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► To cite this version:

Julia Jouan, Julia Heinrichs, Wolfgang Britz, Christoph Pahmeyer. Legume production challenged by European policy coherence: a case-study approach from French and German dairy farms. 172. EAAE Seminar 'Agricultural policy for the environment or environmental policy for agriculture?', European Association of Agricultural Economists (EAAE). INT., May 2019, Bruxelles, Belgium. 19 p. hal-02197018

HAL Id: hal-02197018

<https://hal.science/hal-02197018>

Submitted on 29 Jul 2019

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Legume production challenged by European policy coherence: a case-study approach from French and German dairy farms

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**Paper prepared for presentation at the 172nd EAAE Seminar
'Agricultural policy for the environment or environmental policy for agriculture?'**

May 28-29, 2019.

Brussels.

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Abstract

Legumes can contribute to a more sustainable agriculture by limiting N fertilisation, diversifying crop rotation and substituting imported protein-rich feed. However, their production remains low in the European Union, which had led to specific policies. For instance, following the reform of the Common Agricultural Policy, France established Voluntary Coupled Support (VCS) scheme for legumes. Germany did not introduce a VCS, but provides more favourable implementation of the Nitrates Directive (ND) for legumes by allowing spreading manure on these crops. Our study quantifies economic and environmental impacts of the VCS and measures of the ND affecting legume production in France and Germany. We employ the bio-economic model FarmDyn, parameterised for a typical dairy farm in France and Germany, to analyse different levels of VCS per hectare and to compare the French versus the German implementation of the ND. Results suggest that VCS leads to a significant increase in legume production. The implementation of the German ND can foster legume production due to the possibility of spreading manure on legumes. The policy induced increase in legume production is lower in the German farm due to higher opportunity costs of legumes. In both farms, the profit slightly increases but the share of VCS in the profit rises. Environmental indicators are overall improved. Thus, VCS, coupled with an adapted implementation of the Nitrate Directive, is an effective policy to foster environmental benefits from increased legume production. However, the effectiveness of these policies highly depends on the opportunity costs of legumes in each country.

Keywords

Protein crop, Policy coherence, Mathematical programming, Protein self-sufficiency, Pea, Faba beans, Alfalfa, Leaching, Global warming potential, Legumes, Nitrate Directive, FarmDyn, Bio-economic model

1. Introduction

Increased legume production can foster agricultural sustainability in several dimensions (Drinkwater et al., 1998). As legumes can fix atmospheric nitrogen (N), they need no, or limited, N fertilisation and may even supply N to the soil, reducing N fertilisation needs of the following crop (Peoples et al., 2009). They can contribute to crop diversification and thus to reduced pesticide application (Nemecek et al., 2008). Additionally, legumes used as protein-rich feed can substitute vegetable meals, often derived from imported crops and linked to loss of natural habitats (Sasu-Boakye et al., 2014).

After decades of a declining trend, legumes, including forage legumes and soybeans, covered on average less than 4% of the utilised agricultural area (UAA) between 2012 and 2017 in the European Union (EU) (Eurostat, 2018). That reflects firstly that their use in feed can mostly not compete against substitutes such as imported soybean meal (Häusling, 2011). Second, at the scale of the European agro-food chain, legumes suffer from a lock-in situation that tends to favour cereal and non-legume oilseed crops (Magrini et al., 2016), while sales of legumes face high transaction costs (Jouan et al., 2019). Third, legumes are generally less profitable for farmers compared to other major crops such as wheat and rapeseed, even if, at the rotation scale, their profitability is equivalent (Preissel et al., 2015). Farmers are also reported to assess their production risk as higher (von Richthofen et al., 2006), though there is no consensus in the scientific community that the yield variability of legumes exceeds that of other crops (Cernay et al., 2015; Reckling et al., 2018).

