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The use of lysimeters in forest hydrology research in north-east Germany

Jürgen Müller* and Andreas Bolte*

Abstract

Broad areas of the northeast German lowlands are characterised by low precipitation, distinct periods of summer drought and sandy soils with low water retention capacity. In this region, forest hydrology research looks into the influence of differently structured forest on the landscape hydrology, and on the components of the hydrologic equation. The aim is to provide scientific guidance in the development of productive forests that enhance the quantity and quality of seepage water. In unconsolidated rock substrate lysimeters can be used to measure seepage and evaporation. The use of different types of lysimeters in the Eberswalde region has a tradition of more than 100 years. In 1972, nine new large-scale lysimeters with a depth of 5 m and a surface area of 100 m^2 (10 x 10 m) were installed near Britz, near Eberswalde, and were planted with the tree species Scots pine, European beech, European larch and Douglas fir at plant spacings corresponding to those adopted in forestry practice.

In this region, groundwater recharge under forests is affected considerably by tree species. In deciduous European beech, and European beech mixed stands at the polewood stage (ca. 20- to 60-years old), seepage rates of 15 % to 25 % of open field precipitation are found, whereas the seepage rates recorded in Scots pine stands of the same age are insignificant. In Scots pine stands, the ground vegetation evaporation ranges between 20 % and 35 % of the precipitation depending on its composition and ground coverage. In particular, a dense grass cover of *Calamagrostis epigejos* limits the amount of soil water available to plants during the growing season substantially, and ultimately, can limit tree growth. These results can be obtained with the assistance of specially developed weighable lysimeters.

Keywords: Climate change, lysimeter type, water budget, tree species, Brandenburg, Calamagrostis epigejos

Zusammenfassung

Der Einsatz von Lysimetern in der forsthydrologischen Forschung in Nordostdeutschland

Das nordostdeutsche Tiefland ist in weiten Teilen geprägt durch geringe Niederschläge, ausgeprägte sommerliche Trockenphasen und Sandböden mit geringer Wasserhaltkapazität. Die forsthydrologische Forschung in der Region befasst sich mit dem Einfluss unterschiedlich strukturierter Wälder auf den Landeswasserhaushalt und auf die Teilglieder der Wasserhaushaltsgleichung. Ziel ist, den Aufbau solcher produktiver Wälder wissenschaftlich zu begleiten, die sich positiv auf die Menge und Qualität des Sickerwassers auswirken. Im Lockergesteinsbereich sind Lysimeter geeignete Messeinrichtungen zur Ermittlung von Sickerung und Verdunstung. Der Einsatz von Lysimetern unterschiedlicher Bauart hat im Raum Eberswalde eine über hundertjährige Tradition. 1972 wurden am Standort Britz bei Eberswalde neun Großlysimeter mit einer Tiefe von 5 m und einer Oberfläche von 100 m^2 (10 x 10 m) angelegt, die mit den Baumarten Kiefer, Buche, Lärche und Douglasie in praxisüblichen Verbänden bepflanzt wurden.

Die Grundwasserneubildung unter Wald wird in der Region entscheidend von der Baumart beeinflusst. Winterkahle Buchen- und Buchen-Mischbestände weisen im Stangenholzalter (Alter ca. 20 bis 60 Jahre) eine Sickerungsrate von 15 % bis 25 % des Freilandniederschlags auf, während in Kiefernbeständen gleichen Alters keine nennenswerte Sickerung zu verzeichnen ist. In Kiefernbeständen verdunstet die Bodenvegetation je nach Zusammensetzung und Bodenbedeckung zwischen 20 % und 35 % der Niederschläge. Insbesondere dichte Grasdecken mit *Calamagrostis epigejos* begrenzen die maßgeblich die pflanzenverfügbare Bodenwassermenge innerhalb der Vegetationsperiode und können zu Einschränkungen des Baumwachstums führen. Diese Ergebnisse wurden mit Hilfe speziell entwickelter wägbarer Lysimeter erzielt.

Schlüsselwörter: Klimawandel, Lysimetertypen, Wasserhaushalt, Baumarten, Brandenburg, Calamagrostis epigejos

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1 Introduction

Given its current low precipitation levels and predominantly sandy soils with low water retention capacity, the lowlands in northeastern Germany are regarded one of the country's regions with the highest vulnerability to a climate change bringing more frequent and more intense drought periods in the future (Schröter et al., 2005). In northeastern Brandenburg, the long-term annual precipitation of about 570 mm is well below the overall national average of 780 mm (Müller, 2002).

With a forested area of 1.1 million ha, covering 35.3 % of its surface area, Brandenburg, including Berlin, is the state with the fourth largest forest area in Germany (BMELV, 2008). The forest has a major effect on the landscape hydrology as a consequence of its multi-layered structure and its expanse. Therefore investigations into relationships among site, forest structure and water regime in the region are of particular interest. In view of the anticipated intensification of drought in wide areas of northern and central Germany as a consequence of climate change, the forest hydrology studies presented here may provide some direction for many other regions in Germany, particularly investigations of water consumption and forest growth in the case of declining water resources during the growing season.

This review paper provides a historical outline of forest hydrology research at Eberswalde, an overview of current and future research activities, and a summary of the most important results.

2 The use of different types of lysimeters

Lysimeters are appropriate for ascertaining the water budget of individual plants and stands. Due to the existing site conditions, the use of different types of lysimeters in investigations around Eberswalde has a long tradition (Table 1).

2.1 The Drachenkopf lysimeter

Already in 1907, the first investigations into the water budget of young trees were conducted with very small-scale lysimeters on Drachenkopf Mountain, in Eberswalde. In 1929, these small-scale lysimeters were replaced by a larger weighable station consisting of three lysimeters, which, in 1954, were supplemented by four additional lysimeters. To our knowledge, the Drachenkopf research station is the oldest lysimeter station used for forest hydrological purposes in the world (Müller, 2008). The weighable lysimeters have a surface area of one square meter and a depth of 1.5 m (Figure 1). The square lysimeter tanks are installed to cover the same ground surface area, and overgrown with vegetation corresponding to the surrounding vegetation for investigation. The Drachenkopf lysimeters are filled with soil, and hence represent disturbed lysimeters. The soil substrate is medium-grained sand with a horizon sequence corresponding to the sandy brown earths typical of the region.

The lysimeter balance scales are located in the cellar, where seepage water also is recorded.

The investigations focus on the determination of the water budget components, evaporation, transpiration and seepage, under defined weather and soil conditions for different types of vegetation.

The quantity of seepage water found under conditions of low regional precipitation was of particular interest because only this component of precipitation, which flows into the groundwater, is of hydrological use.

In addition to quantifying seepage water, lysimeters are an excellent means for determining plant evaporation (ET). Evaporation is the remainder after subtracting the seepage (S) and the change in soil moisture (dM) from precipitation (P) in the hydrologic equation (1).

$$ET = P - S - dM \tag{1}$$

Table 1:

Types of lysimeters used in forest hydrology research at Eberswalde

Year	1907	1929	1966	1972	1994	2005	2009
Site	Eberswalde "Drachenkopf"	Eberswalde "Drachenkopf"	Liepe	Britz	study sites	Britz "Postluch"	Eberswalde open field laboratory "Drylab"
Lysimeter type	smallest-scale lysimeter	small-scale lysimeter	sub-surface lysimeter	large-scale lysimeter	small-scale lysimeter	groundwater lysimeter	small-scale lysimeter
Weighability	non-weighable	weighable	non- weighable	non- weighable	weighable	weighable	non- weighable
Soil	disturbed	disturbed	undisturbed	disturbed	undisturbed	undisturbed	disturbed
Surface area	500 cm²	1 m²	500 cm² 1500 cm²	100 m²	1 m²	1 m²	2 m²
Depth	1.0 m	1.5 m	5 m	5 m	1.8 m	2.0 m	1.5 m

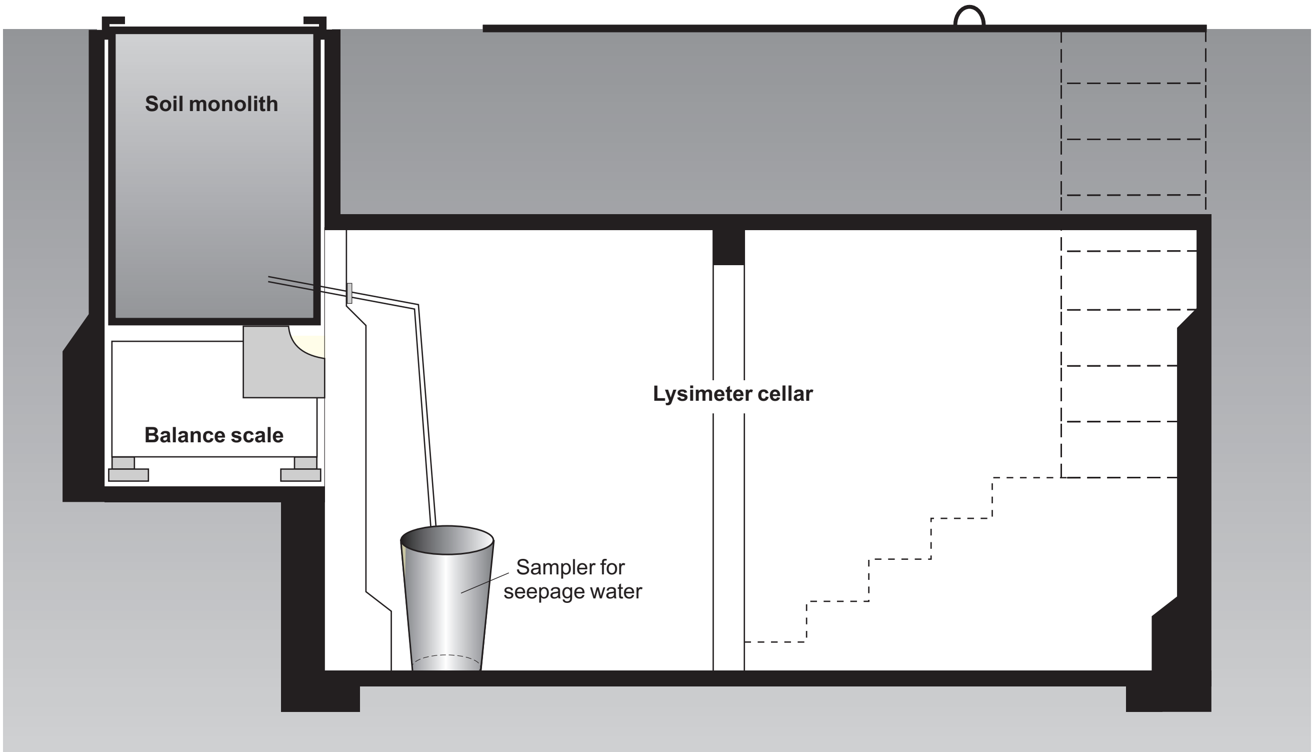


Figure 1:
Diagram of the Drachenkopf lysimeter station

Precipitation is measured with Hellmann rain gauges located 1 m above the ground and at ground level. Seepage is recorded at the seepage discharge point of the lysimeter tank. Soil moisture change is obtained from the difference in the lysimeter weight recorded using balance scales. These scales are accessed from a cellar corridor. The tanks, which themselves weight ca. 2 t, are weighed with an accuracy of within 10 g.

2.2 The large-scale lysimeter at Britz

Forest hydrology research into the effect of different tree species on evaporation and groundwater recharge prompted the construction of large-scale lysimeters at the research station at Britz, near Eberswalde, in 1972 (Müller, 1993).

After experiences gained from using lysimeters in the past, the large-scale lysimeters were installed at a depth of 5 m, necessary for forest lysimeters, having a surface area of 100 m^2 (10 x 10 m) (Figure 2). Nine large-scale lysimeters were set up, and, in 1974, planted with 0.3 ha experimental stands of the tree species Scots pine (3 lysimeters), European beech (2), European larch (2) and Douglas fir (2) at plant spacings corresponding to that applied for each species in forestry practice at the time (Figure 3). The areas surrounding the lysimeters were planted similarly. Thus, the large-scale lysimeters at Britz are unique in Europe in their scale since, although other lysimeters planted with trees have the required area, with depths of 3 m or 3.5 m, they are too shallow (Müller,1993).

The seepage water that collects above the lysimeter surface flows down a measuring shaft next to the lysimeter, and is measured mechanically by a water-meter and registered electrically. Soil moisture is measured with probes to a total depth of 5 m at 50 cm steps. Precipitation in the open, and the stand is recorded with Hellmann rain gauges.

The current forest conversion programme in Brandenburg, in keeping with ecological forest management goals, aims to convert as much of the current pure Scots pine stands as possible into mixed stands with diverse structures (MLUR, 2004). This forest conversion requires scientific supervision and funding; investigations of how sites with unfavourable forest growth and hydrological conditions can be altered by advance planting, and underplanting of European beech and sessile oak under Scots pine and European larch, and how these conditions can be improved through silvicultural measures are needed in particular. There are considerable gaps in knowledge about the effects of sessile oak on the landscape hydrology. To remedy this situation, individual lysimeter stands were modified in 2000 as follows:

- Larch underplanted with European beech,
- Scots pine underplanted with European beech

- Scots pine underplanted with sessile oak,
- New sessile oak plantings.

With the conversion of the lysimeter stands, and by close observation of oak, it will be possible to provide a better estimation of the long-term consequences of conversion for landscape hydrology in the north-eastern lowlands.

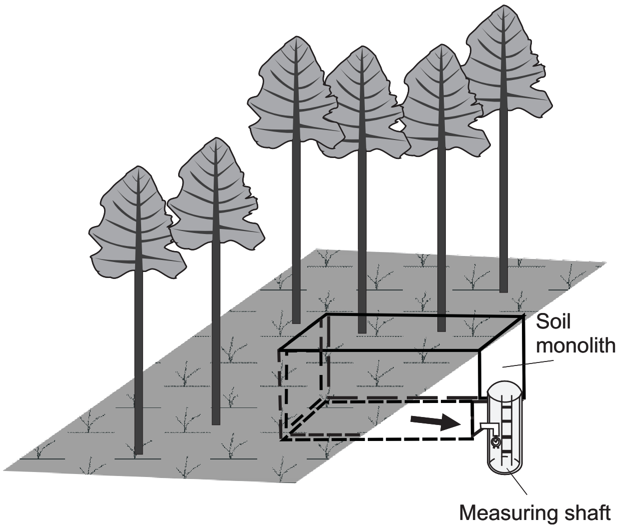


Figure 2:
Diagram of a large-scale lysimeter planted with trees

2.3 The weighable lysimeters

Total evaporation, determined with large-scale lysimeters, provides only a general understanding of the water budget in forest stands. The separation of total evaporation into its individual components crown canopy interception, transpiration from trees and evapotranspiration of soils and ground vegetation helps clarify the interaction between the individual components.

In Scots pine ecosystems in the northeastern German lowlands, the ground vegetation and the tree and shrub regeneration represent a substantial yet, so far, difficult to measure water consumer. Special measuring systems need to be used to ascertain the evapotranspiration of the undergrowth, and hence its specific water consumption separately from transpiration of trees in the stand. Consequently, in 1994, special weighing lysimeters (Figure 4) were designed to fulfil the following special requirements:

- Circular lysimeters with a surface area of 1 m^2,
- Lysimeter depths of 1.8 m so that the roots of the undergrowth do not reach the backwater that potentially could build up on the lysimeter floor,
- Soil monolith with an undisturbed, mature ground vegetation,

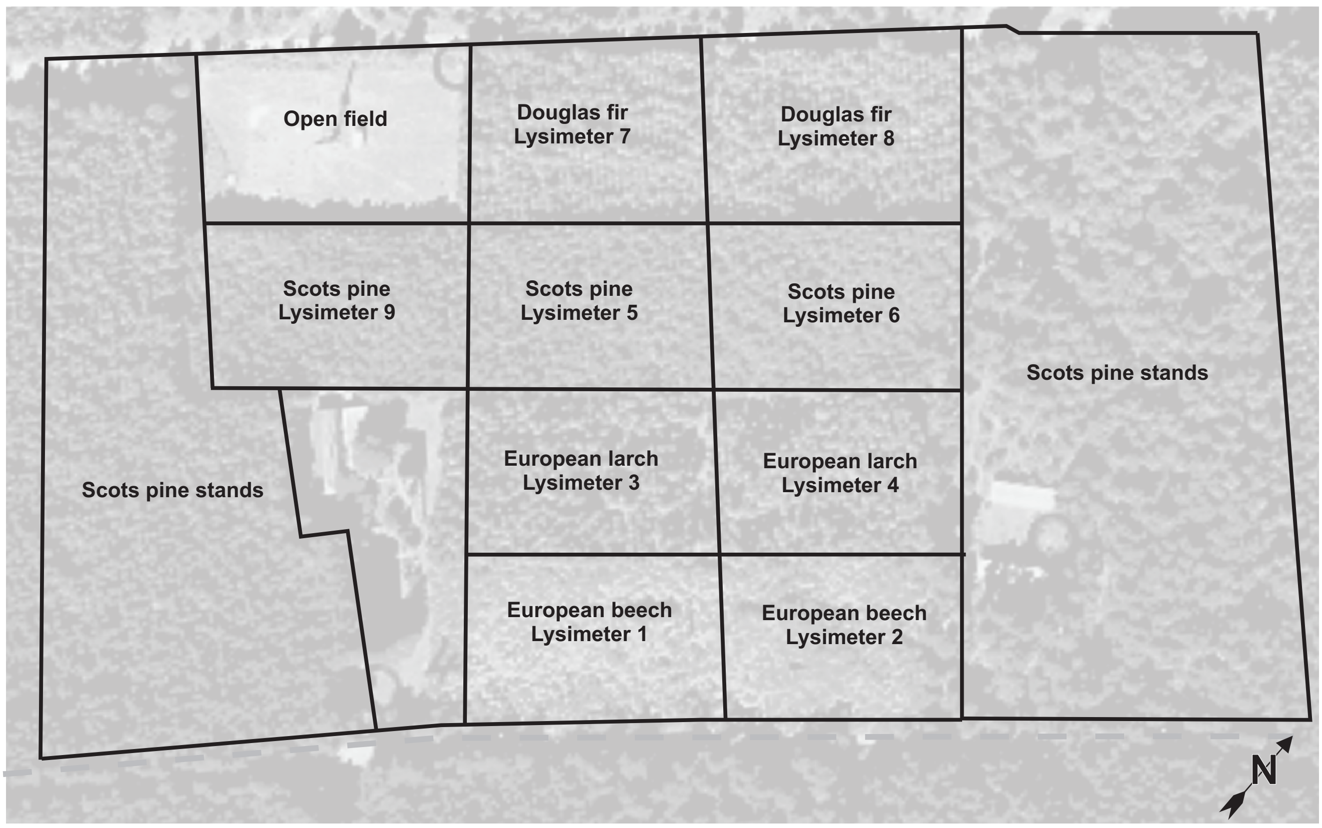


Figure 3:
Aerial photograph of the Britz Ecological Research Station showing the location of the large-scale lysimeters (in 1998)

- Minimal disturbance of the soil and vegetation cover surrounding the lysimeter, and thus maintenance of the homogeneity of the soil conditions and vegetation structures,
- Continual measurements of soil moisture changes and quantity of seepage water with high precision,
- Opportunities for flexible use of the lysimeter.

The new type of lysimeter developed contained an undisturbed soil monolith with sufficient size and weighability, for which the construction of a lysimeter cellar was not necessary. With it, the water budget could be balanced at low cost for different types of applications under open field conditions in the forest. Through the use of special weighing cells, the soil moisture change in the soil monolith and the amount of seepage water discharge could be recorded with an accuracy of 0.1 mm.

Firstly, the lysimeters were used to measure the water consumption of ground vegetation with different species compositions.

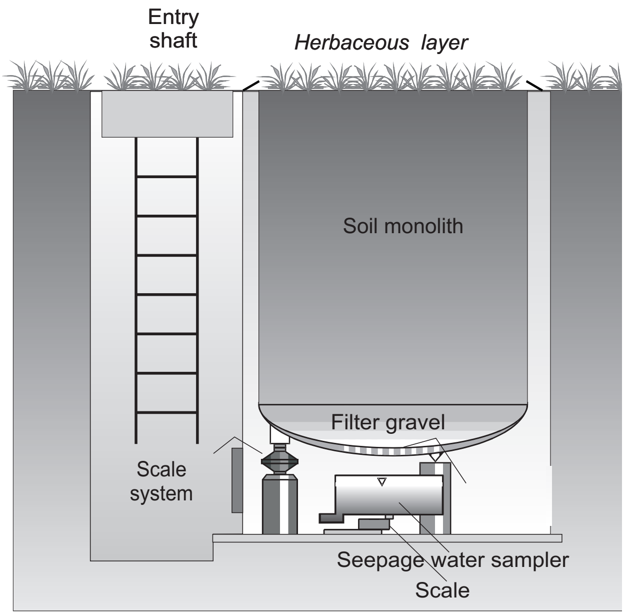


Figure 4:
Diagram of a weighable lysimeter

In 2000, individual lysimeters were extended and overhauled, and afterwards installed for ascertaining the water consumption of young European beech and sessile oak in Scots pine-European beech or Scots pine-sessile oak mixed stands. These investigations assisted explanations of the evaporation of Scots pine relative to European beech, and to the ground vegetation.

The current investigations should look into the influence of drought on the transpiration and young forest tree growth under changing climatic conditions (frequency of extreme summers) more intensively. The clarification of the influence of changing climatic conditions on the development of vegetation and, conversely, of vegetation on climatic conditions is of major environmental importance.

2.4 The weighable groundwater lysimeters

To date the lysimeters have been installed only on terrestrial sites well away from groundwater. In 2004, the installation of lysimeters was extended to sites close to the groundwater.

As enormous water storers, these near natural forest ecosystems are of extreme importance for the strained landscape water regimes in Germany's driest regions.

Consequently, with the assistance of weighable lysimeters, the water consumption of young black alder and common oak trees in an alder swamp are investigated. The aim of the investigation was to determine the transpiration and growth of common oak and black alder at different distances from the groundwater table.

2.5 The open field laboratory "Drylab"

Another recent application of lysimeter technology is being realised currently at the Institute of Forest Ecology and Forest Inventory at Eberswalde with the construction of an open field laboratory. This laboratory enables investigations of the effects of drought on the growth and vitality of young forest trees in the open under largely controlled conditions. Eight lysimeters with a surface area of 2 m² were installed in the open at ground level in isolation from the surrounding soil, and fitted with an automatic retractable roof to eliminate precipitation from the site (Figure 5). The lysimeters are filled with a standardised soil substrate and can be planted with up to 16 plants. Soil moisture sensors, together with equipment fitted for measuring soil water discharge and precipitation, enable accurate determinations of evapotranspiration as well as observations of soil moisture development in the soil column. One focus of the research is the investigation of fine root development using mini-rhizotrones. This is because few investigations of the response of fine roots to drought have been undertaken so far. Here, photographs are taken of the surrounding fine root layer with an endoscopic camera through four vertical glass tubes per column at small time differences, and then analysed by image processing. In this way, the high-resolution data for the turnover of fine roots and root growth are obtained.

