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Research Article – Dossier
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Protein sources in animal feed
Les sources de protéines dans l'alimentation du bétail

Dossier

Feeding proteins to livestock: Global land use and food *vs.* feed competition

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Abstract – Competition between direct consumption of plant production and the feeding of livestock is key to global food availability. This is because livestock consume edible commodities that could be available for (food insecure) populations but also because it diverts arable land from food production. The share of total plant production redirected towards feeding livestock is (roughly) known but estimations of land surfaces virtually occupied by livestock production are scarce. In this study, following up on the *Agrimonde Terra*⋆⋆ project, we estimate areas devoted to the feeding livestock. First, we estimate the protein composition of an averaged feed basket at the global scale in 2005 and detail the evolution of the protein-source feed component during the period 1961–2009. We focus on protein-rich crops such as oil crops and show its proportion in the global livestock diets has tripled since 1960, though only accounting for about one fourth of total proteins. Then, we estimate land virtually occupied by crop feed at the global scale using a set of straightforward hypotheses. Our estimates suggest that, although livestock and feed production has continuously increased and despite uncertainties in available data, competition for land between feed and food uses has decreased over the last two decades. The share of areas cultivated for feed requirements decreased from about 50% in the 1970s to 37% nowadays. This trend is attributable to the increase of crop yields and to a decrease of the share of cereals in livestock diets to the benefit of oilseeds by-products. However, estimating the share of total areas used for feed is complicated by the significant role played by by-products.

Keywords: Land use / competition for land / feed composition / oil crops / food security

Résumé – Les protéines pour le bétail mondial : usage des terres et compétition entre alimentation humaine et animale. La production agricole peut être utilisée directement pour l'alimentation humaine ou servir d'abord pour l'alimentation animale. Cette compétition, qui s'exerce au niveau des produits alimentaires mais aussi en amont sur les terres agricoles, est un facteur clé de la disponibilité alimentaire mondiale. Alors qu'on connaît déjà approximativement la part de la production utilisée en alimentation animale, la prospective *Agrimonde Terra*⋆⋆ nous permet dans cet article d'estimer les surfaces mobilisées pour ces usages, dont certaines le sont indirectement ou virtuellement. Nous analysons d'abord la composition des régimes animaux exprimée en protéines, à l'échelon mondial en 2005, puis son évolution entre 1961 et 2009. La contribution des oléoprotéagineux n'est que de 25 % mais elle a triplé depuis 1961. À partir de là, la formulation de quelques hypothèses est nécessaire pour estimer les surfaces virtuellement cultivées pour l'alimentation animale car définir les terres dédiée à l'alimentation animale n'est pas trivial en raison de la prise en compte des coproduits issus d'une même culture. Malgré des incertitudes importantes dans les données disponibles, nous montrons qu'alors que les productions animales et d'aliments pour le bétail ont continuellement progressé, les surfaces correspondantes et la compétition pour la terre ont même décru ces 30 dernières années. En effet, la part des terres cultivées pour le bétail est passé d'environ 50 % des terres cultivées dans le monde dans les années 1970 à 37 % aujourd'hui. Cette tendance peut être attribuée en partie à l'augmentation des rendements culturaux et à la diminution de la part des céréales dans les rations animales au profit des coproduits des oléagineux.

Mots clés : Usage des terres / compétition pour la terre / alimentation animale / protéagineux / sécurité alimentaire

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Introduction

Global food production has roughly tripled since 1960 to meet a growing demand by an additional 4 billion people. During the same period, livestock protein production roughly tripled with consumption of total animal products reaching 40% of global diets. This means that relative to 1961, humans have transferred large amounts of plant proteins from direct consumption to the feeding of livestock. Quantifying this transfer implies to get a detailed knowledge of the global livestock feed basket. Unfortunately, large-scale data on livestock feed are scarce and incomplete. This is primarily because the composition of livestock diets strongly depends on production systems. For a total of 1 billion tons of feed biomass produced by the feeding industry (Gilbert, 2004), a significant additional quantity is directly produced and consumed on farm (*i.e.*, locally grown fodder, various wastes and by-products). Also, a large part of ruminant livestock diet is based on natural resources – typically pasture grass – in quantities that are poorly known. These sources have compositions (primarily energy and protein contents) that vary according to location, season and browsing feeding preferences (Archimède *et al.*, 2011). FAOSTAT global agricultural data provide detailed information on crop feed sources but omit other important feed sources such as fodder, wastes, grass and leaves and some by-products (*i.e.*, pulps and dregs). For year 2005 though, combining data from FAO (Gerber, com. pers.) we are able to estimate a detailed protein feed mix for the global livestock, but with no distinction between production systems.

In the first section, we focus on the global livestock feed mix. We use FAOSTAT data, other sources and expert estimations to review global feed production and consumption dynamics over the last five decades. In section two, we estimate cropland used to sustain global feed production as an indicator of the land-based competition between feed and food. In section three we elaborate on pasture land. The last section analyses drivers of the evolution of global feed protein production to propose several paths for the future.

1 Data

We use data from food and agriculture organization (FAO) commodity balances (CB) to study domestic crop supply (FAO, 2013). CB data provide quantitative information on crop supply allocation to feed, food, processed, other utilization, wastes and seed. We also use FAOSTAT data on land use for characterizing land allocation between the various agricultural products and computing yields and on the processing of commodities (in particular item trees from (FAO, 1996)). FAOSTAT data thus constitute the body of the present article. We also use feed mix data at global scale from unpublished FAO sources (Gerber P., com. pers.; data unpublished used for the GLEAM model (Gerber *et al.*, 2013)) estimated for the year 2005 for four livestock categories (*i.e.*, ruminant meat and dairy, pig and poultry). Note that our computations of land areas dedicated to feed production are performed at the global scale. Hence, there is no need to consider trade explicitly.

