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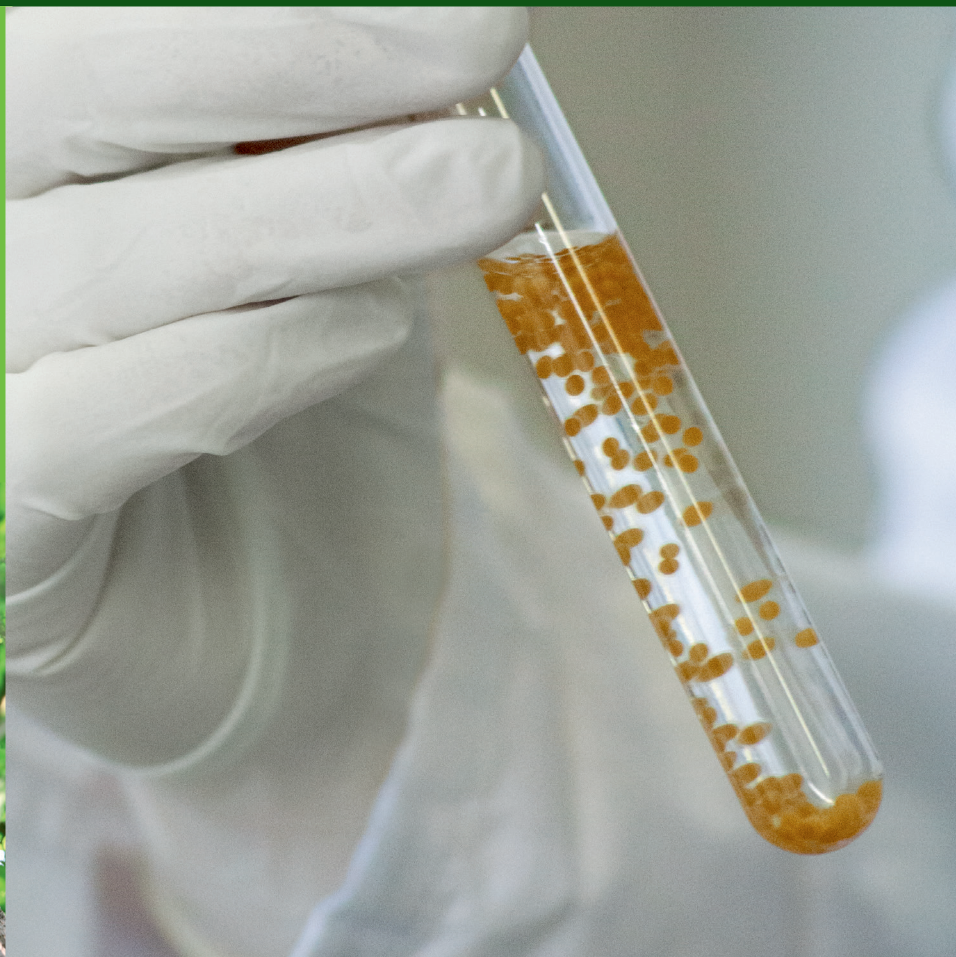

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Thünen-Baseline 2013-2023: Agri-economic projections for Germany

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Abstract

This article presents selected results of the Thünen-Baseline as well as the assumptions upon which these results are based. The Thünen-Baseline is established using and combining several models of the Thünen model network. It provides a reference scenario for the analysis of the impacts of alternative policies and developments. The projections are based on data and information available as of winter 2013/14. The baseline assumes a continuation of the current policy framework and the implementation of already decided policy changes. For the Thünen-Baseline 2013 to 2023, this implies the implementation of the EU-CAP reform decided in 2013 and its national implementation according to the decisions made at the German Ministers of Agriculture conference.

Overall, the Thünen-Baseline 2013 to 2023 draws a picture of a competitive agricultural sector in Germany, which adapts well to the changes of the latest policy reform and seizes the opportunities for expanding production, especially in the dairy sector. On the other hand, the projections also highlight that – under the assumptions made and with unchanged policy conditions – the problems that may accompany intensive livestock production will not simply dissolve. In contrast, in view of the projected high profitability of intensive pig and poultry production the related challenges could increase.

Keywords: *agricultural policy, impact assessment, modelling, Germany*

Zusammenfassung

Thünen-Baseline 2013-2023: Agrarökonomische Projektionen für Deutschland

Die Thünen-Baseline 2013 bis 2023 ist eine auf den deutschen Agrarsektor fokussierte modellgestützte Projektion der erwarteten Entwicklungen auf der Grundlage der im Winter 2013/14 vorliegenden Daten und Informationen. Sie stellt eine Referenzsituation für die Analyse von Auswirkungen alternativer Politiken und Entwicklungen dar. Die Thünen-Baseline geht von einer Beibehaltung der derzeitigen Agrarpolitik bzw. der Umsetzung bereits beschlossener Politikänderungen aus. Für die vorliegende Baseline bedeutet dies im Wesentlichen die Umsetzung der 2013 beschlossenen Reform der Europäischen Agrarpolitik und ihrer nationalen Umsetzung entsprechend des Beschlusses der deutschen Agrarministerkonferenz.

Insgesamt zeichnet die Thünen-Baseline 2013 bis 2023 das Bild einer wettbewerbsstarken Landwirtschaft in Deutschland, die sich gut an die Veränderungen der jüngsten Agrarreform anpasst und die Möglichkeiten zur Produktionsausdehnung, insbesondere im Milchbereich, wahrnimmt. Auf der anderen Seite zeigen die Projektionen, dass sich unter den getroffenen Annahmen und unveränderten politischen Rahmenbedingungen die Probleme, die sich aus der intensiven Tierproduktion ergeben können, nicht im Zeitablauf „von selbst“ lösen, sondern im Gegenteil angesichts der projizierten Rentabilität der Veredlungsproduktion weiter an Bedeutung gewinnen könnten.

Schlüsselwörter: *Agrarpolitik, Politikfolgenabschätzung, Modellierung, Deutschland*

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1 Introduction

This article presents and discusses selected results of the Thünen-Baseline 2013 to 2023 as well as the assumptions upon which these results are based.[1] The projections are based on data and information available as of winter 2013/14. It is important to stress that the Thünen-Baseline is not a forecast about the future. Rather, the baseline describes expected developments should the current agricultural policy be continued in accordance with specific assumptions about the development of exogenous influences. The Thünen-Baseline thus serves as a reference scenario for analyses of the impacts of alternative policies and developments. It complements the more general and highly aggregated results of the baseline reports of the EU-Comission (2013) and the OECD-FAO (2013) by offering a detailed picture of the projected situation of German agriculture in 2023, taking into account national policies.

The assumptions for the development of the exogenous factors and the agricultural policy conditions selected for the baseline were chosen in close consultation with experts from the German Ministry of Food and Agriculture. Preliminary baseline results were discussed with representatives from the federal as well as Länder ministries. This approach enabled the integration of expert knowledge as well as the definition of a scenario that is widely accepted as a relevant basis for further policy impact analyses.

2 Methodology

The Thünen-Baseline is established using and combining several models of the Thünen model network. The Thünen model network connects farm, regional and sector partial and general equilibrium models for the joint application for policy impact assessments. With the help of the model network, the impacts of a wide range of trade, agricultural and environmental policies on various facets of the agricultural sector, e.g. markets, production, environment, income, can be analyzed at different levels (Figure 1). In the analysis, a coordinated, parallel and/or iterative implementation of the model takes place. This implementation allows for the alignment of important assumptions, the exchange of model results as a basis for other models of the network, and the reciprocal check of the model results. This approach aims at providing a consistent overall result. The databases and characteristics of models used for the establishment of the Thünen-Baseline 2013 to 2023 are briefly described below.

The MAGNET model (Modular Applied GeNeral Equilibrium Tool) is a multiregional, general equilibrium model covering global economic activity as well as single countries and regions (Woltjer et al., 2013). It provides a detailed representation of the interactions between agriculture, the input sector and the food industry as well as commercial economics and the service sector, and accounts for the intra- and interregional linkages between markets and actors. MAGNET is based on a simultaneous system of non-linear equations, which ensure an equilibrium in the model and the identity between expenses and income. Behavioural equations describe the economic activities of different actors (for example, consumers and producers). Product demand, product supply and factor demand functions are specified so that consumers and producers maximize their utility or profit. Linking supply and demand, the model endogenously determines prices and quantities that lead to balanced product and factor markets. Trade modelling differentiates products by origin based on the Armington assumption (Armington, 1969) and considers transport requirements, and describes trade structure in the form of a matrix of bilateral trade flows (see Hertel and Tsigas, 1997). The GTAP data base 8.2 used for this study includes 57 sectors and 129 regions for the base year 2007 (https://www.gtap.agecon.purdue.edu/databases/v8/v8_doco.asp).

AGMEMOD (http://www.agmemod.eu) is a partial, multinational, multiple-product model based on econometrically estimated parameters and a recursive-dynamic approach. It covers production, consumption, trade, inventories and prices for 20 agricultural and 17 processing sectors of the EU member states, accession candidates and other neighbouring countries. The German model provides a detailed representation of grains and oilseed, potatoes, cattle and calves, sheep, pigs, poultry and milk as well as their processed products (Salamon and von Ledebur, 2005). Coupled with each other and the appropriate world markets, the models create a combined EU Model for the individual EU Member States (van Leeuwen et al., 2011). In the present model, version 7, the world markets are endogenous, but calibrated to fit to the OECD price projections (OECD-FAO, 2013). The data base covers the years 1973 to 2012.

The regionalized agricultural and environmental information system RAUMIS (Henrichsmeyer et al., 1996) is employed to analyze medium and long-term agricultural and environmental policy impacts. The model consolidates various agricultural data sources with the national agricultural accounts as a framework of consistency. It comprises of more than 50 agricultural products, 40 inputs with exogenously determined prices, and reflects the German agricultural sector with its sector linkages. According to data availability, the spatial differentiation is based on administrative bodies, i.e., 326 regions (NUTS III level) treated as single „region farms." Production adjustments caused by changes in the general framework conditions such as agricultural policies are determined by using a comparative-static mathematical programming approach that maximizes a non-linear objective function for regional farm income. The model is calibrated to observed production decisions using a positive mathematical programming approach (Howitt, 1995; Cypris, 2000). Model base years are available in four-year intervals from 1979 to 2010.

Farm level aspects are covered by FARMIS, a process-analytical programming model for farm groups (Osterburg et al., 2001; Offermann et al., 2005; Deppermann et al., 2013) based on information from the farm accountancy data network (FADN). Production is differentiated for 27 crop and 15

1 The full report with detailed results is published in German as Offermann et al. (2014).

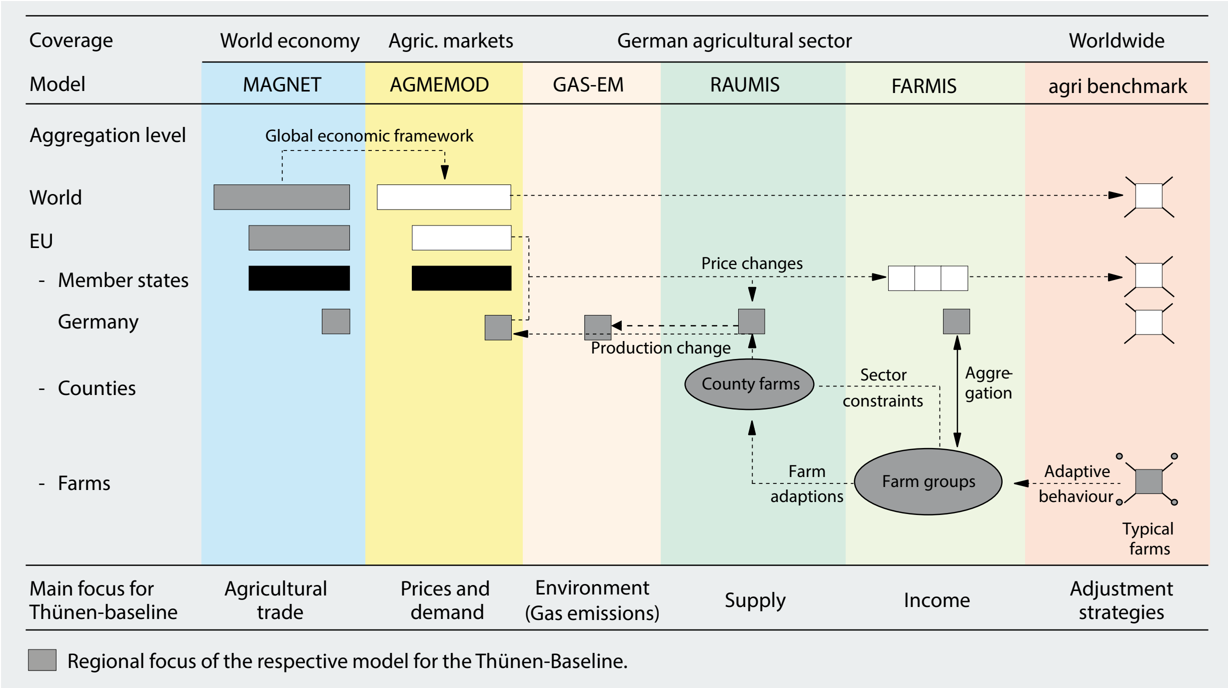


Figure 1
The use of models of the Thünen model network for the establishment of the Thünen-Baseline 2013 - 2023

livestock activities. The matrix restrictions cover the areas of feeding (energy and nutrient requirements, calibrated feed rations), intermediate use of young livestock, fertilizer use (organic and mineral), labour (seasonally differentiated), crop rotations and political instruments (e.g., set-aside and quotas). The model is calibrated to observed production decisions and elasticities using a positive mathematical programming approach. For this study, the model specification is based on data from the accounting years 2009/10, 2010/11 and 2011/12. The farm sample was stratified by region, type, system and size, resulting in 646 farm group models (of which 90 groups represent organic farming). Results are aggregated to the sector using farm group specific weighting factors. To account for structural change, econometrically estimated farm exit probabilities were applied to the aggregation factors for the projection. Within regions, farms compete for land on rental markets (Bertelsmeier, 2005).

TIPI-CAL und TYPICROP are accounting models applied within the framework of the global agri benchmark network (www.agribenchmark.org). They represent in detail production technology and physical interrelationships at farm level. As part of the model network, these models are mainly used to analyze the impacts of changes in policy, economic, and regulatory framework on selected farms, and to investigate the financial consequences of different alternative farm adjustments and development strategies. The database comprises typical farms, which are established based on a globally harmonized Standard Operating Procedure together with more than 40 partners in different countries. Data are collected annually, and the validation of results and specification of adjustment strategies is done in cooperation with farmers and advisors.

For the projection of greenhouse gas and ammonia emissions from agriculture in the baseline scenario, the Thünen model network is linked to the model GAS-EM. GAS-EM is a modular spreadsheet programme to estimate gaseous and particulate emissions from animal agriculture and crop production including professional horticulture. GAS-EM was first described in Dämmgen et al. (2002) and has been developed further continuously since then. The assessment of emissions within GAS-EM uses the definitions of agriculture according to the definitions of IPCC. All calculation procedures involved are based on the rules provided by the respective conventions and the current guidance documents. In addition, the German agricultural inventory uses differing methods in specific circumstances in order to improve the description of national emission conditions (Haenel et al, 2014). It is used to generate the official National Emission Inventory Reports for Germany. For this study, the projections of gaseous emissions in 2023 are based on the RAUMIS projections for land use and livestock numbers in the baseline scenario.

For the analysis of the impact of the new greening requirements (see section 3.2), the extent of existing landscape elements was established based on the ATKIS 'Basic Landscape Model' (ATKIS Basic DLM). The ATKIS describes the topographic features of the landscape in vector format. The features are assigned to a certain feature type and defined on the basis of their spatial position, their geometrical type, descriptive attributes and relations to other objects (relations) (AdV, 2008).

Spatial analysis of ATKIS adopts a method used to establish the 'Index of regional proportions of ecotones' (Enzian and Gutsche, 2004). Since 2002 this GIS-based register is established in German pesticide risk management. It adjusts pesticide risk mitigation measures for differences in landscape composition according to the amount of semi-natural habitats. The method involves a topological analysis of the landscape features and the land use/land cover (LULC) types represented by ATKIS. It allows the identification and quantification of transition areas between LULC types and landscape features. Transition areas are grouped into (1) transition areas with direct proximity of two LULC types (e.g. the zone between a crop field and grassland, crop field and settlement, crop field and forest) and (2) indirect proximity of two LULC types interrupted by streams, ditches, hedges, roads etc.

3 Assumptions

3.1 General economic framework

The Thünen-Baseline 2013 to 2023 builds on external projections for macroeconomic developments from 2013 to 2023, as compiled in secondary sources like the USDA (2011, 2012). The baseline scenario is characterized by an annual growth of the world economy of 3.3 %, and a more modest growth in Germany (1.75 % p. a.). World population growth is projected to increase by 1 % p. a., while the population in Germany is slightly declining (-0.2 % p. a.). The baseline scenario assumes that the Euro continuously gains in value compared to the US-Dollar, resulting in an exchange rate of 1.41 $/€ in 2023 (EU-Commission, 2013). As international trade mostly takes place in US-Dollar, this lowers world market prices from the point of countries of the Eurozone.

Inflation in Germany remains low at 1.7 % p. a. Agricultural land in Germany is assumed to continue to be lost at an annual rate of -0.1 %, accompanied by structural change at historic rates with a decline of farm numbers by -3.4 % each year. The assumptions for the development of input prices in Germany are generally based on historical trends from 2003 to 2012. For energy inputs, the oil price projections used in the OECD-FAO-outlook (2013) are applied, which imply continuously high price increases (+3.1 % p. a). Due to the high importance of energy costs for the production of nitrogen fertilizers, fertilizer prices were also linked to the price forecasts of oil.

World market price projections[2] for agricultural products from the OECD-FAO (2013) are used as a calibrated basis in the AGMEMOD model to establish price developments in the EU and Germany. For the projection period international prices for livestock products, expressed in Euro, rise further (+10 % to +30 %) compared to the already high price level in 2009 to 2011, whereas world market prices for crop products decrease slightly.

3.2 Policy framework

The baseline assumes a continuation of the current policy framework and the implementation of already decided policy changes. For the Thünen-Baseline 2013 to 2023, this implies the implementation of the EU-CAP reform decided in 2013 and its national implementation according to the decisions made at the German Ministers of Agriculture conference. The most important policy assumptions of the baseline can be summarised as follows:

- Trade policy framework: The baseline accounts for the EU accession of Croatia, and numerous bilateral trade agreements which will be implemented over the following years (e.g. with countries in South America and North Africa and the Balkan states).
- Price and quota policies: EU regulation No. 1308/2013 foresees a safety net with public intervention mechanisms for selected products. In addition, the EU commission has at its disposal a reserve fund for crisis prevention and management measures, to be able to react to general market disturbances. The Thünen-Baseline presumes that neither these measures nor export support for milk products are applied during the projection horizon due to the prevailing world market conditions. The baseline scenario takes into consideration the stepwise increase of the milk quota until 2013/14 and its abolishment in 2015. The sugar market reform is implemented based on the study by Gocht et al. (2012), and covers the end of the quota regime in 2017 while maintaining border protection. In view of the OECD-FAO projection of world market prices, an EU-internal sugar price of 390 €/t in 2023 results from these calculations.
- Direct payments of the first CAP pillar: The redistribution of funds between EU member states, the national redistribution of 4.5 % of the budget to the second pillar, and support for young farmers lead to a base payment of 175 €/ha and a greening payment of 85 €/ha. To support smaller farms, a top-up is granted of 50 €/ha for the first 30 ha and 30 €/ha for the next 16 ha.
- Greening: Eligibility for a part of the direct payments depends on the fulfillment of the so-called 'greening' requirements. These comprise protection of permanent grasslands, minimum crop diversity and provision of ecological focus areas (EFA). For the Thünen-Baseline it is assumed that the share of EFA remains fixed at 5 % of arable area throughout the projection period, and that all options for elements counting as ecological focus area are accepted in Germany.
- Support measures of the second CAP pillar: The cut of EU funds for second pillar measures in Germany is compensated by the national redistribution of funds from the first pillar. The baseline assumes that the distribution to individual measures remains unchanged compared to the previous finance period.
- Support for bioenergy: Electricity stemming from biogas is supported in Germany by the Renewable Energy Sources Act (EEG), which guarantees a certain price for electricity generated from renewable energy sources. It is expected that the amendment to the EEG in 2012 will slow down the expansion of biogas plants (Gömann et al., 2013), leading to a demand for 1.2 million ha of energy maize in 2023. Taking into account projections for fuel demand, it is assumed that the new policy framework will reduce demand for biofuels until 2015, with only a modest increase in the following years, whereas demand for ethanol from cereals remains constant.

2 All price developments refer to nominal prices.

4 Results

4.1 Changes in agricultural trade pattern

Macroeconomic developments as well as changes in the political framework (e.g. the implementation of bilateral trade agreements, the end of milk and sugar quota regimes, biofuel targets) influence trade flows in the baseline. Figure 2 provides an overview of the changes in world trade between 2010 and 2023. Total agricultural exports increase from 702 bn € in 2010 to 843 bn € in 2023. The share of EU-28 internal-trade as a percentage of world agricultural trade decreases from 30 % to 26 %. EU exports to non-EU countries increase slightly from 70 bn € to 76 bn €.

A regional disaggregation (Figure 3) shows that EU-exports increase to all regions with the exception of the Commonwealth of Independent States (CIS). Exports to CIS-countries are projected to stagnate as a consequence of expected population decline and the related impacts on demand. Imports from Central and South America, Asia and Africa increase markedly due to the implementation of trade agreements with the EU, which offer export opportunities for the respective countries. Imports from North America and Oceania do not change significantly.

4.2 Farm gate prices

In addition to world market prices and macroeconomic developments, the (politically influenced) demand for

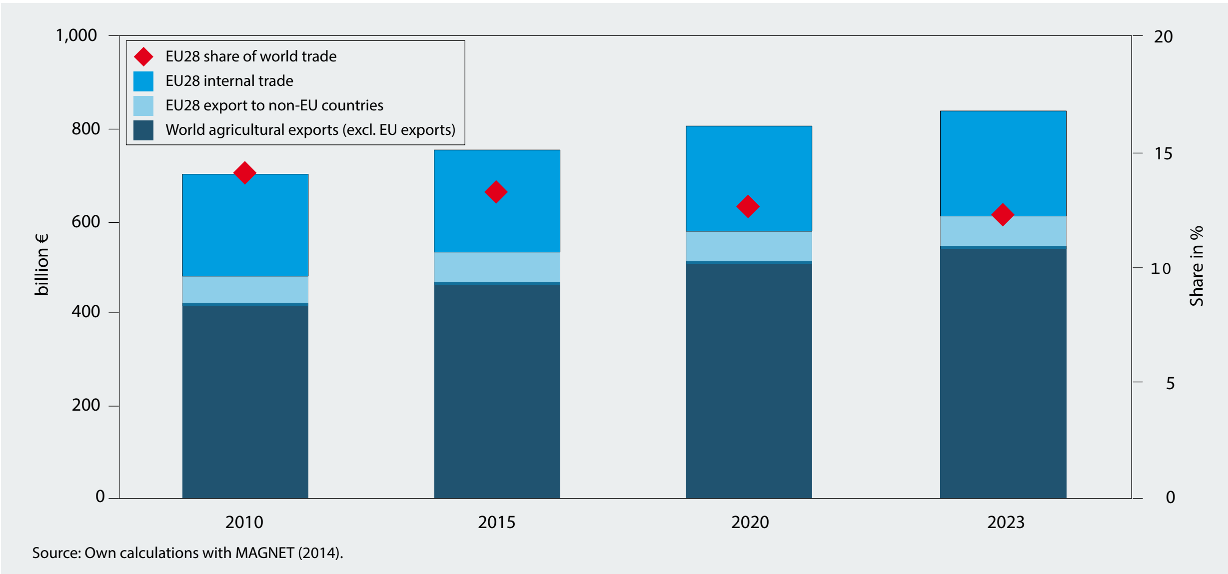


Figure 2:
Agricultural world trade and share of EU-28 (exports)

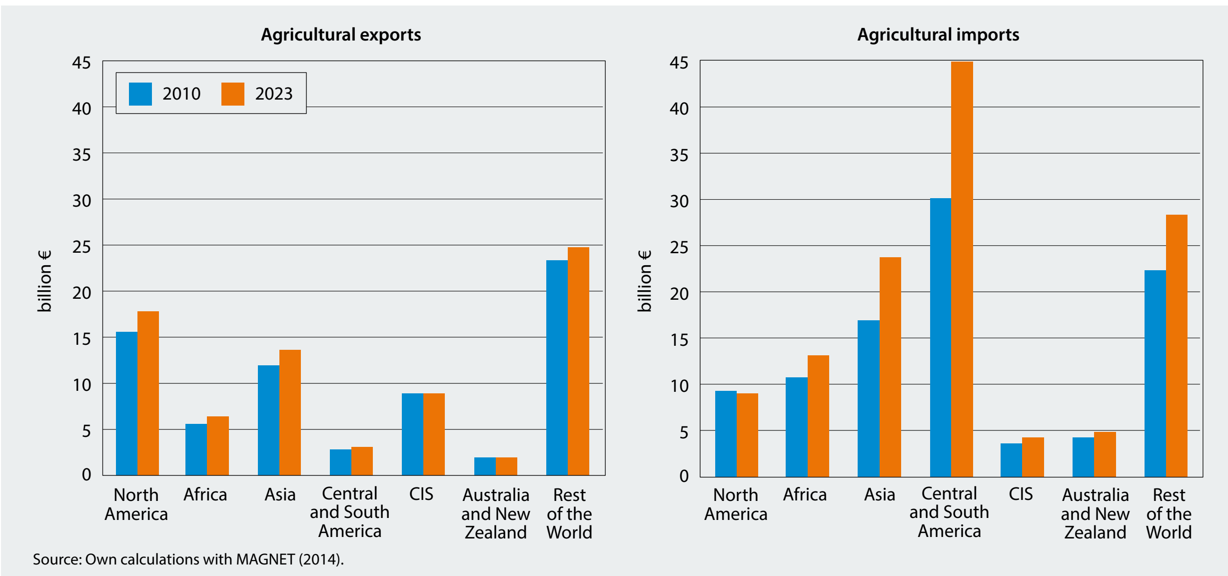


Figure 3:
Agricultural exports and imports of EU-28 in 2010 and 2023

biofuels and biogas is a further important determinant of prices for agricultural products in Germany.

Wheat prices are projected to decrease slightly during the beginning of the projection period (Figure 4), and then remain constant at around 200 €/t, thus being significantly higher than intervention prices. Feed cereal (e.g. maize, barley) prices stabilize at the comparatively high level of approximately 170 €/t. World market developments support prices for rapeseed in Germany. Therefore, despite the drop in domestic demand for rapeseed for biofuels, the decrease of the rapeseed price is moderate and prices remain rather constant at 370 €/t. This means that the rapeseed price is significantly lower than in the record year 2012, but 11 % higher than during the period 2009 to 2011.

Solid demand from the world market leads to an increase in nominal prices for livestock products of 10 to 30 % in 2023 compared to the period 2009 to 2011. In Germany, an increase in beef production as a consequence of higher dairy cow numbers following the end of the quota regime dampens the price development for beef. The broiler prices shown in Figure 4 represent wholesale prices. The prices on farm gate level are expected to rise less dynamically due to an assumed substantial increase in the trade margin that could already be observed in the past.

The developments in the dairy sector are strongly influenced by the end of the quota scheme. Despite currently quite strong world market prices, a decrease of prices until 2015/16 can be expected. The extent of this decrease can however not be projected with the equilibrium models used for this study. In the subsequent period until 2023, prices for milk products are projected to remain stable despite the anticipated production increase, due to a persistent demand from abroad. The farm gate price for milk stands at 33 €/100 kg milk with 3.7 % fat and 3.4 % protein (excluding VAT). Prices for cheese increase, not least due to rising production costs. Whole milk powder production is expanded following an increased demand from Asia, which towards the end of the projection period diminishes the price differentiation between whole and skimmed milk powder. The butter price in Germany follows world market trends and remains comparatively stable after 2015.

4.3 Agricultural production

Table 1 provides an overview of the development of land use and agricultural production in the Thünen-Baseline. Despite the projected increase of cereal prices by about 27 % in 2023 compared to the average of the period 2009 to 2011, cereal area decreases slightly (-7 %). This is due to the increase of energy maize to approximately 1.2 million ha, and the continuing loss of agricultural land. Within the cereal production, there is a marked shift to wheat growing, with a decrease of the area used for more extensively grown cereals like summer barley. This shift in cropping structure and the increase of yields over time lead to an increase of cereal production by approximately 50 million t by 2023, despite the smaller

Table 1

Development of production, land use and income in German agriculture

	Unit	1999	2007	2010	Baseline 2023	Baseline 2023 vs. 2009/11
		Absolute				in %
Land use						
Cereals	1,000 ha	6,840	6,830	6,662	6,184	*-7*
Wheat	1,000 ha	2,706	3,131	3,257	3,607	*11*
Barley	1,000 ha	2,196	1,948	1,706	1,378	*-19*
Rye	1,000 ha	851	664	667	452	*-32*
Oilseeds	1,000 ha	1,137	1,408	1,409	1,369	*-3*
Potatoes	1,000 ha	298	270	259	297	*15*
Pulses and root crops	1,000 ha	804	732	731	680	*-7*
Silage maize	1,000 ha	1,203	1,017	1,050	1,027	*-2*
Other arable fodder	1,000 ha	469	599	750	688	*-8*
Energy maize	1,000 ha	51	444	809	1,217	*50*
Set aside [1]	1,000 ha	720	593	244	601	*146*
Cattle	1,000 head	14,831	12,749	12,772	12,951	*1*
of which: Dairy cows	1,000 head	4,765	4,123	4,191	4,308	*3*
Milk production[2]	1,000 t	26,768	28,057	30,051	35,372	*18*
Beef and veal production	1,000 t	1,396	1,136	1,221	1,207	*-1*

[1] Incl. unused grasslands.

[2] Actual fat and protein content.

Source: Own calculations with RAUMIS (2014).

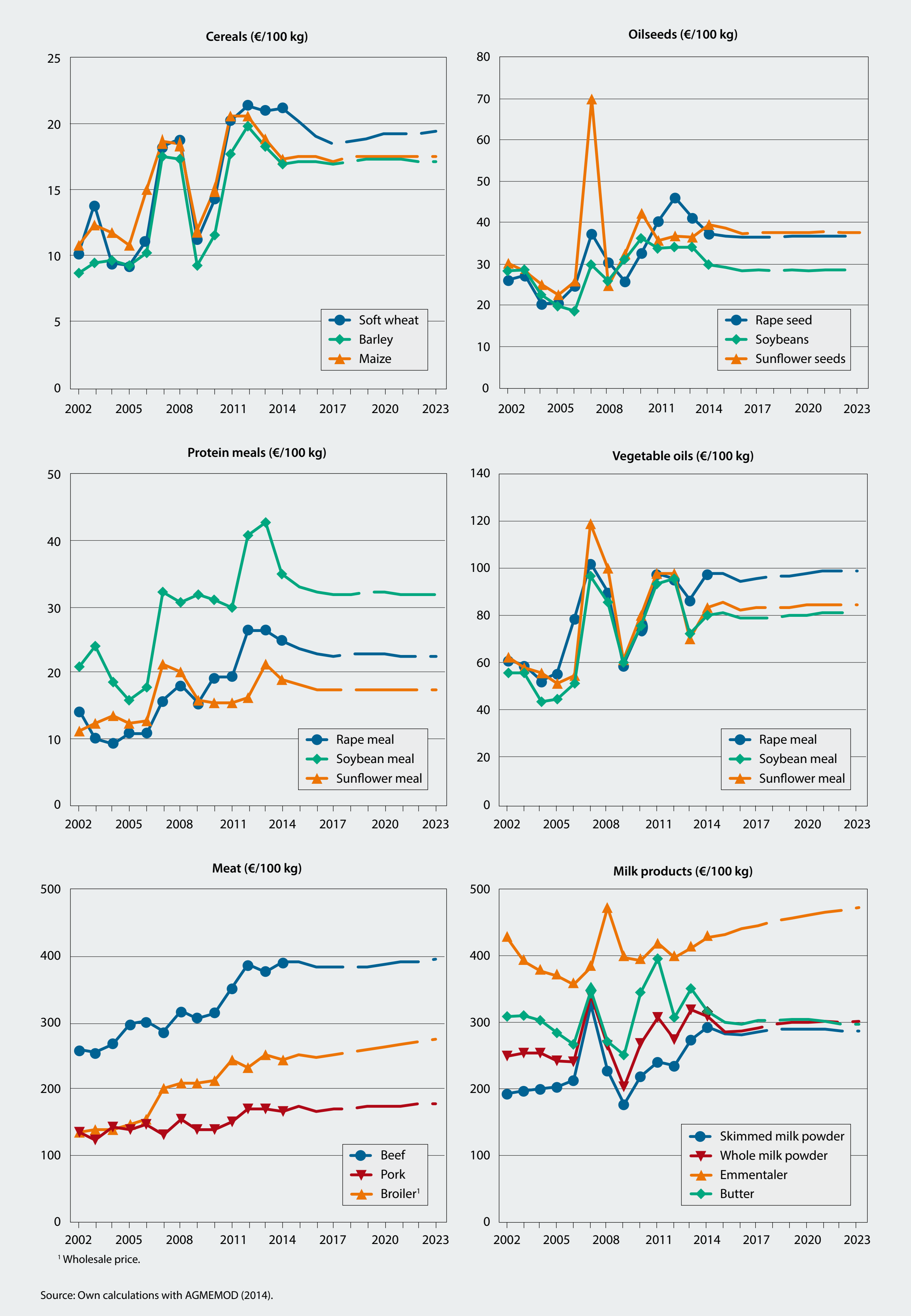


Figure 4:
Development of farm gate prices in Germany

cropping area. Oilseed areas remain constant, while production increases by 4 %. Silage maize and other arable fodder area is slightly reduced, as fodder yield increases while cattle numbers remain more or less constant.

