoting the widespread adoption of
16 more sustainable agricultural practises.

17 **KEYWORDS**

18 Cropping plan; Decision support tool; Common Agricultural Policy; Greening rules

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26 1. INTRODUCTION

27 The Common Agricultural Policy (CAP) is the agricultural policy of the European
28 Union (EU) that aims to improve the agricultural productivity ensuring both a fair
29 standard of living of the EU farmers and reasonable food prices without compromising
30 the availability of supplies for consumers. The CAP has always been updated to respond
31 to the challenges of its time. Recently, a new reform entitled —The CAP towards 2020:
32 Meeting the food, natural resources and territorial challenges of the future¹ (European
33 Commission, 2011) has been released.

34 The new EU's CAP, which will be active from 2015 to 2020, introduces a novel
35 payment scheme that will potentially induce changes at the individual farm level. The
36 main objective of this new payment scheme is to redistribute the subsidies both between
37 and within EU Member States and farmers in an equity manner so as to move towards a
38 more sustainable agricultural production. All EU Member States are therefore expected
39 to implement in the short term the new payment scheme based on a uniform payment
40 per hectare by adopting a national or regional approach (based on administrative or
41 agronomic criteria) (European Parliament and European Council, 2013). The previous
42 Single Payment Scheme is therefore replaced in this reform by a new Basic Payment
43 Scheme. Broadly similar to the single payment, the basic payment is a direct payment
44 per hectare to active farmers based on their entitlements, which correspond to the
45 eligible hectares.

46 In addition to the Basic Payment Scheme, the CAP reform introduces a —Payment for
47 agricultural practices which are beneficial for the climate and the environment¹. This is
48 commonly known as —greening payment¹ and represents an additional direct aid per
49 hectare rewarding agricultural sustainable practices. The Greening payment may
50 potentially encourage farmers to meet certain environmental requirements in return for

51 governmental support payments. This greening aid rewards farmers complying three
52 basic EU measures (or equivalent practices). These are: (1) crop diversification, (2)
53 maintenance of existing permanent grassland and (3) establishment of an ecological
54 focus area on arable land.

55 Several EU farms will fulfil these greening measures without having to implement
56 major changes to their current cropping acreage. In contrast, many other farmers will
57 have to take decisions concerning land use at the farm level to get adapted to the
58 greening rules. These decisions involve the choice of crops to be grown, their acreage
59 and their allocation (Nevo et al., 1994).

60 A cropping plan decision is the result of a decision-making process subject to various
61 objectives and constraints fitted into different spatial and temporal dynamics (Dury et
62 al., 2011). These decisions made in a farming system (e.g. cropping plan or crop
63 rotation) are crucial for farmers, since they affect the productivity and profitability on
64 the short and long-term of the farm management. Therefore, it is of paramount
65 importance for the farmers to establish a new cropping plan for the next five years that
66 will satisfy the policy constraints while at the same time maximize their profit (e.g.
67 maximum gross margin, annual profit or net benefit). In this context, decision support
68 models can play a key role in assisting farmers on how to manage their farms.

69 Mathematical programming can provide valuable decision-support in agriculture
70 (Butterworth, 1985). A wide variety of approaches of this type have been developed for
71 supporting cropping plan decisions. An excellent review of cropping plans decision
72 models was provided by Dury et al. (2011). Among the tools available, linear
73 programming (LP) has been the most widely used optimization approach used, maybe
74 because of its great simplicity compared to other techniques. Other tools applied to this
75 area include mixed-integer linear programming (MILP), which was applied to the crop

76 rotation problem (Dogliotti et al., 2006), and evolutionary algorithms, which were used
77 to identify optimal cropping plan decisions at the farm level (Sarker and Ray, 2009).
78 In the modelling approaches reviewed, the cropping plan problem was optimized within
79 a given context and considering one or multiple objectives. Some models optimized a
80 single objective (e.g. the farmer's profit), while others focused on several criteria (e.g.
81 environmental and economic objectives) (Bartolini et al., 2007). The latter case arises
82 when conflicting objectives, such as economic sustainability, resources use and
83 environment protection, must be taken into account simultaneously in the decision-
84 making process. This is sometimes enforced by policy reforms that prompt farmers to
85 adapt their practices (Louhichi et al., 2010; Oñate et al., 2007).

86 The overwhelming majority of the models that support cropping plan decisions assume
87 a single time period and steady state operation, that is, they provide a single set of
88 decisions for a given period, typically one year. In practice, however, a cropping plan
89 contains several time periods, so the underlying decision-making problem is multi-stage
90 in nature (the decisions must be made over multi-year periods). Some authors applied
91 dynamic programming (DP) to deal with this issue. This approach was used to identify the
92 optimal management of agricultural resources over planning horizons (Kennedy, 1986),
93 and also for optimizing agricultural management problems that are decomposed into sub
94 problems (Janová, 2011; Parsons et al., 2009; Sartra et al., 2013).

95 This paper proposes a mathematical programming model to support farmers' cropping
96 plan decisions in response to the CAP reform. The decision-making tool developed
97 herein takes the form of a multi-stage linear programming model (LP) that identifies the
98 optimal cropping plan at the farm level that maximizes the farmer's net return in the
99 CAP reform horizon (i.e. from 2015 to 2020). The model provides insight into whether
100 farmers should adopt the greening measures (i.e. policy constraints) and therefore

101 receive the subsidy, or grow the most profitable crop without meeting the greening
102 rules.
103 The capabilities of our approach are illustrated through its application to the Spanish
104 payment CAP regionalization model. Our model provides as output the optimal
105 cropping plan for rain-fed farms in each agricultural Spanish region. The model can be
106 used in turn to determine the minimum subsidy value that would make the
107 implementation of greening rules economically appealing.

108 The remaining of the article is organised as follows. Section 2 describes the problem
109 statement that motivates the development of our mathematical model to support farmers
110 in cropping plan decisions facing the CAP reform. This model is then described in detail
111 in Section 3 and applied to the Spanish agricultural regularization in Section 4. Finally,
112 the results are shown and discussed in Section 5, whereas the main conclusions of the
113 study are drawn in Section 6.

114 **2. PROBLEM STATEMENT**

115 We consider an active farmer from an EU Member State who needs to decide whether
116 to adapt his/her cropping plan in order to fulfil the CAP reform greening measures and
117 therefore receive the greening subsidy. The farmer seeks to maximize his/her revenues
118 over the CAP reform horizon, that is, the farmer seeks to optimize cropping plan
119 decisions for the next five years maximizing his net return.

120 As already mentioned, the three basic greening rules of the CAP reform to be fulfilled
121 by the farmer in order to receive the greening subsidy are: (1) crop diversification, (2)
122 maintenance of permanent grassland and (3) establishment of ecological focus areas.

123 The constraints imposed by each greening rule vary depending on the size of arable land
124 (see Table 1).

125 **Table 1** Greening rules of the CAP reform to be fulfilled in order to receive the
 126 greening subsidy.

Greening rules	10 ha > Arable land > 30 ha	Arable land > 30 ha
Crop diversification	At least two different crops must be cultivated every year.	At least three different crops must be cultivated every year.
	The main crop shall not cover more than 75% of the arable land.	The largest crop must not cover more than 75% of the arable land. The two largest crops together must not cover more than 95% of the arable land.
Maintenance of permanent grassland	Area of permanent grassland shall be at least 5% of the total arable land.	Area of permanent grassland shall be at least 5% of the total arable land.
Establishment of ecological focus areas	At least 5% of the total arable land shall be ecological focus area.	At least 5% of the total arable land shall be ecological focus area.
	This percentage shall be increased from 5% to 7% from 2017 onwards.	This percentage shall be increased from 5% to 7% from 2017 onwards.

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128 To derive our approach, let us consider that the active farmer owns a piece of arable
 129 land of A hectares where i different crops may be grown. We consider a planning period
 130 of t years (i.e., 5 years of the CAP reform horizon), with one growing season per year.
 131 We are also given the crop yields and the cost of exploitation of each crop. Moreover,
 132 the price received by farmers for each crop and the value of the CAP basic payment are
 133 available.

134 It is assumed that there are no constraints on crop conversion and rotations regarding
 135 the major rules of crop rotations (Castellazzi et al., 2008). The following assumptions
 136 are made when building the model:

- 137 • A minimum return period between the same crop is considered.

138 • There are no agronomic limitations to crop successions. Benefits and risks of
 139 successions are not considered.

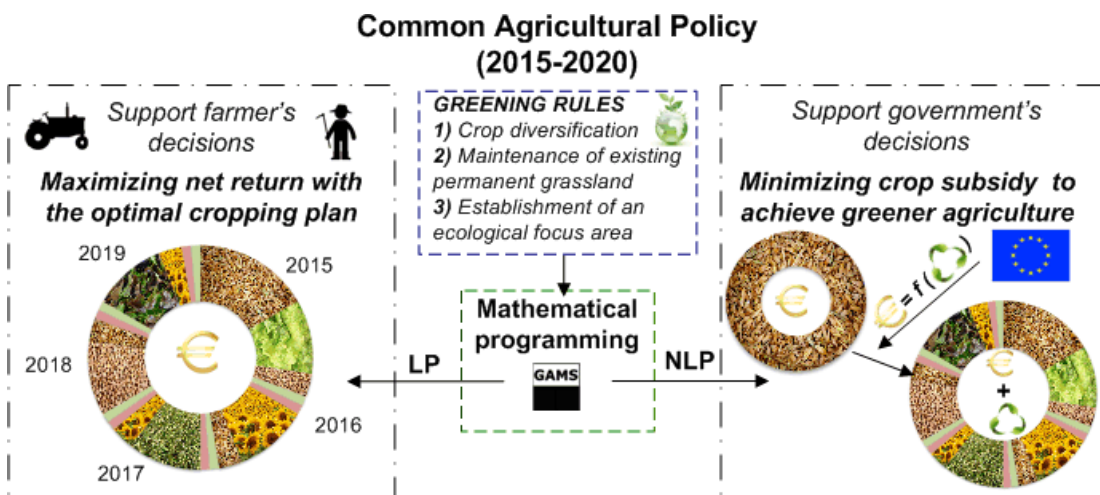
140 • The timing of sowing and harvesting between consecutive crops is compatible.

141 • There are no work limitations and no change in machinery equipment.

142 The goal is to determine the optimal cropping plan by choosing the crops to be grown
 143 every year and their acreage in order to maximize the farmer's economic net return over
 144 the CAP reform horizon.

145 Our analysis might reveal that there are regions in which it is more profitable for the
 146 farmer not to meet the CAP greening rules. If this is the case, an additional analysis
 147 should then be carried out in order to identify more equitable basic payments that would
 148 eventually encourage all farmers to move towards more sustainable agricultural
 149 practices by following the greening CAP measures.

150 Therefore, our mathematical model described in the next section can provide valuable
 151 insight to both farmers and Governments. Fig. 1 shows the general framework of this
 152 study.



154 **Fig.1** General overview of the proposed framework.

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156

157 3. MULTI-STAGE LINEAR PROGRAMMING MODEL

158 In this section, we present a multi-stage LP model that determines the optimal cropping
159 plan (i.e. crops to be grown and their acreage) in each agricultural region in order to
160 maximize the farmer's economic net return during the planning horizon. Note that the
161 model will decide on whether it is convenient for each region to meet or not the CAP
162 greening rules. The model consists of a linear objective function that determines the net
163 present value and a set of linear constraints, which represent the greening rules of the
164 CAP reform.

165 ***Objective function***

166 The objective function is defined via Eq.1 in which NPV represents the net present
167 value of the farmer's net return (€) during the complete planning horizon.

$$168 \quad NPV = \sum_t Z_t / (1 + ta)^{t-1} \quad (1)$$

169 In Eq. 1, Z_t denotes the net return (€) in a particular agricultural region in time period t .
170 Note that for the calculation of the NPV , each Z_t is discounted back to its present value
171 using the discount rate ta . The value of Z_t is obtained via Eq.2:

$$172 \quad Z_t = \sum_i [(Y_i \cdot P_{it}) + BP_i + GP_i - C_{it}] \cdot A_{it} \quad \forall t \quad (2)$$

173 Where Y_i is a parameter that represents the yield of crop i in a particular agricultural
174 region ($t \cdot ha^{-1}$), P_{it} is a parameter that denotes the price received by the farmer in the
175 market for crop i in period t ($€ \cdot t^{-1}$) whereas BP_i and GP_i are parameters that account for
176 the basic payment and the greening payment of the CAP for crop i in the agricultural
177 region ($€ \cdot ha^{-1}$) and C_{it} represents the production cost of the crop i in period t ($€ \cdot ha^{-1}$). A_{it}
178 is a continuous variable denoting the area of the region cultivated with crop i in year t .
179 GP_i is a given percentage α of the value of BP_i calculated via Eq.3 and will only be
180 given to the farmer if he/she fulfils the greening rules:

181 $GP_i = \alpha \cdot BP_i \quad \forall i$ (3)

182 **Model constraints**

183 The maximization of the objective function (Eq.1) in each agricultural region is subject
 184 to a set of CAP greening constraints which vary depending on the surface of arable
 185 land.

