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Fostering sustainable legume-based farming systems and agri-feed and food chains in the EU

**Milestone MS20**

***Achievement of model development suitable for simulation***

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# Summary

The present document represents the output from Task 4.3 with the aim to predict the effects of different policy design options through mathematical models. Modelling activities concerned using simple land allocation models to understand farm level incentives and to design different policy options. The background to this work is to be found in Task 4.1, 4.2 and Task 4.4 of the WP4 of the LEGVALUE project. The main objective of T4.1 and T4.2 was to analyse the effects of different existing and prospective policy instruments and their contribution towards increasing the production of legumes in Europe. This was conducted through an identification of policy needs, instruments, and intervention pathways associated with emerging policy developments. Where to Task 4.4 the objective was the identification of good practices and prospective policy measures to promote legumes production in the EU. The objective was reached by launching series of national and EU level workshops designed to gather expert views across countries on the role of policy in providing incentives for legume production. One of the outcomes of this work was the identifications of a long list of policy instruments related to legumes.

For the modelling exercise we decided to focus on one single instrument and rather to devote effort at investigating the relationship between the main design variables and context conditions. In light of the policy instruments under Task 4.2 and 4.4 and considering as well the list of practical policy instruments introduced by EC (EC, 2021) we chose to work on the eco-scheme measure. The measure represents one of the most innovative components in the last CAP reform. In particular, we refer to ecoschemes as annual payments for the uptake of voluntary measures related with environment, biodiversity, and climate change. In particular, a specific eco-scheme measure concerning the inclusion of legumes in rotation is considered in the models studied in T4.3. The theoretical framework and the results of the different model elaborated are presented in more details in the D3.4 submitted in May 2021

# The Linear Programming model (LP)

At first instance, we modelled different farm types in Emilia Romagna (Italy) and simulated optimal crop mixes. In a second step, a sensitivity analysis to the introduction of legume cultivation was carried out in order to make explicit heterogeneity among farms in the opportunity cost of dedicating a growing share of land to legumes. Lastly, we searched for optimal design of eco-schemes using a Principal agent model. We also carried out a wide sensitivity analysis in order to check the effect of external variables or other policy measures on the optimal policy design. Three different farm types with a farm seize of 100 ha were used in the analysis. Moreover, the models were calibrated using FADN data. By running the Linea programming (LP) model under a set of constraints, we determined a different cropping system for each farm type.

We develop a linear programming model, whose decision variable is the land use per crop. The objective of the research is to assess the potential production and profit performance of the farm under alternative-crop land allocation scenarios. The model maximizes farm profit under different cropping systems, and the ultimate result is farm’s marginal and opportunity cost of increasing the share of legume crops in the cropping systems. The first assumption is that only gross margin of legumes is not sufficient to encourage farmers to cultivate legume crops, compared to other regional crops (i.e. tomato, wheat, maize). Although, the beneficial agronomic role of legumes and the non-market advantages may be enough to convince farmers to introduce legumes in rotation with other crops.

The LP model is described by equations (1) to (6). Farmers maximize their profits, defined by the difference of total revenues and costs, depending on how the land is allocated among different crops. Total revenues, described by equations (2), are given by the sum of price and yield for the activity level for each crop $i$ and product $s$. While the costs are described by equations 3-5. Equation (3) refers to fertilizer costs, equation (4) indicated labour costs and equation (5) refer to total costs. Total costs express other costs apart from fertilizer and labour and include sowing, plowing, soil preparation, herbicides, pesticides or other. The maximization is subject to a resource constraint equation (6) such as land and labour. The constraint in equation (6) indicates that the resource used for crop production have to be lower than the amount of the available resource $b\_{j}$.

|  |  |
| --- | --- |
| $$\max\_{x\_{i}}Z=R-FER-LBC-TOC $$ | (1) |

|  |  |
| --- | --- |
| $$R=\sum\_{i=1}^{n} \sum\_{s=1}^{k}P\_{i,s}y\_{i,s}x\_{i}$$ | (2) |

|  |  |
| --- | --- |
| $$FER=\sum\_{i=1}^{n}PF\_{i}F\_{i}x\_{i}$$ | (3) |

|  |  |
| --- | --- |
| $$LBC=\sum\_{i=1}^{n}LB\_{i,j}a\_{i,j}x\_{i}$$ | (4) |

|  |  |
| --- | --- |
| $$TOC=\sum\_{i=1}^{n}TC\_{i}x\_{i}$$ | (5) |

|  |  |
| --- | --- |
| $$\sum\_{i=1}^{n}a\_{i,j}x\_{i}\leq b\_{j}$$ | (6) |

In particular, the variables used in the above equations are described in the following Table.