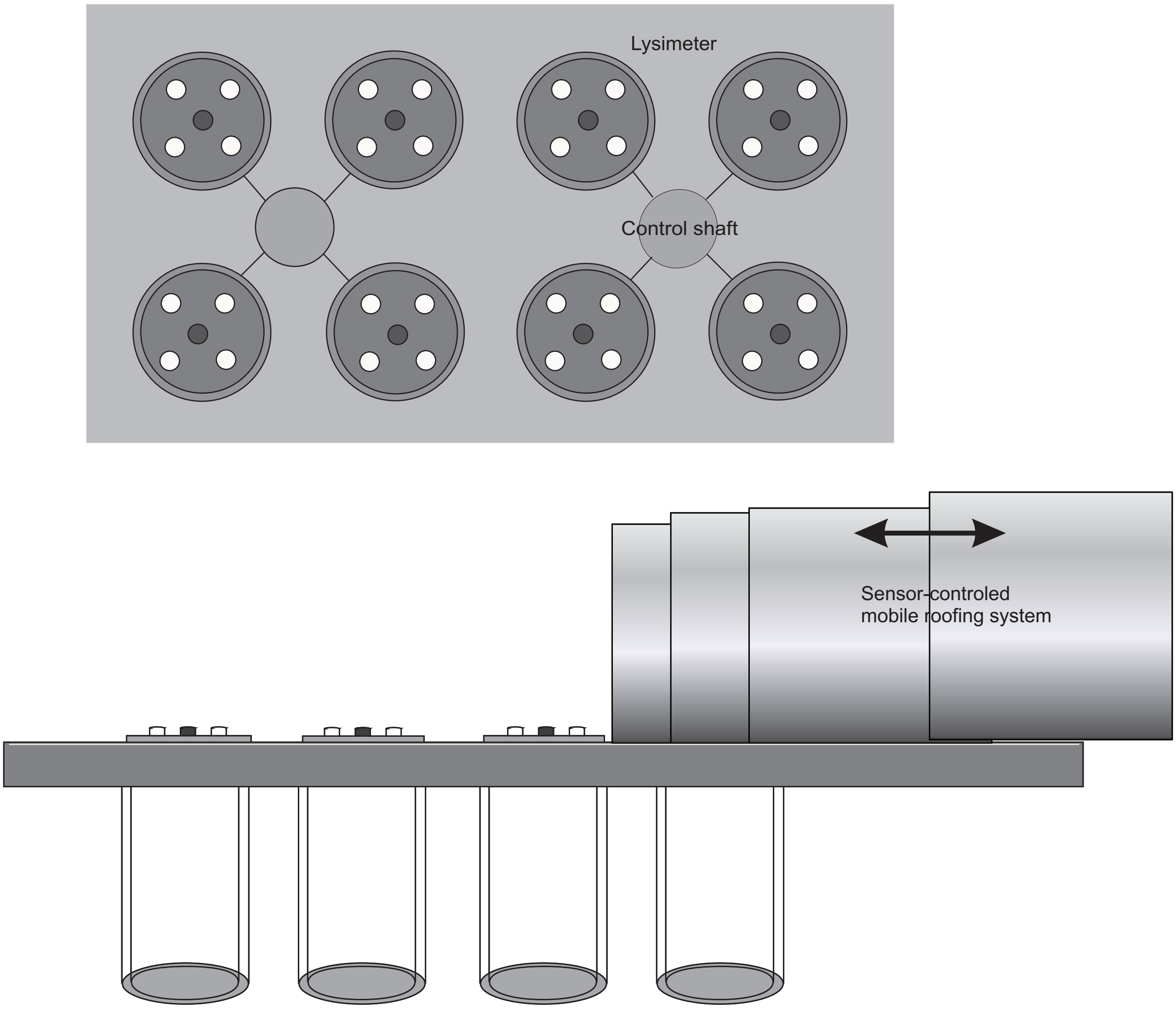


Figure 5:
Diagram of the open field laboratory "Drylab" showing the location of lysimeters and the retractable roof system

3 Results and discussion

The aim of the lysimeters at Drachenkopf was to provide the range of results required for subsequent investigations into the influence of landuse on landscape water catchment hydrology (Lützke, 1958, 1961; Müller, 2008).

One important finding is that, under comparable weather and soil conditions, plant species and the degree of vegetation cover influence the amount of, and temporal variation in seepage and evaporation. Under perennial grasses, three times the amount of water seeps into the depths than under the Scots pine stand (Figure 6). The features of the evaporation area in the forest ecosystem – height, surface area, distinct vertical stand structure in the tree, shrub and herbaceous layers, and the extent of forest area in the landscape - explains the higher evaporation in forests.

The investigations at the Britz large-scale lysimeter station showed that tree species have an important effect on seepage under forests.

The effect of differences in vegetation structure at different growth stages in a Scots pine forest, a European beech forest and a mature mixed stand with Scots pine and European beech on the amount of seepage and evaporation is shown in Figure 7.

In the Scots pine stand, total evaporation increases rapidly with growth whereas seepage declines. In the polewood stage, total evaporation is about 100 % so that seepage is largely absent. Scots pine growth culminates at this age, and thus the transpiration rates are high (about 60 % of the annual precipitation) and, as a consequence of the dense crown cover, interception losses are also high (about 40 %) (Müller, 2002, 2005).

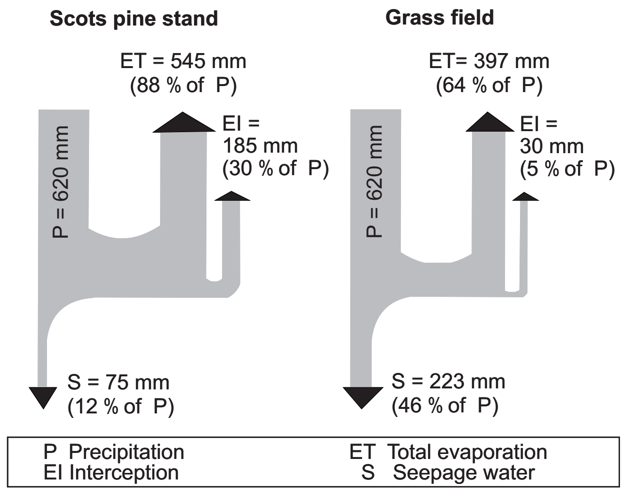


Figure 6:

Comparison of seepage and evaporation in a Scots pine stand and a grass field on sandy soil

The natural reduction in tree numbers and thinnings cause transpiration and interception to decline gradually, and the seepage percentage increases. However, the proportion of evapotranspiration from the ground vegetation increases relatively strongly due to the opening up of the canopy (Müller et al., 1998).

In the European beech stand, evaporation also increases quickly with stand growth, and, in the polewood stage, attains values of almost 80 % of the annual precipitation. This value remains relatively constant over a long period up to the saw-timber stage, so that steady seepage levels of over 20 % of the annual precipitation also are recorded. Transpiration increases slightly with stand growth, and interception declines as a result of the increasing stemflow (it reaches values of ca. 20 % of the annual open field precipitation). Due to the low-light regime in closed European beech stands (Emborg, 1998), the evaporation from the forest soil is of minor importance. Seepage is higher in European beech stands in all age phases than in Scots pine. Thus, for example, in mature European beech stands, 50 mm more precipitation seeps into the soil substrate than in mature Scots pine stands under comparable soil and weather conditions (Müller, 2002, 2005).

Under the lysimeter, planted with sessile oak in 1999, seepage amounted to 52 % of the average total precipitation in the period from 1999 to 2003 (637 mm). The evaporation of intercepted and transpired water in sessile oak regeneration is still low, and seepage correspondingly high. The percentage of seepage in 7-year old oak is comparable to that of European beech of the same age (Müller, 2002, 2005, 2007).

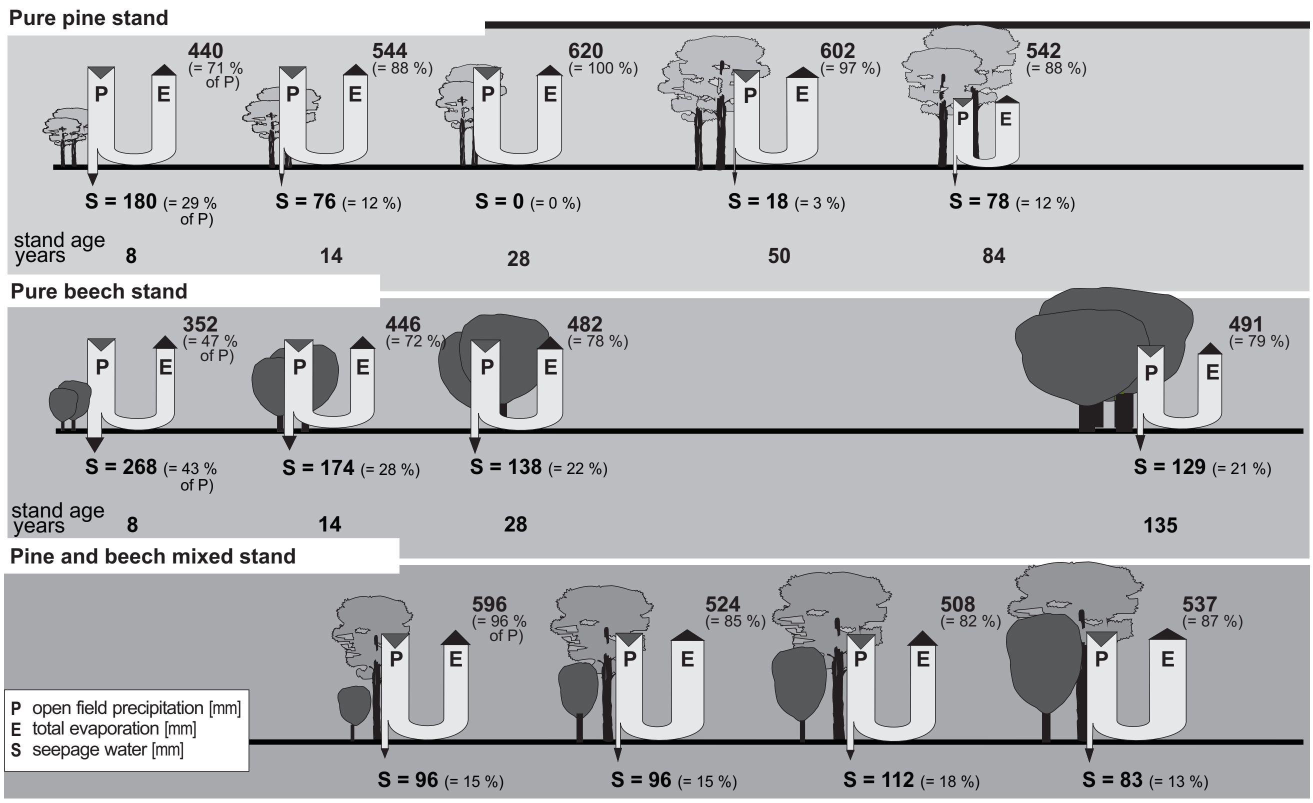


Figure 7:

Influence of vegetation structures of Scots pine and European beech at different growth stages on the water budget parameters, evaporation and seepage - (Finowtaler sandy brown earth, 620 mm annual precipitation)

Investigations in pine-beech mixed stands of different ages on sandy soil showed that the amount of seepage fell somewhere between that of the pure Scots pine and pure European beech stands depending on forestry operations performed, stocking density and the tree size of European beech (Müller, 2006, 2007). Measurements of seepage to 5 m depth in the 28-year old pure Scots pine stand growing on the large-scale lysimeter station at Britz, which was underplanted with European beech and sessile oak in 1999, already show improvements in the groundwater recharge as a result of the Scots pine thinning.

The **weighable lysimeters** were installed in Scots pine stands with a typical ground cover in the northeastern lowlands to determine the water consumption of these ground vegetation types. The typical ground cover consisted of wood small-reed (*Calamagrostis epigejos)*, wawy hair grass (*Deschampsia flexuosa),* wawy hair grass/raspberry *(Deschampsia flexuosa / Rubus idaeus)* and blueberry (*Vaccinium myrtillus)*.

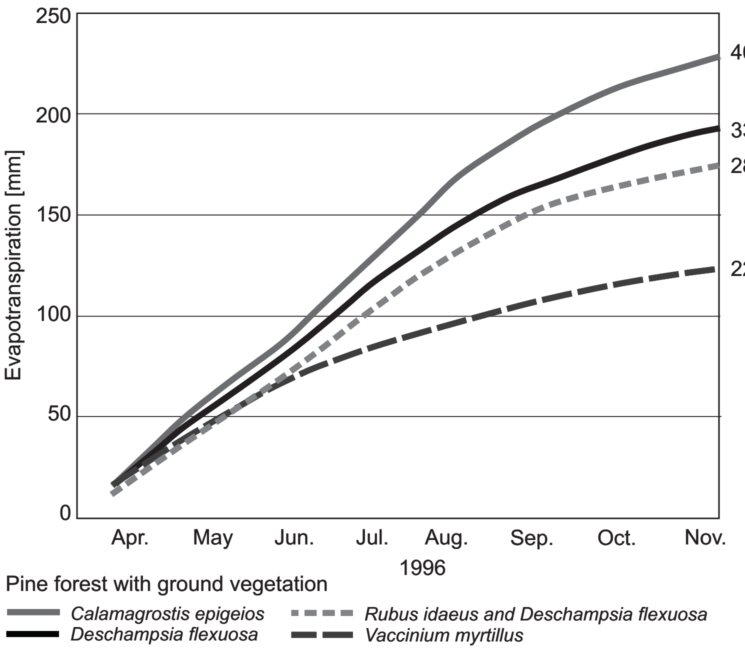
Investigations showed that evapotranspiration increased with increasing grass cover. The low shrub layer consumed less water. Thus, closed wood small-reed cover consumed more than one third, and the wavy hair grass almost 30 % of the annual precipitation of 620 mm. Where a low shrub layer was present, the evaporation from the wawy hair grass/raspberry layer, a little more than 25 %, and the blueberry/wawy hair grass layer, with almost 20 % of the annual precipitation, was sometimes distinctly lower than the pure grass cover (Figure 8). In addition to the evaporation from the ground vegetation layer, for which the annual sum varied, the seasonal development of evapotranspiration during the growing season is also ecologically meaningful.

In water limiting periods, the higher water consumption by grass cover leads to a reduction in the amount of plant available soil water, enhancing the water limitation for trees, and thereby impacting upon tree growth (Müller et al., 1998).

The composition and cover of the ground vegetation influence considerably the amount of water consumed by trees. The ground vegetation becomes a major consideration in the water budget in Scots pine forests (Müller et al., 1998; Müller and Seyfarth, 1999; Müller, 2002).

To explain the relationship between soil water removal, soils water availability, root distribution patterns and growth development of the overstorey and understorey in mixed stands with Scots pine and European beech, the evapotranspiration of both species need to be determined separately. The use of weighing lysimeters in European beech underplantings made separate determinations of transpiration from trees, and evaporation from forest soils possible (Figure 9). Thus, per lysimeter, the evapotranspiration of two European beech trees growing in an undisturbed soil monolith could be ascertained. In the overstorey, Scots pine transpiration was determined with Granier sensors.

In Figure 9, the relative changes in evaporation for Scots pine and European beech over time are presented



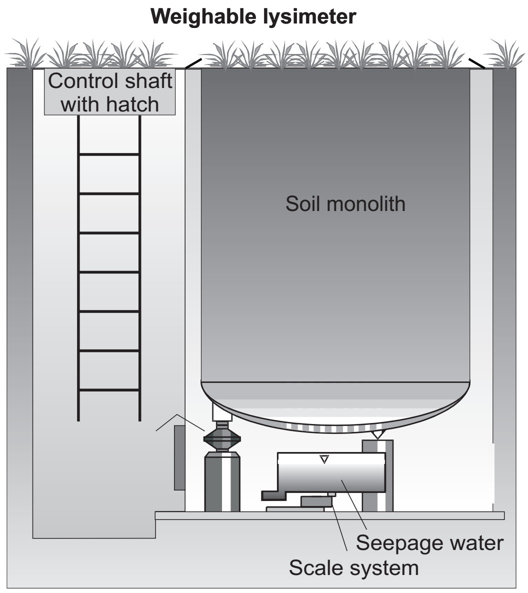


Figure 8:

Cumulative evaporation of different ground vegetation cover in Scots pine stands from March to October based on the average of the years 1996 to 1998

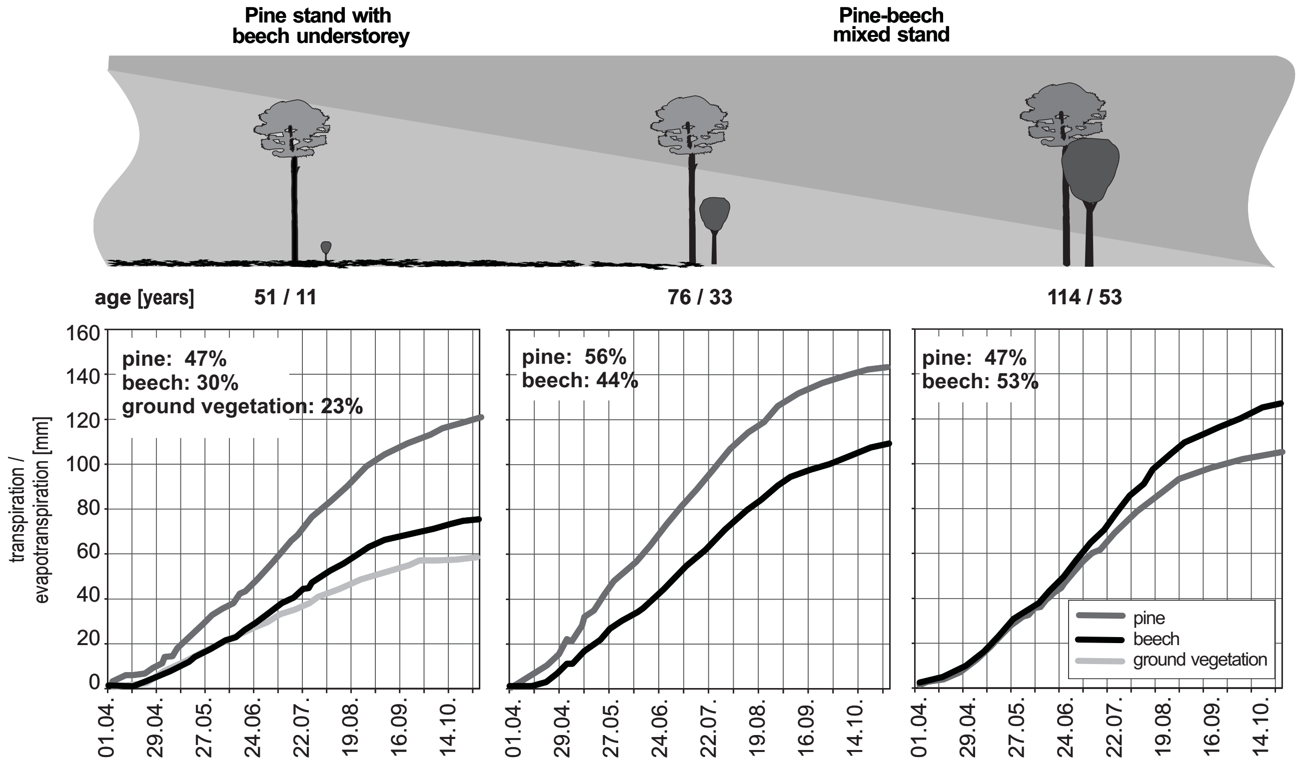


Figure 9:

Transpiration of European beech and Scots pine trees and evapotranspiration of the ground vegetation in the Scots pine-European beech mixed stand at different stand ages

separately. With increasing canopy closure, the proportion of evaporation of the ground vegetation declines. In the youngest stage, the ratio of Scots pine to European beech to ground vegetation is 47 % : 30 % : 23 %. As European beech develops, the evaporation percentage increases steadily, whereas that of the ground vegetation layer decreases or drops away entirely so that, in the next growth stage, the ratio was 56 % (Scots pine) to 44 % (European beech). With the upgrowth of European beech into the canopy layer of Scots pine, European beech transpiration in the oldest stand stage finally increased above that of Scots pine. The evaporation ratio of Scots pine to European beech then was found to be about 47 % : 53 % (Anders and Müller, 2006; Müller, 2006).

4 Conclusions from the research to date

Often a major problem of hydrological investigations in different types of ecosystems is the dissimilar conditions, or inability to control sufficiently the environmental conditions in the study sites. Thus, the effects of the parameters of interest may be blurred or false in the results. If one aims to determine the effect of the vegetation on hydrology in the unconsolidated rock substrate, then lysimeter measurements are appropriate for excluding conditions, which are not relevant. Assuming the lysimeters were constructed correctly and adequate in size, they can also be applied for forest ecosystems.

Only by considering the special features of the forest structure can one accurately evaluate the hydro-ecological effects.

Thus, with the assistance of large-scale lysimeters, the influence of tree species on seepage and evaporation in mature stands can be quantified. It shows that the crown canopy structure considerably influences the amount of seepage and the distribution of the precipitation in the stand as it affects the soil water availability.

Total evaporation provides only a general understanding of the water budget in forest stands. The separation of total evaporation into its individual components leads to more meaningful explanations of the interactions between the compartments. During the growing season, the water consumption of the individual vegetation layers is important in the assessment of possible occurrence of water stress.

The main advantage of lysimeter techniques is the opportunity to balance energy and nutrient flows at a high temporal resolution under carefully differentiated conditions. This makes the lysimeter increasingly more interesting for both scientific and practical applications in very different disciplines. Due to their innovative measurement techniques, e.g. weighing cells for determining moisture changes and seepage flows as well as soil moisture sensors and tensiometers for observing seepage water movement, lysimeters are an important instrument for the parameterisation of process models for modelling energy and nutrient cycling. This also applies to forest hydrology research. Lysimeters are indispensable in investigations of water consumption of small forest trees of different origin in the face of increasingly limiting water resources arising from climate change.

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Potential correlation of heavy metals in surface soils with infestation of *Viscum album* in poplar trees

Prasesh Sharma*, Heike Steckel**, Andrea Koschinsky* and Ewald Schnug**

Abstract

Bioavailable heavy metal fractions in soil and *Viscum album* (mistletoe) samples from three areas of different contamination levels were analysed with ICP-OES to study the variability of heavy metal contamination in surface soils in Goslar, Germany, an area influenced by acid mine drainages from the Harz Mountains and long-term mining activities. The representativeness of single sampling points, and a potential correlation between soil contamination and mistletoe growth on trees were investigated in specific locations in which mistletoe numbers on trees seemed to be related to the contamination level of the soil. Significant variation was found in the concentration of heavy metals in the three locations with metals such as Pb, Cd and Cu showing average values of almost an order of magnitude higher (75 mg/kg, 0.40 mg/kg, and 10.5 mg/kg, respectively) in high contamination area compared to low metal contamination area (15 mg/kg, 0.09 mg/kg, and 1.2 mg/kg, respectively). Apart from the high contamination area, the concentrations of metals in context decrease with depth. Also, Pb and Fe show the highest, Zn and Cu show medium, and Cd and Ni show the lowest concentrations of all heavy metals measured in all areas. Mistletoe leaves samples from the low contamination area show interestingly high concentrations of heavy metals (12 mg/kg Cd, 13 mg/kg Cu, 5 mg/kg Ni, 0.9 mg/kg Pb, and 675 mg/kg Zn) compared to the high contamination area (<0.1 mg/kg Cd,10 mg/kg Cu, 0.4 mg/kg Cu, 1.1 mg/kg Pb, and 123 mg/kg Zn), indicating a possible threshold of metal contamination for the effective exclusion of metals by the plants. The results of this micro-ecosystem study elucidate the high variability between single sampling points within a contamination area and need to be considered in a large-scale geostatistical analysis of correlation of a mistletoe-heavy metal contamination.

*Keywords: heavy metals, soil contamination, mistletoe (*Viscum album*)*

Zusammenfassung

Mögliche Korrelation von Schwermetallen in Oberflächen-Böden mit dem Befall von Pappeln durch die Laubholzmistel (*Viscum album*)

Um die Variabilität der Schwermetallkontamination in Oberflächenböden in Goslar zu untersuchen, wurde der Anteil bioverfügbarer Schwermetalle in Böden und Misteln (*Viscum album*) mit ICP-OES analysiert. Das Gebiet ist stark durch lange Bergbauaktivitäten beeinflusst. Ziel war es festzustellen, wie repräsentativ einzelne Bodenproben sind für drei spezifische Gebiete, in denen die Zahl der Misteln auf den Bäumen einen Bezug zum Kontaminationsgrad der Böden zu zeigen schienen, und ob eine mögliche Korrelation zwischen dem Grad der Bodenkontamination und dem Bewuchs von Bäumen mit Misteln besteht. Die Metallgehalte in dem stark kontaminierten Gebiet lagen fast eine Größenordnung über den Gehalten im gering kontaminierten Gebiet (75 mg/kg Pb, 0,40 mg/kg Cd und 10,5 mg/kg Cu gegenüber 15 mg/kg Pb, 0,09 mg/kg Cd und 1,2 mg/kg Cu). Außer im stark kontaminierten Gebiet wurde eine Abnahme der Metalle mit der Tiefe im Boden festgestellt. Insgesamt waren von allen untersuchten Schwermetallen die Konzentrationen von Pb und Fe am höchsten und für Cd und Ni am niedrigsten. Interessanterweise zeigten die Mistelblätter höhere Metallgehalte im gering kontaminierten Gebiet im Vergleich zum hoch kontaminierten Gebiet, was möglicherweise auf einen Mechanismus zur Verhinderung von Metallaufnahmen durch die Pflanze zurückzuführen ist, der erst bei gewissen höheren Metallbelastungen wirksam ist. Die Ergebnisse dieser Mikro-Ökosystemstudie zeigen eine hohe Variabilität zwischen einzelnen Beprobungspunkten innerhalb eines untersuchten Gebietes, die bei einer großskaligen geostatistischen Analyse von Korrelation zwischen Schwermetallkontaminationen und Mistelbefall berücksichtigt werden müssen.