We classify all fodder in broad classes. Cereals silage or forage production is assigned to the cereal category and Rye grass, "Grasses Nes", Clover, Alfalfa, "Forage products" are assigned to a "Forage" category. "Green oilseeds for silage" are included in a so-called "Other oilcrops" category; "Leguminous for Silage" to "Pulses" category; "Vegetables Roots Fodder" to "Roots and Tubers" category and "Beets for Fodder" or other vegetables "for fodder" to "Other feed crops" category. As from 1985, a significant area (around 100 million hectares) of "Pumpkins for fodder" appears in the data. We supposed this break to be artificial and probably due to data or methodology updating. In order to facilitate the reading of the trend on the Figure 7, a constant 100 Mha is added to its category between 1961 and 1984.

2 Results and discussion

2.1 Proteins in livestock diets

In this first section, by combining data sources, we provide ranges of values for the protein content of different feed sources *i.e.*, crop-source feed, grasses, fodder and residues. We then estimate the composition of the feed basket at the global scale in 2005 and elaborate on the dynamics of feed crop production since 1961. In this section, we choose to express all dietary components in proteins. In fact, consumption of proteins has a considerable importance for amino-acids balance and availability at tissue level in animals. Alternative possibilities (*i.e.*, calorie/energy or in biomass) are more common in the literature (Bouwman *et al.*, 2005; Wirsenius *et al.*, 2010). But, considering proteins allows to draw a complementary representation of global feed with a stronger emphasis on feed quality.

Oilcrops, in the form of cake or meal (150 to 535 g of protein per kg DM[1]) as well as pulses (211 g/kg DM on average) are protein rich crops. Cereals protein content is lower, with 53 to 89 g/kg DM, but up to 118 k/kg DM for brans and pure protein in the form of gluten. Vegetables and tubers only contain negligible protein quantities in fresh matter (around 10 g/kg) but comparable to cereals in dry matter (77 and 160 g/kg DM for tomatoes and onions; up to 63 g/kg DM for potatoes). Fruits are poor sources of proteins, even dried (max 29 g/kg DM for bananas). Most cereals lack lysine with secondary deficiencies in threonine and tryptophan (Gilbert, 2004). Breeding and selection did not significantly improve cereal protein status, except for quality protein maize (QPM), which is richer in lysine, tryptophan, and crude Proteins (Vasal, 2004). Among oil crops, soy is key because of its good balance in amino acids, in particular rich in lysine, and its low content in antinutrients. Since the beginning of the 1990s, new varieties of rapeseed have been selected to also present low contents in antinutrients (Speedy, 2004).

Herds also feed on other resources than crop feed: fodder of poaceae and legumes (fresh grass, hay or silage, containing between 80 and 190 g/kg DM) or fish and meat meals (with 620 and 730 g/kg DM). Poorer feeds may also be used,

[1] Content data are provided by FAO in (FAO, 2001) for some products. They are converted in dry matter (DM) equivalent using other sources. For the remaining products content information come from GLEAM data.

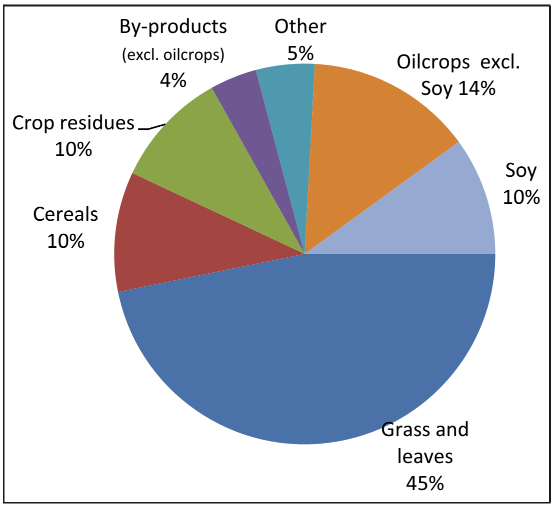

Fig. 1. Share of various feed sources in total protein intake for global livestock production.

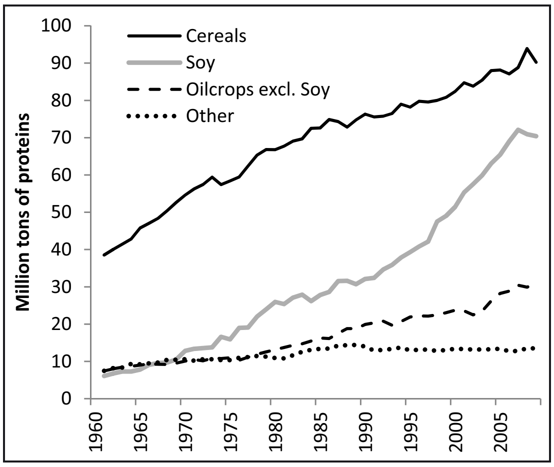

Fig. 2. Production of major arable feed sources (1961–2009) from FAOSTAT data in million tons of proteins. A category "other" is created to aggregate various sources of comparative lower importance (pulses, roots and tubers, animal meals. . .).

for example household wastes (35 g/kg DM on average) or leaves (22 g/kg DM on average), mostly in developing countries. Those feeds may be pivotal in arid regions during dry periods (Archimède *et al.*, 2011).

