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RESEARCH ARTICLE OPEN ACCESS

Assessment of the impact of a decrease in crude protein content in monogastric feed on oilseeds meals and legumes, prospective approach☆

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Abstract – The present study evaluates the consequences of a change in pig and poultry protein nutrition through compound feed over time in France, on raw materials consumption, economic performances, and environmental impacts. It has been conducted using the "Prospective Aliments" model by Céréopa, which applies the principles of linear programming at a national scale (France). The study is based on a prospective approach. A decrease of 1 and 2 percentage points in pig and poultry feed crude protein (CP) content is applied (CP-1 or CP-2, respectively). As a consequence, consumptions of raw materials for total French compound feed production change drastically, by using rapeseed meals, over soybean meals (−425 000 t for CP-2) and sunflower meals, and including more grains, with maize replacing wheat. This shows that the feed CP content of commercial feed can be decreased at a national scale, yielding significant environmental benefits. This raises the question of developing an incentive-based policy to absorb potential over costs.

Keywords: protein nutrition / environmental impact / France / over costs

Résumé – Évaluation de l'impact d'une baisse de la teneur en matière azotée totale (MAT) des aliments composés destinés aux monogastriques sur les utilisations de tourteaux d'oléagineux et de graines de protéagineux – Approche prospective. Cette étude vise à évaluer les conséquences des changements actuels et futurs de nutrition azotée dans les aliments composés des porcins et des volailles. Ces changements sont explorés au travers de l'évolution des consommations de matières premières, des performances économiques et environnementales et ce, à l'échelle de la France. Ce travail a été conduit grâce à la mise en œuvre du modèle « Prospective Aliment » du Céréopa qui repose sur une technique d'optimisation par programmation linéaire à une échelle nationale (France). Cette étude repose sur une approche prospective. Une baisse de 1 puis 2 points de pourcent de la teneur en matière azotée totale (MAT) dans les aliments porcins et volailles est appliquée (respectivement CP-1 et CP-2). De tels changements induisent des évolutions majeures de consommations de matières premières : les tourteaux de colza remplacent pour une part importante les tourteaux de soja (−425 000 t à CP-2) ainsi que les tourteaux de tournesol. La part de céréales augmente et une part du blé est remplacée par du maïs. Cette étude étaye la possibilité d'une baisse de la teneur en MAT des aliments à l'échelle nationale, cette baisse étant associée à des bénéfices environnementaux significatifs. Ces résultats posent également la question de la définition de politiques incitatives permettant de compenser les surcoûts.

Mots clés : nutrition azoté / impacts environnementaux / France / surcoûts

☆ Contribution to the Topical Issue "Soybean / Soja".
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1 Introduction

Decrease of CP content in animal feed could be interesting to improve French agricultural autonomy, to reduce deforestation risks, to cut down surplus nitrogen in animal feed, in turn mitigating pododermatitis risks.

The increased availability of feed-grade AA beyond Val (Val, Ile, Leu, Arg and His) in the European market allow to further decrease dietary crude protein without impacting animal performance (Cappelaere *et al.*, 2022; Nozeran *et al.*, 2022).

The present study aims to project us into the future when implementing a 1% or 2% points decrease of dietary CP with the currently available portfolio of feed-grade AA.

An economic analysis was performed, by following up the cost of supplying raw materials to compound feed producers (CFPs). Moreover, this study includes an environmental analysis, through the assessment of greenhouse gases (GHG) emissions caused by production and transportation of these raw materials, and ammonia emissions associated with monogastric manure management.

2 Material and methods

2.1 Presentation of the Prospective Aliments model

2.1.1 Model structure

This work is based on the "Prospective Aliments" model developed by Cereopa. The model has been used since 1989 to study raw material procurement strategies in the animal feeding sector. It is based on a rigorous zootechnical approach, using the same optimisation technique applied by compound feed manufacturers. This model evaluates the relative competitiveness of raw materials. It has been used at French scale (France Prospective Aliments) for this article, but it is also available for several representative European countries.

Prospective Aliments was conceived to work on various time scales. For this work, it was implemented on a unique scale time corresponding to the 2017–2018 marketing year named "initial situation". Thus, considered raw material prices are averages of monthly quotations over the 12 months of the marketing year (July 2017 to June 2018).

The France Prospective Aliments model integrates:

- 72 raw materials, which are representative of the raw materials processed by CFPs in France;
- 65 feed formulas used for six groups of animals: poultry, pigs, dairy cows, fattening beef, small ruminants and rabbits. When it is relevant, feed is duplicated in a "GMO-free" version; which incorporates the key determinants of raw material consumptions;
- 9 French regions allowing to consider transportation cost differences;
- 90 nutritional and technical variables, which allow the characterization of raw materials and feed.

The incorporation rates of each raw material in feed are defined by linear programming (simplex algorithm). The optimisation function (or "objective function") represents the national cost of supply and is minimized.

Raw material consumptions at regional scales are calculated from regional incorporation rates and regional feed tonnages. National tonnages are determined by summing up regional tonnages.

Simulations cover 93% of the feed volumes produced by French CFPs, excluding organic feed. These 93% come from the statistics provided by the French Animal Feed Industry Union and the French Agricultural Cooperatives Union (SNIA-CDF Unions). The remaining 7% correspond to small CFP companies and some species (horses and aquaculture for instance) not included in Prospective Aliment. These 93% correspond to 19 million of tons of commercial compound feed split into about 20% to dairy cattle, 10% to beef cattle, 25% to pigs, 25% to poultry, 10% to laying hens and 10% to other species (goat, sheep, rabbit, duck).

