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

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ABSTRACT

The new European Union's Common Agricultural Policy will cover the period from 2015 to 2020. Significant novelties in the payment scheme have been introduced which may potentially encourage farmers to implement changes at the farm level by meeting certain environmental requirements in return for support payments. The mandatory requirements, commonly known as 'greening rules', consist of crop diversification, maintenance of permanent grassland and establishment of an ecological focus area.

This paper presents a decision-support tool based on a multi-stage linear programming model that identifies optimal cropping plan decisions under the new Common Agricultural Policy. The capabilities of our tool are illustrated through its application to the Spanish agricultural regions. Our method identifies the optimal cropping plan (i.e., crops to be grown and their acreage each year during the reform horizon) that maximizes the farmer's net return in each region. Furthermore, the model can also be used to calculate the minimum subsidy value that would make the implementation of greening rules economically appealing, thereby promoting the widespread adoption of more sustainable agricultural practises.

1. Introduction

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

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

In addition to the basic payment scheme, the CAP reform introduces a "Payment for agricultural practices which are beneficial for the climate and the environment". This is commonly known as "greening payment" and represents an additional direct aid per hectare rewarding agricultural sustainable practices. The Greening payment may potentially encourage farmers to meet certain environmental requirements in return for governmental support payments. This greening aid rewards farmers complying three basic EU measures (or equivalent practices). These are: (1) crop diversification, (2) maintenance of existing permanent grassland and (3) establishment of an ecological focus area on arable land.

Several EU farms will fulfill these greening measures without having to implement major changes to their current cropping

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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. The largest crop (main crop) shall not cover more than 75% of the arable land.	At least three different crops must be cultivated every year. The largest crop (main crop) shall 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. This percentage shall be increased from 5% to 7% from 2017 onwards.	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.

acreage. In contrast, many other farmers will have to take decisions concerning land use at the farm level to get adapted to the greening rules. These decisions involve the choice of crops to be grown, their acreage and their allocation (Nevo et al., 1994).

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

Mathematical programming can provide valuable decision-support in agriculture (Butterworth, 1985). A wide variety of approaches of this type have been developed for supporting cropping plan decisions. An excellent review of cropping plans decision models was provided by Dury et al. (2011). Among the tools available, linear programming (LP) has been the most widely used optimization approach, mainly due to its great simplicity compared to other techniques. Other tools applied in this area include mixed-integer linear programming (MILP), which was applied to the crop rotation problem (Dogliotti et al., 2006), and evolutionary algorithms, which were used to identify optimal cropping plan decisions at the farm level (Sarker and Ray, 2009).

In the modeling approaches reviewed, the cropping plan problem was optimized within a given context and considering one or multiple objectives. Some models optimized a single objective (e.g., the farmer's profit), while others focused on several criteria (e.g., environmental and economic objectives) (Bartolini et al., 2007). The latter case arises when conflicting objectives, such as economic sustainability, resources use and environment protection,must be taken into account simultaneously in the decision-making process. This is sometimes enforced by policy reforms that prompt farmers to adapt their practices (Louhichi et al., 2010; Oñate et al., 2007).

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

This paper proposes a mathematical programming model to support farmers' cropping plan decisions in response to the CAP reform. The decision-making tool developed herein takes the form of a multi-stage linear programming model (LP) that identifies the optimal cropping plan at the farm level that maximizes the farmer's net return in the CAP reform horizon (i.e., from 2015 to 2020). The model provides insight into whether farmers should adopt the greening measures (i.e., policy constraints) and therefore receive the subsidy, or grow the most profitable crop without meeting the greening rules.

The capabilities of our approach are illustrated through its application to the Spanish payment CAP regionalization model. Our formulation provides as output the optimal cropping plan for rainfed farms in each agricultural Spanish region. The model can be used in turn to determine the minimum subsidy value that would make the implementation of greening rules economically appealing.

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

2. Problem statement

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

As already mentioned, the three basic greening rules of the CAP reform to be fulfilled by the farmer in order to receive the greening subsidy are: (1) crop diversification, (2) maintenance of permanent grassland and (3) establishment of ecological focus areas. The constraints imposed by each greening rule vary depending on the size of arable land (see Table 1).

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

It is assumed that there are no constraints on crop conversion and rotations regarding the major rules of crop rotations