INTERNATIONAL CONFERENCE OF AGRICULTURAL ECONOMISTS
ICAE
29th | Milan Italy 2015
UNIVERSITÀ DEGLI STUDI DI MILANO AUGUST 8 - 14
AGRICULTURE IN AN INTERCONNECTED WORLD

Increase of legume production as an alternative protein source for animal feed in a livestock-intensive region

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Abstract

Protein is of vital importance for the nutrition of animals and humans. A growing world population is dependent on the efficient *supply of proteins. It is also dependent on* sustainable *production of proteins since environmental impacts associated with animal-based protein provision are widely perceived as surpassing ecological boundaries in the long run. Connecting this perception with consumer demand for regional products the study computes regional animal demand and feed crop supply of crude protein in the state of North Rhine-Westphalia. The results show that self-sufficiency of crude protein for livestock farming cannot be reached by increasing high-protein legume cultivation alone: either a third of pig- or cattle-livestock would have to be reduced. Alternatively, plant-based sources like sunflower proteins could serve as substitutes – these, however, do need further research in order to reach comparable functionality and market potential as soy products.*

Keywords: crude protein, legumes, self-efficiency, sunflower

JEL codes: D5, Q11, Q17

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1 Introduction

The production of meat in modern animal management systems relies to a large extent on high-protein feedstock. While the diet of animals for meat production varies significantly due to physical and digestive differences of cattle, pigs and poultry, all share as a main ingredient of their nutrition crops containing protein. Although grain, corn and grass (land) consist of up to 20 % protein, oilseeds like soya, rapeseed or sunflower play a major role in protein supply: These plants (especially their byproducts from oil production) contain up to 50 % protein (BOHNENKEMPER et al. 2005). Given the high oil content and biological value of soybean due to its advantageous amino acid profile, soybean is the Top 3 agricultural trading product, directly followed by soybean meal. In 2013/2014, the main producing countries USA, Brazil, Argentina and Paraguay planted soybeans on 85.7 Mio ha (Toepfer 2014), after having exported soybeans for 41 billion US$ in 2011 (FAO 2011). 80 % of the globally produced soybeans are of genetically modified origin (ISAAA 2013). In the European Union this is a controversial issue: It is expected that in a few years unmodified soybeans will no longer be available. Therefore, strategies have been developed to enhance the cultivation of protein crops in Europe, reducing thus reliance on imports from North and South America. To date, however, the main producers in Italy, France, Austria, Romania and Hungary account for only 3 % of Europe's total soybean import (TransGEN 2014).
Selecting a livestock-intensive region as a case study, this paper researches the demand for proteins in animal keeping and whether self-sufficiency of protein supply can be reached. It will be shown which crops are grown to date and which implications a shift towards more cultivation of protein crops might bring in terms of direct land-use change. In addition to that, it will be discussed whether direct protein supply for human consumption, namely by proteins from vegan sources, are a feasible solution to the so-called "protein deficit" (Fischler 2001).

2 Data and Methodology

In order to calculate the total crude protein requirement for animal keeping in North Rhine-Westphalia (NRW), statistical data of the agricultural census 2010 and the agricultural structure survey 2013 were used. While the agricultural census 2010 was an exhaustive survey with 325,900 agricultural and forestry enterprises, the agricultural structure survey comprised only a sample of 80,000 enterprises (destatis 2014b, 2013). Both surveys collected data on the 1st of March, the survey parameters were identical and the results are thus comparable. Tab. 1 gives an overview of

the livestock for 2010 and 2013 in NRW. One has to consider that in the case of young cattle rearing and bull fattening the figures of male and female calves were taken as a calculation basis.

Tab. 1: Livestock in NRW, agricultural census 2010 and agricultural structure survey 2013

Report date: 1st of March	Agricultural census 2010	Agricultural structure survey 2013	relative change
Piglets	1,966,561	2,115,417	+7.6%
Breeding sows	502,438	477,600	-4.9%
Other pigs	4,200,885	4,637,264	+10.4%
Dairy cows	392,466	407,514	+3.8%
Suckle cow husbandry[1]	64,939	54,649	-15.8%
Young cattle rearing	198,306	196,714	-0.8%
Bull fattening	282,275	280,751	-0.5%
Young hens	2,103,516	2,740,151	+30.3%
Laying hens	3,418,408	3,598,316	+5.3%
Fattening chickens	4,483,440	5,185,876	+15.7%
Turkeys	1,557,910	1,536,897	-1.3%
Animals in total	**19,171,144**	**21,231,149**	**+10.7%**

data: (destatis 2013, 2014c)

The data show an increase of the livestock by more than 10 % mainly due to increases in young hen and fattening chicken population.

The calculations for crude protein requirements for feeding the animals are based on the findings of the DLG, volume 199. These data are also used in the German legislation for nutrient and fertilizer management. The feed expenses as well as the amount of crude protein contained in the feed are thus calculated and presented in Tab. 2 to Tab. 4 according to Bohnenkemper et al..

[1] For the production methods suckle cow husbandry, young cattle rearing and bull fattening the livestock figures are allocated to the respective procedures.

Tab. 2: Crude protein requirements for cows, young cattle and pigs

Piglet rearing feed, standard, 22 piglets per sow and year				
Standard feed sows, 1.150 kg per sow and year				
Standard feed pig fattening				
		Feed uptake (kg/year)[2]		**Crude protein in feed (g/kg)**
Dairy cows 8,000 kg ECM		*grassland 50 %*	*arable fodder 50 %*	
	Pasture grass	1,600	1,000	190
	Grass silage	2,200	1,300	160
	Corn silage	700	2,200	80
	Straw	200	200	40
	Post extraction soya meal	100	300	440
	Wheat	200	200	121
	Dairy concentrate (18/3)	1,700	1,500	180
	Mineral feed	15	25	0
Suckle cow husbandry		*500 kg liveweigt 50 %*	*700 kg liveweight 50 %*	
	Pasture grass	2,000	2,300	190
	Grass silage	600	1,200	160
	Straw	300	600	40
	Hay	0	200	110
	Hay (nature preservation)	800	0	80
	Dairy concentrate (16/3)	100	100	160
	Mineral feed	100	100	0
Young cattle rearing		*grassland 50 %*	*stable 50 %*	
	Pasture grass	1,500	0	190
	Grass silage	1,700	2,500	160
	Corn silage	1,500	2,000	80
	Straw	200	300	40
	Hay	100	100	110
	Whole Milk	40	40	34
	Milk substitute	40	40	220
	Calf concentrate	150	150	180
	Dairy concentrate (18/3)	300	400	180
	Mineral feed	30	30	0

data: own calculations according to BOHNENKEMPER et al. 2005

[2] Concerning dairy cows, 50 % of feed was allocated to grassland and 50 % to arable fodder. For suckle cow husbandry, 50 % of the animals were allocated to extensive (50 kg liveweight) and intensive (700 kg liveweight) keeping each. For young cattle rearing, 50 % each for grassland and livestock housing were calculated, while for bull fattening 40 % were considered with 580 kg growth and 60 % with 655 kg growth based on breed relations, see destatis (2014a).

Tab. 3: Crude protein requirements bull fattening

Bull fattening		*580 kg weight gain 40%*	*655 kg weight gain 60%*	*Crude protein in feed (g/kg)*
	Corn silage	2,200	2,200	80
	Hay	100	100	110
	Whole milk	40	80	34
	Milk substitute	40	40	220
	Calf concentrate	150	150	180
	Post extraction soya meal	0	550	440
	Grain	0	550	121
	Cattle fattening concentrate (22/3)	9	0	220
	Mineral feed	0	40	0

data: own calculations according to BOHNENKEMPER et al. 2005

Tab. 4: Crude protein requirements poultry

Turkey, cocks		**Feed uptake (kg/week | phase)**	**Crude protein in feed (g/kg)**
	Week		
	1st	0.15	285
	2nd	0.32	285
	3rd	0.54	265
	4th	0.82	265
	5th	1.08	265
	6th	1.41	230
	7th	1.73	230
	8th	2.03	230
	9th	2.21	230
	10th	2.46	210
	11th	2.69	210
	12th	2.90	210
	13th	3.04	210
	14th	3.21	180
	15th	3.40	180
	16th	3.60	180
	17th	3.69	180
	18th	3.89	160
	19th	4.09	160
	20th	4.30	160
	21st	4.50	160
Young hens	*Fattening phase*		
	Starter up to 3rd week	0.3	210
	Rearing 4th to 8th week	1.5	185
	Rearing 9th to 16th week	4.0	145
	Final 17th to 19th week	1.1	175
Fattening chickens	*Fattening phase*		
	Starter	0.3	230
	Rearing	2.8	220
	Final	1.1	210
Laying hens	Standard feed	40.0	175

Data: BELLOF 2014, BOHNENKEMPER et al. 2005

To determine the crude protein quantity supplied by the crops in North Rhine-Westphalia, the yield data of the agricultural census 2010 were examined. Tab. 5 shows the yields per hectare, the average crude protein contents and the proportion of the harvest used for feeding according to additional statistical data (BMEL 2013a, 2013b). Together with the area utilized for cultivation for the main crops, the total crude protein quantity supplied for the livestock in the state was calculated.