Since 2014, in the light of their advantages but low crop share, European member states can establish Voluntary Coupled Support (VCS) for legumes under the Pillar I of the European Common Agricultural Policy (CAP). The budget for VCS can be increased by 2% of the direct payment ceilings, if at least 2% of their ceilings for direct payments are set out to support legume production, (Regulation No 1307/2013, (European Parliament, 2013)). That measure helped to reverse the downward trend in legume production but heterogeneously across member states and regions, reflecting different levels of implementing that measure. For instance, both France and Germany count legume acreage with a factor of 1 towards the Ecological Focus Area (EFA) requirement as part of “Greening”. However, only France introduced VCS for legumes, reaching 145 million euros in 2017 (European Commission, 2017). The VCS might explain why the French area of legumes nearly doubled between 2013 and 2017 but only increased by 35% in Germany. It is also interesting

to notice that the share of legumes in France on arable land is half as large in regions focused on livestock production compared to regions specialized in arable crops (Eurostat, 2018). This may be due to the French implementation of the Nitrate Directive (latter called “French ND”) (91/676/CEE), which prohibits manure application on most legumes, discouraging their production in farms with high stocking densities. The German implementation of the Nitrate Directive (latter called “German ND”) allows spreading manure on legumes as long as the mandatory N fertilisation planning at the farm scale is respected.

This study aims at quantifying economic and environmental impacts of key policy measures affecting legume production, comparing in detail a French and German case study. We focus on the interactions of two different policy fields: VCS for legumes under CAP Pillar I and national implementations of the European ND, while taking into account the “Greening” measures. Our hypothesis is that first, implementing the same minimum VCS per hectare in Germany as now in France, will increase legume production in both countries. Second, that implementing the German ND in France, will lead to a further increase in legume production in France. Third, that these increases have positive environmental and economic implications at farm-scale. Fourth, that an increase in VCS would foster these developments. To test these hypothesis, we employ the bio-economic programming farm-scale model FarmDyn (Britz et al., 2014).

So far, only few studies analysed policies directly designed to increase legume production with farm-scale models (Cortignani et al., 2017; Helming et al., 2014; Mahmood et al., 2017). Studies using bio-economic models to analyse the ND are more common (Belhouchette et al., 2011; Ondersteijn et al., 2002; Peerlings and Polman, 2008). Other tools were also employed to study this directive, such as N flow models (Cardenas et al., 2011) or agent-based models (Van der Straeten et al., 2011). Nevertheless, to the best of our knowledge, there is no analysis considering potential interactions between CAP Pillar I measures related to legume production and the implementation of the ND, as an example for often neglected policy coherence (Nilsson et al., 2012). Besides, impacts of legumes production are so far mostly analysed in arable cropping systems (Reckling et al., 2016), except for Schläfke et al. (2014) and Helming et al. (2014) who also considered legumes as feed in livestock farms. Finally, as far as we know, the study of Küpker et al. (2006) is the only one comparing in detail different farms in France and Germany. Other models at the European scale cover also the French and German productions (Louhichi et al., 2018), but as they are far more aggregated, they do not take into account detailed measures e.g. differentiated implementations of the ND according to

countries. Our study thus addresses several gaps in literature by (1) considering jointly multiple policies affecting legume production, (2) by introducing legumes as cash-crops but also as on-farm feed and (3) by developing an in-depth analysis of representative dairy farms in two European countries, France and Germany, which are the main milk producing countries in EU, and whose regulations on legumes and manure management differ.

2. Method

2.1. Overview of the FarmDyn model

Mathematical programming models represent a valuable tool to analyse technical changes or the introduction of (new) crops as they describe in detail farm management and investment decisions (Britz et al., 2012; Jacquet et al., 2011). Among them, bio-economic models aim quantify both economic and environmental indicators and their trade-off by accounting for joint production of agricultural outputs and environmental externalities (Janssen and van Ittersum, 2007). FarmDyn is such a highly detailed single farm bio-economic model, building on fully dynamic mixed integer linear programming. It is written in the General Algebraic Modelling System (GAMS development Corporation, 2018). The model provides a framework for the simulation of economically optimal farm-level plans and management decisions as well as related material flows and environmental indicators. Thereby, farm management decisions such as adjustments of crop shares, feeding practices, fertiliser management and manure treatment are depicted with monthly resolution. FarmDyn maximises the farm net present value under (1) the farms' production feasibility set, (2) working-time and (3) liquidity constraints as well as (4) environmental and policy restrictions. In the underlying study, the comparative-static version of FarmDyn is used. As dynamics such a path dependencies are not considered as relevant in our study – the machinery pool used in the legumes considered by us is already available to manage the benchmark crop rotation - the use of the simpler static version model seems appropriate and eases model application and result analysis.

Indicators on farm performance are implemented such as the total profit of the farm, the protein self-sufficiency (i.e., the ratio between protein produced to feed the herd, and total protein consumed by the herd), and different environmental indicators. The global warming potential (GWP) of the farm is calculated by measuring the emission of different greenhouse gases and expressing their GWP as a factor of carbon dioxide. Since the ND aims to protect water quality by preventing nitrates polluting

water bodies, we include a nitrogen leaching (latter called “N leaching”) indicator, which calculates a probabilistic value for N leaching by considering different sources of N.