186 *Arable land.* The land allocated to the crops, the permanent grassland area and the
 187 ecological focus area must not exceed the total farm arable land each year.

188 $TS_t \geq GRA_t + ECO_t + \sum_i A_{it} \quad \forall t$ (4)

189 In Eq. 4, TS_t represents the total surface of the arable land, GRA_t represents the
 190 permanent grassland area in period t (ha) and ECO_t represents the ecological focus area
 191 in period t (ha).

192 *Maintenance of permanent grassland.* The permanent grassland has to be at least 5% of
 193 the total arable land every year.

194 $GRA_t \geq 0.05 \cdot TS_t \quad \forall t$ (5)

195 *Establishment of ecological focus areas.* The ecological focus area has to be greater
 196 than 5% of the total arable land in the early years, and greater than 7% from 2017 on.

197 $ECO_t \geq 0.05 \cdot TS_t \quad \forall t \leq 2$ (6)

198 $ECO_t \geq 0.07 \cdot TS_t \quad \forall t \geq 3$ (7)

199 *Crop diversification.* The farmer must grow at least two different crops for arable land
 200 between 10 ha and 30 ha and at least three different crops for arable land bigger than 30
 201 ha. The main crop (i.e. the crop occupying the largest area) must not cover more than
 202 75% of the total arable land in each period t (Eq. 8). The two largest crops together must
 203 not cover more than 95% of the arable land (Eq. 9).

204 $A_{it} \leq 0.75 \cdot TS_t \quad \forall i, t$ (8)

205 $A_{it} + A_{ip,t} \leq 0.95 \cdot TS_t \quad \forall i \neq ip, t$ (9)

206 Eq. 10 enforces the application of crop rotations, that is, the same crop cannot be grown
207 in the same area in sequential seasons. The arable land occupied by one crop in period t
208 should be lower or equal to the surface not occupied by this crop during the previous
209 period.

$$210 \quad A_{it} \leq TS_t - GRA_t - A_{i,t-1} \quad \forall i, t > 1 \quad (10)$$

211 *Non-negativity constraints.*

$$212 \quad A_{it} \geq 0; GRA_t \geq 0; ECO_t \geq 0; \quad \forall i, t \quad (11)$$

213 Taking as a basis the constraints described above, we define three models that reflect
214 the potential strategies that the farmer can follow during the CAP reform horizon (see
215 Table 2). Model I corresponds to not fulfilling the CAP greening measures. This implies
216 that the farmer will receive the basic payment but not the greening one. Models II and
217 III illustrate the strategy of fulfilling the greening rules and therefore granting the
218 farmer the greening payment for farms smaller and greater than 30ha, respectively. All
219 the models take the form of an LP. Note that LP models of up to hundreds of thousands
220 of variables and constraints can be efficiently solved on a standard PC using state of the
221 art optimization packages.

222 **4. CASE STUDY**

223 The capabilities of the multi-stage LP model are demonstrated through a case study that
224 analyses the application of the CAP reform in Spain (BOE, 2014a). In particular, we
225 aim to obtain the optimal cropping plan from 2015 to 2020 in each Spanish agricultural
226 region so as to maximize the farmer's economic net return for a representative rain-fed
227 farm. The reason for choosing a rain-fed farm is two-fold: (i) rain-fed agriculture is the
228 predominant farming practice over the Spanish territory, and (ii) the economic

229 feasibility of rain-fed crops largely depends on EU CAP subsidies (Sánchez-Girón et
 230 al., 2007).

231 The three models described in Table 2 are solved for a rain-fed farm in each of the
 232 agricultural regions defined by the Spanish payment regionalization CAP model (Fig.3).

233 Each of these scenarios represents a potential strategy that the farmer can follow during
 234 the CAP reform horizon. Model I corresponds to not fulfilling the CAP greening
 235 measures, which implies that the farmer will receive the basic payment but not the
 236 greening one. Models II and III illustrate the strategy of fulfilling the greening rules and
 237 therefore granting the farmer the greening payment for farms smaller and greater than
 238 30ha, respectively. The overall problem description and the constraints involved in each
 239 case are those shown in Table 2.

240 **Table 2** Model types.

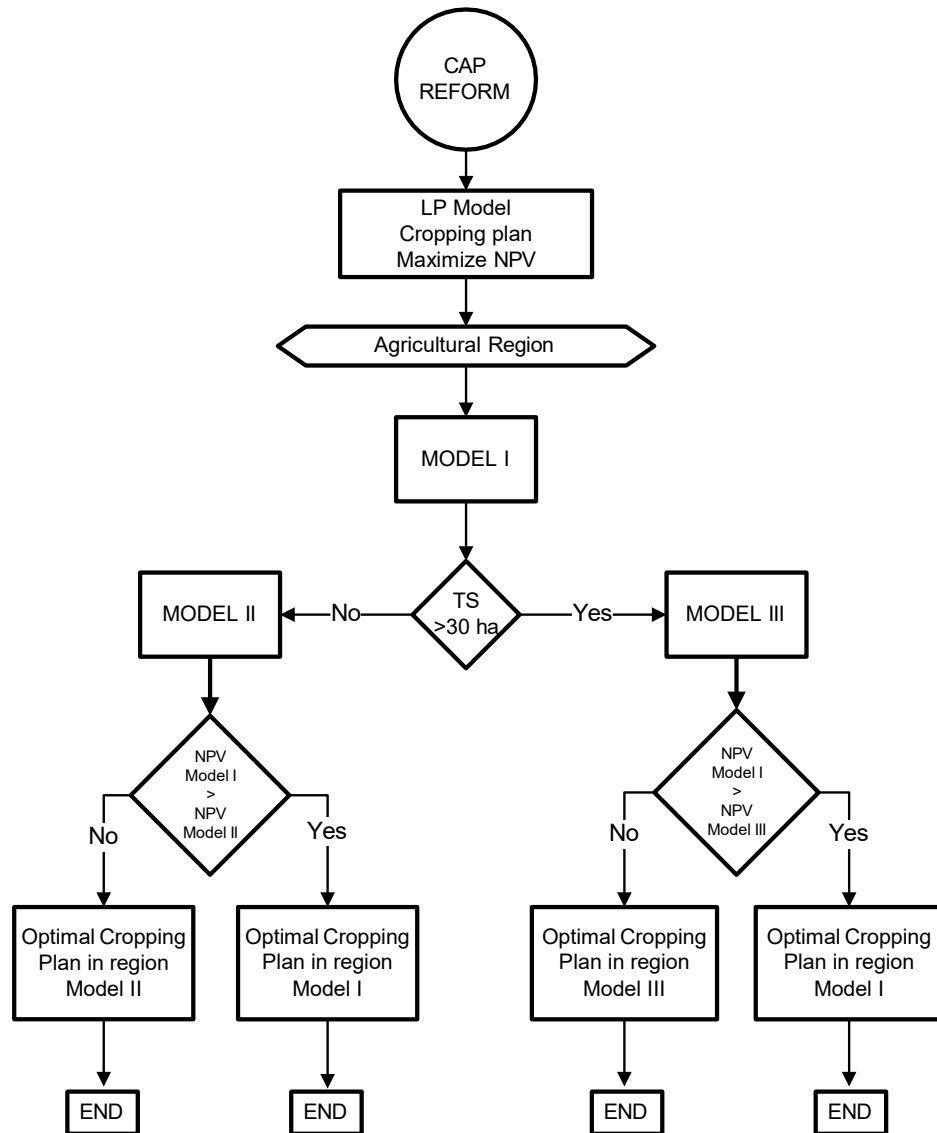
	Model I	Model II	Model III
Description	Not to meet the greening measures	To fulfill the greening measures	To fulfill the greening measures
	No greening payment	Arable land 10-30 ha	Arable land >30 ha
Model	s.t. constraint 4	s.t. constraints 4-8, 10-11	s.t. constraints 4-11

f_i is the objective function which represents the net present value and continuous variables x represent the surface of a crop in the arable land in a specific region.

241

242 The LP model explained in Section 3 is run to determine the optimal cropping plan for
 243 each scenario. The optimal strategy to follow by the farmer corresponds to the cropping
 244 plan that maximizes the farmer's net present value (i.e. farmer's benefit during the CAP
 245 reform horizon). Fig.2 shows the flow chart describing the decision making process that

246 a farmer from a particular agricultural region will follow in order to select the optimal
 247 strategy that maximizes its net return. This approach identifies in a systematic manner
 248 the optimal cropping plan to be implemented at the farm level by modifying the current
 249 cropping plan acreage.



250

251 **Fig.2** Flow chart of the decision making process to determine the farmer's optimal
 252 cropping plan during the CAP reform horizon.

253 We will assume that 6 rain-fed crops can be planted each year and that there are no
 254 constraints on crop conversion and rotations. Note, however, that the approach
 255 presented herein is flexible enough to handle other crops. Table 3 shows the rain-fed

256 crops considered and their selling price and exploitation cost. These crops have been
 257 selected because they represent 70% of the total area dedicated to crops in Spain
 258 (MAGRAMA, 2014a). The price received by a farmer per tonne of crop ($\text{€}\cdot\text{t}^{-1}$)
 259 corresponds to the national average price from the period 1990 -2012 (MAGRAMA,
 260 2014b), while the production cost for each crop ($\text{€}\cdot\text{ha}^{-1}$) correspond to the average value
 261 at the national level in 2011 (MAGRAMA, 2013).

262 **Table 3** Crops considered, selling prices and production costs per crops.

i	Crop	Price ($\text{€}\cdot\text{t}^{-1}$)	Cost ($\text{€}\cdot\text{ha}^{-1}$)
1	Wheat	230.1	604.1
2	Barley	194.8	598.1
3	Rye	181.5	377.6
4	Oat	183.6	585.7
5	Dried Pea	223.6	455.6
6	Sunflower	380.1	430.9

263

264 The price received by the farmer and the exploitation cost of the crops are capitalized
 265 each year via Eqs.19 and 20 by recursively updating the current price and cost of the
 266 corresponding crop (P_i and C_i , respectively) at a given inflation rate (i.e. consumer price
 267 index) r (%).

$$268 \quad P_{it} = P_i \cdot (1+r)^t \quad \forall i, t \quad (19)$$

$$269 \quad C_{it} = C_i \cdot (1+r)^t \quad \forall i, t \quad (20)$$

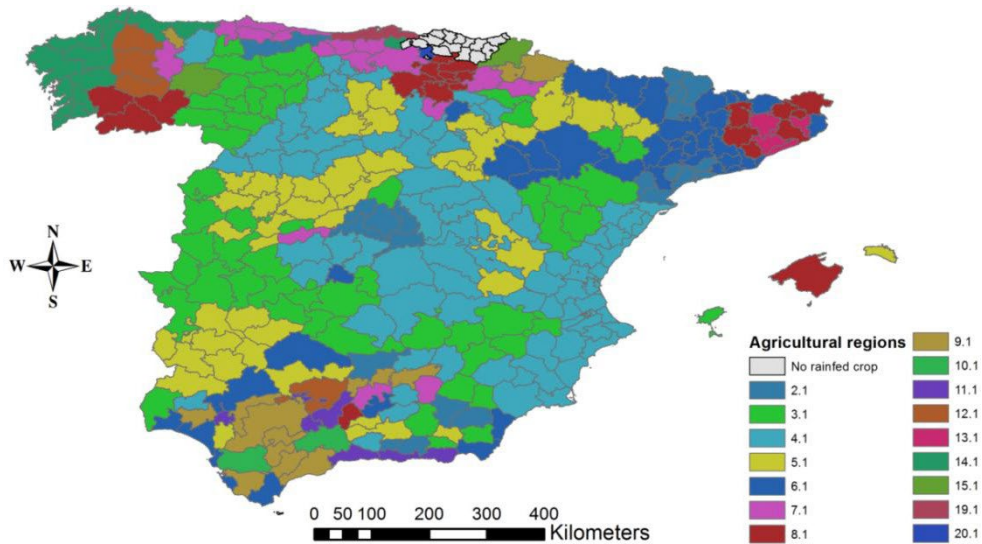
270 We consider a discount rate of 5% to update the net return in each year during the CAP
 271 horizon and a yearly increase inflation rate of 4% for the crop prices and exploitation
 272 cost, which corresponds to the average consumer price index for agriculture in the
 273 period 2004-2014 (INE, 2014).