*Schlüsselwörter: Schwermetalle, Bodenkontamination, Misteln (*Viscum album*)*

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Introduction

High heavy metal contamination in the Harz Mountains (northern central Germany, Figure 1) has been known for a long time. Mining in the area has been carried out at least since the year 968 AD (Liessmann, 1992) but may have lasted for more than 2000 years. Evidence from 3rd and 4th centuries from slag and ore dating in addition to geochemical investigations show that mining activities took place in the region which exists till today (Klappauf, 1985; Matschullat et al., 1997). A quarter of the lead in the ore lost during processing reached the floodplains during flooding by rivers. Periodical contamination deposits can be distinguished in the region (Dreschoff, 1974). In addition to Pb, other heavy metals involved contaminating the soil are Zn, Cu, Cd, Ni etc. The heavy metal contamination in the area varies in the range of 0.2 to 200 mg//kg for Cd, 10 to 30,000 mg/kg for Pb, 7 to 10,000 mg/kg for Cu and 50 to 55,000 mg/kg for Zn in the soil (Gäbler, 2000). Mines are located in the heavily mined Rammelsberg area south of Goslar, and the smelting sites are found northwest of Goslar (Innerste reservoir) and on the east (Oker reservoir). Rivers (Innerste, Grane and Oker) flowing around the Goslar area have created respective floodplains in the north-west, west and east of the Goslar county respectively depositing the tailings from the mines and causing high heavy metal contamination in the region. Storage areas and slag heaps were sources of direct contamination and through time, the pollution was also spread out by wind. The study area of the project falls in the floodplains of the Innerste and Oker rivers in the northern forelands of the Harz Mountains.

The mistletoe (*Viscum album* ssp. *album*) is a parasitic flowering plant with functional chlorophyll which lives on a wide range of deciduous woody plant species (Zuber, 2004). Low to severe infestations by mistletoes have been observed in the deciduous trees in the Harz leading to a speculation that high infestation level of mistletoes in the area is assisted by high concentration of heavy metals in the surface soils of Goslar. The idea behind this hypothesis is that heavy metal contamination in the soil weakens the tree making it more susceptible to parasitic infection. No detailed study of this potential correlation has been carried out before. Preliminary investigation of information retrieval techniques for mistletoes using infrared techniques were carried out at the Julius Kuehn-Institute, Federal Research Centre for Cultivated Plants (JKI) (by Heike Steckel, Braunschweig). Simultaneously, a terrestrial mapping campaign was conducted in March 2004 to record the mistletoe distribution. A soil and plant sampling (mistletoe sampling) campaign was conducted in July and September 2005 for the micro-ecosystem study presented here.

Results from heavy metal analyses in soil and plant samples (mistletoe leaf and stem, and tree leaf) are presented here to investigate the representativeness of single samples in the three different contamination areas (high, medium and low contamination areas were chosen by Heike Steckel (PhD thesis) based on pre-existing data at JKI) and the occurrence of potential correlation between ground contamination and mistletoe growth in a 'micro-ecosystem' level.

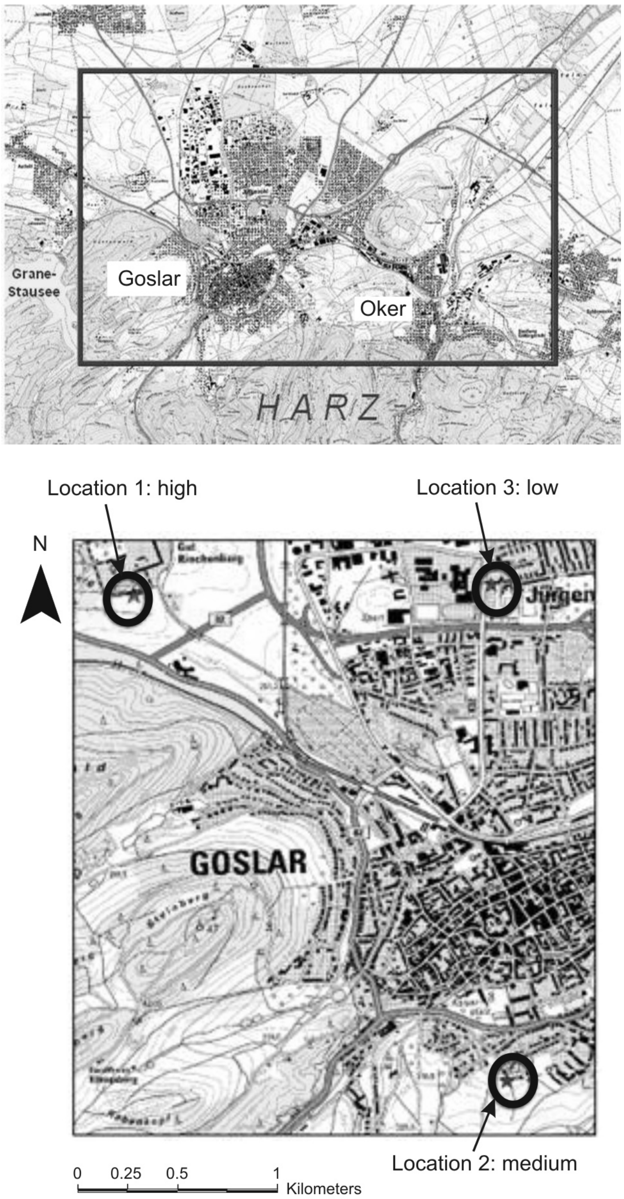

Figure 1:

Overview of the Harz mountains and Goslar county with the study sites (high, medium and low contamination)

Materials and methods

Site description:

The study was carried out in three different contamination areas (high, medium and low) in the city of Goslar, in the Federal state of Lower Saxony, Germany. The different contamination areas for the project were selected by evaluating soil contamination data from "Bodenplanungsgebiet" (Landkreis Goslar) and terrestrial mapping of mistletoes conducted by FAL, Braunschweig. Goslar lies in the northern part of the Harz Mountains at about 10° 25′ E, 51° 54′ N at an altitude of 260 to 360 m above sea level (Figure 1). The majority of the area is contaminated with heavy metals due to the mining activities carried out for centuries.

Soil and plant sampling and soil description:

The sampling campaign was carried out in the summer months of July (high contamination site) and August 2005 (medium and low contamination sites). Summer months were chosen because growth due to transport of nutrients (along with heavy metals) is maximum in the season and will give a good account of a quantitative measure of bioavailability of heavy metals. The sampling scheme was correlated with the large-scale investigation carried out by Heike Steckel (PhD thesis at JKI) where e.g. no separate investigation of the upper humus layer was done, but a general separation scheme in 30 cm depth steps was followed. In the high and medium contamination areas, sampling was carried out at depth intervals of 0 to 30 cm, 30 to 60 cm and 60 to 90 cm. In the low contamination area, due to the hard bedrock, sampling depth of 60 to 90 cm had to be excluded.

Soil and mistletoe samples were taken in each location. For soil sampling, buffer zones of 1 m, 3 m and 7 m were calculated on one half of the tree and of 1 m, 5 m, and 10 m in the other half. Eight spots were sampled in each concentric ring in an octagonal fashion. A soil corer 1.20 m long and 1 inch in diameter was used for coring. A total of 185 samples were taken from the three different contaminations areas (high-72, medium-65, low-48), all three depth layers (0 to 30 cm, 30 to 60 cm, 60 to 90 cm) included.

Soil profiles were taken in each area for characterization. Gleysol was predominant in the high contamination area (an open field in a farming area) with considerable amount of water content in the topsoil (0 to 30 cm) and the soil horizons below could not be properly distinguished. Profiles taken closer to the tree were relatively drier than that from the farming field. Soil components were a mixture of coarse sand and silt material with schists embedded in the column. The medium contamination area consisted of relatively dry brown earth (cambisol) with components ranging between medium silt to fine sand, a significant amount of schists present and no clear distinction between the horizons. The area of low contamination consists of parabrown earth (luvisol) with composition including schists similar to that of the medium contamination area but comparatively more water content than in the medium contamination area. The soil types mentioned in the three contamination sites are only representative for the specific sites chosen for sampling.

Mistletoe samples (leaf and stem) and tree leaf samples were taken in the three contamination areas (one poplar tree was chosen in each location) from two heights (3 m and 4.5 m) above ground level. A total of 21 plant samples were taken from the three contamination sites. For the high contamination area, the average number of mistletoes per tree was 12 for 16 trees where as for medium and low contamination areas it was 8 (for 6 trees) and 6 (for 12 trees), respectively.

Sample pre-treatment and analysis:

Soil samples were initially air dried for 7 days in a dust-free room after which the organic materials (twigs and leaves) and visible stone particles were removed from the dried sample and then gently crushed using a mortar and pestle. Sieving was then carried out with a 2 mm sieve and 8 g of each sample was weighed for further steps.

An ammonium acetate/di-Na-EDTA (AAAc-EDTA) (Lakanen and Erviö, 1972; Silanpää, 1982) extraction method was used for extraction of the bioavailable trace and heavy metals from the soil samples. 1 l of extract solution was prepared with 7.44 g di-Na-EDTA, 37.4 ml NH_3 (25 %) and 57.2 ml of acetic acid (96 %). 8 g of each sieved fraction were added to 80 ml (solid suspension density of 1:10) of extract solution in a 100 ml polyethylene bottle for shaking. After shaking for 1.5 hours in an automatic horizontal shaker (150/min), the mixture was filtered through folded filters. 25 ml of each filtrate was collected in porcelain cups and fumed off in a sandbath at 170 °C for 3 hours. The samples were then cooled at room temperature and then ashed in a muffle furnace for 4 hours at 490 °C for incineration. The samples were cooled for 2 hours after which 5 ml of 10 % HNO_3 was added and left for 2 hours. 20 ml of deionized water was then added to the sample and the mixture filtered with folded filter (size 593.5). An inductively coupled plasma – optical emission spectrometer (ICP-OES, Spectro Ciros) was used to analyse the concentrations of metals in soil in the filtrates (Al, Ca, Cd, Cu, Fe, K, Li, Na, Ni, P, Pb, Mn, Mg, S, Si, Ti, V, Zn).

Plant samples were dried until weight constancy was achieved at 50 °C and gently crushed. 0.5 g of sample material was weighed into the tubes in a liner. 6.0 ml HNO_3 and 1.5 ml H_2O_2 were pipetted into the tubes (4:1 ratio), and allowed for 10 minutes of reaction after which it was placed in a microwave oven. Samples were sequentially heated at 120 °C for 5 minutes and again at 200 °C for 5 minutes allowing 2 minutes of waiting time before raising the heating temperature. After cooling the samples for over 30 minutes they were filled with deionized water, shaken and the extracts were then filtered. Analysis was carried out with ICP-OES.

The chemical data obtained from ICP-OES were analysed using the statistics package SPSS (Version 12.0.1). Uni/multivariate and factor analyses were performed on the data sets where variation in concentration of heavy metals within one contamination area and in between different contamination levels were tested at $P<0.05$. Concentration data for the elements were interpolated using the ArcGIS 9.0 to visualize the lateral distribution of heavy metals around the trees in context.

Results

Descriptive statistics was used to illustrate the variation in concentration of different elements in various contamination and depth levels. Data for Cd, Cu, Fe, Ni, Pb and Zn, which are the environmentally most relevant metals of the elements analysed, are presented in Table 1, 2 and 3 for all three depth layers for all contamination areas. In all cases, concentrations for Pb and Fe are highest followed by Cu and Zn and lastly by Cd and Ni. Most metals show high surface values and the concentrations decrease with depth, except for some instances. In the high contamination area, in contrast, Fe, Cu, and Pb values increase with depth. This may be related to a stronger input of mining contaminants during former times and covering with younger, less contaminated material. Results from the high and medium contamination areas were comparable for some elements, and in general show values of almost an order of magnitude higher compared to samples from the low contamination area. Highest concentrations as well as dispersion are shown by Pb and Fe, followed by Cu and Zn and then by Cd and Ni. Heavy metals, when considered individually, show a large variability in concentration values as shown by the range (minimum and maximum values) and also the standard deviation.

Table 1:

Heavy metal statistics (AAAc-EDTA extraction) in 0 to 30 cm layer for high, medium and low contamination areas. Index: min-minimum, max-maximum, S.D.-standard deviation

	High contamination area (mg/kg)				Med. contamination area (mg/kg)				Low contamination area (mg/kg)			
	Mean	Min	Max	S.D.	Mean	Min	Max	S.D.	Mean	Min	Max	S.D.
Cd	4.01	0.37	8.98	2.24	3.87	0.31	6.89	2.16	0.87	0.23	1.18	0.2
Cu	105	23	238	55	44	6	71	22	12	1	21	4
Fe	806	233	3524	698	194	75	387	89	100	35	172	37
Ni	1.67	0.42	6.14	1.31	0.82	0.24	1.41	0.34	0.43	0.13	0.72	0.14
Pb	745	183	1107	273	698	97	2298	424	159	10	203	37
Zn	203	89	442	105	85	10	159	43	26	11	48	10

Table 2:

Heavy metal statistics (AAAc-EDTA extraction) in 30 to 60 cm layer for high, medium and low contamination areas. Index: min-minimum, max-maximum, S.D.-standard deviation

	High contamination area (mg/kg)				Med. contamination area (mg/kg)				Low contamination area (mg/kg)			
	Mean	Min	Max	S.D.	Mean	Min	Max	S.D.	Mean	Min	Max	S.D.
Cd	3.33	0.72	6.62	1.46	1.33	0.24	2.68	0.72	0.45	0.21	2.3	0.43
Cu	120	15	219	59	35	2	67	19	8	2	13	3
Fe	877	194	2482	520	186	39	553	121	85	35	166	36
Ni	1.19	0.26	2.19	0.65	0.55	0.09	1.04	0.28	0.32	0.11	0.61	0.12
Pb	811	292	1257	220	446	38	869	231	101	24	462	82
Zn	174	42	325	86	46	8	122	31	15	6	51	9

Table 3:

Heavy metal statistics (AAAc-EDTA extraction) in 60 to 90 cm layer for high and medium contamination areas (no samples from this layer for the low contamination area). Index: min-minimum, max-maximum, S.D.-standard deviation, bdl: below detection limit = <0.1 mg/kg

	High contamination area (mg/kg)				Med. contamination area (mg/kg)			
	Mean	Min	Max	S.D.	Mean	Min	Max	S.D.
Cd	3.04	0.44	7.83	1.67	0.44	0.08	1.56	0.36
Cu	148	12	237	55	12	bdl	36	11
Fe	1016	131	3041	715	107	28	534	104
Ni	1.71	0.18	5.81	1.66	0.29	0.03	0.92	0.18
Pb	859	265	1367	329	205	12	558	171
Zn	171	29	592	129	17	0	119	25

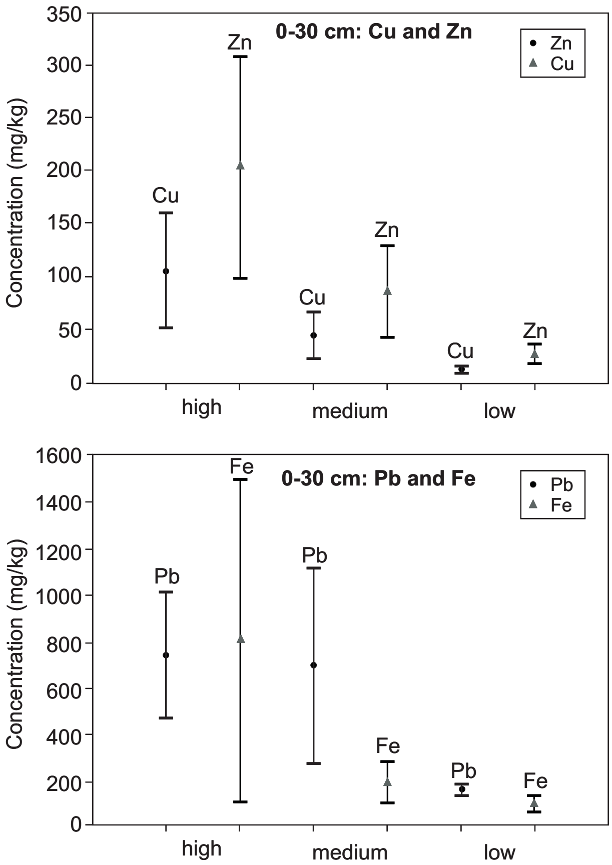

Figure 2:

Variability in concentrations of Cu, Zn, Pb and Fe in the 0 to 30 cm depth layer in different contamination areas

The results from the statistical analysis were plotted with Sigma plot 9.01. to depict the variability of metals with the standard deviations plot for 0 to 30 cm layer for Pb, Fe, Zn and Cu for all contamination areas (Figure 2). The standard deviation is plotted for the estimated marginal means obtained from SPSS. The large absolute standard deviation of the elements shows the variability of heavy metals within a single contamination site as well as between different contamination sites.

Factor analysis was conducted on the chemical data from soil samples. Principal component analysis (PCA) was chosen to extract the factors for analysis to investigate the depth-wise distribution of heavy and trace metals analysed (Figure 3). The general trend of the major heavy metals (Fe, Pb, Zn, Cu etc.) can be seen in the first component and represents a contaminant-bearing oxide phase. The second component consists of elements associated with sulphur (Ni, Co) probably from the mined ores. The last two components consist of elements present in the detrital fractions and ultimately the bed rock (Al, Ca, Mn, Si, Li etc). Degrees of factor loading of most elements do not vary significantly in different depth layers.

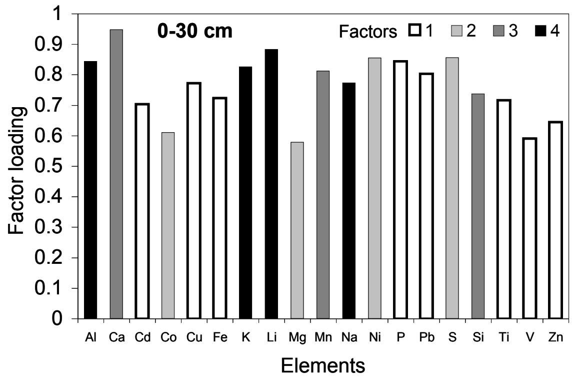

Figure 3:

Results from factor analysis for depth layer 0 to 30 cm

Plant samples showed a high degree of variability in the three sites with Fe and Zn showing the highest and Pb, Cd, Ni and Cu showing lowest concentrations. Table 4 and Table 5 list the enrichment factors in plant samples (above 3 m height from ground level) compared to soil samples (ratio of plant/soil concentrations) in the high and low contamination areas (0 to 30 cm) for samples within 2 m distance from the tree. Cd, Ni, Pb and Zn generally show higher concentrations in plant samples from the lower contamination area than in the high concentration area, however, Cu shows almost equal concentrations in both the contamination areas. Enrichment factors in plants from the low contamination area show values much higher compared to medium contamination area.

Table 4:

Concentrations and enrichment of heavy metals in plant samples (above 3 m in height from the ground level) compared to soil samples (AAAc-EDTA extraction) within 2 m distance from the tree in the high contamination area (0 to 30 cm) (T-L: tree leaf, Mis-St: Mistletoe stem, Mis-L: mistletoe leaf, EF: L - Enrichment factor in tree leaf, EF: M-St - Enrichment factor in mistletoe, bdl: below detection limit = <0.1 mg/kg).

Elements	Concentrations in soil (mg/kg)	Concentrations in plants (mg/kg)			Enrichment factors		
		T-L	Mis-St	Mis-L	EF:L	EF:M-St	EF:M-L
Cd	4.1	bdl	0.1	bdl	bdl	bdl	bdl
Cu	120	8.5	14.2	10.5	0.1	0.1	0.1
Ni	1.51	0.13	0.21	0.42	0.1	0.1	0.3
Pb	907	1.73	1.12	1.10	bdl	bdl	bdl
Zn	197	198	140	123	1	0.7	0.6

Table 5:

Concentrations and enrichment of heavy metals in plant samples (above 3 m in height from the ground level) compared to soil samples (AAAc-EDTA extraction) within 2 m distance from the tree in low contamination area (0 to 30 cm). For abbreviations, see Table 4.

Elements	Concentrations in soil (mg/kg)	Concentrations in plants (mg/kg)			Enrichment factors		
		T-L	Mis-St	Mis-L	EF:L	EF:M-St	EF:M-L
Cd	0.92	16.1	10.7	11.6	17.5	11.6	12.6
Cu	12.4	9.2	14.7	13.3	0.7	1.2	1.1
Ni	0.53	1.16	1.84	4.8	2.4	3.8	10.3
Pb	167	1.17	bdl	0.9	bdl	bdl	bdl
Zn	26.2	1065	557	675	40.6	21.3	25.8

Discussion

The variability in concentrations of the heavy metals tells us how representative the single samples from one area are with respect to the specific contamination level, which is an important result for the large-scale study carried out at JKI. The research at JKI focused on the relationship between heavy metals in soil, tree and mistletoe, and the correlation between the occurrence of mistletoes and the contamination levels at the in the vicinity of the tree. This was conducted by grid mapping and sampling in the Goslar area, analysing the soil and mistletoe samples as well as comparing and appraising the found data. However, a possible statistical relationship between mistletoe infestation and contamination level will depend upon the representativeness of single point samples analysed for different heavy metals. Results from all contamination levels show that the concentrations of heavy metals within each contamination area are highly variable. Thus, since the data for geostatistical analysis of the large scale study is dependent upon representativeness of single sampling points in the three different contamination sites it makes a significant difference where the sample is taken from. The top soil (0 to 30 cm), from which the tree takes up most of the nutrients shows highest variability in heavy metal concentrations in the high and medium contamination areas. Therefore, to compare mistletoe infestation with heavy metal contamination, it is important to understand the heavy metal distribution in a local scale as well and take representativeness of samples into account.

Heavy metal concentrations analysed from the collected samples in the 0 to 30 cm (surface) layer are comparable to values in literature with the average values for the top soil falling in the BW III (BW: Bodenwert) in the classification scheme of Eikmann and Kloke (1993) (BW is based on the classification scheme that classifies total heavy metal content in soils according to land use, vegetation and groundwater). A high variability in concentrations of different heavy metals with respect to contamination level in a single contamination site as well as in between different areas is well illustrated by Tables 1 to 3 and Figure 2. Concentrations of heavy metals in the medium and high contamination areas are comparable, with mean bioavailable values of some elements within 5 % of each other. Absolute variability of soil samples is highest in the high contamination area compared to that of the low contamination area. Concentrations of heavy metals in plant samples show extreme variability within a single tree as well and branches at different heights (3.0 and 4.5 m) showed different concentrations.

The idea behind a potential correlation of heavy metal contamination with mistletoe infestation of trees is as follows. It is known that heavy metal contamination causes biotic and abiotic stress in plants and above toxic levels it can cause symptoms such as chlorosis and necrosis, stunting, leaf discoloration and inhibition of root growth (William et al., 2000; Greger, 2004). Deciduous plants are susceptible to such stress which weakens their resistance and growth physiology further (Greger, 2004). As a result, parasites and hemiparasites such as *Viscum album* could find a perfect host for living as a parasite. Some correlation has been found between mistletoe infection and damaged host trees in deciduous trees; in a study conducted with pine trees, infected chlorotic pines hosted more mistletoes than healthy pines (Hartmann, 1990).

The average number of mistletoes on the trees was highest in the high-contamination area and lowest in the low-contamination area. Still, interpretation of mistletoe growth as a result of heavy metal contamination in surface soils is not straightforward because of various reasons. Firstly, studies of direct correlation between heavy metal contamination in surface soils and mistletoe growth have not been carried out before and therefore results from this study cannot be compared with those from others. Secondly, large variability of heavy metal concentration in soil and plant samples in a single contamination site make it difficult to interpret any association between soil contamination and the parasitic growth of mistletoes. Moreover, plant samples from low contamination area have the highest amount of heavy metals, and samples from high and medium contamination area show opposite results, i.e. the concentration in soil is significantly higher but the concentration of metals in the plant samples is significantly lower in comparison to the low contamination area. In addition, the concentrations obtained from the extraction procedure represent only a specific fraction of heavy metals in soil which gives an estimation of availability and not the amount which the plant really uptakes. Studies have shown that high level of heavy metals in soil do not always indicate similar high concentration in plants (Mulgrew and Williams, 2000). A study carried out by a specific kind of lichen illustrated that Cu, Pb and Zn concentrations in plants often correlate with aerial deposition but not with soil concentrations where as Ni and Cd correlated with deposition and soil concentration (Pilegard, 1984). Another possible explanation could be that the defence mechanisms of the trees against toxic metal uptake only become active when a certain threshold triggering this mechanism is reached. In our case, the low contamination site would be characterized by concentration below and in the high contamination area above that threshold. The complexity of mechanisms in uptake of heavy metals from soil makes it difficult to study a direct association of heavy metals and mistletoe infestation.

Moreover, the distribution of mistletoes in all contaminated sites is patchy. In the high contamination area the average number of mistletoes per tree was 12.6 (no. of mistletoes ranged from 4 to 17 per tree for 16 trees). For the medium concentration area the number of mistletoes ranged from 7.9 per tree for (number of mistletoes from 6 to 13 for 6 trees) and 5.7 per tree (number of mistletoes range from 2 to 8 for 8 trees) in the low contamination area. The average number of mistletoes per tree holds only during the time the soil was sampled for the project. The number of mistletoes definitely seems to follow contamination pattern numberwise, but interpretation in terms of a correlation between heavy metal contamination and mistletoe infestation has to be done with care.