2.2. Case-studies and data implemented

We analyse as case studies one French and one German intensively managed dairy farm (Table 1), located in Pays de la Loire (PDL) in France and North Rhine-Westphalia (NRW) in Germany. The case studies are defined based on longer time series data from agricultural institutions and extension services. The French farm is based on the farm type “1b Pays de la Loire”, from Inosys Réseaux d’Elevage (IDELE, 2016) as one of the most common types of dairy farms in that region. . Quite detailed data are available for this farm-type, such as crop rotation, stable inventory, and grass management. Besides, the crop rotation of this farm corresponds to the main crop rotation of PDL (Jouy and Wissocq, 2011). The German farm is based on farm type « Niederrhein NR_SB » from (Steinmann, 2012), one of the most common types of dairy farms in NRW. Since no information on typical crop shares is provided by that source, the crop rotation of the German farm is taken from Kuhn and Schäfer (2018) who derived typical crop rotations for different farm-types in NRW, based on data from agricultural census and expert interviews. For both farm types, yields are based on regional data, and input and output prices on national ones (mean 2013-2017) (French Ministry of Agriculture, 2018; IT.NRW, 2019; KTBL, 2019; La Dépêche - Le Petit Meunier, 2018).

Table 1 : Description of the dairy farms implemented in the FarmDyn model

	French farm	German farm
Arable land (ha)	49	60
Grassland (ha)	27	20
Number of dairy cows	62	75
Stocking rate (cow.ha ⁻¹)	0.82	0.94
Breed	Holstein	Holstein
Milk yield (kg.cow ⁻¹ .year ⁻¹)	8 600	8 800
Crops	Grassland, wheat, silage maize	Grassland, wheat, silage maize

The model was calibrated by adjusting the working-hours available on the farm, as well as the grazing periods for the herd and the energy content of grass. In the German farm, the average yield of wheat was adjusted within a 5% tolerance level. The size of the herd was fixed according to the number of dairy cows in the observed farm types as the study is a short-term one and does not aim to analyse changes in terms of herd size and investments.

2.3. Introduction of legumes related data

We cover three legumes in FarmDyn model: peas, faba beans and alfalfa (Table 2). In the French region, a cooperative offers a dehydration service to its members: alfalfa is harvested by the cooperative, dehydrated and then returned to farmers as a conserved fodder of high nutritional quality (Leterme et al., 2019).

Table 2 : Characteristics of legumes implemented in the FarmDyn model

		Alfalfa	Faba bean	Pea
Yield (t.ha ⁻¹)	France	10.2	3.0	4.1
	Germany	8.5	4.2	4.7
Selling price (€.t ⁻¹)	France	-	208	212
	Germany	-	190	190
Buying price (€.t ⁻¹)	France	-	270	246
	Germany	-	297	306
N from mineralisation of residues	France	25	30	20
	Germany	20	10	10

One of the main advantages of legumes is their positive effect on following crops: legumes have the ability to fix nitrogen and hence fertilise the following crops by mineralising their residues. Thus, N from legume residues enters in the fertilisation balance besides N from manure and synthetic fertilisers, as shown in equation (1).

$$Nneed_c \cdot X_c \leq Nmanure_c + Nsynt_c + NLeg_c \quad (1)$$

Where, for each arable crop c , $Nneed_c$ is the need for N, X_c is the cropping area, and $Nmanure_c$, $Nsynt_c$ as well as $NLeg_c$ are, respectively, N available from manure, synthetic fertilisers, and mineralisation of legume residues.

As the FarmDyn model was used as a comparative-static model, N stemming from mineralisation of legume residues was introduced as an additional pool of N, integrated at the farm scale (equation 2 to 4) and not explicitly modelled by providing N to following crops:

$$\sum_c NLeg_c = NLegPool \quad (2)$$

$$\text{With } NLegPool = \sum_{leg} X_{leg} \cdot NcarryOver_{leg} \quad (3)$$

$$NLeg_c < X_c \cdot NcarryOver_{leg} \quad (4)$$

Where, for each arable crop c , $NLeg_c$ is N available from mineralisation of legume residues, $NlegPool$ is the pool of N available at the farm scale from mineralisation of legume residues; X_{leg} is the cropping area of each legume at the farm; $NcarryOver_{leg}$ is the quantity of N mineralised from residues of each legume.