Getting a full description of livestock diet protein contents is difficult, especially for fodder, residues and grasses. Information available often combines expert estimates (Wirsenius *et al.*, 2010) and global model outputs (REF) both associated with large uncertainties. According to Sebillotte and Messéan (2003), in 2000 a rough 57%, 23% and 17% of total protein sources came from grass, cereals and oil crops, respectively. Another 3% of protein intake in total feed was attributed to other sources including animal meals. Estimations for year 2005 (P. Gerber, com. pers.) indicates that grass and leaves supply the greatest share of proteins for livestock production altogether (45%, see Fig. 1). This is because ruminants feed weight 72% of total feed intake and monogastrics do not consume roughages like grass. The second most important protein source is oil crops (24%) with soy accounting for 42% of this total, other feed types being relatively marginal as protein sources. Cereals compose about 10% of livestock diets in protein. Soy which is usually pointed out as having a dominant position among protein rich feed crops actually provides slightly less proteins than other oilcrops (a category that groups rapeseed, sunflower seeds, cotton seeds and secondary oilseeds for feed) and a similar share than cereals and crop residues. In biomass, animal fish and meat meals represent each approximately 1% of total feed proteins. Animal meals are forbidden for ruminant since 1990 in France and 1994 in Europe. Their use was totally abolished for all animal species at the end of 2000 all over Europe. However, fishmeal and animal by-products can be cited as one of the main source of quality proteins, together with oilseed (Gilbert, 2004). Compound industrial synthetic amino acids are sometimes inserted to balance feed ration and their use is known to have increased globally the last decades (Toride, 2004). However, their share in total diets is negligible. It is important to note that feed sources are substitutable: their combination may vary with regard to total nutritive composition or relative to prices variation. For example, when cereal prices are high, oil crops such as soy are used both as caloric and proteins sources. On the contrary, decreasing cereal prices tend to challenge the use of soy as a caloric source.

An increasing fraction of total feed is consumed by aquaculture, which now produces a volume of food equivalent to that of bovine meat. Aquaculture uses about 29 million tons of feed biomass, *i.e.* 2.6% of total feed use in FAOSTAT, but only 2.2% of vegetal products that directly use land[2] (Tacon *et al.*, 2011).

FAOSTAT reports lower quantities of proteins from crop feed than those given by GLEAM and reported in Figure 1. This is the case for oilcrops and maize, with 195 000 tons of crop feed reported by FAOSTAT *versus* 276 000 tons reported by GLEAM, *i.e.* a 41% gap. This gap increases to 44% if proteins used by aquaculture are included (30 million tons of feed). The hierarchy of the contribution of various protein-feed sources is also different between FAOSTAT and GLEAM: cereals-soy-other oilcrops and other oilcrops – soy-cereals respectively.

Although data on past consumption of forages are missing, FAOSTAT data enable to draw a picture of the past evolution of crop-feed proteins production and consumption. The production of crop-feed proteins has been continuously increasing since 1961. This is principally because of a rise in cereals and oilcrops production, the latter being driven by a sharp increase in soy production (Fig. 2). According to FAOSTAT, the most significant change since 1961 has been the replacement in livestock diets, of secondary cereal products (*i.e.*, brans, barley, oats, sorghum and millet) with soy (10% in 1961 and 35% in 2009, Fig. 3). Data also indicate a relative increase in the use of rapeseed products. Interestingly, the share of maize and wheat in total feed proteins has remained rather constant throughout the period (on average 16%

[2] There is no data available on the composition of the feed basket for aquaculture. This information is in biomass and not in terms of proteins. The average protein content calculated for poultry ration was used to estimate a quantity of proteins for aquaculture.

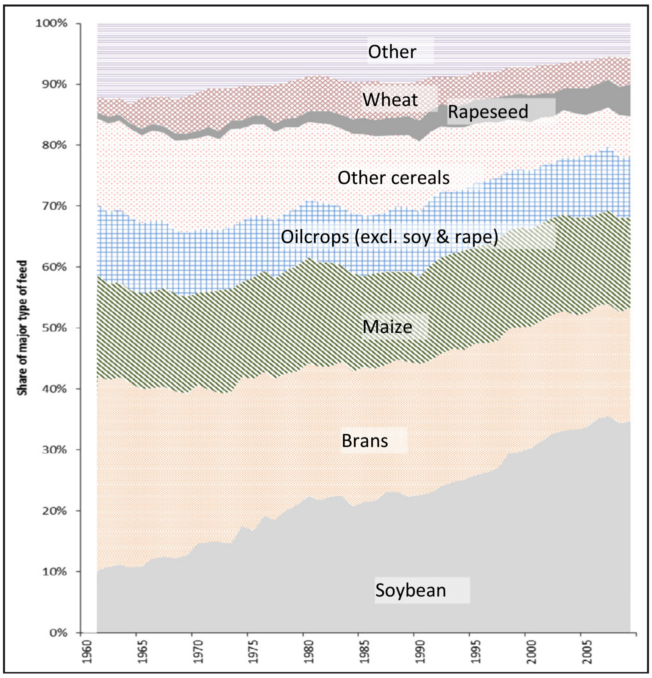

Fig. 3. Evolution of the crop-source feed basket for all livestock categories (including aquaculture) for the period 1961–2009 according to FAOSTAT data. Values expressed in percentage of total protein intake. The category "Other cereals" is composed by all cereals excluding maize and wheat.

and 5%, respectively). The share of concentrate feedstuff in livestock diets has globally increased, in particular in developing countries between 1980 and 2006 (De Haan *et al.*, 2010). Its composition has been diversifying since 1960 with the development and trade of various raw materials (Verstegen and Tamminga, 2001). Although informative, this global picture hides important heterogeneities. The composition of livestock diets is first and foremost dependent on production systems: maize-soy has certainly become dominant in intensive systems by replacing traditional protein crops and other cereals but, this is less true in extensive systems where diets include larger share of roughage and wastes (Steinfeld *et al.*, 2006). The composition of feed also varies regionally. For instance in Asia, livestock diets contain higher percentages of tuber and oilcrops as energy and protein sources respectively (FAO, 2006).

Characterizing flows of proteins from crop products to livestock is necessary to estimate conversion efficiency. An estimation of animal edible protein output[3] to crop feed protein intake indicates that this partial efficiency of total livestock production has remained rather stable in time (with value ranging from 0.35 to 0.4 between 1961 and 2009 and a slight decrease at the beginning of the period). Partial conversion efficiencies are relevant when estimating the impacts of an increase in edible animal protein demand by a growing population on plant proteins available for human consumption. However, this increase in efficiency may also correspond to an increase of the use of other sources of proteins in feed, notably grasses.