To give an enlightening example of the contribution of Prospective Aliment, French national statistics tools provide the quantity of wheat, which is used by CFPs. Prospective Aliment model is used to calculate the allocation of this total quantity of wheat to different species, categories of age and regions.

2.1.2 Performance indicators

Several economic and environmental indicators can be calculated from raw material inclusion levels proposed by the model.

The economic cost, measured in euros (€) or in euros per tons of feed (€/t), is calculated in the model as a combination of incorporation rates and raw material prices. These feed costs can be aggregated by species, by region, or at the scale of the French territory such as defined in "Prospective Aliment" model.

Greenhouse gas (GHG) emissions are calculated in the model in units of mass of carbon dioxide equivalent (CO_2-eq). They result from the application of environmental coefficients specific to each raw material. These are derived from Life Cycle Analysis (LCA) produced as part of the ECO-ALIM program (RMT Breeding and Environment, 2019).

The French protein autonomy, expressed in percentage, is derived from coefficients applied to each raw material and representing the part of French production in the consumption by CFPs. These shares, combined with the CP content of raw materials, provide an evaluation of the protein autonomy of French CFPs.

Lastly, calculated ammonia emissions from monogastric manure management are based on the amount of nitrogen contained in industrial feed, considering the amount of nitrogen issued from farm-made feed is supposed stable.

More precisely, the amount of excreted nitrogen has been defined according to the CORPEN model (CORPEN, 2003, 2006). Rates of nitrogen volatilized as ammonia are taken from the EMEP/EEA model (EMEP/EEA, 2019), moderated by reduction coefficients that depend on feed CP content, according to the equations of Belloir *et al.* (2017) and Cappelaere *et al.* (2021). Ammonia emissions from ruminant manure management are not calculated in this model because the ratio of commercially purchased feed is too low in the total ration of this cattle.

2.2 Settings of simulations

For this evaluation, specifications in amino acids have been set at 100% of METEX NØØVISTAGO recommendations for

Table 1. Applied restrictions to amino acid volumes for the assessment of the impact of a decrease in crude protein content in monogastric feed at commercial feed producers in France.

	Volumes of amino acids used by CFPs ($\times 10^3$ tons)	
	Initial situation	**"CP-1" and "CP-2" simulations**
L-Arginine L-Histidine L-Isoleucine L-Leucine	0	Calculated optimal value for reduced CP content scenarios
L-Lysine L-Threonine L-Tryptophan L-Valine	Calculated optimal value CP content 2017–2018	Calculated optimal value for reduced CP content scenarios

lysine, and 97% of the same standards for other amino acids. For the "Initial Situation", feed-grade amino acid volumes were let free in the model, which means reported values represent the optimal volume for this supply cost.

Two scenarios were tested by decreasing the CP content in monogastric formulas (pig, broiler, laying hen), compared with 2017–2018 initial situation: "CP-1" (decrease of monogastric feed CP content by 1 percentage point through the decrease of compound feed CP content) and "CP-2" (decrease of monogastric feed CP content by 2 percentage points through the decrease of compound feed CP content[1]). We have chosen these scenarios because it corresponds to current CFPs' best practices. Indeed, CP content reduction in compound feed has already been a trend over the last 30 years to optimize economic and environmental performances. Feed grade amino acids are not included in ruminants feed and CP content are not modified for these animals in our simulations. However, ruminants feed compositions can be impacted by raw materials substitutions occurring in other species feed.

L-Leucine, L-Isoleucine, L-Histidine and L-Arginine volumes are considered null in the initial situation, since currently sold volumes were marginal in 2017–2018 ("0" value in Tab. 1). However, in "CP-1" and "CP-2" simulations, their consumption levels are set by algorithmic optimization ("Calculated optimal value" value in Tab. 1). The formulation prices of the feed-grade AA (especially the newest ones) were taken as fixed references but may vary depending on demand and supply of those specific AA.

The CP contents defined in the model are presented in Table 2 for each feed.

3 Results

3.1 Impact on raw materials, in particular oilseeds consumption

A decrease of the CP content in monogastric feed has an impact on raw material consumption.

[1] The CP content of farm feed is considered as stable in this study. Indeed, we consider that feed CP adjustments are made through the use of compound feed essentially in pig and poultry productions.

If we consider all the animal productions included in the Prospective Aliments model (Fig. 1), both situations (CP-1 and CP-2) show an increase in rapeseed meals and grains consumptions, with a significant substitution of maize for wheat (not shown in Fig. 1): + 1.7 million tons of maize, hence a 70% increase in scenario "CP-1", and + 2.7 million tons of maize, hence a 110% increase in scenario "CP-2". CP-2 scenario requires 230 000 additional tons of rapeseed meals, compared with the initial situation. They replace soybean meals, sunflower meals, and peas. Soybean meals volumes are down by 420 000 t in CP-2 compared to the initial situation. Substitutions are amplified in CP-2 situation compared to CP-1 situation.