274 The crop yields were obtained from the Agricultural Statistics Yearbooks
 275 (MAGRAMA, 2014b), using the average nominal values in each Spanish province
 276 (administrative division) in the period 1997-2012. These data were then aggregated at
 277 the agricultural region level by considering surface ratios. Table 4 shows the crop yield
 278 in each agricultural region, which is regarded as a parameter in the LP model.
 279 **Table 4** Crop yields in each agricultural region.

Agricultural rain-fed regions	Yield (t·ha ⁻¹)					
	Wheat	Barley	Rye	Oat	Dried Pea	Sunflower
2	2.396	2.334	1.468	1.642	0.811	0.774
3	2.178	2.199	1.300	1.699	0.828	0.710
4	2.132	2.161	1.319	1.562	0.833	0.739
5	2.542	2.407	1.560	1.683	0.986	0.863
6	2.272	2.303	1.609	1.709	1.060	0.882
7	2.991	2.438	1.852	2.259	1.209	1.202
8	3.316	2.993	2.350	2.403	1.147	0.920
9	2.515	2.278	1.043	2.192	1.063	1.136
10	2.255	2.373	0.530	2.372	0.842	1.024
11	1.985	1.879	0.854	1.608	0.792	0.949
12	2.744	2.479	1.643	1.918	0.596	0.414
13	3.395	2.754	2.792	2.001	1.227	1.066
14	3.136	2.558	1.918	2.026	0.355	0.140
15	3.117	3.031	1.597	3.232	1.234	1.159
19	2.593	1.676	1.931	1.509	1.043	1.399
20	5.184	4.924	3.947	4.850	3.073	1.875

280
 281 Regarding the application of the basic payment scheme, the Spanish Ministry of
 282 Agriculture, Food and Environment has defined a regionalization model of the subsidies
 283 that includes 50 agricultural regions with similar agronomic, socio-economic and

284 agricultural potential features (see Annex II (BOE, 2014b)). We consider 16 agricultural
 285 regions which correspond to the regions where rain-fed crops are cultivated. Fig. 3
 286 shows the Spanish agricultural regions for rain-fed crops for which the LP model will
 287 be solved.



288
 289 **Fig.3** Agricultural regions for rain-fed crops in Spain.

290 In this regionalization model, the basic payment consists of a fixed subsidy per hectare
 291 specific for each agricultural region and type of crop (rain-fed crops, irrigated crops,
 292 livestock and permanent crops). According to the law, the initial value of the rights of
 293 basic payment will be performed by applying a fixed percentage to the amount that the
 294 farmer has received in 2014 (BOE, 2014b). The average value of the basic payment per
 295 type of crop in each region will be published at some point during 2015.

296 Due to lack of data, the average value of the right of basic payment is estimated
 297 employing the same methodology that was used to compute the analogue quantities in
 298 the previous legislation (i.e. the single payment scheme). Following the derogated
 299 Spanish legislation on the application of the single payment (BOE, 2005, 2004), the
 300 average basic payment values are obtained via Eq.21.

301
$$BP_i = Aid_{decoupled} \cdot Percentage_{decoupled} \cdot Yield_i + Aid_{coupled} \cdot Yield_i \quad \forall i \quad (21)$$

302 Where BP_i denotes the specific basic payment per crop i in agricultural region ($\text{€}\cdot\text{ha}^{-1}$);
303 $Aid_{decoupled}$ represents the direct aid per hectare (i.e. $63\text{€}\cdot\text{t}^{-1}$ for cereals);
304 $Percentage_{decoupled}$ is the aid percentage decoupled from the production (i.e. 75% for
305 cereals); $Aid_{coupled}$ represents the direct aid coupled with the production (i.e. $15.75\text{€}\cdot\text{t}^{-1}$
306 for cereals); and $Yield_i$ represents the yield ($\text{t}\cdot\text{ha}^{-1}$) for crop i in a region (Table 4).
307 Table 5 shows the values of the aid per crop and region, which are assumed to be equal
308 to the average value of the basic payment. The estimated basic payment for dried peas
309 ($181\text{€}\cdot\text{ha}^{-1}$) corresponds to the direct payment for legumes and is the same for all
310 agricultural regions.

311 **Table 5** Basic payment for rain-fed crops in each agricultural region.

Agricultural rain-fed regions	Basic Payment ($\text{€}\cdot\text{ha}^{-1}$)					
	Wheat	Barley	Oat	Rye	Dried Peas	Sunflower
2	150.96	147.05	92.46	103.45	181.00	48.73
3	137.24	138.51	81.92	107.06	181.00	44.71
4	134.33	136.16	83.02	98.40	181.00	46.58
5	160.17	151.62	98.26	106.03	181.00	54.39
6	143.16	145.06	101.35	107.68	181.00	55.57
7	188.44	153.57	116.66	142.28	181.00	75.74
8	208.93	188.56	148.03	151.40	181.00	57.97
9	158.43	143.49	65.68	138.06	181.00	71.56
10	142.07	149.51	33.38	149.41	181.00	64.53
11	125.08	118.38	53.78	101.33	181.00	59.80
12	172.90	156.18	103.53	120.84	181.00	26.10
13	213.89	173.50	175.89	126.06	181.00	63.37
14	197.59	161.16	120.85	127.66	181.00	8.83
15	196.34	190.97	100.62	203.62	181.00	73.04
19	163.36	105.61	121.66	95.07	181.00	88.12
20	326.62	310.20	248.63	305.54	181.00	118.11

313 The "Greening Payment" is a percentage of the total value of the rights of basic
314 payment that the farmer activates each year. This percentage, slightly above 50%, will
315 be determined annually and published on the website of the Spanish Agrarian Guarantee
316 Fund of the Ministry of Agricultural, Food and Environment (Spanish Ministry of
317 Agricultural Food and Environment, 2015). The calculations consider that this value
318 will be 51.8% of the Basic Payment.

319 **5. RESULTS AND DISCUSSION**

320 The multi-stage LP model was implemented in the General Algebraic Modelling
321 System (GAMS) software version 24.2.1 and was solved with the CPLEX 12.6.0.0
322 solver using an AMD A8-5500 APU with Raedon 3.20 Ghz and 8.0 GB RAM. The LP
323 model I features 36 continuous variables and 41 equations, whereas models II and III
324 contain 46 continuous variables and 225 equations, respectively. The solution time
325 varied depending on the instance being solved, but was always within the range 8 to 9
326 CPU seconds in the aforementioned computer.

327 The solution of the LP model for each scenario in each agricultural region is given by an
328 optimal cropping plan that maximizes the farmer's net return per hectare in the CAP
329 reform horizon. The optimal cropping plan in all the agricultural regions when the
330 greening rules are not fulfilled consists of growing wheat every year in all the arable
331 land except for regions 11 and 19, which grow sunflower. The optimal cropping plans
332 fulfilling the greening rules are provided in detail in the Supplementary Material (Table
333 S.1, Table S.2), whereas the resulting net returns per hectare in each agricultural region
334 for each scenario are shown in Table 6.

335 **Table 6** Optimal farmer's net present value per hectare ($\text{€}\cdot\text{ha}^{-1}$) in each agricultural
336 region and scenario. The best strategy for the farmer is highlighted in bold.

Agricultural rain-fed regions	Model I	Model II	Model III
2	434.33	496.55	487.38
3	128.15	252.86	244.62
4	63.23	196.00	191.38
5	639.82	651.08	642.82
6	260.16	387.08	386.22
7	1270.84	1119.10	1115.00
8	1728.23	1582.31	1580.59
9	601.11	676.33	662.71
10	235.87	400.48	397.59
11	-47.20	91.63	81.99
12	924.06	851.29	843.46
13	1839.06	1851.77	1810.15
14	1475.24	1235.44	1232.22
15	1447.33	1478.73	1471.96
19	921.92	964.45	947.27
20	4355.09	4033.73	4019.85

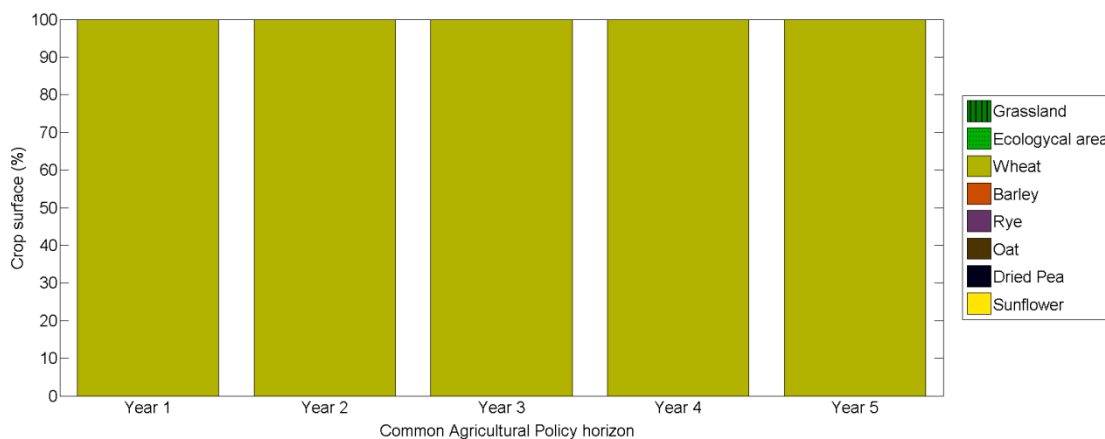
337

338 As observed in Table 6, the farmer's net economic return varies greatly between
339 regions, even when the same strategy (I, II and III) is followed. The new basic payment
340 scheme introduced by the CAP reform might not be equitable, since it might benefit
341 certain agricultural regions with high productivity, whereas many regions that are more
342 dependent on supports might receive only a small share of the basic payment.
343 Furthermore, in all the agricultural regions, the farmers' net return in model II is larger
344 than in model III. This is because in arable lands above 30 hectares it is mandatory to
345 grow an additional third crop that is less profitable than the two others selected by the
346 model. This suggests that setting specific subsidy values for each scenario would result
347 in a more equitable situation.

348 The highest net return for the farmer in each agricultural region, indicated in bold in
349 Table 6, represents the best possible strategy that could be implemented. As can be

350 observed, there are some agricultural regions where the farmer's net return per hectare
 351 is bigger in model I compared to models II and III. This implies that the best strategy
 352 consists of not complying with the greening rules (and therefore not receiving the
 353 corresponding greening payment). This is the case of farmers owning an arable land
 354 between 10 ha and 30 ha in regions 7, 8, 12, 14 and 20, and for farmers owning an
 355 arable land bigger than 30 ha in regions 7, 8, 12, 13, 14 and 20. These regions are
 356 therefore not moving toward agricultural practises beneficial for the climate and the
 357 environment.