Tab. 5: Yield per hectare, crude protein content and utilization for feed[3], agricultural census 2010

	yield 2010 (dt/ha)	crude protein (g/kg)	utilized for feed (%)
Wheat	77.8	121	50%
Barley	66.4	109	70%
Silage corn	427.9	80	65%
Grain maize and CCM	94.6	90.5	65%
Rapeseed	40.1	227	100%
Triticale	53.8	111	70%
Sugar beets	689.5	n.a.	n.a.
Field grass / cultivation of grass on farmland	80.0	190	100%
Potatoes	473.6	n.a.	n.a.
Rye and meslin	57.6	90	54%
Oats	40.4	106	70%
Grains for complete plant harvest	295.2	100	100%
Legumes for complete plant harvest	71.5	200	100%
Field beans	35.7	262	100%
Peas	36.2	221	100%
Sweet lupine	23.6	293	100%
Soya beans	n.a	300	100%
Grassland and pasture	64.4	190	100%

Data: destatis 2013, BOHNENKEMPER et al. 2005, BMEL 2013a, BMEL 2013b

3 Results

Based on the livestock of the agricultural census 2010, a total requirement for the keeping of pigs, cattle and poultry of 1.5 Mio. t crude protein has been calculated, see Tab. 6 for details. These figure results primarily in pig fattening (one third of the total quantity) and keeping of dairy cows (27 % of crude protein requirement).

[3] These figures do not include crude protein supplied through byproducts or other fractions (meals of bread, dried stillage etc.) which can sum up to a 20 %-share of the livestockfeed industry DVT (2013). The contents of crude protein in these materials cannot be estimated with sufficient precision.

Tab. 6: Crude protein requirements for livestock in NRW based on agricultural census 2010 data

Agricultural census 2010	**Animals**	**Feed requirement per animal (kg dry matter)**	**Crude protein in feed (g/kg ration)**	**rotations per year**	**Crude protein per year (kg)**
Piglets	1,966,561	35	185	6.5	82,767,636
Breeding sows	502,438	1,150	170	1	98,226,629
Other pigs	4,200,885	259	175	2.7	514,093,804
Dairy cows	392,466	6,720	156	1	412,560,259
Suckle cow husbandry[4]	64,939	4,200	150	1	40,879,101
Young cattle rearing	198,306	5,560	133	1	146,679,016
Bull fattening	282,275	3,242	127	1	115,986,233
Young hens	2,103,516	6.9	161	2.2	5,259,247
Laying hens	3,418,408	40.0	175	1	23,928,856
Fattening chickens	4,483,440	4.2	218	6.7	27,441,098
Turkey	1,557,910	52.1	192	2.2	34,252,256
Animals in total	19,171,144			**Crude protein requirement**	**1,502,074,135**

Data: own calculations according to destatis 2013 and BOHNENKEMPER et al. 2005

The livestock figures based on the agricultural structure survey of 2013 show an increase of 10 %, since primarily the poultry livestock grew, the crude protein requirement rose only by 4.6 %, see Tab. 7.

Tab. 7: Crude protein requirements for livestock in NRW based on agricultural structure survey 2013 data

Agricultural structure survey 2013	**Animals**	**Feed requirement per animal (kg dry matter)**	**Crude protein in feed (g/kg ration)**	**rotations per year**	**Crude protein per year (kg)**
Piglets	2,115,417	35	185	6.5	89,032,613
Breeding sows	477,600	1,150	170	1	93,370,800
Other pigs	4,637,264	259	175	2.7	567,496,775
Dairy cows	407,514	6,720	156	1	428,378,717
Suckle cow husbandry[5]	54,649	4,200	150	1	34,401,546
Young cattle rearing	196,714	5,560	133	1	145,501,477
Bull fattening	280,751	3,242	127	1	115,360,024
Young hens	2,740,151	6.9	161	2.2	6,850,973
Laying hens	3,598,316	40.0	175	1	25,188,212
Fattening chickens	5,185,876	4.2	218	6.7	31,740,390
Turkey	1,536,897	52.1	192	2.2	33,790,264
Animals in total	21,231,149			**Crude protein requirement**	**1,571,111,791**

Data: own calculations according to destatis 2014c and BOHNENKEMPER et al. 2005

4 & 5 For the production methods suckle cow husbandry, young cattle rearing and bull's mast the livestock figures are allocated to the respective procedures.

By means of the scenario technique an expansion of the legume cultivation and its consequence of the crude protein supply for North Rhine-Westphalia were researched. In addition to a "baseline" scenario that uses the data of the agricultural census 2010 (AC 2010) six other scenarios were defined. The scenario "demand" assumes the livestock of the agricultural structure survey of 2013 (ASS 2013). Increased yields for the legumes with cultivation areas of 2010 are assumed in the scenario "yields", the yield assumptions are concluded from current research (Alpmann et al. 2014) and expected breeding progress. The scenarios „legumes 5/10/20%" expect an increase to 5/10/20% legume cultivation area related to the main crops of the state (the main crops in Tab. 5 account for 95 % of the arable acreage). The portions of the various legumes were specified, as Tab. 8 shows, in relation to their current portions and in view on possible future developments. The area needed for the legumes in these scenarios reduces proportionally the cultivation areas currently used for crops. In contrast to this, the scenario "legumes 10 % CP-opt." reduces cultivation of those crops most which contribute least to crude protein generation. The crops with lowest crude protein contents are reduced or even their cultivation abandoned until 10 % of the arable acreage could be allocated to legume farming. The crops with lowest crude protein content are oats, rye, triticale and barley. Tab. 8 gives an overview of the defined scenarios with differences highlighted.

Tab. 8: Scenario overview

		Scenario						
		baseline	**demand**	**yield**	**legumes 5 %**	**legumes 10 %**	**legumes 10 %- CP-opt.**	**legumes 20 %**
Livestock		AC 2010	**ASS 2013**	AC 2010	AC 2010	AC 2010	AC 2010	AC 2010
Cultivation area	**Legumes for complete plant harvest**	AC 2010	AC 2010	AC 2010 **85 dt/ha**	**2 %** 85 dt/ha	**3 %** 85 dt/ha	3 % 85 dt/ha	**6 %** 85 dt/ha
	Field beans	AC 2010	AC 2010	AC 2010 **50 dt/ha**	**1.5 %** 50 dt/ha	**3.5 %** 50 dt/ha	3.5 % 50 dt/ha	**5 %** 50 dt/ha
Yield	**Peas**	AC 2010	AC 2010	AC 2010 **45 dt/ha**	**1.5 %** 45 dt/ha	**3.5 %** 45 dt/ha	3.5 % 45 dt/ha	**5 %** 45 dt/ha
	Sweet lupine	AC 2010	AC 2010	AC 2010 **30 dt/ha**	AC 2010 30 dt/ha	AC 2010 30 dt/ha	AC 2010 30 dt/ha	**1 %** 30 dt/ha
	Soya beans	AC 2010	AC 2010	AC 2010 **35 dt/ha**	0 % 35 dt/ha	0 % 35 dt/ha	0 % 35 dt/ha	**3 %** 35 dt/ha
Remarks			Increased crude protein requirement	Yield increase assumed	Cultivation areas proportionally adjusted	Cultivation areas proportionally adjusted	**Cultivation areas adjusted according to crude protein**	Cultivation areas proportionally adjusted

Data: own table

In the baseline scenario, the legume area has a small share of only 0.7 % of the cultivation area. Wheat dominates with 28.5 %, followed by barley (17 %), silage corn (15.9 %) and grain maize/CCM (9.8 %). These three crops already have a combined share of more than 70 % of the arable acreage of North Rhine-Westphalia.