If we focus on poultry (Fig. 2), the same trends are emerging. Rapeseed meals, unshelled sunflower meals (LP) and cereals consumptions increase at the expense of soybean meals and sunflower meals high protein (HP). Soybean meal is the raw material decreasing the most in CP-1, and even more significantly in CP-2. A decrease of crude protein content in monogastric feed leads to an important decrease of soybean meal consumption in poultry feed industry.

Regarding the pig industry (Fig. 3), changes in the consumption of raw materials are less significant than those observed in poultry industry. Moreover, changes in consumption of raw material are not the same as those at the national scale. Indeed, in CP-2 situation, volumes of rapeseed meals are down by 50 000 t, while milling by-product, cereals and amino acids consumptions increase. Milling by-product volumes rise in CP-1 (+60 000 t) and demand is even higher in CP-2 (+170 000 t) whereas consumption of protein seeds like peas decreases by 100 000 t in both CP-1 and CP-2.

In the dairy cattle industry (Fig. 4), rapeseed meals are more included in the feed: +140 000 t in CP-1 scenario, and +290 000 t for CP-2. They replace milling by-products and cereals. This is explained by the fact that in dairy cattle, consumption of milling by-products decreases a lot (−80 000 t in CP-1 and −100 000 t in CP-2), due to a lack of volumes available for these raw materials. Prospective Aliments model leads to allocate milling by-product to pig feed (increasing overall profitability by decreasing the sum of all formula costs), which decreases their availability for dairy cattle.

Table 2. Crude protein percentage of different monogastric feed.

Feed	Initial situation (% of CP in feed)	CP-1 point (% of CP in feed)	CP-2 point (in % of CP in feed)
Turkey growing feed	20.1	19.1	18.1
Turkey starter feed	25.2	24.2	23.2
Guinea fowl	18.6	17.6	16.6
Laying hen	15.3	14.3	13.3
Broiler starter feed	21.3	20.3	19.3
Broiler finishing feed	19.0	18.0	17.0
Label broiler feed	15.3	14.3	13.3
Breeding pigs	16.5	15.5	14.5
Pig finishing feed	14.0	13.0	12.0
Piglet/Pig starter feed	19.2	18.2	17.2
Concentrated proteins compound feed	28.0	27.0	26.0
Sow gestation feed	12.1	11.1	10.1
Sow lactation feed	15.1	14.1	13.1

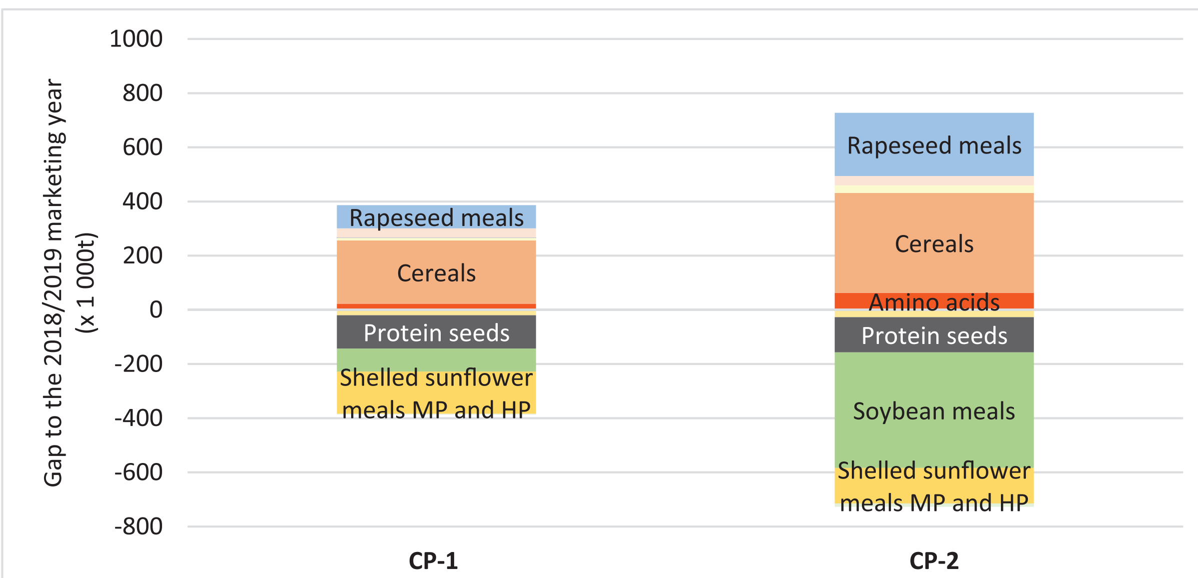

Fig. 1. Evolution of oilseeds and protein crops consumption during a decrease of CP content in monogastric feed – All animal productions.

In the beef cattle industry (Fig. 5), changes in the scenarios are less impacting feed composition than for other animal productions. It represents less than 200 000 t of raw materials in CP-2. Consumption of rapeseed meal decreases (−50 000 t in CP-2) whereas consumption of soybean meal increases slightly (+20 000 t in CP-2). Like in dairy feed, consumption of milling by-products decreases (−110 000 t in CP-2), due to a redistribution of these co-products for pig feed.

The decrease of the crude protein content of monogastric feed is made possible by using synthetic amino acids. Their consumption is up +63 000 t in CP-2, most of which are used by the poultry industry (+49 000 t) and the pig industry (+14 000 t). This crude protein content decrease leads to a redistribution of raw materials among all the animal feed: consumptions of imported soybean meal and sunflower meal drop while rapeseed meal and cereals replace them in the formulas.