With the abolishment of the milk quota and rising milk prices, milk production increases to 34.5 million t by 2023. Compared to the period 2009 to 2011, this corresponds to a growth of milk output in Germany by 18 %. Breaking the historic trend, dairy cow numbers increase slightly. Total cattle numbers – and thus beef production – remain almost constant.

The observable trend of a regional concentration of dairy production accelerates following the end of the dairy quota system. On average, milk production increases by 300 kg/ha UAA from 2009/11 to 2023. According to the model results, an above-average expansion of dairy production will take place in the coastal regions and in the lower Rhine region, in some middle mountain areas, as well as in the Allgäu and pre Alpine regions (Map 1). These grassland and lower-yielding arable crop areas have generally shown a particularly competitive dairy production in the past, and already exhibit high dairy production densities. A withdrawal from dairy production can in particular be observed on arable locations, such as for example the Cologne-Aachen area, the Hildesheim plain and the northeast of Brandenburg. In addition, some grassland regions lose production shares. This affects, for example, the Black Forest as well as parts of Hesse, and thus grassland regions that have proven to be less competitive for dairy production in the past and in which dairy production has been declining. These regions are often found near urban centres which offer comparatively good off-farm job opportunities.

The share of milk production produced in farms with larger dairy herds further increases significantly. This trend is especially marked in the northern regions, where over 90 % of the milk is produced in farms with more than 60 cows in 2023. Many farms with smaller herds either exit milk production, or use the opportunities offered by the end of the milk quota scheme to enlarge their herds. In the southern regions, this leads to an increased importance of medium-sized farms, which in the baseline provide approximately 50 % of the regional production.

4.4 Income

The following analysis of income developments at the farm level focuses on the indicator 'farm net value added (FNVA) per agricultural working unit (AWU)'. FNVA measures the return to the factors land, labour and capital, and is put in relation to the amount of labour input to account for differences and changes in farm size. All income figures are adjusted for inflation and refer to 2010 prices.

Compared to the base period of 2009/10 to 2011/12 (Figure 5), the average FNVA/AWU increases by 13 %, and is thus markedly higher than average income over the last ten years. The decrease of farm gate prices in real terms and the reduction of direct payments are partly offset by multiple factors:

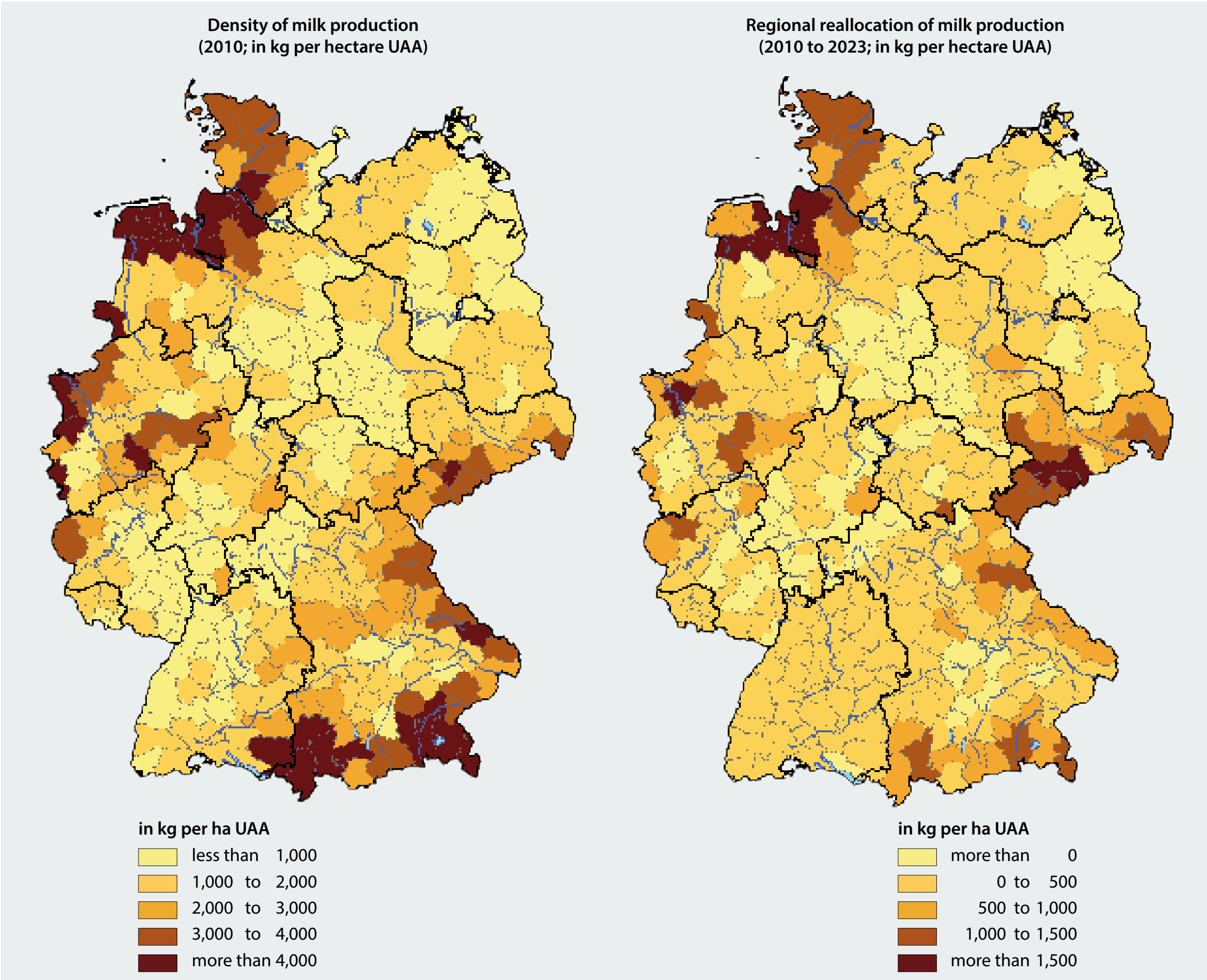
- the opportunities for an increase of milk production following the end of the quota scheme;
- the growing importance of income generation from producing energy maize for biogas generation;
- lower costs for protein feed;
- the continuing structural change, with high exit rates especially of small farms with below-average income potential and the resulting opportunity for growth for remaining farms;
- the reduced labour requirements as a consequence of technical change; and
- improvements in crop and dairy yields.

The large differences in the income of farms of different size observed in the base period persist. However, income developments differ by farm type (Figure 5), which can be mainly attributed to the different price developments for agricultural products (Section 4.2). In addition, the reduction of direct payments, the introduction of nationally uniform basic and greening payments and the redistributive payments for smaller farms lead to changes in support payments whose size and direction strongly depend on region (federal state) and individual farm characteristics (e.g., volume of direct payments in base period and land area).

On the one hand, arable farms are especially affected by the strong increase of fertilizer and energy prices and the decrease of prices for rape and sugar beet. On the other hand, they benefit from the still growing demand for energy maize. The average land area of arable farms increases markedly, due to the high exit rates of small arable farms with lower incomes. Overall, income of arable farms stabilizes at the comparatively high level of the base period. Dairy farms profit from the elimination of quota costs and a strong increase in the average milk production quantity. Despite an above-average reduction of direct payments, the income of dairy farms rises by 24 % and thus reaches a level comparable to that of arable farms. Due to the increase in prices for farm inputs, other grazing livestock farms cannot increase their income above the low level of the base period (–3 %) despite the positive developments of beef prices. Mixed and pig and poultry farms profit from rising pork and poultry prices in the Thünen-Baseline. In addition, pig and poultry farms are less affected by the reduction and reformation of direct payments than other farm types. While on average farms receive 50 €/ha less than in the base period, the payments in pig and poultry decrease by only 5 €/ha. Income increases by 11 % in mixed and 44 % in pig and poultry farms. However, higher regulatory requirements are currently under discussion, e.g. as part of the fertilizer directive, and could increase production costs for these farms in the future.

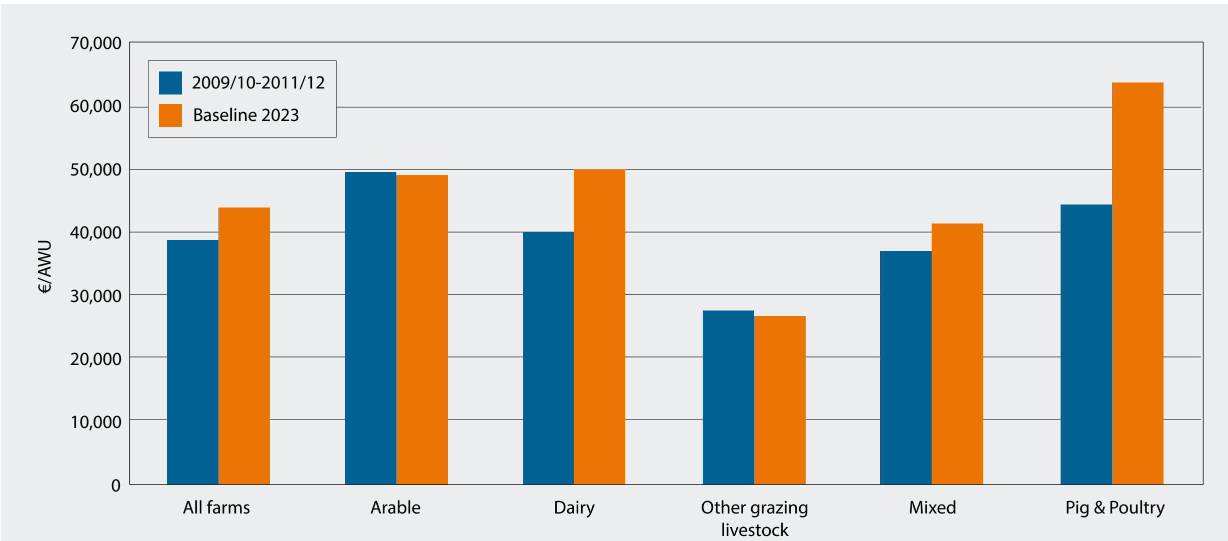
The increase of rental prices for grassland especially affects other grazing livestock farms due to the high share of grasslands in combination with an often high share of rented land. According to the model results, rents are projected to increase strongly especially in regions with intensive livestock farming.

The income of organically managed farms declines slightly in the baseline compared to the base year period as



Source: Own calculations based on RAUMIS (2014).

Map 1:
Regional relevance and reallocation of milk production in Germany



Source: Own calculations based on FARMIS (2014).

Figure 5:
The development of farm net value added per agricultural work unit by farm type (in real terms in prices of 2010)

shown in Figure 6. Yield and price increases and relative gains from the reform of direct payments are generally not sufficient to compensate rising input prices. Only organic arable farms increase their income (+9 %), which is mainly due to the growing size of the average farm in the wake of structural change. The FNVA/AWU decreases in organic dairy (-4 %), other grazing livestock (-14 %) and mixed farms (-11 %).

4.5 Environmental impacts

One of the key indicators for the environmental impacts of agriculture is the N-surplus, which the difference between all nutrient inputs and outputs on agricultural land. For the soil surface nitrogen balance, inputs include mineral and organic fertilizers, atmospheric deposition, and symbiotic and asymbiotic N-fixation, while output refers to the quantity of nitrogen in harvested crop production. A positive balance or surplus reflects inputs that are in excess of crop and forage needs. A modified calculation of the N-surplus is used to assess the potential impact of excess nitrogen on water, by subtracting nitrogen loss through the volatilization of ammonia to the atmosphere from livestock housing and stored manure.

Compared to the historic developments during the past decade, the trend of declining livestock numbers is not sustained in the baseline scenario, while the increase of biogas production leads to a rise in the quantity of nitrogen from fermentation residues, which has a lower utilization rate than mineral fertilizers. Inputs from organic fertilizers increase by 13 % in 2023 (Table 2), while inputs from mineral fertilizers stagnate due to higher fertilizer prices and increased nitrogen use efficiency . Overall, the sectoral nitrogen soil surface surplus remains almost constant at 70 kg/ha UAA.

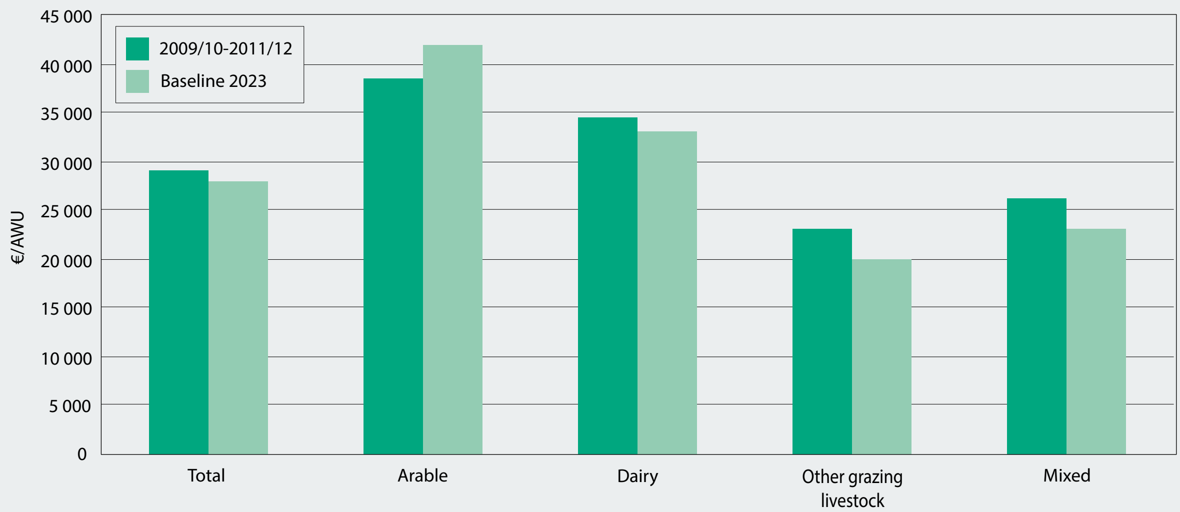
Regional nitrogen balances are to a large extent influenced by the amount of regionally produced manure and energy maize. Map 2 provides an overview of regional stocking rates and nitrogen from livestock excretions and fermentation residues from biogas production in 2023. Stocking rates vary greatly, with an average of 0.9 livestock units (LU) per ha, and values of more than 2 LU/ha in the northwest of Germany. High nitrogen inputs from organic fertilizers are projected especially for the northwestern part of Germany, and some regions in Schleswig-Holstein and Bavaria. While average nitrogen input from organic fertilizers are around 94 kg N/ha UAA, values exceeding 300 kg N/ha UAA are observed in some regions with intensive livestock production in Lower Saxony.

Ammonia is one of the most important airborne pollutants. Directive 2001/81/EC of the European Parliament and

Table 2
Development of the nitrogen balance

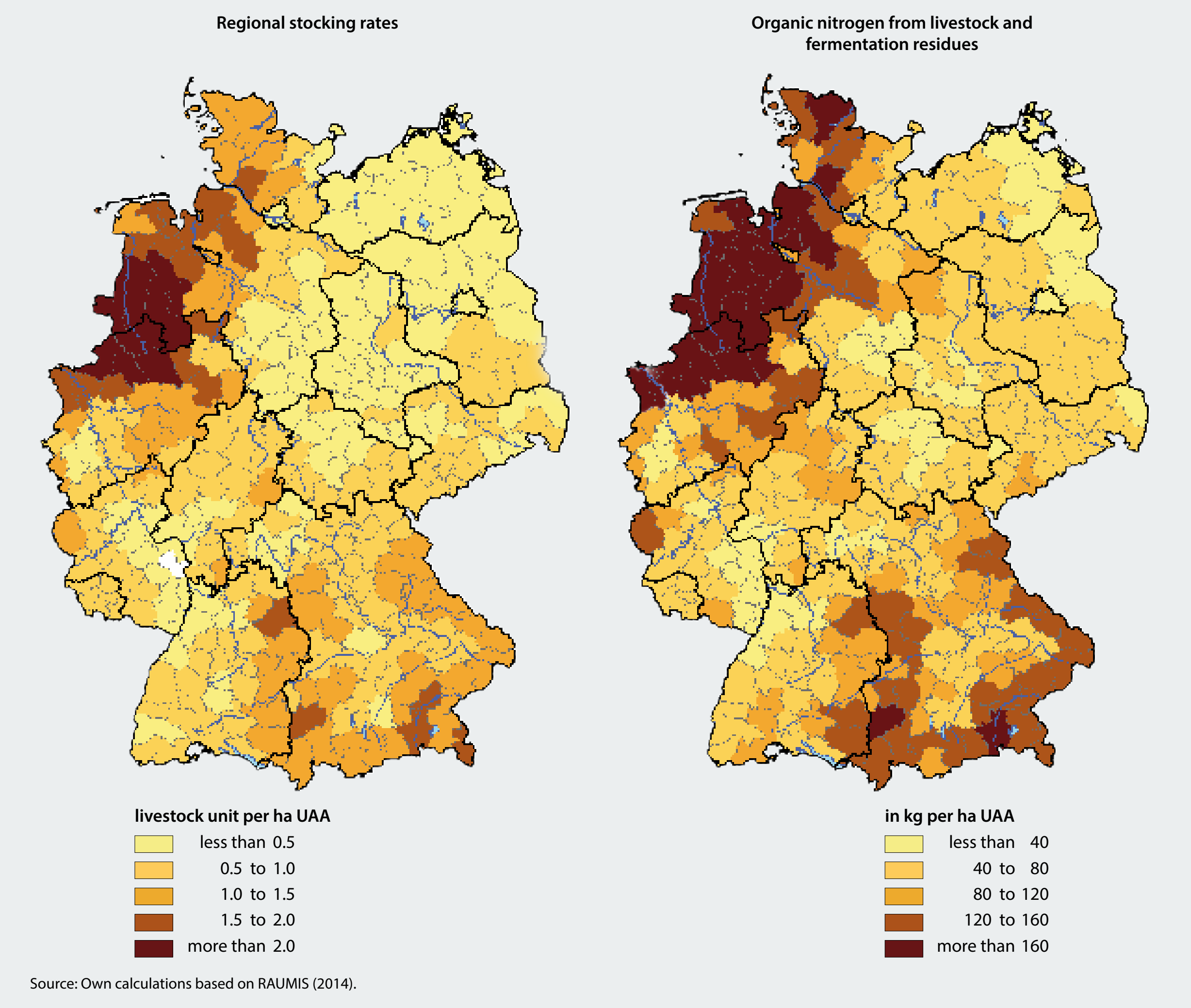
Elements of the nitrogen balance	2009/2011 (kg N/ha UAA)	2023 (kg N/ha UAA)	Change in % to 2009/11
Inputs			
Organic fertilizer	81	94	13
Mineral fertilizer	98	98	0
Symbiotic fixation Asymbiotic fixation Asymbiotic deposition	36	35	-1
Total inputs	215	229	6
Outputs/losses			
N in harvested yields Ammonia losses	-146	-159	8
Nitrogen balance (soil surface balance)			
Denitrification Leaching Accumulation in soils	69	70	2

Source: Own calculations based on Raumis (2014).



Source: Own calculations based on FARMIS (2014).

Figure 6:
The development of farm net value added per agricultural work unit in organic farms (in real terms in prices of 2010)



Map 2:
Regional stocking rates and organic nitrogen from livestock and fermentation residues (2023)

the Council on National Emission Ceilings for certain pollutants (NEC Directive) foresees a reduction of ammonia emissions in Germany to less than 550,000 t after 2010. The European Commission already suggested further reductions. Figure 7 provides an overview of the past and projected development of ammonia emissions in Germany. The reduction of livestock numbers in the eastern part of Germany in the early 1990s, the continuous decrease of cattle numbers and technical progress with respect to the management of organic fertilizers all have contributed to the decrease of ammonia emissions in the past. Total ammonia emissions fluctuated around the emission limit during the years 2010 to 2012. The emissions are projected to increase again above the limit until 2023 due to an increase in livestock numbers. Ammonia emissions from storage and spreading of fermentation residues from biogas production are not yet accounted for in the guidelines for emission calculations. These could add another 40,000 t of ammonia emissions per year. The projections thus highlight that additional measures for ammonia reductions will be necessary to ensure full compliance with legal emission limits.

Greenhouse gas emissions will slightly increase (+1 %) compared to 2005, due to a small rise in cattle numbers and an increase of nitrous oxide (N_2O) emissions as a consequence of a higher turnover of nitrogen in soils.

5 Relevance and impact of the „Greening" obligations

The exemption of very small farms from the greening obligations is relevant for only a marginal share of total arable and grassland (0.7 % and 1.6 % respectively), whereas the exemption of organic farms refers to 6 % of total agricultural area. Based on the cropping patterns of 2012, approximately 25,000 farms will need to adjust their land use by reducing the share of the dominant main crop(s) by 9 % (125,000 ha in total). In the majority of the concerned farms, farmers have to reduce the share of either maize or winter wheat.

In Germany, in total 550,000 ha are required to fulfill the obligations for EFA. Current fallow land already accounts for 100,000 ha; however its regional distribution is quite uneven

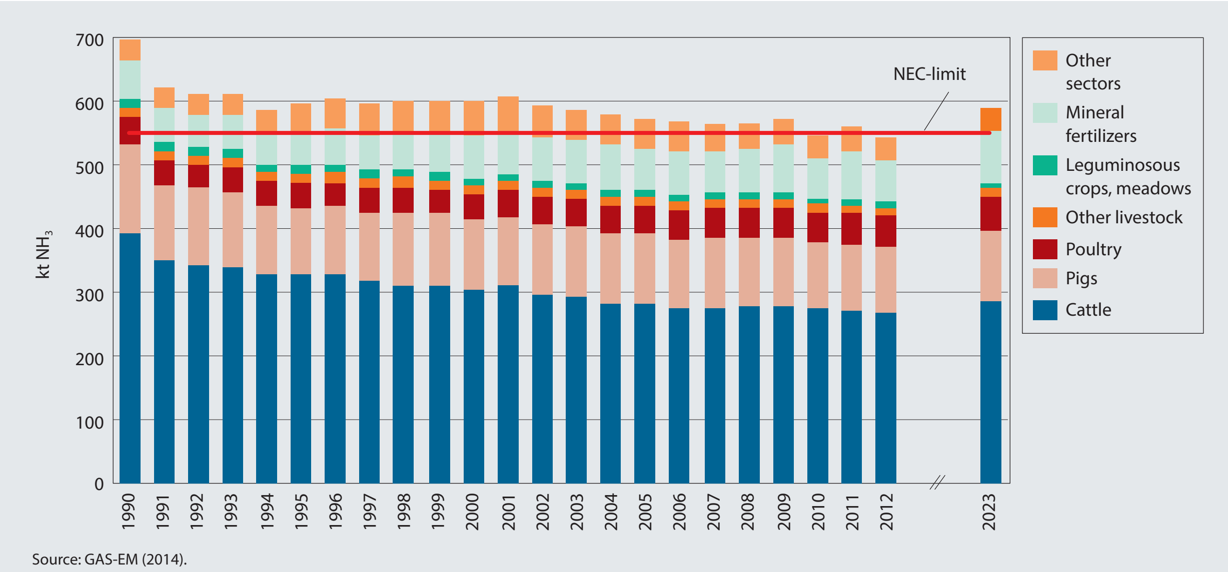
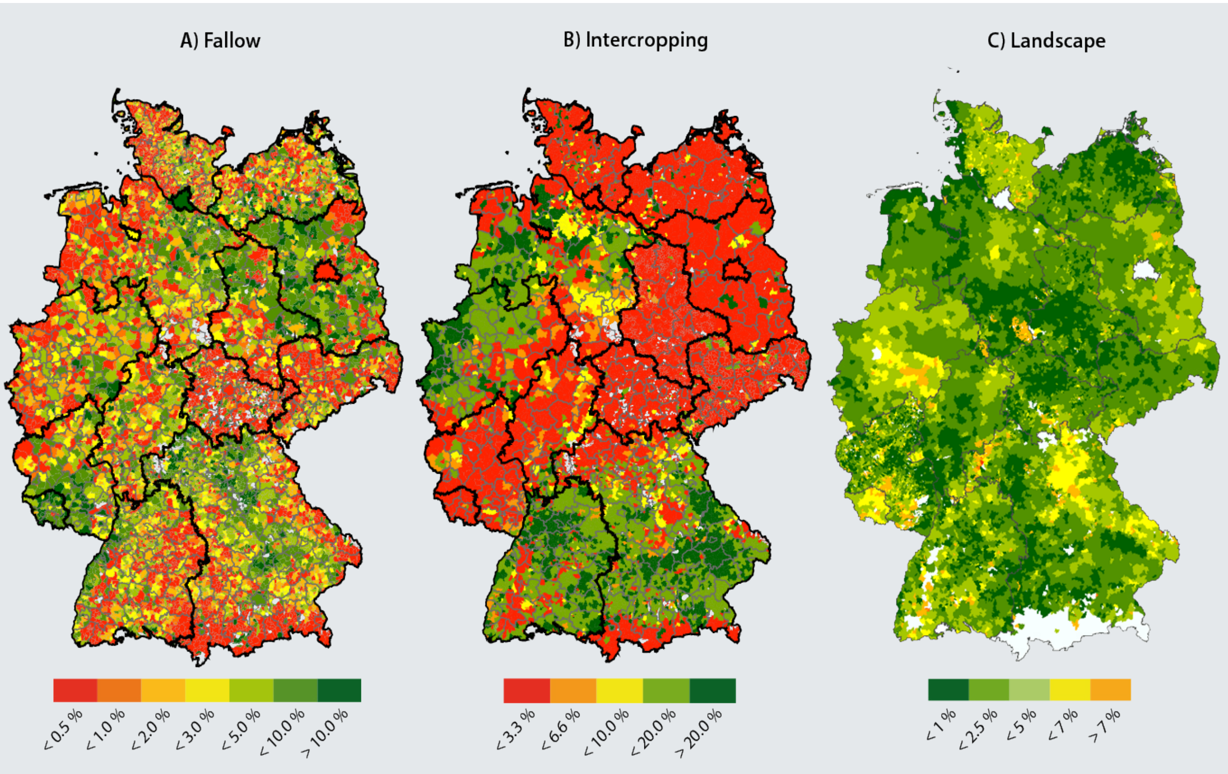


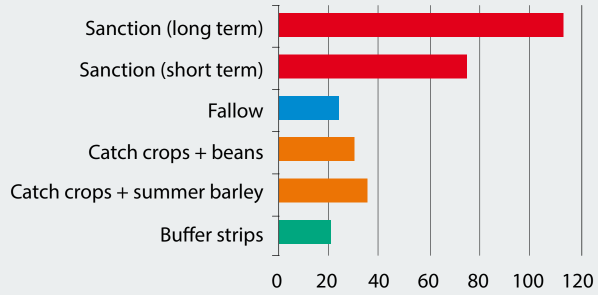
Figure 7:
Development of ammonia emissions in Germany



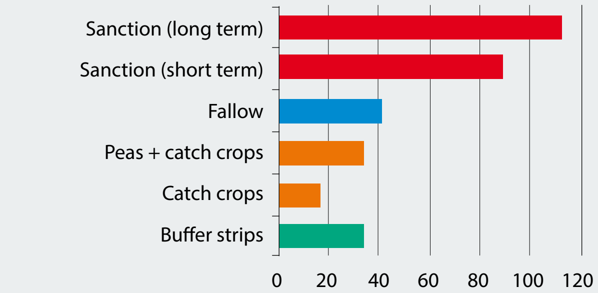
Map 3:
Regional shares of fallow land, intercropping / catch crops and landscape elements as percentage of arable area

(Map 3, A). Taking into account the eligibility of leguminous crops, current cropping levels could provide another 100,000 ha of EFA. Especially the eligibility of catch (or inter-tillage) crops can significantly reduce the impact of the EFA obligations. In 2010, catch crops were grown on 1.2 million ha (Statistisches Bundesamt, 2011), with high shares especially in northwestern and southern Germany (Map 3, B). Taking into account existing fallows as well as leguminous and catch crops, only 40,000 ha (<0.4 % of arable area) remain. Depending on the region, existing landscape elements cover 1.5 to 4.6 % of the arable area (Map 3, C). The data shows that even at smaller regional levels the existing

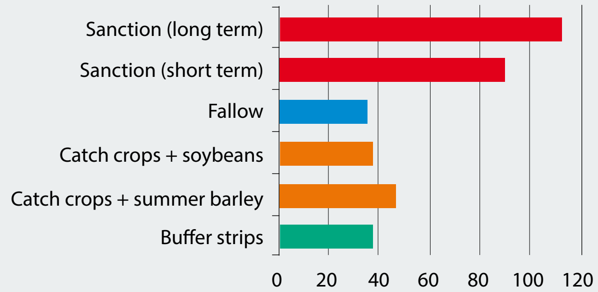
Adjustment costs of the **arable farm in Ostholstein** range from 21 to 36 €/ha UAA, and are thus considerably lower than sanctions (75 to 113 €/ha). The best option combines the inclusion of barley in the crop rotation and buffer strips to fulfill the EFA obligation. Fallow is also a competitive option, as it fulfills both crop diversity and EFA requirements. Catch crops however are an expensive option for this farm, as the necessary introduction of summer crops reduces whole farm gross margin.



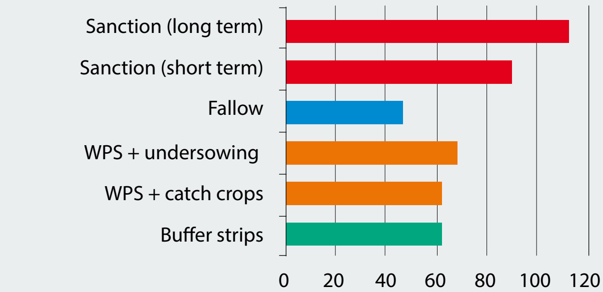
For the **arable farm in southern Lower Saxony**, cost are lowest (17 €/ha UAA) if catch crops are used to fulfill EFA obligations and barley is grown to extend crop rotations. The reason is that this farm already grows mustard before sugar beets, and only needs to replace mustard by a seed mixture. The alternative options are more than twice as costly (34 to 42 €/ha UAA). Not fulfilling the greening obligations would lead to losses of 90 to 113 €/ha.



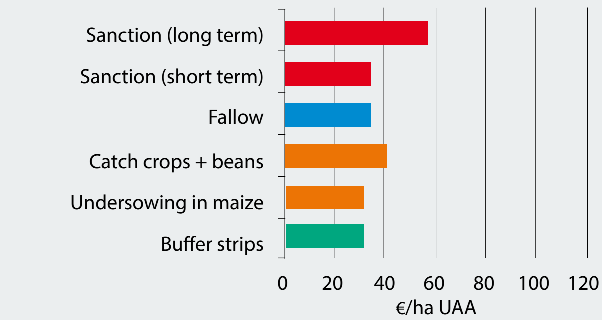
The best option for the **arable farm in Saxony-Anhalt** is to leave some land fallow. This strategy only causes costs of 36 €/ha UAA. The options of buffer strips as EFA and barley for extending the crop rotation, or the combination of catch crops and soybeans are, however, only marginally more expensive (38 €/ha). Thus, greening could promote cultivation of soybeans in some regions.



Adjustments costs of the **bull fattening farm in North Rhine-Westfalia** range from 47 to 69 €/ha UAA, while sanctions would lead to losses of more than 100 €/ha UAA in the long run. Based on the calculations the combination of fallow and purchase of fodder maize is the most competitive option. The reason is a) that maize purchase is comparatively cheap, and b) gross margin loss of wheat is comparatively small. However, as the availability of fodder maize is generally limited, in most cases one the alternative options will be realized.