With the scenarios demand and yield the cultivation area was not changed, the changes in livestock from 2010 to 2013 and respectively the higher legume yields were considered. Increased livestock leads to a 4.6 % increase in crude protein, resulting in a total demand of 1.57 Mio. t. Higher yields for legumes do not bring significant change due to the smaller cultivation areas: crude protein supply gains 0.2 % from 1.255 Mio. t and results in a total crude protein supply of 1.256 Mio. t.

Looking at the different legume scenarios, a cultivation of legumes on 5 % of the land would reduce the cultivation area of wheat from 28.5 % to 27.3 %, Barley would be down to 16.3 %, and silage corn would only demand 15.2 % of the state's arable acreage. As described above, the decrease is not equally distributed on all crops but according to their original share. Field beans and peas would be grown on 1,5 % of the land each (resulting in 31,000 ha cultivation area for both), legumes for complete plant harvest are allocated another 2 % which corresponds to 21,000 ha (see Fig. 1). The total amount of crude protein produced would rise by 2.1 % to 1.28 Mio. t compared to the baseline scenario.

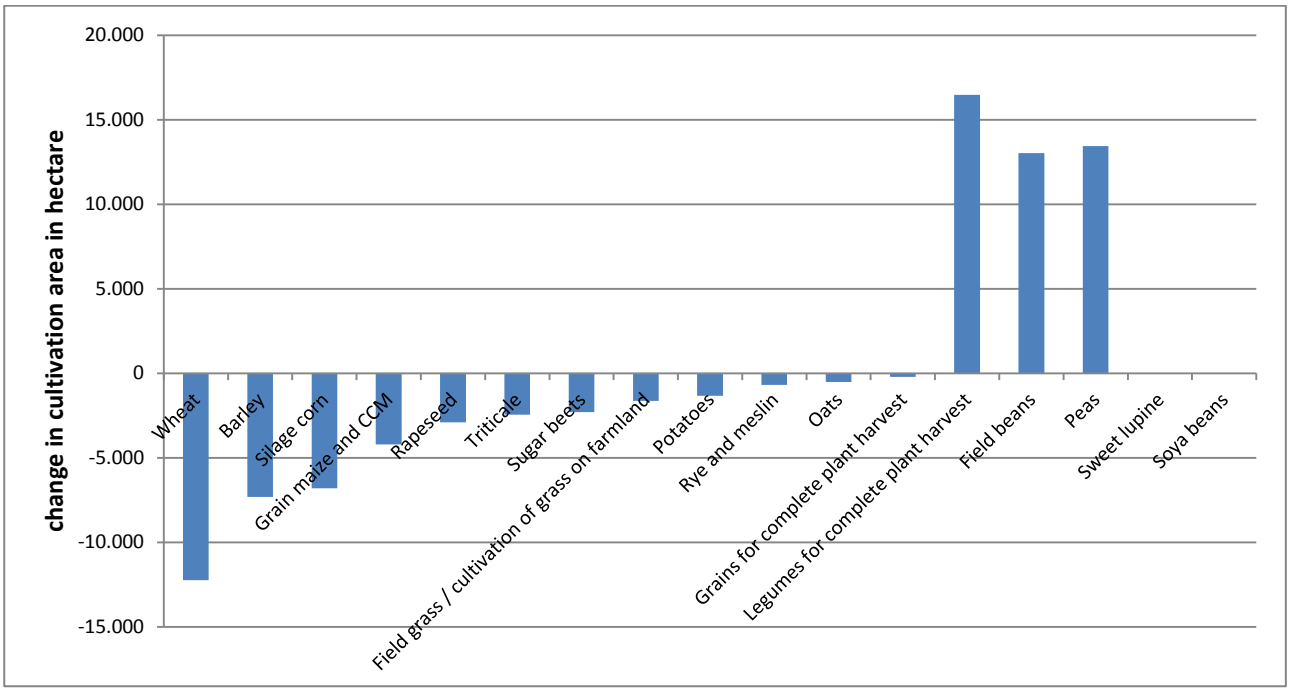

Fig. 1: Scenario legumes 5%, change in cultivation area in hectare

In the scenario legumes 10 % the share of field beans and peas in the cultivation area is raised to 3.5 % each, legumes for complete plant harvest are allocated another 3 %. This results in a total land requirement of 105,000 ha, the share of wheat, barley and corn is reduced below 65 %, see Fig. 2. Comparing to the baseline scenario, the crude protein production is increased by 4 % to 1.3 Mio. t.

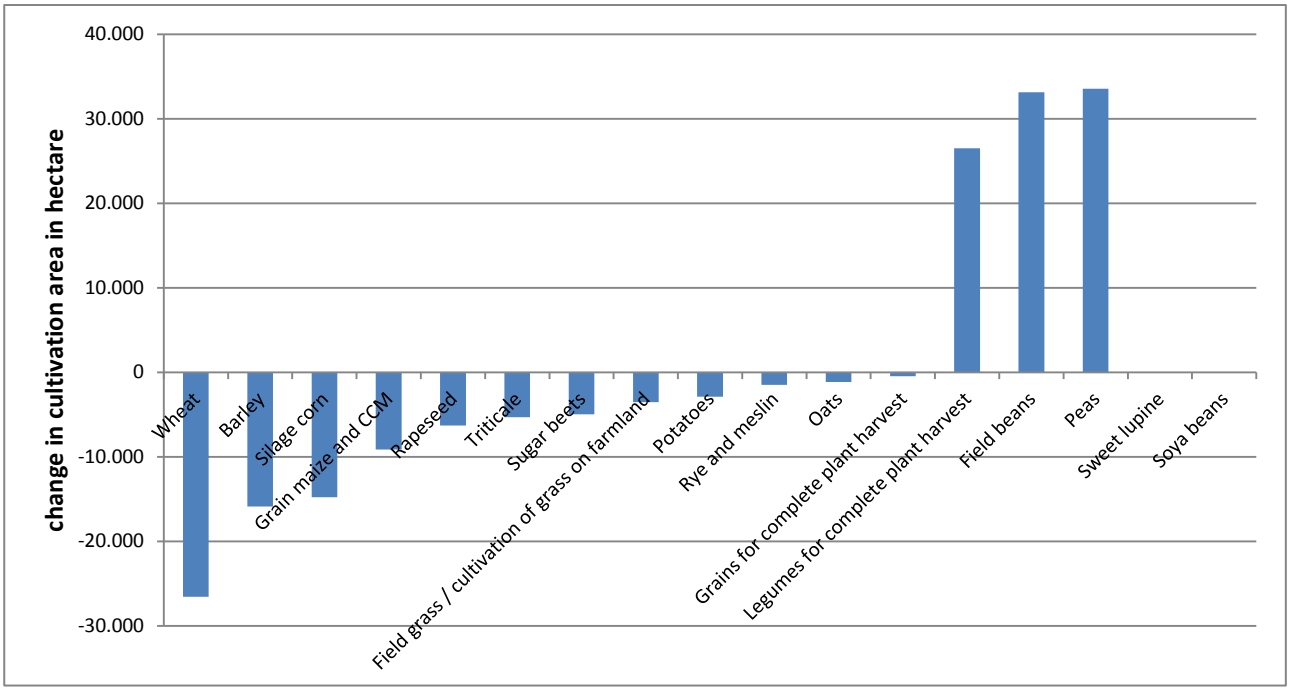

Fig. 2: Scenario legumes 10%, change in cultivation area in hectare

If the increased share of legume cultivation on 10 % of the arable acreage would be reached at the cost of those crops with below average crude protein contents, the changes in cultivation area would look differently. This scenario legumes 10 % CP-opt. would result in a total abandonment of the cultivation of oats, rye and triticale, the area of barley cultivation had to be reduced by 7,500 ha (Fig. 3). In comparison to the baseline scenario 7 % more crude protein would be produced, resulting in a total amount of 1.34 Mio. t crude protein. Whether such a reduction in cultivation diversity would be sensible from a plant management point of view is definitely disputable.