3.2 Impact on raw materials cost

Scenarios including a lower CP content in monogastric feed have an impact on the supply cost of CFPs (Fig. 6). A decrease of one point of crude protein (CP-1) has a limited impact on the supply cost (+60 M€), which represents +1.4% of the supply cost. Feed cost increases in all animal production except for beef cattle. The sharpest increase is seen in poultry, with +5 € per ton of feed.

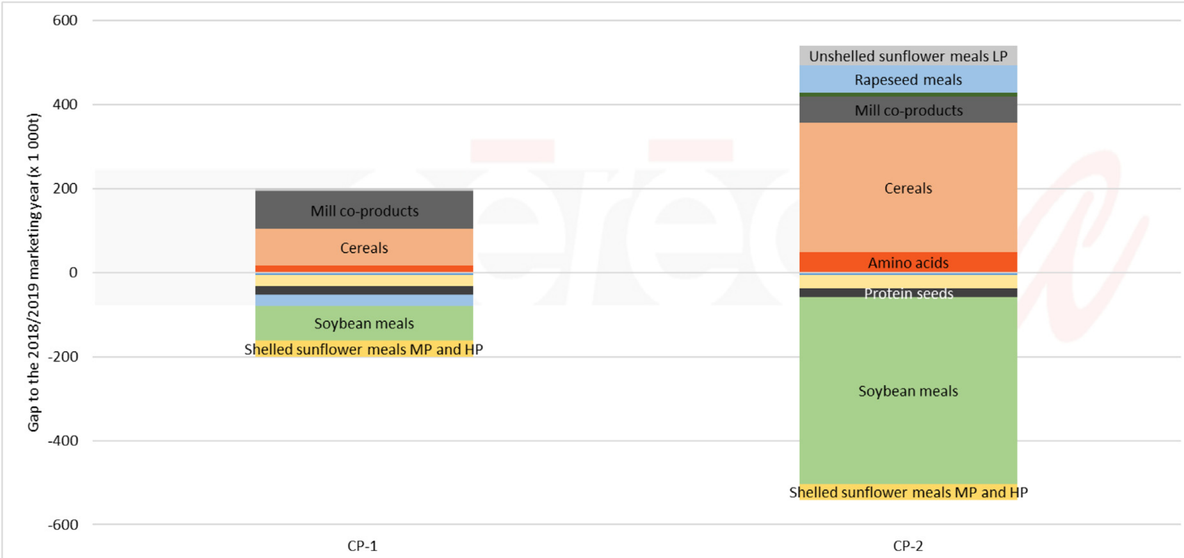

Fig. 2. Evolution of oilseeds and protein crops consumption after a decrease of CP content in monogastric feed – Poultry feed.

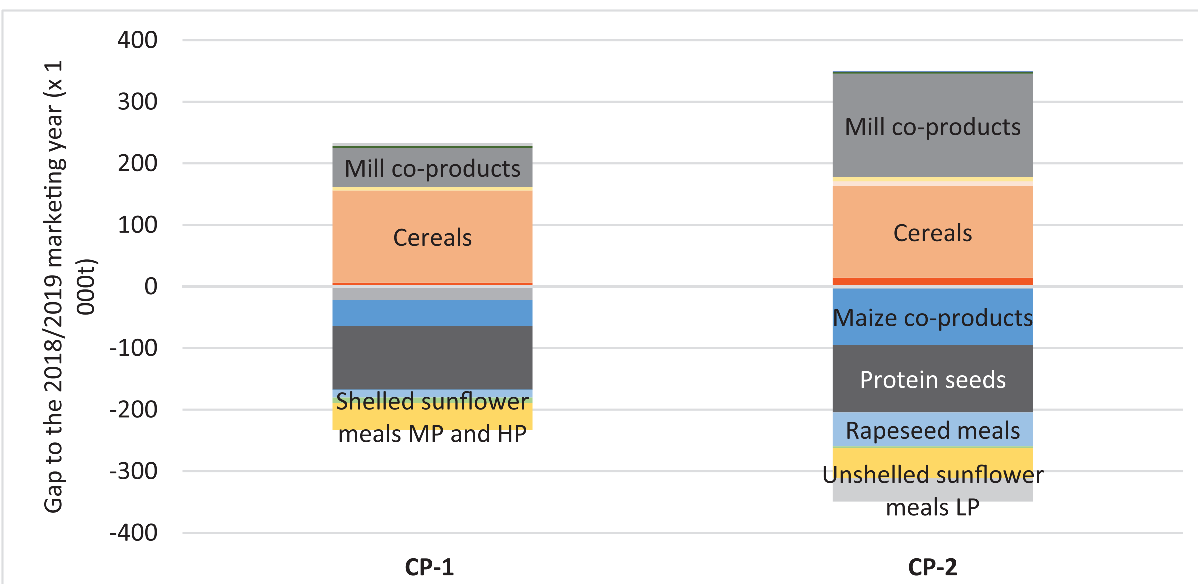

Fig. 3. Evolution of oilseeds and protein crops consumption after a decrease of CP content in monogastric feed – Pigs feed.