The **dairy farm in Schleswig-Holstein** would face sanctions equal to 35 €/ha UAA in the short run if greening obligations are not fulfilled. As this is only slightly higher than the adjustment costs (32 to 41 €/ha UAA), it could be beneficial for the farm not to participate in (part of) the greening payments, especially if regional availability of maize is poor or maize prices are high. However, in the long run, sanctions would increase to 57 €/ha UAA. In this situation, growing ley grass and rye silage as well as catch crops on part of the maize area will become the best option.



Source: Own calculations based on TIPI-CAL and TYPICROP (2014).

Figure 8
Cost of adjustments to greening obligations in €/ha UAA

levels of eligible land use and landscape elements suffice to fulfill the EFA requirements of the greening obligations.

It is therefore expected that overall, the impact of the greening obligations will be limited. However, depending on the circumstances, the obligation may require a noticeable change of land use in individual farms. We investigate five constellations of intensive farms which are particularly affected by one or more of the greening obligations to illustrate the related impacts at farm level and to analyze the profitability of different potential adjustment strategies (Figure 8).

6 Reflection of results, assumptions and model restrictions

The results of a baseline projection depend on the assumptions on the development of exogenous factors and the assumptions on biophysical and economic causalities inherent in the model specifications. This chapter aims to reflect the results of the Thünen-Baseline against the outcome of similar projections of the EU-Commission (2013), to identify the key uncertainties in model assumptions and specifications and to discuss their implications for the results.

The projections of domestic price levels of the EU-Commission (2013) and the Thünen-Baseline are quite similar. For cereals, absolute prices in the target year are very close, though the gap to respective world market prices is higher in the EU-Commission projections. The price developments for oilseeds and protein meals are also very similar. For meat and milk, the Thünen-Baseline projections of prices in Germany are a bit lower than the prices projected by the EU-Commission for the EU market (Figure 9), which reflects differences in the development of regional market and supply conditions. Milk production is projected to increase strongly in Germany, which explains a lower national price. As a consequence of the slight increase in beef production and the sluggish development of respective demand in Germany, beef prices are projected to increase less than in the EU-Commission's outlook. Increasing competition from imported pigs for slaughtering restricts the increase of farm gate pork prices in Germany in the Thünen-Baseline.

The Thünen-Baseline relies on a number of assumptions concerning the development of factors and variables not explicitly covered in the models used. Some of the areas concerned are characterized by high uncertainties:

- While the basic elements of the reform of the EU-CAP 2014 to 2020 have been decided, the final design of many regulatory details as well as their national implementation were still under discussion at the time of this study. Especially the final implementation of greening requirements may differ from the assumptions made for this study, which could impact the results of the model projections. In addition, the still open decisions of other member states concerning the degree of remaining coupled payments could also affect agriculture in Germany. With respect to trade agreements, the impact of the currently negotiated free trade agreement with the United States on trade as well as on production is an important issue.
- Uncertainty also exists with respect to the development of the oil price, which affects the prices of agricultural inputs as well as, via the so-called „bushel-barrel-correlation," the level of world market prices for agricultural products.

All the models used for this study are based on a detailed depiction of policies and economic relationships and interdependencies in agricultural production. They have successfully been applied for many policy impact analyses (e.g., Gömann et al., 2008; Gocht et al, 2012), and are continuously developed further. Still, due to specific model characteristics and restricted data availability, it is inevitable that some policy instruments or new technical developments cannot be modelled, or only in a simplified way. The most important restrictions in this respect are:

- The static models are not explicitly taking into account short-term fluctuations, e.g., of world market prices. During the last years, especially world market prices of milk fluctuated markedly within a single year, often due to climate events in some export countries. These effects are not covered.
- The end of the milk quota scheme, which restricted milk quantities in the EU for 30 years, represents a structural break, whose impacts are difficult to project, especially during the first years. Higher price fluctuations may occur, in particular if climatic events or demand shifts occur during this period. These phenomena cannot be projected with the used model system, which is simulating equilibrium markets.
- Supply and demand of agricultural products for energy production is currently not comprehensively modelled. Thus, the area cropped with energy maize is determined by the current and the expected expansion of the number of biogas plants.
- New methodological guidelines for the calculation of gaseous emissions will lead to changes in the results for greenhouse gas emissions (obligatory implementation of new guidelines in 2015; IPCC, 2006) and ammonia emissions (new Guidebook, EEA, 2013) in the future.

7 Conclusions

Overall, the Thünen-Baseline 2013 to 2023 draws a picture of a competitive agricultural sector in Germany, which adapts well to the changes of the latest policy reform and seizes the opportunities for expanding production, especially in the dairy sector. On the other hand, the projections also highlight that the problems that may accompany intensive livestock production will not simply dissolve. In view of the projected high profitability of intensive pig and poultry production the related challenges could even increase.

The Thünen-Baseline 2013 to 2023 provides the basis for subsequent policy impact analysis. Potential future studies include the analysis of the impacts of adjustments to the CAP following the midterm review in 2017, as well as the investigation of a more fundamental reform after 2020.

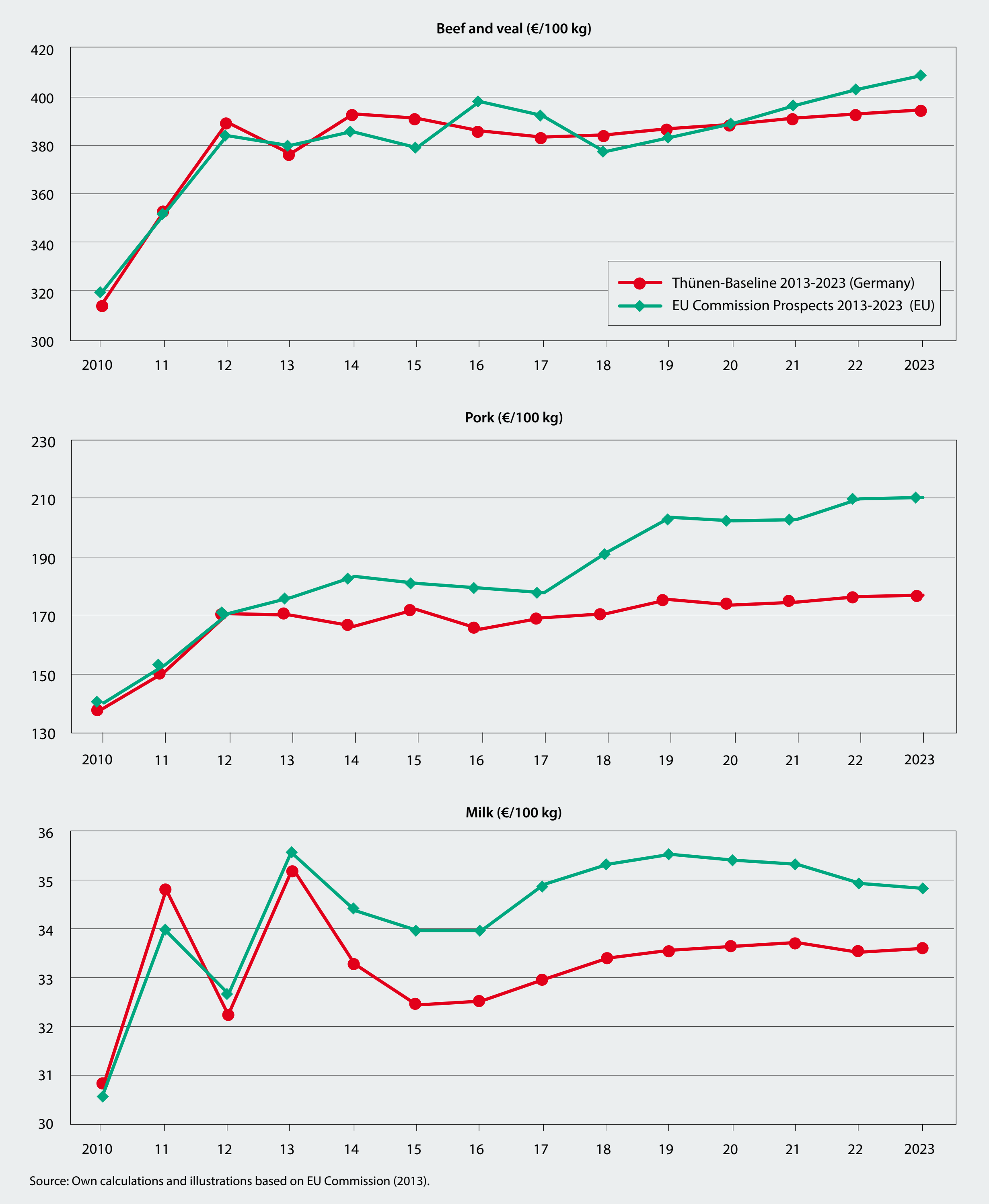


Figure 9
Comparison of price projections for meat and milk – Thünen-Baseline 2013–2023 vs. EU-Commission prospects (2013)

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Der Einfluss länderspezifischer Berechnungsverfahren auf den betrieblichen Nährstoffvergleich gemäß Düngeverordnung

Andrea Machmüller* und Albert Sundrum*

Zusammenfassung

Mit der vorliegenden Untersuchung sollte der Frage nachgegangen werden, ob durch die Anwendung der länderspezifischen Berechnungsverfahren bei der Erstellung des betrieblichen Nährstoffvergleichs eine Gleichbehandlung landwirtschaftlicher Betriebe in Deutschland gewährleistet ist. Von 16 Betrieben lagen die betrieblichen Nährstoffvergleiche von 2012 mit den zugrundeliegenden Rohdaten vor. Die Rohdaten aller 16 Betriebe wurden über das Programm AODüngeverordnung jeweils in 11 länderspezifische Berechnungsverfahren eingegeben. Folgende Variablen wurden ausgewertet: (1) Stickstoff-(N)-Saldo, N-Zufuhr über mineralische und organische Düngemittel, N-Bindung durch Leguminosen sowie N-Abfuhr über Erntegut; und (2) Phosphat-(P)-Saldo, P-Zufuhr über mineralische und organische Düngemittel sowie P-Abfuhr über Erntegut. Die Ergebnisse zeigen auf, dass eine Reproduzierbarkeit des betrieblichen Nährstoffsaldos bei Anwendung der unterschiedlichen Berechnungsverfahren nicht gegeben ist. Im berechneten N-Saldo ergab sich für die Betriebe ein mittlerer Variationskoeffizient von 187 %, im berechneten P-Saldo von 37 %. Die maximalen Spannweiten bei der Berechnung des N- und P-Saldos lagen innerhalb eines Betriebes bei 91 kg N/ha bzw. 23 kg P_2O_5/ha. Die Variationsursachen für die Streuung der N- und P-Salden waren betriebsindividuell. Das Berechnungsverfahren selbst hatte auf alle Variablen, mit Ausnahme der N- und P-Zufuhr über mineralische Düngemittel, einen signifikanten Einfluss. Aus den Ergebnissen der vorliegenden Untersuchung wird abgeleitet, dass aufgrund der unterschiedlichen, länderspezifischen Berechnungsverfahren eine Gleichbehandlung der landwirtschaftlichen Betriebe in Deutschland in Hinblick auf die Erstellung des betrieblichen Nährstoffvergleichs derzeit nicht gegeben ist.

Schlüsselworte: *EU-Nitratrichtlinie (91/676/EWG), Düngeverordnung, betrieblicher Nährstoffvergleich, Stickstoff, Phosphat, Saldo*

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Abstract

The effect of German federal state-specific calculation methods on the farm nutrient comparison according to the German fertilizer application ordinance

The aim of the present investigation was to answer the question if there is an equal treatment of German farms despite using federal state-specific calculation methods to generate the farm nutrient comparison. From 16 farms the farm nutrient comparisons for 2012 and the underlying raw data were available. The raw data of all 16 farms have been typed into 11 federal state-specific calculation methods using the software AODüngeverordnung. The following variables have been evaluated: (1) nitrogen-(N)-balance, N-input through mineral or organic fertilizer, N-binding through legumes as well as N-output through harvest; and (2) phosphate-(P)-balance, P-input through mineral or organic fertilizer as well as P-output through harvest. The results show that when using different calculation methods a reproducibility of the farm nutrient balances is not given. In the calculated N-balance, the farms had an average coefficient of variation of 187 % and for the calculated P-balance an average coefficient of variation of 37 %. Within one farm the maximum range for the calculated N- and P-balances was 91 kg N/ha and 23 kg P_2O^5/ha, respectively. The variation causes for the variance of the N- and P-balances have been farm specific. The calculation method itself had a significant effect on all variables except for the N- and P-input through mineral fertilizer. From the results of the present investigation it can be derived that due to the different federal state-specific calculation methods an equal treatment of German farms in terms of the generation of the farm nutrient balance is currently nonexistent.

Keywords: *EU Nitrates Directive (91/676/EEC), German fertilizer application ordinance, farm nutrient comparison, nitrogen, phosphate, balance*

1 Einleitung

Gemäß Düngeverordnung (DüV, 2007) sind landwirtschaftliche Betriebe in der Bundesrepublik Deutschland verpflichtet, jährlich einen betrieblichen Nährstoffvergleich für Stickstoff und Phosphat für das abgelaufene Düngejahr als Flächenbilanz oder aggregierte Schlagbilanz zu erstellen (§ 5 Abs. 1) und der nach Landesrecht zuständigen Stelle vorzulegen (§ 6 Abs. 1). In der Flächenbilanz werden bezogen auf die gedüngte landwirtschaftliche Nutzfläche eines Betriebes die Summe der Nährstoffzufuhren in einem Bilanzzeitraum von 12 Monaten mit der Summe der Nährstoffabfuhr im gleichen Bilanzzeitraum verglichen. Die Differenz zwischen Nährstoffzufuhr und -abfuhr entspricht dem betrieblichen Nährstoffsaldo. Die Obergrenze des betrieblichen Nährstoffsaldos bzw. Nährstoffüberschusses liegt für Stickstoff (N) derzeit bei 60 kg N/ha und Jahr (Durchschnitt der drei letzten Düngejahre; DüV, 2007, § 6 Abs. 2) und für Phosphat bei 20 kg P_2O_5/ha und Jahr (Durchschnitt der sechs letzten Düngejahre; DüV, 2007, § 6 Abs. 2).

Die Bund-Länder-Arbeitsgruppe zur Evaluierung der Düngeverordnung plädierte in ihrem Abschlussbericht dafür (Osterburg und Techen, 2012), dass bei Überschreitung dieser Obergrenzen zukünftig (1) eine kostenpflichtige Beratungspflicht des betroffenen Betriebes entsteht, (2) bei wiederholten oder hohen Überschreitungen der Obergrenzen behördliche Anordnungen angewendet werden und (3) eine Verletzung der Beratungspflicht oder behördlichen Anordnungen als Ordnungswidrigkeit geahndet wird. Für schärfere Sanktionen bei Verstößen sprachen sich auch die Wissenschaftlichen Beiräte für Agrarpolitik (WBA) und für Düngungsfragen (WBD) beim Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz (BMELV) sowie der Sachverständigenrat für Umweltfragen der Bundesregierung (SRU) in ihrer Kurzstellungnahme zur Novellierung der Düngeverordnung aus (WBA/WBD/SRU, 2013). Die Umsetzung juristisch relevanter Sanktionen setzt jedoch voraus, dass es bei der Berechnung des betrieblichen Nährstoffsaldos eine Gleichbehandlung aller Betriebe gibt.

Mit Einführung der Düngeverordnung (DüV, 1996) wurde die Aufgabe der Umsetzung der Bundesverordnung den einzelnen Bundesländern übertragen. Dies führte zu länderspezifischen Berechnungsverfahren für die Erstellung des betrieblichen Nährstoffvergleichs. Erst 2006, mit der Neufassung der Düngeverordnung (DüV, 2007), wurde den Bundesländern mit den Anlagen ein umfassender Wertekatalog vorgeschrieben (u. a. für den Stickstoffgehalt pflanzlicher Erzeugnisse (Anlage 1) und den Nährstoffanfall bei landwirtschaftlichen Nutztieren (Anlage 5)). Im Abschlussbericht der Bund-Länder-Arbeitsgruppe zur Evaluierung der Düngeverordnung (Osterburg und Techen, 2012; Anhang 3, A3.5 Nährstoffvergleiche – Methoden und Salden) wird daher für die Erstellung der betrieblichen Nährstoffvergleiche angenommen, dass eine bundeseinheitliche Vorgehensweise in der Regel sichergestellt ist, da die Rechenwege und die zu verwendenden Daten in den Anlagen der DüV (DüV, 2007) weitgehend vorgegeben sind. Diese Annahme wurde aber bislang noch nicht anhand von Praxisdaten überprüft, da eine solche Überprüfung voraussetzt, dass betriebliche Einzeldaten verfügbar gemacht werden (Osterburg, 2013). Mit der vorliegenden Untersuchung sollte daher der Frage nachgegangen werden, ob bei der Berechnung des betrieblichen Nährstoffsaldos eine bundeseinheitliche Vorgehensweise bzw. eine Gleichbehandlung deutscher Betriebe gewährleistet ist.

2 Material und Methoden

Die vorliegende Untersuchung ist Teil eines umfangreicheren Projektes zur systemischen Erfassung und Optimierung der Nährstoffeffizienz auf milchviehhaltenden Betrieben. Der Untersuchung lagen betriebliche Einzeldaten von 16 milchviehhaltenden Betrieben aus dem Jahr 2012 zugrunde. Tabelle 1 gibt einen Überblick über die Eckdaten der 16 Betriebe. Die Anzahl der Milchkühe variierte auf den Betrieben von 69 bis 1.119 Milchkühe. Die Milchleistung lag zwischen 7.498 und 10.563 kg ECM/Kuh und Jahr (ECM, energiekorrigierte Milchleistung, Milch mit 4 % Fett- und 3,4 % Eiweißgehalt). Bei der den Betrieben zur Verfügung stehenden landwirtschaftlichen Nutzfläche ergab sich eine Spannweite von 61 bis 2.612 ha mit einer Variation im Grünlandanteil von 0 bis 67 %. Die 16 Betriebe verteilten sich auf insgesamt 9 Bundesländer (Tabelle 2).

Von jedem der 16 Betriebe lag der betriebliche Nährstoffvergleich für 2012 inklusive der zugrunde liegenden Rohdaten vor. Die Rohdaten umfassten detaillierte Informationen (1) zum Tierbestand: Anzahl Tiere und Haltungsbedingungen (Gülle, Mist oder Weide), (2) zum Düngemitteleinsatz: Art und Menge verkaufter bzw. an andere Betriebe abgegebener organischer Düngemittel und Art und Menge zugekaufter bzw. aus anderen Betrieben aufgenommener organischer oder mineralischer Düngemittel, sowie (3) zum pflanzlichen Erntegut: angebaute Pflanzenarten, Flächen und Erträge. Für das Management des Tierbestandes benutzen alle Betriebe das Programm „Herde" von dsp-Agrosoft GmbH (Paretz, Parkring 3, 14669 Ketzin). Von allen Betrieben lag eine Datensicherung mit den Tierbestandsdaten von 2012 vor.

Zur Berechnung des betrieblichen Nährstoffvergleichs gemäß Düngeverordnung wurde das Programm „AODüngeverordnung" verwendet. AODüngeverordnung ist ein Teil von AOAgrar-Office und somit ein Softwareprodukt der LAND-DATA Eurosoft GmbH & Co. KG (Rennbahnstr. 7, 84347 Pfarrkirchen). Für die vorliegenden Auswertungen wurde die Programmversion 1.13.12.926 mit dem Module Stand vom 15.04.2013 verwendet, d. h. die zu diesem Zeitpunkt aktuelle Version für die Erstellung des betrieblichen Nährstoffvergleichs 2012. In AODüngeverordnung werden nach Angaben des Softwareherstellers immer die aktuellsten gesetzlichen Ländervorgaben zur Erstellung des betrieblichen Nährstoffvergleichs eingearbeitet (Schlegel, 2013). Länderspezifische Vorgaben gibt es in AODüngeverordnung für folgende 11 Bundesländer: Baden-Württemberg, Bayern, Brandenburg, Hessen, Mecklenburg-Vorpommern, Niedersachsen, Nordrhein-Westfalen, Rheinland-Pfalz, Sachsen, Sachsen-Anhalt und Thüringen. Keine länderspezifischen

Tabelle 1
Eckdaten der 16 Betriebe, Bezugsjahr 2012

Betriebe	Milchkühe Anzahl	Milchleistung kg ECM/Kuh und Jahr	Nutzfläche ha	Ackerfläche ha	Grünlandfläche ha	Grünlandfläche % der Nutzfläche
1	93	9.291	113	67	46	41
2	69	9.075	61	49	12	20
3	974	8.463	1.399	1.024	375	27
4	371	10.563	1.752	1.694	58	3
5	445	9.207	1.253	1.086	167	13
6	137	8.462	143	74	69	48
7	128	8.746	128	75	53	42
8	444	9.664	1.432	1.412	20	1
9	137	8.860	187	101	85	46
10	729	8.640	767	641	127	17
11	196	9.355	271	271	0	0
12	207	9.380	235	78	157	67
13	1.119	8.956	2.612	1.907	705	27
14	146	7.498	101	37	64	63
15	437	9.947	889	861	28	3
16	920	9.189	1.475	1.260	215	15
Median	**289**	**9.132**	**519**	**456**	**66**	**23**
Mittelwert	**409**	**9.081**	**801**	**665**	**136**	**27**
Standardabweichung	**345**	**691**	**774**	**659**	**179**	**22**

Tabelle 2
Verteilung der 16 Betriebe auf die Bundesländer

Bundesländer	Betriebe Anzahl
Brandenburg	3
Hessen	2
Niedersachsen	2
Nordrhein-Westfalen	2
Rheinland-Pfalz	1
Sachsen	2
Sachsen-Anhalt	2
Schleswig-Holstein	1
Thüringen	1
Summe	**16**

Tabelle 3
Verwendete Berechnungsverfahren zur Bestimmung des N-Saldos der Betriebe

Berechnungsverfahren	Nr
Baden-Württemberg	1
Bayern	2
Brandenburg	3
Hessen	4
Mecklenburg-Vorpommern	5
Niedersachsen	6
Nordrhein-Westfalen	7
Rheinland-Pfalz	8
Sachsen	9
Sachsen-Anhalt	10
Thüringen	11

Zuordnung der restlichen Bundesländer:
Berlin wie Sachsen
Bremen, Hamburg und Schleswig-Holstein wie Nordrhein-Westfalen
Saarland wie Rheinland-Pfalz

Vorgaben liegen für die restlichen fünf Bundesländer (Bremen, Schleswig-Holstein, Hamburg, Saarland und Berlin) vor. Für Bremen, Schleswig-Holstein und Hamburg gibt es im Programm AODüngeverordnung eine Verknüpfung zu den länderspezifischen Vorgaben von Nordrhein-Westfalen, das Saarland ist mit den länderspezifischen Vorgaben von Rheinland-Pfalz verknüpft und Berlin mit denen von Sachsen.

Die von den 16 Betrieben vorliegenden Rohdaten wurden im Programm AODüngeverordnung zur Berechnung des betrieblichen Nährstoffvergleichs in die Eingabemasken der Bundesländer eingegeben, bei denen das Programm länderspezifische Vorgaben ausweist (11 Berechnungsverfahren, Tabelle 3). Das bedeutet, es wurden 11 Mal die gleichen betrieblichen Rohdaten eingegeben und für jeden der 16 Betriebe 11 länderspezifische, betriebliche Nährstoffvergleiche berechnet bzw. 11 Berechnungsverfahren angewendet. Insgesamt ergaben sich damit 16 x 11 = 176 Datensätze.

Bei der Eingabe der betrieblichen Rohdaten sind in der Auswahl- bzw. Eingabemöglichkeit des Tierbestandes und des geernteten Pflanzenmaterials Unterschiede zwischen den länderspezifischen Berechnungsverfahren aufgefallen. In Bezug auf das geerntete Pflanzenmaterial: (1) bei 12 Berechnungsverfahren müssen die Grünlanderträge als Trockenmasseerträge angegeben werde, bei 4 Berechnungsverfahren (3, 5, 7 und 10) als Frischmasseerträge; (2) der Leguminosenanteil im Grünland konnte bei 4 Berechnungsverfahren (1, 4, 7 und 8) nicht angegeben werden; (3) für Silomais gab es bei den Berechnungsverfahren 3, 5, 9 und 10 nur die Möglichkeit einen Trockenmassegehalt von 28 % anzuwählen; und (4) die Eingabe von Nebenernteprodukten wie Strohbergung bei Getreide oder Blattbergung bei Zuckerrüben war nur bei Berechnungsverfahren 1 anwählbar. Hinsichtlich der Eingabe der Tierbestandsdaten unterschieden sich die Bundesländer in der Eingabemöglichkeit der Tierart und Tierklasse (Alters- oder Leistungsgruppen). Es wurden vier unterschiedliche Eingabemöglichkeiten (Tiergruppierungen) identifiziert: (1) Berechnungsverfahren 3, 4, 5, 8 und 10: Kühe, Nachzucht 0-27 Monate und Nachzucht über 27 Monate; (2) Berechnungsverfahren 1, 2 und 7: Kühe, Nachzucht in Altersstufen 0-6, 7-12, 13-24 und über 24 Monaten; (3) Berechnungsverfahren 6: Kühe, Nachzucht in Altersstufen 0-4, 5-27 und über 27 Monaten; sowie (4) Berechnungsverfahren 9 und 11: Kühe, Nachzucht in Altersstufen 0-3, 4-6, 7-12, 13-24 und über 24 Monaten. Darüber hinaus wurde festgestellt, dass im Berechnungsverfahren 3, 4, 5, 8 und 10 „Milchkühe mit 0,9 Kälber“ anzugeben waren und in Berechnungsverfahren 1, 2, 6, 7, 9 und 11 Milchkühe ohne Kalb, d. h. eine separate Angabe der Kälber erforderlich war. Auch in der Abstufung der Milchleistung unterschieden sich die Berechnungsverfahren. Im Berechnungsverfahren 2 konnte die durchschnittliche Jahresmilchleistung der Kühe kilogrammgenau eingegeben werden, in Berechnungsverfahren 1, 10 und 11 musste die Milchleistung der Kühe des Betriebes in 1.000 kg-Abstufungen eingeordnet werden und in Berechnungsverfahren 3, 4, 5, 6, 7, 8 und 9 gab es zur Einordnung nur eine 2.000 kg-Abstufung in der Milchleistung. Die benötigten Angaben zu den Tiergruppen gemäß länderspezifischen Vorgaben wurden für die einzelnen Betriebe aus der Betriebsdatensicherung zum Programm Herde ausgelesen. In der Anlage 5 der DüV (DüV, 2007) wird für die Milchviehhaltung eine dreigeteilte Tiergruppierung angegeben: (1) Kälberaufzucht, 0-16 Wochen; (2) Jungrinderaufzucht, Erstkalbealter 27 Monate; und (3) Milchkuh mit 0,9 Kälbern und einer 2.000 kg-Abstufung in der Milchleistung.

Für die nachfolgenden statistischen Auswertungen in Excel (Microsoft Excel 2010) und SPSS (IBM SPSS Statistics 20) wurden folgende Variablen betrachtet: (1) Stickstoff-(N)-Saldo (kg N/ha), N-Zufuhr über (a) mineralische Düngemittel (kg N/ha) und (b) organische Düngemittel (kg N/ha), N-Bindung durch Leguminosen (kg N/ha) sowie N-Abfuhr über Erntegut (kg N/ha); und (2) Phosphat-(P)-Saldo (kg P_2O_5/ha), P-Zufuhr über (a) mineralische Düngemittel (kg P_2O_5/ha) und (b) organische Düngemittel (kg P_2O_5/ha), sowie P-Abfuhr über Erntegut (kg P_2O_5/ha). Der Wert für die N-Zufuhr über organische Düngemittel ergab sich aus der Verrechnung des N-Anfalls in Form des Wirtschaftsdüngers tierischer Herkunft aus dem eigenen Tierbestand abzüglich des N-Verkaufs bzw. Abgangs von Wirtschaftsdünger, zuzüglich des N-Zukaufs bzw. Zugangs von organischen Düngemitteln und abzüglich der N-Verluste aus der Lagerung und Ausbringung der organischen Düngemittel. Diese Verfahrensweise wurde gewählt bzw. war für die Vergleichbarkeit der Daten nötig, da in der Zusammenstellung der Daten zum betrieblichen Nährstoffvergleich nur bei vier Berechnungsverfahren (2, 4, 7 und 8) „gasförmige N-Verluste“ bzw. „Ausbringverluste“ separat ausgewiesen wurden, bei den restlichen Berechnungsverfahren aber nicht.

Innerhalb der 16 Betriebe wurde (1) zur Beurteilung der Reproduzierbarkeit der Variablen des betrieblichen Nährstoffvergleichs über die 11 unterschiedlichen Berechnungsverfahren der Variationskoeffizient bestimmt und (2) zur Erklärung einer mögliche Streuung im N-Saldo der Korrelationskoeffizient (Pearson) zwischen N-Saldo und den für die Berechnung des N-Saldos zugrundeliegenden Variablen ermittelt. Darüber hinaus wurde innerhalb der 11 Berechnungsverfahren zur Beurteilung möglicher Unterschiede zwischen den Berechnungsverfahren für alle Variablen die Abweichung der betrieblichen Einzelwerte zum Durchschnittswert des jeweiligen Betriebes berechnet und anschließend eine einfaktorielle Varianzanalyse mit Mittelwertvergleich (Tukey-B-Test) durchgeführt. Der über die 11 Berechnungsverfahren ermittelte Durchschnittswert des jeweiligen Betriebes wird im Rahmen der vorliegenden Untersuchung als die bestmögliche Schätzung für den unbekannten „wahren“ Wert angesehen.

3 Ergebnisse

3.1 Betrieblicher Nährstoffvergleich für Stickstoff

Für die 16 Betriebe ergab sich im N-Saldo im Durchschnitt ein Mittelwert von 25 kg N/ha. Den niedrigsten Mittelwert hatte Betrieb 1 (-24 kg N/ha), den höchsten Betrieb 11 (86 kg N/ha). Bei 11 der 16 Betriebe lag im Mittel ein N-Überschuss vor. Eine Übersicht über die Variabilität der kalkulierten N-Salden der 16 Betriebe bei Anwendung der 11 unterschiedlichen Berechnungsverfahren gibt Abbildung 1. Die Streuung innerhalb der Betriebe war zum Teil beträchtlich. Die Spannweite zwischen dem niedrigsten und dem höchsten Wert im berechneten N-Saldo lag zwischen 8 kg N/ha (Betrieb 15) und 91 kg N/ha (Betrieb 14), im Mittel bei 43 kg N/ha. Für den Variationskoeffizienten im N-Saldo ergaben sich Werte zwischen 6 % (Betrieb 4) und 2.236 % (Betrieb 12), im Mittel von 187 %. Abbildung 2 zeigt einen exponentiellen Zusammenhang zwischen dem Variationskoeffizienten und dem Absolutwert des betrieblichen N-Saldo-Mittelwerts. Je näher der betriebliche N-Saldo dem Wert Null kam, desto höher war der Variationskoeffizient im berechneten N-Saldo bei Anwendung der 11 verschiedenen Berechnungsverfahren.