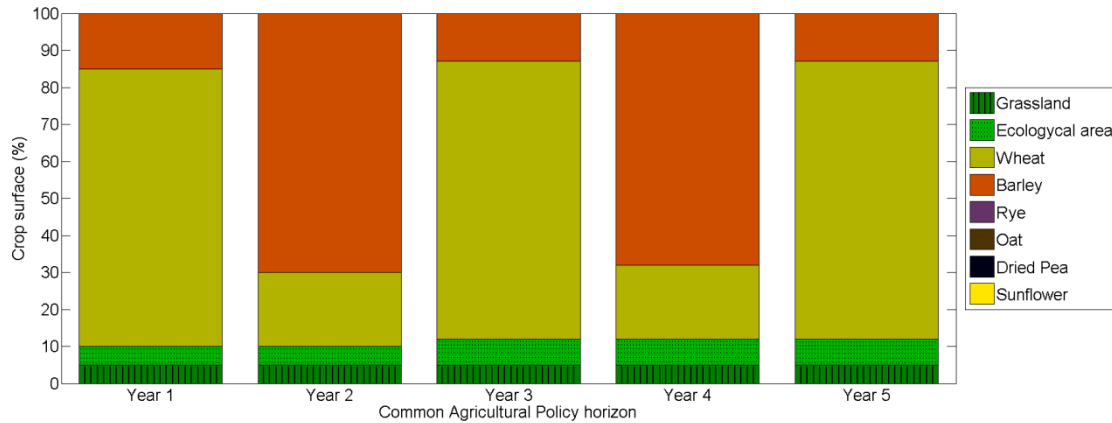
358 In all these regions (where the best strategy consists of not fulfilling the greening rules)
 359 the optimal cropping plan consists of growing wheat every year in all the arable land, as
 360 illustrated in Fig.4. However, the agricultural practice of cropping a single crop
 361 continuously shows major shortcomings. Particularly, it might decline yields and might
 362 lead as well to the appearance of some diseases, among other drawbacks.



363
 364 **Fig.4** Optimal cropping plan in agricultural regions without fulfilling the greening rules
 365 (those for which model I provides the maximum NPV).

366 In the regions where the farmer's economic net return per hectare is bigger in model II
 367 and/or model III than in model I, the best strategy consists of fulfilling the greening
 368 rules. This is for instance the case in region 3, in which complying the greening rules
 369 would increase the profit in 124.71 € per hectare (for an arable land between 10 ha and

370 30 ha) and in 116.47 € per hectare (arable land above 30 ha). The optimal cropping
 371 plans in Region 3 for scenario II and scenario III are shown in Fig.5 and Fig.6,
 372 respectively. In these figures, the surfaces occupied are expressed as a percentage of the
 373 total surface of arable land.

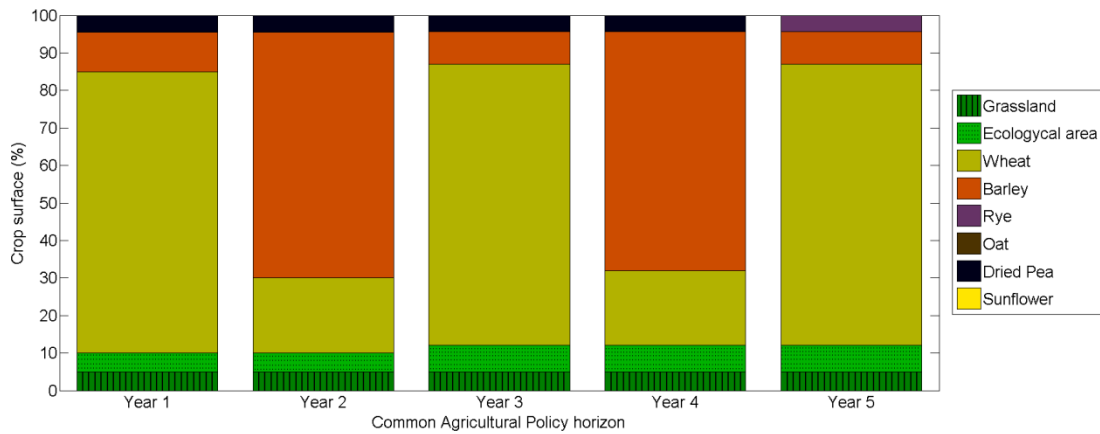


374

375 **Fig.5** Optimal cropping plan in region 3 for arable land between 10 ha and 30 ha.

376 As observed in Fig.5, in the cropping plan that maximizes the farmer's economic net
 377 return, 5% of the total arable land is permanent grassland and 5% ecological focus area
 378 (note that the latter percentage is increased to 7% from the third year onwards). The
 379 crops selected to be cultivated are wheat and barley. Wheat occupies 75%, 20%, 75%,
 380 20% and 75% of the total arable land each year during the CAP reform horizon,
 381 whereas barley is cultivated in 15%, 70%, 13%, 68% and 13% of the total arable land.
 382 This optimal solution allows making crop rotations over the total arable land by
 383 growing different crops selected in the same area during sequential seasons (each one at
 384 a time). Note that this crop rotation can only be achieved if ecological focus areas are
 385 allocated to different surfaces of land in consecutive years. For instance, wheat can only
 386 be cultivated in 20% of the arable land in the second year, if all arable land dedicated to
 387 other crops in the previous year (15% cultivated with barley and 5% of ecological focus
 388 area) is now cultivated with wheat. Crop rotations on the arable land constitute an
 389 appropriate farm land management to improve the sustainability of agriculture. This

390 strategy benefits in turn the producer, since it increases crop yields by increasing
 391 nitrogen supply, soil organic matter and water availability. In addition, it improves soil
 392 conditions and reduce pest, diseases and weed competition (Castellazzi et al., 2008).

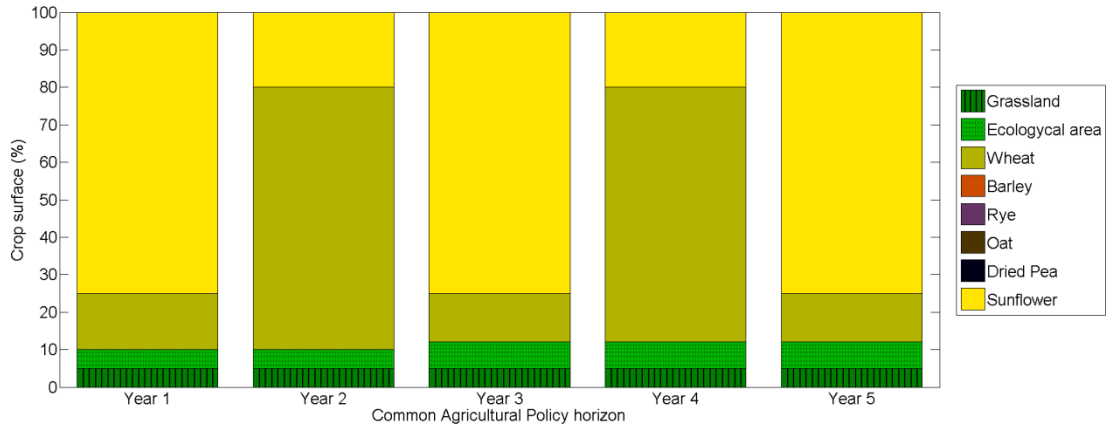


393

394 **Fig.6** Optimal cropping plan in region 3 for arable land bigger than 30 ha.

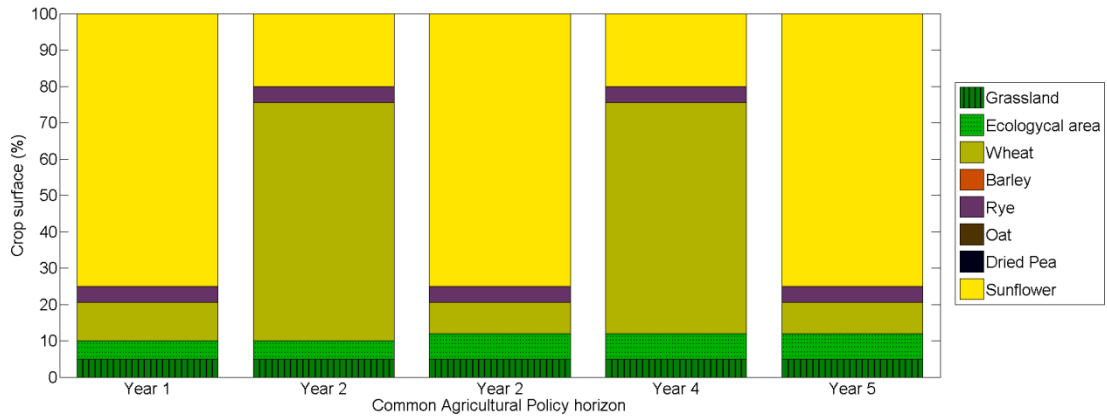
395 Fig.6 shows the cropping plan in region 3, which maximize the farmer's economic net
 396 return for an arable land bigger than 30 ha. The surface reserved to permanent grassland
 397 is 5% of the total arable land during the policy horizon, whereas the ecological focus
 398 area is 5% during the first two years and 7% during the latest three. Three different
 399 crops are grown each year during the CAP reform horizon. Wheat is grown in 75%,
 400 20%, 75%, 20% and 75% of the arable land each year; barley is cultivated in 10.5%,
 401 65.5%, 8.6%, 63.6% and 8.6%; whereas dried pea is grown the first four years in 4.5%,
 402 4.5%, 4.4% and 4.4% of the arable land; and rye in 4.4% of the arable land the last year.
 403 Recall that this solution also requires ecological focus areas to be allocated in different
 404 portions of land in consecutive years in order to ensure crops rotation.

405 The whole set of optimal cropping plans are provided as Supplementary Material. The
 406 optimal cropping plans tend to involve different crops in every region. As an example,
 407 Fig.7 and Fig.8 show the plans in region 19 for cases II and III, respectively. These
 408 cropping plans involve sunflower, wheat and rye, whereas the optimal cropping plans in
 409 region 3 (Figs. 5 and 6) relay on barley and wheat.



410

411 **Fig.7** Optimal cropping plan in region 19 for arable land between 10 ha and 30 ha.



412

413 **Fig.8** Optimal cropping plan in region 19 for arable land bigger than 30 ha.

414 The fact that each agricultural region presents an optimal cropping plan involving
 415 different crops and different acreages reserved to them reveals the importance of
 416 assisting farmers in making the new decisions facing the CAP reform.

417 **5.1. BASIC PAYMENT VALUE ADJUSTED**

418 As previously discussed, there are certain agricultural regions in which the best strategy
 419 to maximize the farmer's benefit consists of not fulfilling the greening rules and
 420 therefore not receiving the greening additional payment. It could be possible, however,
 421 to increase the basic payment in order to encourage all farmers to meet the greening
 422 rules. Likewise, there could be agricultural regions in which the basic payment may be

423 higher than the one required. The establishment of an appropriate payment value is
424 hence essential to ensure the widespread adoption of more sustainable agricultural
425 patterns. The initial value of the right of basic payment specific to each Spanish region
426 has not been published yet. Hence, an analysis of the optimal values that should be
427 defined in each region would be very useful for policy makers.

428 This minimum value of the subsidy that would encourage all farmers to fulfil the
429 greening rules in all the agricultural regions can be obtained by slightly modifying the
430 mathematical model proposed in this manuscript. The subsidy identified by the model
431 should be therefore large enough to compensate for the losses derived from the
432 implementation of the greening rules imposed by the CAP reform policy.

433 First, the net present value originally defined as a variable, should be now redefined as a
434 parameter equal to the values obtained previously in each region with model I, that is, to
435 the net present value obtained when the greening rules were not met (see Table 6). On
436 the contrary, the basic payment in each region, which was originally treated as a
437 parameter, must now be redefined as a continuous variable. The modified model takes
438 the form of a non-linear programming formulation (NLP) that provides as output the
439 minimum basic payment per hectare in each agricultural region that makes the net
440 present value equal to the one obtained when the greening rules are not met.

441 Unfortunately, this model is nonconvex, which means that standard software packages
442 might get trapped in local optima during the search. To avoid this, a global optimization
443 package is used to guarantee convergence to the global optimum within an epsilon
444 tolerance in a finite number of iterations. Note that the solution of the NLP could also
445 be obtained by solving the original LP model iteratively for different values of the
446 subsidy and then selecting as final value the one that makes the objective function equal
447 to the net present value of model I.

448 The NLP model was implemented in the General Algebraic Modelling System (GAMS)
 449 software version 24.2.1 and solved with BARON version 12.7.3 solver (Tawarmalani
 450 and Sahinidis, 2005) using an AMD A8-5500 APU with Raedon 3.20 Ghz and 8.0 GB
 451 RAM. The NLP model for strategy II features 47 continuous variables and 76 equations
 452 and the solution time ranges between 26 and 29 CPU seconds. For strategy III, the NLP
 453 model features 47 continuous variables and 226 equations and the solution time varies
 454 within the range 30 to 36 CPU seconds in the aforementioned computer.