Mistletoe distribution depends upon available hosts and migration routes of birds as well, as they spread the seed from the mistletoe flowers (Zuber, 2004; Wangerin, 1937). Heavy metal contamination might not have a direct influence on mistletoe distribution, however, it can have an indirect effect that once a mistletoe seed is dropped into one branch, contamination and mistletoe could have an interacting factor in weakening the tree. On the other hand, old and weak trees are more susceptible to mistletoe attack (Nierhaus-Wunderwald and Lawrenz, 1997). This could include trees which have already been weakened by heavy metal contamination. Mistletoe infestation causes reduced transport of nutrients and water to the host. Thus, there is a possibility that trees that have already had some stress due to high concentration of heavy metals could be prone to mistletoe attack (Tsopelas et al., 2003). Hence, high heavy metal concentration areas might host deciduous trees that are more susceptible to mistletoe infestation.

The work carried out in this study demonstrates the variability of heavy metals in a single location within a sampling area and the importance of single data points as the range of heavy metal contamination in any contamination site is very large, especially in the topsoil where the plants get their nutrients from. Therefore, single data points from the catchment area of the tree might not be representative of the average contamination influence on the tree. The correlation between mistletoe infestation and contamination of surface soils cannot be explained simply by measuring the concentration levels of heavy metals and number of mistletoe per tree because of various factors such as bird migration, bioavailability and susceptibility of hosts come into play. If these factors can be considered constant within the investigated area, a relationship might become obvious. Due to the lack of time in the project, the number of trees sampled was restricted to three (one tree per contamination area). For better results, more trees per contamination area should be considered. Possibly a correlation can be established based on statistical data from a larger number of trees within an area. Also, mistletoe ratings in different areas can be used to quantify the infestation levels. Sampling should be carried out in more than a single site for each of the contamination areas to quantify the variability of heavy metals. Lastly, proper soils profiling and better understanding of heavy metal uptake by deciduous trees and mistletoes would give a better understanding of the potential correlation of soil contamination and occurrence of mistletoes. If a statistical relationship between metal contamination of surface soil and mistletoe infestation could be established, this would offer a simple and cheap opportunity to provide a rough assess of potential metal contamination of soils in areas where no data on the soil contamination are available.

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Gross soil surface nutrient balances: The OECD approach implemented under German conditions

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Abstract

Plant and therefore food and feed production require an adequate supply of nutrients. Efficient nutrient use is a major task to ensure economically and environmentally sound food production minimizing the impact of nutrients on ground water, the risk of eutrophication caused by rising nutrient concentrations in surface waters and the emission of trace gases such as nitrous oxide (N_2O) and ammonia (NH_3). Agri-environmental indicators (AEI) developed by the OECD shall identify and quantify the extent of impacts by agricultural management on the environment and track the effects of policy measures. Nutrient balances for nitrogen (N) and phosphorus (P) on the national level are two of these agri-environmental indicators used by the OECD to compare member states and draw conclusions about nutrient loads from agriculture into the environment.

OECD member states are required to calculate and provide gross soil surface nutrient balances for N and P on an annual base. The German N gross soil surface balance for the time period from 1992 to 2006 shows a surplus between 89 and 121 kg ha^{-1} a^{-1} N. Because nutrient balances are simplifications of complex and variable processes they comprise a series of uncertainties. These uncertainties are mainly associated with either the statistical data base or the coefficient library used to convert the statistical data into nutrient quantities. Therefore, it is essential to be aware that the absolute balance values do not reflect the actual situation in a country. Nevertheless, in case that a consistent method of balance calculation is used for all years a comparison between these years to derive trends in nutrient surpluses or deficits is possible.

Keywords: OECD guideline, nutrients, gross soil surface balance, data uncertainties, nitrogen coefficients

Zusammenfassung

Das Wachstum von Pflanzen und damit die Erzeugung von Nahrungs- und Futtermitteln erfordern eine bilanzorientierte Zufuhr von Nährstoffen. Die effiziente Ausnutzung von Nährstoffen ist für eine wirtschaftliche und umweltgerechte Nahrungsmittelproduktion entscheidend und ermöglicht die Einflüsse dieser auf das Grundwasser, das Eutrophierungsrisiko durch ansteigende Nährstoffkonzentrationen in Oberflächengewässern und die Emission von Spurengasen wie z. B. Distickstoffmonoxid (N_2O) und Ammoniak (NH_3) zu minimieren. Von der OECD entwickelte Agrar-Umweltindikatoren sollen den Einfluss der Landwirtschaft auf die Umwelt identifizieren und quantifizieren sowie dazu dienen, Auswirkungen politischer Maßnahmen zu verfolgen. Nationale Stickstoff- (N) und Phosphorbilanzen (P) zählen zu diesen Agrar-Umweltindikatoren, die von der OECD zur Bewertung von Nährstofffrachten aus der Landwirtschaft in die Umwelt herangezogen werden.

Mitgliedsstaaten der OECD sind verpflichtet, jährliche brutto Flächenbilanzen für N und P zu berechnen und bereitzustellen. Die Berechnung der N brutto Flächenbilanz für Deutschland zeigt N-Überschüsse zwischen 89 und 121 kg ha^{-1} a^{-1} im Untersuchungszeitraum von 1992 bis 2006. Da es sich bei Nährstoffbilanzen um die vereinfachende Zusammenfassung und Berechnung von komplexen und sowohl räumlich als auch zeitlich variablen Prozessen handelt, sind diese fehlerbehaftet. Die meisten Unsicherheiten beruhen entweder auf der statistischen Datenbasis oder der verwendeten Koeffizienten zur Umrechnung von statistischen Daten in Nährstoffmengen. Daher ist nicht davon auszugehen, dass die absoluten Bilanzsalden die tatsächliche Nährstoffsituation eines Staates wiedergeben. Jedoch sind jährliche Bilanzen geeignet um Trends in der Entwicklung von Nährstoffüberschüssen oder -defiziten zu verfolgen. Für vergleichende Betrachtungen muss allerdings sichergestellt sein, dass die Berechnungen mit einer konsistenten Methode erfolgen.

Schlüsselwörter: OECD Richtlinie, Nährstoffe, brutto Flächenbilanz, Datenunsicherheiten, Stickstoffkoeffizienten

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Introduction

Plant and therefore food and feed production require an adequate supply of nutrients. Cassman et al. (2003) reveal the complex relationship between nutrient availability, crop yield and nutrient efficiency considering the difficulty to meet food demands while protecting natural resources. Soils will lose their fertility if nutrient mining takes place over a longer period. Then again, nutrient loads from agriculture into the environment increase the risk of eutrophication in surface waters caused by rising phosphorus (P) concentrations, can have a severe impact on ground water quality by increasing nitrate (NO_3^-) or P concentration and can emit trace gases such as nitrous oxide (N_2O) and ammonia (NH_3) into the air. For a better protection of natural resources like for example soil and water, it is important to identify where and to what extent persistent nutrient surpluses or deficits occur.

Impacts of agriculture and agricultural policies on the environment are a major issue in OECD (Organisation for Economic Cooperation and Development) member states. A set of agri-environmental indicators (AEIs) was developed by the OECD to identify and quantify the extent of these impacts and to better understand the effects of policy measures on the environment (OECD, 1999). Nutrient balances for nitrogen (N) and P calculated on the national level are commonly used as AEIs by policy makers. OECD member states are required to keep record about nutrient surpluses and deficits from agriculture on an annual base.

Nutrient balances can be calculated using different approaches. In addition to the gross soil surface balance calculation recommended by the OECD (OECD/EUROSTAT, 2003), these are the net soil surface balance, the livestock balance and the farm gate balance. Each of these approaches balances nutrients added to an agricultural system and nutrients removed from the system per hectare of agricultural land. Depending on the balance to be calculated nutrient input and output variables vary (Table 1).

Besides of different approaches to calculate balances they can also be calculated in a variety of spatial scales. Whereas for example Bach and Frede (1998) calculated N balances for Germany, Bach et al. (2003) and Osterburg and Schmidt (2008) calculated balances on a regional scale. An overview regarding some of the different approaches was published by Bach and Frede (2005). To evaluate fertiliser strategies on the farm level it is necessary to calculate balances for single farms or even better fields. This was shown by Quirin et al. (2004), who demonstrated how N surpluses could be tracked back to varying fertilisation practises on different fields of one farm. In Germany farmers are required to keep so called annual and multi-year nutrient management plans to record the farm nutrient in- and outputs.

Table 1:

Input and output variables of gross- and net soils surface balances, livestock balances and farm gate balances

	Gross soil surface balance	Net soil surface balance	Live-stock balance	Farm gate balance
Input				
Mineral fertiliser	+	+		+
Organic fertiliser	+	+		+
Livestock manure	+	+		
Atmospheric deposition[1]	+	+		+
Biological N-fixation[1]	+	+		+
Seed and planting material	+	+		+
Imported fodder			+	+
Fodder from domestic food industry			+	+
Fodder (internal production)			+	
Output				
Total harvested crops and fodder	-	-		
Cash crops				-
Livestock marked products			-	-
Livestock manure			-	
N emissions[1]		-		
N demand for turn over processes[1]		-		
Surplus/deficit	= Sum	= Sum	= Sum	= Sum

[1] for N balances only

Nutrient balances will be calculated as difference between input and output in the agricultural system. For the N and P balances similar statistical input variables and corresponding N and P coefficients are required. Whereas in N balances emission from agriculture into soil, water and air are included, these paths are not considered for P. The remainder of this paper emphasis on N balances. The OECD handbook on gross N balances was first published in 2003 (OECD/EUROSTAT, 2003) and is used as guidance for the calculation. The gross balance methodology is considered the appropriate indicator for OECD member states to allow comparisons. It ensures as far as possible a consistency of the used method between countries.

The aim of this paper is to outline the implementation of the OECD gross N balance for Germany. Assumptions and estimations made to overcome data shortages in the German data bases are highlighted and uncertainties critically discussed. The N gross soil surface balance for Germany is calculated for the years 1992 to 2006 and some interpretation avenues are shown.

Materials and method of the OECD nitrogen balance

The following calculations are based on data from 1992 to 2006 covering a 15 year time period after the German reunification. Calculations of N balances for years before and short after the German reunification need some special considerations because of the differences in data availability. This issue will not be discussed in this paper.

Statistical and other input data

Data required for the calculation of the national gross N soil surface balance are mineral and organic fertiliser, livestock manure, biological N fixation, seeds and planting material and the total harvested crops and fodder (Table 1). Each of these variables is further segmented (Table 2). Additional, land use data is required for calculations referring

Table 2:

OECD codes, in- and output variables, N coefficients and units used to calculate the gross N soil surface balances for Germany according to the OECD method

OECD code	Variables and N coefficients[1]	Unit of N coefficients
L1	Total area	
L11	Total land area	
L111	Agricultural land (arable crop land, permanent crop land and permanent pasture)	
F1	Total fertilisers	
F11	Total inorganic fertilisers (N fertilisers)	
F12	Total organic products (sewage sludge [39.5], urban compost [14.3])	kg Mg^{-1} N
A1	Livestock manure production	
A11	Total cattle (calves for slaughter, other male and female calves (<1 yr) [25], male and female cattle (1-2 yrs) [47], male cattle, breeding heifers, heifers for slaughter (>2yrs) [59], dairy cows [115] and other cows [98])	kg $head^{-1}$ yr^{1} N
A12	Total pigs (piglets (<20kg [4] and 20-50 kg [13]), fattening pigs [13], breeding boars [13] and sows (>50 kg) [26])	kg $head^{-1}$ yr^{1} N
A13	Total sheep and goats (sheep [10], lambs [10] and goats [13])	kg $head^{-1}$ yr^{1} N
A14	Total poultry (broilers [0.29], layers [0.73] and other chickens [0.28]), ducks [0.55], turkeys [1.6] and other poultry [0.8])	kg $head^{-1}$ yr^{1} N
A19	Total other livestock (horses [68])	kg $head^{-1}$ yr^{1} N
C2	Total harvested crops and forage	
C21	Total harvested crops	
C211	Total cereals (spring wheat [18], winter wheat [22], durum wheat [18], barley [17], maize [15], oats [15], rye [15], other coarse grains [14], triticale [18] and others cereals [17])	kg Mg^{-1} N
C212	Total oil crops (sunflowerseed [28], rapeseed [33] and other oil crops [35])	kg Mg^{-1} N
C213	Total dried pulses and beans [39]	kg Mg^{-1} N
C214	Total root crops (potatoes [3.5])	kg Mg^{-1} N
C215	Total fruit area (fruit [44] and viticulture [25])	kg ha^{-1} N
C216	Total vegetables [2.9]	kg Mg^{-1} N
C217	Total industrial crops (sugar beet [1.8], tobacco [30] and hop [30])	kg Mg^{-1} N
C22	Total forage	
C221	Total harvested fodder crops (fodder beets [1.4], other fodder roots [1.4], clover [25], alfalfa [25], silage maize [3.8] and other harvested fodder crops [3.5])	kg Mg^{-1} N
C222	Total pasture consumption (temporary [24], permanent pasture consumption [22] and alpine pasture and rough grazing [15.5])	kg Mg^{-1} N
C23	Total crop residues removed from the field (straws [5] and other crops residues [3])	kg Mg^{-1} N
C11	Total seeds and planting materials	
C111	Total cereals (wheat [18], barley [16.1], maize [15], oats [15], rye [15] and other cereals [18])	kg ha^{-1} N
C112	Total oil crops (sunflowerseed [28], rapeseed [33] and other oil crops [35])	kg ha^{-1} N
C113	Total root crops (potatoes [3.5])	kg ha^{-1} N
C213	Total dried pulses and beans	kg ha^{-1} N
B1	Biological N fixation	
B11	Total area of legume crops (pulses [176], clover [198] and alfalfa [285])	kg ha^{-1} N
B12	Free living organisms (permanent pasture [30])	kg ha^{-1} N
D1	Atmospheric deposition	

[1] N coefficients are shown in [brackets] and are based on 86 % dry matter (DM) for cereals, 91 % DM for rapeseed and 28 % DM for silage maize

to the area unit. Most of these in- and output variables are provided by the Federal Statistical Office (Destatis). The annually published statistic for nutrition, agriculture and forestry builds most of the data base (exemplarily: Statistisches Jahrbuch, 2005). Since 2002/2003 on-line statistical tables (GENISIS) are used when available from the Destatis homepage (https://www-genesis.destatis.de/genesis/online/logon). Table 2 enlists the code of the OECD, the corresponding necessary variables and coefficients for the calculation and the units in which they are provided. Additional data for the atmospheric deposition, was derived from long term trends in deposition loads of air pollutants in Germany and was set to 23 kg ha^{-1} a^{-1} N (Gauger et al., 2002).

Nitrogen coefficients

All statistical livestock and crop production data needs to be converted into N equivalents which allow to sum up the total amount of N inputs and outputs and to balance these. To convert the various variables from their original recorded unit into common units, N coefficients are used. Most of the N coefficients are derived from the German Fertiliser Application Ordinance (MVV, 1996). In case of some animal coefficients, a different data source was used (VwV, 1996). Table 2 shows the used coefficients in brackets after the variables. Table 3 and Equation 1 reveal exemplarily the calculation of the N amount removed by 'total cereals'. It can be seen, that some of the OECD specified variables like e.g. rice and sorghum are not relevant for German balances. In other cases the German statistics and coefficient data base allow to improve the calculation by further diversification.

Nitrogen coefficients for compost and sewage sludge are not provided by the German Fertiliser Application Ordinance (MVV, 1996), these coefficients are derived from other available sources. The N coefficients for compost were derived from the Federal Environmental Agency (Bannick et al., 2001) and for sewage sludge from the triennial compiled German report about sewage sludge for the European Commission (BMU, 2004; BMU, 2007). For the data presented in this paper an average of 39.5 kg Mg^{-1} N in sewage sludge was used for all years drawn from the 2004 report (BMU, 2004). If this series is continued it might be possible to use annual values instead of averages in future calculations.

Table 3:

Nitrogen coefficients to calculate the total harvested N from cereals

C211	**Total harvested cereals [Mg]**	**N coefficient[5] [kg Mg^{-1} N]**
C2111	Wheat	
C21111	Common wheat	
C211111	Spring wheat (SW_y)	18
C211112	Winter wheat (WW_y)	22
C21112	Durum wheat (DW_y)	18
C2112	Rice	
C2113	Coarse grains	
C21131	Barley[1] (B_y)	17
C21132	Maize (M_y)	15
C21133	Millet	
C21134	Oats (O_y)	15
C21135	Rye[2] (R_y)	15
C21136	Sorghum	
C21139	Other coarse grains[3] (CG_y)	14
C2119	Other cereals	
C21191	Triticale (T_y)	18
C21199	Other cereals types[4] (OC_y)	17

[1] winter barley; [2] winter rye; [3] brewing barley; [4] spring barley, [5] based on 86 % DM

$$\text{total cereals}_{[\text{kg N}]} = (SW_y * 18 + WW_y * 22 + DW_y * 18) + (B_y * 17 + M_y * 15 + O_y * 15 + R_y * 15 + CG_y * 14) + (T_y * 18 + OC_y * 17) \quad \text{[Equation 1]}$$

Data uncertainties

Statistical data

Statistical data published by Destatis have an effect on balance calculations mainly through the following three uncertainties: (i) input data are not recorded on an annual base, (ii) input data are estimations and (iii) by OECD requested input variables are not supported by the statistic. Depending on the proportion of the input variables on the gross N soil surface balance, their influence on the overall uncertainty can be substantial (Figure 1). As can been seen, mineral fertiliser and livestock manure are the major contributing input variables in the balance. Both data sources of these input variables have their uncertainties. Whilst the N input from mineral fertiliser is based on sales figures and not on the actual applied amount of N fertiliser, the input from livestock manure is calculated from animal numbers. Cattle and pigs are counted twice a year (May and November) and it was decided to use the November count in the balance. All other animals are not counted annually, whereas for years without counts, the number of the previous year is used. Because of the necessity to update the balance on an annual basis, it is not possible to use a mean value from a previous and following year, because the latter data is not available yet. Furthermore some data are only estimates, like the number of goats.

Sewage sludge and urban compost which are cumulated to the variable organic fertilisers are only erratically recorded in German statistics and therefore missing data were replaced by data of previous years.

The N output values are mainly driven by cereals, pasture and harvested fodder crops (Figure 1). Yields of crops, sugar and fodder beet leaves, pasture, fruits, viticulture and vegetables are estimated by the state statistical offices in Germany and reported to Destatis. In case of cereals, potatoes and winter rape actual yield values of selected fields (maximum of 10,000) are recorded and extrapolated onto the national level. Sugar beet yields are provided by the sugar industry and are based on the amounts of beets delivered to the sugar factory. Grape yields are also based on notifications about vintage to the viticulture register (Weinbaukartei). Calculations of fruit yields are based either on the cropping area or on tree yields. Yields of vegetables are estimated according to the cropped area.

A general major concern is the estimation of the pasture yields because of the large proportional influence of this variable (Figure 1). Not only is this variable estimated, it is further required to account for N losses during agricultural management. In Germany, a loss of 15 % in pasture yield is assumed, which is lower than the proposed 30 % of the OECD.

The amount of straw removed from the field needs to be considered in the calculation. Because of the lack of statistical data it is estimated that straw in the dimension of 10 % of the grain yield is removed annually from agricultural fields. This value might need to be reconsidered for future calculations because it can be expected that the rising demand on renewable energy sources will increase the straw collection practice of farms.

Changes in agricultural management practice also influence the provided statistical data, as crops which are not commonly or not any longer cultivated will be removed from the statistical data set. Fodder beet yields are for example not any longer published since 2003. This inconsistency in data series results in some inaccuracies when calculating balances. A further difficulty is the allocation of statistical data from management years (July to June) to balance years (January to December). Most variables are reported in balance years, but mineral fertiliser and seeds and planting material are listed for management years. Hence the data were assigned to the balance years as follows: It is assumed that the majority of mineral fertiliser and seeds and planting material bought in the management year is used to achieve the yield of the second named management year (e.g. management year 2004/2005 will be allocated to the balance year 2005).

Furthermore, the subsequent precision of statistical data causes confusions when comparing an actual balance of one time period to an older one and discovering that the surplus calculated for one of the previous years has been altered. Even though changes are generally minor considering the overall imprecision of the method, they tend to irritate users of nutrient balances.

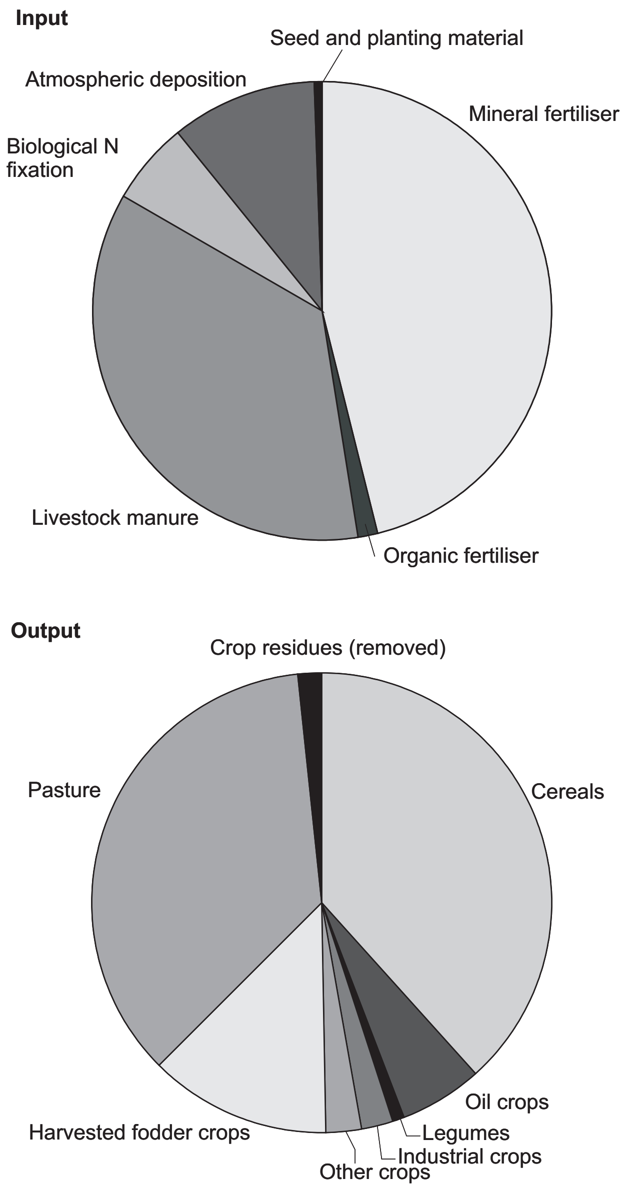

Figure 1:

Proportional share of N input and output variables on the N balance (average 1992 to 2006)

Nitrogen coefficients

Coefficients used for national balances are provided by the German Fertiliser Application Ordinance (MVV, 1996; DüV, 2007). These published values are derived from various sources like the German Agricultural Society (DLG) who publishes for example coefficients for N contents of animal manure (DLG, 2005).

Uncertainties in the balance are caused by the following inconsistencies when using N coefficients: (i) reported N coefficients are not congruent with the classification of variables and (ii) N coefficients are modified by revised legislations.

Examples for the non consistency between N coefficients and variables as classified by the OECD code are:

- Differentiation of the OECD variables into male and female cattle (1 to 2 yrs) is not matched by the German N coefficients (MVV, 1996) which are segmented depending on the feeding management, like for example grassland or forage cropping.
- The Fertiliser Application Ordinance (MVV, 1996) differentiates the N coefficients for cereals further than the variables of the OECD code are classified. For example, the barley production is summarized into one variable but German N coefficients for winter barley, malting barley and feeding barley are reported with 17, 14 and 17 kg Mg^{-1} N, respectively.
- The OECD code differentiates only between temporary and permanent grassland, whilst the German Fertiliser Application Ordinance (MVV, 1996) separates further into the number of annual grass cuts.

Changes of coefficients in the German Fertiliser Application Ordinance result also in inconsistencies when balances are calculated with the emphasis to evaluate long term trends. This is actually the case with the newly published Fertiliser Application Ordinance, coming into effect 2007 (DüV, 2007). The presented results are calculated using the coefficients of the former Fertiliser Application Ordinance (MVV, 1996). Comparisons of N balances calculated with the same statistical input data but old and new coefficients showed, that the gross N soil surface balances from 1992 to 2006 would have been in average 3.8 kg ha^{-1} N lower when calculated with the newer coefficients. This poses the question how to proceed after changes in the coefficient library especially when balances over long time periods are compared and interpreted. It can be expected that, on grounds of changes in crop varieties, cultivation and management practices, several adoptions of coefficients will have been taken place over the last decades. It is therefore questionable, if actual coefficients can be used for longer time periods. In cases when different coefficients for certain time periods are used, it is necessary to quantify the changes and to comment these in the interpretation of the balances. Otherwise changes in balances can be misleading and the use as evaluation tool for policy measures is restricted. The second possibility would be to use the actual coefficients in retrospective. This would also need to be commented in the balance interpretation. Both methods are obviously unsatisfactory, but unavoidable when longer time series will be studied.