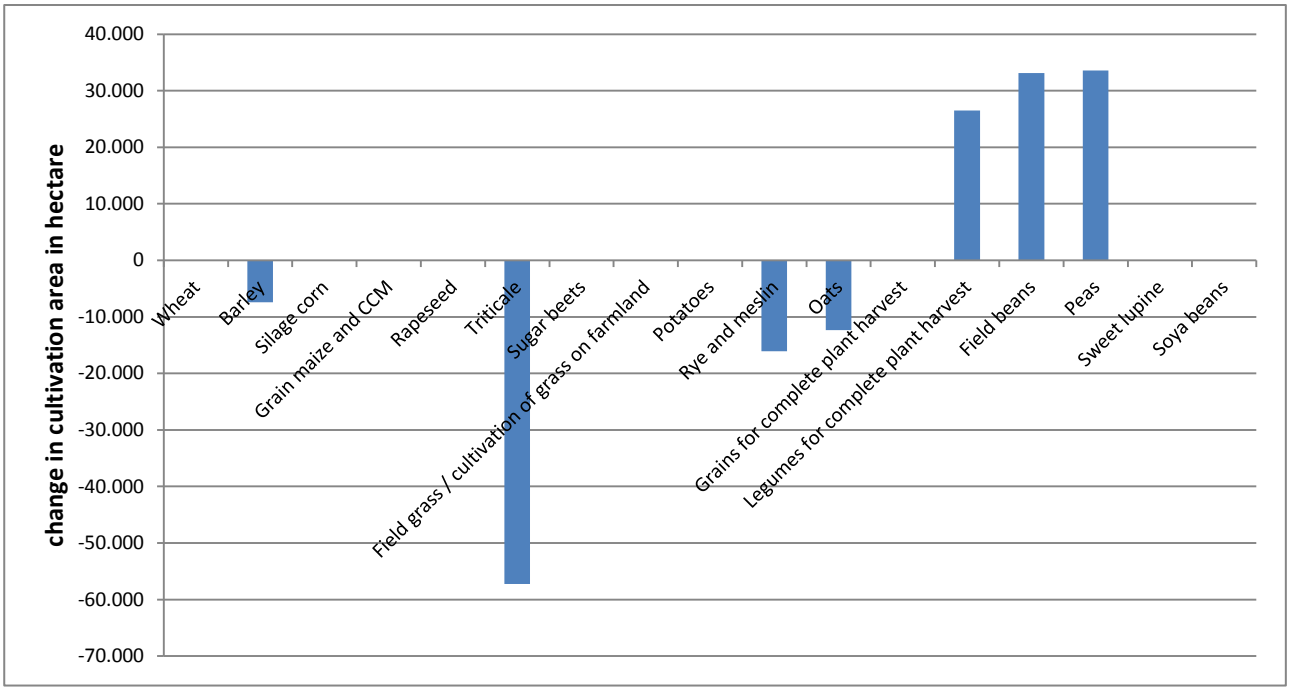

Fig. 3: Scenario legumes 10% CP-opt., change in cultivation area in hectare

The remaining legumes 20 %-scenario allocates a 3 % share of the arable acreage to soya and 1 % to sweet lupine. In total numbers, this means a soya cultivation area of 31,500 ha and a sweet lupine cultivation area of 10.500 ha. The distribution of the residual (proportionally reduced) cultivation area is shown in Fig. 4. The production of crude protein rises compared to the baseline scenario by 7.7 % to 1.35 Mio. t.

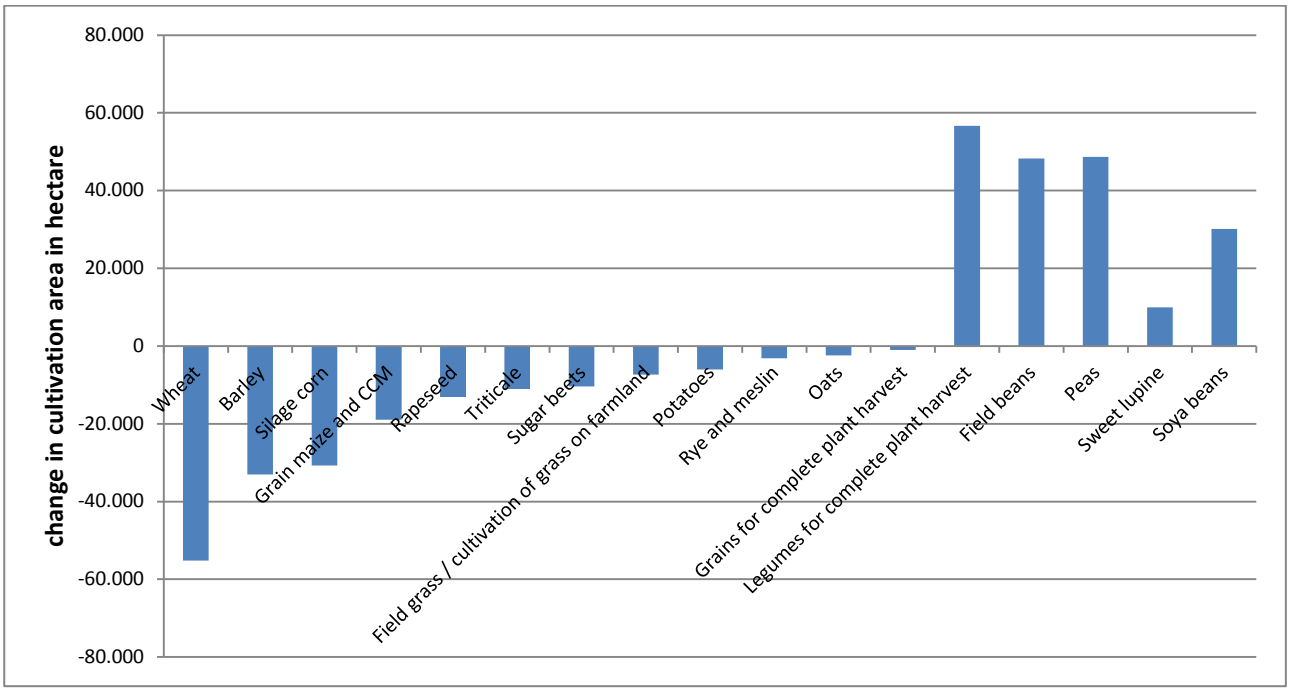

Fig. 4: Scenario legumes 20%, change in cultivation area in hectare

A general depiction of the shares of the mainly cultivated crops in North Rhine-Westphalia and the scenario results legumes 5/10/20% are presented in Fig. 5.

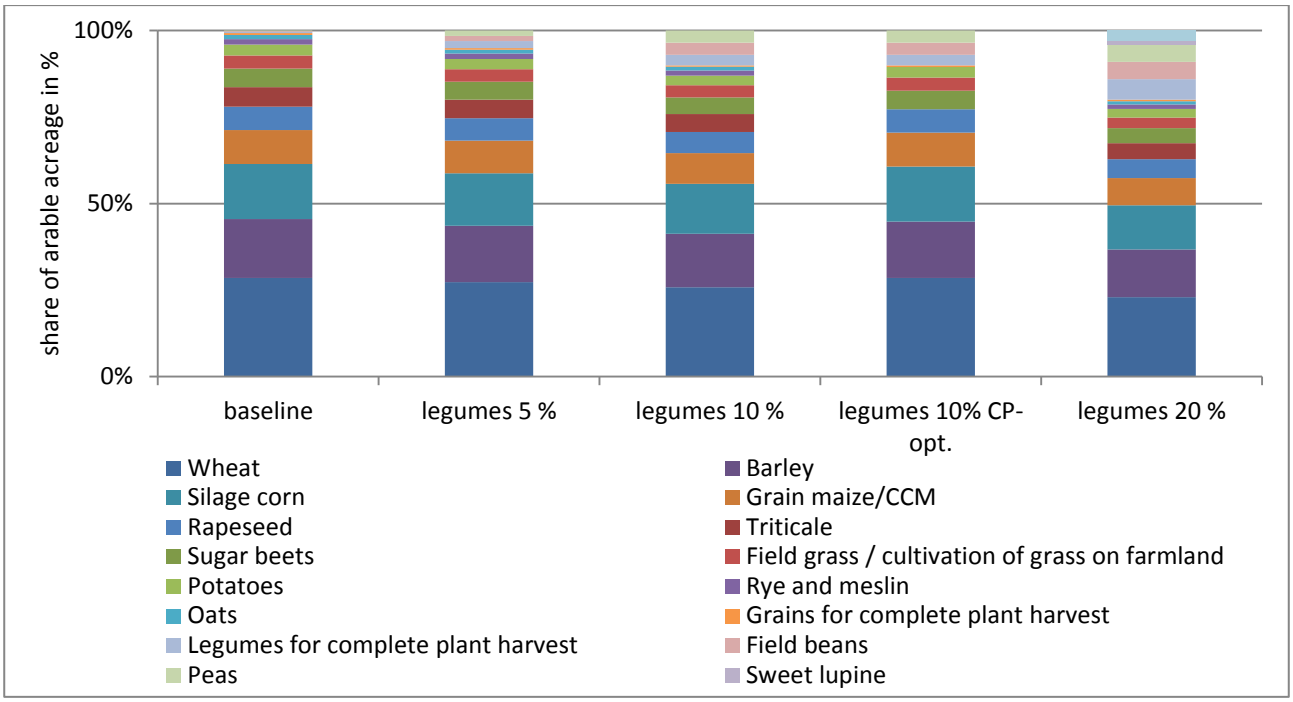

Fig. 5: scenario overview, cultivation increase in legumes

In a final step, the crude protein production based on the crop yields was related to the total agricultural area of North Rhine-Westphalia. For each scenario an average crude protein supply (kg/ha) was calculated. Additionally, the degree of self-sufficiency[5] for the livestock's crude protein demand was worked out; both ratios are presented in Fig. 6 for all scenarios.