455 The minimum subsidy per hectare in each agricultural region that would encourage all
 456 farmers to fulfil the greening rules are shown in Table 7. Note that there is just one
 457 basic payment value proposed in each agricultural region. This is because all of the
 458 crops considered in the case study are rain-fed crops and therefore they present the same
 459 basic payment. The subsidy values for these rain-fed crops should compensate for the
 460 loss of income resulting from the implementation of greening rules. Therefore, higher
 461 values than the proposed ones would ensure the adoption of greening strategies
 462 beneficial for the climate and the environment.

463 **Table 7** Minimum subsidy ($\text{€}\cdot\text{ha}^{-1}$) in each agricultural region to encourage farmers to
 464 meet the greening rules.

Agricultural region	Scenario II	Scenario III
2	104.35	121.22
3	90.30	100.62
4	83.69	91.82
5	112.47	135.08
6	85.95	96.82
7	116.95	161.58
8	139.59	198.03
9	96.44	104.22
10	97.38	75.99
11	104.35	49.99

12	125.99	158.32
13	123.35	189.75
14	146.30	197.11
15	132.12	179.72
19	129.72	102.99
20	213.08	352.20

465

466 As observed, the minimum basic payment to encourage all farmers to fulfil the greening
 467 rules differs significantly from one region to another. For instance, in region 11 the
 468 minimum basic payment should be above 49.99 €·ha⁻¹, whereas in region 20 it should be
 469 higher than 352.20 €·ha⁻¹. These results reveal that there are regions with higher
 470 agricultural potential requiring lower subsidy to be economically profitable.

471 6. CONCLUSION

472 The new CAP offers incentives for farmers to modify their cropping plan at the farm
 473 level in order to receive the greening payment. This work introduced a multi-stage LP
 474 model that identifies the cropping plan that maximizes the net return over a given time
 475 horizon. Our model provides decision support for cropping planning considering the
 476 CAP reform greening measures.

477 The capabilities of our tool were tested through its application to Spain. The optimal
 478 cropping plan for each agricultural Spanish region was obtained maximizing the
 479 farmer's net return. Results show that each region optimizes its profit by implementing
 480 a different cropping plan entailing different crops and acreages reserved to them.

481 Furthermore, results show that the establishment of an adequate basic payment value is
 482 essential to ensure an equitable distribution among farmers. Several regions may not
 483 fulfil the CAP greening rules because the economic incentive is too small to compensate
 484 for the loss in profit resulting from their implementation. For each of them, a minimum

485 subsidy value was determined that makes the greening rules economically appealing.
486 These values vary from one region to another, suggesting that specific subsidies should
487 be defined for each separate region in order to ensure a more effective transition
488 towards agricultural practises beneficial for the world's climate and environment.

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- 572

SUPPLEMENTARY MATERIAL

The multi-stage LP model developed allows obtaining the optimal cropping plan for a rain-fed farm in each region during the CAP reform horizon which maximizes the farmer's economic net return.

Table S.1 and Table S.2 show the optimal cropping plan in each region for farms smaller a bigger than 30 ha respectively fulfilling the CAP greening rules and therefore the farmer is rewarded with the greening payment. In these tables the crop acreages are expressed as percentage of the total surface of the arable land.

Table S.1 Optimal cropping plan in each agricultural region for an arable land between 10 ha and 30 ha fulfilling the greening rules (Model II).

		Permanent Grassland	Ecological focus area	Wheat	Barley	Rye	Oat	Dried Pea	Sunflower
Region 2	Year 1	5	5	75	15	-	-	-	-
	Year 2	5	5	20	70	-	-	-	-
	Year 3	5	7	75	13	-	-	-	-
	Year 4	5	7	20	68	-	-	-	-
	Year 5	5	7	75	13	-	-	-	-
Region 3	Year 1	5	5	75	15	-	-	-	-
	Year 2	5	5	20	70	-	-	-	-
	Year 3	5	7	75	13	-	-	-	-
	Year 4	5	7	20	68	-	-	-	-
	Year 5	5	7	75	13	-	-	-	-
Region 4	Year 1	5	5	75	15	-	-	-	-
	Year 2	5	5	20	70	-	-	-	-
	Year 3	5	7	75	13	-	-	-	-
	Year 4	5	7	20	68	-	-	-	-
	Year 5	5	7	75	13	-	-	-	-
Region 5	Year 1	5	5	75	15	-	-	-	-
	Year 2	5	5	20	70	-	-	-	-
	Year 3	5	7	75	13	-	-	-	-
	Year 4	5	7	20	68	-	-	-	-
	Year 5	5	7	75	13	-	-	-	-
Region 6	Year 1	5	5	75	-	15	-	-	-
	Year 2	5	5	20	-	70	-	-	-
	Year 3	5	7	75	-	13	-	-	-

	Year 4	5	7	20	-	68	-	-	-
	Year 5	5	7	75	-	13	-	-	-
Region 7	Year 1	5	5	75	-	-	-	-	15
	Year 2	5	5	20	-	-	-	-	70
	Year 3	5	7	75	-	-	-	-	13
	Year 4	5	7	20	-	-	-	-	68
	Year 5	5	7	75	-	-	-	-	13
Region 8	Year 1	5	5	75	-	15	-	-	-
	Year 2	5	5	20	-	70	-	-	-
	Year 3	5	7	75	-	13	-	-	-
	Year 4	5	7	20	-	68	-	-	-
	Year 5	5	7	75	-	13	-	-	-
Region 9	Year 1	5	5	75	-	-	-	-	15
	Year 2	5	5	20	-	-	-	-	70
	Year 3	5	7	75	-	-	-	-	13
	Year 4	5	7	20	-	-	-	-	68
	Year 5	5	7	75	-	-	-	-	13
Region 10	Year 1	5	5	75	15	-	-	-	-
	Year 2	5	5	20	70	-	-	-	-
	Year 3	5	7	75	13	-	-	-	-
	Year 4	5	7	20	68	-	-	-	-
	Year 5	5	7	75	13	-	-	-	-
Region 11	Year 1	5	5	75	-	-	-	-	15
	Year 2	5	5	20	-	-	-	-	70
	Year 3	5	7	75	-	-	-	-	13
	Year 4	5	7	20	-	-	-	-	68
	Year 5	5	7	75	-	-	-	-	13
Region 12	Year 1	5	5	75	15	-	-	-	-
	Year 2	5	5	20	70	-	-	-	-
	Year 3	5	7	75	13	-	-	-	-
	Year 4	5	7	20	68	-	-	-	-
	Year 5	5	7	75	13	-	-	-	-
Region 13	Year 1	5	5	75	-	15	-	-	-
	Year 2	5	5	20	-	70	-	-	-
	Year 3	5	7	75	-	13	-	-	-
	Year 4	5	7	20	-	68	-	-	-
	Year 5	5	7	75	-	13	-	-	-
Region 14	Year 1	5	5	75	-	15	-	-	-
	Year 2	5	5	20	-	70	-	-	-
	Year 3	5	7	75	-	13	-	-	-
	Year 4	5	7	20	-	68	-	-	-
	Year 5	5	7	75	-	13	-	-	-
Region 15	Year 1	5	5	75	-	-	15	-	-
	Year 2	5	5	20	-	-	70	-	-
	Year 3	5	7	75	-	-	13	-	-
	Year 4	5	7	20	-	-	68	-	-

	Year 5	5	7	100	-	-	13	-	-
Region 19	Year 1	5	5	15	-	-	-	-	75
	Year 2	5	5	70	-	-	-	-	20
	Year 3	5	7	13	-	-	-	-	75
	Year 4	5	7	68	-	-	-	-	20
	Year 5	5	7	13	-	-	-	-	75
Region 20	Year 1	5	5	75	15	-	-	-	-
	Year 2	5	5	20	70	-	-	-	-
	Year 3	5	7	75	13	-	-	-	-
	Year 4	5	7	20	68	-	-	-	-
	Year 5	5	7	75	13	-	-	-	-

Table S.2 Optimal cropping plan in each agricultural region for an arable land bigger than 30 ha fulfilling the greening rules (Model III).

		Permanent Grassland	Ecological focus area	Wheat	Barley	Rye	Oat	Dried Pea	Sunflower
Region 2	Year 1	5	5	75	10.5	4.5	-	-	-
	Year 2	5	5	20	65.5	4.5	-	-	-
	Year 3	5	7	75	8.6	4.4	-	-	-
	Year 4	5	7	20	63.6	4.4	-	-	-
	Year 5	5	7	75	8.6	4.4	-	-	-
Region 3	Year 1	5	5	75	10.5	-	-	4.5	-
	Year 2	5	5	20	65.5	-	-	4.5	-
	Year 3	5	7	75	8.6	-	-	4.4	-
	Year 4	5	7	20	63.6	-	-	4.4	-
	Year 5	5	7	75	8.6	4.4	-	-	-
Region 4	Year 1	5	5	75	10.5	-	-	4.5	-
	Year 2	5	5	20	65.5	-	-	4.5	-
	Year 3	5	7	75	8.6	-	-	4.4	-
	Year 4	5	7	20	63.6	-	-	4.4	-
	Year 5	5	7	75	8.6	4.4	-	0	-
Region 5	Year 1	5	5	75	10.5	4.5	-	-	-
	Year 2	5	5	20	65.5	4.5	-	-	-
	Year 3	5	7	75	8.6	4.4	-	-	-
	Year 4	5	7	20	63.6	4.4	-	-	-
	Year 5	5	7	75	8.6	4.4	-	-	-
Region 6	Year 1	5	5	75	4.5	10.5	-	-	-
	Year 2	5	5	20	4.5	65.5	-	-	-
	Year 3	5	7	75	4.4	8.6	-	-	-
	Year 4	5	7	20	4.4	63.6	-	-	-
	Year 5	5	7	75	4.4	8.6	-	-	-
ion	Year 1	5	5	75	-	4.5	-	-	10.5
	Year 2	5	5	20	-	4.5	-	-	65.5

	Year 3	5	7	75	-	4.4	-	-	8.6
	Year 4	5	7	20	-	4.4	-	-	63.6
	Year 5	5	7	75	-	4.4	-	-	8.6
Region 8	Year 1	5	5	75	4.5	10.5	-	-	-
	Year 2	5	5	20	4.5	65.5	-	-	-
	Year 3	5	7	75	4.4	8.6	-	-	-
	Year 4	5	7	20	4.4	63.6	-	-	-
	Year 5	5	7	75	4.4	8.6	-	-	-
Region 9	Year 1	5	5	75	-	-	-	4.5	10.5
	Year 2	5	5	20	4.5	-	-	-	65.5
	Year 3	5	7	75	4.4	-	-	-	8.6
	Year 4	5	7	20	4.4	-	-	-	63.6
	Year 5	5	7	75	4.4	-	-	-	8.6
Region 10	Year 1	5	5	75	10.5	-	4.5	-	-
	Year 2	5	5	20	65.5	-	4.5	-	-
	Year 3	5	7	75	8.6	-	4.4	-	-
	Year 4	5	7	20	63.6	-	-	-	4.4
	Year 5	5	7	75	8.6	-	-	-	4.4
Region 11	Year 1	5	5	75	-	-	-	4.5	10.5
	Year 2	5	5	20	-	-	-	4.5	65.5
	Year 3	5	7	75	-	-	-	4.4	8.6
	Year 4	5	7	20	-	-	-	4.4	63.6
	Year 5	5	7	75	-	-	-	4.4	8.6
Region 12	Year 1	5	5	75	10.5	4.5	-	-	-
	Year 2	5	5	20	65.5	4.5	-	-	-
	Year 3	5	7	75	8.6	4.4	-	-	-
	Year 4	5	7	20	63.6	4.4	-	-	-
	Year 5	5	7	75	8.6	4.4	-	-	-
Region 13	Year 1	5	5	75	4.5	10.5	-	-	-
	Year 2	5	5	20	4.5	65.5	-	-	-
	Year 3	5	7	75	4.4	8.6	-	-	-
	Year 4	5	7	20	4.4	63.6	-	-	-
	Year 5	5	7	75	4.4	8.6	-	-	-
Region 14	Year 1	5	5	75	4.5	10.5	-	-	-
	Year 2	5	5	20	4.5	65.5	-	-	-
	Year 3	5	7	75	4.4	8.6	-	-	-
	Year 4	5	7	20	4.4	63.6	-	-	-
	Year 5	5	7	75	4.4	8.6	-	-	-
Region 15	Year 1	5	5	75	4.5	-	10.5	-	-
	Year 2	5	5	20	4.5	-	65.5	-	-
	Year 3	5	7	75	4.4	-	8.6	-	-
	Year 4	5	7	20	4.4	-	63.6	-	-
	Year 5	5	7	75	4.4	-	8.6	-	-
Region 19	Year 1	5	5	10.5	-	4.5	-	-	75
	Year 2	5	5	65.5	-	4.5	-	-	20
	Year 3	5	7	8.6	-	4.4	-	-	75

	Year 4	5	7	63.6	-	4.4	-	-	20
	Year 5	5	7	8.6	-	4.4	-	-	75
Region 20	Year 1	5	5	75	10.5	-	4.5	-	-
	Year 2	5	5	20	65.5	-	4.5	-	-
	Year 3	5	7	75	8.6	-	4.4	-	-
	Year 4	5	7	20	63.6	-	4.4	-	-
	Year 5	5	7	75	8.6	-	4.4	-	-

Table 1 Greening rules of the CAP reform to be fulfilled in order to receive the greening subsidy.