[3] These calculations rely on protein contents of edible animal proteins of 0.18 for meat, 0.119 for eggs and 0.033 for dairy products.

The primary input of livestock production is land (Garnett, 2009). Land-based efficiency allows adopting a more integrative view of the competition between feed and food. For arable lands, however, this issue is complicated by the presence of by-products, as detailed in the next section.

2.2 Cropland used for feed production

Livestock production is the first user of available agricultural land: it mobilizes large areas of pasture and crop land with pastures covering about 2.2 times more land than arable crops. The use of land for livestock production is pointed out as an impediment to food security because of the diversion of land to grow feed. As previously emphasized, livestock production systems are characterized by protein conversion efficiencies lower than 0.5; therefore consuming grain proteins directly is more efficient than eating grain fed animal proteins. Feeding livestock with inedible feed (by-products, grass, residues and wastes) may be less inefficient because humans cannot consume these products. If land is used to produce inedible feed, however, there may still be competition with human food, if crops could be grown instead. Competition between feed and food is therefore better framed in term of "land opportunity". In this section we calculate land virtually attributed to feed production and elaborate on the land-based competition between feed and food.

We calculate, for each crop category (cereal, oilcrops, pulses, roots and tuber), a total amount of land used for feed production at the world level. The main difficulty is the attribution of a given surface to either food or feed because most crops have both outlets. For instance, cereals grown on a given land area are harvested and processed into flour therefore producing significant amounts of bran by-products. One may imagine that even without bran production, cereals would have been grown for food use. In such a case, no land should be assigned to brans used as feed. On the other hand, one may also imagine that for the processor, the revenue from bran is important and may impact his/her decisions, so the farmers' decisions and the land area devoted to cereals. Under this assumption some land area should be attributed to the bran used as feed. Thus duality is also relevant for oil cakes. In fact, human-grade grains used to feed animals are in direct competition with human consumption. But, this is less straightforward for by-products, since only a part of the production is used as feed.

We propose two contrasting methodologies to account for by-products. In the first method, the totality of the commodity cropping area is attributed to feed or food according to its principal outlet, when accounting for 50% of the monetary value of the crop and above. In this case there is no overlap between food and feed areas: joint use of cropland is approximated to one single use.

In the second method, crop areas are split according to shares of the primary product used as processed products and by-products. We thus apply the percentage use of a primary product to land use.

For instance, if soybeans processing leads to 80% cake and 20% oil, and all cakes are fed to livestock, 80% of the land used to produce these soybeans is attributed to livestock use.

This is equivalent to a breakdown of land into two virtual surfaces, for feed and food. This approach amounts to considering that crops with different partitioning between food and feed can be used, allowing to choose any relevant partitioning criterion of land for feed and food. Brans, for instance, account for about 5% of total processed cereals. The first method attributes no land to brans and the second attributes 33 Mha (or 22% of total cereal feed area) to feed production.

Defining a production main outlet for the first methodology is not exactly straightforward for oilcrops. We use the literature to identify each oilcrops main outlet. In general, oil crop production is driven by oil demand for food (Sébillotte, 2001). The exception is soy, as its growth is primarily driven by feed demand (Wassenaar, 2008): for instance, 90% of the soy imported into the EU is directed to feeding pigs and poultry (Garnett, 2009). The production of soy cakes leverages competition with food (REF) (Chapagain and Hoekstra, 2004), therefore, soy cake cannot be fully considered a by-product: its production leverages competition with food (Garnett, 2009).

In the first methodology, an area is assigned to livestock feed if the quantity of primary product is used as feed as its main outlet (directly for cereals for instance or after processing for soy):

$$S_p = \left(F_p + Proc_p\right)/Y_p, \qquad \text{(1st method)}$$

where S_p is the area assigned to feed for a primary product p grown with an average global yield Y, F_p is the quantity of primary product used as feed, $Proc_p$ is the processed quantity for soy. Note that this formula implies neglecting the quantities of cake that are used for other industrial utilizations than feed (1.7% of the cake weight).

In the second method, for a primary product p with yield Y_p, with F_p the quantity used as feed, F_d the quantity of derived feed products (meals typically), the area S assigned to feed for this crop is

$$S = \left(F_p + F_d\right)/Y_p \qquad \text{(2nd method).}$$

The share of arable land dedicated to the production of feed was estimated to 33% of total cropland in 2003, (Paillard *et al.*, 2010). Depending on the methodology, we now estimate that 37% or 42% of total arable land was occupied by feed production in 2003 (35 or 39% for our most recent estimates in 2009). These numbers would be higher using GLEAM estimates. Those two data sources indeed differ in their estimates of "Other oilcrops". Using GLEAM number would increase areas attributed to feed of about 7% and 41%[4] for the first and second method respectively. We were not in position to calculate a competition ratio using GLEAM because we do not know if the missing quantities in FAOSTAT data should be added to feed uses, *i.e.*, to be deduced from other utilizations without changing production quantities and cropland area or to production, with a corresponding change into total cropland area. In the latter case, the competition in 2009 would decrease to 32% and rise to 47% whether the first or the second method is chosen. This illustrates the considerable uncertainty in available data as well as the roughness of our estimation procedures.

According to our estimations, and using FAOSTAT data, while feed production has continuously increased since 1961, feed surfaces remained almost constant (Fig. 4a). Interestingly, following an increase period between 1970 and 1983 with peaks at 46% and 51%, of total land; proportion of feed surfaces show a decreasing trend (Fig. 5a). From 1961 to 2009, the partial productivity of cropland has been multiplied by 2.7 at the global scale (Fig. 4b). Arable land used for cereal production has decreased in favor of oil crops and soy production. This recent trend explains the decoupling between total and cereal land. Other types of feed surfaces (forages, sugar crops, roots and tuber, vegetables) remained somewhat constant during the whole period. The decrease in cereal areas has only partially been compensated by oil crops surfaces (including soy).