2.4. Differentiated implementation of the nitrate directive in FarmDyn model

As all European directives, the ND (91/676/CEE, (European Council, 1991)) must be implemented into national law, which implies differences across member states. For our analysis, we introduce the key aspects of the implementations in PDL and NRW (BMEL, 2017; DREAL Pays de la Loire, 2018) into FarmDyn. Apart from slightly different blocking periods for the application of manure, the main divergence relevant for this study is the possibility of spreading manure on legumes or not. In France, it is forbidden to spread manure on grain legumes (e.g., peas, faba beans) but not on alfalfa, being a forage legume. In Germany, it is possible to spread manure on legumes as long as the surplus of the nutrient balance at the farm gate does not exceed $50\text{kgN}\cdot\text{ha}^{-1}$. Both, the French PDL region and the whole of Germany are designated as nitrate vulnerable zones where organic N application is limited to $170\text{kgN}\cdot\text{ha}^{-1}$ on farm level.

2.5. Scenarios

We define a baseline scenario (SU0) without VCS for legumes and with the French ND in the French farm and the German ND in the German farm. In the first scenario (SU100), we implement a VCS for legumes in both countries, keeping the national implementations of the ND. Even though the total VCS budget for legume is stable among years in France, the VCS per hectare depends on the legume variety and on the total area of legume cultivated during the year. Therefore, we chose to implement the minimum level established in France: $100\text{€}\cdot\text{ha}^{-1}$ for peas, faba beans and alfalfa produced for dehydration. In the second scenario (SU100ge), the German ND was introduced to the French farm, the VCS still being available. Lastly, we defined a set of scenarios where the VCS per hectare was increased in both farms, with steps of 10%, starting from $110\text{€}\cdot\text{ha}^{-1}$ to $300\text{€}\cdot\text{ha}^{-1}$ (SU110 to SU300), under the French or the German ND in the French farm, and the German ND in the German farm. This increase in VCS per hectare per is deliberately extreme in order to explore impacts of increasing VCS and the implications of resulting legume shares not yet observed in farms.

3. Results

3.1. Baseline scenario

In the baseline scenario (SU0), both farms produce three crops in addition to pasture: wheat, maize for silage, and one legume. However, the legume species is different according to the farm: while the French farm produces peas, the German farm produces faba beans. These legumes are present in the farms only to comply with the greening regulation and represent 5.0% of the arable land in both farms. Besides, the wheat share in the German farm is higher.

3.2. Scenario SU: Implementation of coupled support for legumes

When VCS for legumes is implemented, the legume area increases in both farms: in the French farm, legume share doubles with peas reaching 10% of arable land, whereas in the German farm the share is increasing by 50% with faba beans reaching 8% of arable land (Table 3). Legumes substitute against wheat, while the acreage of maize remains constant. Alfalfa is not yet produced with this level of VCS.

In both farms, the rise of legume share goes along with a moderate increase in the protein self-sufficiency: +2% in the French farm and +1% in the German farm (Table 3). The application of synthetic N fertiliser decreases in both farms for two reasons. First, legumes provide N through the mineralisation of their residues. Second, the demand of N is lower as there is less wheat produced, this crop having high fertilisation needs. Concerning economic indicators, the farm profit is quite constant. There is no significant improvement of environmental indicators.

3.3. Scenario SU100ge: German implementation of the ND in both farms

The scenario SU100ge focuses on the French farm. Compared to the scenario discussed above, it introduces the German ND. The main difference is that now spreading manure on legumes is allowed as long as the surplus of nutrient balance and the threshold of organic N are respected. In this scenario, the area of legumes does not change and no manure is spread on legumes. The protein self-sufficiency, the profit and the GWP are the same as under the French implementation of the ND (scenario SU100). The application of synthetic N fertiliser slightly increases from 91kg.ha⁻¹ to 95kg.ha⁻¹, due to changes in the application periods for manure and thus in the management of

fertilisation. N leaching decreases by 7% due to changes in the months when spreading of manure on wheat, maize and pasture is allowed.