A further critical point is the comparison of OECD balances internationally caused by the differences in N coefficients of the member states. The OECD therefore enforces a harmonisation of the coefficient library as far as possible, but this task is still in process. An absolute agreement will probably not be achieved because of regionally specific influences on the coefficients.

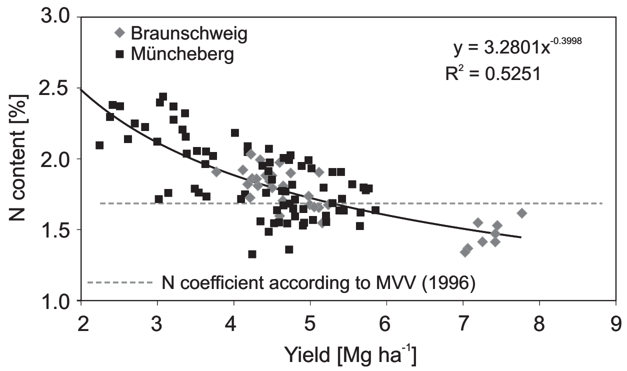

Figure 2:

Relationship of yield and N content of spring feeding barley derived from long-term field experiments in Müncheberg and Braunschweig, Germany, 1976 to 2005

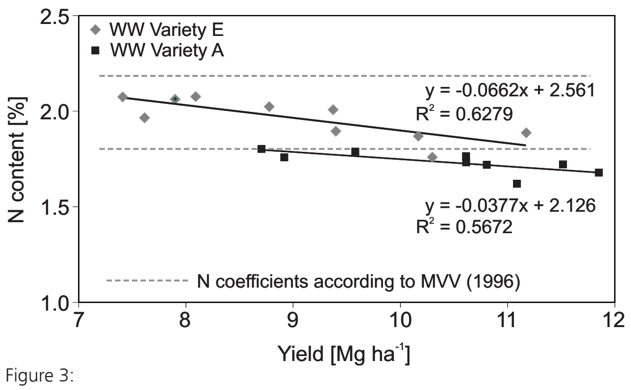

Figure 3:

Relationship of yield and N content of two winter wheat varieties in Clauen, Germany 1995 to 2007. The data was provided by the Federal Office of Plant Varieties in Germany and derived from the variety testing database

Additionally, it has to be clear that coefficients are generally mean values agreed on and can vary substantially for example between regions, years, fields, varieties and fertilisation management. Figure 2 demonstrates the dependency of N content in spring feeding barley and yield level. It can be seen that with increasing yield the N content of spring feeding barley grain decreases. Obviously, a single N coefficient used for the calculation of N balances can not comprehend the variability of grain N contents. This can also be seen in a second example when comparing two winter wheat varieties (Figure 3). As expected are the N contents of variety A lower as of variety E. Figure 3 also confirms that winter wheat yield and the N content of grain are correlated negatively.

Considering the variety and nature of the above mentioned uncertainties it can be concluded, that some of these could be improved like for example the annual data availability. Others will always be a compromise and agreement of common knowledge, like N coefficients. Because of these uncertainties it is most important that the calculation of nutrient balances is kept as transparent and open as possible to allow users of the balance insights into the calculation parameters.

Gross soil surface nitrogen balance for Germany 1992 to 2006

The gross soil surface N balance was calculated for the years 1992 to 2006 (Figure 4). Therefore the results exclude issues like the above mentioned influence of the altered N coefficients of the new legislation (DüV, 2007). Further, the incomparability of statistical data compiled by the two former German countries until 1989 and the transition years of 1990 and 1991 are irrelevant. Data in nutrient balances always refers to the agricultural land use area (AL).

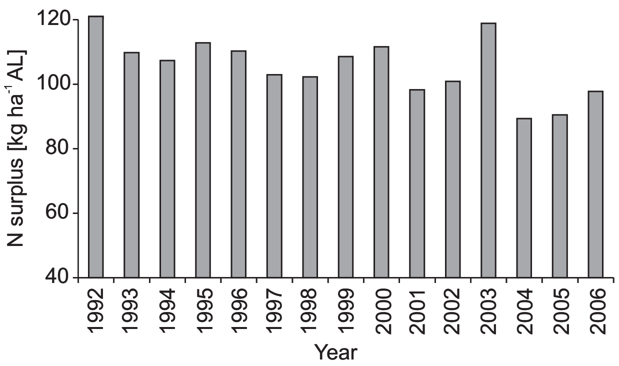

Figure 4:

Gross soil surface N balance for Germany 1992 to 2006 calculated according to the OECD method

During this 15 year time period the agricultural land use, including arable land, permanent crop land and permanent pasture (Table 2) was reduced from 16,950,072 to 16,939,300 ha, which equals a reduction of less then 0.1 %. The annual N surpluses show a slight overall declining trend, hence with constant outliers. The year 2003 had an exceeding high N surplus, which was caused by unusual weather conditions. While the years 1999 to 2003 were classified as too wet, the summer of 2003 was exceptional hot and dry. Average weather conditions at the beginning of the year supported farmers to average nutrient supply, but the hot and dry weather throughout Germany during the summer resulted in high yield losses (Figure 5) which returned the high N surplus.

Whereas the yearly fertiliser and manure application are controlled by the farmers and based on average yield expectations, the subsequent yield depends on weather conditions and is therefore difficult to predict. Because of this, long term trends are much more reliable than single or short term calculations and therefore the only source to verify policy measures.

The results of N balances are in regards to input variables mostly affected by the amount of mineral fertiliser and manure application. Nitrogen deposition is accounted for with a constant factor and the N input from sewage sludge, urban compost, biological N fixation and seed and planting material contributes in average only a small amount with together about 18 % (Figure 1). The changes in N input by mineral fertiliser and livestock manure in kg ha^{-1} from 1992 to 2006 are shown in Figure 5.

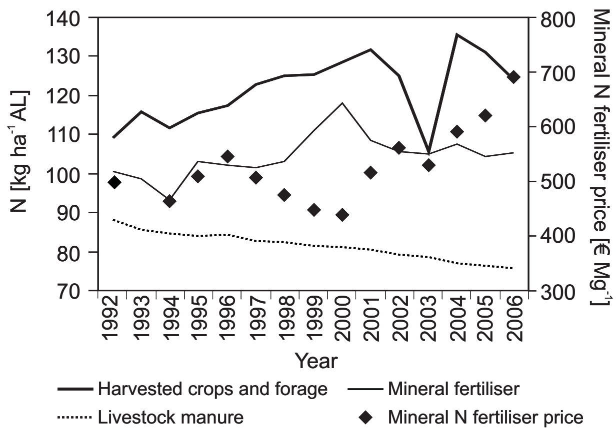

Figure 5:

Changes of the N input variables mineral fertiliser and livestock manure, the N output variable harvested crops and forage and the mineral fertiliser price from 1992 to 2006

The amount of livestock manure and therefore N input with manure decreased during this time period, caused by a decrease in total animal production (Figure 6). While the manure production of pigs, sheep and poultry remained on a constant level, the number of cattle was reduced from 16,207,340 head in 1992 to 12,676,800 head in 2006. Nevertheless, cattle manure contributes 22 % N as input to the balance. The sales numbers of mineral fertiliser varied for the same time period between 93 and 118 kg ha^{-1}. Mineral fertiliser application rates are influenced by a number of factors. Besides the implementation of good agricultural practice it can be seen that for example mineral fertiliser prices bias the application rates. This is obvious for the year 2000, for which higher fertiliser application rates are correlated to lower prices of mineral N fertiliser (Figure 5).

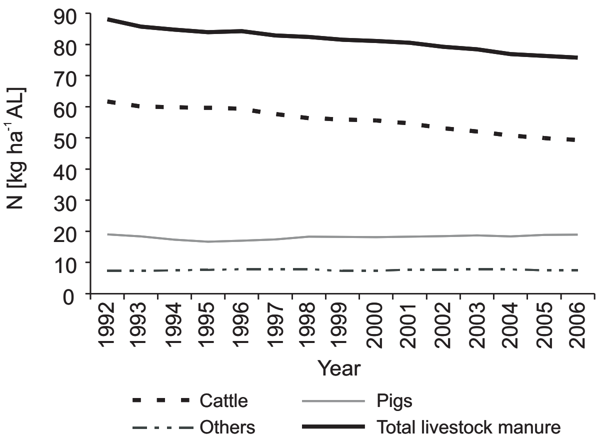

Figure 6:

Changes of the N input by total livestock manure as well as split for cattle, pigs and others (sum of sheep and goats, poultry and horses) from 1992 to 2006

Implementation issues of soil surface nutrient balances

Langeveld et al. (2007) summarized that agri-environmental indicators (AEIs) should (i) refer to relevant issues, (ii) be based on sound science, (iii) be quantifiable, (iv) be relevant for target groups involved, (v) be easy to interpret, (vi) be cost-effective, and (vii) facilitate communication. These demands will be used in the following as a guideline to evaluate the gross soil surface balance approach as AEI for Germany on the national level and in the context of international comparisons like between OECD member countries.

Based on the knowledge about the potential risk nutrient surpluses impose on the environment and natural resources like for example soil and water, the quantification of this risk is a relevant task. Obviously, to ensure that risk assessments based on nutrient balances can be reliable, the science should be sound. Unfortunately, national nutrient balances will always be a compromise. Besides of the lack of statistical data for certain variables or years, the N coefficients used are not able to reflect regional distinctions between land use and management practice, varieties used or annual variations caused by weather dependent yield fluctuations. Two main issues arise from the used coefficients. First, because nutrient balances need to be calculated over longer periods to be meaningful, changes in the coefficient library caused by changes of coefficients in official data bases can result in inconsistencies of the calculations. Second, if national balances are used to compare countries, like it is the case with the OECD balances, different coefficients are used in the calculation of different countries. This poses some risk in the interpretation of national balance in an international context. Therefore the OECD aims to define a common coefficient library, but this is not yet available.

Nutrient balances are a tool to quantify nutrient surpluses and they can be used to demonstrate trends in the development over longer time periods. Nevertheless, because of the lack in data and coefficient availability and accuracy the absolute N surplus calculated comprises a high uncertainty which is difficult to overcome. On the contrary the comparison between years calculated with the same method can be evaluated considering weather conditions, prizes for fertilisers and crops as well as policy measures introduced. Cautious interpretations and conclusions can be drawn if all influencing factors are considered.

National nutrient balances are one of the AEIs relevant for policy makers and researchers and build the base to communicate developments in environmental performance and to perform risk assessments. Farmers need to compile their own nutrient management plans to ensure that they comply with the German Fertiliser Application Ordinance (MVV, 1996; DüV, 2007) and to assess the applied fertilisation strategy. Quirin et al. (2004) discussed the use of these farm and field related balances. The costs to calculate national nutrient balances are moderate after the sources for statistical data and coefficients are explored, the calculation method is adopted and adjustments of the method to the available data are made. As long the statistical data base and coefficient library are not altered the annual update of the balance involves only an extension of the data input and can be considered as minor.

Because of the uncertainties inhered in the calculation of nutrient balances it is inevitable to keep the calculation procedures as well as input and output data as transparent as possible. On base of this insight into the calculation a sound communication between users of nutrient balances is possible. Even though, this bears the risk that instead of focusing on much-needed solutions to overcome nutrient surpluses or deficits, discussions around insufficient databases and coefficients develop.

Conclusions

Gross soil surface nutrient balances are influenced by numerous uncertainties in the data base and the coefficient library. To be able to use nutrient balances as AEIs it is essential to be aware that the absolute balance values do not mirror the actual situation in a country. Nevertheless, in case that a consistent method of balance calculation is used for all years a comparison between these years to derive trends in nutrient surpluses or deficits is possible.

Finally it can be followed the conclusion of Langeveld et al. (2005), that gross soil surface balances should be used with care and that always be kept in mind that indicators are simplifications of complex and variable processes.

Acknowledgement

We are most grateful for the data from the variety testing database provided by the Federal Office of Plant Varieties in Germany.

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Good, but not good enough? Research and development needs in Organic Farming

Gerold Rahmann*, Rainer Oppermann*, Hans Marten Paulsen* and Friedrich Weißmann*

Abstract

With the development of independent production concepts and emergence from its agricultural niche status, organic farming has fulfilled its promise to a large extent. Organic agriculture has also become a recognized part of the agricultural world - not only in Germany - and retains a very positive image. Against this background, predictions of further growth are not just wishful thinking.

In recent years, now that organic agriculture has matured, it has been confronted with more intensive questioning by the public, consumers and conventional farmers on actual yields and their sustainability (Niggli, 2005). Also, new questions (i.e., climate change, food security, globalization) have emerged or play a more important role than they did several years ago.

In this context, it is imperative that organic farming deal with its problems and deficits in a sober, pro-active and self-confident manner. Due to the diversity of structures and problem situations, general evaluations make no sense. Nonetheless, from a research perspective, they permit the basic topics and lines of discussion to be identified.

In the opinion of the authors, the development of organic farming is too closely tied to certification regulations and too far from trying to achieving organic farming goals. The limitations of the guideline-oriented monitoring and certification of organic farming are not adequate for a comprehensive check of the self-set goals. For this reason, a further development of certification beyond the goals and targets met would make sense. Here research can help to find the decisive indicators.

Keywords: Organic farming, principles, R and D

Zusammenfassung

Viel erreicht und doch nicht genug? - Forschungs- und Entwicklungsbedarf für den Ökologischen Landbau -

Der Ökologische Landbau hat konzeptionell viel versprochen und tatsächlich hat er in der Vergangenheit viel geleistet. Er hat ein eigenständiges Produktionskonzept entwickelt and die Nische verlassen. Der Ökologische Landbau ist – nicht nur in Deutschland – zu einem anerkannten Bestandteil der Agrarstruktur geworden and verfügt über ein sehr positives Image. Vor diesem Hintergrund ist es keine Wunschvorstellung, ihm weiteres Wachstum vorauszusagen.

In den letzten Jahren ist der Ökologische Landbau, indem er zur Normalität gereift ist, jedoch auch intensiver Fragen der Öffentlichkeit, der Konsumenten und auch der konventionellen Kollegen ausgesetzt, die sich auf die tatsächlichen Leistung und ihre Belegbarkeit beziehen (Niggli, 2005). Hinzu kommt, dass neue Fragen (unter anderem Klimawandel, Welternährung, Globalisierung) aufgetaucht sind oder sich brennender stellen als noch vor einigen Jahren.

In diesem Kontext ist es für den Ökologischen Landbau unerlässlich, sich mit den Problemen und Defiziten nüchtern, engagiert und mit Selbstbewusstsein auseinander zu setzen. Angesichts der Vielfalt der Strukturen und Problemlagen sind pauschale Bewertungen unsinnig. Dennoch lassen sich mit Blick auf die Forschung einige grundlegende Themenschwerpunkte und Diskussionslinien benennen.

Nach Einschätzung der Autoren wird die Entwicklung des Ökologischen Landbaus zu sehr von der Einhaltung der Richtlinien und zu wenig von dem Erreichen nachhaltiger Ziele dominiert. Die Beschränkung auf richtlinienorientierte Kontrolle und Zertifizierung des Ökologischen Landbaus reicht nicht zur umfassenden Überprüfung der selbst gesetzten Ziele Aus diesem Grund ist eine Weiterentwicklung der Zertifizierung über die erbrachten Leistungen und Ziele sinnvoll. Hier kann die Forschung helfen, die entscheidenden Indikatoren zu finden.

Schlüsselworte: Ökologischer Landbau, Prinzipien, F und E

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1 Introduction

Organic farming has developed enormously in the past, not only in Germany but all over the world (Willer and Yussefi, 2008). In many cases it has emerged from its niche. It also serves as a model for sustainable agriculture for many people. In some spheres, conventional agriculture even has adopted concepts from organic farming. Despite the worldwide success, organic farming has no reason to sit back and stop developing. Without doubt fundamental progress has certainly been achieved in the past years, but on the other hand, some new development problems have emerged and deficits have become clearer. These problems are above all related to the question of how organic farming stands as measured against its own high goals.

Up until today, it has not been systematically studied in how far the 30-year-old goals (IFOAM, 1980) have been achieved (Gerber et al., 1996). The basic goals of organic farming, above all the goals of environmental protection, animal welfare and healthy foods, are truly demanded by consumers and the public. Even if much of this is merely based on general expectations based on general consumer awareness, and not based upon differentiated knowledge of agricultural production processes, these expectations are the basis of the sector's image and thus a basic requirement for marketing. One always has to keep in mind that trust is only generated, and consumers only willing to pay a higher price for organic products, because a large group of consumers welcomes the goals of organic farming and believes that they can be implemented by farmers. Furthermore, the goals of organic farming are also the starting point for manifold societal expectations on organic farming, in particular with regard to natural protection and the preservation of the natural landscape. Whether the great public trust in organic farming is justified, is one reason that evaluation is of great importance. And here some doubts have sprung up in the past. They even have led to uncertainty in development paths among concerned actors (Braun and Plagge, 2008). For example, the BNN, an association which represents organic food processors and traders in Germany, published a Codex (set of guidelines) in 2008 in order to strengthen the traditional catalogue of organic farming objectives (BNN, 2008). The competition with the conventional food chain is obvious.

With the market successes on the one hand, and with old, as well as some new, challenges on the other hand (food quality and quality assurance, climate change, globalization, securing world nutrition, biodiversity, strengthening endogenous rural development, income security for farmers), it must also be considered which potential organic agriculture truly has within the general framework of conditions and challenges that are valid for the whole of agriculture. Agricultural sciences should certainly be the first to raise these questions (Alrøe and Kristensen, 2002; Watson et al., 2008).

The following evaluation and suggestions refer to the situation of Germany. With our contribution an attempt is made to evaluate the development of organic farming on the basis of the original basic principles of organic farming. Here the results available from the research and development projects of the German Federal Program for Organic Farming (www.bundesprogramm-oekolandbau.de), as well as publications in the database http://orgprints.org, were used for database searches. Requirements for research and development of organic farming are derived. The suggestions do not lay claim to completeness, but the selected topics in the following are, in our opinion, absolutely representative of organic farming. Processing and trading of organic products is not considered.

2 Organic Farming – its Vision

Organic farming[1] is based on the idea of practices that are environmentally friendly, animal welfare oriented and geared toward improving the living conditions of farmers. To strive for close-to-nature farming is a central piece of the farmers' own concept.[2] Beyond agricultural practices and their technical and economic bases, organic farming was and is a life model and thus includes important aspects for social reform.[3] But these ideas are in part very complex and far reaching, and in part very concrete and tied to individual forms of working and living. It is therefore difficult to present a complete list of guiding principles which are understood and accepted by all actors in the same way. Even some eclectic traits are undeniable.

In the beginning organic farming started without public support and without any access to public financial resources. The pioneers promulgated organic farming as an alternative model to intensive, specialized and partially industrialized – "anonymous and soulless" – food production (Rusch, 1968; Meadows et al., 1973; Krieg, 1981, Brand, 1985). From the perspective of the participants this was a fully acceptable and comprehensive critical attitude which could be integrated into the overriding field of so called "new social movements" (Heldberg, 2008).

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[1] The term „organic farming" is imprecise since it is used for both the production of food as well as off-farm processes (farm inputs, processing, trade, consumption).

[2] Defined by the International Federation of Organic Agriculture Movements (www.ifoam.org).

[3] Politically, ecologically and socially oriented activities, such as for example the support of anarchist, feminist, pacifist and spiritual groups, demonstrations against large industrial or infrastructural facilities (nuclear power plants, airports, etc.). Activities in NGOs like one world and environmental protection groups was important. Organic food production was one part of the activities.

The German-speaking area (Germany, Switzerland, Austria) was and is one of the most important regions of origin and development for organic farming. Even before the First World War, people started to find alternatives to "chemical food production," particularly in gardening. For example, in 1893, some vegetarians established the Eden settlement (orchards and gardens) close to Berlin as one of the living reform projects (Lebensreform-Bewegung). In 1924, the agricultural course of Rudolf Steiner (*1861; † 1925) motivated a group of farmers to follow new paths of food production. Biological dynamic farming was developed from this with the Demeter Association. Agricultural reform policy, especially in defending small scale farms and rural traditions, was also evident.

Organic farming was further developed after the Second World War by Hans Müller (*1891; † 1988), his wife Maria (*1894; † 1969) and Hans-Peter Rusch (*1906; † 1977), and served as inspiration for the largest German organic farming association Bioland, founded in 1971.[4] Particularly in the 1970s and 1980s, farmers, and a number of non-farmers ("city refugees") - the latter often with no specific agricultural knowledge or resources - began to produce food for self-sufficiency or for small local (regional) markets (Seymour, 1973).

Sometimes even regarded as "social dropouts," many of them lived in communities and practiced an alternative and often altruistic lifestyle. Self determination and self realization were central spiritual goals combined with a disdain for economic interests. The economic exchange relationships normally were personal and direct. Products were sold from farm to farm or hand to hand, or in some cases traded on a restricted level. In the cities, food coops were started, organic stores opened and farmers markets created (Heldberg, 2008). In the beginning, these living and working forms were hardly more than tolerated in village communities. Examples of integration were rare (Baeumer, 1986).

The period in which development goals targeted at integration in the total economy began later. One has to go back to the late 1980s and the early 1990s to identify professionalisation and market oriented strategies at a strong level (Oppermann, 2001). But within a decade, competitive infrastructures were built up (pre and post harvest facilities, marketing, trade, certification, monitoring) (Heldberg, 2008). Economic success was set as a prerequisite for a blossoming development of farms and the improvement of the own living conditions, and in this context, the importance of esoteric or social Utopian images and behavioural standards reduced significantly. Since about the year 2000, production and processing were developed further on the basis of a systematic inclusion of research and professionally bundled development experiences.

3 Evaluation of the IFOAM-objectives from 1980

Organic agriculture is considered an environmentally sound and socially acceptable land use system with "natural" food production (FAO, 2000). Different studies in the 1990s confirmed the high production and processing quality of organic farming in contrast to conventional farming (compiled in Tauscher et al., 2003; Schnug et al., 2006).

In the last decade organic farming has left its niche and is spreading worldwide. Organic farming is a food production label and is becoming more and more popular throughout the world (Organic Monitor, 2008). In 2007, about 32 million hectares were certified according to organic standards and the world market volume was 46 billion US-$ (Willer et al., 2008). The EU and the US are the biggest markets with an annual growth of 10 to 20 %.

Nowadays, organic production and its certification system are seen as the best monitoring food production chain (www.bmelv.de).[5] In the areas of food quality, for example, pesticide residues are found in conventional products more often than in organic products (Baker et al., 2002; www.n-bnn.de). The low contamination risks of organic products are an important reason for consumer choice and market success.

Today, organic food production is clearly defined with legal standards and regulations. The EU Regulation 2092/91 gave mandatory standards and guidelines for the entire EU and for importing third countries. Since the beginning of 2009 regulation schemes were reformed and replaced with Regulation 834/2007 and the implementation regulation 889/2008. These regulations integrate goals for organic agriculture (834/2007 §3 ff.). Non-food products (i.e. textiles, cosmetics, building materials, medical substances) have not been implemented yet. Private standards for these products have, however, been set (see IFOAM Basic Guidelines, www.ifoam.org).

The evaluation shall – strikingly and certainly incompletely – be done on the basis of the IFOAM principles from 1980. This evaluation is justified because the new EU Organic Regulation 834/2007 – which since 2009 the previous "untargeted" EU Organic Regulations 2092/91

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[4] There were also other people inspiring organic farming outside of the German speaking countries (including Albert Howard (*1873; † 1947) and Eve Balfour (*1898; † 1990)). The history of organic farming was compiled by Vogt (2000).

[5] Cases where conventional products are renamed and sold occur now and then. Most cases are discovered by the organic farming monitoring system itself.

replaces – sets similar goals. This shall be addressed in the subsequent research and development requirements. The discussion about the research needs for the further development of organic farming therefore should not last start with the acknowledgement of some clearly identified deficits (Watson et al., 2008).

3.1 IFOAM-objective: Work as much as possible in a closed system and rely on local resources

A basic principle of organic farming is to work in cycles and to use local resources in the entire processing chain. For a long time this goal was the core of the concept. One of the greatest achievements of organic farming was the re-integration of crops and animal husbandry through the cycle of fodder crops and the manure fertilization. This has been lost in conventional farming in the non-land related intensive animal husbandry.[6] Stock densities (max. 2 livestock units per ha) limit the number of livestock on the farm to avoid ground water contamination with nutrients.