The limitations of our calculations should be underlined. First, conversion coefficients (to cake and oil or to flour and brans) are variable in time and between countries: we assumed these were constant in time. Our computations rely on Commodity Balances FAOSTAT coefficients that consider country specific coefficients but have not been fully updated for several decades. This means that we may have underestimated technology improvement: for instance, it is certain that improved efficiency of mills reduced the quantity of brans from grain processing. Second, computing commodity balances at the global scale alleviates our task by hiding feed trade. However, it implies to work with rough global averages for yields or feed use proportion in domestic supply. Obviously, we are not able to take into account regional specificities. In particular, the trade of primary or transformed products would not be the same if regions were considered and transformation coefficients differed by region. Finally, there are other parts of primary products that are also by-products fed to livestock: notably broken or damaged grains or tubers. Similarly to oilcrops cakes, these should be considered in proportion of crop production (in the 2nd method). Depending on available statistics we either assimilate those products to feed products, in competition with food uses or ignore them.

Our methods are thus not fully satisfying. In the first method, by-products do not require land, although their monetary value influences allocated surfaces. The assumption of free by-products may be valid for brans because of the relatively minor quantities (about 5% of milled cereals) and low prices, but it is not true for oilcakes. Even when surface changes are predominantly driven by oil demand, cake value could still have some influence on farmer choices. In the second method, co-products are associated to a share of land even if it is a true by-product, that is, destroying it would not change the land-use by farmers, as it may be the case for bran.

Another improvement would be to assign areas to other uses, such as industrial and energy production uses. The land-use based indicator of the competition between food and feed used does not account for positive feedbacks livestock rearing has on land-based production through those other products. Draft power and manure for cultivation may indeed allow an

[4] These gaps are only orders of magnitude because they were obtained by applying the percentage of gap between feed quantities in FAO and GLEAM to areas, without taking into account differences of yields between crops.

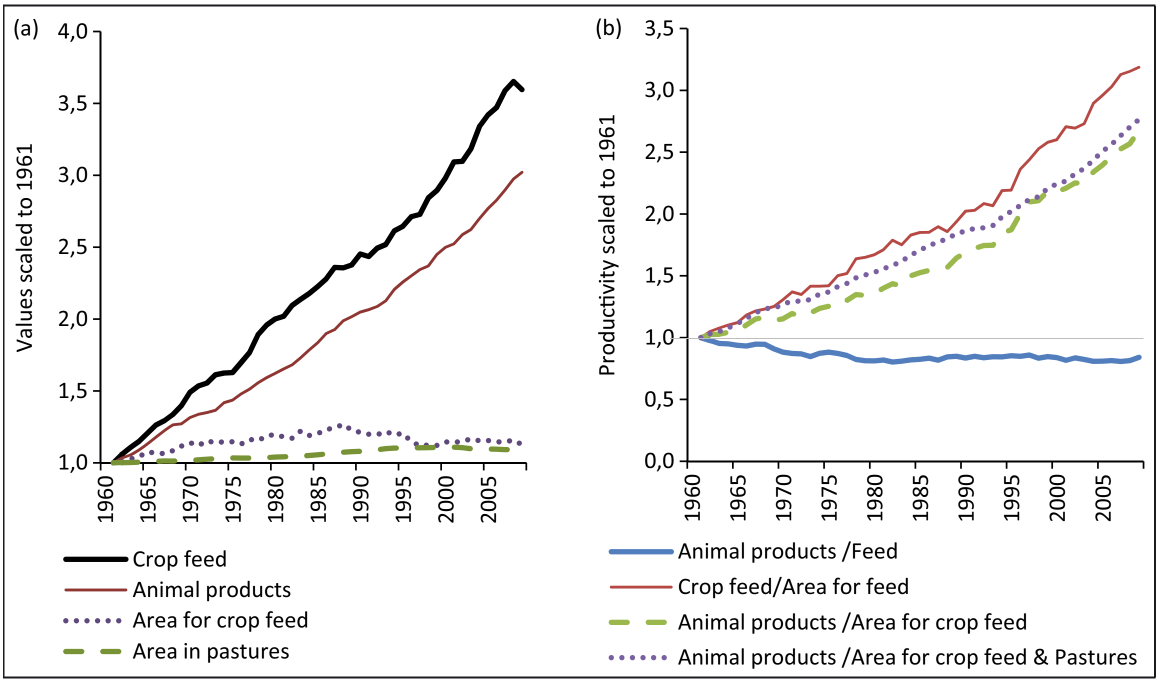

Fig. 4. Relative increase of livestock production to feed intake and land use. Values scaled to 1961. (a) Total animal production (red line), total crop feed (black line), area in pastures (dotted green) and crop feed surfaces (dotted purple), estimated by method 1. (b) Productivities in protein conversion efficiency (blue line), overall feed yield (red line) and land based efficiency: crop feed area (dotted green) and pastures area (dotted purple).