3.4.Scenario SU_X: changing the value of the coupled support for legumes

- French farm results

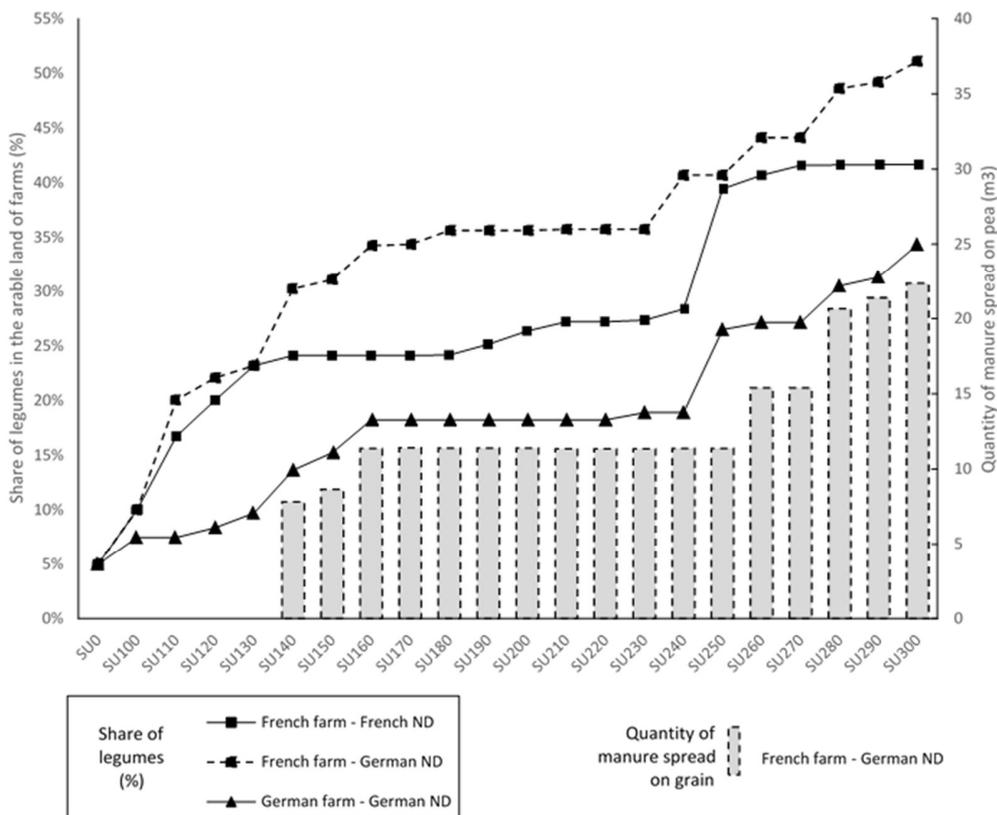
The VCS per hectare was gradually increased starting from 100 €.ha⁻¹ in both farms, by +10% to +200% (scenario SU110 to scenario SU300) (Figure 1). In the French farm, the legume share increases quite similar under the French and German ND up to scenario SU130 (Table 3). At this stage, legume (i.e., peas) represents 23% of arable land under both ND. Slight differences before this point reflect different periods where manure spreading to wheat, maize and pasture are allowed. With further subsidy increases, from SU140 to SU240, the share of legumes continues to grow but now with significant differences between the two implementations of ND: under the German ND, the share of legumes is about 10% higher than under the French ND. This reflects that under the French ND increasing peas or beans reduces areas where manure spreading is allowed. Under the German ND, spreading of manure on peas begins under SU140 with 8m³.ha⁻¹ of manure and reaches 11m³.ha⁻¹ in SU240. From SU250 to SU270, the gap between the two implementations of ND is lowered, the share of legumes reaching about 43% of arable land with both ND. This convergence is due to growing alfalfa area under the French ND where spreading manure is allowed. Finally, from SU280 to SU300, the gap between the two implementations of ND increases again through the production of beans under the German ND. The share of peas is no longer increasing because it reaches a maximum of one third of arable land. At this stage, the total share of legumes reaches 42% of arable land under both NDs. In all cases, the acreage of maize remains constant such that the share of wheat is reduced.

Clearly, this increase of legume production also fosters protein self-sufficiency. From the baseline scenario to SU130, it grows similarly under both NDs to reach 72%. Then, up to SU240, a small gap can be observed between the two implementations of ND. This gap is due to the higher production of legumes which are used for feed under the German ND. In SU150, the protein self-sufficiency strongly increases with both ND and stays stable at about 87%. It is 21 percentage points more than in the baseline scenario. This rise can be explained by the increasing use of own-produced legumes, the additional production of legumes under the German ND being sold. These improvements in

protein self-sufficiency go along with a decrease in the use of concentrates, soybean meal and purchased beans.