This cyclical concept has lost significance in current practice. In today's organic farming mixed farms are losing importance (Rahmann et al., 2004). Supra-regional and partially globalized input and output markets form a strong trend in the external economic relationships of the farms. The most striking example is feed import (i.e.. organic soy) and manure export (to other organic farms). Today, organic farmers are delivering their products to wholesalers trading on national or international markets. Also the local consumption of locally produced organic products has lost ground. A strong shifting of weight between the marketing paths towards centralized concepts with dominating top-down approaches has to be acknowledged. The nationally and internationally organized food dealers (including discounters) are already at the peak with a market percentage of nearly 60 %,[7] while direct marketing and the trade marketing via bakeries and butchers are continuing to lose on percentage of sales (ZMP, 2008). The recycling of nutrients from consumers back to farms is not possible.

Evaluation: Closed cycles in production and more regionally oriented structures in sales and consumption of food products are apparently not competitive today. The cyclical concept and the local or regional relationship to farm inputs have lost importance.

6 Also for conventional animal husbandry today a linkage to land area is demanded. According to the German Fertilization Regulations (DüV from February 17, 2007) all farms can only hold so many animals that they maximally distribute 170 kg N manure fertilizer per hectare and year. This is in accordance with the requirements for organic farming and is thus no longer a criterion for differentiation.

7 In other EU countries and the US the share of discounters and large retailers in organic food marketing is even higher.

Research and Development needs: *As the antipode to global competitiveness (food sovereignty, rural development) due to increasing transportation costs, ecological advantages and risk minimization (disease, contamination, etc.), local or rather regional cycles are of new importance. Above all there is a strong need for research on economically sustainable concepts for farm, local and regional food cycles. For this purpose, locally adapted as well as efficient production technologies and products must be developed. Target group oriented marketing and product innovation are of particular interest in this domain.*

3.2 IFOAM-objective: Maintenance of long term soil fertility

Soil fertility is determined by water, air, temperature, nutrient level and organic carbon levels of the soil. Biological and physical factors must be stabilized in organic farming to a level that makes good and sustainable plant growth possible. The addition and mobilization of adequate nutrient amounts in addition to a stabilized soil structure are required for the yield development. If no organic fertilizer is available with which the nutrient transfer from grassland or from animal husbandry in other farms can be attained, the planting of legumes in the crop sequence is essential for an adequate input of nitrogen.

The decrease of soil fertility is due to cropping practices that do not follow these principles over a long period of time. Increasing cereal cropping in organic crop rotations and the reduction of grain legumes (Gruber and Tietze, 2008; Zöllner, 2008) is critical with regard to humus production, above all in pure crop farms. The nutrient cycles are broken with the export of the products (see above). Thus, after a while, the soil fertility decreases through a loss of nutrients such as potassium, phosphorous and trace elements (Watson et al., 2002; Stolze et al., 2001; Newmann, 1997). The use of sludge and household compost (Adam et al., 2008; Pinnekamp et al., 2008) is, however, not permitted in organic farming, since it could be contaminated with undesirable substances (Kratz and Schnug, 2006). Other purchased fertilizers are usual in organic agriculture today, particularly in vegetable crops. An increasing portion comes from non-renewable sources (i.e., crude phosphates, peat) or from risky conventional sources (i.e., medicinal residues in feathers, blood and horn meal). Their availability is either limited and/or not sustainable (Schnug et al., 2003; Déry and Anderson, 2002). Consistent analyses on the on-farm value of biogas substrates for the maintenance of the soil fertility and the reduction in the nutritional losses in organic farms were until now not decision-making criteria for the building of biogas facilities and are not consistently analysed.

Consistent organic fertilizing and diverse crop sequences promote the stability of soil aggregates (Munkholm et al., 2002) as well as the infiltration ability of soil (Rogasik et al., 2006). The specialization and expansion of organic farms also leads to higher wheel load through larger machinery. Impacts on the soil fertility can be expected.

Evaluation: Soil fertility remains a central challenge of organic farming. It is dependent on crop rotation management and the return of nutrients to the soil. Here the negative consequences of non-closed nutrient cycles between production and consumption are particularly evident. The trend towards heavy machines has a negative impact on soil texture.

Research and development requirements: *For the long term conservation of soil fertility, local nutrient cycles must be optimized and nutrients must be used efficiently. Possibilities for cooperation concepts beyond individual farms strongly have to be taken into consideration. The drop in legume cropping must be counteracted. An efficient use of the green growth linked nutrients must become a central part of inner farm management. For the return of non contaminated sludge and compost (or the nutrients won from them) in the production cycle, technical and structural solutions should be developed so that possible risks can be excluded. Research on these possibilities must also concentrate on the conditions of social acceptance and cooperation between farmers. Further soil compaction should be avoided and reduced with farming concepts and crop planting measures. Here, soil conserving tillage processes, and mechanical and biological processes to eliminate compaction, must be found (Munkholm, 2005). The attractiveness of clover grass cropping and the improvement of nitrogen and humus supply linked to it could be strengthened with the inclusion of biogas facilities in organic commercial farms (Stinner et al., 2008).*

3.3 IFOAM-objective: Avoiding any type of pollution through agricultural technology

Most of the great environmental problems of conventional agriculture can be traced back to the use of pesticides, easily soluble mineral fertilizer and too dense animal populations. Thus, biodiversity, as well as abiotic resources, are endangered (soil, air, water), and in part food as well (pesticide residues in fruit and vegetables). That is why one of the central concerns of organic farming is to avoid these inputs. The lower production yields are accepted. The fears that the product qualities are lower have been not confirmed (Meier et al., 2000; Ellner, 2000; Döll et al., 2000; Obst et al., 2000; Backes, 1998; Marx et al., 1995; Usleber et al., 2000; Paulsen and Weissmann, 2002; Paulsen et al., 2004; Oldenburg et al., 2008).

Some pesticides are allowed in organic farming, i.e., copper and natural substances. The main problem is the use of copper in fruit, potato, grape and hop crops. According to the organic regulation 889/2008, 6 kg copper are allowed per ha and year, the private organic farming associations have restricted themselves to 3 kg. An accumulation which is toxic for the biodiversity can nonetheless occur with the low levels and thus may not be ignored. Even if through the copper input much less pollution can be assumed as in the pesticide use in conventional farming, one cannot be satisfied with this pollution (Kühne, 2008). Long term convincing solutions have still not been found.

In addition to fungicide alternatives and natural insecticides (i.e., Neem and Pyrethrum preparations) natural herbicides are under research and development (Verschwele, 2005). Particularly weeds such as thistle and dock and grasses like wind bent grass and couch grass present enormous problems in organic farming in Germany. Mechanical, pesticide-free management is very difficult or expensive (Böhm et al., 2004). The development of herbicides in difficult environments (i.e., tropical soils) does not conform to the principle of preserving biodiversity and has until now been prohibited in organic farming regulations ("conventional approach"). On the other hand, discrepancies can be seen in influencing of wildlife by harrowing and hoeing for mechanical weed control in organic farming. Ground breeders (Hötker et al., 2004) and small mammals are endangered and an adapted field management is required. The strategy of the stabilization of agrarian ecology to avoid external plant protection inputs is difficult. The application of pesticides with a field sprayer would nonetheless be tied to a negative image in uninformed consumers ("sprayers are bad").

Due to the refusal to use easily soluble mineral fertilizer, the water pollution of organic farming is, in principle, less than in conventional farming (Köpke, 2002). Erosion of soil without vegetation is also an increasing problem in organic farming. Nitrate pollution is still possible in organic farming through the autumn ploughing of clover grass (biomass with a lot of nitrogen). In frost free winters with much precipitation, nutrients will also be leached from organic farming if no catch crops are planted after ploughing. Here, also, special management options should be used to minimize nitrogen effluxes. A comparison of organic and conventional cultures should take into account that clover grass comprises only part of the agriculturally cultivated land. A correct consideration must take the crop sequence, the farm level, or a budget per product level used as unit for ecological indicators.

Animal medications also pollute the environment (Winckler and Grafe, 2000). The prohibition of preventive animal treatments and the prohibition of hormones and yield-increasing medications lead to lower pollution than in conventional animal husbandry. But conventional husbandry has achieved significant improvements in the past years (mostly through legal prohibitions). Pollution could come from yards and pastures of organically raised animals (noise, odour, water pollution with faeces, local climate gas emissions). On the other hand, pasture husbandry is an important instrument for animal protection, landscape, biodiversity, water protection and for humus protection and carbon sequestration. Here organic goals compete with each other, and optimization concepts must be sought that are not only oriented on a single goal. Complete life cycle analysis's are demanded. Above all this holds true for improvements in yard, pasture and fertilizer management.

Current critique of the environmental compatibility of organic animal husbandry is due to negative climate impact (Foodwatch, 2008). In the field of climate relevant emissions, the discussion centres on a basic interrelationship to ecologically conforming housing systems and a correlation of feeding (or rather, nutrient offering) and animal performance (Hirschfeld, 2008; Sundrum, 2002; Williams et al., 2006).

Evaluation: Pollution through organic farming is less than in conventional farming due to the foregoing of artificial pesticides, and most easily-soluble fertilizers, through smaller herd size (livestock per ha) and the restrictive use of animal medications. The foregoing does however lead to significant drops in production (lower area yields and animal productivity). Several studies show that organic farming has less impact to the green house effect than comparable conventional farms. Nevertheless, organic farming can pollute the environment as well. Problems also exist in the further use of copper as fungicide, nitrate leaching and the climatic impact.

Research and Development Requirements: The production (productivity, efficiency) must also be increased in organic farming without increasing the risk of environmental pollution. Research must develop improved, environmentally-sound practices in crop and animal farming. The use of copper must be reduced (avoided) and better methods for health maintenance, or disease/parasite as well as weed control must be developed without losing sight of organic stability (avoiding "conventional" strategies: external input-related solutions). Indoor and outdoor husbandry must be optimized and analysed in terms of environmental impact and performance.

3.4 IFOAM-objective: Producing enough food of high nutritional quality

Organic agriculture is also suited to cover the increasing need for food for a growing world population. Decisive is the question of whether additional food needs will truly be covered by the further intensification of high input systems, or whether the existing low input systems (about half of all farms and areas on earth, above all in developing countries and subsistence economies, FAO, 2007) can be improved technically and in their management practices. In low input systems with very backward technical ability, or management deficits, a production increase of 20 to 50 % is possible by following the guidelines for organic agricultures. Also in medium input systems or in regions with long summer droughts, the yield differences between conventional and organic systems are "only" 0 to 20 % (Pimentel et al., 2005; Mäder et al., 2002). In high input systems in the better climate areas of central Europe, the yields in conventional farming are, as a rule, 30 to 50 % higher than in organic farming (Badgley et al., 2007). Here organic farming will not be able to achieve the yields of conventional farming as long as they can use high energy inputs to a broad extent.

It has until now not been proven that organic foods are healthier, or rather that they can be differentiated from conventional products (Kahl et al., 2007). But the risk of contamination with undesirable substances (heavy metals, pesticides) is generally less in organic products than in conventional products which, for example, has been shown for years in studies by the public food monitoring agency in Baden Wurttemberg and trade organizations as well as market tests by Greenpeace, Foodwatch and Ökotest (FQH, 2005). Not all organic products are absolutely free of pesticides. (Monitoring data can be found under www.bvl.bund.de).

The rejection of genetic modified organisms in organic farming and the significant monitoring mechanisms tied to this create a meaningful quality factor for customers who reject products with GMOs. This is a steadily increasing differentiation factor with a view to product quality in comparison to conventional products. Furthermore in animal and plant production, organic farming relies to a large extent on conventional breeding practices which do not meet many of the original organic farming ideas (land varieties, local breeds). Conventional strategies like CIS-genetic breeding and gene mapping are discussed in organic farming. Independence from conventional breeding systems is not possible yet but necessary in the future to keep the label of GMO-free and develop adapted varieties and breeds for organic farming. The organic sector is too small for companies to go the way of organic breeding.

Evaluation: The production performance and increases lag behind that of conventional farming. But, measured on the outset conditions, it can also be seen as positive that organic foods today also achieve the same product quality as conventional food products, although the trading classes for the latter are firmly established. Proof that there are fewer negative ingredients in organic products exists, while proof of positive ingredients is not significantly available. GMO-free products have become a core image for organic products. There is still a dependence on conventional strategies and systems (i.e., breeding) that is increasingly going the way of GMOs or related techniques.

Research and Development Requirements: *The production yields per hectare and the animal performance must be increased in organic farming. Productivity and efficiency oriented concepts require more consideration. For this reason new crop and husbandry concepts must be developed without leaning on genetic engineering and conventional breeding structures. In animal and plant breeding, the limits and level of tolerance of organic farming for breeding methods must be defined and clarified (i.e., gene mapping, CIS-genetics, artificial insemination). The product quality must be further improved. The presence of positive ingredients has to be assessed. New expectations of consumers and behavioural patterns of different target groups must be considered. Animal nutrition must be improved in order to achieve better product quality and animal welfare. Organic trade classes must be developed to avoid conventional production strategies for conventional product standards.*

3.5 IFOAM-objective: Reducing the input of fossil fuels in agricultural practice to a minimum

In a study for the Enquete Commission of the German Parliament, "Protection of the global atmosphere," Haas et al. (1994) compared the energy input per hectare for typical and comparable organic and conventional full-time farms. Here a 65 % lower energy use by organic farms was found, particularly through the refusal to use high energy produced synthetic nitrogen fertilizer and plant protection substances (organic: 6.8 GJ ha^{-1} a^{-1}, conventional: 19.4 GJ ha^{-1} a^{-1}). The land relations must be critically viewed in this case since the production levels achieved in organic farming are lower (see above). In a production related evaluation organic farming does not always fare as well. Energy hungry production systems are above all greenhouse cultivation as well as pig and poultry fattening (Rahmann et al., 2007). In organic farming there is also a trend toward stronger mechanization linked to an increase in fuel input per hectare (with sinking use of fuel, for example, in the minimal tillage in conventional farming).

Evaluation: Organic farming needs less fossil energy than conventional farming because mineral fertiliser and chemical pesticides are not used. Nevertheless fossil fuel per ha to run the farm machinery can be above the conventional level. However, there are still exceptions and on the part of conventional farming, new, more energy efficient systems are developed (i.e., minimal tillage systems). Thus the advantage of organic farming is reduced. Systems for the production and use of renewable energies were often introduced very early in organic farms. But conventional farming has here followed suit and above all reached a positive position with large scale biogas facilities. But in this area, they generally show a series of negative ecological and economic consequences (i.e., landscape changes through maize monocultures, production competition "Table or Tank," increasing food prices).

Research and Development Requirements: *The use of energy saving technologies and regenerative energy must be developed and implemented in organic farming. The technical, social and economic impacts of regenerative energy production and energy saving strategies must be considered. Above all the chances for local or regionally optimized energy systems must be developed.*

3.6 IFOAM-objective: Providing farm animals with living conditions based on animal welfare and an ethical basis.

Animal protection is a central objective of organic farming and one of the most important purchase motives for consumers (Ökobarometer, 2007 and 2008). Since the Regulation 2092/91 (implemented with 1804/1999), many conventional animal husbandry practices (beak cutting, tail or horn removal, single animal housing, etc.) are either not permitted in organic animal husbandry or only allowed in exceptional cases. Animal medication shall not be given preventively and "natural healing practices" should be the priority in the treatment of sick animals.

The reality, however, often differs from the goals. The removal of horns from beef cattle is still broadly practiced (Rahmann et al., 2004). Hybrid poultry - bred for cage and intensive keeping - kept on organic farms often show severe difficulties in behaviour and health. Feather picking and cannibalism are still unsolved problems (Hörning et al., 2004; Berg, 2001; Fiks et al., 2003). Male chicks from laying hen populations are still killed instead of fattend. There are no races of poultry or double purpose breeds used because they do not fulfil the performance and production requirements of the farmers. Poultry is still kept in large flocks with several thousand animals in one barn.

An example for a conflict of goals is the castration of piglets in the range of unsolved problems or alternatives (i.e., pain alleviation, immuno-castration, breeding, sperm sexing, boar fattening) with impact on animal welfare (i.e., castration, keeping of boars), environmental aspects (i.e., climatic impact of anaesthesia), economic viability (i.e., production cost advantages, marketing sacrifices), consumer acceptance (i.e., consumer expectations, consumer protection) and meat quality (boar odour – tenderness, juiciness, low intramuscular fat content). The life performance of dairy cows is not higher and the animal medication input not significantly less than in conventional animal husbandry (Krutzinna et al., 1996; Brinkmann and Winckler, 2005; Sundrum and Ebke, 2005). The use of natural medications is the exception (Rahmann et al., 2004). The young animal losses in pigs are in fact much higher than in conventional husbandry (Löser, 2007).

As a rule, stables in organic husbandry offer more space for animals than stables in conventional agriculture. This makes sense from the perspective of animal welfare. There are, however, exceptions. The tethering of cows is still widely practiced in organic farms and can be maintained in small farms (< 35 cows). The target of the EU organic standards 2092/91 to terminate tethering was postponed to 2013 because of German organic farmer intervention. Further problems in organic cattle keeping: grazing is not obligatory and cereals are still the basis for milk production (40 % concentrates are allowed in the ration, 50 % in the high lactation phase).

Feeding of livestock is one of the most difficult problems. As a consequence of the BSE crisis, omnivore animals (meat and plant eaters like pigs and poultry) have been turned into pure vegetarians while maintaining high daily weight gains and accordingly essential amino acid requirements. Synthetically produced essential amino acids, as in conventional animal husbandry, are not allowed in organic agriculture. The protein gap resulting here (Zollitsch et al., 2002) has not been closed with plant based organic feeds in fast growing young animals (piglets, chicks) and high yield animals (sows, laying hens). In addition to the according economic losses (Löser and Bussemas, 2007) this is also problematic from an animal welfare perspective (Zollitsch, 2007). As of 2012, 100 % organic feeding will be required by law. This is just a few years from now, but a solution is nowhere in sight. Above all essential amino acids are missing in feed rations for poultry and pigs (Wlcek and Zollitsch, 2004). That is why conventional feed is allowed in specific portions until 2012 (i.e., potato protein, corn gluten). The target of the private organic associations Bioland and Demeter in 2003 to require 100 % organic feeding already in 2005 was rejected by the member farms. The EU regulation 834/2007 does not define the origin of organic feed. All feed can be purchased on the organic market. Private standards are more restrictive (50 % of the feed shall come from the farm).

<u>Evaluation</u>: Organic animal husbandry is still the most fragile and least developed element in the system of organic farming, particularly the production of chicken and pigs. Animal husbandry on many organic farms (certainly not on all farms) is, from the perspective of animal welfare and with a view to production yields, unsatisfactory. Here is an economic risk, but also an image risk. Many of the problems are related to management deficits. Appropriate organic feeding, breeding and housing techniques are available, but the implementation on a larger scale is still at the outset. Natural therapy and disease prevention strategies are not developed.

<u>Research and Development Requirements</u>: The development of natural healing practices including natural medicines and livestock keeping with high animal welfare standards must be strengthened. Breeding can be a core element for improvements. Many problems in organic animal husbandry have, from a scientific perspective, either been solved or can be solved. Acceptance and implementation problems in practice play a large role. Sociological and economic studies are necessary in order to understand the problem and develop solutions which seem acceptable for all concerned actors. The impact of improved animal protection of the economic viability of animal husbandry systems must be evaluated.

3.7 IFOAM-objective: To provide farmers the opportunity to earn an acceptable living and to develop their professional and personal abilities

In 2008, the German organic market volume of 5.8 billion Euros was slightly more than 3 % of the total food market (BÖLW, 2009). Based on turnover, organic food has been the most strongly growing segment for years in food markets, especially since the organic seal was introduced. Already more than 3,108 farms and companies of the overall food-sector have had more than 51,368 products certified (www.biosiegel.de, Status 31.12.2008). All in all more than 26,820 companies (producers, processors, importers and dealers) are state certified by the Federal Agency for Agriculture and Food (BLE).

In Germany, the conversion of farms toward organic farming is not as fast as the market development. In 2008, about 19,824 certified organic farms cultivated 911,385 ha (+5.3 % compared to 2007). Very characteristic for the structures of organic farming in Germany is a relatively large number of farms that are active both in primary production as well as in the domain of further processing (2,655 farms). However, more than 50 % of the raw materials of organic products sold in Germany are imported (Haccius, 2008).

The professionalisation of organic farming has led to the situation that the income in organic farming is now comparable with according conventional colleagues or even higher. In the recent past there has even been a trend favouring the organic farms (Nieberg et al., 2007). Whether this trend is permanent cannot yet be determined (Oppermann et al., 2009). The prices and demand for organic products swing quite strongly (ZMP several years, found under www.zmp.de).

The work stress in many farms, particularly dairy farms, is problematic. Regular vacations and appropriate free time are seldom found here (Rahmann et al., 2004). This too is a reason for the strong trend to establish organic farms without keeping animals. In organic farming, farmers are also forced to thrive and give way. Small and smallest farms are often economically fragile and do not always have an heir. In the future a strong structural change will also take place in organic farming, and as we have seen in conventional agriculture for decades, the question emerges of how the structural change can be better accompanied socially and politically.

Organic farming creates jobs. It is estimated that organic farming has created 50,000 new jobs up until today (BMELV, 2006). Organic farming, in contrast to conventional farming, also offers space for decidedly socially-oriented employment concepts (handicapped persons, persons requiring care for other reasons, etc.). For example, handicapped persons are employed on about 150 organic farms (www.gruenwerkstatt.de). Ultimately organic farms have often played a progressive role in the building of regional economic concepts (www.reginet.de).

Evaluation: The economic viability of organic farming is comparable to that of conventional farming. Meaning: there are known differences in the results with a large group of farms with weak income and hardly any investment ability. In both systems there will be growth and a giving way and production will be further specialized and intensified on this basis. International competition presents great challenges to both systems if they want to keep their place on the market. On the other hand, organic agriculture offers jobs that are no longer available in other businesses, not even on conventional farms. Multiple occupations and social aspects are important development potentials for the future.

Research and Development Requirements: Resource efficient production processes, new types of products and marketing paths as well as new, additional sources of income (tourism, handicapped facilities, school groups, biotope management and nature protection, energy production) must be developed and explored for organic farming. The policy framework conditions have to be defined and assessed (i.e., second pillar of CAP).

4 Further adaptation and development needs of organic farming

The development of organic farming can not only focus on internal conditions and be limited to self-discussion (Nieberg and Kuhnert, 2007; Rahmann and Oppermann, 2008). Organic agriculture must show that it has the right stuff to achieve improvements or can lead to convincing solutions, at least in the long-run (Watson et al., 2006). As the most important challenges can be named:

- Food security for an ever-growing world population with multi-functional land area demands (biomass, natural protection), loss of production areas (desertification, contamination, sealing).
- Develop adaptation strategies so that agriculture can achieve good yields even under changing climate conditions (agrarian climate impact, farming adaptation).
- Contribution to the demand of the public for the improvement and maintenance of human health (reduction of malnourishment, minimization of health-threatening, and maximization of health-promoting, substances in food).
- The conservation and maintenance of both agricultural as well as natural genetic resources.

Parallel to the major global topics, a range of national or "only" regional challenges can be named, demanding new answers from society. These include:

- Preservation of biotic and abiotic resources (reproduction functions) for urban areas (soil and water resources, fresh air).
- The maintenance of attractive, diverse landscapes and conservation of rural, and particularly agrarian, traditions for rural tourism.

This is all tied to the changes in international business exchange structures (globalisation) and forces all production systems to adapt.

Ultimately agriculture in all of its production forms is under "sharper observation" in its achievements by the public. It must deal with changing values and a new position in the society vs. food and its production forms (animal protection, consumption and eating habits, recreation). The point of departure is thus marked by the paradox situation that knowledge of most people on the basics of agricultural production has dropped considerably, while, on the other hand, a trend has emerged to judge agriculture and to censure it if it appears to be worthy of criticism.

Also, there is a popular perception in the world about "good farming" that is extremely emotionalized (the feelings of the topic and the aspects shown) and romanticized. The media and advertisements play a major role here. It should not be underestimated what this means for the judgement ability of people and what it means for the ideal perception of agriculture that, in turn, flows into the political consensus process. Organic farming today is also confronted with this problem. In many ways it was shown to be an alternative to conventional farming and must therefore suffer under expectations that are obviously exaggerated.

In this context, it is imperative that organic farming deal with its problems and deficits in a sober, pro-active and self-confident manner. Due to the diversity of structures and problem situations, general evaluations make no sense. Nonetheless, from a research perspective, they permit the basic topics and lines of discussion to be identified.

Even if a classification of the problem fields seems to make no sense, it soon becomes apparent that a large portion of the deficits as well as a large portion of the solution discussions can be ordered under the main concept of "professionalisation." Here not only gaps in professional knowledge are prevalent, but also problems in the implementation, which are in turn very strongly dependent on the motivation of actors, the business conditions and the infrastructure. Secondly, a large part of the problem emerges due to areas with which conflicts of goals, which previously did not exist or were not apparent, have arisen with organic farming. The third complex is most related to the fact that additional, absolutely new, challenges must be integrated into the organic farm production concept.