Tabelle 4 gibt die Mittelwerte, Standardabweichungen, Spannweite und Variationskoeffizienten der N-Zufuhr,

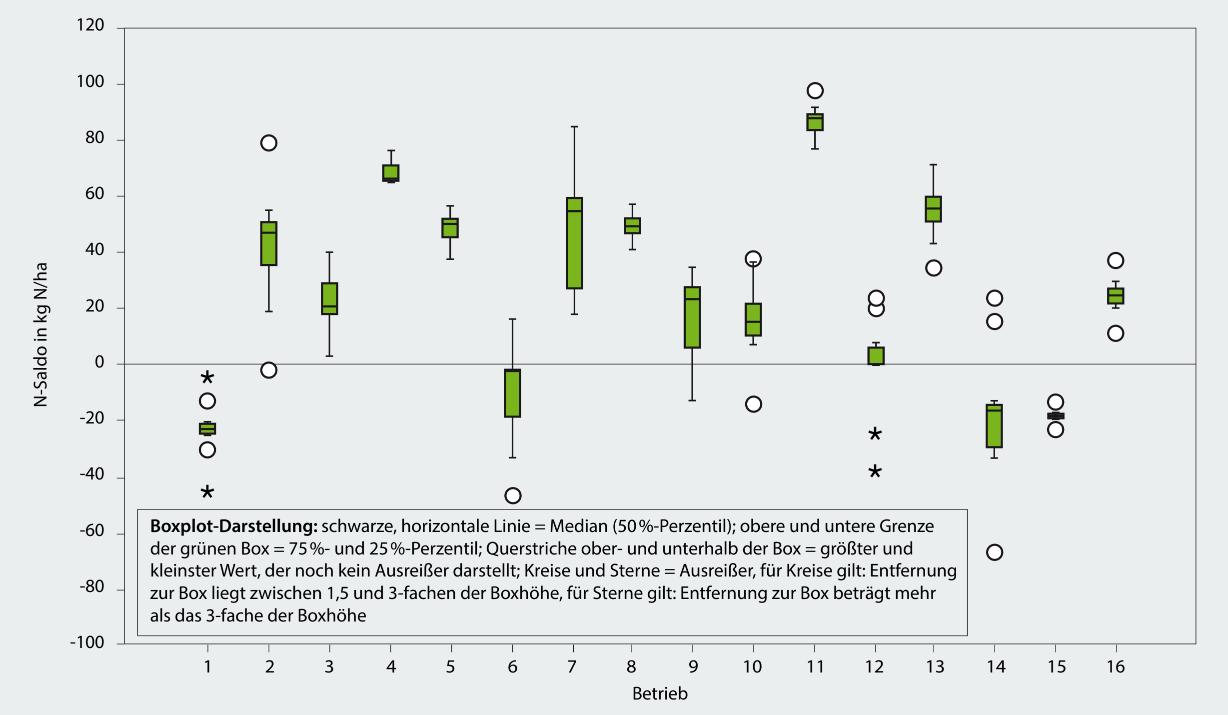

Abbildung 1
Variabilität der N-Salden (kg N/ha) von Betrieben bei Anwendung unterschiedlicher Berechnungsverfahren (n = 11)

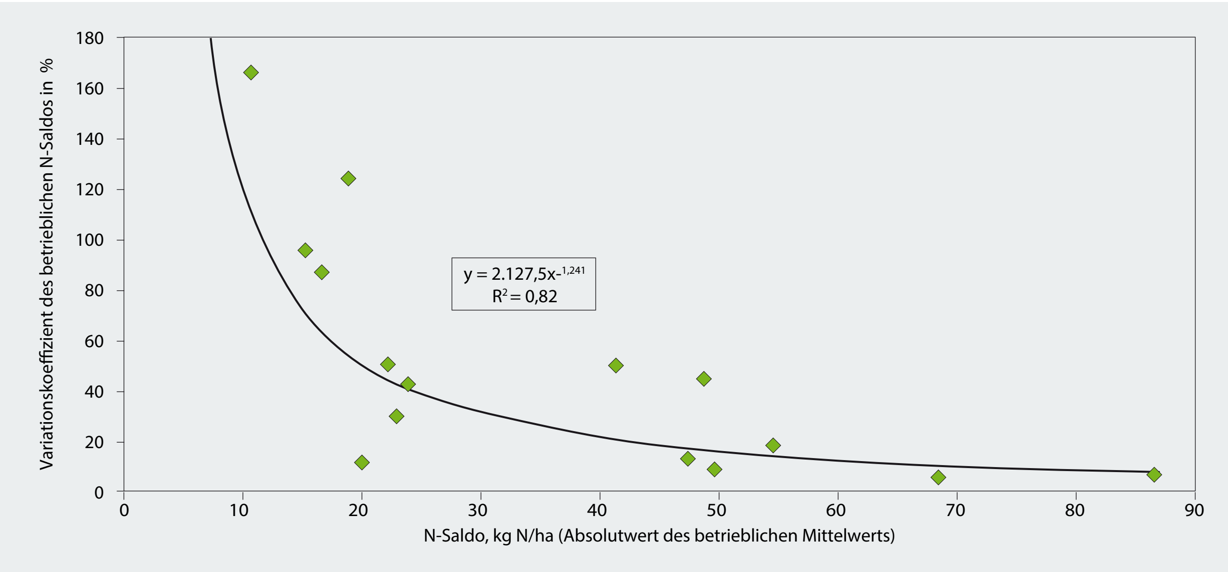

Abbildung 2
Variationskoeffizient des betrieblichen N-Saldos in Bezug zum Absolutwert des betrieblichen N-Saldo-Mittelwertes (n = 16, das Wertepaar für Betrieb 12 befindet sich außerhalb der Darstellung, Betrieb 12 hatte einen mittleren N-Saldo von -0,78 kg N/ha, eine Standardabweichung von 17,55 kg N/ha und einen Variationskoeffizient von 2.236%)

N-Bindung und N-Abfuhr der Betriebe bei Anwendung der 11 unterschiedlichen Berechnungsverfahren wieder. Bei der Berechnung der N-Zufuhr über mineralische Düngemittel ergab sich innerhalb der Betriebe keine Streuung, d. h. mit jeder der 11 Berechnungsverfahren wurde die gleiche betriebliche Einsatzmenge an Mineraldünger in kg N/ha ermittelt. Zwischen den Betrieben variierte die N-Zufuhr über mineralische Düngemittel und lag bei 7 kg N/ha (Betrieb 1) bis 184 kg N/ha (Betrieb 11). In der berechneten N-Zufuhr über organische Düngemittel variierten die Betriebe zwischen 21 kg N/ha (Betrieb 15) bis 130 kg N/ha (Betrieb 14). Innerhalb der Betriebe ergaben sich Spannweiten für die N-Zufuhr über organische Düngemittel von maximal 50 kg N/ha (Betrieb 14). Der Variationskoeffizient lag

Tabelle 4

Mittelwert, Standardabweichung, Spannweite und Variationskoeffizient der N-Zufuhr, N-Bindung und N-Abfuhr der Betriebe bei Anwendung unterschiedlicher Berechnungsverfahren (n = 11)

	Betrieb															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
N-Zufuhr über mineralische Düngemittel, kg N/ha																
Mittelwert	7	120	102	168	116	81	163	109	122	125	184	113	106	100	109	100
Standardabweichung	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Zufuhr über organische Düngemittel, kg N/ha																
Mittelwert	101	123	69	33	42	102	111	31	82	25	90	82	65	130	21	83
Standardabweichung	3	8	3	2	2	11	9	3	8	13	5	8	2	13	1	2
Spannweite	10	24	11	8	6	44	31	10	32	44	15	32	7	50	4	6
Variationskoeffizient, %	3	6	4	7	6	11	8	10	10	53	5	10	3	10	7	2
N-Bindung durch Leguminosen, kg N/ha																
Mittelwert	27	20	12	7	14	12	11	11	10	9	17	16	8	17	1	18
Standardabweichung	7	8	6	2	2	5	4	1	5	2	5	7	3	6	0	6
Spannweite	23	32	20	7	7	19	17	3	18	5	17	27	10	25	1	20
Variationskoeffizient, %	24	43	51	34	17	42	37	7	50	28	33	44	39	37	49	36
N-Abfuhr über Erntegut, kg N/ha																
Mittelwert	159	222	161	140	124	206	237	101	199	141	204	212	124	266	150	177
Standardabweichung	7	17	8	4	4	9	17	1	12	7	2	14	8	22	2	3
Spannweite	30	70	25	14	14	34	58	4	30	23	5	52	34	92	7	11
Variationskoeffizient, %	5	8	5	3	3	4	7	1	6	5	1	6	7	8	1	2

zwischen 2 % (Betrieb 16) und 53 % (Betrieb 10) und im Durchschnitt bei 10 %. In der kalkulierten N-Bindung durch Leguminosen ergab sich innerhalb der Betriebe ein mittlerer Variationskoeffizient von 36 % bei einer Variation von 7 % (Betrieb 8) bis 51 % (Betrieb 3). Die berechneten Werte für die N-Bindung reichten von 1 kg N/ha (Betrieb 15) bis 27 kg N/ha (Betrieb 1). Die Spannweite innerhalb der Betriebe lag bei der N-Bindung zwischen 1 kg N/ha (Betrieb 15) und 32 kg N/ha (Betrieb 2). Für die N-Abfuhr über Erntegut gab es zwischen den Betrieben eine Variation, die zwischen 101 kg N/ha (Betrieb 8) und 266 kg N/ha (Betrieb 14) lag. Innerhalb der Betriebe variierte die N-Abfuhr über Erntegut mit maximalen Variationskoeffizienten von 8 % (Betrieb 2 und 14) und Spannweiten, die von 4 kg N/ha (Betrieb 8) bis 92 kg N/ha (Betrieb 14) reichten.

Tabelle 5 enthält für die einzelnen Betriebe die berechneten Korrelationskoeffizienten zwischen N-Saldo und N-Zufuhr, N-Bindung sowie N-Abfuhr. Eine signifikante Korrelation zwischen N-Saldo und N-Zufuhr über organische Düngemittel konnte für Betrieb 5, 6, 7, 8, 10 und 11 nachgewiesen werden. Für Betrieb 6 ergab sich auch eine signifikante Korrelation zwischen N-Saldo und N-Bindung durch Leguminosen. Weitere signifikante Korrelationen zwischen N-Saldo und N-Bindung wurden für Betrieb 1, 3 und 16 nachgewiesen. Für 11 der 16 Betriebe ergab sich eine signifikante Korrelation zwischen den Variablen N-Saldo und N-Abfuhr über Erntegut.

Tabelle 6 gibt den Mittelwert und die Standardabweichung der Abweichungen zum betrieblichen Mittelwert im N-Saldo, in der N-Zufuhr, N-Bindung und N-Abfuhr für die 11 Berechnungsverfahren wieder. Abhängig vom Berechnungsverfahren ergab sich eine mittlere Abweichung im N-Saldo, die zwischen +11 kg N/ha (Berechnungsverfahren 11) und -15 kg N/ha (Berechnungsverfahren 7 und 10) lag. Das Berechnungsverfahren hatte einen signifikanten Einfluss auf den N-Saldo (Varianzanalyse, $p < 0{,}001$). Die Abweichung im N-Saldo waren mit dem Berechnungsverfahren 7 und 10 im Vergleich zu den anderen Berechnungsverfahren signifikant verschieden (Tukey-B-Test, $p < 0{,}05$). In der N-Zufuhr über mineralische Düngemittel ergab sich für alle Berechnungsverfahren eine mittlere Abweichung von 0 kg N/ha und damit kein Unterschied zwischen den Berechnungsverfahren. Dahingegen variierte die Abweichung in der N-Zufuhr über organische Düngemittel zwischen +3 kg N/ha (Berechnungsverfahren 1) und -6 kg N/ha (Berechnungsverfahren 7). Das Berechnungsverfahren hatte einen signifikanten Effekt auf die N-Zufuhr über organische Düngemittel (Varianzanalyse, $p < 0{,}001$). Die Abweichungen von Berechnungsverfahren 7 unterschieden sich signifikant zu sieben anderen Berechnungsverfahren (Tukey-B-Test, $p < 0{,}05$). Auch auf die Abweichungen in der ermittelten N-Bindung hatte das Berechnungsverfahren einen signifikanten Einfluss (Varianzanalyse, $p < 0{,}01$). Mit dem Berechnungsverfahren 6 wurde im Durchschnitt der 16 Betriebe immer die höchste N-Bindung ermittelt (+5 kg N/ha im Vergleich zum betrieblichen Mittelwert), mit dem Berechnungsverfahren 7 im Durchschnitt immer die niedrigste (-6 kg N/ha im Vergleich zum betrieblichen

Tabelle 5

Korrelation zwischen N-Saldo (kg N/ha) und N-Zufuhr, N-Bindung sowie N-Abfuhr innerhalb der Betriebe bei Anwendung unterschiedlicher Berechnungsverfahren (n = 11)

	Betrieb															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
NORG	0,22	0,22	0,47	0,58	0,85 **	0,84 **	0,61 *	0,96 ***	0,49	0,90 ***	0,72 *	0,30	0,52	0,37	0,23	0,07
NBIN	0,69 *	0,51	0,73 *	0,36	0,30	0,74 *	0,52	0,48	0,43	0,48	0,49	0,59	0,33	0,32	0,22	0,87 ***
NABF	-0,70 *	-0,87 ***	-0,64 *	-0,51	-0,89 ***	-0,57	-0,82 **	-0,75 **	-0,74 **	-0,26	0,10	-0,80 *	-0,93 ***	-0,80 **	-0,63 *	-0,39

NORG = N-Zufuhr über organische Düngemittel, kg N/ha
NBIN = N-Bindung durch Leguminosen, kg N/ha
NABF = N-Abfuhr über Erntegut, kg N/ha

Korrelationskoeffizient nach Pearson, Signifikanz (2-seitig), *** $p < 0{,}001$, ** $p < 0{,}01$, * $p < 0{,}05$

Tabelle 6

Mittelwert und Standardabweichung der Abweichungen zum betrieblichen Mittelwert im N-Saldo, in der N-Zufuhr, N-Bindung und N-Abfuhr nach Berechnungsverfahren (Betriebe innerhalb Berechnungsverfahren, n = 16)

Abweichung zum betrieblichen Mittelwert	Berechnungsverfahren										
	1	2	3	4	5	6	7	8	9	10	11
N-Saldo, kg N/ha											
Mittelwert	2^{a}	1^{a}	3^{a}	2^{a}	3^{a}	7^{a}	-15^{b}	-1^{a}	1^{a}	-15^{b}	11^{a}
Standardabweichung	14	13	4	8	4	9	14	10	5	16	14
N-Zufuhr über mineralische Düngemittel, kg N/ha											
Mittelwert	0	0	0	0	0	0	0	0	0	0	0
Standardabweichung	0	0	0	0	0	0	0	0	0	0	0
N-Zufuhr über organische Düngemittel, kg N/ha											
Mittelwert	3^{a}	-4^{ab}	1^{a}	1^{a}	1^{a}	1^{a}	-6^{b}	-1^{ab}	0^{ab}	1^{a}	1^{a}
Standardabweichung	13	8	2	6	2	6	10	5	3	3	3
N-Bindung durch Leguminosen, kg N/ha											
Mittelwert	2^{abc}	2^{ab}	-2^{bcd}	2^{a}	-2^{cd}	5^{a}	-6^{d}	1^{abc}	-3^{d}	-2^{cd}	1^{abc}
Standardabweichung	2	2	3	4	2	5	9	2	2	2	3
N-Abfuhr über Erntegut, kg N/ha											
Mittelwert	3^{b}	-3^{cd}	-3^{cd}	1^{b}	-3^{cd}	-1^{cd}	2^{b}	1^{b}	-4^{cd}	15^{a}	-8^{d}
Standardabweichung	7	11	4	4	3	4	4	10	4	17	13

^{a,b,c,d} Mittelwerte, die sich signifikant voneinander unterscheiden (Tukey-B-Test, $p < 0{,}05$)

Mittelwert). Die Abweichung zum betrieblichen Mittelwert in der N-Abfuhr über Erntegut variierte zwischen +15 kg N/ha (Berechnungsverfahren 10) und -8 kg N/ha (Berechnungsverfahren 11). Das Berechnungsverfahren zeigte einen signifikanten Einfluss (Varianzanalyse, $p < 0{,}001$), das Berechnungsverfahren 10 unterschied sich dabei signifikant von allen anderen Berechnungsverfahren (Tukey-B-Test, $p < 0{,}05$).

3.2 Betrieblicher Nährstoffvergleich für Phosphat

Im P-Saldo ergab sich für die 16 Betriebe im Durchschnitt ein Mittelwert von -19 kg P_2O_5/ha. Den niedrigsten P-Saldo hatte Betrieb 15 mit -58 kg P_2O_5/ha, den höchsten Betrieb 6 mit 19 kg P_2O_5/ha. Von den 16 Betrieben wiesen 13 im Durchschnitt einen flächenbezogenen P-Verlust auf. Abbildung 3 zeigt die Variabilität im betrieblichen P-Saldo der 16 Betriebe bei Anwendung der 11 unterschiedlichen Berechnungsverfahren. Innerhalb der Betriebe lag die Spannweite zwischen dem niedrigsten und dem höchsten Wert im berechneten P-Saldo bei 4 kg P_2O_5/ha (Betrieb 4, 8, 15 und 16) bis 23 kg P_2O_5/ha (Betrieb 7 und 14) und im Mittel bei 12 kg P_2O_5/ha. Der Variationskoeffizient im P-Saldo lag zwischen 2 % (Betrieb 15) und 286 % (Betrieb 14), im Mittel bei 37 %.

Die Mittelwerte, Standardabweichungen, Spannweite und Variationskoeffizienten der P-Zufuhr und P-Abfuhr der Betriebe bei Anwendung der 11 unterschiedlichen Berechnungsverfahren sind in Tabelle 7 dargestellt. Bei der Berechnung der P-Zufuhr über mineralische Düngemittel ergab sich innerhalb der Betriebe keine Streuung. Mit jeder der 11 Berechnungsverfahren wurde die gleiche betriebliche Ein-

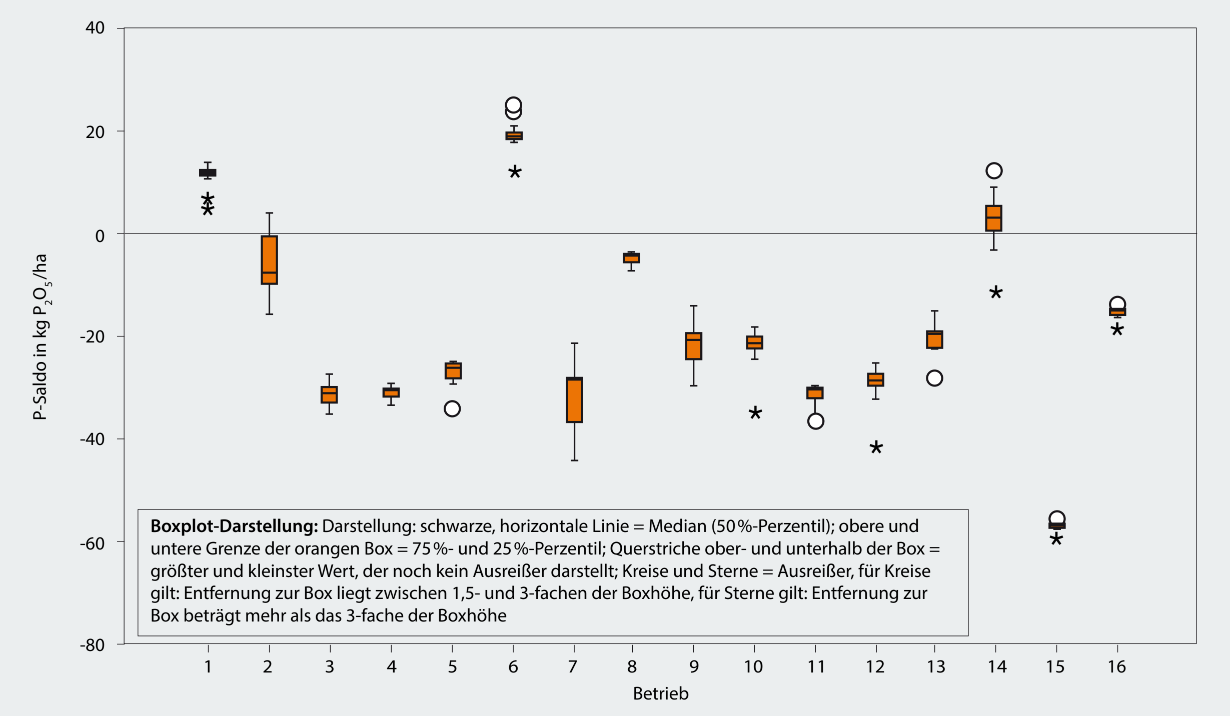

Abbildung 3
Variabilität der P-Salden (kg P_2O_5/ha) von Betrieben bei Anwendung unterschiedlicher Berechnungsverfahren (n = 11)

Tabelle 7
Mittelwert, Standardabweichung, Spannweite und Variationskoeffizient der P-Zufuhr und P-Abfuhr der Betriebe bei Anwendung unterschiedlicher Berechnungsverfahren (n = 11)

	Betrieb															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	P-Zufuhr über mineralische Düngemittel, kg P_2O_5/ha															
Mittelwert	11	15	0	10	6	42	10	12	12	4	0	0	4	16	3	16
Standardabweichung	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	P-Zufuhr über organische Düngemittel, kg P_2O_5/ha															
Mittelwert	56	64	36	19	23	59	50	26	51	36	43	54	31	87	5	41
Standardabweichung	1	7	1	1	1	0	3	1	2	2	2	2	1	2	0	1
Spannweite	4	18	4	3	2	1	9	3	6	7	6	7	4	6	1	3
Variationskoeffizient, %	2	11	4	5	4	0	7	3	4	5	4	4	4	2	7	2
	P-Abfuhr über Erntegut, kg P_2O_5/ha															
Mittelwert	58	85	68	61	57	82	93	44	84	62	76	84	56	101	66	73
Standardabweichung	2	6	2	1	2	3	6	1	5	3	1	5	3	7	1	1
Spannweite	9	25	9	2	9	11	21	2	15	13	2	20	13	24	4	5
Variationskoeffizient, %	4	7	4	1	4	4	7	1	6	6	1	6	6	7	2	2

satzmenge an Mineraldünger in kg P_2O_5/ha ermittelt. Zwischen den Betrieben variierte die P-Zufuhr über mineralische Düngemittel von 0 kg P_2O_5/ha (Betrieb 3, 11 und 12) bis 42 kg P_2O_5/ha (Betrieb 6). Für die berechnete P-Zufuhr über organische Düngemittel ergab sich zwischen den Betrieben eine Variation von 5 kg P_2O_5/ha (Betrieb 15) bis 87 kg P_2O_5/ha (Betrieb 14). Die nach den unterschiedlichen Verfahren berechnete P-Zufuhr über organische Düngemittel variierte auch innerhalb der Betriebe. Es ergaben sich Variationskoeffizienten, die zwischen 0 % (Betrieb 6) und 11 % (Betrieb 2) lagen, im Durchschnitt bei 4 %. Die Spannweite reichte dabei von 1 kg P_2O_5/ha (Betrieb 6 und 15) bis 18 kg P_2O_5/ha (Betrieb 2). In der kalkulierten P-Abfuhr über Erntegut gab es zwischen den Betrieben eine Variation, die zwischen 44 kg

P_2O_5/ha (Betrieb 8) und 101 kg P_2O_5/ha (Betrieb 14) rangierte. Innerhalb der Betriebe variierte die P-Abfuhr über Erntegut mit maximalen Variationskoeffizienten von 7 % (Betrieb 2, 7 und 14) bei einer maximalen Spannweite von bis zu 25 kg P_2O_5/ha (Betrieb 2).

Die Korrelationskoeffizienten zwischen P-Saldo und P-Zufuhr sowie P-Abfuhr innerhalb der Betriebe sind in Tabelle 8 wiedergegeben. Eine signifikante Korrelation zwischen P-Saldo und P-Zufuhr über organische Düngemittel konnte für die Betriebe 2, 4, 5, 8, 10 und 11 nachgewiesen werden. Mit Ausnahme eines Betriebes (Betrieb 2) ergab sich für alle anderen Betriebe eine signifikante Korrelation zwischen P-Saldo und P-Abfuhr über Erntegut.

Tabelle 9 gibt den Mittelwert und die Standardabweichung der Abweichungen zum betrieblichen Mittelwert im P-Saldo, in der P-Zufuhr und P-Abfuhr für die 11 Berechnungsverfahren wieder. Abhängig vom Berechnungsverfahren ergab sich eine mittlere Abweichung im P-Saldo, die zwischen 2 kg P_2O_5/ha (Berechnungsverfahren 3, 5, 9 und 11) und -4 kg P_2O_5/ha (Berechnungsverfahren 1 und 10) lag. Das Berechnungsverfahren hatte einen signifikanten Einfluss (Varianzanalyse, $p < 0,001$) auf den P-Saldo. Die Abweichung im P-Saldo waren mit dem Berechnungsverfahren 1 und 10 im Vergleich zu den anderen Berechnungsverfahren signifikant verschieden (Tukey-B-Test, $p < 0,05$). Die berechnete P-Zufuhr über mineralische Düngemittel unterschied sich nicht zwischen den Berechnungsverfahren. Die Abweichungen in der P-Zufuhr über organische Düngemittel variierte zwischen 1 und -2 kg P_2O_5/ha. Das Berechnungsverfahren hatte auch hier einen signifikanten Effekt (Varianzanalyse, $p < 0,001$). Die Abweichung in der P-Zufuhr über organische Düngemittel im Berechnungsverfahren 2 (-2 kg P_2O_5/ha) unterschied sich signifikant zu sieben anderen Berechnungsverfahren (Tukey-B-Test, $p < 0,05$). Die Abweichung zum betrieblichen Mittelwert in der P-Abfuhr über Erntegut variierte zwischen 5 kg P_2O_5/ha (Berechnungsverfahren 10) und -2 kg P_2O_5/ha (Berechnungsverfahren 2, 7 und 11). Das Berechnungsverfahren zeigte einen signifikanten Einfluss auf die P-Abfuhr über Erntegut (Varianzanalyse, $p < 0,001$). Das Berechnungsverfahren 10 unterschied sich mit Ausnahme von Berechnungsverfahren 1 signifikant zu allen anderen Berechnungsverfahren (Tukey-B-Test, $p < 0,05$).

Tabelle 8

Korrelation zwischen P-Saldo (kg P_2O_5/ha) und P-Zufuhr sowie P-Abfuhr innerhalb der Betriebe bei Anwendung unterschiedlicher Berechnungsverfahren (n = 11)

	Betrieb															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
PORG	0,28	0,62 *	0,25	0,89 ***	0,66 *	0,01	0,39	0,86 **	0,02	0,77 **	0,95 ***	-0,20	0,50	-0,43	-0,38	0,30
PABF	-0,83 **	-0,41	-0,83 **	-0,61 *	-0,96 ***	-0,99 ***	-0,86 **	-0,65 *	-0,93 ***	-0,94 ***	0,70 *	-0,91 ***	-0,94 ***	-0,97 ***	-0,90 ***	-0,74 **

PORG = P-Zufuhr über organische Düngemittel, kg P_2O_5/ha
PABF = P-Abfuhr über Erntegut, kg P_2O_5/ha

Korrelationskoeffizient nach Pearson, Signifikanz (2-seitig), *** $p < 0,001$, ** $p < 0,01$, * $p < 0,05$

Tabelle 9

Mittelwert und Standardabweichung der Abweichungen zum betrieblichen Mittelwert im P-Saldo, in der P-Zufuhr und P-Abfuhr nach Berechnungsverfahren (Betriebe innerhalb Berechnungsverfahren, n = 16)

Abweichung zum betrieblichen Mittelwert	Berechnungsverfahren										
	1	2	3	4	5	6	7	8	9	10	11
	P-Saldo, kg P_2O_5/ha										
Mittelwert	4^{b}	-1^{a}	2^{a}	0^{a}	2^{a}	-1^{a}	1^{a}	0^{a}	2^{a}	-4^{b}	2^{a}
Standardabweichung	4	4	2	3	2	2	2	4	2	5	3
	P-Zufuhr über mineralische Düngemittel, kg P_2O_5/ha										
Mittelwert	0	0	0	0	0	0	0	0	0	0	0
Standardabweichung	0	0	0	0	0	0	0	0	0	0	0
	P-Zufuhr über organische Düngemittel, kg P_2O_5/ha										
Mittelwert	-1^{bc}	-2^{c}	1^{a}	0^{ab}	1^{a}	-1^{abc}	-1^{bc}	1^{ab}	1^{ab}	1^{a}	1^{ab}
Standardabweichung	2	2	2	3	2	2	2	1	2	2	2
	P-Abfuhr über Erntegut, kg P_2O_5/ha										
Mittelwert	3^{ab}	-2^{c}	-1^{c}	0^{c}	-1^{c}	0^{c}	-2^{c}	1^{bc}	-1^{c}	5^{a}	-2^{c}
Standardabweichung	3	4	2	1	1	1	3	4	1	6	3

^{a,b,c,d} Mittelwerte, die sich signifikant voneinander unterscheiden (Tukey-B-Test, $p < 0,05$)

4 Diskussion

4.1 Reproduzierbarkeit betrieblicher Werte zur Bestimmung des betrieblichen Nährstoffvergleichs bei Anwendung unterschiedlicher länderspezifischer Berechnungsverfahren

Der Variationskoeffizient gilt als Maß für die Wiederholbarkeit (wiederholte Messungen unter Einhaltung gleicher Messbedingungen) und Reproduzierbarkeit (wiederholte Messungen bei unterschiedlichen Messbedingungen) von Messergebnissen (DIN ISO 3534-2). In der vorliegenden Untersuchung wurde innerhalb der 16 Betriebe der Variationskoeffizient für die Variablen des betrieblichen Nährstoffvergleichs für Stickstoff und Phosphat ermittelt, um eine Aussage über die Reproduzierbarkeit der betrieblichen Werte bei Eingabe der gleichen betrieblichen Rohdaten unter Anwendung unterschiedlicher Berechnungsverfahren machen zu können. Es zeigte sich, dass eine Reproduzierbarkeit der betrieblichen Werte mit den unterschiedlichen Berechnungsverfahren häufig nicht gegeben war. Bei Eingabe gleicher betrieblicher Rohdaten kann erwartet werden, dass der Variationskoeffizient bei Null liegt, d. h. dass man mit jedem Berechnungsverfahren für die Variablen des betrieblichen Nährstoffvergleichs das gleiche Ergebnis erhält. Dies war in der vorliegenden Untersuchung jedoch nur für die betriebliche N- und P-Zufuhr über mineralische Düngemittel der Fall.

Angesichts der ermittelten Variationskoeffizienten stellte sich die Frage nach einem maximalen Wert für den Variationskoeffizient, der noch eine akzeptable Reproduzierbarkeit der betrieblichen Variablen wiedergibt. Für die vorliegende Untersuchung wurde zur ersten Beurteilung der Ergebnisse angenommen, dass ein Variationskoeffizient ≤10 %, d. h. eine Abweichung von maximal 10 %, noch eine akzeptable Reproduzierbarkeit widerspiegelt.

Für die 16 Betriebe ergab sich im N-Saldo ein durchschnittlicher Variationskoeffizient von 187 %, in der N-Zufuhr über organische Düngemittel ein Wert von 10 %, in der N-Bindung von 36 % und in der N-Abfuhr von 4 %. Nur 3 der 16 Betriebe hatten im N-Saldo einen Variationskoeffizient ≤10 %, in der N-Zufuhr über organische Düngemittel hatten 14 von 16 Betrieben einen Wert ≤10 %, in der N-Bindung 1 von 16 Betrieben und in der N-Abfuhr alle Betriebe einen Variationskoeffizient ≤10 %. Daraus kann abgeleitet werden, dass im N-Saldo, der N-Zufuhr über organische Düngemittel und der N-Bindung eine Reproduzierbarkeit der Ergebnisse bei Anwendung der unterschiedlichen Berechnungsverfahren nicht gegeben ist, sich dagegen in der N-Abfuhr mit den unterschiedlichen Berechnungsverfahren aber vergleichsweise reproduzierbare Ergebnisse ermitteln lassen. Innerhalb der Betriebe ergaben sich jedoch in der berechneten N-Abfuhr bei Anwendung der unterschiedlichen Berechnungsverfahren Spannweiten von bis zu 92 kg N/ha. Nur bei drei Betrieben lag der Wert für die Spannweite unter 10 kg N/ha. Dies zeigt auf, dass für die Beurteilung der Reproduzierbarkeit der berechneten N-Abfuhr ein Variationskoeffizient von ≤10 % als zu hoch angesehen werden muss. Für eine abschließende Beurteilung sollten daher Variationskoeffizient und Spannweite, d. h. relative und absolute Streuwerte Berücksichtigung finden.

In Bezug auf den betrieblichen Nährstoffvergleich für Phosphat ergaben sich für die 16 Betriebe ein durchschnittlicher Variationskoeffizient von 37 % im P-Saldo und ein durchschnittlicher Variationskoeffizient von 4 % für die P-Zufuhr über organische Düngemittel sowie für die P-Abfuhr. Im P-Saldo hatten nur 5 der 16 Betriebe einen Variationskoeffizient ≤10 %, in der P-Zufuhr über organische Düngemittel hatten 15 von 16 Betrieben einen Wert ≤10 %, in der P-Abfuhr alle Betriebe einen Variationskoeffizient ≤10 %. In Bezug auf die Spannweite der Werte zeigte sich, dass in der P-Zufuhr über organische Düngemittel 15 der 16 Betriebe einen Wert unter 10 kg P_2O_5/ha aufwiesen, in der P-Abfuhr die Spannweite aber nur bei der Hälfte der Betrieben unter 10 kg P_2O_5/ha lag. Daraus wird abgeleitet, dass sich mit den unterschiedlichen Berechnungsverfahren in der P-Zufuhr über organische Düngemittel vergleichsweise reproduzierbare Ergebnisse ermitteln lassen. Nicht sichergestellt ist jedoch eine Reproduzierbarkeit der Ergebnisse bei Anwendung der unterschiedlichen Berechnungsverfahren im kalkulierten P-Saldo und der P-Abfuhr der Betriebe.