The decline in synthetic fertilisation continues and even accelerates with higher shares of legumes. Compared to SU100, the amount of synthetic N fertiliser per hectare is reduced by 70% under the French ND, and by 80% under the German ND, in scenario SU300. Regarding farm profit, it slightly increases by 3% and 4%, respectively under both NDs. Nevertheless, the share of VCS in the farm profit rise from 0.6% in SU100 to 7.0% in scenario SU300 under the French ND, and to 8.5% under the German ND.

Figure 1: Share of legumes per farm and implementation of Nitrate Directive (ND) and value of VCS



Regarding environmental indicators, the evolution of N leaching differs considerably between the two NDs. Under the French ND, linked to the increase in legume share, N leaching decreases almost continuously to reach a maximal decrease of 38% in SU300, compared to SU100. Under the German ND, N leaching decreases by 25% until SU250. With further increasing VCS, N leaching begins to increase again due to spreading of manure on peas, resulting in over fertilization. Thus N leaching

only decreases by 5% between scenario SU100 and SU300. GWP also decreases with higher share of legumes with smaller differences between the two NDs. It slowly decreases by 6% until SU240 and then plummets to reach -18% under the French ND, and -16% in the German ND, in SU300. This drop is due to a high decrease in the purchases of inputs, especially feed which is now substituted by own-produced legumes.

- German farm results

Compared to the two scenarios for the French farm discussed so far, the legume share increases less in the German case study. It slowly grows from scenario SU100 to SU150, and remains constant at 18% of the arable land up to SU220. With further increasing subsidies, legumes production continues to grow to a maximum of 34% in SU290 (Figure 1): only bean area increases up to that point where it reaches its maximum rotational share. As in France, legumes substitute for wheat at constant maize production.

The protein self-sufficiency follows the same evolution as legume area but its increase is more moderate, with values from 62% in scenario SU100 to 74% in scenario SU300 (Table 3). This improvement reflects reduced use of concentrate and soybean meal, replaced by own produced faba beans. The farm profit slightly increases by 2% with a simultaneously rising share of VCS in this profit from 0.4% in SU100 to 5.5% in SU300. The application of synthetic fertilizer decreases by 75% between SU100 and SU300. It is interesting to notice that manure is only spread on legumes at its maximum crop share from SU290. Before, the amount of manure spread per hectare to wheat, maize and grass is increasing. The improvement of the environmental indicators is rather limited. N leaching decreases by 6% and the GWP by 16% between the scenario SU100 and SU300. Since the number of cows as a main driver of greenhouse gas emissions is kept constant in the study the decrease in GWP is rather small.

Table 3: Comparison of main indicators between the scenarios, per farm and implementation of the Nitrates Directive (ND)

	French farm - French ND					French farm - German ND					German farm – German ND				
	SU0	SU100	SU150	SU200	SU300	SU0	SU100	SU150	SU200	SU300	SU0	SU100	SU150	SU200	SU300
Share of legumes	5%	10%	24%	26%	42%	5%	10%	31%	36%	51%	5%	8%	18%	18%	34%
• <i>Peas</i>	5%	10%	24%	25%	34%	5%	10%	31%	34%	34%	0%	0%	0%	0%	0%
• <i>Faba beans</i>	0%	0%	0%	0%	0%	0%	0%	0%	0%	11%	5%	8%	18%	18%	34%
• <i>Alfalfa</i>	0%	0%	0%	1%	7%	0%	0%	0%	1%	6%	0%	0%	0%	0%	0%
Protein self-sufficiency	66%	68%	72%	74%	87%	66%	68%	75%	77%	87%	61%	62%	67%	67%	74%
Manure on legumes (m ³ .ha of legumes ⁻¹)	0	0	0	2 ^a	14 ^a	0	0	9	12	21	0	0	0	0	4
Synthetic fertiliser (kg.ha ⁻¹)	112	91	42	30	28	115	95	33	28	18	183	170	116	116	43
Farm Profit (€·ha ⁻¹)	1,111	1,116	1,123	1,131	1,153	1,111	1,116	1,123	1,134	1,161	1,360	1,364	1,369	1,376	1,395
Share of VCS in profit	0.0%	0.6%	2.1%	3.0%	7.0%	0.0%	0.6%	2.7%	4.1%	8.5%	0.0%	0.4%	1.5%	2.0%	5.5%
N leaching (kgN.ha ⁻¹)	40	40	38	36	25	38	37	37	36	36	20	20	20	20	18
GWP (kgCO ₂ eq.kg milk ⁻¹)	1.38	1.37	1.33	1.30	1.13	1.38	1.37	1.34	1.31	1.16	1.52	1.50	1.40	1.40	1.28
• <i>Enteric fermentation</i>	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.76	0.76	0.76
• <i>Fertilisation</i>	0.09	0.09	0.07	0.08	0.07	0.09	0.09	0.07	0.07	0.07	0.10	0.09	0.09	0.09	0.07
• <i>Input</i>	0.40	0.39	0.38	0.36	0.17	0.40	0.39	0.39	0.36	0.19	0.54	0.52	0.43	0.43	0.33
• <i>Dehydration</i>	0.00	0.00	0.00	0.01	0.03	0.00	0.00	0.00	0.01	0.03	0.00	0.00	0.00	0.00	0.00
• <i>Other</i>	0.12	0.12	0.11	0.10	0.08	0.12	0.12	0.11	0.11	0.10	0.11	0.11	0.11	0.11	0.11