Greening rules	10 ha > Arable land > 30 ha	Arable land > 30 ha
Crop diversification	At least two different crops must be cultivated every year.	At least three different crops must be cultivated every year.
	The main crop shall not cover more than 75 % of the arable land.	The largest crop must not cover more than 75% of the arable land. The two largest crops together must not cover more than 95% of the arable land.
Maintenance of permanent grassland	Area of permanent grassland shall be at least 5% of the total arable land.	Area of permanent grassland shall be at least 5% of the total arable land.
Establishment of ecological focus areas	At least 5% of the total arable land shall be ecological focus area.	At least 5% of the total arable land shall be ecological focus area.
	This percentage shall be increased from 5% to 7% from 2017 onwards.	This percentage shall be increased from 5% to 7% from 2017 onwards.

Table 2 Model types.

	Model I	Model II	Model III
Description	Not to meet the greening measures	To fulfill the greening measures	To fulfill the greening measures
	No greening payment	Arable land 10-30 ha	Arable land >30 ha
Model	s.t. constraint 4	s.t. constraints 4-8, 10-11	s.t. constraints 4-11

f_1 is the objective function which represents the net present value and continuous variables x represent the surface of a crop in the arable land in a specific region.

Table 3 Crops considered, selling prices and production costs per crops.

<i>i</i>	Crop	Price (€·t ⁻¹)	Cost (€·ha ⁻¹)
1	Wheat	230.1	604.1
2	Barley	194.8	598.1
3	Rye	181.5	377.6
4	Oat	183.6	585.7
5	Dried Pea	223.6	455.6
6	Sunflower	380.1	430.9

Table 4 Crop yields in each agricultural region.

Agricultural rain-fed regions	Yield (t·ha ⁻¹)					
	Wheat	Barley	Rye	Oat	Dried Pea	Sunflower
2	2.396	2.334	1.468	1.642	0.811	0.774
3	2.178	2.199	1.300	1.699	0.828	0.710
4	2.132	2.161	1.319	1.562	0.833	0.739
5	2.542	2.407	1.560	1.683	0.986	0.863
6	2.272	2.303	1.609	1.709	1.060	0.882
7	2.991	2.438	1.852	2.259	1.209	1.202
8	3.316	2.993	2.350	2.403	1.147	0.920
9	2.515	2.278	1.043	2.192	1.063	1.136
10	2.255	2.373	0.530	2.372	0.842	1.024
11	1.985	1.879	0.854	1.608	0.792	0.949
12	2.744	2.479	1.643	1.918	0.596	0.414
13	3.395	2.754	2.792	2.001	1.227	1.066
14	3.136	2.558	1.918	2.026	0.355	0.140
15	3.117	3.031	1.597	3.232	1.234	1.159
19	2.593	1.676	1.931	1.509	1.043	1.399
20	5.184	4.924	3.947	4.850	3.073	1.875

Table 5 Basic payment for rain-fed crops in each agricultural region.

Agricultural rain-fed regions	Basic Payment (€·ha ⁻¹)					
	Wheat	Barley	Oat	Rye	Dried Peas	Sunflower
2	150.96	147.05	92.46	103.45	181.00	48.73
3	137.24	138.51	81.92	107.06	181.00	44.71
4	134.33	136.16	83.02	98.40	181.00	46.58
5	160.17	151.62	98.26	106.03	181.00	54.39
6	143.16	145.06	101.35	107.68	181.00	55.57
7	188.44	153.57	116.66	142.28	181.00	75.74
8	208.93	188.56	148.03	151.40	181.00	57.97
9	158.43	143.49	65.68	138.06	181.00	71.56
10	142.07	149.51	33.38	149.41	181.00	64.53
11	125.08	118.38	53.78	101.33	181.00	59.80
12	172.90	156.18	103.53	120.84	181.00	26.10
13	213.89	173.50	175.89	126.06	181.00	63.37
14	197.59	161.16	120.85	127.66	181.00	8.83
15	196.34	190.97	100.62	203.62	181.00	73.04
19	163.36	105.61	121.66	95.07	181.00	88.12
20	326.62	310.20	248.63	305.54	181.00	118.11

Table 6 Optimal farmer's net present value per hectare (€·ha⁻¹) in each agricultural region and scenario. The best strategy for the farmer is highlighted in bold.

Agricultural rain-fed regions	Model I	Model II	Model III
2	434.33	496.55	487.38
3	128.15	252.86	244.62
4	63.23	196.00	191.38
5	639.82	651.08	642.82
6	260.16	387.08	386.22
7	1270.84	1119.10	1115.00
8	1728.23	1582.31	1580.59
9	601.11	676.33	662.71
10	235.87	400.48	397.59
11	-47.20	91.63	81.99
12	924.06	851.29	843.46
13	1839.06	1851.77	1810.15
14	1475.24	1235.44	1232.22
15	1447.33	1478.73	1471.96
19	921.92	964.45	947.27
20	4355.09	4033.73	4019.85

Table 7 Minimum subsidy (€·ha⁻¹) in each agricultural region to encourage farmers to meet the greening rules.

Agricultural Region	Scenario II	Scenario III
2	104.35	121.22
3	90.30	100.62
4	83.69	91.82
5	112.47	135.08
6	85.95	96.82
7	116.95	161.58
8	139.59	198.03
9	96.44	104.22
10	97.38	75.99
11	104.35	49.99
12	125.99	158.32
13	123.35	189.75
14	146.30	197.11
15	132.12	179.72
19	129.72	102.99
20	213.08	352.20

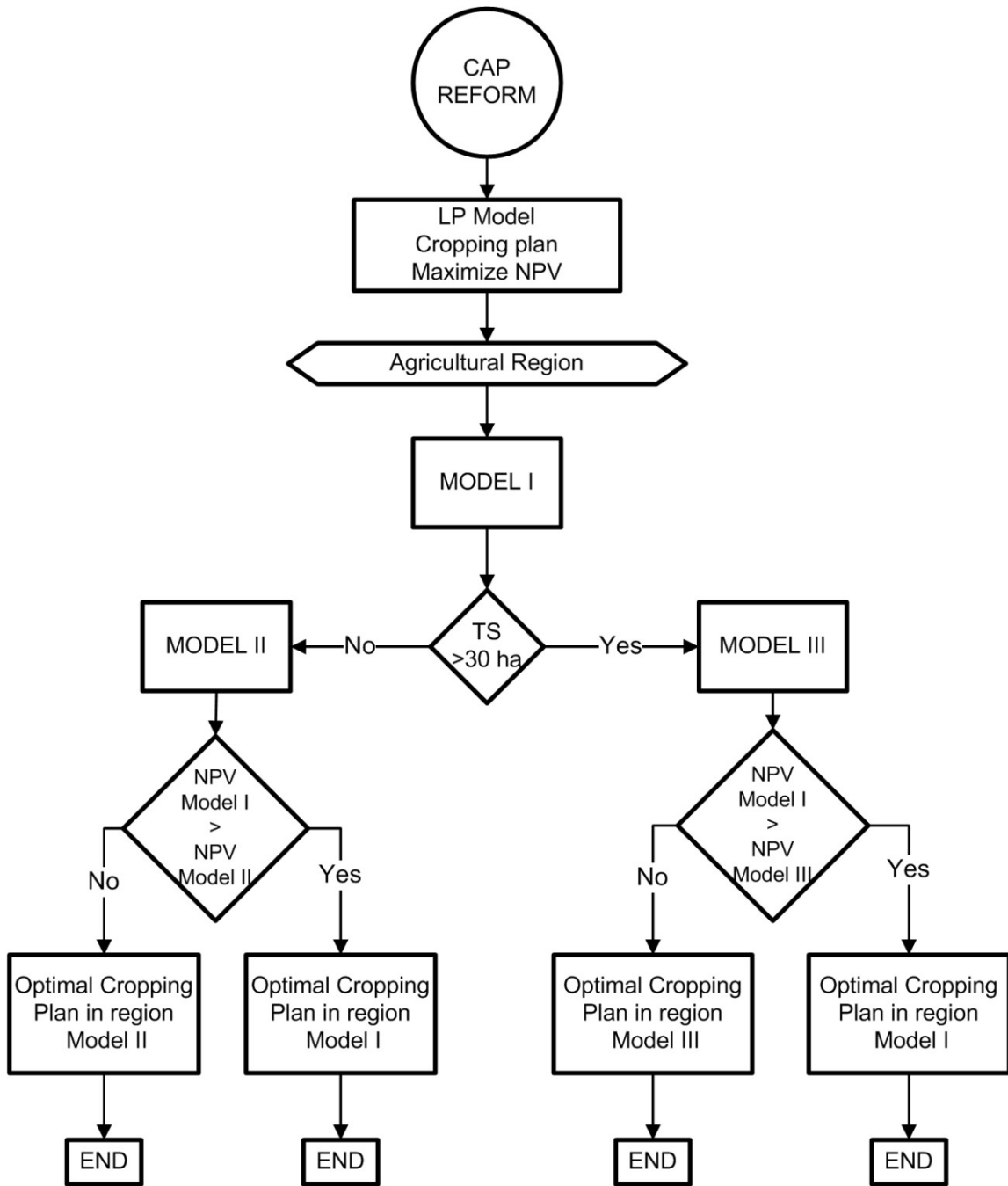


Fig.2 Flow chart of the decision making process to determine the farmer's optimal cropping plan during the CAP reform horizon.

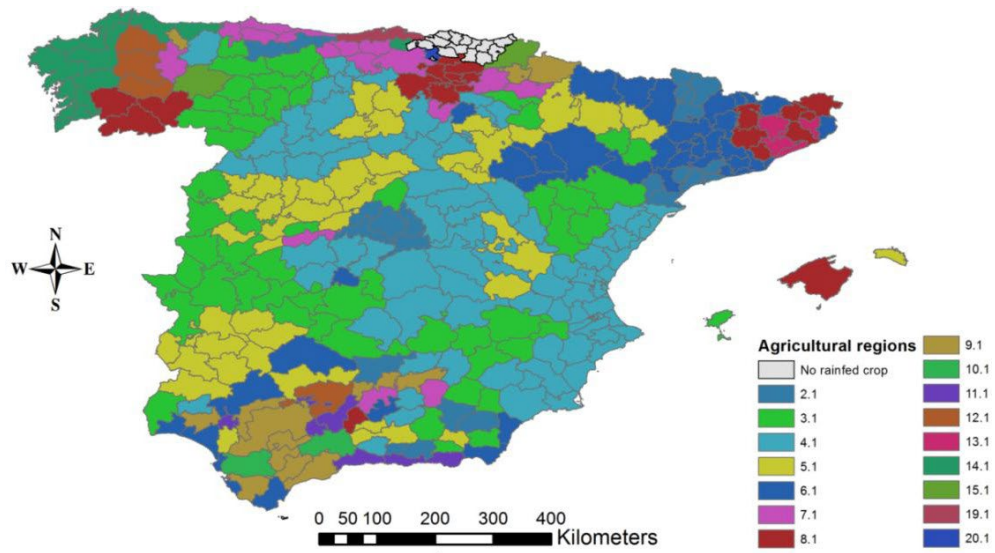


Fig.3 Agricultural regions for rain-fed crops in Spain.