In CP-2, supply cost is up by +200 M€. This increase is particularly noticeable in poultry and pig feed. The cost of feed rises in every animal production. Weighted average extra costs are 16.4 €/t for poultry, 9.3 €/t for pigs, 6.1 €/t for dairy cattle, and 2.9 €/t for beef cattle.

3.3 Environmental impacts

This study also aims to assess the environmental impacts of a decrease of CP content in monogastric feed. Evolutions of GHG, as well as ammonia emissions, have thus been estimated.

3.3.1 GHG emissions

The GHG emissions assessment associated with a reduction of CP content in monogastric feed was estimated with the raw material GHG emissions database from ADEME.

However, there is a high uncertainty on deforestation-related emissions for imported soybean. Hence, two values of emissions have been tested for this raw material: the ADEME value (0.839 kg CO_2-eq/kg soybean) and another higher sensitivity test value (2.5 kg CO_2-eq/kg soybean) considering the uncertainty associated to this emissions evaluation. For scenario CP-1, additional GHG emissions are between 0% (high soy value) and +1% (Ademe soy value) (Fig. 7). In

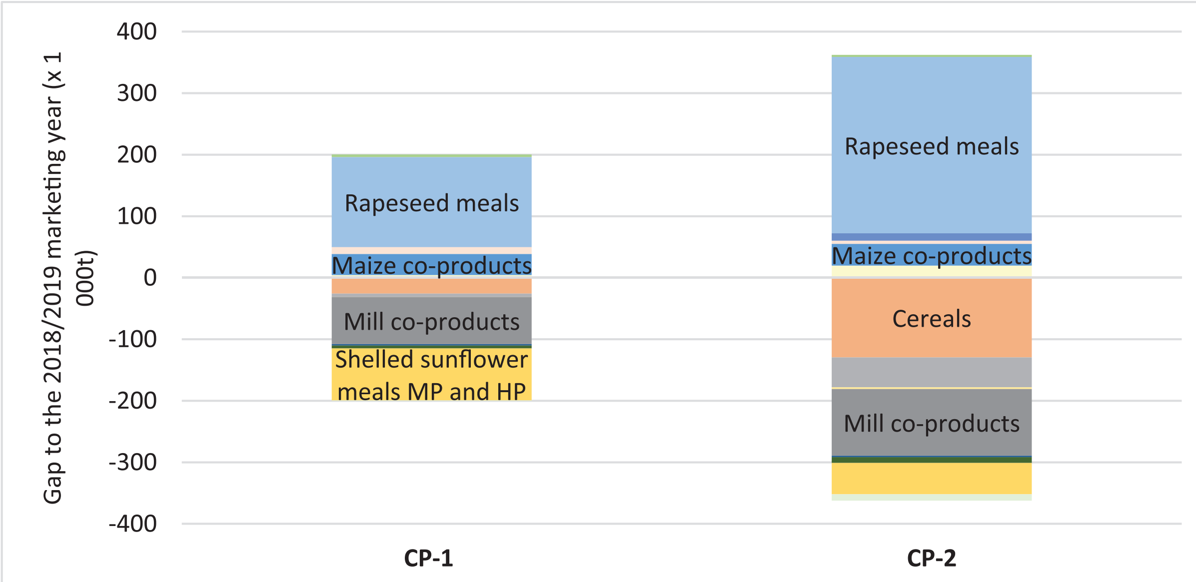

Fig. 4. Evolution of oilseeds and protein crops consumption after a decrease of CP content in monogastric feed – Dairy cattle feed.

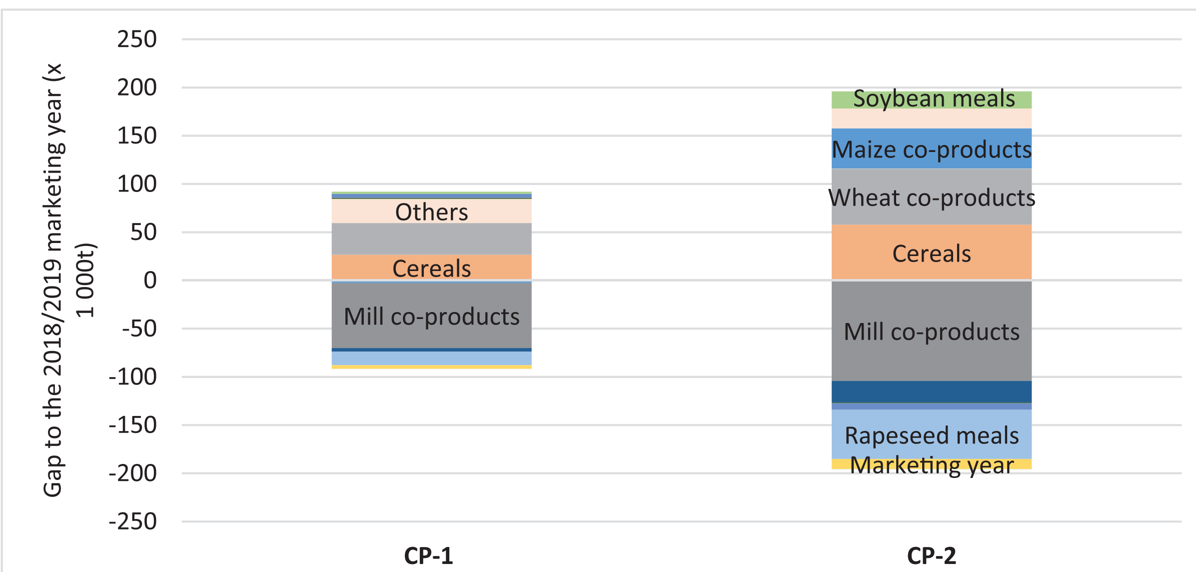

Fig. 5. Evolution of oilseeds and protein crops consumption after a decrease of CP content in monogastric feed – Beef cattle ration.

scenario CP-2, the evolution of emissions is between −4% (high soy value) and +1% (Ademe soy value) (Fig. 7).