[5] The degree of self-sufficiency is defined as the quotient of crude protein supply for feed from agricultural area and demand for crude protein by the livestock. Other authors have calculated a "degree of self-sufficiency with feed-proteins" of 35 %, not including the protein in grains (OVID 2012).

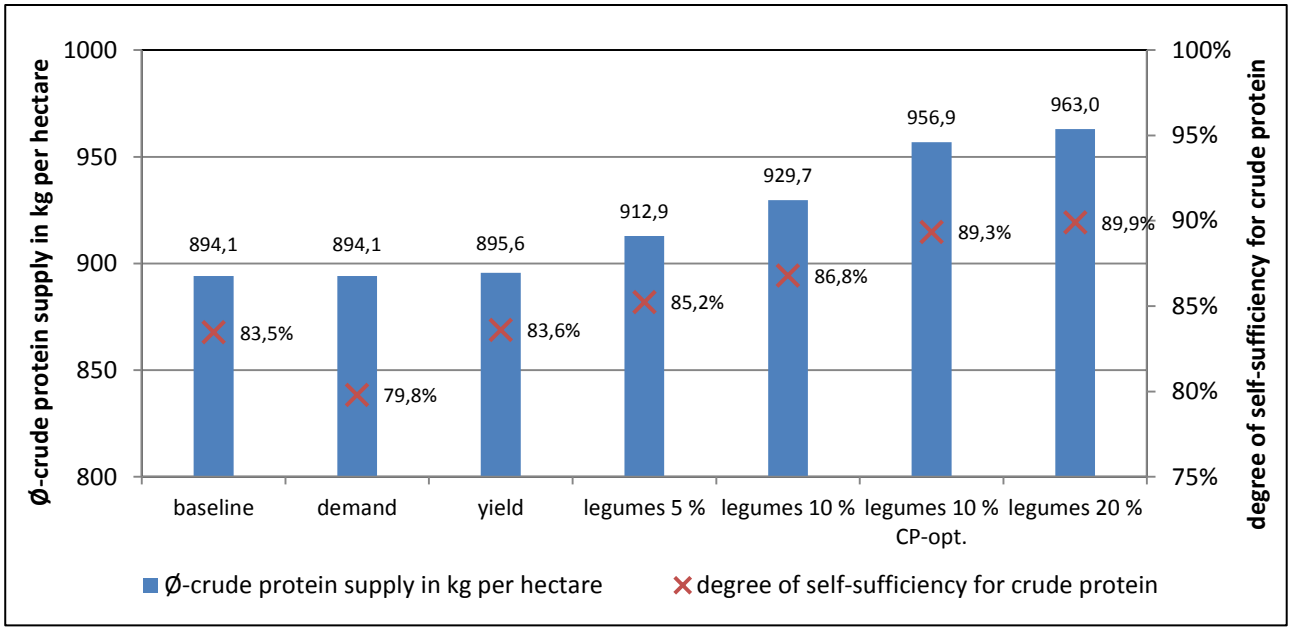

Fig. 6: scenario overview, average crude protein supply per hectare and degree of self-sufficiency

The baseline scenario provides almost 895 kg crude protein per hectare. This value does not change for the demand scenario since the cultivation is not altered from the baseline scenario. However, since in the demand scenario the livestock is higher (more recent data of the agriculture structure survey 2013), the degree of self-sufficiency decreases. Rising yields and increasing shares of legumes in the cultivation (cf. Tab. 8 for assumptions in legume yield) lead to an increase in average crude protein supply. The maximum is reached with 963 kg per ha, the degree of self-sufficiency peaks at 89.9 % in the legume 20 % scenario.
If the remaining gap of 10 % crude protein were to be filled by high-protein post extraction soya meal (48 % crude protein content), this would mean an amount of 316,000 t or require, given a relatively high soya bean yield of 35 dt per ha a cultivation area of 124,000 ha. In the scenario demand with less than 80 % degree of self-sufficiency the demand for cultivation area would double to 250,000 ha. Tab. 9 gives an overview of the remaining soya demand, assuming that the beans produce 73 % post extraction soya meal (Witzke et al. 2014).

Tab. 9: scenario overview, demand for soya or cultivation area and share of arable acreage

	Demand for high-protein post extraction soya meal (48% crude protein) in kg	Demand soya cultivation area (assuming 35 dt/ha yield) in ha	Share of arable acreage in North Rhine-Westphalia in %
Baseline	517,236,031	202,441	19.2
Demand	661,064,479	258,734	24.6
Yield	512,880,673	200,736	19.1
Legumes 5 %	462,202,767	180,901	17.2
Legumes 10 %	413,227,819	161,733	15.4
Legumes 10 % CP-opt.	333,767,827	130,633	12.4
Legumes 20 %	315,971,359	123,668	11.8

Data: own research

Simply by way of calculation, a balanced crude protein budget could also be reached by reducing the livestock. Taking the baseline scenario as reference, a decrease of the pig or cattle livestock by 35 % would be required to balance supply and demand. Only by reducing the poultry livestock a balanced budget and total self-sufficiency cannot be reached in North Rhine-Westphalia as the crude protein demand of poultry is relatively low.

4 Discussion

The findings presented in this paper show the demand for crude protein in cattle-, pig- and poultry-keeping and the cultivation of crops utilized for feed in the German state of North Rhine-Westphalia. In 2010 1.5 Mio. t crude protein for feed were required. The crops grown in the state supplied 1.25 Mio. t suitable for feeding purposes. Based on the scenario analysis, an increase in legume cultivation could elevate crude protein supply to 1.35 Mio. t. However, a complete self-sufficiency of crude protein while keeping the same number of cattle, pigs and poultry in North Rhine-Westphalian stables is, based on the assumptions for these scenarios, hardly possible. The scope of the research did not allow for full consideration of the animal's physiological features, neither was the cultivation framework (crop rotation, phytosanitary aspects) looked at in detail. In addition to that the economic viability of increased legume production in the state and reduced soya imports were not questioned. Regardless of the economic decisions farmers have to take, the German Alliance for Agricultural Research (DAFA) gives a number of reasons why the cultivation of legumes should receive more attention, focusing on ecosystem services like preceding crop effects, the positive contribution to the soil's humus balance, biodiversity, enhanced nutrient efficiency and other aspects (DAFA 2012). In order to capture the cultivation value of legumes as an indicator, the ideas presented by research to date seem limited and do not reflect the whole perspective. However, based on the scientific findings for legume cultivation further agricultural economic research might be able to integrate external effects in order to gain a broader view on the ecosystem services of legume cultivation.

The different scenarios and the amount of crude protein demanded and supplied therein allow a partial view on the protein situation. Also the calculated degrees of self-sufficiency do not include all sources of crude protein, e.g. byproducts of the food industry. Nevertheless does the German Association of Animal Nutrition (DVT) specify a degree of crude protein self-sufficiency of 73 % for the whole country, which is relatively close to the current *scenario demand* (livestock data from 2013) with a calculated value of 79.8 % (DVT 2014)

It is disputable whether reaching a degree of self-sufficiency of 100 % for crude protein is an objective worth striving for, especially given the comparative advantage of the grain production in North Rhine-Westphalia with exceptional high yields and potential downside effects for crop rotation if cultivation of crops with low protein content were abandoned. In addition to that looking at self-sufficiency from the input side only leads

to distortion: the degrees of self-sufficiency on the output side (meat, milk and other animal products) have been well above 100 % in Germany for years (BMELV 2013).