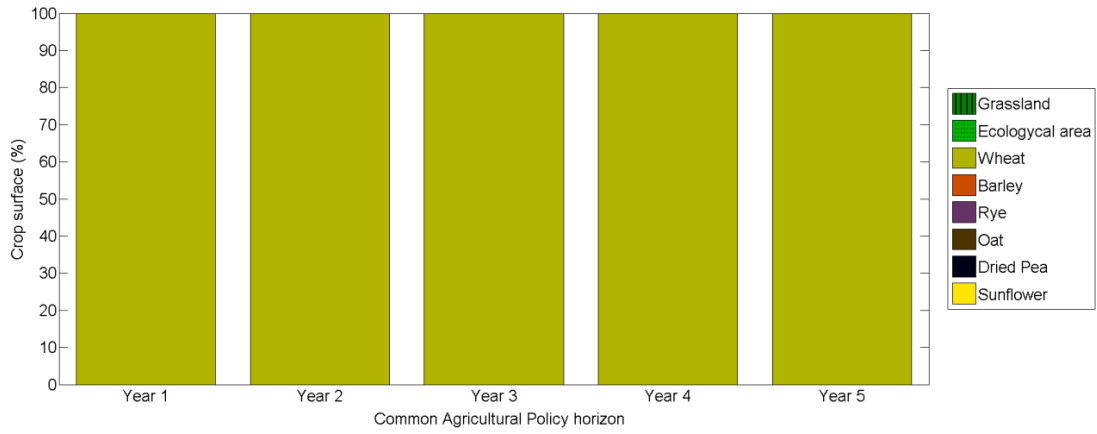


Fig.4 Optimal cropping plan in agricultural regions without fulfilling the greening rules (those for which model I provides the maximum NPV).

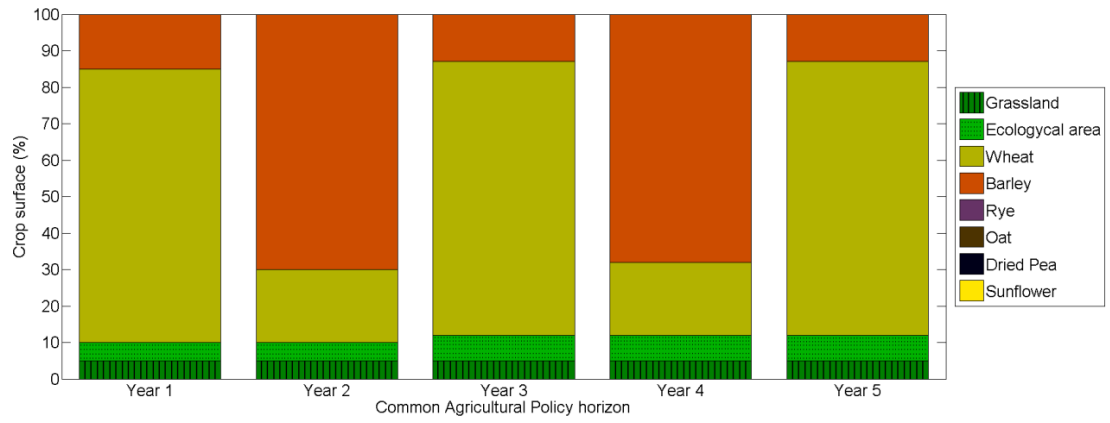


Fig.5 Optimal cropping plan in Region 3.1 for arable land between 10 ha and 30 ha.

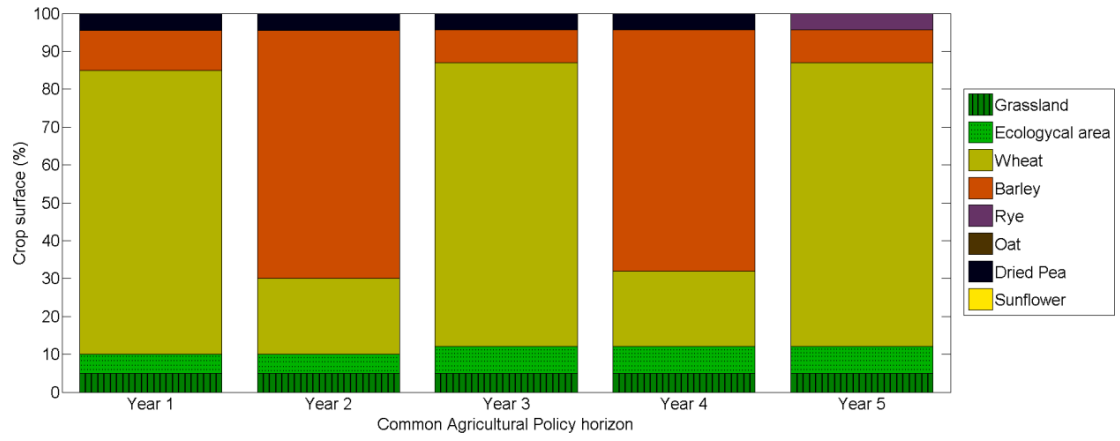


Fig.6 Optimal cropping plan in Region 3.1 for arable land bigger than 30 ha.

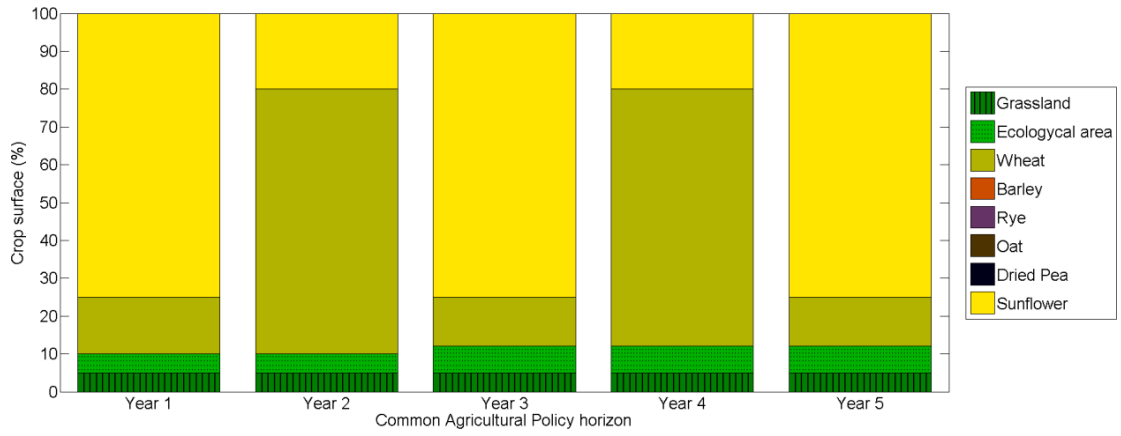


Fig.7 Optimal cropping plan in Region 19.1 for arable land between 10 ha and 30 ha.

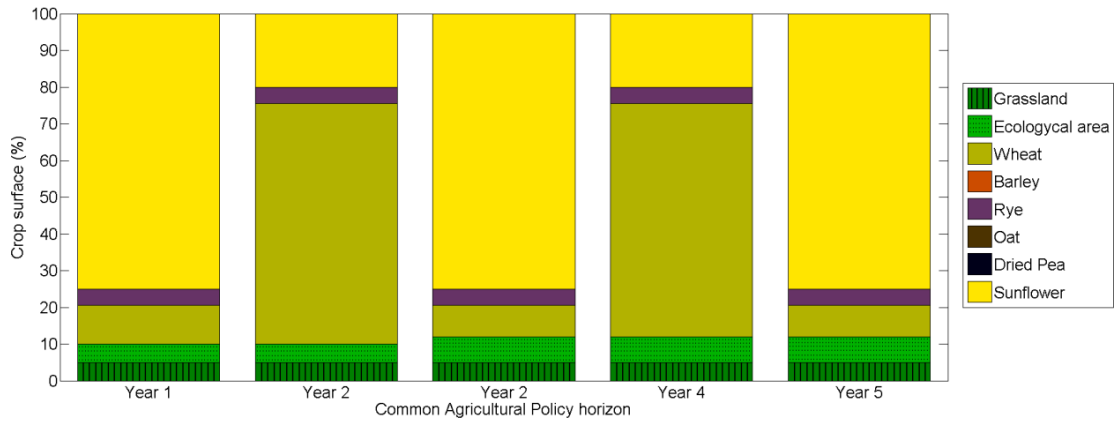


Fig.8 Optimal cropping plan in Region 19.1 for arable land bigger than 30 ha.

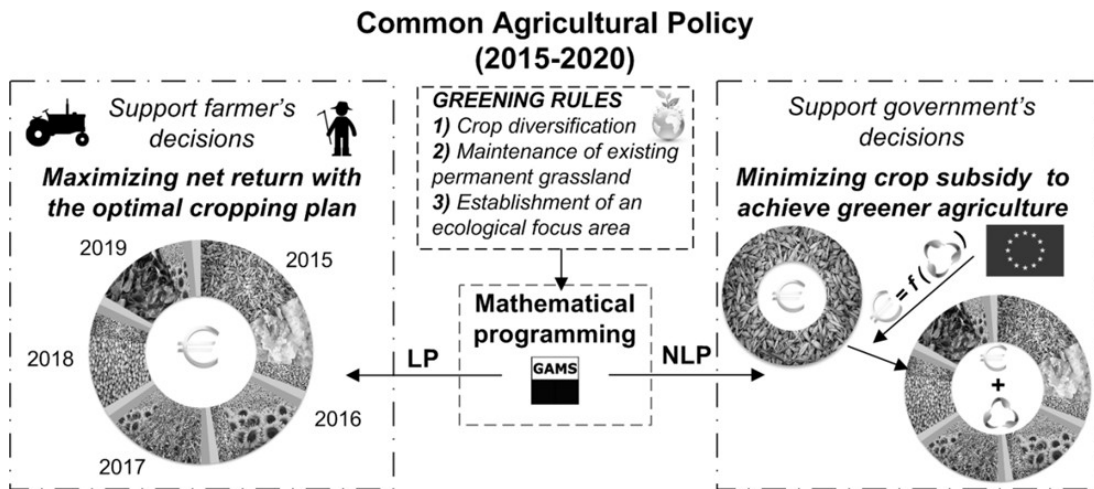


Fig.1 General overview of the proposed framework.