Ultimately, in many fields of production, and in some products, overlaps between the structures and qualities of organic and conventional farming emerge. This is a positive point of departure for a strategy for change and the further development of farms and structures. It forces organic farmers to approach problems in cooperation with conventional farmers, and to protect themselves from a self-glorifying and ideological perspective. Organic farming needs intensive, critical and constructive accompaniment by agricultural science to solve its problems.

The EU Organic regulation 834/2007 provide the legal groundwork naming objectives for organic farming (§3-6). According objectives must, however, permit reasonable benchmarking in the area of tension between absolute and relative indicators. Research should develop solutions for organic food production which can produce and prove its own goals in process and product quality without exceptions.

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Performance of organic goat milk production in grazing systems in Northern Germany

Gerold Rahmann*

Abstract

Organic farming has emerged from its niche. This holds true for organic goat milk, yoghurt and cheese as well. Particularly in the EU, many dairy goat farms have converted or want to convert towards organic farming to profit from the positive image and the good prices for milk (+100 % in Western Europe and Alpine regions).

High performance dairy goats demand excellent feedstuffs, a sound environment and top management. It was not clear how organic farming can fulfil these demands. The restrictive factors influencing the productivity of the animals in organic farming are as follows: limited concentrate feeding (<40 % of ration), grazing systems with seasonal and annual changes in roughage qualities due to weather conditions and the prohibition of preventive and allopathic veterinary intervention.

High performance dairy goat breeds like Alpine goats can produce about 600 to 800 kg milk with 40 to 50 kg fat and protein per 240-days under organic farming standards. The yield is limited due to roughage quality and management (health, breeding). Considering the high price (conventional: 0.38 Euro, organic: 0.70 Euro kg^{-1}), organic goat milk is a profitable product.

Keywords: Organic Farming, Dairy goats, milk performance, grazing system

Zusammenfassung

Milchleistung von Ziegen im Ökologischen Landbau mit Weidewirtschaft in Norddeutschland

Der Ökologische Landbau hat die Nische verlassen. Dies gilt auch für Ziegenmilch, -jogurt und -käse. In der EU haben viele Milchziegenbetriebe auf Ökologischen Landbau umgestellt, um vom positiven Image aber auch den guten Preisen zu profitieren (+100 % in West-Europa und besonders den Alpenregionen).

Hochleistungsziegen benötigen bestes Futter, eine die Gesundheit erhaltende Umwelt und bestes Herdenmanagement. Es ist nicht bekannt, ob der Ökologische Landbau diese Bedingungen erfüllen kann. Begrenzter Kraftfuttereinsatz (<40 % Futteranteil in TS) und die Weidewirtschaft (Wetter, stark schwankende Raufutterqualitäten) und die Einschränkungen bei den veterinär-medizinischen Maßnahmen (Verbot des vorbeugenden Einsatzes von Tierarzneimitteln wie z. B. Entwurmungsmitteln) wirken sich auf die Leistung der Tiere aus.

Hochleistungsrassen wie die Bunte Deutsche Edelziege können im Ökologischen Landbau mit Weidewirtschaft 600 bis 800 kg Milch mit 40 bis 50 kg Fett und Eiweiß pro Jahr produzieren (240-Tage-Leistung). Die Raufutterqualität und die Witterung haben einen großen Einfluss auf die Leistung. Bei feuchtem Wetter bzw. Regen grasen Ziegen nicht gerne, die Raufutterqualität ist durch die extremen Wachstumsphasen nicht immer in gleich guter Qualität verfügbar und die Raufutterwerbung für das Winterhalbjahr besonders bei Heuproduktion immer wieder durch unvorhersehbare Witterungsereignisse beeinflusst (überständiges oder verregnetes Raufutter). Aufgrund der hohen Preise für ökologisch produzierte Ziegenmilch (konventionell: 0,38 Euro, ökologisch 0,70 Euro pro kg) ist die ökologische Ziegenmilchproduktion ökonomisch wettbewerbsfähig.

Schlüsselwörter: Ökologischer Landbau, Milchziegen, Milchleistung, Weidewirtschaft

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1 Standards for organic goat farming in the EU

Organic agriculture is considered an environmentally sound and socially acceptable land use system with "natural" food production (FAO, 2000). Organic farming is a food production label and is becoming more and more popular throughout the world (Organic Monitor, 2008). In 2006, about 30.4 million hectares were certified according to organic standards and the world market volume was 38.6 billion US-$ (Willer et al., 2008). The EU and the US are the biggest markets with an annual growth of 10 to 20 %.

Principles and norms define the entire course of production, processing, packaging, transporting and marketing of organic products (IFOAM, 2005; FAO/WHO, 1999). The most important governmental organic farming standards are 2092/91/EEC (from January 1st, 2009: 834/2007/EC) of the EU, the NOP (USA) and JAS (Japan) (Schmid et al., 2007). They precisely lay down the production and manufacturing requirements for agricultural produce and foods labelled as organic products. All organic goods produced and sold must meet the national governmental standards set by these regulations. The standards of organic agriculture cover conversion periods, stock densities, breeding, feedstuffs and feeding, standards in animal welfare, health and hygiene and inspection and certification (Rahmann, 2004).

1.1 Farmland-related animal husbandry

Livestock plays an important role on organic farms, e.g., in nutrient cycling. Landless animal husbandry is not organic and thus prohibited. The limited livestock density does not exceed 170 kg nitrogen ha^{-1} a^{-1} and is measured in livestock units (1 LU = 500 kg live weight). About 13.3 adult goats ha^{-1} a^{-1} are allowed (2092/91/EEC, Annex I B 7. and Annex VII).

1.2 Feedstuff and feeding

Organic goats have to be fed with 100 % organic feedstuff (Table 1). Ruminants have to be fed with a minimum of 60 % of roughage (50 % is allowed only in the first three months of high lactation). Organic feeds can be purchased from other organic farms. A maximum of 40 % (purchased) and 60 % DM (own production) of "in-conversion feedstuff" (after 12 months of conversion) is allowed. Permitted organic feedstuffs are listed (positive lists). Only single components, but not processed and mixed feeds, are considered in 2092/91/EEC Annex II.

Table 1:

Feeding recommendations for dairy goats (Drochner et al., 2003)

	DM (kg)	nXP (g)	MJ ME	Ca (g)	P (g)
Minimum body maintenance	1.4	85	9.7	3.6	2.7
per liter milk (3,5 % fat, 3,1 % protein)	0.4	75	4.4	2.2	1.4
5th month gestation	1.5	200	13.0	6.6	3.4

Protein lactation and gestation with 75 % solubility in rumen; nXP = 50 % utilisation for milk protein

Energy demand per liter milk 3,7 % FCM: 4,4 MJ ME (+0,047(F-40)) with F = g fat per kg milk

A long discussion in the design of the regulation was the feeding of young stock. Kids have to be fed 45 days with "natural milk, preferably maternal milk." It is not established whether "natural milk" must originate from the same species; only that the physiological needs have to be fulfilled. Organic cow milk is accepted for kid rearing.

In organic farming it is not permissible to use anything produced using GMOs (genetically modified organisms) or derivatives. This includes feed for livestock (conforming to definition of animal feeds in 471/82/EEC) and has been valid since September 24, 1999. Fermentation-supports for silage-making are allowed as long as they do not contribute to animal nutrition. Permissible minerals, vitamins and pro-vitamins for animal feed are listed in Annex II. Artificially produced vitamins are allowed in winter for ruminants. Only vitamins derived from raw materials occurring naturally in feedstuffs are allowed for herbivores (70/524/EEC).

It is not obligatory, but recommended, that ruminants should graze on pastures ("free-range") and not be fed in stables as long as the animal, weather and pasture conditions are suitable. Conventionally kept livestock from extensive grazing systems (950/97/EC) can graze on organic pastures as long as no organic livestock is present. For this grazing period, non-organic livestock must follow the rules of organic livestock keeping. This grazing has to be accepted and approved by the certification body.

Final indoor fattening of kids is possible if this period is less than one fifth of the animal's life, and a maximum of three months of the fattening animal's life. Every animal has the possibility of permanent access to feedstuff and water. That means that a minimum of one feeding place per goat has to be available.

1.3 Animal health and veterinary treatments

The guiding principle of animal health is to prevent disease rather than to cure or treat it. Robust, adapted and disease-tolerant livestock ensure fit and healthy animals. Local breeds are considered to fulfil these targets. Preventive treatments with "chemically-synthesised allopathic veterinary medicinal products" or antibiotics, as well as oestrus synchronisation, are forbidden. Vaccinations are allowed even when the vaccine is produced with the use of GMOs. Treatment of parasites and vaccinations are not considered as "chemically-synthesised allopathic veterinary medicinal products". De-worming can be done after a veterinarian has recommended that a heavy infection requires treatment. With such a recommendation, the whole flock of small ruminants can be de-wormed. This is not possible under the US-Organic standards (USDA-NOP).

If an animal is sick, a veterinary treatment is allowed (animal welfare). This has to be checked and carried out by a veterinarian. Natural methods of disease treatment are to be preferred as long as they help the animal. If these natural treatments do not help, chemical-synthesised allopathic treatments are allowed (even antibiotics). The withholding period is twice as long (minimum of 48 hours) as requested for the applied drugs. If an animal has been treated more than three times with chemical allopathic drugs, the products can not be sold under the "organic" label. Only one chemical allopathic treatment is allowed for livestock for which the production period is less than one year (kid meat). All health-related data have to be noted in a herd book and be presented at inspection.

1.4 Husbandry management practices, transport and slaughtering

The breeding of ruminants should take place with natural mating. Artificial insemination is allowed, but not embryo transfer, oestrus synchronisation, etc. Male breeding stock has to be kept on the farm, requiring extra farm resources (space, labour and feeds).

Animal cruelty of any kind is prohibited. Dehorning of goats is not allowed and may only be performed under special circumstances, regulated by the certification authorities (e.g., hygiene, animal welfare or bio-security aspects). Castration of male stock is allowed to maintain traditional animal husbandry practices. The castration should be done at a very young age (<1 month), or under anaesthesia by a veterinarian.

Ruminants have to be kept in groups to meet their social needs. How social needs can be fulfilled via farm conditions has not been defined. The transport of livestock is not clearly defined either. Stress-reduced loading, transporting and unloading of livestock without the use of allopathic tranquillisers, electrical shockers or similar tools is required.

1.5 Housing and stocking rates

If grazing is not possible, and goats have to be kept indoors, a permanently accessible open-air run is obligatory. Free movement stables with permanent access to open-air runs are organic standard for all livestock. Only with permanent summer pasture grazing is an outdoor run not necessary. The tethering of goats is prohibited. The minimum indoor space of an adult goat (net) is 1.5 m^2 and 0.35 m^2 for a kid. The out-door run should have a minimum of 2.5 m^2 for adult goats and 0.5 m^2 for kids (2092/91/EEC Annex VIII 1). A maximum of 50 % of the stable surface can be slatted or grid floor, the rest has to be a flat and non-slippery surface. The boxes have to be strewed-in with organic materials (e.g., straw or wood chips; peat is difficult in terms of environmental issues).

1.6 Conversion, inspection and certification

Comparable to cash crop production, the conversion period for grassland for ruminants is 24 months. The conversion period starts after the last conventional utilisation. After 12 months without prohibited treatments, grassland is viewed as "in-conversion feedstuffs/feed materials". Livestock has a conversion period as well. After 6 months of being kept under organic standards, goats are considered as converted (2092/91/EEC Annex I B 2.1.1. and 2.2.1.).

It is possible to convert just one branch of the farm to organic production, e.g., only the goat milk production. If there is a clear spatial separation (farm land, feed and dung storage as well as stables), the same animal species can be kept organically and conventionally by one farmer. This is very often done under NOP. A clear separation is needed to avoid contamination (e.g., prohibited disinfectants or feedstuffs/feed materials which are not in the 2092/91/EEC Annex II) and mixing of inputs (e.g., feeds and dung).

For example, goat milk can be sold under the label "organic" 18 months after the start of conversion: after 12 months 60 % DM (dry matter) of own "in-conversion feedstuff" is available and 40 % DM can be purchased (e.g., concentrates). After further six months with this feed, goats are converted and milk can be declared as "organic".

All organic farms, processors, traders and merchants are inspected annually by an independent certification body. Inspected products can only be declared organic if all standards and norms are fulfilled.

2 Organic goat milk production

Since 2003, between 44 and 65 dairy goats were kept at the experimental station of the German Federal Institute of Organic Farming to assess the production potential of high performance goats under the standards of organic farming. The goats were kept in modern stables, had seasonal access to pasture and received only farm produced feedstuff.

Organic goats obtain high prices in Germany. The price structure for organic goat milk is different from price structure for cow milk. There are seasonal price differences (all per kg): transition period (Mar/Apr, Sep/Oct = +0.205 Euro, summer period (May to Aug = +0.19 Euro) and winter period (Nov to Feb = +0.29 Euro). Bonuses are paid for fat (+0.07 Euro per %) and protein (+0.085 Euro per %). A bonus is also paid for low somatic cell counts (SCC) (<0.6 million SCC = +0.01 Euro) and for long delivery contracts (5 years = +0.01 Euro). An average of +0.70 Euro/kg organic goat milk is paid (without VAT, free dairy plant). Reductions can be made for transport (-0.05 to 0.10 Euro/kg) and when bacteria and/or SCC are too high: bacteria (>100,000 germs/ml: 1st month = -0.02 Euro, 2nd month = -0.04 Euro and 3rd month = -0.06 Euro and so on… In summer months, milk with more than 1 million SCC is penalized with -0.01 Euro in the 1st month, -0.02 Euro in the 2nd month and -0.03 in the 3rd month. In winter the limit is 1.4 million SCC. More than 2 million SCC are generally penalized with -0.02 Euro and -0.02 Euro more in each additional month. Milk delivery has to stop when SCC is above the tolerance level for more than 4 months.. If inhibitors (antibiotics) or cow milk are detected, the farm can be sued for damages.

2.1 Feeding

In Trenthorst about 30 ha grassland are available for roughage feeding. The ground covering is classified as *Cynosurion cristati* with 80 to 98 % grass species. Dominating species are *Poa trivialis* (biomass-share of 3 to 30 %), *Alopecurus pratensis* (2 to 30 %), *Festuca pratensis* (1 to 5 %) and *Taraxacum officinale* (0.1 to 15 %). The goats graze from May to November. Surplus grass is used for hay production. In winter this hay was fed *ad libitum*. The quality of grass and hay was between 9 and 10 MJ ME with 140 – 150 nXP. The goats can select, therefore about 50 % of the roughage is not used. The energy and protein quality of the roughage intake could not be measured. In relation to the milk yield, the goats got between 500 and 800 g concentrate per day via transponder feeding and partly while milking in the barn. About 180 kg of concentrate are used per lactation and goat (without dry season ration). The concentrate feed was made from wheat, oat and peas in different relations (between 12 and 13 MJ ME and 150 and 165 nXP). Minerals are fed *ad libitum*. Fresh water is always available. Throughout the lactation the fat-protein-relation was between 1.00 and 1.15.

2.2 Reproduction

The breeding was done naturally, with some exceptions with artificial insemination for breeding buck production. First mating is done with 1.5 years and the lambing season is in February/March. On average between 1.98 and 2.21 kids are born per mother (Table 2). The average herd age (without young stock) increased during the experiment from 3 to 4.9 years (1 – 2.9 lactation numbers).

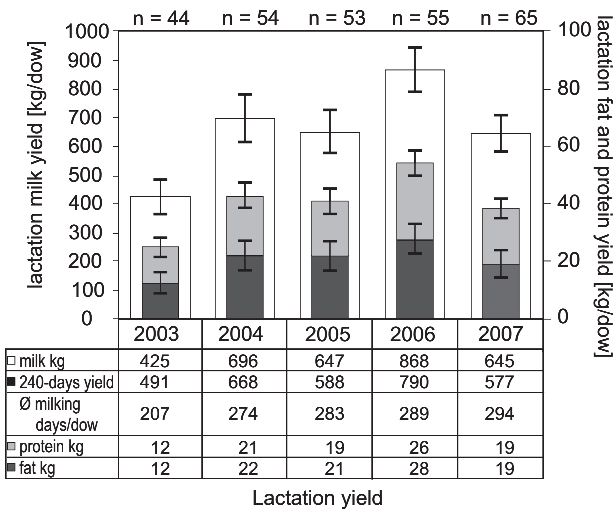
Table 2:

Herd performance and lambing rates

	Lactation number						Average Lactation years	Lambing rate in %
	n	1.	2.	3.	4.	5.		
2003	44	44					1.00	176
2004	54	17	37				1.71	196
2005	53	13	11	29			2.27	194
2006	55	10	12	11	22		2.85	212
2007	65	20	9	11	7	18	2.91	221

2.3 Milk production

The milking was done in a milking barn with modern equipment. The lactation yield was measured by the milking equipment and verified by monthly milk control (IDF B2-method: lactation and 240-days yield). The milk yield increased with the average age of the herd (average lactation years). The annual differences in milk yield are due to weather and roughage qualities. 2005 was a wet summer, the goats did not like to graze and the hay quality was bad as well. The summer weather in 2006 was excellent for goats grazing. The milk, fat and protein yield increased significantly, the summer 2007 was extremely wet, the milk yield dropped back to the level of 2005 (Figure 1). Important was the high milk yield early in the year (Figure 2).



		milk kg		fat kg		protein kg	
	n	average	s	average	s	average	s
2003	44	485.23	113.20	14.21	3.40	14.21	3.13
2004	54	667.25	144.82	20.79	4.51	19.64	3.73
2005	53	587.53	136.90	19.49	5.04	17.22	3.95
2006	55	790.11	134.56	24.93	4.79	23.77	3.91
2007	65	576.72	130.24	17.54	4.27	16.98	3.51

240-days yield

Figure 1:

Milk, fat and protein yield in organic goat milk production

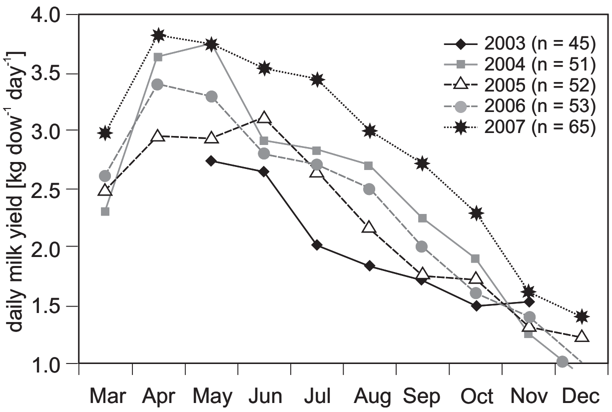


Figure 2:

Average daily milk yield of organic goats 2003 to 2007

2.4 Health

Somatic cells can indicate mastitis. Somatic cell counts of goat milk are not comparable to cow milk. 100,000 somatic cells ml^{-1} in cow milk is defined as healthy udder. Goat milk can have more than one million SCC and the udder health is okay. Therefore no international SCC standards are defined for udder health. Only some cases (2 to 6) of clinical mastitis occurred per milking season, particularly in the first two months of lactation. The somatic cell counts SCC have changed throughout the season and years (Figure 3). This does not necessarily refer to sub-clinical mastitis (Aulrich & Barth, 2008). Organic dairy factories pay extra for goat milk with less than 600,000 SCC (+0.01 Euro/kg) and penalize milk with more than 1.0 million SCC in summer and 1.4 million SCC in winter (KTBL, 2008). Above 2.0 million SCC, -0.02 Euro/kg are charged.

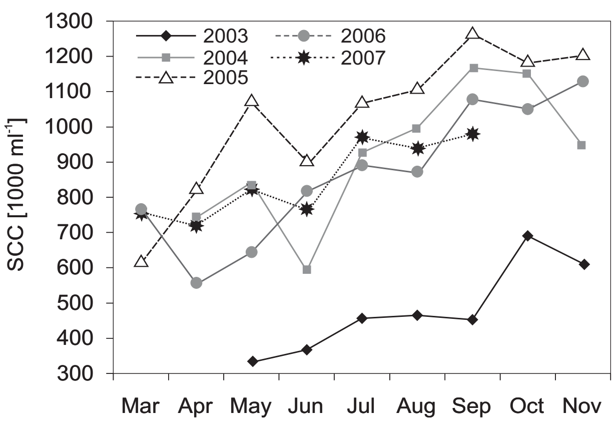


Figure 3:

Seasonality of somatic cell count of the bulk milk 2003 to 2006

2.5 Conclusion

At the experimental station of the Institute of Organic Farming between 44 and 65 German Brown Alpine goats have been kept since 2003 to assess the milk production potential under the standards of organic farming (EU 2092/91/EEC resp. 834/2007/EC). The goats were kept in modern stables, had seasonal access to pasture (May to November) and received only farm-produced feedstuffs. In average 650 kg milk yield ± 100 kg in 240 days was possible with high performance goats in organic grazing systems in Northern Germany. This is about 25 % less than comparable conventional dairy goat farming. The weather conditions in summer and the roughage quality have the main impact on the organic dairy goat milk yield. Usually, conventional farms do not keep dairy goats in grazing systems and do not have a minimum daily intake of roughage. Goats do not like wet conditions and reduce feed intake on pasture. Concentrates can supplement the deficit, because organic farming standards do not allow more than 40 % of concentrate in the daily rations.

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Fütterung und Haltung von Hochleistungskühen
3. Ab- sowie Aufbau von Körpersubstanz und erzielbare Leistung

Klaus Walter*

Zusammenfassung

Milchkühe verfügen über die Fähigkeit Körpersubstanz in Milchleistung umzuwidmen. Dieses im Zuge der Evolution entwickelte Potential wird in der Milchproduktion erfolgreich genutzt, um hohe Leistungen und Gewinne zu erzielen. Die vom NRC (2001) dazu entwickelten algorithmischen Beziehungen bilden die Grundlagen zur Bewertung der Fähigkeit Körpersubstanz in zusätzliche Milchleistung umzuwandeln.

Mittels Simulation lässt sich zeigen, dass eine Kuh mit 675 kg Lebendgewicht und ausgewogener Fütterungskondition am Beginn der Laktation bei einer Umwidmung von 8 % (16 %) der Körpersubstanz, entsprechend einem Rückgang des bcs um 1 Punkt (2 Punkte), eine um 1.000 kg (1.800 kg) höhere Laktationsleistung erreichen kann.

Kühe mit flacher Laktationsfunktion und hoher Persistenz sind in der Lage höhere Leistungszuwächse durch Umwidmung von Körpersubstanz in Leistung zu erzielen als Kühe mit steilem Anstieg und schnellem Abfall der Tagesleistung.

Je höher das Gewicht der Kühe in ausgewogenem Futterzustand ist, umso größer fällt der Leistungszuwachs aus. Ausgehend von 675 kg ermöglicht ein um 100 kg höheres Gewicht einen Extraleistungszuwachs von 250 kg Milch, mit zunehmender Tendenz bei noch höheren Gewichten.

Ein stärkeres Ausfüttern vor Laktationsbeginn erhöht theoretisch die in Leistung umwandelbare Körpersubstanz. Weitere Kalkulationen zeigen jedoch, dass die bei fetteren Kühen beobachtete reduzierte Futteraufnahme diesen Zuwachs nahezu aufzehren kann. Weil gleichzeitig die gesundheitlichen Risiken ansteigen, verliert diese Strategie ihre Attraktivität.

Den gesundheitlichen Risiken der Umwidmung von Körpersubstanz in Leistung stehen bedeutende Leistungszuwächse gegenüber, auf die eine Milchproduktion angewiesen ist, wenn Leistungssteigerungen langfristig unabdingbar sind. Die Schlussfolgerung kann nur sein, die Risiken zu minimieren und diesen Ansatz zur Leistungssteigerung zu nutzen.

Schlüsselworte: Milchleistung durch Abbau von Körpersubstanz, Tiergesundheit, Body condition score

Summary

The feeding and husbandry of high performance cows
Part 3. Mobilization and repletion of body reserves and achievable yield

Dairy cows have the ability to turn body reserves into milk. This potential, developed by nature in the course of evolution, is successfully used in dairy production to attain high yield and profits. The algorithmic relations developed for this purpose by the NRC (2001) serve as the basis to evaluate the ability of body substance to be transformed into additional milk.

Simulation allows us to show that a cow with a balanced feeding condition weighing 675 kg at the start of lactation can reach 1000 kg (1800 kg) milk yield, with a redistribution of 8 % (16 %) of its body reserves resulting in a drop in the bcs of 1 point (2 points).*

Cows with a flat lactation curve and high persistence are capable of more performance growth by rededication of body reserves into performance than cows with a sharp increase and fast drop in daily performance.

The higher the cow's bodyweight in a balanced feeding condition, the greater the yield increases. Assuming 675 kg, an 100 kg higher live weight enables an extra yield of 250 kg milk with an increasing tendency at even higher weights.