^a Manure spread only on alfalfa;

4. Discussion and conclusions

This study aimed at quantifying impacts on the interactions of two key policy measures affecting legume production in Europe: VCS for legumes and the national implementation of the ND. The French ND, unlike the German one, prohibits manure application on most legumes, which can discourage their production in livestock farms. Economic and environmental impacts were analysed in two case studies: a French and a German dairy farm, using the bio-economic model FarmDyn. Different scenarios with regard to the level of VCS per hectare and details of the ND were set.

In the French farm, the legume share is doubled with VCS of 100€·ha⁻¹ in comparison to the baseline scenario and increases by 37% of arable land with VCS of 300€·ha⁻¹. In the German farm, the increase is more limited mainly due to the high prices and yields of wheat that make the opportunity costs of legumes higher. Still, the legume share increases by 3% of arable land with VCS of 100€·ha⁻¹ and by 29% of arable land with VCS of 300 €·ha⁻¹. The results suggest that VCS are an effective policy to foster legume production. However, the effectiveness of the VCS depends on economic context. These results are in line with findings of (Helming et al., 2014) analysing the effect of different policy measures aiming at fostering legume production in Europe. They found a maximum increase of +15% in legume area with subsidies from 210 €·ha⁻¹ to 422€·ha⁻¹ and thus concluded that besides other measures subsidies on legumes are an effective tool to increase legume share. However, their study is limited in scope as the results are not detailed by type of production. Regarding the implementation of the German ND in the French farm, it leads to a further increase in the legume share under certain conditions. In fact, allowing for manure spreading to legumes promotes further legume production, but only if manure spreading area becomes restricting. In this case, there is an additional 9% share of legumes in arable land in the French farm with the German ND when the VCS has a value of 300€·ha⁻¹. Thus, the implementation of the ND has important impacts on the production of legumes in dairy farms with high stocking rates. Besides, in both farms, the profits rise slightly, the decreasing revenues from crops being compensated by the VCS. These results differ from those of (Helming et al. (2014) who found a slight decrease of incomes due to the partial shift of direct farm payments from pasture farmers to producers of grain legumes. Moreover, the increase in legume share decreases the usage of inputs. On the one hand, the decrease in purchased feed provokes a rise of the protein self-sufficiency, by 21 percentage points in the French farm, and by 13 percentage points in the German farm with VCS of 300€·ha⁻¹. On the other hand, the application of synthetic N fertilizer decreases by at least 75% in the farms in SU300. This result is in line with findings of Carrouée et al. (2012) where the adoption of grain legumes in crop

rotations reduces the application of nitrogen fertiliser. The decrease in inputs also goes along with significant improvements of the environmental indicators, especially with high shares of legumes. The GWP is reduced, mainly due to a lower use of feed inputs and synthetic N fertilizer. This is coherent with the study of (Nemecek et al., 2008), even though the use as of legumes as own-produced feed is not taken into account in this study. The impact on N leaching is less explicit. Under the French ND, N leaching is almost constantly decreasing, linked to the increase in legume share. However, under the German ND the effect is less distinct as manure spreading to legumes leads to a significant over fertilisation of legumes provoking additional N leaching. However, the overall decrease in N leaching observed in the different scenarios is coherent with results found in other studies (Crews and Peoples, 2004). Finally, it should be mentioned that alfalfa, the only forage legume studied, needs high VCS (i.e., 240€·ha⁻¹) in order to be introduced in farms. However, once produced in large quantities, it represents an interesting lever to increase significantly the self-sufficiency in proteins.