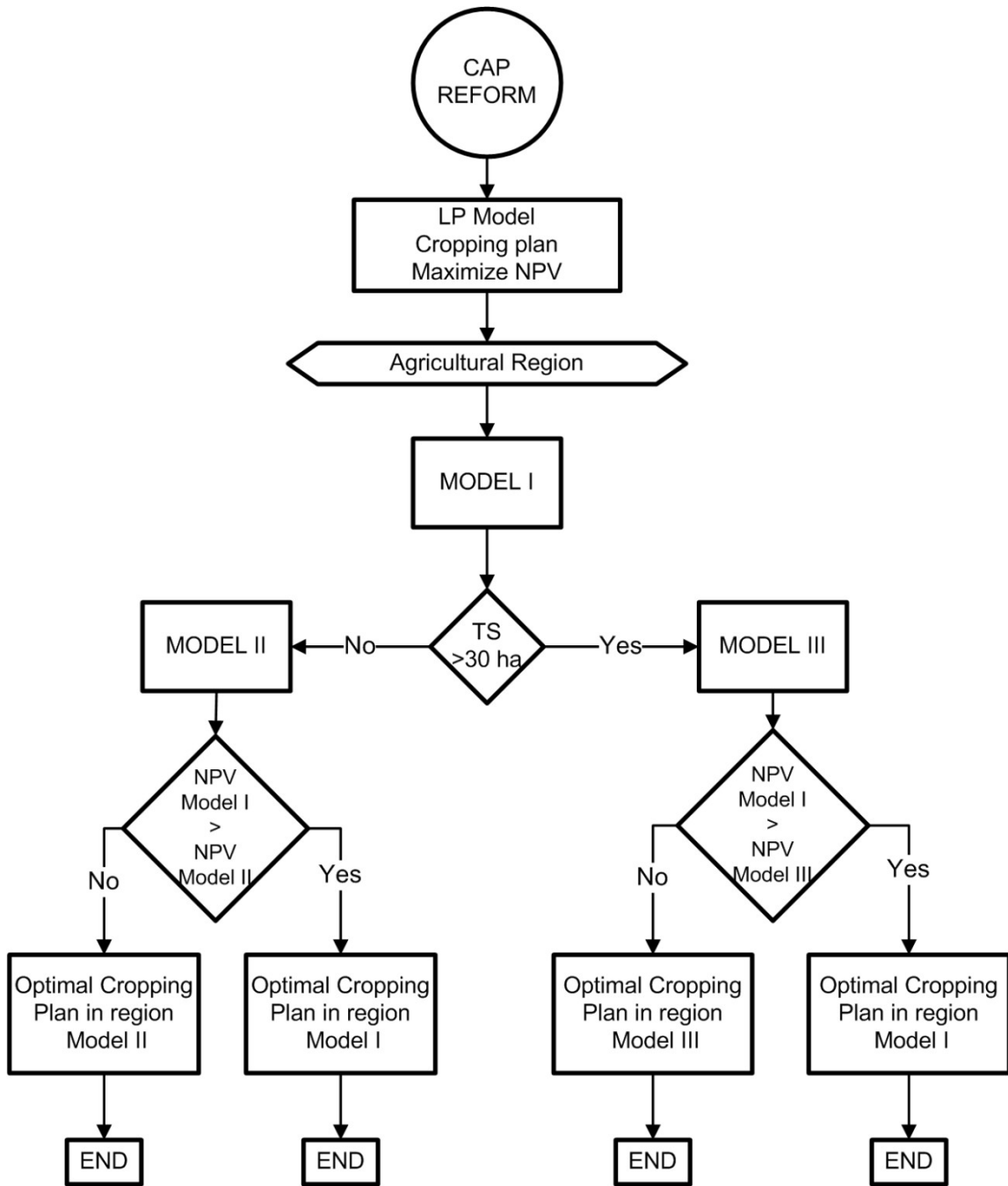


Fig.2 Flow chart of the decision making process to determine the farmer's optimal cropping plan during the CAP reform horizon.

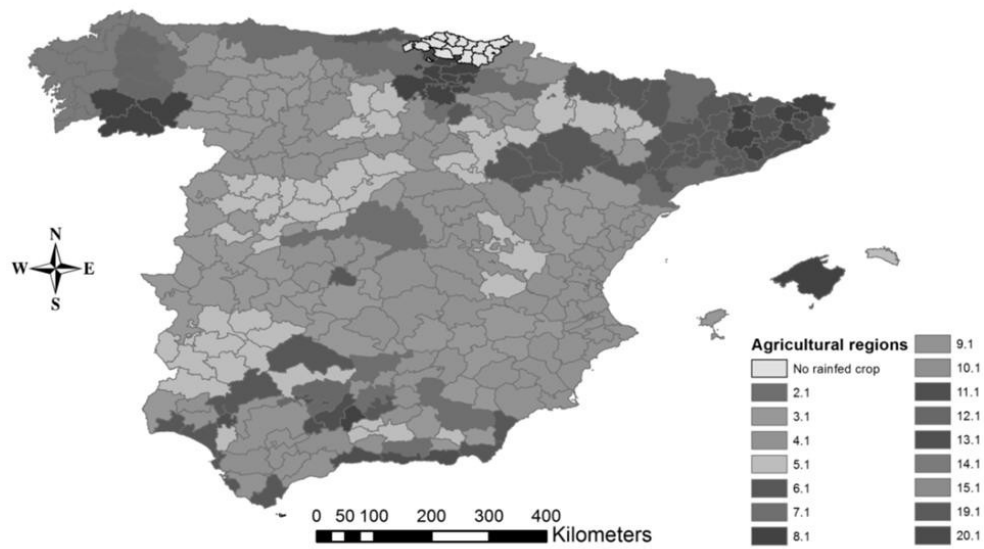


Fig.3 Agricultural regions for rain-fed crops in Spain.

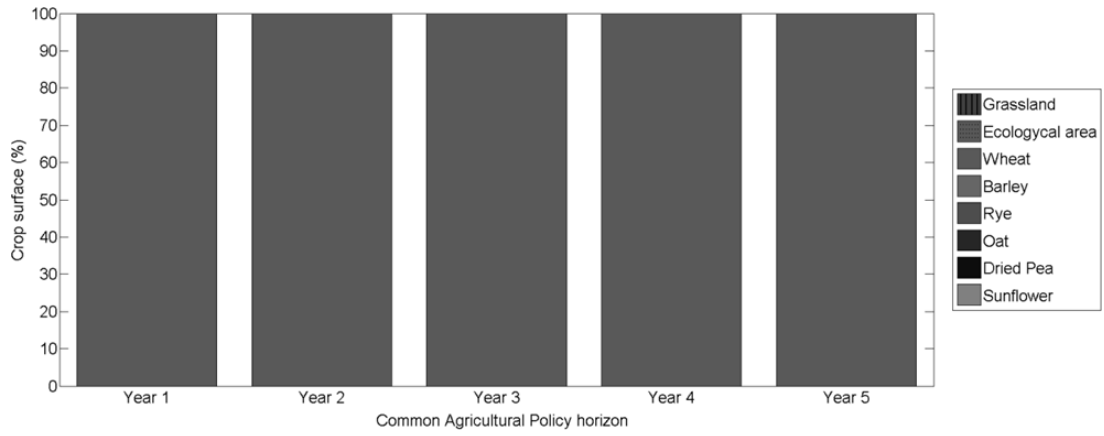


Fig.4 Optimal cropping plan in agricultural regions without fulfilling the greening rules (those for which model I provides the maximum NPV).

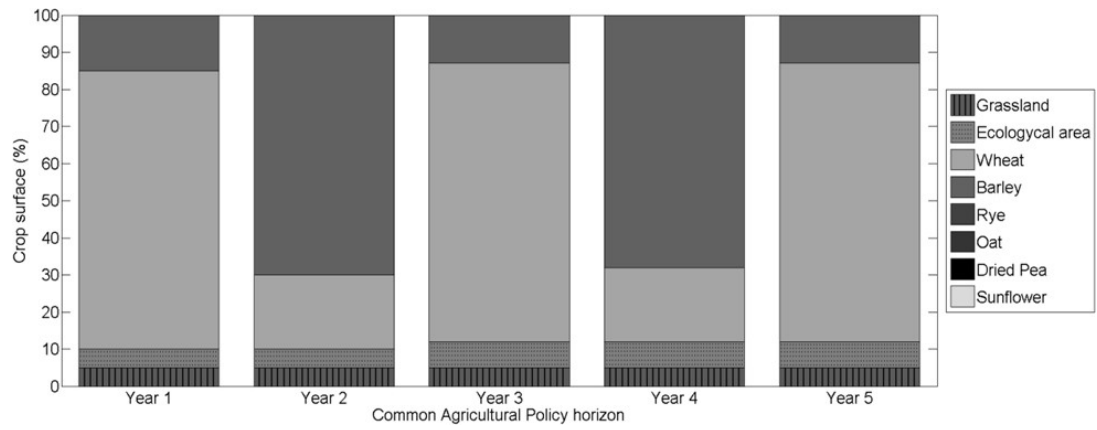


Fig.5 Optimal cropping plan in Region 3.1 for arable land between 10 ha and 30 ha.

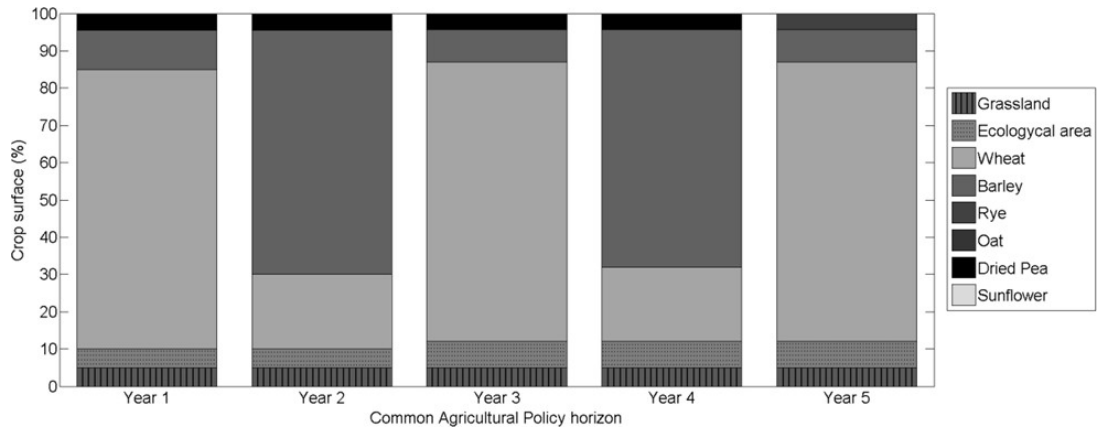


Fig.6 Optimal cropping plan in Region 3.1 for arable land bigger than 30 ha.

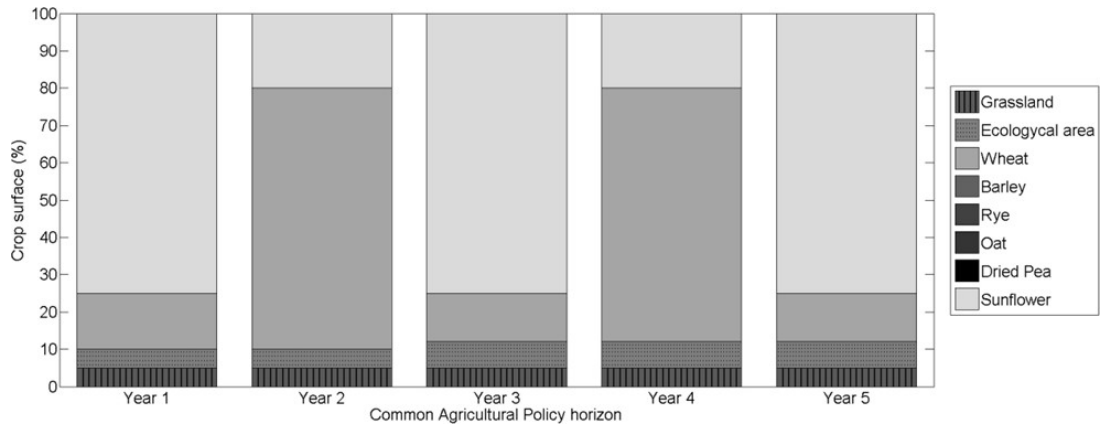


Fig.7 Optimal cropping plan in Region 19.1 for arable land between 10 ha and 30 ha.

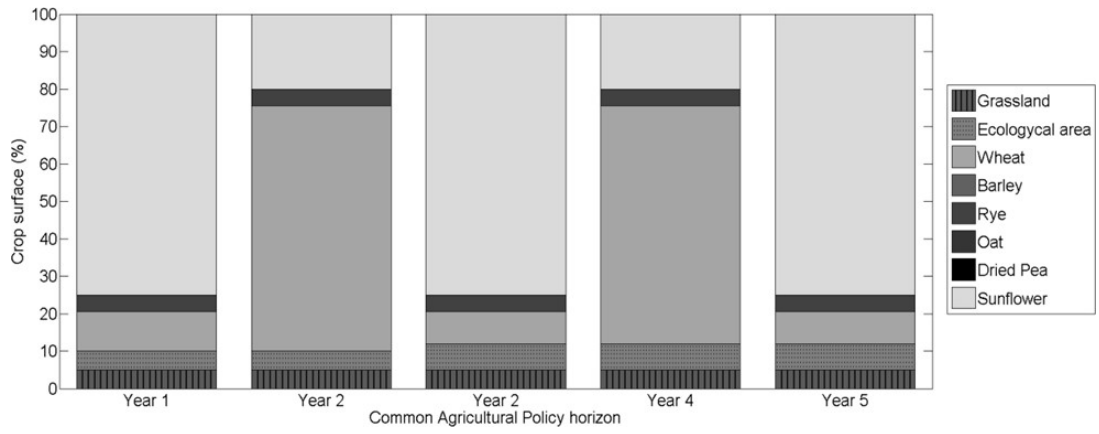


Fig.8 Optimal cropping plan in Region 19.1 for arable land bigger than 30 ha.