Das Berechnungsverfahren 2 beinhaltete als einziges Berechnungsverfahren eine Überprüfung der Grundfuttererträge im Vergleich zum Grundfutterbedarf des angegebenen Tierbestandes. Diese so genannte „Plausibilisierung der Nährstoffabfuhr über Grundfutter" hat zum Ziel, die nicht oder selten gemessene Nährstoffabfuhr über Futterpflanzen besser einschätzen zu können und ein plausibles Verhältnis (Grundfutterfaktor) zu den Nährstoffausscheidungen der Tiere einzuhalten, die dieses Futter aufnehmen und verwerten (Kapitel 3.5.1: Plausibilisierung der Nährstoffabfuhr über Grundfutter; Osterburg und Techen, 2012). Bei 10 der 16 Betriebe waren die angegebenen Grundfuttererträge plausibel, bei 5 der 16 Betriebe wurden zu hohe Grundfuttererträge festgestellt (d. h. um 1, 4, 13, 14 oder 38 % zu hohe Grundfuttererträge) und bei einem der 16 Betriebe wurde ein um 198 % zu niedriger Grundfutterertrag ermittelt. Die vom Berechnungsverfahren 2 als zu hoch oder zu niedrig eingeschätzten Grundfuttererträge wurden im Berechnungsverfahren 2 nicht korrigiert, da nachvollzogen werden konnte, dass es bei diesen Betrieben auch einen wesentlichen Export bzw. Import von Grundfutter gab. Im Berechnungsverfahren 2 kam es daher zu keinerlei Abänderungen der Rohdaten. Somit hatte in der vorliegenden Untersuchung die so genannte „Plausibilisierung der Nährstoffabfuhr über Grundfutter" keinen Einfluss auf die Streuung bzw. Reproduzierbarkeit der Ergebnisse.

4.2 Einflussfaktoren auf die Reproduzierbarkeit des Nährstoffsaldos bei Anwendung unterschiedlicher länderspezifischer Berechnungsverfahren

Der N-Saldo ergibt sich aus der Differenz zwischen N-Zufuhr (über Düngemittel und N-Bindung) und N-Abfuhr. Durch die Berechnung der Korrelationskoeffizienten zwischen N-Saldo und N-Zufuhr über organische Düngemittel, N-Bindung sowie N-Abfuhr konnte ermittelt werden, welche Zusammenhänge zwischen N-Saldo und den anderen Variablen vorlagen bzw. wodurch die zum Teil sehr hohe Streuung im berechneten N-Saldo innerhalb der 16 Betriebe verursacht wurde.

Mit Ausnahme von Betrieb 4, der im N-Saldo einen Variationskoeffizient von nur 6 % aufwies, ergaben sich für alle anderen Betriebe zwischen dem N-Saldo und einem oder zwei der untersuchten Variablen signifikante Korrelationen. Für 6 der 16 Betriebe wurde eine signifikante Korrelation zwischen N-Saldo und N-Zufuhr über organische Düngemittel ermittelt, für 4 der 16 Betriebe eine signifikante Korrelation zwischen N-Saldo und N-Bindung sowie für 11 der 16 Betriebe eine signifikante Korrelation zwischen N-Saldo und N-Abfuhr. Das bedeutet, dass es abhängig von der betriebsindividuellen Struktur war, welche Variablen bei Anwendung der 11 verschiedenen Berechnungsverfahren einen signifikanten Einfluss auf das Ergebnis des N-Saldos hatten. So lässt sich aus den Ergebnissen der Korrelationsanalyse ableiten, dass die extrem große Spannweite zwischen dem niedrigsten und höchsten Wert im berechneten N-Saldo bei Betrieb 14 und 2 (91 und 80 kg N/ha) vor allem durch die kalkulierte N-Abfuhr beeinflusst war. Auch bei den Betrieben 9, 12, 13 und 15 hatte die N-Abfuhr den größten Einfluss auf den berechneten N-Saldo. Für Betrieb 10 und 11 zeigte sich, dass die Variation im N-Saldo durch die Anwendung der unterschiedlichen Berechnungsverfahren hauptsächlich durch die Variation in der N-Zufuhr über organische Düngemittel beeinflusst war. Bei Betrieb 16 beeinflusste in erster Linie die berechnete N-Bindung die Variation des N-Saldos. Für die restlichen 6 der 16 Betriebe wurden für den N-Saldo signifikante Korrelationen zu zwei Variablen ermittelt.

Ein betriebsindividueller Einfluss der Variablen P-Zufuhr über Düngemittel und P-Abfuhr ergab sich auch für den berechneten P-Saldo der Betriebe bei Anwendung der 11 verschiedenen Berechnungsverfahren. Bei allen Betrieben wurden signifikante Korrelationen mit einem (bei 11 Betrieben) oder zwei (bei 5 Betrieben) der untersuchten Variablen gefunden. Bei 6 der 16 Betriebe zeigten sich signifikante Korrelationen zwischen P-Saldo und P-Zufuhr über organische Düngemittel und bei 15 der 16 Betriebe zwischen P-Saldo und P-Abfuhr.

Aus diesen Ergebnissen wird abgeleitet, dass der über die unterschiedlichen Berechnungsverfahren ermittelte Wert für den betrieblichen N- und P-Saldo und seine Variabilität davon abhängig ist, welche betriebsindividuelle Struktur der Betrieb hat (z. B. Zusammensetzung und Haltung des Tierbestandes, angebaute Pflanzen, Grünlandanteil) und dass bestimmte Betriebsstrukturen bei einigen Berechnungsverfahren Vor- bzw. Nachteile haben.

4.3 Unterschiede zwischen den länderspezifischen Berechnungsverfahren

Zur Feststellung möglicher Unterschiede in der Berechnung der Variablen zur Bestimmung des betrieblichen Nährstoffvergleichs bei Anwendung der 11 länderspezifischen Berechnungsverfahren wurde innerhalb der Berechnungsverfahren für alle Variablen die Abweichung der betrieblichen Einzelwerte zum Durchschnittswert des jeweiligen Betriebes ermittelt. Mit Ausnahme von N- und P-Zufuhr über mineralische Düngemittel hatte das Berechnungsverfahren auf alle anderen Variablen des betrieblichen Nährstoffvergleichs einen signifikanten Einfluss, d. h. es gibt in Abhängigkeit vom eingesetzten Berechnungsverfahren Unterschiede in der Berechnung dieser Variablen.

Die Spannweite der durchschnittlichen Abweichung zum betrieblichen Durchschnittwert bei Eingabe gleicher betrieblicher Rohdaten lag bei den Variablen zum betrieblichen Nährstoffvergleich für Stickstoff bei 26 kg N/ha (N-Saldo), 23 kg N/ha (N-Abfuhr), 11 kg N/ha (N-Bindung) bzw. 10 kg N/ha (N-Zufuhr über organische Düngemittel).

In Bezug auf den N-Saldo wurde im Vergleich zu allen anderen Berechnungsverfahren mit den Berechnungsverfahren 7 und 10 für die Betriebe im Durchschnitt ein signifikant geringerer N-Saldo ermittelt. Dies erklärt sich für Berechnungsverfahren 7 zu gleichen Teilen durch signifikant niedrigere Werte in der N-Zufuhr über organische Düngemittel und durch signifikant niedrigere Werte in der N-Bindung. Hinsichtlich der N-Bindung wurde festgestellt, dass Berechnungsverfahren 7 das einzige Verfahren war, bei dem sich für einzelne Betriebe auch eine N-Bindung von Null ergab. Im Gegensatz zu anderen Berechnungsverfahren, bei denen Grünland eine pauschale N-Bindung von 30 kg N/ha zugeordnet wird (beispielhaft: Landesanstalt für Entwicklung der Landwirtschaft und der ländlichen Räume Schwäbisch Gmünd (LEL) Baden-Württemberg, 2014) wird mit dem Berechnungsverfahren 7 die N-Bindungsfähigkeit im Grünland sehr differenziert beurteilt (Landwirtschaftskammer Nordrhein-Westfalen, 2014). So bekommt Weide im Berechnungsverfahren 7 eine N-Bindung von 30 kg N/ha zugeordnet, Mähweide mit einem oder zwei Schnitten eine N-Bindung von 10 kg N/ha, Mähweide mit drei Schnitten eine N-Bindung von 5 kg N/ha und Mähweide mit vier Schnitten oder Wiese mit 5 Schnitten eine N-Bindung von 0 kg N/ha. Für Betrieb 11 wurde im Vergleich zwischen Berechnungsverfahren 7 und 10 festgestellt, dass bei Anbau von Kleegras (30:70) im Berechnungsverfahren 7 mit einer N-Bindung von 0,386 kg N/dt Ertrag gerechnet wurde (Landwirtschaftskammer Nordrhein-Westfalen, 2014), im Berechnungsverfahren 10 aber nur mit 0,160 kg N/dt Ertrag (LLFG - Landesanstalt für Landwirtschaft, Forsten und Gartenbau Sachsen-Anhalt, 2014). In Bezug auf die mit Berechnungsverfahren 7 im Vergleich zu anderen Berechnungsverfahren signifikant niedrigeren Werte in der N-Zufuhr über organische Düngemittel wird vermutet, dass das Berechnungsverfahren 7 bei Einsatz einiger organischer Düngemittel mit höheren N-Ausbringverlusten rechnet. So zeigte sich am Beispiel von Betrieb 6, der größere Mengen an Biogasgärresten importierte, dass Berechnungsverfahren 7 mit 36 % N-Ausbringverlusten kalkulierte, dagegen z. B. Berechnungsverfahren 1 nur mit 18 %. Ein zweites Beispiel ist Betrieb 14, bei dem die Milchkühe im Sommer alle auf die Weide gehen. Hier kalkuliert Berechnungsverfahren 7 für die Zeit des Weideganges mit 75 % N-Verlusten, Berechnungsverfahren 1 aber nur mit 40 % (Elsäßer, 2008). Gemäß Anlage 6 der DüV (DüV, 2007) liegt die Mindestanrechnung der N-Ausscheidungen für Weidehaltung derzeit bei 25 %. Derzeit noch keine Vorgaben macht die DüV (DüV, 2007) für maximal anrechenbare Ausbringverluste bei Einsatz von Gärresten aus Biogasanlagen.

Für Berechnungsverfahren 10 erklärt sich der signifikant geringere N-Saldo allein durch die im Vergleich zu den anderen Berechnungsverfahren signifikant höheren Werte in der N-Abfuhr. Zum Beispiel gibt es im Berechnungsverfahren 10 für das Grünland abgestuft nach Anzahl der Aufwüchse (1 bis 5) ansteigende N-Entzugs-Koeffizienten: 0,33, 0,45, 0,55, 0,68 und 0,70 kg N/dt FM (LLFG - Landesanstalt für Landwirtschaft, Forsten und Gartenbau, Sachsen-Anhalt, 2014). Bei Berechnungsverfahren 7 wird für diese unterschiedlichen Grünlandvarianten aber nur mit einem einheitlichen N-Entzugs-Koeffizienten von 0,54 kg N/dt FM kalkuliert (Landwirtschaftskammer Nordrhein-Westfalen, 2014).

Bei den Variablen zum betrieblichen Nährstoffvergleich für Phosphat ergaben sich Spannweiten der durchschnittlichen Abweichung zum betrieblichen Durchschnittwert bei Eingabe gleicher betrieblicher Rohdaten von 6 kg P_2O_5/ha (P-Saldo), 7 kg P2O5/ha (P-Abfuhr) und 4 kg P_2O_5/ha (P-Zufuhr über organische Düngemittel). Im P-Saldo wurde im Vergleich zu den anderen Berechnungsverfahren mit den Berechnungsverfahren 1 und 10 für die Betriebe im Durchschnitt ein signifikant geringerer Wert ermittelt. Dies erklärt sich für beide Berechnungsverfahren überwiegend durch die im Vergleich zu den anderen Berechnungsverfahren signifikant höheren Werte in der P-Abfuhr. Bei Berechnungsverfahren 1 lag dies an höheren Koeffizienten bei Berücksichtigung der Erntenebenprodukte Stroh oder Blatt, bei Berechnungsverfahren 10 ist dies vor allem auf die ansteigenden P_2O_5-Entzugs-Koeffizienten im Grünland mit ansteigender Anzahl an Aufwüchsen zurückzuführen.

Es stellt sich letztendlich die Frage, womit die dargestellten Unterschiede in den länderspezifischen Berechnungsverfahren begründet werden und ob diese Unterschiede gerechtfertigt sind. Nach den vorliegenden Ergebnissen ergibt sich für einen Betrieb in Sachsen-Anhalt, der einen N-Saldo von 59 kg N/ha hat, bei Eingabe seiner betrieblichen Rohdaten in Brandenburg ein N-Saldo von 77 kg N/ha, in Sachsen von 75, in Niedersachsen von 81 und in Thüringen sogar ein N-Saldo von 85 kg N/ha. Gemäß geplanter Novellierung der Düngeverordnung gäbe es für den Betrieb in Sachsen-Anhalt keine behördlichen Sanktionen, würde er aber nur ein paar Kilometer weiter in einem anderen Bundesland liegen, müssten ihm behördliche Sanktionen auferlegt werden. Ähnliches gilt für den P-Saldo. Ein Betrieb mit einem P-Saldo von 19 kg P_2O_5/ha in Sachsen-Anhalt hätte in Niedersachsen einen P-Saldo von 22 kg P_2O_5/ha und in Brandenburg, Sachsen und Thüringen einen P-Saldo von 25 kg P_2O_5/ha.

Außer Frage steht, dass die einzelnen für die Erstellung des Nährstoffvergleichs berechneten Variablen einer Variabilität unterliegen. So beeinflusst das Fütterungsregime maßgeblich die N- und P-Ausscheidungen der Tiere (Cerosaletti et al., 2004; Steinwidder et al., 2009) sowie die N-Verluste aus den N-Ausscheidungen der Tiere während der Lagerung und Ausbringung (Frank et al., 2002; Misselbrook et al., 2005; van der Stelt et al., 2008). Das Haltungsverfahren bzw. die Stalltechnik hat einen Einfluss auf die N-Verluste im Stall (Döhler et al., 2002), die Aufbereitung und eingesetzte Technik einen Einfluss auf die N-Verluste während der Ausbringung von organischem Dünger (Döhler et al., 2002; van der Stelt et al., 2007; Dämmgen et al., 2013) sowie die Anbautechnik einen Einfluss auf die N-Bindungskapazität der Leguminosen (Peoples et al., 1995). Diese das Betriebsmanagement betreffenden Einflussfaktoren können in keinem Fall als bundeslandspezifisch gelten. Auch Unterschiede im Bodentyp und Klima, die einen Einfluss auf den Rohproteingehalt von geerntetem Pflanzenmaterial (Piergiovanni et al., 2011; Wang und Frei, 2011) und damit auf den N-Entzug angebauter Pflanzen haben, können keine Unterschiede zwischen den Bundesländern begründen, da es sich um Einflussfaktoren handelt, die nicht in den Grenzen eines Bundeslandes Beschränkung finden. In einer zukünftigen Diskussion dieser Thematik sollte dies Berücksichtigung finden.

5 Schlussfolgerungen

Im Abschlussbericht der Bund-Länder-Arbeitsgruppe zur Evaluierung der Düngeverordnung (Osterburg und Techen, 2012) wird die Annahme geäußert, dass bei der Erstellung der betrieblichen Nährstoffvergleiche eine bundeseinheitliche Vorgehensweise in der Regel sichergestellt ist. Diese Annahme wird mit den Ergebnissen der vorliegenden Untersuchung in soweit widerlegt, dass dargestellt werden konnte, dass (1) die Reproduzierbarkeit der betrieblichen Werte bei Anwendung unterschiedlicher länderspezifischer Berechnungsverfahren nicht gegeben ist und (2) es statistisch signifikante Unterschiede zwischen den Berechnungsverfahren der einzelnen Bundesländer zur Erstellung des betrieblichen Nährstoffvergleichs gibt.

In Bezug auf den N-Saldo zeigte sich in der vorliegenden Untersuchung, dass eine schlechte Reproduzierbarkeit der Ergebnisse vor allem Betriebe mit einem N-Saldo unter 60 kg N/ha betraf (Abbildung 2). Die Bund-Länder-Arbeitsgruppe zur Evaluierung der Düngeverordnung (Osterburg und Techen, 2012; Anhang 4, A4.5 Nährstoffvergleiche – Methoden und Salden) nimmt an, dass derzeit im Durchschnitt 80 % der Betriebe in Deutschland im N-Saldo unter 60 kg N/ha liegen. Sechzehn milchviehhaltende Betriebe bilden sicherlich nicht die Gesamtheit der deutschen Betriebe ab. Abgeleitet aus den vorliegenden Ergebnissen kann aber gemutmaßt werden, dass unter den derzeitigen Bedingungen (Anwendung unterschiedlicher länderspezifischer Berechnungsverfahren) bis zu 80 % der Betriebe in Deutschland in den Bereich der schlechten Reproduzierbarkeit des N-Saldos fallen. Ob letztendlich der bestimmte N-Saldo nah am „wahren" Wert für den Betrieb liegt, hängt dann davon ab, welches Berechnungsverfahren angewendet wird bzw. in welchem Bundesland sich der Betrieb befindet.

Aus den vorliegenden Ergebnissen wird geschlussfolgert, dass durch die in Deutschland zur Anwendung kommenden länderspezifischen Berechnungsverfahren für den betrieblichen Nährstoffvergleich für Stickstoff und Phosphat eine Ungleichbehandlung der landwirtschaftlichen Betriebe resultiert. Um das System justiziabel zu machen und im Sinne der Gleichbehandlung aller Betriebe fairer zu gestalten, plädieren die Autoren daher hinsichtlich der Erstellung des betrieblichen Nährstoffvergleichs für ein bundeseinheitliches

Berechnungsverfahren mit einheitlichem Wertekatalog, der die derzeitige Variabilität der Betriebe abbildet, d. h. eine realitätsnahe Zuordnung jedes Betriebes gewährleistet.

Ein für alle Bundesländer einheitlich geltender Wertekatalog hat auch den Vorteil, dass er viel schneller an neue, betriebliche und technische Entwicklungen angepasst werden kann. Abgeleitet aus den vorliegenden Betriebsdaten sehen die Autoren derzeit vor allem in zwei Bereichen die Notwendigkeit, die Berechnung des betrieblichen Nährstoffvergleichs an Veränderungen im Management der Betriebe anzupassen bzw. diese zu berücksichtigen: (1) die Anwendung N-reduzierter Fütterungsstrategien (Nachweisbarkeit für den Milchviehbereich: Spiekers und Obermaier, 2007); und (2) der Einsatz N-Verlust-minimierender Ausbringtechniken organischer Düngemittel (Döhler et al., 2002; Dämmgen et al., 2013). Beide Aspekte dienen der Reduzierung umweltrelevanter N-Verluste. In diesem Zusammenhang sollte nicht vergessen werden, dass die Düngeverordnung das zentrale Instrument des deutschen Aktionsprogramms zur Umsetzung der Richtlinie 91/676/EWG des Rates zum Schutz der Gewässer vor Verunreinigung durch Nitrat aus landwirtschaftlichen Quellen ist (Europäische Kommission, 2013). Die Autoren unterstützen daher die Empfehlung der Bund-Länder-Arbeitsgruppe zur Evaluierung der Düngeverordnung (Osterburg und Techen, 2012), dass zur Erhöhung der Transparenz zukünftig im Nährstoffvergleich auch Brutto-Werte und Brutto-N-Saldo vor Abzug von N-Verlusten aufgezeichnet werden, da nur so der eigentliche N-Überschuss und das mögliche N-Einsparpotential eines Betriebes sichtbar wird.

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Effect of intercropping winter peas of differing leaf type and time of flowering on annual weed infestation in deep and shallow ploughed soils and on pea pests

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Abstract

The performance of organic pea production largely depends on preventive and cultural control strategies for weeds and pests. Field experiments were carried out to study the effect of intercropping a normal-leafed (cv. E.F.B. 33) or a semi-leafless, early-flowering winter pea (cv. James) and triticale on the infestation with annual weeds, pea aphids and moths in comparison to the respective sole crops. Also, shallow ploughing (10 to 12 cm) vs. deep ploughing (25 to 27 cm) was investigated with regard to an infestation with annual weeds. The higher weed suppressive ability of normal-leafed winter pea cv. E.F.B. 33 compared with semi-leafless cv. James was due to a lower light transmission to the weed canopy level. In contrast to E.F.B. 33, intercropping James significantly reduced the weed infestation compared to the respective sole crop. The ploughing system had no significant effect on the weed infestation in crops differing in their ability to suppress annual weeds. Sole crops were found to have higher pea aphid density, incidence and cumulative aphid-days than the corresponding intercrops. Intercropping winter peas and triticale, however, was not beneficial in reducing an infestation with pea moths.

Keywords: *organic farming, ploughing system, weed suppression, Acyrthosiphon pisum Harris, cumulative aphid-days, Cydia nigricana Fabricius*

Zusammenfassung

Einfluss des Mischfruchtanbaus von Wintererbsen mit unterschiedlichen Blatttypen und Blütezeitpunkten auf das annuelle Unkrautaufkommen in tief- und flachwendend bearbeiteten Böden und auf Erbsen-Schädlinge

Die Leistungsfähigkeit des ökologischen Erbsenanbaus hängt in hohem Maße von vorbeugenden Kontrollstrategien für Unkräuter und Schädlinge ab. Untersucht wurde der Einfluss des Reinsaat- und des Mischfruchtanbaus einer normalblättrigen (E.F.B. 33) und einer halbblattlosen, frühblühenden Wintererbsen-Sorte (James) mit Triticale auf das annuelle Unkrautaufkommen sowie den Befall mit Erbsenblattlaus und -wickler. Zudem wurde eine flach- (10 bis 12 cm) mit einer tiefwendenden (25 bis 27 cm) Bodenbearbeitung hinsichtlich des Unkrautaufkommens verglichen. Die normalblättrige Sorte E.F.B. 33 wies aufgrund einer geringeren Lichttransmission zum Unkrautbestand eine bessere Unkrautunterdrückung als die halbblattlose Sorte auf. Der Mischfruchtanbau von James führte im Gegensatz zur Sorte E.F.B. 33 zu einer signifikanten Reduzierung des Unkrautaufkommens. Die Bodenbearbeitung hat das Unkrautaufkommen in Kulturen mit unterschiedlichem Unkrautunterdrückungsvermögen nicht signifikant beeinflusst. Die Blattlausdichte, der Anteil befallener Pflanzen und die kumulierten Blattlaustage lagen in den Reinsaaten über den Werten der Mischsaaten. Der Befall mit dem Erbsenwickler konnte durch den Mischfruchtanbau mit Triticale jedoch nicht wirksam reduziert werden.

Schlüsselwörter: *Ökologischer Landbau, Pflugsystem, Unkrautunterdrückung, Acyrthosiphon pisum Harris, kumulierte Blattlaustage, Cydia nigricana Fabricius*

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1 Introduction

Weed and pest management largely influences crop performance and organic farmers rely first of all on cultural and other preventive management strategies. Effective weed and pest management therefore is a challenge and often a weakness in organic farming. Intensive tillage, e.g., deep mouldboard ploughing is known as an effective preventive weed management strategy in organic farming (Kouwenhoven et al., 2002). The need to reduce the environmental impact of agricultural management practices and to improve soil quality has increased the interest in a reduction of tillage intensity, e.g., shallow ploughing. Shallow ploughing was found to decrease fuel consumption and CO_2 release from the soil, and to increase soil aggregate stability and topsoil microbial activity (Børresen and Njøs, 1994; Chen and Huang, 2009; Curci et al., 1997; Kouwenhoven et al., 2002; Reicosky and Archer, 2007; Vian et al., 2009). However, the results of most studies indicate that shallow ploughing results in an increase in annual, and in particular perennial, weed infestation in organic and conventional farming (Børresen and Njøs, 1994; Brandsæter et al., 2011; Håkansson et al., 1998). Pranaitis and Marcinkonis (2005) reported that the grain yield of semi-leafless peas (*Pisum sativum* L.) decreased with decreasing ploughing depth which was attributable to an increase in weed infestation.

Normal-leafed peas have a better weed suppressive ability than semi-leafless pea cultivars and their yield performance is therefore less affected by weed competition (Spies et al., 2011). Owing to the low lodging resistance, aeration and harvest of normal-leafed pea crop stands is often problematic. An intercropping with cereals improves the lodging resistance of normal-leafed winter peas (Urbatzka et al., 2011) and the weed suppressive ability of semi-leafless peas (Begna et al., 2011; Corre-Hellou et al., 2011; Poggio, 2005), which deserves special attention in reduced tillage systems under organic management.

Pea aphids (*Acyrthosiphon pisum* Harris) cause direct damage to pea plants by sucking plant sap. Honeydew excretion by pea aphids facilitates colonisation of saprophytic moulds on the plant surface (Biddle, 1985). Much more critical, however, is their ability to vector plant viruses (Brisson and Stern, 2006; Seidenglanz et al., 2011). Aphid feeding on peas causes a decrease in yield performance and nitrogen-fixing activity (Hinz, 1991; Maiteki and Lamb, 1985; Sirur and Barlow, 1984). The pea moth (*Cydia nigricana* Fabricius) larva feeds on the developing pea seeds in the pod and a high infestation reduces grain yield and quality (Huusela-Veistola and Jauhiainen, 2006). Although pea moth related damages are more relevant in green pea and pea seed production than in grain pea production for feeding purposes, a reduction of a moth infestation in grain peas is important to reduce the risk for neighbouring pea fields (Huusela-Veistola and Jauhiainen, 2006). The severity of pea aphid and moth infestations and thereby related damages are dependent on environmental and weather conditions as well as on the coincidence of pest occurrence and sensitive pea growth stages (Huusela-Veistola and Jauhiainen, 2006; McVean et al., 1999; Schultz and Saucke, 2005). McVean et al. (1999) and Thöming et al. (2011) suggested that peas should be sown early and only early-maturing cultivars should be used for pea production as one preventive management strategy to avoid coincidence and therefore high pea aphid and moth infestation levels. Owing to the fact that time of flowering and maturity is earlier than in spring peas, cultivation of winter peas could be advantageous to minimize pea aphid and moth damages in grain pea production. Moreover, the data that do exist indicate that intercropping peas and cereals can be effective in reducing an infestation with some pea pests, e.g., pea aphids (Bedoussac et al., 2008; Bedoussac, 2009; Seidenglanz et al., 2011).

The aim of this study was to: (1) evaluate the effects of ploughing system and intercropping on the annual weed infestation in semi-leafless and normal-leafed winter peas and their underlying causes, (2) determine whether winter pea cultivars differing in leaf type, as well as in time of flowering and maturity, vary in their susceptibility to pea aphid and moth attacks and (3) examine the impact of pea sole and pea-triticale intercropping on an infestation with pea aphids and moths.

2 Material and methods

2.1 Site characteristics, experimental design and crop management

The field experiments were conducted at the experimental station of the Thünen Institute of Organic Farming at Trenthorst, Northern Germany (53°46'N, 10°30'E, 43 m a.s.l.) in the seasons 2009/10 and 2010/11. According to the World Reference Base for Soil Resources, the soil type at the experimental site was classified as a Stagnic Luvisol and the soil texture as a loam. Post-sowing soil characteristics are presented in Table 1. The 30-year mean annual precipitation at the nearest National Meteorological Service weather station in Lübeck-Blankensee (53°52'N, 10°42'E) is 706 mm with a mean temperature of 8.8 °C. The weather conditions during the experimental years were recorded at the experimental site and are given in Table 2. Triticale (2009/10, *Triticosecale* Wittmack) and oilseed rape (2010/11, *Brassica napus* L.) were the previous crops at the experimental site.

Table 1

Characteristics of the topsoil (0 to 20 cm) at the experimental site in 2009/10 and 2010/11

	2009/10	2010/11
pH ($CaCl_2$)	7.0	6.5
P (CAL, mg kg^{-1})	92	96
K (CAL, mg kg^{-1})	133	147
Mg ($CaCl_2$, mg kg^{-1})	169	121
N_t (%)	0.12	0.14
C_t (%)	1.10	1.38

Table 2
Air temperature and precipitation during the 2009/10 and 2010/11 experimental year and departure from 30-year average

	2009/10				2010/11			
	Air temperature (°C)		Precipitation (mm)		Air temperature (°C)		Precipitation (mm)	
Month	Average	Departure[1]	Total	Departure[1]	Average	Departure[1]	Total	Departure[1]
August	18.9	+2.0	19	-58	17.1	+0.2	189	+112
September	15.0	+2.0	27	-45	13.2	+0.2	94	+23
October	8.1	-0.8	57	+12	9.2	+0.3	41	-5
November	8.0	+3.8	78	+19	4.2	0	98	+39
December	0.5	-1.6	56	-16	-7.0	-6.1	24	-48
January	-4.1	-5.4	8	-53	1.8	+0.5	21	-41
February	-0.8	-2.4	14	-33	0.9	+0.7	51	+5
March	4.0	+0.1	11	-50	4.3	+0.4	10	-51
April	8.4	+0.7	19	-25	11.7	+4.0	10	-34
May	9.9	-2.5	97	+56	13.4	+1.0	24	-17
June	15.5	+0.5	73	0	16.4	+1.4	77	+5
July	20.8	+3.5	11	-74	16.8	-0.5	50	-35

[1] Departure from 30-year average (1978 to 2007)

Table 3
Proportion of annual weed species in total weed ground coverage and weed species order of dominance averaged over all crop stands and ploughing systems at the experimental field in 2009/10 and 2010/11

	2009/10		2010/11	
Scientific name	% of total weed coverage	Order of dominance	% of total weed coverage	Order of dominance
Capsella bursa-pastoris (L.) Medic.	8.5	4	6.4	7
Chenopodium album L.	0	-	0.3	11
Galeopsis tetrahit L.	0	-	0.3	11
Galium aparine L.	0.2	9	24.6	1
Geranium dissectum L.	0	-	0.9	9
Geranium rotundifolium L.	0.8	7	0	-
Lamium purpureum L.	37.6	1	13.4	4
Myosotis arvensis (L.) Hill.	3.1	6	8.3	6
Matricaria chamomilla L.	5.0	5	11.4	5
Poa annua L.	0.3	8	1.6	8
Polygonum persicaria L.	0	-	0.1	-
Stellaria media (L.) Vill./Cyr.	35.8	2	17.5	2
Veronica hederifolia L.	0	-	14.4	3
Vicia hirsuta (L.) Gray	0.1	10	0	-
Viola arvensis Murr.	8.6	3	0.8	10

The experimental factor ploughing system consisted of deep (DP, stubble tillage: precision cultivator, soil depth 8 to10 cm; primary tillage: mouldboard plough to a soil depth of 25 to 27 cm) and of shallow ploughing (SP). Stubble and primary tillage in the shallow ploughing system were performed with a skim plough (Stoppelhobel, Zobel-Stahlbau, Germany) to a soil depth of 4 to 6 cm and 10 to 12 cm, respectively. Long-term mouldboard ploughing to a soil depth of 25 to 30 cm was performed at the experimental site before the start of the experiment.

The factor crop stand included five treatments: the semi-leafless, white-flowered winter pea cultivar James and the normal-leafed, colored-flowered cultivar E.F.B. 33 (shortened EFB) were grown as sole crops (SC, James SC, EFB SC, 80 germinable kernels m^{-2}) and in intercrops (IC) with triticale (cv. Grenado, James-TR IC, EFB-TR IC). The intercrop consisted of 40 germinable kernels winter pea and 150 germinable kernels triticale m^{-2}. Component crops were arranged in alternate rows with a 12.5-cm row distance. A triticale sole crop (Triticale SC, 300 germinable kernels m^{-2}) was grown for weed infestation comparison purposes.

The experimental layout was a split-plot design with four replicates. Ploughing systems were arranged as main plots and crop stands as subplots. The plot size was 2.75 × 15 m. Sowing was performed on September 10, 2009 and October 11, 2010. As a result of the high precipitation in late summer and autumn 2010 (Table 2), sowing was delayed by one month in the second experimental year.

Crop management occurred in accordance with European organic farming standards (Commission Regulation (EC) No. 889/2008). No mechanical weed control was performed in the experiments. The most prevalent annual weed species in 2009/10 were *Lamium purpureum* L. and *Stellaria media* (L.) Vill., whereas *Galium aparine* L. dominated the weed community in the second experimental year. The weed species composition at the experimental fields and their order of dominance are listed in Table 3.