The scenarios with 5/10/20 % legumes in the crop rotation have been calculated based on the relatively high yields of the legumes. This has been done in expectation of improving cultivation competence and more focused breeding activities with increased shares of legumes on arable acreage. Adding to that more cultivation was shifted to conventional farms having more options in plant management (fertilizer, crop protection etc.).

Nowadays conventional farming shows indeed more interest in legumes than it has in the past. This might be due to consequences of the Common Agricultural Policy of the EU for the period of 2014 to 2020. It is planned that ecological priority areas which conventional farming will have to provide on 5 % of the land will be useable for the cultivation of legumes in environmental interest. Legume cultivation will be given a so-called greening factor of 0.7 while e.g. catch crop cultivation will only be granted a factor of 0.3 (BMEL 2014). New attractiveness for the cultivation of legumes may also be the result of the food retail industry: these market players do push their suppliers for products free of genetic modifications which is becoming more and more difficult to get when it comes to imported proteins. Should the food retailers ban genetically modified products in the supply chain, this might stimulate tremendous momentum in favor of regionally grown legumes while at the same time leading to significant price increases.

5 Conclusions and Recommendations

Amino acids form an integral part of the human diet. They are "constituents of protein" and vitally important for our nutrition. An "adequate supply of dietary protein is essential to maintain cellular integrity and function, and for health and reproduction" (Otten et al. 2006). Human nutrition leans especially in developed countries heavily on animal protein. Researchers list a number of reasons for this fact such as high nutritional values, a large variety of physical functionalities (such as the solubility of proteins, water- and fat-binding capacities, foaming and whipping abilities etc.) and the relatively low cost of animal protein (DAY 2013). As has been shown in this paper, production of meat for human consumption requires significant amounts of plant protein for feed. In addition, scientists argue that the conversion of plant- into animal-proteins by means of fattening livestock is inefficient. Less than 15 % of the protein in feedstock reaches the human dining table (AIKING 2011; PIMENTEL & PIMENTEL 2003). The question whether this indicates a sustainable development in view of a growing world population is a rhetorical one. BOLAND et al. therefore propose three simultaneous changes: shifting protein sources up the supply chain (e.g. whey has been considered as waste three decades ago, nowadays it is used as a valuable food ingredient), use of plant-based substitutes, and use of novel sources for nutrition (BOLAND et al. 2013). Considering the option of plant-based substitutes, sunflower protein has in recent time stirred increasing interest by food producers. This plant-based protein accrues as a byproduct of sunflower oil production. However, the functionalities require fragile handling as denaturation of the proteins can occur in the process. Discoloration may also create problems in food applications, phenolic compounds have been identified as the root cause for this issue (GONZÁLEZ-PÉREZ & VEREIJKEN 2007; WEISZ 2013). Given the advantages of sunflower proteins (low amounts of antinutritional factors, favorable amino acid composition except for lysine) and the relatively easy farming and processing conditions (sunflower can be produced in areas where soya grows less successful, the sunflower oil production is well established) further research towards elimination of the disadvantages that impede sunflower proteins from reaching full market potential is necessary (GONZÁLEZ-PÉREZ & VEREIJKEN 2007).

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Tab. 10: data table baseline scenario

Crude protein requirement					
	Amount animals	Feed uptake per animal (kg)	Crude protein in feed (g/kg)	Rotation per year	Crude protein per year (kg)
Piglets	1.966.561	35	185	6,5	82.767.636
Breeding sows	502.438	1.150	170	1	98.226.629
Other pigs	4.200.885	259	175	2,7	514.093.804
Dairy cows	392.466	6.720	156	1	412.560.259
Suckle cow husbandry	64.939	4.200	150	1	40.879.101
Young cattle rearing	198.306	5.560	133	1	146.679.016
Bull fattening	282.275	3.242	127	1	115.986.233
Young hens	2.103.516	6,9	161	2,2	5.259.247
Laying hens	3.418.408	40,0	175	1	23.928.856
Fattening chickens	4.483.440	4,2	218	6,7	27.441.098
Turkey	1.557.910	52,1	192	2,2	34.252.256
Total amount animals	19.171.144			Crude protein requirement NRW	1.502.074.135
Agricultural census 2010					
Crude protein production	**Cultivation in 2010 = baseline scenario**				
Arable acreage NRW	1.052.326	ha			
Areas of permanent grassland NRW	396.792	ha			
Arable acreage utilized for main crops	1.005.541	ha	**scenario: baseline**		
	% of arable acreage for main crops	crude protein supplied for feed (kg)	% of arable acreage for main crops	crude protein supplied for feed (kg)	change in cultivation area (ha)
Wheat	28,5	134.979.771	28,5	134.979.771	0
Barley	17,0	86.840.778	17,0	86.840.778	0
Silage corn	15,9	355.091.617	15,9	355.091.617	0
Grain maize and CCM	9,8	54.855.460	9,8	54.855.460	0
Rapeseed	6,8	61.951.156	6,8	61.951.156	0
Triticale	5,7	23.926.136	5,7	23.926.136	0
Sugar beets	5,3	-	5,3	-	0
Field grass / cultivation of grass on farmland	3,8	58.103.520	3,8	58.103.520	0
Potatoes	3,1	-	3,1	-	0
Rye and meslin	1,6	4.503.276	1,6	4.503.276	0
Oats	1,2	3.706.032	1,2	3.706.032	0
Grains for complete plant harvest	0,5	14.674.392	0,5	14.674.392	0
Legumes for complete plant harvest	0,4	5.218.070	0,4	5.218.070	0
Field beans	0,2	1.918.382	0,2	1.918.382	0
Peas	0,2	1.308.033	0,2	1.308.033	0
Sweet lupine	0,01	69.839	0,01	69.839	0
Soya beans	0,0	-	0,0	-	0
Grassland and pasture	92,0	446.654.379	92,0	446.654.379	0
	total	1.253.800.841	total	1.253.800.841	
		share of legumes: 0,7 %		share of legumes: 0,7 %	
		Ø-crude protein supply: 894,1 kg/ha		Ø-crude protein supply: 894,1 kg/ha	
		degree of self-sufficiency: 83,5 %		degree of self-sufficiency: 83,5 %	

Tab. 11: data table demand scenario

Crude protein requirement					
	Amount animals	**Feed uptake per animal (kg)**	**Crude protein in feed (g/kg)**	**Rotation per year**	**Crude protein per year (kg)**
Piglets	2.115.417	35	185	6,5	89.032.613
Breeding sows	477.600	1.150	170	1	93.370.800
Other pigs	4.637.264	259	175	2,7	567.496.775
Dairy cows	407.514	6.720	156	1	428.378.717
Suckle cow husbandry	54.649	4.200	150	1	34.401.546
Young cattle rearing	196.714	5.560	133	1	145.501.477
Bull fattening	280.751	3.242	127	1	115.360.024
Young hens	2.740.151	6,9	161	2,2	6.850.973
Laying hens	3.598.316	40,0	175	1	25.188.212
Fattening chickens	5.185.876	4,2	218	6,7	31.740.390
Turkey	1.536.897	52,1	192	2,2	33.790.264
Total amount animals	21.231.149			Crude protein requirement NRW	1.571.111.791
Agricultural structure survey 2013					
Crude protein production	**Cultivation in 2010 = baseline scenario**				
Arable acreage NRW	1.052.326	ha			
Areas of permanent grassland NRW	396.792	ha			
Arable acreage utilized for main crops	1.005.541	ha	**scenario: demand**		
	% of arable acreage for main crops	crude protein supplied for feed (kg)	% of arable acreage for main crops	crude protein supplied for feed (kg)	change in cultivation area (ha)
Wheat	28,5	134.979.771	28,5	134.979.771	0
Barley	17,0	86.840.778	17,0	86.840.778	0
Silage corn	15,9	355.091.617	15,9	355.091.617	0
Grain maize and CCM	9,8	54.855.460	9,8	54.855.460	0
Rapeseed	6,8	61.951.156	6,8	61.951.156	0
Triticale	5,7	23.926.136	5,7	23.926.136	0
Sugar beets	5,3	-	5,3	-	0
Field grass / cultivation of grass on farmland	3,8	58.103.520	3,8	58.103.520	0
Potatoes	3,1	-	3,1	-	0
Rye and meslin	1,6	4.503.276	1,6	4.503.276	0
Oats	1,2	3.706.032	1,2	3.706.032	0
Grains for complete plant harvest	0,5	14.674.392	0,5	14.674.392	0
Legumes for complete plant harvest	0,4	5.218.070	0,4	5.218.070	0
Field beans	0,2	1.918.382	0,2	1.918.382	0
Peas	0,2	1.308.033	0,2	1.308.033	0
Sweet lupine	0,01	69.839	0,01	69.839	0
Soya beans	0,0	-	0,0	-	0
Grassland and pasture	92,0	446.654.379	92,0	446.654.379	0
	total	1.253.800.841	total	1.253.800.841	
		share of legumes: 0,7 %		share of legumes: 0,7 %	
		Ø-crude protein supply: 894,1 kg/ha		Ø-crude protein supply: 894,1 kg/ha	
		degree of self-sufficiency: 79,8 %		degree of self-sufficiency: 79,8 %	