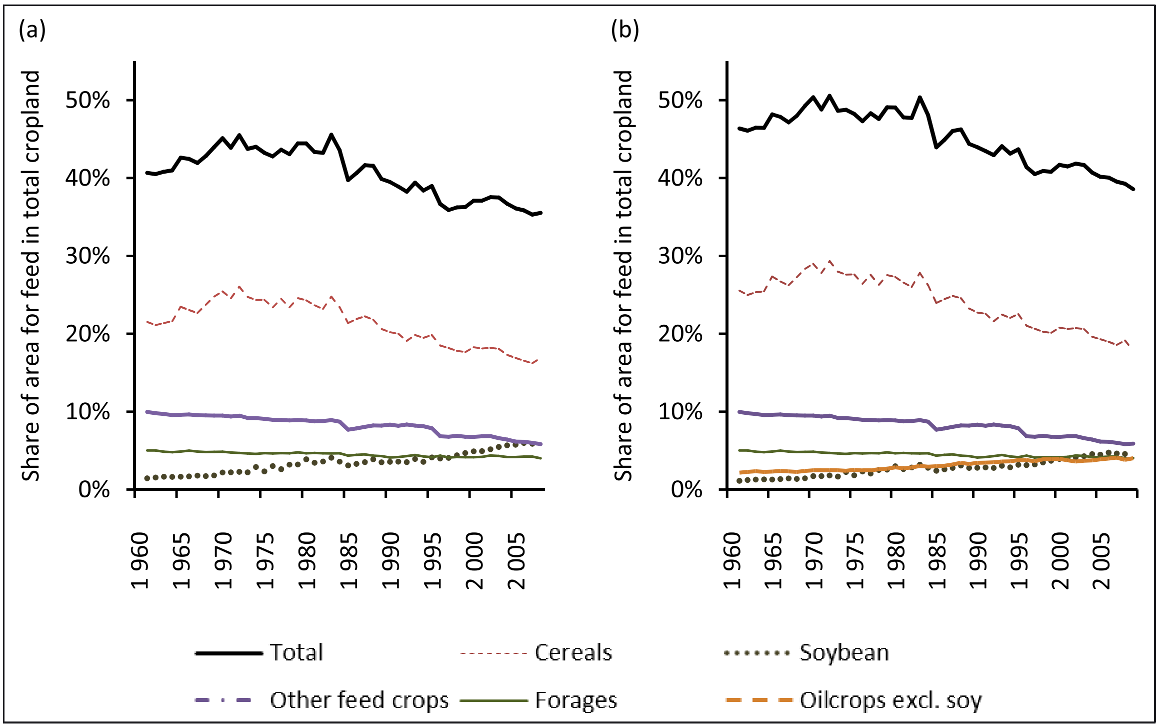

Fig. 5. Calculated virtual surfaces used for feed production according to two alternative methodologies (see Sect. 2.2). (a) Method 1: assuming that the principal use (outlet) of its production determines whether the whole surface is attributed to food (resp. feed) production. (b) Method 2: assuming that the percentage of crop production outlet (food *versus* feed) is equal to its surface allocation. Note that "Other feed crops" is a composite category (sugar crops, vegetables; see method section). Pulses and roots and tuber are not represented on this graph because of their relative minor importance. 100 Mha are added to the "Other feed crops" category between 1961 and 1984 for statistical reasons (see Data section).

increase of areas and yields. Although virtually complex, a first assessment could be achieved with information on yield changes and corresponding land use reduction for crop allowed by animal manure or draft power.

Feed or food outlets can change based on dietary modifications or products transformation. Currently oil crop cakes are not used for human consumption, but this could simply be due to high livestock demand. In case of a change in diets, it may be possible to envision food uses of cakes digestible fractions, or even the development of more digestible varieties. Taking these effects into account – including changes in trade – could allow refining the indicators of land-use competition.

Nonetheless, our indicators are interesting because they allow an assessment of land use for livestock *versus* food in a given location. They are not very useful, however, to take into account indirect land-use changes. The issue of direct *versus* indirect land-use change is an important topic of biofuel policies assessments (Searchinger, 2008). Similarly, with fixed demands, land use changes with less land dedicated to livestock production could lead to a corresponding increase in another region.

Building on the idea of an assessment that would take into account indirect land-use change; land-use competition could also be studied by comparing different land-uses enabling to meet the same total demand. If demand is exactly the same, on a detailed product-by-product basis, the possibilities for change are likely to be small, unless the agricultural system is inefficient. If demands are allowed to change through substitutions between equivalent products, while keeping similar diets (same amount of calories and proteins) and non-food demands, then a modelling of the land-use change could allow to draw another vision of land-use opportunities, *i.e.* by comparing the amount of land required by those different demands, as in (Stehfest *et al.*, 2009), or by assessing the suitability of land freed for human edible crop production. But, this requires to model the global agricultural sector, at the global scale, with more uncertainties than the direct land-use competition estimate we presented. Such an approach, however, allows to take into account indirect land-use change and the possibilities of substitutions among crops precisely. In temperate latitudes, for example, rapeseed is the crop that allows to produce the highest quantity of vegetable oil for human consumption per unit of land, still with a cake by-product amounting to 60% of crop biomass. Therefore, if rapeseed replaced other oil crops and even if no livestock production was needed, this amount of cake would be available. In equatorial climates, oil palm allows to produce vegetal oil with a very low kernel cake production. These examples show that changes in trade could change the land-use substitution opportunities. Substitutions in diets and use of new products for food, such as cake, would also change the possibilities of substitution between different land uses, while still fulfilling the same global demand.

2.3 Pastoral land use for livestock production

Grasslands have a critical role in the valorization of non-arable land for producing food. The FAO estimates to 1.4 billion ha surfaces of total high productivity pastures and 2 billion ha low productivity extensive pastures (FAO, 2006).

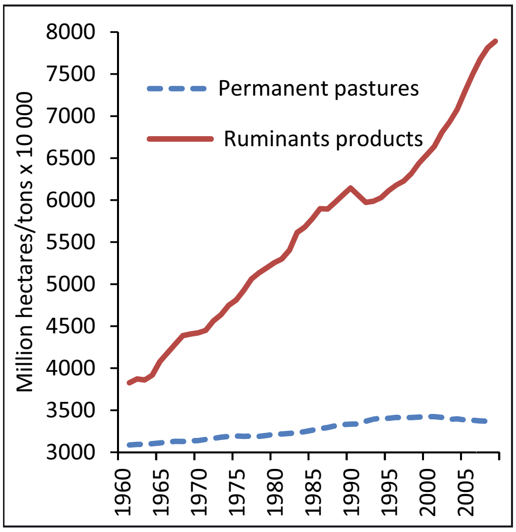

Fig. 6. Ruminant production (in 10 000 × tons of fresh matter) and permanent pastures (FAO estimates, in million hectares) increase. This figure is somewhat misleading since ruminant also consume other feed sources but shows that although the production of ruminant products have more than doubled during the study period, pastures and meadows surfaces have remained somewhat constant.