2.2 Sampling procedures, measurements, counts and calculations

Ground coverage of weeds was estimated five times per plot using rectangular frames with an area of 0.5 m^2 at the end of stem elongation in EFB corresponding to the inflorescence emergence in James (Table 4). Annual weed biomass samplings were performed in June (pea flowering/beginning of pod development) and July (pea ripening/maturity) from an area of 0.5 m^2 and 1 m^2 per plot, respectively. The sampling dates and the corresponding crop growth stages are given in Table 4. Annual weeds were cut 1 cm above the soil surface and dried at 60 °C to constant weight. The fresh weight and the dry matter of the weed samples were measured to estimate the water content of the weed biomass. The above-ground crop biomass was as well determined at the June biomass sampling date and the proportion of weeds in total aboveground biomass was calculated. Weed and pea biomass samples were milled (0.5 mm, Foss Tecator 1093, Denmark) and analyzed to total nitrogen (N) content (CNS elemental analyzer, HEKAtech, Germany).

Simultaneous photosynthetically active radiation (PAR) measurements above the crop stand and on the weed canopy level were carried out using a SS1-SunScan Canopy Analysis System and a reference BF5 Sunshine Sensor (Delta-T Devices, UK). Five measurements per plot were taken across the rows on a weekly basis starting at the end of winter pea stem elongation. The proportion of total PAR transmitted to the weed canopy level was calculated by relating the value measured on the weed canopy level to the incident PAR above the crop stand.

The density of live pea aphids (number per shoot tip) was counted and the incidence (proportion of infested plants) was determined during the entire infestation period twice or three times a week in deep ploughed plots according to the EPPO standards (EPPO, 2005). The pea BBCH growth stages were recorded at each assessment. Cumulative aphid-days were calculated following Ruppel (1983).

Winter pea grain samples of a plot combine harvest from an area of 17.5 m^2 were used to determine the pea moth infestation level. In doing so, four times 200 grains per plot were screened for symptoms of attack.

2.3 Statistical Analysis

Owing to the differing sowing dates, the statistical analysis was conducted separately for both experimental years. Winter pea cropping system and cultivar were analyzed as combined factor crop stand, in order to allow a comparison with triticale sole crops concerning the infestation with annual weeds. ANOVA followed by Tukey's post hoc was performed by using the MIXED procedure of SAS 9.2. Weed coverage data were transformed using arcsine square root transformation, whereas data for weed biomass and weed N uptake were log transformed to achieve normality. Proc NLMIXED was used to fit nonlinear regression models. A negative binomial model was fitted to the aphid density data using Proc GLIMMIX to account for overdispersion in both experimental years (Littell et al., 2006; Liu and Cela, 2008; O'Hara and Kotze, 2010). A binomial distribution and the logit link in Proc GLIMMIX were used for the analysis of the pest incidence data (Madden et al., 2002; Piepho, 1999). Due to the fact that aphid counting and the PAR measurements were made on non-equal time intervals, unequal repeated measure analysis was performed (Littell et al., 2006).

Table 4

Dates of weed coverage estimation and biomass samplings with the corresponding crop growth stages (BBCH) in 2009/10 and 2010/11

	2009/10				2010/11			
	Date 2010	Growth stage			Date 2011	Growth stage		
		EFB	James	Triticale		EFB	James	Triticale
Ground coverage of weeds	22 April	39	55	30	4 May	39	51	31
Weed and crop biomass sampling 1	15 June	65	72	65	14 June	67	72	71
Weed biomass sampling 2	19 July	88	89	87	16 July	83	89	83

3 Results

3.1 Weeds

3.1.1 Weed ground coverage, weed biomass and weed-crop biomass relationship

The experimental factor crop stand had a significant effect on the weed ground coverage in both experimental years. The weed ground coverage was highest in James sole crops and least in triticale sole crops and did not differ significantly between EFB and James in either sole crops or in intercrops (Table 5). Intercropping winter peas and triticale tended to reduce the weed ground coverage in 2009/10 and resulted in significantly lower weed ground coverage values in 2010/11.

Also, the proportion of weeds in total aboveground biomass and the weed biomass in 2009/10 were significantly affected by the experimental factor crop stand. Additionally, the analysis of variance showed a significant sampling date × crop stand interaction for the weed biomass data in 2010/11. The proportion of weeds in the total aboveground biomass was significantly greater in James sole crops than in the other examined crop stands in both experimental years (Table 5). James-triticale intercrops exhibited significantly lower proportions of weeds in total aboveground biomass than James sole crops. There were no significant differences between EFB sole crops, triticale sole crops and winter pea-triticale intercrops in 2009/10. Unlike in 2009/10, EFB sole cropping resulted in a significantly higher proportion of weeds in total aboveground biomass compared with triticale sole cropping and intercropping in 2010/11.

The significantly highest weed biomass accumulation was determined in James sole crops in both experimental years (Table 5, Figure 1). The EFB sole and intercrops were found to have significantly lower weed biomass values than James and triticale sole as well as intercrops in 2009/10. Besides, there was no significant difference between EFB sole and EFB-triticale intercrops concerning the weed biomass accumulation at the June as well at the July sampling date in 2009/10, whereas James-triticale intercropping resulted in a significantly lower weed biomass accumulation compared with James sole cropping at both sampling dates in the same year.

The weed infestation in 2010/11 was higher than in the previous experimental year (Table 5, Figure 1). EFB sole crops showed a significantly lower biomass accumulation than James sole crops in 2010/11 (Table 5). In contrast, no varietal difference was revealed in winter pea-triticale intercrops. Intercropping winter peas and triticale reduced the biomass accumulation at the first sampling date independent of the pea cultivar. At the second sampling date, however, a significant lower weed biomass accumulation in the intercrop than in the sole crop was solely present for cultivar James. The weed biomass accumulation in triticale sole crops was significantly lower than that in EFB sole crops at the first sampling date and comparable at the second sampling date. Moreover, no significant differences occurred between triticale sole crops and winter pea-triticale intercrops at both sampling dates in 2010/11.

Triticale was found to have a lower aboveground biomass accumulation at pea flowering in 2009/10 (Triticale SC: 335.8, EFB-TR IC: 123.5, James-TR IC: 184.4 g d.m. m^{-2}) than in 2010/11 (Triticale SC: 663.2, EFB-TR IC: 480.7, James-TR IC: 596.7 g d.m. m^{-2}). Therefore, total crop biomass accumulation of triticale sole crops and winter pea-triticale intercrops was considerably lower than that in 2010/11 (Figure 1). There was a relationship between crop and weed aboveground biomass accumulation at the June sampling date (Figure 1). Weed aboveground biomass exponentially decreased as the crop aboveground biomass increased, most notably in the second experimental year.

There was neither a significant interaction comprising the experimental factor ploughing system nor a significant

Table 5
Effect of crop stand on the weed infestation in 2009/10 and 2010/11. Values are means ± SEM

Crop stand	Weed ground coverage (%) April/May	Weed biomass in total aboveground biomass (%) June	Weed biomass (g d.m. m^{-2}) June	Weed biomass (g d.m. m^{-2}) July
2009/10				
EFB SC	44.0 ± 2.4 ab	1.7 ± 0.6 b	7.4 ± 2.4 d	9.1 ± 3.7 c
EFB-TR IC	33.4 ± 2.0 bc	1.0 ± 0.3 b	6.0 ± 1.7 d	6.0 ± 2.9 c
James SC	53.4 ± 4.9 a	21.0 ± 3.2 a	96.4 ± 13.6 a	76.4 ± 19.6 a
James-TR IC	43.6 ± 4.9 ab	8.4 ± 2.4 b	37.4 ± 11.8 b	32.0 ± 3.7 b
Triticale SC	26.4 ± 2.4 c	4.2 ± 1.0 b	13.2 ± 2.7 c	24.4 ± 5.3 b
2010/11				
EFB SC	16.6 ± 0.9 a	14.2 ± 2.5 b	85.9 ± 10.1 b	21.1 ± 9.6 b
EFB-TR IC	7.4 ± 0.5 b	6.1 ± 1.0 c	47.4 ± 4.3 c	25.6 ± 3.2 b
James SC	18.0 ± 1.4 a	39.2 ± 6.5 a	186.3 ± 21.2 a	202.3 ± 20.2 a
James-TR IC	6.3 ± 0.5 b	4.9 ± 0.7 c	37.1 ± 5.3 c	34.5 ± 6.6 b
Triticale SC	5.5 ± 0.3 b	6.9 ± 1.2 c	49.8 ± 10.0 c	23.8 ± 4.0 b

Means within each column and experimental year with different letters are significantly different (P < 0.05))

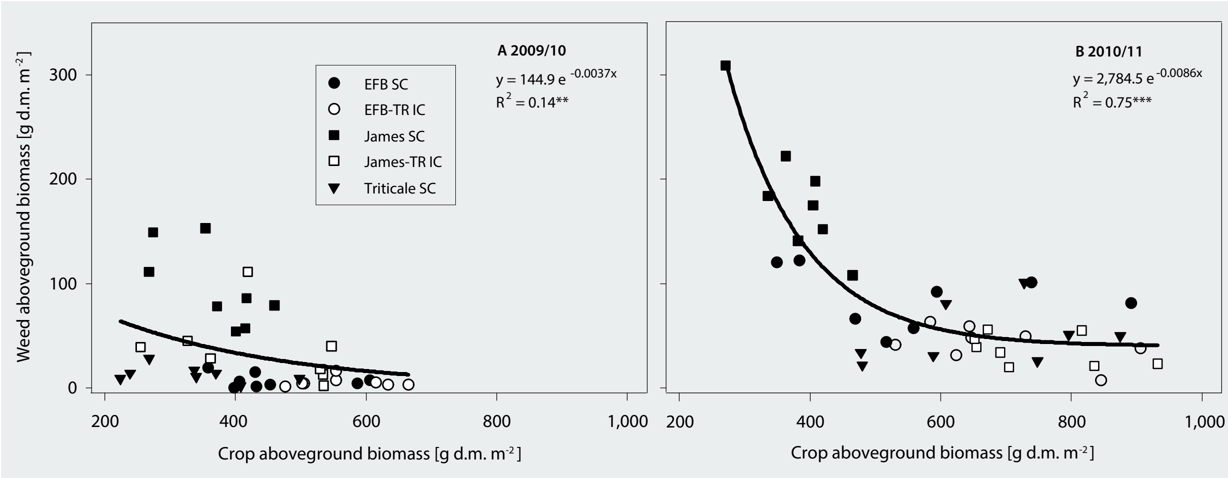

Figure 1
Relationship between weed and crop aboveground biomass at the June sampling date in 2009/10 (A) and 2010/11 (B) independent of ploughing system. ** and *** indicate that exponential regression is significant at $P < 0.01$ and $P < 0.0001$.

Table 6
Effect of ploughing system on weed parameters in 2009/10 and 2010/11. Values are means of one rating/sampling date (weed ground coverage, weed biomass in total aboveground biomass) or two sampling dates (weed biomass, N content, N uptake and dry matter content) ± SEM

	Ploughing system			
	2009/10		2010/11	
	DP	SP	DP	SP
Weed ground coverage (%)	37.4 ± 3.0 a	43.0 ± 3.0 a	10.9 ± 1.3 a	10.3 ± 1.4 a
Weed biomass in total aboveground biomass (%)	6.5 ± 2.1 a	8.0 ± 2.0 a	15.0 ± 2.9 a	13.5 ± 4.1 a
Weed biomass (g d.m. m^{-2})	26.5 ± 5.4 a	35.1 ± 6.6 a	75.3 ± 11.2 a	67.9 ± 11.7 a
Weed biomass N content (%)	1.72 ± 0.08 a	1.63 ± 0.07 a	1.48 ± 0.06 b	1.68 ± 0.07 a
Weed biomass N uptake (kg ha^{-1})	3.9 ± 0.8 a	5.0 ± 0.9 a	10.8 ± 1.6 a	10.4 ± 1.6 a
Weed biomass dry matter content (%)	27.4 ± 2.2 a	27.7 ± 2.0 a	22.8 ± 0.8 a	20.7 ± 0.7 b

Means on the same line within the same experimental year with different letters are significantly different ($P < 0.05$)

ploughing system main effect for weed infestation parameters. Weed ground coverage, proportion of weeds in total aboveground biomass and weed aboveground biomass after shallow and deep ploughing thus revealed comparable results (Table 6). Also, total crop aboveground biomass accumulation did not differ significantly between shallow and deep ploughing (data not shown).

3.1.2 Weed N content and N uptake in aboveground biomass

The N content of the weed biomass was significantly affected by a crop stand main effect in 2009/10 and a sampling date × crop stand interaction in 2010/11. The highest weed N content was detected in EFB sole crops in both experimental years (Table 7). At the first sampling date in June, weeds in EFB-triticale intercrops were found to have significantly lower weed N contents than EFB sole crops, whereas no significant differences in weed N content occurred between EFB sole and intercrops at the July sampling date. Also, the weed biomass in James sole crops possessed a significantly lower N content than that in EFB sole crops. Unlike in 2009/10, the weed biomass N content in James sole and intercrops did differ significantly in 2010/11with lower values in the intercrop at the June and higher values at the July sampling date. Triticale sole cropping resulted in a tendentially or significantly lower weed biomass N content than EFB sole or intercropping. No significant differences were found between triticale and James sole crops in 2009/10 or between triticale sole crops and James-triticale intercrops in both experimental years. The ploughing system did not affect the weed biomass N content in 2009/10, whereas significantly higher values were found after shallow ploughing in 2010/11 (Table 6).

The statistical analysis of the weed N uptake in aboveground biomass revealed a significant crop stand main effect in 2009/10 and a significant sampling date × crop stand interaction in 2010/11. James sole crops showed the highest weed N uptake of all crop stands and significantly higher values than EFB sole crops in both experimental years (Table 7). Moreover, the weed N uptake was significantly higher in James-triticale intercrops than in EFB-triticale intercrops in 2009/10, whereas no significant differences were found between winter pea-triticale intercrops in 2010/11. Triticale sole crops took up an intermediate position between crop stands with James and those with EFB in 2009/10. In 2010/11, however, there were no significant differences between triticale sole and winter pea-triticale intercrops with regard to weed N uptake. The ploughing system had no effect on the weed N uptake in either experimental year (Table 6).

3.1.3 Weed dry matter content

A sampling date × crop stand interaction and a crop stand main effect significantly affected the dry matter content of the weed biomass in 2009/10 and 2010/11, respectively. The dry matter content of the weed biomass did not differ significantly between winter pea sole and intercrops in 2009/10, whereas winter pea-triticale intercrops had significantly higher values than winter pea sole crops in 2010/11 (Table 7). Crop stands with James showed a higher weed biomass dry matter content than those with cultivar EFB. Furthermore, the weed biomass in triticale sole crops was comparable to the level in James-triticale intercrops except for the July sampling date in 2009/10. Neither a significant main effect nor an interaction containing the experimental factor ploughing system had an impact on the dry matter content in 2009/10. In contrast, deep ploughing resulted in a significantly higher weed biomass dry matter content than shallow ploughing in 2010/11 (Table 6).

3.1.4 Transmission of incident photosynthetically active radiation to weed canopy level

The proportion of incident photosynthetically active radiation (PAR) transmitted to the weed canopy level was significantly affected by a measurement date × crop stand interaction in both experimental years and by a crop stand × ploughing system interaction in 2009/10. The PAR transmission to the weed canopy level was significantly higher with winter pea James than with EFB in sole as well as in intercrops throughout the complete period of measurement in 2009/10 (Figure 2A). James sole crops were found to have significantly higher values than James-triticale intercrops until the end of flowering in James (BBCH 67, 17 May), but thereafter lower PAR transmission was measured in James sole crops. There was no significant difference between EFB sole and intercrops at the beginning of the PAR measurement in 2009/10. Subsequently, PAR transmission was significantly lower in EFB sole crops than in EFB intercrops. This trend continued until the end of May, respectively the inflorescence emergence (BBCH 51) in EFB. Thereafter, sole and intercropped EFB crop stands showed a comparable PAR transmission. The PAR transmission to the weed canopy in triticale sole crops was between the level of James and EFB crop stands until the middle of May. After the beginning of booting, triticale sole cropping resulted in the highest PAR transmission compared with all other examined crop stands.

The 2010/11 data deviate to a large extent from data gathered in the first experimental year. The PAR transmission was as well highest in James sole crops until the end of May (BBCH 65) and tendentially or significantly higher than in EFB sole crops at all measurement dates (Figure 2B). Winter pea intercrops and triticale sole crops, however, did not differ significantly during the initial phase of measurement. Moreover,

Table 7

Effect of crop stand on weed biomass N content, N uptake and dry matter content at two sampling dates in 2009/10 and 2010/11. Values are means ± SEM

	Weed biomass					
	N content (% d.m.)		N uptake (kg ha^{-1})		Dry matter content (%)	
Crop stand	June	July	June	July	June	July
2009/10						
EFB SC	2.56 ± 0.09 a	1.82 ± 0.23 a	1.8 ± 0.6 cd	1.3 ± 0.4 b	10.9 ± 0.5 b	37.3 ± 3.7 ab
EFB-TR IC	1.95 ± 0.07 b	1.59 ± 0.13 ab	1.2 ± 0.3 d	0.9 ± 0.5 c	9.7 ± 1.7 b	31.7 ± 2.6 b
James SC	1.65 ± 0.11 c	1.23 ± 0.09 b	15.0 ± 1.4 a	9.0 ± 2.1 a	23.2 ± 0.9 a	43.7 ± 2.1 a
James-TR IC	1.54 ± 0.05 c	1.35 ± 0.08 b	5.7 ± 1.8 b	4.0 ± 0.4 a	22.6 ± 1.9 a	42.9 ± 1.1 a
Triticale SC	1.73 ± 0.04 c	1.32 ± 0.07 b	2.3 ± 0.5 c	3.2 ± 0.7 ab	22.1 ± 2.0 a	33.8 ± 2.1 b
2010/11						
EFB SC	2.33 ± 0.11 a	1.94 ± 0.06 a	19.5 ± 1.9 b	4.1 ± 1.9 b	15.4 ± 0.5 c	14.6 ± 1.5 c
EFB-TR IC	1.51 ± 0.12 bc	1.94 ± 0.06 a	6.5 ± 1.1 c	4.9 ± 0.6 b	23.6 ± 1.1 ab	21.0 ± 0.6 b
James SC	1.63 ± 0.09 b	1.11 ± 0.06 c	29.7 ± 2.6 a	22.7 ± 2.9 a	21.6 ± 0.5 b	19.9 ± 0.6 b
James-TR IC	1.30 ± 0.04 cd	1.40 ± 0.07 b	4.8 ± 0.7 c	4.8 ± 0.9 b	24.2 ± 1.0 a	26.6 ± 1.4 a
Triticale SC	1.23 ± 0.10 d	1.37 ± 0.08 b	5.9 ± 1.1 c	3.2 ± 0.6 b	25.1 ± 1.2 a	25.7 ± 2.1 a

Means within each experimental year and column with different letters are significantly different ($P < 0.05$)

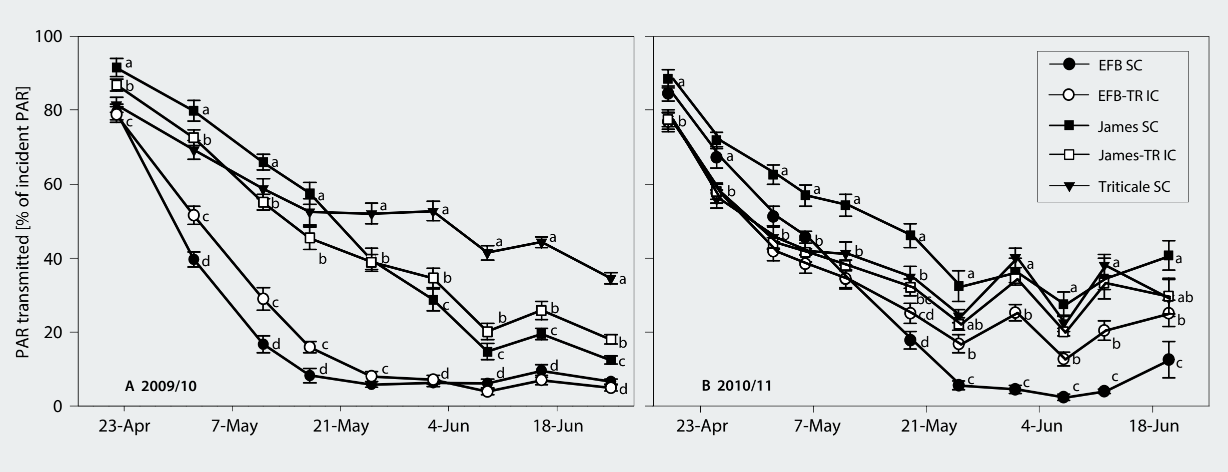

Figure 2

Proportion of PAR transmitted to the weed canopy level in sole crops (SC) and intercrops (IC) of winter peas and triticale in 2009/10 (A) and 2010/11 (B) averaged over both ploughing systems. Values are means ± SEM (error bars). Different letters indicate significant differences ($P < 0.05$) between crop stands at the same measurement date.

significantly lower PAR transmission was revealed in these three crop stands compared with the winter pea sole crops until the beginning of May. Thereafter, the course of the PAR transmission in intercrops paralleled the trend in triticale sole crops with EFB-triticale intercrops demonstrating the lowest and triticale sole crops the highest value. Contrary to the relatively continuous trend in winter pea sole crops, the PAR transmission in triticale sole and winter pea-triticale intercrops fluctuated all through June. At the same time, EFB sole cropping resulted in the lowest and James sole cropping mostly in the highest PAR transmission to the weed canopy level.

The significant crop stand × ploughing system interaction in 2009/10 was caused by a significantly higher PAR transmission in triticale sole crops after shallow ploughing (52.7 %) than after deep ploughing (43.4 %). In contrast, the ploughing system did not significantly influence the PAR transmission in all other crop stands. In 2010/11, any effect comprising the experimental factor ploughing system significantly affected the PAR transmission to the weed canopy level.

3.2 Pests

3.2.1 Pea aphid density and incidence

In the first experimental year, first pea aphids were observed on 2nd June at the beginning of flowering in EFB (BBCH 60) and at flowering declining in James (BBCH 67). The number of pea aphids on sole and intercropped EFB increased until the declining of EFB flowering (BBCH 67), but thereafter decreased continuously (Figure 3A). The proportion of infested EFB plants in sole and intercrops showed comparable trends to the pea aphid density data in EFB (Figure 3E). The highest proportion of infested EFB plants was detected 26 days post infestation, analogous to the highest aphid density. Shortly after the detection of first aphids, the number of pea aphids on EFB and the proportion of infested plants were significantly lower when intercropping than sole cropping was performed. At the maximum infestation level, EFB sole crops were found to have 71 % aphid-infested plants with 21 aphids per shoot tip, whereas 8 aphids per shoot and 44 % infested plants were detected in EFB-triticale intercrops. James aphid infestation peaked 6 days post infestation in intercrops and 8 days after the detection of first aphids in sole crops at the end of flowering (BBCH 69) respectively the beginning of pod development in James (BBCH 71) (Figure 3C, G). No further aphids were detected 22 days and 26 days post infestation in sole and intercropped James, respectively. Intercropping James and triticale significantly reduced the density and incidence of pea aphids compared with James sole crops. The maximum number of aphids per James shoot tip was by 6 aphids lower than in EFB sole crops, whereas no difference was found between the maximum density in intercropped EFB and James. Pea aphids were found on 80 % of sole cropped and on 65 % of intercropped James plants at the infestation peak, which was higher than with winter pea cultivar EFB.

Low aphid infestation levels were found in 2010/11, with a maximum number of 3 aphids per shoot tip in both pea cultivars 23 days post infestation at full flowering in EFB (BBCH 65) and the beginning of pod development in James (BBCH 72) (Figure 3B, D). The pea aphid incidence fluctuated between 0 % and 26 % in EFB sole crops respectively 8 % in EFB intercrops (Figure 3F). A similar range of values was found for James sole and intercrops (Figure 3H). The aphid infestation period was simultaneous in both winter pea cultivars. Despite a low infestation level, there were significantly higher numbers of pea aphids per shoot tip and more infested plants in winter pea sole crops than in intercrops at most counting dates.

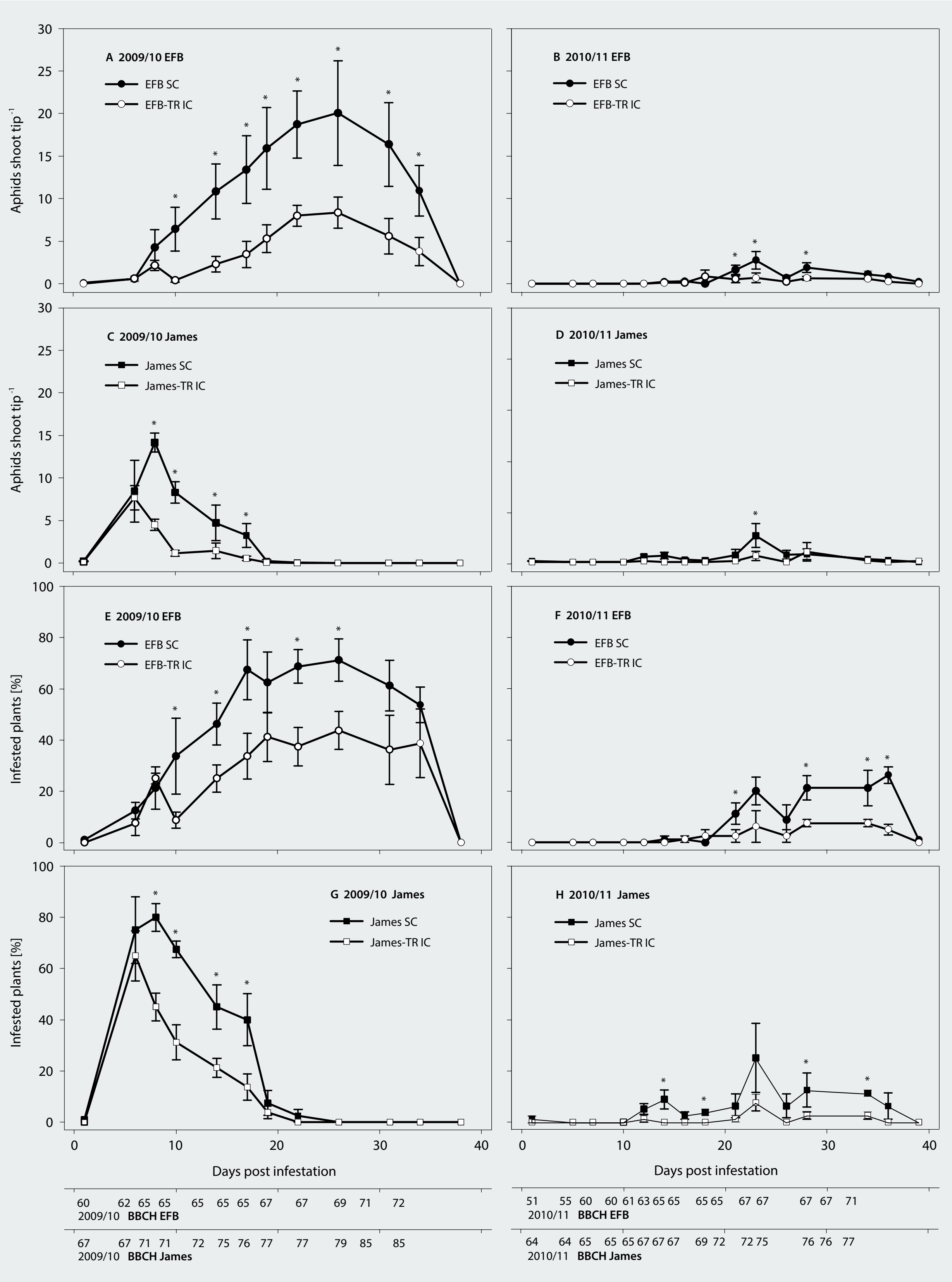

Figure 3
Density (number of aphids per shoot tip, A-D) and incidence (proportion of infested pea plants, E-H) of pea aphids in sole and intercropped winter peas in 2009/10 (A, C, E, G) and 2010/11 (B, D, F, H) with the corresponding growth stages of James and EFB. First aphids were detected on 2nd June, 2010 and 19th May, 2011. Values are means ± SEM (error bars). Asterisks indicate significant differences (P < 0.05) between sole and intercrops.

3.2.2 Cumulative aphid-days

Cumulative aphid-days were significantly higher in EFB sole crops and intercrops than in the corresponding James crop stands in 2009/10 (Table 8). In addition, intercropping winter peas and cereals significantly reduced cumulative aphid-days. Compared to the first experimental year, cumulative aphid-day values were considerably lower in 2010/11. The experimental factor crop stand did not significantly affect the values in the second experimental year. There was, however, the tendency of lower cumulative aphid-days in winter pea-triticale intercrops than in winter pea sole crops.

Table 8
Effect of crop stand on cumulative aphid-days in 2009/10 and 2010/11. Values are means ± SEM

	Cumulative aphid-days	
Crop stand	2009/10	2010/11
EFB SC	400 ± 79 a	29 ± 2 a
EFB-TR IC	139 ± 20 b	12 ± 4 a
James SC	128 ± 11 b	23 ± 9 a
James-TR IC	56 ± 3 c	11 ± 4 a

Means within each column with different letters are significantly different (P < 0.05)

3.2.3 Pea biomass N content

The pea biomass N content at the June biomass sampling date was significantly higher in sole cropped than in intercropped winter peas in both experimental years, with the exception that sole cropped James solely tended to have higher values than intercropped James in 2010/11 (Table 9). There was no significant difference in pea biomass N content between winter pea cultivars in 2009/10, whereas sole and intercropped EFB were detected to have significantly higher values than the corresponding crop stands with James in 2010/11.

Table 9
Effect of crop stand on pea biomass N content at the June biomass sampling. Values are means ± SEM

	Pea biomass N content (%)	
Crop stand	2009/10	2010/11
EFB SC	3.00 ± 0.09 a	2.78 ± 0.04 a
EFB-TR IC	2.78 ± 0.07 b	2.60 ± 0.05 b
James SC	3.10 ± 0.04 a	2.51 ± 0.04 bc
James-TR IC	2.60 ± 0.04 b	2.39 ± 0.04 c

Means within each column with different letters are significantly different (P < 0.05)

3.2.4 Pea moth larvae damaged peas

A significantly higher proportion of pea moth larvae-damaged winter peas was detected in winter pea cultivar EFB, sole or intercropped, than in cultivar James in both experimental years (Table 10). There was no difference in proportion of damaged peas between sole and intercrops in 2009/10. Intercropping winter peas and triticale in 2010/11, however, significantly increased the proportion of damaged peas. Furthermore, winter pea cultivar EFB showed comparable values in both experimental years, whereas James was found to have a considerably higher proportion of damaged peas in 2010/11.

Table 10
Effect of crop stand on the proportion of pea moth larvae-damaged peas. Values are means ± SEM

	Pea moth larvae damaged peas (%)	
Crop stand	2009/10	2010/11
EFB SC	32.3 ± 3.2 a	32.4 ± 1.1 b
EFB-TR IC	37.6 ± 2.3 a	37.4 ± 1.6 a
James SC	7.4 ± 1.7 b	18.2 ± 1.0 d
James-TR IC	4.3 ± 0.9 b	23.0 ± 1.2 c

Means within each column with different letters are significantly different (P < 0.05)

4 Discussion

4.1 Weed infestation

The weed infestation level differed considerably between both experimental years. Annual weeds covered a higher proportion of the soil in the examined crop stands in spring in the first experimental year compared with 2010/11 (Table 5). However, the weed biomass accumulation in 2010/11 mostly exceeded the level of the first experimental year. This may be due to differences in sowing date, weather conditions and in weed species composition at the experimental fields (Table 2, 3). *L. purpureum* and *S. media*, the most dominant weed species in 2009/10, were already well-developed and covered a large part of the soil before winter, whereas few scattered weeds were present at the 2010/11 experimental field before winter and in early spring. *L. purpureum*, however, began to senesce at the end of May, which resulted in high weed biomass dry matter content at the July sampling date (Table 7). Owing to the droughty conditions in spring 2011, weed growth and development was reduced until the onset of rainfall in the middle of May 2011, but increased considerably thereafter. This was most notable for the predominant weed species *G. aparine*, which resulted in severe weed problems. Thus, an early weed infestation, with a decrease towards maturity, was present at the experimental fields in 2009/10, whereas a late-season weed infestation dominated in the second experimental year.

Weed biomass accumulation and N uptake, as well as the proportion of weed biomass in total aboveground biomass, were significantly higher in James than in EFB sole crops (Table 5, 7, Figure 1). The normal-leafed winter pea cultivar, thus, better suppressed weeds than the semi-leafless cultivar, which correlates well with the literature for spring and winter peas (Spies et al., 2011; Urbatzka, 2010; Urbatzka et al., 2011). EFB sole crops were found to have a lower PAR transmission to the weed canopy level than James sole crops

(Figure 2), which may be related to higher pea biomass accumulation (Figure 1). The better weed suppressive ability of the normal-leafed winter pea EFB may therefore be associated with lower light availability for weeds. The weed ground coverage at the end of April 2010, respectively the beginning of May 2011, however, did not differ significantly between semi-leafless winter pea cultivar James and normal-leafed cultivar EFB (Table 5). The PAR transmission to the weed canopy level in James sole crops marginally or significantly exceeded the level of EFB sole crops at the same time (Figure 2). PAR transmission values, however, were at a high level in both winter pea sole crops, which may be responsible for the slight varietal difference with regard to weed ground coverage.