Tab. 12: data table yield scenario

Crude protein requirement						
	Amount animals	Feed uptake per animal (kg)	Crude protein in feed (g/kg)	Rotation per year	Crude protein per year (kg)	
Piglets	1.966.561	35	185	6,5	82.767.636	
Breeding sows	502.438	1.150	170	1	98.226.629	
Other pigs	4.200.885	259	175	2,7	514.093.804	
Dairy cows	392.466	6.720	156	1	412.560.259	
Suckle cow husbandry	64.939	4.200	150	1	40.879.101	
Young cattle rearing	198.306	5.560	133	1	146.679.016	
Bull fattening	282.275	3.242	127	1	115.986.233	
Young hens	2.103.516	6,9	161	2,2	5.259.247	
Laying hens	3.418.408	40,0	175	1	23.928.856	
Fattening chickens	4.483.440	4,2	218	6,7	27.441.098	
Turkey	1.557.910	52,1	192	2,2	34.252.256	
Total amount animals	19.171.144			Crude protein requirement NRW	1.502.074.135	
Agricultural census 2010						
Crude protein production	**Cultivation in 2010 = baseline scenario**					
Arable acreage NRW	1.052.326	ha				
Areas of permanent grassland NRW	396.792	ha				
Arable acreage utilized for main crops	1.005.541	ha	**scenario: yield**			
	% of arable acreage for main crops	crude protein supplied for feed (kg)	% of arable acreage for main crops	crude protein supplied for feed (kg)	change in cultivation area (ha)	
Wheat	28,5	134.979.771	28,5	134.979.771	0	
Barley	17,0	86.840.778	17,0	86.840.778	0	
Silage corn	15,9	355.091.617	15,9	355.091.617	0	
Grain maize and CCM	9,8	54.855.460	9,8	54.855.460	0	
Rapeseed	6,8	61.951.156	6,8	61.951.156	0	
Triticale	5,7	23.926.136	5,7	23.926.136	0	
Sugar beets	5,3	-	5,3	-	0	
Field grass / cultivation of grass on farmland	3,8	58.103.520	3,8	58.103.520	0	
Potatoes	3,1	-	3,1	-	0	
Rye and meslin	1,6	4.503.276	1,6	4.503.276	0	
Oats	1,2	3.706.032	1,2	3.706.032	0	
Grains for complete plant harvest	0,5	14.674.392	0,5	14.674.392	0	
Legumes for complete plant harvest	0,4	5.218.070	0,4	6.203.300	0	
Field beans	0,2	1.918.382	0,2	2.686.810	0	
Peas	0,2	1.308.033	0,2	1.626.008	0	
Sweet lupine	0,01	69.839	0,01	88.779	0	
Soya beans	0,0	-	0,0	-	0	
Grassland and pasture	92,0	446.654.379	92,0	446.654.379	0	
	total	1.253.800.841	total	1.255.891.413		
		share of legumes: 0,7 %		share of legumes: 0,7 %		
		Ø-crude protein supply: 894,1 kg/ha		Ø-crude protein supply: 895,6 kg/ha		
		degree of self-sufficiency: 83,5 %		degree of self-sufficiency: 83,6 %		

Tab. 13: data table legumes 5 % scenario

Crude protein requirement						
	Amount animals	**Feed uptake per animal (kg)**	**Crude protein in feed (g/kg)**	**Rotation per year**	**Crude protein per year (kg)**	
Piglets	1.966.561	35	185	6,5	82.767.636	
Breeding sows	502.438	1.150	170	1	98.226.629	
Other pigs	4.200.885	259	175	2,7	514.093.804	
Dairy cows	392.466	6.720	156	1	412.560.259	
Suckle cow husbandry	64.939	4.200	150	1	40.879.101	
Young cattle rearing	198.306	5.560	133	1	146.679.016	
Bull fattening	282.275	3.242	127	1	115.986.233	
Young hens	2.103.516	6,9	161	2,2	5.259.247	
Laying hens	3.418.408	40,0	175	1	23.928.856	
Fattening chickens	4.483.440	4,2	218	6,7	27.441.098	
Turkey	1.557.910	52,1	192	2,2	34.252.256	
Total amount animals	19.171.144			Crude protein requirement NRW	1.502.074.135	
Agricultural census 2010						
Crude protein production	**Cultivation in 2010 = baseline scenario**					
Arable acreage NRW	1.052.326	ha				
Areas of permanent grassland NRW	396.792	ha				
Arable acreage utilized for main crops	1.005.541	ha	**scenario: legumes 5 %**			
	% of arable acreage for main crops	crude protein supplied for feed (kg)	% of arable acreage for main crops	crude protein supplied for feed (kg)	change in cultivation area (ha)	
Wheat	28,5	134.979.771	27,3	129.215.404	-12.247	
Barley	17,0	86.840.778	16,3	83.132.206	-7.320	
Silage corn	15,9	355.091.617	15,2	339.927.281	-6.815	
Grain maize and CCM	9,8	54.855.460	9,4	52.512.834	-4.210	
Rapeseed	6,8	61.951.156	6,5	59.305.506	-2.906	
Triticale	5,7	23.926.136	5,4	22.904.360	-2.444	
Sugar beets	5,3	-	5,1	-	-2.295	
Field grass / cultivation of grass on farmland	3,8	58.103.520	3,6	55.622.185	-1.632	
Potatoes	3,1	-	3,0	-	-1.327	
Rye and meslin	1,6	4.503.276	1,5	4.310.962	-687	
Oats	1,2	3.706.032	1,2	3.547.764	-528	
Grains for complete plant harvest	0,5	14.674.392	0,5	14.047.716	-212	
Legumes for complete plant harvest	0,4	5.218.070	2,0	34.188.394	16.462	
Field beans	0,2	1.918.382	1,5	19.758.881	13.032	
Peas	0,2	1.308.033	1,5	15.000.158	13.448	
Sweet lupine	0,01	69.839	0,01	88.779	0	
Soya beans	0,0	-	0,0	-	0	
Grassland and pasture	92,0	446.654.379	92,0	446.654.379	0	
	total	1.253.800.841	total	1.280.216.807		
		share of legumes: 0,7 %		share of legumes: 5 %		
		Ø-crude protein supply: 894,1 kg/ha		Ø-crude protein supply: 912,9 kg/ha		
		degree of self-sufficiency: 83,5 %		degree of self-sufficiency: 85,2 %		