This means that almost 60% of all permanent pastures are areas that can be characterized as efficiently used for producing food with no direct competition with cropland for food production.

Pasture extent apparently remained quite constant (+9%) over the last four decades: an obvious decoupling with ruminant production (Fig. 6). The partial productivity of permanent pastures at the global scale has been multiplied by 2.9 (2.7 for cropland partial productivity).

But this global picture hides important regional differences. There are in fact three main types of observed trends. First, world regions (*i.e.*, China, Brazil, Middle East North Africa, and Former Soviet Union) where permanent pastures areas increased significantly between 1961 and 2009 but to a much smaller extent than ruminant production. In contrast, pasture areas decreased in other regions (*i.e.*, India: −26%, OECD: −17%, Canada and the U.S.: −10%, Asia excluding India and China: −14% and UE27: −14%). Finally, pasture areas remained rather constant in Latin America (excl. Brazil) and Sub-Saharan Africa.

Pasture based ruminant systems are associated with deforestation in Latin America (note that this relation is less clear in other tropical forests in central Africa or tropical Asia). In Brazil, 70–80% of total deforestation is estimated to have resulted from the development of extensive livestock systems (Tourrand *et al.*, 2004). Productivity increase on existing pastures could allow increase in livestock production without further expansion into natural habitats (Strassburg, 2012). It is important to keep in mind though, that deforestation is also an indirect effect response to extension of soy production on pastures (Bowman *et al.*, 2012).

Estimations of pasture production and productivity, instrumental in regard to the importance of pasture-based feed in total ruminant feed mix (*i.e.*, an estimated 63% according to GLEAM data), are associated with high levels of uncertainties.

Dossier

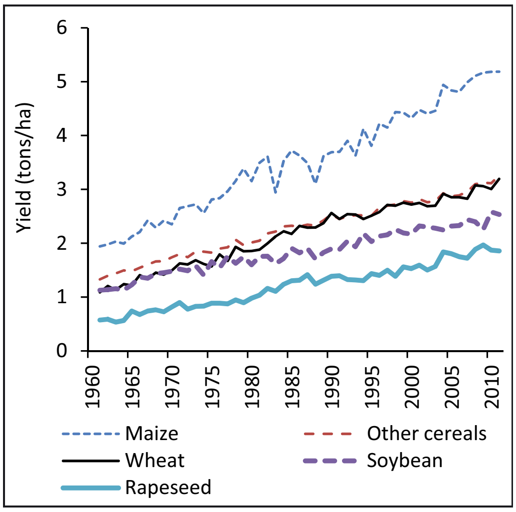

Fig. 7. Yield of major crop feeds. Category "Other cereals" groups all cereals excluding maize and wheat.

Estimates of permanent pastures show a high range of values in area and production levels (Erb *et al.*, 2009). Also, temporary pastures are under-reported in statistics since FAOSTAT data do not document temporary pastures consistently. Grass productivity and availability are estimated by satellite measurements or land surface models. However, pasture use intensity (quantity consumed by ruminants on a given surface) is critical for land use by global models (Bouwman *et al.*, 2005; Wirsenius *et al.*, 2010), but not directly documented. This is important because estimating potential for intensification of ruminant production on existing surfaces implies quantifying grass intake and pasture quality, in particular protein contents (Searchinger, 2013).

2.4 Drivers of evolutions of global feed protein production

Use of land for feed crops has decreased since the 1980s and, overall, pastures did not increase as much as livestock production. Several factors have to be examined in the attempt to explain this overall picture: increase in crop and pastures productivity, feed baskets and conversion efficiency changes. Livestock production has been increasingly recognized as a productive economic activity and thus efforts were made to cut down costs of production (Millen and Arrigoni, 2013). The data does not allow to analyze who has benefited from the decrease of area used for feed production and the impact it has had on livestock products quality.

It is apparent that productivity increase of arable land explains a large part of the large continuous increase in total livestock production (Fig. 4b) without major increase of land use for feed production. Feed production benefited from a quick increase in major feed crops yields (Fig. 7): yield of rapeseed was multiplied by 3.1; maize and wheat by 2.5; soy by 1.4 and other cereals by 1.9 on average. This largely explains the rise in productivity but as previously explained (Sect. 2.3), lack of accurate data prevent the same kind of analysis for pastures. Genetic improvement and improved agronomic practices have played a major role in these changes. In the future, is there still room for major yield improvements, at least in some regions? What could be the impacts of climate variability on feed crop productivity and quality? Another significant part of the evolution corresponds to a notable shift of livestock systems from ruminants to monogastrics and toward more intensive production systems (De Haan *et al.*, 2010; Le Cotty and Dorin, 2012). This leads to an increased use of concentrate feed in place of grass and roughages accompanied by an increase of livestock efficiency (in calories, proteins or land), since the conversion efficiency of these systems is higher than that of ruminants and extensive systems (Bouwman *et al.*, 2005; Wirsenius *et al.*, 2010). This process also explains the decrease of partial crop-source feed efficiency (Fig. 4b). Efficiency increase is also achieved by increasing animal size, age at slaughter, harvest rate from carcass to live weight, or decrease use for draft energy (Bouwman *et al.*, 2005). Estimating a share of total efficiency increase corresponding to other factors, for instance from changes in animal health or from metabolic breakthrough is very difficult because of lack of information. In the future, will the changing livestock farming practices continue to lead to decrease land use?