Table 5.1. Definition of variables, functions, parameters and scalars

|  |  |
| --- | --- |
| $$Z$$ | farm profit |
| $$R$$ | farm revenue |
| $$FER$$ | fertilizer costs |
| $$LBC$$ | labour costs  |
| $$P\_{i,s}$$ | market price for the crop $i$ and product $s$ (i.e. grain or straw) |
| $$y\_{i,s}$$ | amount of yield for crop $i$ for product $s$ |
| $$x\_{i}$$ | level of $ith$ farm activity (i.e. the cultivated hectare of $ith$ crop) |
| $$PF\_{i}$$ | fertiliser prices per $kg$ used to crop $i$ |
| $$F\_{i}$$ | quantity of fertilizer used per one unit of activity level $i$ |
| $$LB\_{i,j}$$ | unitary cost of resource $j$ (labour) per each crop $i$  |
| $$a\_{i,j}$$ | the quantity of $j$th resource required to produce one unit of the $i$th activity  |
| $$TC\_{i}$$ | total cost of crop $i$ per one unit of activity level $i$ |
| $$a\_{i,j}$$ | the quantity of $j$th resource required to produce one unit of the $ith$ activity |
| $$b\_{j}$$ | the amount of the $j$th resource availiable  |
| $$RO\_{i,RT}$$ | rotation rows $RT $for crop $i$  |
| $$RT$$ | notation of row for rotation  |
| $$m$$ | number of rows |
| $$x\_{LA}$$ | share of land cultivated by legume crops |
| $$v$$ | percentage share of legume crop cultivated in the farm  |
| $$NR\_{i}$$ | non rainfed crops |

Through linear programming, first, it was estimated the profit performance of the farm by assuming a farm applying a crop rotation. In addition to equation and constraints described above (equations 1-6), we have developed different models with additional constraint.

***Model 1:*** it includes the rotation constraint showing the cropland allocation under different scenarios. In particular, the share of legume crops cultivated in the farm must be greater than a defined $v$ percent of the total cultivated area.

***Model 2*:** under this model, we assume a farm cultivating only rainfed crops with the introduction of an additional constrain.

***Model 3:*** Thecropland allocation in the farm allows a higher degree of flexibility of crop rotation in the farm plan.

The elaboration and the results of the models introduced above are shown in more detailed in the D4.3 submitted in May 2021.

# Discussion

The cultivation of legume crops is driven by several factors including market demands and agronomic conditions. One possible option to increase the share of legume cultivation in the farming system is providing direct economic incentives to farmers in relation to the area allocated of legume cultivation per farm. This type of instrument is already in place in the EU, as the CAP allows coupled payments on selected crops, which, in some countries, are used to support legumes.

A more recent proposed instruments are the Ecoschemes, that propose, among other measures, to introduce an additional payment for farmers wiling to voluntary include legumes in their rotation. To search the optimal design of eco-schemes, it was decided in the study to use a *Principal- Agent* model. The model considers the presence of asymmetric information between the two actors involved: principal and the agent. Using this type of model, the study attempts to identify a menu of contract by public authority (Principal) that could be used to incentivize farmers (Agent) to increase the share of legume cultivation on the farm. The assumption is that the regulator is willing to induce farmers to voluntarily increase the share of legume cultivation in the farm cropping mix and, doing so, remunerating the behaviour with a payment per hectare based on the degree of compliance. In this sense, the model represents a social welfare maximization model, where the Principal, responsible for the public funds, acts on behalf of society. As a fact, the Principal attempts to maximize social welfare expressed by $W$ by inducing farmers to provide an environmental benefit by cultivating a share of legumes $x\_{i}$ and remunerating them with a direct payment $P\_{i}$ ( equal to the their opportunity cost). The environmental benefits achieved from the cultivation of legumes are numerous, but for this modelling purpose, we restricted our analysis only to two types: *a)* the environmental benefit due to the reduction of nitrogen fertilizer N; and *b)* a biodiversity benefit based on the degree of crop diversification.

The achieved level of these environmental benefits entitles some public costs, represented by the public money allocated to farmers for the promotion of legumes in their cropping system. The public costs are associated with the payment $P\_{i}$ which is a decision variable in the model and transaction costs $vP\_{i}$ generated from the transfer of money from the Principal to the Agent. The basic idea is that farmer changes its cropping pattern from more profitable crops (i.e. tomato, maize) to less profitable crops (i.e. alfalfa, soybean) recognizing the opportunity costs expressed by $c\_{i}\left(x\_{i}\right)$. The direct economic incentive provided by the Principal must ensure to farmers a positive utility $U\_{i}\geq P\_{i}-c\_{i}\left(x\_{i}\right)$, being the value of the utility at least equal to the opportunity cost. This condition is necessary to convince the farmers complying with the voluntary measure.