On the one hand, the reduction of soybean meal imports leads to a decrease of GHG emissions associated with these imports. But on the other hand, the rise of rapeseed meal, cereals and amino acids consumption increases emissions, which partly offsets the total improvement. The choice of the GHG emission value for imported soybean meal has an impact on the result of this assessment. In addition, the LCA values of AA differ between country of production and this may also affect the results on this study (Agribalyse 3.1). Further research on this topic is currently ongoing.

3.3.2 Ammonia emissions

Ammonia emissions studied in this part correspond to ammonia emissions associated with manure management in France, which take into account ingested nitrogen from CFPs' feed, and feed produced on farms. Emissions from soil fertilization, crop input production or raw material transportation are considered stable.

At model's scale (Fig. 8), ammonia emissions are reduced by 10% (−8 thousand of tons NH_3 emitted) and 20% (−15 thousand of tons NH_3 emitted) in CP-1 and CP-2, respectively. In both cases, this reduction is significant. Ammonia emissions decrease the most in laying hen, broiler production, and then swine production.

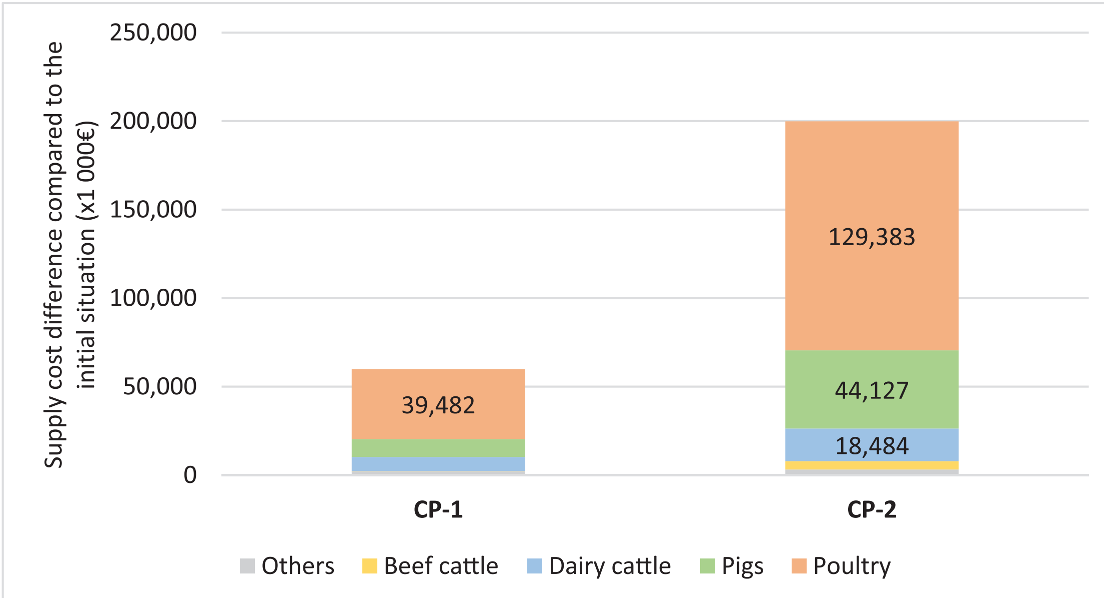

Fig. 6. Evolution of the supply cost after a decrease of CP content in monogastric feed – Contribution of all the animal productions.