The high weed biomass production in James sole crops in the second experimental year (Table 5) was related to a complete crop stand overgrowth with *G. aparine*, which indicates a good soil nitrogen supply. This was due to the short plant height of James being within a range of 23 to 31 cm at flowering. The weed growth aggravation towards maturity may as well have contributed to the increase in weed biomass in James sole crops from the June to the July sampling date in 2010/11, which stands in contrast to all other crop stands. The tall growing cultivar EFB exhibited severe lodging after flowering in sole crops. However, weed overgrowth in lodged crop stands of sole cropped EFB was observable neither in 2009/10 nor in 2010/11 and the weed biomass accumulation remained at the same level (2009/10) or decreased between the June and the July sampling date (2010/11, Table 5).

Intercropping winter pea James and triticale as well as sole cropping triticale resulted in a significantly lower weed biomass accumulation, proportion of weed biomass in total aboveground biomass and weed N uptake than James sole cropping (Table 5, 7). Moreover, James-triticale intercrops showed lower weed ground coverage values than James sole crops (Table 5). These results confirm the efficient weed suppressive ability of pea-cereal intercrops that has been shown in previous studies for intercrops of semi-leafless winter as well as spring peas and cereals (Begna et al., 2011; Corre-Hellou et al., 2011; Hauggaard-Nielsen et al., 2001; Urbatzka, 2010). Despite higher weed pressure towards maturity in 2010/11, resulting in higher weed biomass accumulation and N uptake in James sole crops compared to the first experimental year, values in James-triticale intercrops had a comparable level in both experimental years (Table 5, 7). This may be related to problems in winter triticale emergence, establishment and winter survival in 2009/10, which involved poor sole and intercropped triticale stands with only 30 % of the projected plant density and a by 49 to 74 % lower aboveground biomass accumulation than in 2010/11.

Corre-Hellou et al. (2011) suggested that the higher weed suppression in semi-leafless pea-barley intercrops compared to pea sole crops is mainly due to higher nitrogen competition in case of low soil N availability. The authors also found that high soil N availability contributes to an increase in crop leaf area. They concluded that weed suppression is under these conditions attributable to a strong light competition. Apart from the June biomass sampling in 2010/11, the weed biomass N content of James-triticale intercrops was comparable or significantly higher than in James sole crops (Table 7). In addition, triticale sole cropping resulted solely in a significantly lower weed biomass N content than James sole cropping at the first sampling date in 2010/11. Apart from that, comparable or significantly higher values were detected in the weed biomass from triticale sole crops. These results indicate that nitrogen competition does not sufficiently explain the high weed suppressive ability in James-triticale intercrops and triticale sole crops.

The PAR transmission to the weed canopy level was significantly higher in James sole crops than in James-triticale intercrops and triticale sole crops until the end of May, but did thereafter mostly not differ from or exceed the level of James sole crops (Figure 2). Thus, in the case of the early weed pressure in 2009/10, the high weed suppressive ability of James-triticale intercrops and triticale sole crops may have predominately originated from a stronger light competition than in James sole crops. The non-significant difference in PAR transmission to the weed canopy level between James sole crops and James-triticale intercrops after the end of May in 2010/11 (Figure 2B) demonstrates that shading cannot be responsible for the significantly lower late-season weed infestation in James-triticale intercrops in the second experimental year. The weed biomass dry matter content did not differ significantly between James sole crops and James-triticale intercrops at either the June or the July biomass sampling in 2009/10. In contrast to 2009/10, weed biomass in James-triticale intercrops was found to have significantly higher dry matter content than that of James sole crops in the second experimental year (Table 7). Our results suggest that the good weed suppressive ability of James-triticale intercrops was due to a higher water competition compared to James sole crops. This observation is in accordance with results of Mohler and Liebman (1987) for spring pea-barley intercrops. The presumably higher crop-weed competition for water in James-triticale intercrops than in James sole crops in 2010/11 may have resulted from the droughty conditions in spring 2011 inhibiting the biomass formation in James but not in triticale.

Despite the low triticale aboveground biomass accumulation in 2009/10, the weed infestation in EFB-triticale intercrops was comparable to the low weed infestation level in EFB sole crops and significantly lower than in the triticale sole crops (Figure 1A, Table 5). Owing to the absent competition between winter peas and triticale in the intercrop, the crop biomass accumulation in EFB-triticale intercrops obtained the level of the biomass accumulation in EFB sole crops (Figure 1A). For this reason, EFB-triticale intercrops paralleled the PAR transmission course of EFB sole crops on a higher level until the end of May, but thereafter reached the low level of EFB sole crops (Figure 2A). The tendency of lower weed biomass values in the intercrop may therefore be explained by higher crop-weed nitrogen competition than in the sole crop, which resulted in a lower weed biomass N content (Table 7).

Intercropping EFB and triticale significantly reduced the weed infestation compared to EFB sole cropping at the June biomass sampling in 2010/11, whereas no differences were found at the July sampling date in the second experimental year (Table 5). The effective weed suppressive ability of EFB-triticale intercrops in June can be attributed, in part, to a significantly lower PAR transmission (Figure 2B). In addition, the weed biomass N content was significantly lower and the dry matter content significantly higher in the EFB-triticale intercrop than in the EFB sole crop (Table 7). We might therefore suppose higher nitrogen and water competition in the intercrop to be important factors for the low weed biomass accumulation in EFB-triticale intercrops at the June sampling date, too. The PAR transmission in EFB sole crops showed a strong decreasing trend towards maturity resulting in a significantly lower PAR transmission level than in EFB-triticale intercrops after the middle of May (Figure 2B). Moreover, the weed biomass nitrogen content was found to be identical in EFB sole and intercrops at the July biomass sampling date (Table 7). The similar weed biomass accumulation in EFB sole and EFB-triticale intercrops in July may thus be attributed to a change in PAR transmission and nitrogen availability in both crop stands.

Most studies suggest that a decrease in ploughing depth is correlated with an increase in annual, and in particular perennial, weed infestation (Børresen and Njøs, 1994; Brandsæter et al., 2011; Gruber and Claupein, 2009; Kouwenhoven et al., 2002; Pranaitis and Marcinkonis, 2005). Despite differences in weed composition and weed pressure at the experimental sites in 2009/10 and 2010/11, deep and shallow ploughing did not differ significantly in annual weed ground coverage, biomass accumulation and N uptake or in the proportion of annual weed biomass in total aboveground biomass in both experimental years (Table 6). Our data therefore differ from those reported by others. Interestingly the ploughing system neither affected crop stands with low weed suppressive ability, e.g., James sole crops nor crops stands possessing good weed suppression, as for instance EFB-triticale intercrops. Even the significantly higher PAR transmission in triticale sole crops in 2009/10 in consequence of a lower emergence and a higher winter kill rate of triticale after shallow ploughing did not influence the annual weed infestation. The weed biomass N and dry matter content were affected by the ploughing system in 2010/11 but not in 2009/10 (Table 6). The significantly higher weed biomass N content and the significantly lower dry matter content after shallow ploughing in 2010/11 did not, however, occur coupled with an increase in weed biomass. These results indicate that a reduction of the ploughing system did not alter the germination environment or considerably change the nutrient and water availability for annual weeds.

4.2 Pea pests

4.2.1 Pea aphid infestation

The occurrence of pea aphids and the duration of the infestation were closely related to the pea flowering period. Flowering occurred earlier in James than in EFB, most notably in 2009/10 (Figure 3). That is the reason why the aphid infestation of winter pea James began at James main flowering and peaked between the end of flowering and the beginning of pod development, whereas first aphids on EFB were observed at the beginning of EFB flowering and the maximum infestation level was found to be in the period between EFB main and declining flowering (Figure 3). Owing to the late appearance of pea aphids in 2009/10, the infestation period was shorter in James than in EFB. The shorter infestation period coupled with a lower aphid density resulted in significantly lower cumulative aphid-days in sole cropped James than in sole cropped EFB (Table 8). These results indicate that early-flowering winter peas will be damaged to a lesser extent than late-flowering winter peas. McVean et al. (1999) suggested as well that spring pea sowing time should be as early as possible to avoid the coincidence of flowering and high aphid occurrence. The comparable density and incidence of pea aphids as well as the non-significant difference in cumulative aphid-days between both pea cultivars in 2010/11 (Figure 3, Table 8) resulted from the low occurrence of pea aphids and the slightly later flowering date in James. Low aphid density and incidence in 2010/11 might be attributed to spring drought. Maiteki et al. (1986) also found low pea aphid densities under drought conditions in spring and early summer.

Peak aphid density was lower in sole cropped James than in sole cropped EFB, whereas the proportion of infested pea plants tended to be higher in James sole crops compared to EFB sole crops in 2009/10 (Figure 3). Owing to the less available space on tendrils than on leaflets, the development of aphid colonies is more restricted on semi-leafless than on normal-leafed peas (Soroka and Mackay, 1990). As a consequence, James might have supported fewer pea aphids which involved a higher number of infested plants. The earlier decline of the aphid infestation in James sole crops in 2009/10 occurred in conjunction with an increase in air temperature. This observation is in accordance with other authors, who suggested that adverse environmental conditions affect pea aphids to a greater extent on semi-leafless or leafless peas than on normal-leafed peas (Buchman and Cuddington, 2009; Legrand and Barbosa, 2000; Soroka and Mackay, 1990).

In agreement with the findings of Seidenglanz et al. (2011) for spring peas, we found that pea aphids appeared at the same time in winter pea sole and intercrops (Figure 3). These data did not support the hypothesis that triticale acts as a barrier and prevents an aphid attack of intercropped winter pea cultivars with short plant height at flowering like James. Intercropping, however, significantly reduced pea aphid density and incidence as well as cumulative aphid-days most notably with the high infestation level in 2009/10 (Figure 3, Table 8). Similar results have been demonstrated by Bedoussac (2009) for semi-leafless winter pea-durum wheat intercrops.

Patriquin et al. (1988) compared the number of *Aphis fabae* in faba bean (*Vicia faba* L.) sole crops and faba bean-cereal intercrops under organic conditions. They found that the aphid density and the leaf N content were significantly higher in sole crops than in intercrops. The authors concluded that colonisation as well as reproduction of aphids may be reduced by the nitrogen competition in intercrops. We found mostly significantly lower biomass N contents in intercropped winter peas during the infestation period with pea aphids (Table 9), which confirms these previous observations in faba bean-cereal intercrops. Thus, the lower pea aphid infestation in winter pea-triticale intercrops might be attributed to a lower nitrogen status in intercropped winter peas. Previous studies, however, have reported contradictory findings pertaining to the effect of pea nitrogen supply on the pea aphid reproduction under greenhouse conditions. Moravvej and Hatefi (2008) showed that the aphid reproduction increased with increasing nitrogen content in pea leaves, whereas Buchman and Cuddington (2009) did not find a relationship between pea nitrogen supply and aphid reproduction. Another possible explanation for the differing aphid infestation in sole and intercropped winter peas could be a difference in aphid feeding behaviour due to a variation in plant nitrogen status. Ponder et al. (2000) found that aphids took longer to reach the phloem sap and showed a shorter feeding period on barley under nitrogen limited than under non-nitrogen limited conditions.

Aphid density and incidence was found to decrease earlier in James-triticale intercrops than in James sole crops in 2009/10 (Figure 3C, G). This observation is in accordance with Seidenglanz et al. (2011), who reported that aphid colonies decreased earlier in semi-leafless spring pea-cereal intercrops than in pea sole crops. The authors concluded that an earlier occurrence and a higher number of predators may be responsible for this earlier decline. A considerable decrease in pea yield performance is ascribable to aphid feeding injuries on flowers and pods (Maiteki and Lamb, 1985). An earlier decline in pea aphid colonies at the end of pea flowering can thus be assumed to prevent yield losses in peas. In contrast to the findings for the semi-leafless cultivar James, a simultaneous decline of pea aphids was observed in EFB-triticale intercrops and EFB sole crops (Figure 2A, E). This fact might be attributed to the more open canopy in the semi-leafless winter pea cultivar James, which offers less protection from predators.

4.3 Pea moth infestation

The pea moth infestation level is dependent on weather conditions and the coincidence between pea moth flying period and susceptible plant growth stages (Huusela-Veistola and Jauhiainen, 2006). Thöming and Saucke (2012) reported that mated pea moth females prefer the flowering and the late bud stage in pea. Previous studies have indicated that the cultivation of early-flowering and maturing peas avoids or reduces this temporal coincidence and therefore the risk of a high pea moth infestation (Schultz and Saucke, 2005; Thöming et al., 2011; van Emden and Service, 2004). The proportion of pea moth damaged peas was significantly higher for winter pea cultivar EFB than for James, independent of the crop stand (Table 10). This fact might be attributed to the earlier time of flowering and maturity in James than in EFB. The flowering stage in EFB started at the end of May in both experimental years, whereas flowering in James was delayed by two weeks in 2010/11. This explains the similar infestation levels in EFB in both experimental years and the higher pea moth damages of cultivar James in 2010/11.

Intercropping winter peas and triticale had no effect on the pea moth damage level in 2009/10 (Table 10). On the contrary, both winter pea-triticale intercrops were found to have a significantly higher proportion of damaged peas than the corresponding sole crops. We might suppose the differing actual intercropping composition with a pea dominated intercrop in the first and a triticale dominated intercrop in the second experimental year to be responsible for this difference. Our results are consistent with Wnuk (1998), who found no beneficial effect of intercropping spring peas and phacelia (*Phacelia tanacetifolia* Benth.) or white mustard (*Sinapis alba* L.) with regard to pea moth damages on pods.

5 Conclusions

Intercropping normal-leafed or semi-leafless winter peas and triticale shows great promise in reducing an infestation with annual weeds and pea aphids. A decrease in pea moth damages could, however, not be achieved by intercropping winter peas and triticale. The weed suppressive ability was significantly higher with normal-leafed winter pea EFB than with semi-leafless cultivar James. Pea pest occurrence and infestation levels were highly dependent on pea flowering time. As a result, the early-flowering winter pea cultivar James had a distinct advantage over the later-flowering winter pea cv. EFB. Future studies are needed to separate the flowering time from the leaf type effect with regard to a pea aphid infestation. Moreover, it is necessary to evaluate the relationship between pea nitrogen status, phloem sap concentration as well as composition and pea aphid infestation in sole and intercropped peas under field conditions. The ploughing system did not affect the annual weed infestation either in sole or in intercrops. On the basis of these results, we conclude that shallow and deep ploughing are therefore both feasible in the cultivation of organic winter pea and triticale sole or intercrops with respect to annual weeds. Whole crop rotations will have to be examined in order to define the long-term effect of a reduction in ploughing depth with regard to an infestation with annual and perennial weeds.

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Practical implications of suckling systems for dairy calves in organic production systems – a review

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Abstract

The growing public awareness of practices in livestock production systems leads to an increased doubt on the existing methods and emphasizes a demand to be closer to nature in livestock production. In most dairy production systems cow and calf are separated immediately after birth discouraging all aspects of maternal behavior. In suckling systems cow and young are allowed to spend time together, so the calf is able to suck on its dam and species-specific behavior can be displayed. This article focuses on the different suckling systems established in organic dairy systems and their effects on cow and calf. The beneficial effect on calf growth and the decrease in the occurrence of abnormal behavior (cross-sucking on other calves) when calves are reared with the dam, are scientifically reported, whereas the improved health status, which farmers give as main reason for introducing dam rearing, could not be verified yet. Concerns arise in regard to cow health and milk yield, since milk ejection can be impaired and therefore less milk is obtained at milking. Also the process of weaning poses more difficulties in dam rearing due to breaking the strong bond between mother and young. Based on the current state of scientific research, foster cow systems with additional milking might be a promising alternative: calves can satisfy their sucking motivation and have social contact to mothers/adult cows; on the other hand, weaning stress might be reduced and milking the cows when suckling calves could lead to an increased total milk production. However, a comparison between dam rearing and foster cow systems, also including economical traits, is still missing, and recommendations have to be made with care. Further research is needed to reconcile consumers' demands and the possibilities of farmers using such systems.

Keywords: *dam rearing, foster cow, animal welfare, suckling, milking*

Zusammenfassung

Praktische Konsequenzen Mutter- bzw. Ammen-gebundener Aufzuchtsysteme für Kälber in der ökologischen Milchviehhaltung – eine Übersicht

Das zunehmende öffentliche Bewusstsein gegenüber Praktiken in der Nutztierhaltung lässt vermehrte Zweifel an den existierenden Methoden aufkommen und verstärkt die Forderung nach „natürlicheren" Produktionssystemen. Der vorliegende Artikel beschreibt verschiedene Formen der Mutter- bzw. Ammen-gebundenen Aufzucht in der ökologischen Milchviehhaltung. Wissenschaftlich konnte nachgewiesen werden, dass bei der Mutter-gebundenen Aufzucht ein besseres Wachstum der Kälber und ein verringertes Auftreten von Verhaltensanomalien, bestehen. Eine verbesserte Kälbergesundheit, die bei den Landwirten als einer der Hauptgründe für die Einführung der Mutter-gebundenen Aufzucht gilt, konnte allerdings noch nicht eindeutig aufgezeigt werden. Weiterhin gibt es Befürchtungen bezüglich des Gesundheitsstatus der Kuh und der Probleme bei der Milchgewinnung. Durch auftretende Milchejektionsstörungen wird während des Melkens weniger Milch gewonnen. Auch das Absetzen der Kälber kann Schwierigkeiten bereiten. Die Kälberaufzucht an Ammen, die zusätzlich gemolken werden, scheint hierbei eine vielversprechende Strategie darzustellen. Jedoch gibt es noch keine Studie, welche die beiden Systeme „Aufzucht an der Mutter" mit der „Aufzucht an der Amme", auch im Hinblick auf ihre Wirtschaftlichkeit, vergleicht. Empfehlungen können deshalb nicht uneingeschränkt gegeben werden. Es besteht weiterer Forschungsbedarf.

Keywords: *Mutter-gebundene Aufzucht, Ammenkuh, Tierwohl, Säugen, Melken*

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1 Introduction

In recent years the awareness of farm practices concerning animal welfare has increased. Consumers demand food that has been produced animal-friendly (Toma et al., 2012) and seek more information about the production methods before they make their choice (Napolitano et al., 2010). It seems that consumers' understanding of animal welfare is close to the natural living approach: animals should have the possibility to perform natural behavior, get feed suitable to their physiology and live in an environment as similar as possible to the habitat natural to the species (Lund, 2006). In the consumer's understanding, pigs should be kept outdoors and calves should be able to suck their mothers. Despite this public demand for increased animal welfare standards, farmers are concerned to change their production since increased levels of animal welfare seem to be linked with extra costs and increased prices of the products. Although Napolitano et al. (2010) reported that consumers were willing to pay more for a product when their expectations both of the production methods and on product quality were met, questionnaires on hedonic and purchase intent might not be representative since consumers may declare willingness to pay more for high-perceived quality, but not buying them under economic constraints (Lange et al., 1999). Elgersma (2012) even stated that the opinion of consumers – cows on pasture are more natural and grazing is beneficial for the animals – caused a major Dutch dairy company to promote grazing and pay a premium price for milk from cows spending 120 days with a minimum of six hours per day grazing.

Organic production systems are known for their endeavor to keep their animals under species-appropriate conditions. In their natural environment calves keep sucking their dams between six months up to one year until natural weaning (Newberry and Swanson, 2008). Suckling represents the cornerstone of maternal care (Val-Laillet et al., 2004) and therefore the most natural way of calf rearing is to let calves stay with the mother to suck freely until natural weaning (Lidfors et al., 2005). However, common practice, even in organic dairy systems, is to separate the cow and her calf within the first 24 hours after birth and to raise the calf without further contact to its mother. So the statement from von Keyserlingk and Weary (2007) that all aspects of maternal behavior are discouraged in dairy production except milk production is also true for organic dairy systems. Standard rule (directive (EG) Nr. 834/2007 and directive (EG) Nr. 889/2008) for organic dairy farms is to feed whole milk to the calves, preferable that from the own mother, over a period of three months, which is an improvement in regard to naturalness compared to conventional systems, which usually feed milk replacer. Additionally, German organic organizations state that cow and calf should be kept together for the first 24 hours after birth (Bioland), or recommend suckling in the first few days post partum (p.p.) (Naturland). However, suckling systems, where calves have the opportunity to suck on their dam or on a foster cow and have social contact with other mature individuals until weaning, might be an even better approach to be closer to nature. It seems that organic farmers are more motivated to introduce a calf rearing system, which is more natural (Zumbrunnen, 2012) and allows natural behavior, since dam rearing is mainly found on organic farms. Thus, as Grøndahl et al. (2007) stated, dam rearing, defined as a system in which calves are able to suck their dams for more than the colostrum period and cows are milked additionally (Barth et al., 2007), may satisfy the public concern regarding immediate separation of cow and calf in commercial milk production. Spinka (2006) mentioned that the opportunity to display natural behavior is effective to stimulate an animal's development, leading to long-term effects, and improves its welfare. For example, calves that spent several days with their dams showed higher levels of socially positive behavior three to six weeks after separation. Although the total number of organic farms in Germany practicing one of the many different types of those „natural" suckling systems is unknown, growing interest of like-minded organic farmers can be reported as the increasing demand on workshops and information about dam rearing suggests. Also the growing number of published research (Fröberg et al., 2008; Langhout, 2003; Lidfors et al., 2010; Loberg et al., 2008; Roth et al., 2009b; Wagenaar and Langhout, 2007; Wagner et al., 2012; Zumbrunnen, 2012) shows that the topic of dam rearing on behalf of animal welfare aspects, still raises questions to be solved.

With this review paper we want to give an overview of the different types of suckling systems, their benefits and implications for practical use.

2 Characteristics of suckling systems

Suckling systems were stated to be more beneficial for the welfare of the calves (Krohn, 2001): calves are thought to learn to eat roughage earlier and have social contact with other cows and calves. During introduction of suckling systems in the modern dairy sector, many different manifestations have developed, according to the situational conditions given on the farm. Furthermore, in scientific research suckling systems are characterized to be either permanent or restricted, sucking either on the own mother or on a foster cow. This leads to difficulties in giving practical recommendations from scientific work. Farm practice even shows mixed forms of those systems as is discussed later on. In his review about suckling systems, Krohn (2001) based his characterization on the purpose and the duration that cow and calf spend together: long-term suckling without and with milking (the latter was described as restricted suckling) until weaning and short-term suckling up to one week p.p. without milking the mother. Although Krohn (2001) suggested that short-term suckling is superior to long-term suckling in regard to production and behavior of the cow, the present article mainly refers to long-term suckling systems, since the prolonged contact of calf and dam occurs to be more natural. Table 1 gives an overview about the main characteristics of the two suckling systems addressed in this article, including the comparison with artificial calf-rearing in organic systems. Artificial calf-rearing in organic systems is defined as immediate separation of cow and calf after birth, housing the calf in a singular pen up for one week followed by group-housing of calves at the same age and feeding whole milk via bucket or automate feeder fitted with an artificial teat. Contrary to Krohn (2001), we classify the systems on the type of contact to the mother: calves having contact to their own mother versus calves having no contact to their mother but contact to a foster cow.

3 Sucking on the dam

3.1 Differences between permanent and restricted suckling

In permanent suckling systems calves are allowed to attend and suck their dam freely at any time until weaning. Dam and young are usually kept together apart from the herd for the first few days after birth and get introduced to the herd afterwards. The strong bond between cow and calf establishes within hours after birth (Newberry and Swanson, 2008) and the calf will prefer its mother over other cows (Spinka and Illmann, 1992). Characterized by affiliative behavior like allogrooming, provision of nourishment, warmth, protection, resting in contact, synchronizing activities and maintaining proximity, the social bond is a preferential mutual, affectionate, emotional attachment that is relatively long lasting and survives temporary separations (Newberry and Swanson, 2008). However, Veissier et al. (1998) could show that when access to the udder is denied for a few hours during the first day of life, lambs did not establish a preferential relationship to the dam. Therefore, the first suckling bouts seem to be necessary for the awareness of the maternal features and after the bond is established within the first three days of life, suckling is not necessary to maintain it anymore. This is also the moment, when in restricted suckling systems, cow and calf are separated for a certain time period (e.g. calves are allowed to have contact with the cows for one hour after each milking). The cow rejoins the milking herd and the calf is introduced to other calves about the same age in a group-housing pen. Further on, the effects of permanent suckling are discussed and additional features of restricted suckling will be discussed where necessary.

3.2 Effects on the calves

3.2.1 Health

Ingestion of colostrum is essential for the establishment of the calf's immune system shortly after birth and associated with the occurrence of diarrhea (Kunz et al., 2009). On most farms calves are bottle-fed colostrum to guarantee sufficient colostrum intake. Edwards (1981) reported that only 6 % of the calves sucked within the first hour p.p. and only 32 % managed to suck within six hours after birth. It can be assumed that the control of colostrum intake should have high priority and calves should be assisted by the farmer. Additionally, Selman et al., (1970a) stated that in wild ungulates and horses the udder represents the highest part of a female's underbelly and the offspring will search for feed at this point. They hypothesize that dairy cows seem unsuitable for suckling calves due to their lower udder and Edwards (1981) confirmed that the latency of first sucking increased with parity due to poorer udder confirmation, which resulted in misdirection for teat-seeking. Furthermore, it has been shown that beef cows were sucked earlier p.p. than dairy cows (Selman et al., 1970b). Nonetheless, it seems that there are beneficial effects of dam suckling as well. Although not affecting colostrum intake significantly, Selman et al. (1971) found that mothered calves were much brighter, much better at standing and more eager to suck at six hours p.p. compared to conventionally reared calves. The same authors could show that mothered calves, although not consuming more colostrum than their non-mothered conspecifics, had significantly higher serum immune globulin concentrations

Table 1
Characteristics of calf-rearing systems

	Dam	Foster cow	Artificial/Automate
Contact to mother	yes	no	no
Milking of cow	yes	after weaning of the calves	yes
Contact to mature individuals	yes	yes	no
Milk intake	up to 17 kg (Bar-Peled et al., 1995)	restricted by the amount of other calves sucking the same cow	restricted up to 10 % of birth weight (Khan et al., 2011)
Control of ingested milk	no control	no control	yes
Weight gain	high	dependent on competition for milk	dependent on milk allowance
Maternal behavior	yes	sometimes	no
Cross-sucking[1]	practically none	practically none	often
Allosucking[2]	practically none	usual	no
Udder health	effects unclear	effects unclear	not impaired by suckling
Milk ejection problems	yes	not reported	no

[1] calf sucks on body parts (udder, scrotum) of other calves
[2] calf sucks on more than one cow (non-maternal)

48 hours p.p.. They attributed this to a prolonged grooming, which could make the mothered calves more efficient absorbers of immune lactoglobulin and Schiessler et al. (2002) hypothesized that the absorption rate with commercial colostrum might be lower. The same authors point out that this could also be due to the quality of the colostrum since higher concentrations of IgG were found in the colostrum of the dam compared to colostrum powder.

Keeping the calf with its dam allows the calf to suck anytime. As a consequence, calves suck more often while ingesting lower amounts of milk at a time. Sommer (1995) recommended feeding smaller amounts at more occasions, because the ingestion of more than 1.5 liter at a time might lead to undesired fermentation of milk in the rumen due to the low capacity of the calf's abomasum. In suckling systems the high milk intake is also associated with diarrhea between the fourth and tenth day p.p., but reported to have no detrimental effects on performance of the calves and to disappear without treatment within a few days (Wolters, 2006). Another reason for the occurrence of benign diarrhea could be allosucking, the sucking of calves on different cows, due to a varying milk composition of the cows (personal communication in Wolters, 2006).

In conclusion, the health status of suckling calves is controversially discussed. Some studies found no improved health of dam-reared calves (Roth et al., 2009b), whereas there are reports of improved health (Magaña Monforte et al., 1996; Wolters, 2006). Many factors influence the health status of the animals as it depends on sufficient intake of colostrum within the first day p.p., the quality of colostrum and the amount of milk provided. Furthermore, health state is affected by husbandry, management and feeding practices (Svensson et al., 2003). In which way the health status of the dam or the other members of the herd can affect the calves' health has yet not been studied. The reduced use of antibiotics and the improved health status of the animals seem to be the superior reasons for farmers to introduce dam suckling (Zumbrunnen, 2012), and Soberon et al. (2012) recently showed that milk production in first lactation was lower in animals, which received antibiotics as pre-weaned calves compared to calves, which had no antibiotic treatment during that time. The decreased milk yield was also most likely due to sickness and nutrient partitioning in the treated animals.

3 2.2 Growth

Better growth rates and higher body weight at weaning of calves sucking their dams have been reported in several studies (Le Neindre et al., 1979; Metz, 1984; Metz, 1987; de Passillé, 2001; Roth et al., 2009b) compared to conventionally reared calves. This is mainly attributed to the higher milk intake of calves sucking freely, which can account for up to 17 kg per day (Table 2).

Milk intake by calves in suckling systems is usually estimated by differences in body weight of the calves before and after sucking (Weight-Suckling-Weight-Method). Calves have to be separated from their dams for a certain amount of time before suckling and differences in the reported milk intakes in Table 2 could be due to different separation times. Therefore, it is more common to report weight gains instead of milk intake. Lidfors et al. (2005) could show that the life weight gain of fostered calves did not differ from calves receiving 8 liter of whole milk per day, but was higher compared to calves reared under standard methods (5 liter whole milk per day). According to Spinka and Illmann (1992) suckling might be superior to teat feeding by resulting in higher milk consumption and fewer digestive problems. In contrast to the hypothesis that only the amount of ingested milk makes the difference in growth rates, it was reported by Krohn et al. (1999) that even when prevented from sucking but allowed contact with their mother, calves gained weight twice the rate of calves separated from their mother immediately after birth. This is in line with a calculation in an on-farm evaluation (Schlooss, 2007) resulting in a numerically higher milk conversion ratio for dam-reared calves when compared to foster cow reared or bucket fed calves (milk intake in kg/kg weight gain: 8.45, 9.28 and 9.92; respectively). Although calves are not able to consume all the milk offered by the dam in the first days of life and preferred the front quarters (Barth et al., 2009), they sucked on all four teats after two to three months. Furthermore, no residual milk was left from

Table 2
Milk intake by calves

Author(s)	Breed	Type of nursing	Milk intake (kg/d)
Plum and Harris, 1971	Holstein		4th week p.p.: 9.2 ± 1.0 12th week p.p.: 11.7 ± 1.1
Bar-Peled et al., 1997	Cows: Holstein Calves: 20 Holstein heifer calves	fostering one calf + milking (3 times daily; udder emptying 6 times in total)	16.9 ± 2,5 (1st week p.p.: 10.5 ± 3.7 42nd day p.p.: 21.6 ± 3.5
de Passillé et al., 2008	Holstein	Dam rearing (suckling 2 x daily, 2 hours post milking)	1st week: 6.5 ± 0.7 9th week: 12.5 ± 1.4
Barth et al., 2009	Holstein and Red Pied	Dam rearing without additional milking	2nd week p.p.: 2.6 ± 1.0$ 12th week p.p.: 4.7 ± 1.7$

$ this was estimated once a day after separation of cow and calf between 3 and 5 hours; so it represents the milk intake per feeding bout.

calves at the age of four months, which was found in a study of Plum and Harris (1971) with Holstein cows under beef cattle management. Objections to high milk consumption might be the higher tendency to rear obese calves (Wolters, 2006) and to delay the intake of solid feeds that is necessary for early rumen development.

Addressing the first point, it was stated that after abrupt weaning suckled calves usually show a growth slowdown and lower daily weight gains for ten weeks after weaning (Price et al., 2003, Veissier et al., 2013). Therefore, higher weaning weights are beneficial to compensate for that time. In addition to this, Soberon et al. (2012) found that higher weaning weights could improve lifetime productivity. To achieve a better performance as first lactating cows and even in subsequent lactations, nutritional manipulation must start immediately after birth and continue for five weeks in form of liquid feed, with whole milk being superior to milk replacer (Moallem et al., 2010). If growing rate is enhanced, bull calves for beef production, can be sold earlier, thus saving costs for rearing (Wolters, 2006).