The originality of our study lies in different aspects. First, it focuses on legumes not only as cash crops, but also as feed for livestock animals. Second, the study is carried out in two farms, representing two member states of EU, France and Germany. Different levers and brakes are thus highlighted between current policies in the two countries, which can help implementing more locally-design policies. Third, to the best of our knowledge, it is the first study focusing on the interactions between economic incentives to produce legumes (i.e., VCS for legumes) and environmental regulation (i.e., the European ND) that might prevent the production of legumes in livestock farms. This double analysis offers a new look at the sometimes contradictory effects of such regulations.

The main limitation of the study is the restriction to two specific case studies at farm scale. As the implementation of farms is based on various assumptions, results might differ with other prices of crops and feeds, as well as with other farms types, in other regions. In particular, in regions with even higher stocking densities, the effect of the ND can be even stronger. As legumes produced in our case studies are partly marketed, it might be useful to consider market feedback. Further, it would be interesting to develop the same type of study at higher scales, through models at regional or even at European scales. Moreover, since the VCS budgets for each legume species is upper bounded at national level, the level of support per hectare depends on the overall national production of each legume. This introduces an additional risk of income to legumes which is not taken into account in the study. Further, the level of VCS per hectare was set arbitrarily in the study. However, this level must be consistent with the ceiling of all productions benefiting from VCS in each Member State (Regulation No 1307/2013, (European Parliament, 2013)), in order to remain in compliance with the World Trade Organization “blue box” criteria. Concerning environmental assessment, the calculation of N leaching results from many factors,

which are hard to compile in a farm scale model. In particular, the mineralisation of N fixed by legumes can lead to higher N leaching, depending on soil types and fertilisation management. Finally, the potential changes in enteric fermentation that might result from the introduction of legumes in the feed are not taken into account in the calculation of GWP (Beauchemin et al., 2008).

Regarding policy implications, VCS represent an effective tool to provoke a first increase in legume production. However, high VCS per hectare are needed to reach significant reduction in input use and thus, an improvement of environmental indicators. Thus, we recommend a combination with other measures (e.g., taxation of N synthetic fertilizer) in order to foster legume production. Finally, allowing to spread manure on legumes in France would be an interesting lever for increasing legumes production in livestock farms. Nevertheless, limits should be set regarding the maximum amounts of manure allowed on these crops in order to avoid over fertilisation.

We focused on the interaction (and coherence) between VCS and the ND, but further policy field could be considered such as interactions between VCS and pesticide policies (Nilsson et al., 2012). Conventional legume production still mostly relies on pesticides, while certain regulations ban pesticides on these crops such as UE 2017/1155 that forbids pesticides on legumes used as EFA. That restriction – which might lead to lower yields and/or higher costs for mechanical plant protection measures – is not considered in our analysis. Besides, as shown in our study, the rise in legume share decreases the use of inputs and improves the overall self-sufficiency of the farms in feed and nitrogen. Therefore, legumes represent an essential tool to reach low-input farming and a necessary step in conversion to organic production. As such, it would be interesting to analyse the interaction between support to organic production and VCS or measures under ND and conversion decision. In addition, our study confirms that legumes represent an interesting tool to reduce GWP, as they can substitute feed inputs associated with high emissions. Similarly to the study of Dequiedt and Moran (2015), an in-depth economic analysis of the potential of legumes used as feed to mitigate climate change, and the cost associated will be necessary. Finally, we deliberately analyse high levels of VCS to explore implications of high legume shares not yet observed in conventional farms. Such legume shares improve environmental indicators but make farm profit more dependent on subsidies, which is a questionable strategy at a time where high subsidies under the CAP are questioned. Alternatively, the profitability of legumes could be fostered by further development of dedicated agri-food chains. The emerging sector of GMO-free feed, using legumes produced in the EU, provides an interesting example, as well as the development of vegetarian products drawing on legumes.

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Acknowledgement

This study was financed by the LIFT project (European Union’s Horizon 2020 research and innovation programme under Grant Agreement No 770747) and the SOS-PROTEIN project (co-financed by two French regions, Brittany and the Pays de la Loire, and the European Agricultural Fund for Rural Development 2014–2020 (PEI 16.1)).