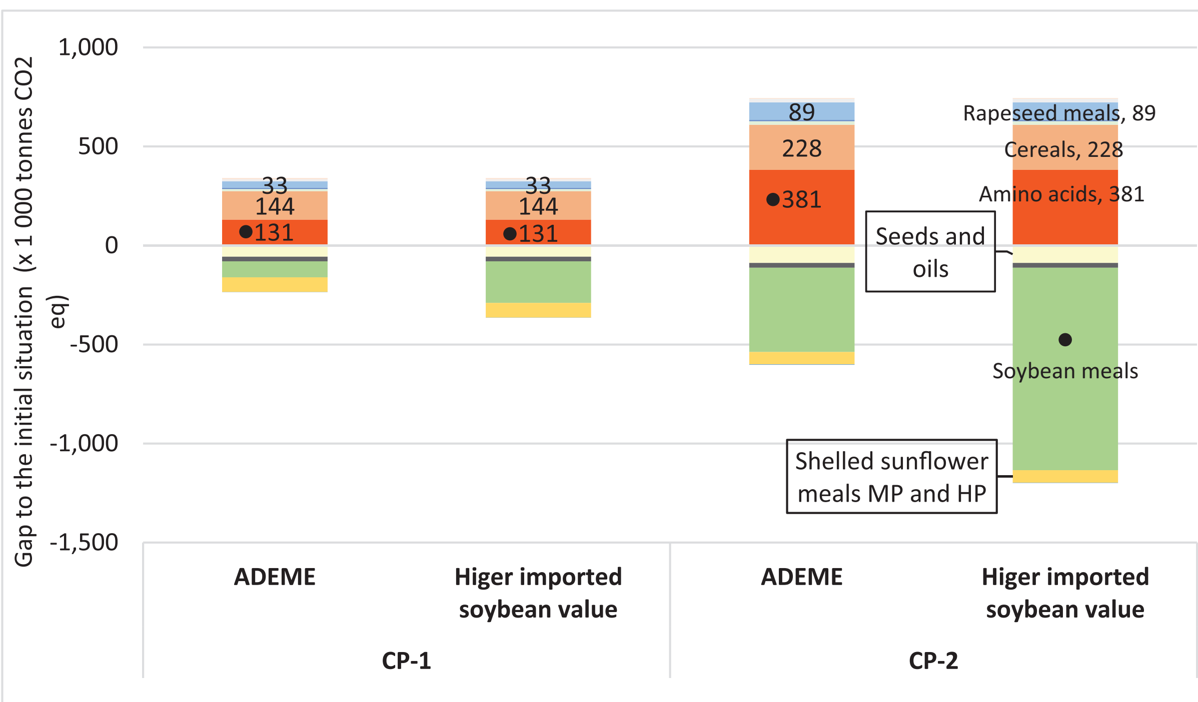

Fig. 7. Evolution of the GHG emissions following the decrease of CP content in monogastric feed – Raw material contribution.

3.4 Impact on protein self-sufficiency

In CP-1 scenario, protein self-sufficiency of CFPs (Fig. 9) rises by 1.2 percentage points. It rises by 3.6 percentage points in CP-2, which corresponds to an increase by about 5% of protein self-sufficiency.

In CP-1, all animal productions increase their autonomy except beef cattle. In CP-2, all of them gain autonomy. Poultry industry increases the most its protein self-sufficiency with a rise of 8.4 percentage points, followed by beef cattle (+3.1 percentage points) and pigs (+2.3 percentage points).

4 Discussion

The prospective analysis of a gradual decrease of crude protein content in monogastric feed shows that it is still possible to reduce consumption of soybean meals at French scale, by around 20% (−425 000 tons) with a 2 percentage

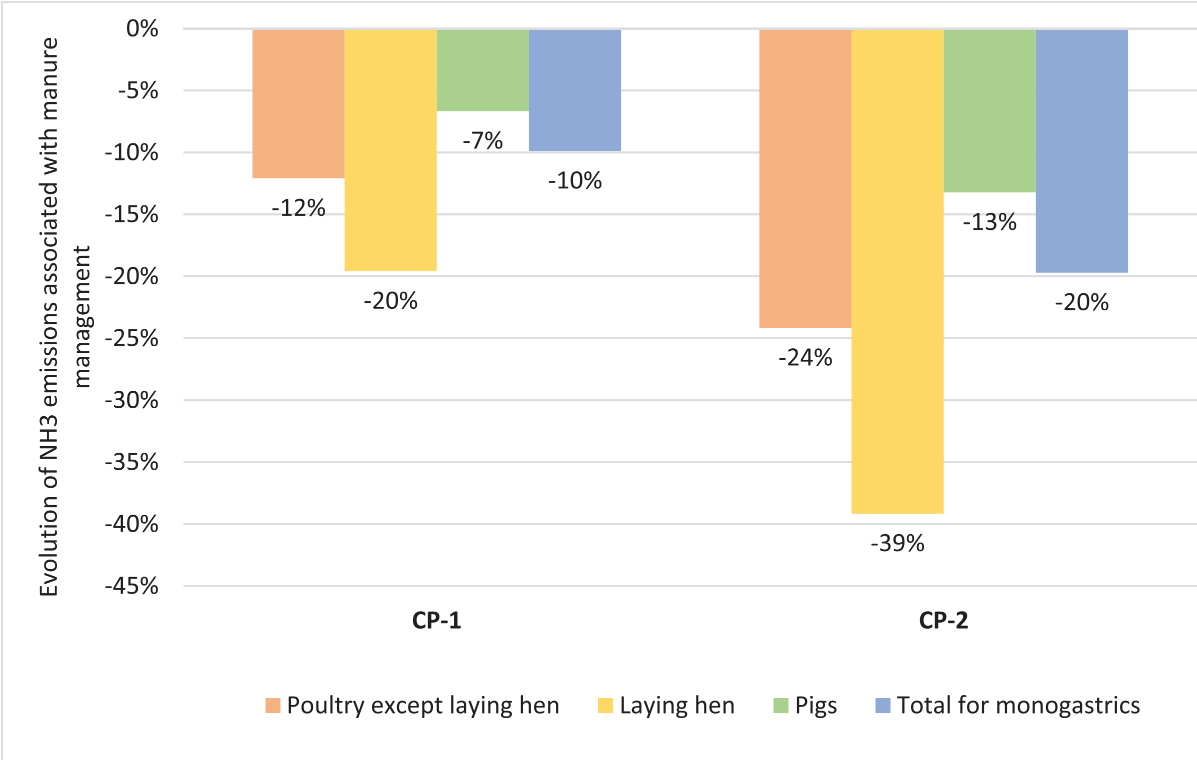

Fig. 8. Evolution of ammonia emissions after a decrease of CP content in monogastric feed.