Global demand for livestock products is projected to increase in response to both population and affluence increases. It is thus argued that demand for feed grain should increase in coming decades (De Haan *et al.*, 2010). Overall evolution of land-use will depend on the evolution of livestock systems, as the global livestock diets exhibits strong differences between monogastrics/ruminants, intensive/extensive and traditional/industrial systems. The intensification and substitutions (from meat to milk, extensive to intensive, ruminant to monogastric) will have a very important impact on land-use for feed. Projections converge to an overall decrease in pastureland due to the expansion of cropland (Havlik *et al.*, 2011; Herrero *et al.*, 2008; Stehfest *et al.*, 2009; Steinfeld *et al.*, 2006; Wirsenius *et al.*, 2010). Amazonian Brazil has been an exception since grassland expansion occurred to the detriment of forest. Commitments for stopping deforestation have been made, but it is uncertain how effective they will be (Barretto *et al.*, 2013; Bowman *et al.*, 2012; Strassburg, 2012).

As we have shown, by-products are important constituent of livestock diets. Trends in land use for feed production will also depend on by-products availability. In fact, as population and food production grows, so do industrial by-products (with variation according to development, policies and transformation location). But, an improved use of by-products as human food could reduce their availability for feeding livestock.

Creation of new crops varieties capable of competing with imported soy is an active field. Alternative crops will have to be grown productively and economically in regions where soybeans are not produced, *i.e.* for cooler northern regions currently dominated by cereal production and/or in arid and saline regions of the globe. In Western Europe, it is argued that forage soy may be grown in locations where grain soybeans cannot be efficiently produced (Gilbert, 2004). It may be possible that economic incentives (and possibly adaptation) could provide some potential for soybean production in these regions (Gilbert, 2004).

Many countries depend on soybean and cakes imports because soybeans only grow productively in certain regions of the world. Increasing concerns are emerging from developing countries on the cost of importing soybeans for animal feed. Efforts are being put into the utilization of diverse local sources of feed ingredients, in particular as protein sources. Cassava for example is cited as a possible valuable source of feed in Southeast Asia (Wanapat, 2004). This should not hide the high variability and low protein contents (at least compared to stable high levels of cakes available at present on global markets) of other sources. Technological and research investments will certainly be necessary for characterizing, and improving local self-sufficiency in plant proteins for feed (Archimède *et al.*, 2011). In India for instance, such experimental programs (associating research and inventory of local products, extension and NTIC technologies) involving small farmers are designed (Garg, 2012). Food safety considerations may hinder these approaches because of restrictions on some by-product materials (but simple treatments may also be developed).

Future proteins for livestock could also come from non-crop sources. Existing sources possibly reached some saturation level. Meals from fish have not increased over the last 20 or so years and specialists think that this trend is unlikely to reverse because of present over-fishing (Speedy, 2004; Tacon *et al.*, 2011). Synthetic amino-acids have diversified thank to new production methods that also decreased their cost. They could help using various types of feed, even when unbalanced in proteins. It was calculated for instance that a little quantity added in a ration enables to replace soy with cereals: if the yield of cereals is higher than soy, crop areas can therefore be saved (Toride, 2004). But a dramatic increase of their use, conditioned by cost-effectiveness, would be necessary for a significant effect.

Some active firms are now foreseeing a "Protein Crunch" to promote path-breaking solutions. Various sources of proteins could be incorporated in future livestock rations: industrially produced insects or food wastes[5]; algae, for instance residues of biofuel production (Bryant *et al.*, 2012). But legal considerations and a necessary change in scale of production constitute potential bottlenecks (Veldkamp *et al.*, 2012).

3 Conclusion

The livestock revolution can be seen as a chance for developing countries where many people have low-protein diets and suffer from under-nourishment (Ehui *et al.*, 1998). However this also carries a possibility that the high growth in animal demand could lead to shortages of plant food for basic human needs. This competition is often presented on the basis of the crop diverted from direct human consumption: it was, for instance, estimated that feed could sustain the energy demand for the entire projected population growth of over 3 billion people (Nellemann *et al.*, 2009). We propose new elements to document the debate about the food-feed competition, from the standpoint of protein consumption and land based competition.

Protein-rich commodities, oil seeds and oilseed cakes, are not the first suppliers of proteins for livestock, grass is, to a much greater extent. Cereals and crop residues are also significant providers of proteins. Yet in the last decades, the main change for global aggregated livestock feed has been the raising of oilcrops to the detriment of secondary cereals and minor feedstuffs.

In this paper we have used data on global livestock diets to estimate areas used for growing feed on a global scale, and its share in total cropland as an indicator of food-feed competition. Our estimations suggest that, although animal and feed production have continuously increased, the area for feed and the competition for land between feed and food uses have decreased over the last two decades. Areas devoted to feed production decreased from about 50% of the total cropland area in the 1980s to 37% nowadays, a trend partially attributable to both crop-yield increase and to the decrease in the share of cereals in livestock diets to the benefit of oilseed by-products. We showed however that estimating the share of total arable land used for feed is not straightforward because of the significant role played by by-products and high levels of uncertainty on data. We proposed two contrasting methods to estimate the area for feed, differentiated by the area associated with by-products used as feed. The two methods conclude a similar evolution of the area for feed and quite similar levels of competition in 2009, 35% *versus* 39%. However, different estimates of feed composition, with a high uncertainty about the consumption of oilseed cakes in particular, lead to a greater range of values: either 32% or 47% according to the estimation method. The high uncertainty on pasture areas and grass consumption also suggests that one should be very careful about the calculated partial productivity increase of pastures.

Our indicators are of interest, because they allow us to assess land use for livestock *versus* food production. However, they do not enable the assessment of how competition changes with indirect land-use changes. A modeling framework could allow estimating the food-feed competition and global land use at fixed demand and to take into account substitution among crops. The substitutions between oilcrops are elements of possible future evolutions of protein supply for livestock that also include changes in products, system shares, substitution between grass and concentrates, crop-yield change, and, to a lesser extent, use of non-crop protein sources.

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[5] See http://www-pub.iaea.org/mtcd/meetings/PDFplus/2010/38586/Presentations/AMRQC12_0069.pdf.

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