Tab. 14: data table legumes 10 % scenario

Crude protein requirement					
	Amount animals	**Feed uptake per animal (kg)**	**Crude protein in feed (g/kg)**	**Rotation per year**	**Crude protein per year (kg)**
Piglets	1.966.561	35	185	6,5	82.767.636
Breeding sows	502.438	1.150	170	1	98.226.629
Other pigs	4.200.885	259	175	2,7	514.093.804
Dairy cows	392.466	6.720	156	1	412.560.259
Suckle cow husbandry	64.939	4.200	150	1	40.879.101
Young cattle rearing	198.306	5.560	133	1	146.679.016
Bull fattening	282.275	3.242	127	1	115.986.233
Young hens	2.103.516	6,9	161	2,2	5.259.247
Laying hens	3.418.408	40,0	175	1	23.928.856
Fattening chickens	4.483.440	4,2	218	6,7	27.441.098
Turkey	1.557.910	52,1	192	2,2	34.252.256
Total amount animals	19.171.144			Crude protein requirement NRW	1.502.074.135
Agricultural census 2010					
Crude protein production	**Cultivation in 2010 = baseline scenario**				
Arable acreage NRW	1.052.326	ha			
Areas of permanent grassland NRW	396.792	ha			
Arable acreage utilized for main crops	1.005.541	ha	**scenario: legumes 10 %**		
	% of arable acreage for main crops	crude protein supplied for feed (kg)	% of arable acreage for main crops	crude protein supplied for feed (kg)	change in cultivation area (ha)
Wheat	28,5	134.979.771	25,9	122.466.415	-26.585
Barley	17,0	86.840.778	15,5	78.790.167	-15.890
Silage corn	15,9	355.091.617	14,4	322.172.700	-14.794
Grain maize and CCM	9,8	54.855.460	8,9	49.770.061	-9.138
Rapeseed	6,8	61.951.156	6,1	56.207.948	-6.309
Triticale	5,7	23.926.136	5,2	21.708.054	-5.306
Sugar beets	5,3	-	4,8	-	-4.982
Field grass / cultivation of grass on farmland	3,8	58.103.520	3,4	52.717.009	-3.544
Potatoes	3,1	-	2,8	-	-2.881
Rye and meslin	1,6	4.503.276	1,5	4.085.798	-1.492
Oats	1,2	3.706.032	1,1	3.362.463	-1.146
Grains for complete plant harvest	0,5	14.674.392	0,4	13.313.996	-461
Legumes for complete plant harvest	0,4	5.218.070	3,0	51.282.591	26.517
Field beans	0,2	1.918.382	3,5	46.104.055	33.143
Peas	0,2	1.308.033	3,5	35.000.368	33.559
Sweet lupine	0,01	69.839	0,01	88.779	0
Soya beans	0,0	-	0,0	-	0
Grassland and pasture	92,0	446.654.379	92,0	446.654.379	0
	total	1.253.800.841	total	1.303.724.782	
		share of legumes: 0,7 %		share of legumes: 10 %	
		Ø-crude protein supply: 894,1 kg/ha		Ø-crude protein supply: 929,7 kg/ha	
		degree of self-sufficiency: 83,5 %		degree of self-sufficiency: 86,8 %	

Tab. 15: data table legumes 10 % CP-opt. scenario

Crude protein requirement					
	Amount animals	**Feed uptake per animal (kg)**	**Crude protein in feed (g/kg)**	**Rotation per year**	**Crude protein per year (kg)**
Piglets	1.966.561	35	185	6,5	82.767.636
Breeding sows	502.438	1.150	170	1	98.226.629
Other pigs	4.200.885	259	175	2,7	514.093.804
Dairy cows	392.466	6.720	156	1	412.560.259
Suckle cow husbandry	64.939	4.200	150	1	40.879.101
Young cattle rearing	198.306	5.560	133	1	146.679.016
Bull fattening	282.275	3.242	127	1	115.986.233
Young hens	2.103.516	6,9	161	2,2	5.259.247
Laying hens	3.418.408	40,0	175	1	23.928.856
Fattening chickens	4.483.440	4,2	218	6,7	27.441.098
Turkey	1.557.910	52,1	192	2,2	34.252.256
Total amount animals	19.171.144			Crude protein requirement NRW	1.502.074.135
Agricultural census 2010					
Crude protein production	**Cultivation in 2010 = baseline scenario**				
Arable acreage NRW	1.052.326	ha			
Areas of permanent grassland NRW	396.792	ha			
Arable acreage utilized for main crops	1.005.541	ha	**scenario: legumes 10 % CP-opt.**		
	% of arable acreage for main crops	crude protein supplied for feed (kg)	% of arable acreage for main crops	crude protein supplied for feed (kg)	change in cultivation area (ha)
Wheat	28,5	134.979.771	28,5	134.979.771	0
Barley	17,0	86.840.778	16,3	83.079.491	-7.424
Silage corn	15,9	355.091.617	15,9	355.091.617	0
Grain maize and CCM	9,8	54.855.460	9,8	54.855.460	0
Rapeseed	6,8	61.951.156	6,8	61.951.156	0
Triticale	5,7	23.926.136	0,0	-	-57.236
Sugar beets	5,3	-	5,3	-	0
Field grass / cultivation of grass on farmland	3,8	58.103.520	3,8	58.103.520	0
Potatoes	3,1	-	3,1	-	0
Rye and meslin	1,6	4.503.276	0,0	-	-16.095
Oats	1,2	3.706.032	0,0	-	-12.363
Grains for complete plant harvest	0,5	14.674.392	0,5	14.674.392	0
Legumes for complete plant harvest	0,4	5.218.070	3,0	51.282.591	26.517
Field beans	0,2	1.918.382	3,5	46.104.055	33.143
Peas	0,2	1.308.033	3,5	35.000.368	33.559
Sweet lupine	0,01	69.839	0,01	88.779	0
Soya beans	0,0	-	0,0	-	0
Grassland and pasture	92,0	446.654.379	92,0	446.654.379	0
	total	1.253.800.841	total	1.341.865.579	
		share of legumes: 0,7 %		share of legumes: 10 %	
		Ø-crude protein supply: 894,1 kg/ha		Ø-crude protein supply: 956,9 kg/ha	
		degree of self-sufficiency: 83,5 %		degree of self-sufficiency: 89,3 %	

Tab. 16: data table legumes 20 % scenario

Crude protein requirement					
	Amount animals	Feed uptake per animal (kg)	Crude protein in feed (g/kg)	Rotation per year	Crude protein per year (kg)
Piglets	1.966.561	35	185	6,5	82.767.636
Breeding sows	502.438	1.150	170	1	98.226.629
Other pigs	4.200.885	259	175	2,7	514.093.804
Dairy cows	392.466	6.720	156	1	412.560.259
Suckle cow husbandry	64.939	4.200	150	1	40.879.101
Young cattle rearing	198.306	5.560	133	1	146.679.016
Bull fattening	282.275	3.242	127	1	115.986.233
Young hens	2.103.516	6,9	161	2,2	5.259.247
Laying hens	3.418.408	40,0	175	1	23.928.856
Fattening chickens	4.483.440	4,2	218	6,7	27.441.098
Turkey	1.557.910	52,1	192	2,2	34.252.256
Total amount animals	19.171.144			Crude protein requirement NRW	1.502.074.135
Agricultural census 2010					
Crude protein production	**Cultivation in 2010 = baseline scenario**				
Arable acreage NRW	1.052.326	ha			
Areas of permanent grassland NRW	396.792	ha			
Arable acreage utilized for main crops	1.005.541	ha	**scenario: legumes 20 %**		
	% of arable acreage for main crops	crude protein supplied for feed (kg)	% of arable acreage for main crops	crude protein supplied for feed (kg)	change in cultivation area (ha)
Wheat	28,5	134.979.771	23,0	108.981.996	-55.233
Barley	17,0	86.840.778	13,8	70.114.812	-33.014
Silage corn	15,9	355.091.617	12,8	286.699.205	-30.737
Grain maize and CCM	9,8	54.855.460	7,9	44.290.025	-18.986
Rapeseed	6,8	61.951.156	5,5	50.019.055	-13.108
Triticale	5,7	23.926.136	4,6	19.317.843	-11.024
Sugar beets	5,3	-	4,3	-	-10.351
Field grass / cultivation of grass on farmland	3,8	58.103.520	3,1	46.912.493	-7.363
Potatoes	3,1	-	2,5	-	-5.985
Rye and meslin	1,6	4.503.276	1,3	3.635.923	-3.100
Oats	1,2	3.706.032	1,0	2.992.232	-2.381
Grains for complete plant harvest	0,5	14.674.392	0,4	11.848.031	-957
Legumes for complete plant harvest	0,4	5.218.070	6,0	102.565.182	56.683
Field beans	0,2	1.918.382	5,0	65.862.936	48.226
Peas	0,2	1.308.033	5,0	50.000.526	48.642
Sweet lupine	0,01	69.839	1,00	8.838.705	9.954
Soya beans	0,0	-	3,0	31.674.542	30.166
Grassland and pasture	92,0	446.654.379	92,0	446.654.379	0
	total	1.253.800.841	total	1.350.407.883	
		share of legumes: 0,7 %		share of legumes: 20 %	
		Ø-crude protein supply: 894,1 kg/ha		Ø-crude protein supply: 963 kg/ha	
		degree of self-sufficiency: 83,5 %		degree of self-sufficiency: 89,9 %	