Calves are usually provided with solid feed a few days after birth to promote intake of roughage and concentrate, which should stimulate rumen development. Bar-Peled et al. (1997) observed no intake of solid feeds in calves, which were allowed to suck three times daily during the first six weeks of their life. Similarly, Fröberg and Lidfors (2009) stated that freely sucking calves ate less solid feed and rested more as the control group. Interestingly, more rumination behavior was observed in the freely sucking calves, which could only be explained as an effect of management differences. However, recent findings show that in calves fed high volumes of milk, dry matter intake (DMI) of solid feed was promoted and rumen development enhanced without affecting weight gain (Khan et al., 2011). Contact with the dam can also stimulate intake of solid feed, whereby social learning from the mother could be the pivotal trigger (Flower and Weary, 2001; Ehrlich, 2003). Schiessler et al. (2002) even hypothesized that the high haematocrit and haemoglobin levels measured in blood of suckled calves might be due to a higher ingestion of iron with hay and straw.

3.2.3 Behavior

Abnormal behavior is often found in artificially reared calves and can lead to impaired performance later on in life. Cross-sucking, especially in older calves, which are more at risk for being cross-sucked, can result in udder trauma and inflammation (Laukkanen et al., 2010). A lot of scientific work has been conducted to find the trigger for this abnormal behavior and it seems that feeding behavior plays a major role. Laukkanen et al. (2010) observed that the place where cross-sucking occurred, shifted with the age of the animals from the rest area when young to the feeder area when older. Almost no abnormal oral behavior, like cross-sucking or tongue-rolling, occurred in calves freely sucking their dams, whereas allosucking, calves sucking on other cows than the own mother, was reported and seemed to occur when milk supply by the mother was insufficient for the calf. The short milk intake time and the amount of small proportions offered at the automatic feeder (Fröberg and Lidfors, 2009), an inappropriate energy supply (Roth et al., 2009a), or the unsatisfied sucking motivation (de Passillé, 2001) were mentioned to be triggers for cross-sucking behavior. When spending more time feeding hay, durations of cross-sucking other calves decreased (Roth et al., 2008).

Contact to the dam not only reduces the occurrence of abnormal behavior but also has positive effects on the development of the social ability of the offspring. Flower and Weary (2001) reported that calves kept with their mother for 14 days exhibited more intense social behavior towards unfamiliar calves. In a study with foster cows, Vaarst et al. (2001) found that calves, which were kept with their mothers three days p.p., sniffed, licked and rubbed a nurse cow more often than calves separated from their dam immediately after birth. Therefore, the first days of a calf's life seemed to influence its behavior towards unknown cows as well as other calves significantly. Social learning in early life is more efficient than later in life and the mother is the major social partner, since the first and strongest bond occurs between the dam and its young (Veissier et al., 1998). The age at the time of contact to conspecifics is important for the strength of the bonds established. Heifers grouped after birth formed closer bonds between each other than heifers grouped at six months (Veissier et al., 1998). Although the relationship between dam and young fades over time and calves begin to form groups with peers, a preferential relationship with the dam seems to remain even after suckling ends. Also when prevented from sucking, the preference for the mother remains (Veissier et al., 1990a,b). Newberry and Swanson (2008) reported that bonds between mother and young can persist even beyond separation and the birth of subsequent offspring. Half as much agonistic behavior at the feeding site was found in groups that consisted of mothers and daughters (Swanson and Stricklin, 1985).

3 2.4 Long-term effects

Not many studies addressing long-term effects of dam rearing of dairy replacements have been published yet (Le Neindre and Sourd, 1984; Le Neindre, 1989a,b; Bar-Peled et al., 1997, Wagner et al., 2012). Heifers reared on a foster cow were socially more active and had clearer social structures relative to individually reared heifers (Le Neindre and Sourd, 1984). Furthermore, dam-reared animals showed prolonged licking and suckling of their calves, which was interpreted as more maternal behavior than cows reared in isolation (Le Neindre, 1989a). A more recent study by Wagner et al. (2012) also revealed long-term effects on social behavior when heifers were introduced to the milking herd shortly before calving. They found that mothered heifers showed more submissive postures, which might reduce the amount of aggression received. Therefore, they seemed to better cope with social challenges, which is in accordance with Latham and Mason (2008), who reported that maternal deprivation could enhance stereotypic behavior or result in animals, which are less able to cope in a low-stress manner with normal social interactions with conspecifics.

Long-term effects on performance traits were reported by Bar-Peled et al. (1997). They could show that heifers, which were allowed to suck during the first 42 days of their life, were younger at their first calving and tended to produce more milk than heifers reared by bucket feeding of milk replacer.

3.3 Effects on the cows

When thinking about the effects of suckling on the cow, first thoughts might be the impairment of milk production and the occurrence of udder health problems like teat damage or infections due to open teat channels after frequent suckling. However, it seems that farmers also introduce suckling systems to prevent mastitis or profit from calves sucking on infected quarters to decrease or even heal the inflammation. The effects on health and milk production will be discussed and moreover metabolism traits, fertility and welfare aspects will be addressed.

3.3.1 Udder health

Although Krohn et al. (1990) suggested that several days of suckling calves may have health benefits for the cow, such as reducing incidence of mastitis, concerns occur that there even could be a transmission of pathogens when the calves are not sucking their dam exclusively. Furthermore, Spinka and Illmann (1992) speculated that the calf might not be able to consume the increasing quantities of milk produced by its dam, which could lead to milk suppression and in further consequence to mastitis.

In a study by Walsh (1974) a very low infection rate in fresh lactating cows, which were sucked twice daily by 4 calves, was found. In contrast, the machine milked cows, which were in the same stage of lactation, had a much higher infection rate (Walsh, 1974). It seemed that stage of lactation played a role, since in late lactation, the infection rate of twice daily machine milked or twice daily sucked cows did not differ anymore (Walsh, 1974). In addition, suckling did not improve the udder health of cows, which were machine milked in mid-lactation (Walsh, 1974). In contrast to this, Thomas et al. (1981) did not find differences in the udder health of cows machine milked or sucked by at least 3 calves independent of the time (morning or afternoon), the frequency and duration (up to eight weeks) of suckling. A combination of milking and suckling could be beneficial as Fröberg et al. (2008) found that cows suckling their calf twice daily in addition to machine milking tended to have lower California Mastitis Test (CMT) scores than machine milked cows.

In contrast to the opinion that cows with mastitis could profit from suckling, it has to be stated that the motivation of calves to suck on infected quarters seems to be relatively low. Nicht (2005) could show that in 69 % of the cases, calves did not suck on infected quarters. Therefore, a health enhancing effect might be doubtful. However, when forced to suck on infected quarters (no other milk source available or all quarters infected), the same author found that after sucking on infected quarters for two weeks, no sign of a clinical mastitis in the sucked quarters was detectable (Nicht, 2005).

Teat damage from suckling has been reported by Thomas et al. (1981). The longer and the more intense teats were sucked by at least 3 calves, the more damaged they were and milking of the cows was difficult. After weaning, damaged teats recovered rapidly without any implications for milking (Thomas et al., 1981). The same authors recommended suckling for shorter periods (one or two weeks) to avoid teat damage and prolonged anoestrous intervals p.p. Similar to this, Rasmussen and Larsen (1998) showed that teat conditions were worse when calves were sucking compared to machine milking. The fear of an increased risk of bacteria colonization on teats with impaired skin condition could not be verified. Moreover, the authors suggested that suckling might help to remove bacteria from the teat skin and the mixture of milk and calf's saliva left on the teats did not support bacterial colonization. Anterior to Rasmussen and Larsen (1998), Rigby et al. (1976) found a lower incidence of mastitis in suckling cows. The authors also attributed this to better udder emptying and bacterial inhibitors in calves' saliva.

3.3.2 Milk production of cows

Beneficial effects of suckling referring to a higher total milk yield of the dams have been reported by Bar-Peled et al. (1995). They showed that total milk production was highest in cows milked three times and suckled additionally (by 2 calves) three times a day compared to six times milking or three times milking, respectively. They hypothesized that mammary development had been enhanced due to the completely emptying of the udder. In agreement with this, Cozma et al. (2013) reported higher total milk yields (total milk = milk gained by machine milking plus milk suckled by the calves) for Saler cows with calf contact at milking. Krohn (2001) mentioned that long-term suckling in early lactation can stimulate milk synthesis to a greater extent than milking alone, which might be due to a higher oxytocin release while suckling compared to milking. Although the 305-days milk production was higher in cows milked and suckled relative to only milked cows, milk, which was gained by machine milking, decreased from 40.7 % to 23 % (of total milk production) until the 6th week p.p. (Bar-Peled et al., 1995). This seemed to be due to the higher amount of milk ingested by the calf. Another detrimental effect has been reported by Krohn (2001), de Passillé (2001) and Lidfors et al. (2005), all describing the poor milk ejection in the milking parlor during the period when cows suckled their calves. During nine weeks of milking twice daily with subsequent nursing two hours afterwards, average milk yields at milking were even 20 % lower than in the control group (de Passillé et al., 1997). According to Thomas et al. (1981) the time, frequency, intensity and duration of sucking does not affect the total milk yield of lactation. The same authors also showed, that for the total milk yield of the lactation it does not make a difference whether a cows is machine milked over the whole lactation or sucked up to the 8th week p.p. and machine milked from then on.

After short term suckling for ten days p.p., the drop in milk yield from machine milking caused by the weaning process lasted for five days (Metz, 1987). Concerted to this, Bar-Peled et al. (1995) also reported a sharp decrease in milk yield after six weeks of suckling and milking when calves were removed. They found that milk yield stabilized in week twelve for the group, which was milked three times a day and sucked three times a day. In contrast to this, it has been stated that milk yield at machine milking returns to the control level within one week after weaning, independent from the duration of the nursing period (Metz, 1987; de Passillé et al., 2008).

The carry-over effect of an increased frequency of udder emptying during the first six weeks of lactation was obvious in cows machine milked six times daily, while cows, which were milked and sucked six times, in total produced much lesser milk for more than four weeks after weaning of the foster calves (Bar-Peled et al., 1995).

Considering the amount of milk ingested by the calf and the remaining residual milk, total milk yield did not differ between machine milked cows and cows, which additionally nursed their calf two times daily (de Passillé et al., 2008). Thus, there was no advantage for milk production in dam rearing (de Passillé et al., 2008).

Measuring the milk production of cows when suckling their calves impairs the breeding value evaluation based on the milk performance recordings since the amount, which is ingested by the calf, can only be defined by the weight-suckle-weight method. However, this method is time consuming and not practical. Using the alternating test method for milk performance recording can be an alternative: gaining just one milk output within twelve hours either from morning or afternoon milking and in the subsequent milking from the alternating time, just requires separating cow and calf for twelve hours. For calves with permanent contact this might be correlated with increased stress compared to calves with restricted contact, which might be another advantage for using restricted suckling in milk production systems.

3.3.3 Milk composition

During a suckling meal, fat content increases and lactose content decreases to a minor extent. Also the fat composition changed during suckling resulting in higher amounts of short-chain fatty acids (SCFA) and lower amounts of C18:1. Costa et al. (1998) reported that after-stimulation was important in regard to milk fat composition: beef cows that were after-stimulated had lower content of SCFA and higher values for C18:1. Furthermore, Costa et al. (1998) showed that saturated fatty acids (SFA) decreased and unsaturated fatty acids (UFA) in milk increased with after-stimulation and that the higher content of α-linolenic acid (C18:3 n-3) could account for higher product quality e.g. healthier for the consumer. Additionally, calf presence at milking increased the milk concentration of palmitic acid (C16:0) and decreased stearic (C18:0), linoleic (C18:2 n-6), α-linolenic and total poly-unsaturated fatty acids (PUFA) in the study of Cozma et al. (2013). When dairy cows, which are allowed to suckle their calves, are milked, fat content in the milk gained by machine milking decreased (Barth et al., 2007; Schneider et al., 2007; Mendoza et al., 2010; Cozma et al., 2013), which might be due to milk ejection problems and hence udder emptying and milking of alveolar milk are incomplete. In contrast to this, milk protein content seems to be unaffected by suckling (Barth et al., 2007; Mendoza et al., 2010). However, Cozma et al. (2013) found a significantly decreased protein content in milk obtained by machine-milking for Saler cows when the calf was present, but only a numerically decrease for Holstein cows.

3.3.4 Milk performance and hormones

The milk of a dairy cow is stored in the alveolar (80 %) and the cisternal (20 %) compartment of the udder. Cisternal milk is the first milk gained by milking and active expulsion is required to force the alveolar milk into the cistern. The most important hormone in this process is oxytocin, which is released after tactile udder stimulation. Bruckmaier and Wellnitz (2008) reported that being sucked by a calf is superior to hand milking and machine milking in regard to oxytocin release. Emotional stress can result in an inhibition of oxytocin release, which leads to losses of milk and can increase the health risk for the cow if the udder is not emptied completely (Bruckmaier and Wellnitz, 2008).

Plasma concentration of hormones (oxytocin, prolactin, growth hormone) during suckling was found to be higher than during machine milking in a study of Bar-Peled et al. (1995). Similarly, prolactin and plasma cortisol concentration increased during suckling, but also machine milking led to an increase in prolactin and cortisol (de Passillé et al., 2008).

Contrary to the findings of Bar-Peled et al. (1995), de Passillé et al. (2008) did not find differences of plasma oxytocin levels in cows milked by machine or in cows nursing their own calf, but during machine milking oxytocin release of nurse cows was depressed. Furthermore, Tancin et al. (1995) could show that even during the first machine milking following a few weeks suckling period the oxytocin release was decreased.

To overcome the problem of impaired milk ejection, Barth et al. (2011) olfactorily stimulated sucked cows in the milking parlor with presenting a cloth rubbed on the coat of the cows own calf, to trigger an increased oxytocin release. The results showed no improvement of milk ejection with the olfactory stimulus. The authors hypothesized that the scent on the cloth might have not been strong enough or that other stimuli such as visual or audible contact are needed additionally to trigger milk ejection.

Milk let-down during machine milking of cows suckling their calf twice a day after milking seemed not to be disturbed in the study done by Fröberg et al. (2008), but the applied method is questionable since only the time of appearance of the cisternal milk was recorded. Since it is not practical to bring calves to the milking unit, there is no advantage for milk production by keeping cow and calf together and suckling and milking during the same period was not recommended by Krohn (2001).

3.3.5 Lactation length

Lactation length was unaffected by any of the treatments applied in the studies of Thomas et al. (1981). According to Everitt and Phillips (1971), cows suckling for the first two months of lactation and being machine milked afterwards remained longer in milk than cows being milked right from the beginning of lactation (e.g. 111 days in milk [DIM] for a milked heifer and 284 DIM for her suckling twin sister).

3.3.6 Metabolism, body weight and body condition

Meeting the high energy demands caused by milk production in early lactation is only possible with the mobilization of body reserves. Therefore, dairy cows usually are in a state of negative energy balance, which makes them more vulnerable to sickness. Carbonneau et al. (2012) revealed that metabolic imbalances can be limited when cows were sucked for five days p.p. and additionally milked from day three onwards. In the studies of Thomas et al. (1981) and Mendoza et al. (2010), the live weight change over the first weeks of lactation was not significantly different between sucked or machine milked cows. However, Mendoza et al. (2010) reported that BCS score did not start to increase until week seven p.p.

In a study from Bar-Peled et al. (1995) cows, which were machine milked three times per day, and in addition suckled tqo foster calves also three times daily, did not compensate their higher milk yield by increasing dry matter intake as cows milked six times daily did. Thus, suckler cows lost significantly more body weight and it took them until the 18th week p.p. to achieve the weight they had at calving. In accordance to this, Everitt and Phillips (1971) reported that cows, which were sucked for the first few months of lactation and being milked afterwards, did not gain as much body weight during lactation as cows, which were machine milked over the whole lactation. Similarly, Boonbrahm et al. (2004) found that suckling cows tended to lose more body weight than milked cows and subsequently gained less weight.

3.3.7 Fertility

In contrast to dairy sheep and goats, which are known for their lactational anoestrus, the main factors affecting the duration of p.p. anoestrus in cattle are the nutritional status and suckling (Montiel and Ahuja, 2005). Suckling prolongs the p.p. anoestrus interval in beef cows for up to 90 days (Montiel and Ahuja, 2005), which is not that distinctive in dairy cows. Holstein cows suckling up to eight weeks p.p. had a 25 days prolonged p.p. anoestrus interval compared to machine milked cows, which showed their first p.p. oestrus after 32 days (Thomas et al. (1981). Also the number of suckled calves seems to influence the anoestrus interval. Wettemann et al. (1978) found that crossbreed range cows suckling only one calf (own offspring or foster) show their first oestrus p.p. significantly earlier than cows of the same breed suckling 2 calves. Nevertheless, the plasma progesterone levels of these cows were increased indicating luteinisation of follicles without ovulation or ovulation without oestrus (Wettemann et al., 1978). Álvarez-Rodríguez et al. (2010) compared the interval to first p.p. oestrus between different types of suckling (once-daily nursing for 30 minutes [RESTR1], twice-daily nursing for 30 minutes [RESTR2] and ad libitum nursing [ADLIB]) and reported no significant differences, although numerically cows nursing ad libitum had the longest p.p. anoestrus (45, 44, and 56 for RESTR1, RESTR2 and ADLIB, respectively).

Another important parameter when discussing the fertility of cows is the calving-conception interval (= days open). In the study of Bar-Peled et al. (1995) conception rates in suckling cows were superior, although their reproductive activity was suppressed until calf removal. In accordance to this, Broucek et al. (1995) reported that cows, which fostered calves for two or three weeks in their first month of lactation, had shorter days open-periods and lesser services per conception than machine milked cows. Furthermore, short term suckling (ten days p.p.) shortened the calving-conception interval of the cows significantly (Metz, 1987).

Williams and Griffith (1995) found that the maternal identification, mainly due to olfactorial and visual recognition, and selectivity of the cow's own calf also has an influence on reproductive performance. Removing the cow's own calf resulted in an increase of serum LH concentrations within 48 hours and suckling unrelated calves did not alter these increases.

Beyond that, Krohn et al. (1990) hypothesized that suckling could reduce the incidence of placental retention and Jainudeen and Hafez (2000) stated that the uterus involutes faster in suckled cows than nonsuckled cows.

3.3.8 Maternal behavior

Dairy cattle production usually discourages all aspects of maternal behavior except milk production (von Keyserlingk and Weary, 2007) by separating mother and offspring immediately after birth. Understanding the importance of maternal behavior should finally attract attention since in recent times the demand for animal-friendly produced products is increasing.

It has been reported by Le Neindre (1989a) that the method of rearing the dam affected the bond to her calf. Mothered cows appeared more „maternal" than non-mothered cows and licked and nursed their calves better. Although Krocker (1996) stated that calves from cows with good mother abilities need less time to first successful sucking, calves from mothered cows needed more sucking attempts before the first sucking relative to calves from non-mothered animals (Le Neindre, 1989a). Nonetheless, dam-reared animals were sucked more often than conventionally reared ones in the same study.

In an on farm case study Wolters (2006) observed that mothers interrupted the offspring when exaggerating. The same author had the impression that primiparous cows had less antagonistic interactions in presence of their calves, which was interpreted as a calming effect of the young towards other cows. Similarly, Szabò et al. (2013) showed that antagonistic interactions were lower when introducing unfamiliar young goats into an adult herd while both adult goats and young goats had kids. According to them, the presence of the kids could either have a distracting effect on the mothers or via suckling-related physiological pathways, alter their mothers' behavior. The role of oxytocin as having a relaxing, „anti-stress" and pro-social effect has been described before (Uvnäs-Moberg and Eriksson, 1996; Uvnäs-Moberg, 1996).

On the other hand, problems might occur when the mother is dislodged by a more dominant cow, which tries to „adopt" the calf. The fact that some cows adopt foreign calves could also be beneficial for calves with mothers showing little interest in their offspring.

Welfare implications occur when the social bond between mother and young gets broken in consequence of the weaning process (Spinka and Illmann, 1992; Price et al., 2003, Loberg et al., 2008).

4 Suckling foster cows

Foster cow systems occur in manifold forms, but mainly differ in the number of foster calves sucking on one cow and the whereabouts of the foster cows own calf.

One of the prior requirements for a well-functioning foster cow system is the calf's experience in the colostrum period. Calves mothered for the first three days after birth performed earlier sucking and more often; thus being more successfully fostered to late-lactating nurse cows compared to bucket fed calves (Vaarst et al., 2001).

4.1 Effects on the calves

No research articles about the health status of calves reared with foster cows compared to sucking on the dam exist in the knowledge of the authors. However, when multiple suckling, e.g. two and more calves sucking on the same cow, occurs, the incidence of diarrhea deriving from an overconsumption of milk might be lessened. Health problems could occur when the foster cow rejects a calf, not allowing it to suck anymore. The rejected calf either has to find another foster cow or will suffer from severe malnutrition, if the farmer does not detect the failed sucking attempts.

4.1.1 Growth

Since calves have to share the foster cow, competition for milk occurs. In a study done by Vichova and Bartos (2005) about allosuckling in a beef suckler cow herd, calves that allosucked most frequently tended to grow less intensively and reached lower weaning weights. The authors reported that the most important effect on growth gain and weaning weight was the birth weight of the calves. They predicted a higher incidence of allosucking in calves with lower birth weight and lower maternal sucking rate. Also the age of the mother played a role since there was a greater allosucking incidence for calves born to younger mothers. Related to foster cow systems, it could be assumed that motherless calves would not gain as much weight as the own calf of the foster cow. It was observed that the cow's own calf sucked more than the foster calf (Le Neindre, 1989a) and therefore the alien calf did not gain as much weight as the own calf (Loberg and Lidfors, 2001).

Limitation of sucking frequency (in this case: two times daily) results in a greater uniformity in weaning weight of foster calves compared to calves, which have unrestricted access to their foster dams (Everitt and Phillips, 1971).

4.1.2 Behavior

When the own mother is available 10 out of 16 calves prefer the mother (Spinka and Illmann, 1992). However, calves display enough behavioral plasticity to obtain milk after losing their own dam when still remaining in a group with other cows. On doing so, 11 out of 13 motherless calves sucked on more than one cow (Spinka and Illmann, 1992). Zumbrunnen (2012) reported that farmers describe the reaction to separation from the mother to be less stressful when calves were able to suck foster cows. The advantage of foster cow systems in regard to bucket feeding is the increased social contact the calf experiences. Even if not getting adopted by a foster cow, calves raised in foster cow systems are in social groups, allowed to suck as often as the cow allows, get fresh warm milk and care from the cow, e.g. licked, rubbed, stimulated to eat what cow eats (Lidfors et al., 2005). Hence foster calves showed more social behavior and sniffing the environment (exploration), but less rumination and eating TMR compared to control calves (Lidfors et al., 2005).

4.2 Effects on the cows

4.2.1 Health

Zumbrunnen (2012) reported that foster cows were often selected due to their impaired milk quality (high SCC) and/or poor udder quality. Farmers believe that suckling has a beneficial effect and can even heal affected quarters. As stated before, calves avoid sucking on infected udders and the beneficial effect must be questioned. In the unpublished study of Barth and Knappstein (unpublished data), nine of the 22 non-infected quarters of 9 cows, which were turned into foster cows from mid-lactation, were infected at drying off. Only 5 of the 14 prior infected quarters were pathogen free afterwards. Thus, the healing effect of suckling of affected quarters seems to be dubious, and therefore more scientific studies are needed. Forcing calves to suck on infected quarters is questionable since the sickness of the cow could influence the growth of the dairy calf due to the lower casein and higher albumin proportions in the milk. Furthermore, the health of the dairy replacement heifers might be negative affected as well, since pathogens received with the milk could establish in the udder and cause problems when lactating.

Schlooss (2007) suggested another beneficial effect on the foster cow: if a cow suckles her own and more than one additional calf, the udder was emptied completely, which might not be the case when only the own calf sucks due to the high milk production of the dam.

4.2.2 Performance

Foster cows, which were not milked but sucked two times daily by 4 calves, produced more milk than twice daily machine milked cows, but it was not clear if this difference was caused by suckling or a better udder health in the sucked cows (Walsh, 1974).

Cows, which fostered calves for two weeks during their first month of lactation, produced more milk in the whole lactation than machine milked control cows. Prolonging this suckling period to three weeks caused a lower yield compared to the control cows (Broucek et al., 1995).

Suckling 2 foster calves three times per day in addition to a three times per day machine milking during the first six weeks p.p. resulted in a significant higher milk yield compared to six times daily machine milking (Bar-Peled et al., 1995).

As expected, changing the frequency of udder emptying from six to three times daily by weaning or reducing the machine milking frequency lowered the milk yield, but more in cows which fostered calves in addition to machine milking (Bar-Peled et al., 1995).

Fostering calves during the first two months of lactation increased the milk production thereafter compared to cows machine milked from the onset of lactation (Chandler and Robinson, 1974; Everitt and Phillips, 1971).

Furthermore, the additional milking of the foster cow might be superior to permanent suckling without milking, because cows can be easier controlled at milking times and the steady contact to humans is advantageous for animal handling.

4.2.3 Behavior

The acceptance of alien calves was supported by the absence of the own calf for 4 to 30 days (Lidfors et al., 2005; Loberg and Lidfors, 2001). Even cows in late lactation (six months) can be used as foster cows and it seems that suitability as foster cow depends more on the individual character of a cow than stage of lactation or breed (Loberg and Lidfors, 2001). Although bonding between foster cow and calf occurs, it has not been proofed yet, if the bond between foster cow and calf is as strong as the dam-calf-bond (Loberg et al., 2007).

5 Restricted suckling

In restricted suckling systems the contact between calf and cow is limited to the time of milk consumption only. Time of contact, before or after cows are milked, the length of contact, only for milk consumption or for a few hours, and the relation to the cow, if it's the own mother or a foster cow, can vary widely.

Restricted suckling systems are less labor intensive than bucket rearing in regard to supplying feed, since milk processing for feeding the calves is no longer required. The sucking motivation of the calves seems to get more satisfied when sucking on a cow and contact to mature animals is given, whereby it might be insufficient concerning the importance of social learning possibilities, e.g. calves are not able to imitate feeding behavior and learn to ingest roughage at an early stage of life. Superior to permanent suckling is the fact that more salable milk can be obtained at milking, although milk ejection problems can still occur (Barth, unpublished data). When restricted suckling systems on foster cows are performed, the milk amount might not be enough for calves, which are allowed to suck after milking and therefore calf's health and growth might be impaired. On the other hand, restricted suckling after milking guarantees the complete emptying of the cow's udder, which might not be the case with milking only. When using the alternating test method for milk performance recording, restricted suckling can help to lessen the stress of both cow and calf during the separation time (twelve hours), since calves are already familiar with the separation from the cow.

At last, the process of weaning might be less stressful for the animals since both mother and young are used to spending only a short time together.

6 Management

6.1 Expenditures

To our knowledge, no scientific reports addressing the expenditures, both of money and time, in suckling systems compared to conventional dairy production systems have been published yet. However, there are some case studies comparing the costs of the different systems. In her on farm evaluation Schlooss (2007) calculated the expenditures of money in different rearing systems and found that costs (including milk and expenses for veterinarian), were lower for dam and foster reared calves than for conventionally reared animals (260, 267, 305 Euro /calf, respectively).

If calves are kept in the same barn with the cows, more work might arise cleaning the lying area of the cows, especially in cubicle housing, since calves dirty parts, which will not get dirty with housing cows alone. Furthermore, the temporary separation of cows and calves, e.g. for milking, is time consuming. Selection gates might be an opportunity to decrease the time exposure, but the extra installation costs have to be kept in mind.

Farmers stated that working in suckling systems was much easier, but the demands for the farmers are higher, since those systems afford more flexibility and are more time consuming in regard to animal observation. Restricted suckling systems with additional milking might possess advantages as cows can be observed at milking and calves can be examined when getting separated from the cows.

It should also be pointed out that scientific inquiries are missing, thus making an interpretation difficult.

6.2 Housing

Keeping cows and calves in permanent contact requires some modifications compared to conventional systems. Providing a separate area for the calves, where they can rest without contact to other cows and have access to feed and water, is recommended. However, calves should have the possibility to watch the cows feeding and to have access to the feed of their mothers, so they might imitate their behavior and start eating roughage and solid feed earlier. Having a separate calf area can be advantageous as well when cows and calves have to be separated for milking or later for gradual weaning. Additionally for foster cow systems, access to the foster cows can be postponed for older calves, thus giving the younger ones the possibility to gain more milk without competing against stronger calves. At the same time it simulates natural weaning process for the older calves since less milk is available after the young ones sucked. Potential dangers for the calves free ranging in the cow barn, which have to be considered and adjusted where necessary, can be scrapers and the manure system, the feed rack of the cows, the partitioning of the cubicles, slippery or slatted floors and other cows, that might act aggressively (Waiblinger et al., 2013) or accidently crush calves as well. If the mother develops strong protective instincts she can be a danger to humans trying to handle her offspring.

To ensure the development of a strong bond between dam and young, the calves should be alone with the mother for the first few days of life, where there's no disturbance from conspecifics and calves can suck on their mothers exclusively. When separated from their mothers immediately after birth, calves lost the ability to suck within six days (Finger and Drummer, 1969), thus it's crucial to keep cow and calf together for a certain amount of time p.p. to ensure calves sucking on their mothers exclusively and to ensure the development of a strong cow-calf bonding. Thereby, a sufficient number of maternity pens have to be available, so it can be assured that cows and calves have „their privacy" in the crucial first days after parturition.

6.3 Weaning

Natural weaning occurs when calves are between six and twelve months; the time when the neonate has grown to four times of its birth weight (Newberry and Swanson, 2008). When milk supply decreased in sheep, the distance between offspring and mother increased, as the young increased grazing activity (Napolitano et al., 2008). In dairy production systems calves are weaned at an age between two and three months. In contrast to the artificial rearing systems, calves allowed to suck not only suffer from the immediate denial of milk but also from the separation to the mother at weaning. Therefore, it has been discussed if suckling systems with abrupt weaning are detrimental in regard to welfare aspects. Krohn (2001) stated that separation after two to three months of suckling is traumatic and influences the behavior of both dam and calf to a larger extent compared to short-term suckling. Furthermore, Stehulova et al. (2008) could show that cows are more influenced by separation from the calf than the other way round when kept together for one day, four days and seven days, respectively. But they also remarked that in long-term suckling systems, the higher stress in cows after later separation only lasted for about one day and therefore may not represent a serious compromise of the well-being of the cow. However, alternatives for the abrupt weaning have been described. Newberry and Swanson (2008) recommend that weaning is easier when the offspring stays in a familiar environment with familiar pen mates. They found that a weaning method, which still allows contact between mother and young, e.g. separation by a fence, is less traumatic. Similar to these findings, Loberg et al. (2007; 2008) found that weaning in two steps, prevention from sucking with a nose-flap two weeks prior to separation, reduces behavioral stress in foster cows (2007) and fostered calves (2008), with the latter expressing less vocalization and walking, hence more lying and ruminating. In contrast to this, Stehulova et al. (2008) could show that the heart rate in dairy calves after separation was not influenced by contact or no contact to the dam and that calf age or contact with the calf after separation had no effects in the heart rates of cows, with the implication that heart rates were only recorded one hour before and one hour after separation. Contrary to the physiological response, the magnitude of both cows and calves behavioral response, e.g. vocalization, sniffing, placing the head out of the pen, was increased when auditory and visual contact between dam and young after separation was allowed.

Another weaning method described as being more natural (Schlooss, 2007) for foster cow systems would be to allow the access to the foster cow for older calves after younger ones already have been sucking, so less milk is available for the older calves. If this strategy is superior to abrupt weaning has not been estimated as far as the authors know.

It seems that each weaning strategy is always associated with stress in both cows and calves and that the best way to wean calves has not been revealed yet.

7 Conclusions

Consumers' demand for more naturally produced animal products has led to changes in animal production systems in the past. Especially in organic production systems, there are approaches to allow more natural behavior of the farmed species. Concerning suckling systems in dairy cow production, the methods applied should use modern technique to achieve more naturalness instead of „going back to the roots". The variety of suckling systems used today emphasizes that farmers choose their system in accordance with the main goal of the farm and the available means e.g. building-related and labor economic aspects. Thus, recommendations for the practice are difficult. Furthermore, studies addressing the evaluation of the overall system, as well as on long-term effects on animal productivity and on economic opportunities, e.g. placing dairy products on the market, which are labeled for their value as animal friendly produced in suckling systems, are still missing.

Not only in respect of the practicability but also in regard to the performance of the cows (milk yield, milk composition, fertility) and the calves (social development), we recommend a mixed system of both dam rearing and foster cows. In this respect, cow and calf are separated after a few days but allowed contact for a certain time period after each milking.

Calves are grouped and mothers have access to the calf group after each milking. The ratio between cows and calves depends on the milk yield of the cows and the number of calves in the group, but each cow suckles her own and at least one additional foster calf. After a certain time period, freshly calved cows replace the suckling cows and therefore the calves of the latter become foster calves. The daily milking allows the control of the cows and maintains the human-animal contact, which makes the milking after weaning easier. On the other hand, it encourages the behavioral needs and gives the cows and calves the opportunity to develop social relationships. Therefore, mother-bonded rearing could contribute to an improved welfare of the animals in dairy production systems.

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