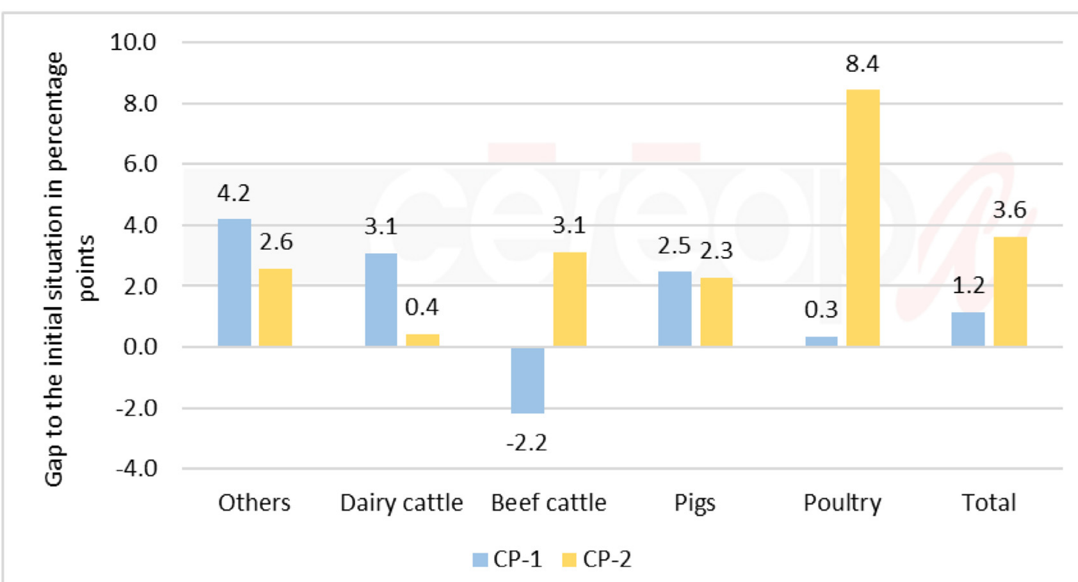

Fig. 9. Evolution of the protein self-sufficiency after a decrease of CP content of monogastric feed.

points decrease of feed CP content. This CP content decrease leads to an important switch in raw materials consumption, with an increasing consumption of rapeseed meal and cereals and a strong substitution of maize for wheat. Even if this consumption level of maize has never been observed at CFPs' level, it seems compatible with the French collect level (12 million tons of maize in 2017/2018). However, the updraft of rapeseed meal at the national scale would possibly be facing some issues, such as a competition with on-farm production or production constraints: drought, reduction of the variety of phytosanitary products available in France, etc.

This study does not show a correlation between the CP content decrease and GHG emissions reduction (−4% of GHG missions at CP-2 for the "higher soybean" value). It can be explained by the chosen scop of GHG emissions, which was limited to production and transport of raw materials used by CFPs. On-farm manure emissions are not taken into account in our GHG assessment. Calculations of the GHG emissions are also strongly correlated with the chosen database for carbon footprint, especially in the case of imported soybean meal. This carbon footprint is largely determined by land-use changes. ECO-ALIM database has been used for this study, but soybean meal carbon footprint varies strongly depending on databases, beyond the maximal value tested in the sensibility analysis conducted in this study. It would be now necessary to align methodologies of GHG emissions assessment including an evaluation of land-use changes to get robust and recognised References

This study shows a potential huge drop in ammonia emissions related to feed CP content reduction (−20% emissions on the evaluated scop). However, consequences of raw materials consumption switches on aggregated field emissions have not been considered in the modelling of ammonia emissions, since the ammonia part of the model only integrates emissions related to monogastric manure management. Besides, in a follow-up study, it would be useful to translate this reduction of ammonia emissions to acidification, but also eutrophication impacts. These impacts are important in public discussions, as France initiates the revision of its "nitrate" national action plan. More generally, scopes of both GHG and ammonia emissions assessments should be aligned to a normalized scope 3.

To finish with, the extra costs due to a decrease in monogastric feed CP content might not seem very high, but since a reduction in CP content isn't more profitable, there is no nutritional based profit to do so. However, there are also functional benefits using amino acids and we could imagine private (brand added value) or public (subsidies) incentives as well, in order to promote this practice. The payment of GHG savings (such as in the Label Bas Carbone) can also be a lever to offset the extra cost. Taking the CP-2 scenario with the higher soybean meal value and a value of 80 €/ton of CO_2 saved, the payment of CO_2 savings could offset around 20% of the extra cost.

5 Conclusion

It is technically possible to reduce the CP content of monogastric feed by using a wide range of amino acids. The decrease of feed CP content results in the substitution of rapeseed meal and cereals for imported soybean and sunflower meal.

The consequences of a decrease of feed CP content are globally neutral in terms of GHG emissions, but it reduces ammonia emissions and improves the national protein self-sufficiency.

However, this decrease of feed CP content comes with a rise of the supply costs of raw materials for French commercial feed producers, especially for poultry feed. Therefore, it is necessary to set up support policies, particularly through the EU common agricultural policy, to support initiatives assessing environmental impacts and improving practices.

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