Starting the lactation with a bcs of 5 theoretically increases the body substance convertable into milk. However, further calculations show that with fatter cows, the observed reduction of feed intake can absorb this growth and increase the health risk.

The health risks in the conversion of body reserves into performance is in contrast to significant yield growth which depends on milk production if it is to be targeted to success over the long term. The conclusions here can only be to reduce the risks and to use this approach to increase milk yield.

Keywords: Milk yield by decrease in body substance, animal health, body condition score

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1 Einleitung und Fragestellung

Hohe Leistungen führen zu Nährstoffdefiziten in den ersten Tagen der Laktation (Abbildung 1) und werden als Risikofaktoren für die Leistungsbereitschaft und Gesundheit der Milchkühe angesehen (Evans, 2003; Drackley, 2005; Kaske, 2006).

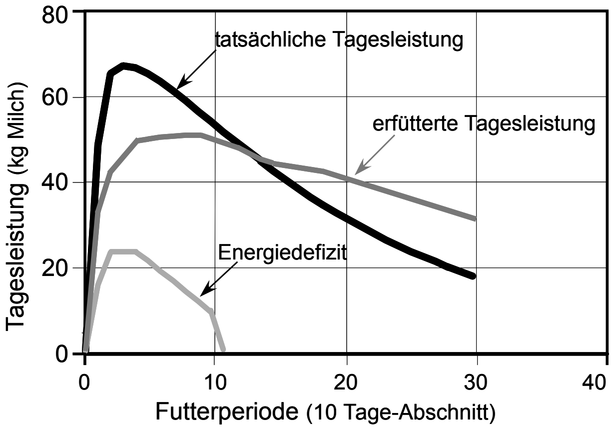

Abbildung 1:

Laktationskurve einer Kuh[1] mit einer Milchleistung von 12.000 Litern und Nährstoffdefiziten im ersten Drittel der Laktation

Je höher das Leistungsniveau, umso mehr Milch wird aus Körperreserven und -substanz erzeugt. Diese Umwandlung von Reserven zu Milch beginnt in den ersten Tagen nach dem Abkalben und kann länger als das erste Drittel der Laktation andauern. Dementsprechend wird diesem Zeitraum in den Fütterungsempfehlungen besondere Aufmerksamkeit gewidmet. Abbildung 2 zeigt das kumulierte Energiedefizit, dessen Maximum erreicht wird, wenn die Tagesnährstoffbilanz der Kuh erstmals ausgeglichen ist. Die Hochleistungskuh befindet sich zu diesem Zeitpunkt in einer kritischen Ernährungssituation, denn sie hat stark abgenommen und ein Großteil ihrer mobilisierbaren Reserven ist aufgebraucht. Die Wiederherstellung einer guten körperlichen Kondition und damit der Ausgleich des entstandenen Nährstoffmangels wird zwingend erforderlich. Die Fütterung im zweiten und gegebenenfalls im dritten Drittel der Laktation darf wegen der zuvor negativen Energie- und Nährstoffbilanz nicht allein an der jeweiligen Tagesleistung bemessen werden, sondern sie hat die Defizite des ersten Drittels zu berücksichtigen und die Kuh wieder in optimale Kondition zu versetzen.

Die Abbildungen 1 und 2 skizzieren die Energiebilanz einer Hochleistungskuh und machen ihre Fähigkeit deutlich, aus Reserven bzw. Körpersubstanz Milch zu erzeugen. Dabei handelt es sich um ein biologisch manifestiertes Konzept, das auch bei anderen Säugetieren zu beobachten ist. Es bietet sich daher an, die Bedeutung dieser genetischen Veranlagung zur Milcherzeugung und zur Leistungssteigerung mittels Simulation zu evaluieren und das Spannungsfeld zwischen erwünschter Leistungssteigerung und unerwünschter Belastung bzw. Gefährdung der Milchkuh detailliert zu analysieren.

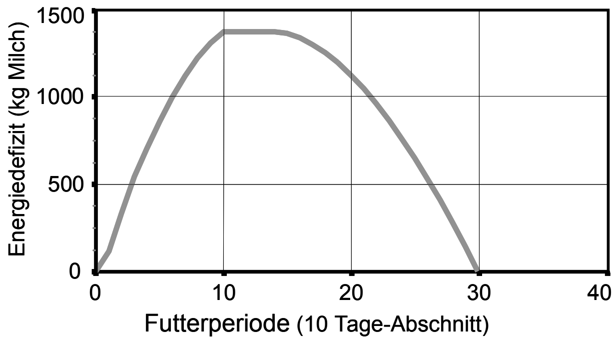

Abbildung 2:

Kumuliertes Energiedefizit bei einer Milchleistung von 12.000 Litern (Pendant zu Abbildung 1)

In diesem Zusammenhang wird zunächst der Fragestellung nachgegangen, um wie viel die Leistung geringer ausfiele, wenn die Kuh nicht in der Lage wäre, Milch aus "Körpersubstanz zu erzeugen". Zum Vergleich wird diese Umwandlung von Lebendgewicht in Milchleistung systematisch variiert, um den Effekt für die Milchproduktion quantitativ darzustellen.

2 Literatur, 'body condition score' und methodischer Ansatz[2]

In den wissenschaftlichen Arbeiten (Evans, 2003; Drackley, 2005; Kaske, 2006) und in der für Milchviehhalter bestimmten Literatur stehen die Risiken, die Erhaltung der Gesundheit und auch die Tierschutzaspekte im Vordergrund, wenn die in den Abbildungen 1 und 2 dargestellten Defizite und die damit verbundenen Gewichtsverluste und Konditionsverschlechterungen diskutiert werden. Die andere Seite, nämlich die positive Beziehung zur Milchleistung, wird dabei nicht genügend gewürdigt. Der Ab- und Wiederaufbau von Körpersubstanz ist jedoch für das Leistungsniveau und damit für die Wirtschaftlichkeit der Milchproduktion von erheblicher Bedeutung.

[1] Wenn nicht explizit erwähnt handelt es sich stets um eine Kuh in 2. Laktation, mit 675 kg Gewicht, mit 25 kg Gewichtszuwachs, einer Zwischenkalbezeit von 360 Tagen, mit einem Geburtsgewicht des Kalbes von 42 kg, die keine Krankheiten hat und nur konserviertes Futter höchster Qualität erhält.

[2] Diese Arbeit basiert auf dem im Institut für Betriebstechnik und Bauforschung der FAL entwickelten methodischen Konzept (Walter, 2007).

2.1 Literatur

Evans (2003), Drackley (2005), Brade (2005), Robinson (2006) und viele Andere weisen auf die Risiken des Abbaues von Körpersubstanz hin und entwickelten eine Vielzahl von Lösungsansätzen zur Vermeidung der mit der Gewichtsabnahme verbundenen gesundheitlichen Risiken. Staufenbiel (1999 und 2001) sieht in der kontrollierten Gabe von sauren Salzen einen Ansatz zur Minderung der Anfälligkeit gegen Ketosen und diskutiert verschiedene Kontrollmöglichkeiten zur Früherkennung, wie Untersuchung des Harns, etc. Drackley (2005) und Kaske (2006) nennen Gewichtsverluste von 50 bis 70 kg bei "Holstein Frisian" im ersten Drittel der Laktation und sehen u. a. in der Erhöhung der Futteraufnahme und –qualität einen Schlüssel zur Minderung von Belastungen und Beanspruchungen der Hochleistungskuh. Diese Empfehlungen sind jedoch nicht nur für den Zeitraum des Körpersubstanzabbaues interessant, sondern sie stellen einen grundsätzlichen Ansatz zur Steigerung der Leistung und der Effizienz der Milchproduktion dar, siehe dazu Walter (2008b).

2.2 „body condition score"

Der „body condition score" (bcs) verbindet Gewichtsverlust und Erscheinungsbild der Kuh. Den Milchviehhaltern gibt es ein Konzept zur Beurteilung der tierindividuellen Kondition an die Hand, wenn sie das Gewicht bzw. die Gewichtsentwicklung nicht detailliert verfolgen können, weil sie nicht über eine Waage verfügen. Der bcs basiert auf einer Bewertungsskala, die beispielsweise von Hulsen (2004), Robinson (2006) und den verschiedenen Zuchtverbänden in einer 5 Punkte Skala vorgegeben wird. Das NRC (1996) entwickelte zunächst eine 9 Punkte Skala, die einer nochmals unterteilten 5 Punkte Skala entspricht.

Im Folgenden wird der bcs gemeinsam mit der Gewichtsentwicklung genannt. Es wird jedoch keine Tierbeurteilung vorgenommen, sondern es liegt hier stets die vom NRC (2001) entwickelte funktionale Beziehung zu Grunde, die vereinfacht besagt, dass ein bcs Punkt etwa 8 % des Lebendgewichts entspricht. Das Simulationsprogramm errechnet das Nährstoffdefizit, bestimmt den zugehörigen Körpersubstanzverlust und kalkuliert erst dann den bcs. Damit handelt es sich nicht um eine Bewertung der Kühe nach dem vorgegebenen Schätzrahmen, sondern um die aus dem Gewichtsverlust abgeleitete kalkulatorische Definition des bcs (NRC, 2001). Dem entsprechend weisen die Abbildungen 6 bis 11 beide Maßsysteme, also das Gewicht in Prozent und den bcs als x-Achse, auf.

Das in Abbildung 2 dargestellte kumulierte Energiedefizit erreicht hier 1.400 kg Milch. Diese Milchmenge wird allein durch den Abbau der Körpersubstanz erzeugt. Die Kuh befindet sich am Beginn der Laktation in einer ausgewogenen Kondition, die wie folgt charakterisiert wird: *„Fett- und Fleischansatz ausgewogen, Sitzbeinhöcker abgerundet",* entsprechend einem bcs von 3 (Hulsen, 2004). Der mit dem Defizit verbundene maximale Gewichtsverlust beträgt rd. 16 % (Abbildung 2) und führt in dieser Konstellation zu einem bcs von 1, der gemäß den Charakteristika wie folgt beschrieben wird: *„ausgemergelt, Sägezahnstruktur der Dornfortsätze sichtbar und Sitzbeinhöcker stark hervorstehend"*.

2.3 Methodischer Ansatz

Die Bedeutung des Ab- und Wiederaufbaues von Körpersubstanz für die damit erzielbare Leistungssteigerung ließe sich nur mit einem immensen experimentellen Aufwand bestimmen. Denn allein wegen der Streuung der Leistung wäre ein großer Stichprobenumfang erforderlich, um den Leistungs-, Gewichts- und Altersunterschieden mit jeweils angepasstem Versorgungsniveau gerecht zu werden. Das NRC (2001) wählte einen anderen Weg. Es analysierte alle geeigneten Fütterungsversuche, um diese spezielle Produktionsfunktion schätzen zu können und so für die Gestaltung der Fütterung[3] nutzbar zu machen. Diese grundlegenden Untersuchungen führten zu Funktionen und Beziehungen, die in das Simulationsprogramm (SMP) "Milchproduktion der Zukunft" (Walter, 2008a) übernommen wurden. Damit lässt sich berechnen, welche Milchleistungssteigerungen durch Abbau von Körpersubstanz erreichbar sind, wenn diese vom NRC (2001) abgeleiteten Beziehungen zwischen Milcherzeugung und Körpersubstanzabbau unterstellt werden. Das Simulationsprogramm stellt weiterhin sicher, dass der Wiederaufbau der Körpersubstanz unter Berücksichtigung der mit dem Ab- und Aufbau verbundenen Verluste innerhalb der Zwischenkalbezeit erfolgt.

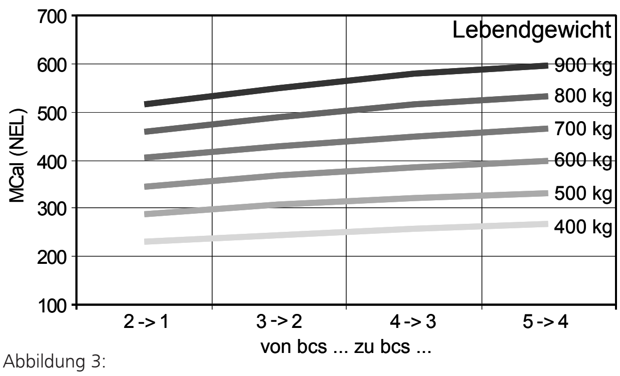

Abbildung 3:

Energiegewinn bei Verlust von je einem bcs Punkt in MCal, Quelle: NRC (2001, table 2.5)

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[3] Die hier genutzten vom NRC (2001) entwickelten Versorgungskonzepte gelten speziell für die Rasse Holstein Frisian, also den Blutlinien, die heute die milchbetonten Milchviehherden in Deutschland prägen.

In Abbildung 3 wird der Energiegewinn je bcs Punkt ausgewiesen. Dabei wird deutlich, dass mit dem Körpergewicht auch die freigesetzte Energiemenge wächst. Die aus der Körpersubstanz freisetzbare Energiemenge nimmt dagegen mit der Kondition ab, sie fällt umso geringer aus, je weiter das Gewicht und der bcs bereits abgesunken sind.

Abbildung 4 zeigt den in Abbildung 3 dargestellten Energiegewinn durch Abbau der Körpermasse um einen bcs Punkt in Milchäquivalenten. Wandelt eine Kuh mit einem Gewicht von 700 kg ihre Körpermasse in Milch um, so kann sie ca. 625 kg Milch erzeugen, wenn sie ausgehend vom bcs 5 einen Punkt, also 8 % ihres Gewichts, verliert und nur noch nach bcs 4 eingestuft wird. Mit einer weiteren Umwidmung der Körpersubstanz in Milch, entsprechend einem Rückgang des bcs von 4 nach 3, liefert die Kuh damit noch 600 kg Milch. Bei der Minderung von bcs 2 nach 1 sind es nur noch 400 kg Milch, die aus der eingeschmolzenen Körpersubstanz von 8 % erzeugt werden können. Der Wiederaufbau der Körpermasse unterliegt einer ähnlichen Relation von Gewichtszuwachs und Energiebedarf, allerdings sind dabei 15 bis 25 % höhere Ansprüche zu berücksichtigen (NRC, 2001, table 2.5). Insgesamt gesehen ist damit auch die auf Ab- und Wiederaufbau von Körpersubstanz basierte Leistung mit einem um 15 bis 25 % höheren Energiebedarf belastet.

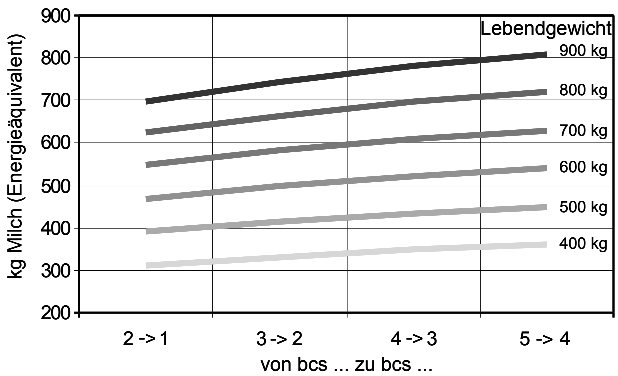

Abbildung 4:

Energiegewinn bei Verlust von je einem bcs Punkt in kg Milchäquivalent errechnet aus: NRC (2001, table 2.5)

Das NRC (2001) geht von rd. 8 % Körpergewichtsdifferenz je bcs Punkt aus. Zwischen dem bcs von 1 (ausgemergelt) und dem von 5 (verfettet) liegen 4 * 8 %, also insgesamt 32 % Gewichtsdifferenz. Die Abbildungen 3 und 4 korrespondieren mit den in Abbildung 5 dargestellten algorithmischen Beziehungen (NRC, 2001). Das Simulationsprogramm (Walter, 2007) beinhaltet diese Funktionen und bestimmt jeweils für eine Zwischenkalbezeit den erforderlichen Ab- und Aufbau der Körpersubstanz, es kalkuliert für jeden Tag der ZKZ das aktuelle Gewicht und errechnet daraus den zugehörigen bcs[4]. Das SMP berücksichtigt zudem

- die bei steigenden Tagesleistungen abfallenden Milchfettgehalte und den dafür erforderlichen geringeren Energiebedarf,
- den Energie- und Nährstoffbedarf für den Wiederaufbau der eingeschmolzenen Körpersubstanz,
- das Wachstum der Kuh und
- den Bedarf des Fötus.

Die Sachverhalte aus den Abbildungen 1 bis 5 verdeutlichen, dass hier keine linearen Ertrags- und Aufwandsrelationen vorliegen und nur eine Marginal- bzw. Grenzwertanalyse das komplexe Geschehen korrekt abbilden kann. Daher werden nicht die von der GfE (2001) entwickelten Fütterungsempfehlungen, sondern die vom NRC (2001) formulierten Versorgungskonzepte genutzt.

Hier stehen sich Abbau von Körpersubstanz und Leistungszuwachs gegenüber, zudem ist der zusätzliche Aufwand für den Wiederaufbau der eingesetzten Körpersubstanz zu berücksichtigen. Derartige Analysen dürfen nicht mittels Durchschnittswerten für Aufwand und Ertrag kalkuliert werden, denn sie basieren auf differenzierten nicht linearen Produktionsfunktionen (NRC, 2001; Walter 2008c). Diese vielschichtigen und sich gegenseitig beeinflussenden Beziehungen lassen sich am besten mit kombinierten Bilanzierungs- und Optimierungsansätzen lösen.

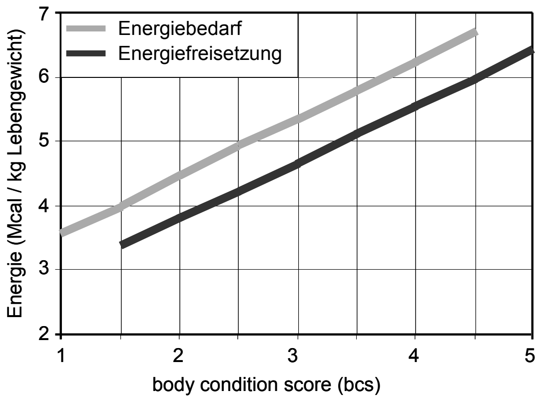

Abbildung 5:

Energiebedarf und -freisetzung je kg Lebendgewicht in Abhängigkeit vom bcs Quelle: NRC (2001, table 2.4)

Die Berechnung der leistungsbezogenen Effekte des Ab- und Aufbaues von Körpersubstanz erfolgt mittels des Simulationssystems „Milchproduktion der Zukunft“ (Walter 2007; Walter 2008c). Für nahezu alle relevanten tierspezifischen Kennzahlen und betrieblichen Ausgangskonstellationen können die Konsequenzen der Umwandlung von Körpermasse in Leistung kalkuliert werden.

[4] In der Praxis wird umgekehrt vorgegangen, es wird zuerst der bcs an Hand der Vorgaben bestimmt und dann die Schlussfolgerung gezogen.

Die ohne Nutzung von Reserven und Abbau von Körpersubstanz maximal erreichbare Milchleistung bei einem bcs von 3, also einer ausgewogenen Kondition, stellt den Vergleich bzw. das Ausgangsniveau dar und wird zunächst vom SMP ermittelt. Anschließend wird die Milchleistung um einen kleinen Betrag (100 kg je Kuh und Jahr) höher angesetzt, die dafür aus Körpersubstanz benötigte Energie kalkuliert und in Gewichtsverlust sowie bcs umgerechnet. Diese Erhöhung der Laktationsleistung wird solange wiederholt bis die Kuh mehr als 16 % ihres Gewichts in Milchleistung transformiert und damit den bcs von 1 unterschritten hat. Die Simulation wird bis in diesen Extrembereich fortgeführt, um festzustellen, ob die Kuh trotz dieser aus produktionstechnischer Sicht „unzulässigen" Konstellation in der Lage ist, ihr Ausgangsgewicht innerhalb der Laktationsperiode wieder zu erreichen. Bei allen hier dargestellten Ergebnissen ist , wenn nicht anders erwähnt, spätestens 30 Tage vor der nächsten Kalbung die Ausgangskonstellation wieder hergestellt und der bcs beträgt wieder 3, das Ausgangsgewicht zuzüglich des Gewichts des Fötus ist wieder erreicht. Im Fall von Erstkalbinnen umschließt das auch den Energie- und Nährstoffbedarf für das Wachstum.

Die Abbildungen 6 bis 11 weisen die Ergebnisse bis zu einem bcs unter 1 aus. Dieses Vorgehen dient ausschließlich der Veranschaulichung des Geschehens und darf keinesfalls als Empfehlung für Experimente oder für Milchviehhalter angesehen werden. Es soll den abnehmenden Grenzertrag verdeutlichen und der Bestimmung des optimalen Aufwandsniveaus dienen. Die Ergebnisse zeigen, dass sich die Effizienz der Milcherzeugung durch Körpersubstanzabbau unter diesen extremen körperlichen Konstellationen drastisch mindert.

Das SMP berücksichtigt stets das komplexe Geschehen im Bereich Futterbau und Milchproduktion. Aus methodischer Sicht ist anzumerken, dass der Ab- und Aufbau von Körpersubstanz ein Merkmal ist, das die Leistung beeinflusst und im Gegensatz zu vielen Anderen seine Bedeutung nicht einbüßt, auch wenn sich die übrigen Kennzahlen ändern.

Die den Abbildungen 3 bis 5 zu Grunde liegenden Funktionen erlauben es nicht, den zugehörigen jährlichen Leistungszuwachs direkt zu berechnen. Einerseits basiert das Leistungsgeschehen nicht auf linearen Beziehungen und andererseits führt die im ersten Laktationsdrittel höhere tägliche Milchleistung zu höheren Tagesleistungen in den nachfolgenden Dritteln.

Bei den Ergebnissen stehen weniger die Stellen nach dem Komma als vielmehr die Beziehungen und Relationen im Vordergrund. Die hier vorgestellten Resultate sind in enger Verbindung mit den bisher vorgelegten Arbeiten zu interpretieren und fügen sich harmonisch in die Strukturen der noch ausstehenden Beiträge zum Thema Krankheit, Klima etc. ein.

3 Abbau von Körpersubstanz und erzielbare Leistung

In Abbildung 6 wird die erzielbare Milchleistung in Abhängigkeit vom Ausmaß der Energiefreisetzung durch Abbau von Körpersubstanz dargestellt. Für eine Kuh

- in 2. Laktation,
- mit einem Lebendgewicht[5] von 675 kg,
- bei einem bcs von 3 am Laktationsbeginn,
- mit einer Zwischenkalbezeit (ZKZ) von 360 Tagen,
- entsprechend 300 Tagen Laktation zuzüglich 60 Tagen Trockenstehzeit,
- bei einem unterstellten Geburtsgewicht des Kalbes von 42 kg,
- mit ganzjähriger Verfütterung von Gras- und Maissilage höchster Qualität[6],
- mit Milchviehmischfutter höchster Energiestufe plus zwei kg Gerstenschrot,
- mit einer Futteraufnahme entsprechend den Vorgaben des NRC (2001) und
- bei einer Produktion ohne Störungen bzw. Erkrankungen

berechnet das SMP zunächst die Milchleistung, die direkt und allein aus dem Futter erzeugt werden kann, das ergibt bei den unterstellten Produktionsbedingungen eine Milchleistung von rd. 9.000 kg (Abbildung 6). Es folgt eine Erhöhung der Leistung, der Abbau von Körpersubstanz wird einbezogen und der zugehörige Gewichtsverlust kalkuliert. Wenn die Kuh ca. 4 % ihres Gewichts für die Leistung mobilisiert, dann steigt die erzielbare Leistung um rd. 500 kg und der bcs sinkt von 3 auf 2,5. Werden weitere Leistungssteigerungen aus Körpersubstanz zugelassen, ermöglicht der nächste halbe bcs Punkt zwar eine weitere Anhebung der Leistung, der jedoch nur noch um 450 kg liegt. Während der Einsatz der ersten 8 % Körpersubstanz (entsprechend eines Rückgangs des bcs von 3 nach 2) ca. 950 kg Mehrleistung erbringt, gestattet ein weiterer Gewichtsabbau von erneut 8 % nur noch eine Mehrleistung von 750 kg. Wird eine dritte Reduktion[7] um nochmals 8 % vorgenommen, reduziert sich der bcs von 1 auf 0 und kann nur noch Energie für ca. 400 kg zusätzliche Leistung freisetzen. Da das "Wiederanfüttern" dieser dritten und letzten mobilisierten 8 % mit einem zusätzlichen Aufwand für das Wiederanfüttern von über 20 % verbunden

[5] Das Gewicht nach dem Abkalben wird als Lebendgewicht angesetzt, wenn sich die Kuh zu diesem Zeitpunkt in durchschnittlicher körperlicher Konstitution befindet, also bei einem bcs von 3.

[6] Die Energie- und Nährstoffkonzentration liegt 10 % über den von der LuFa–Nord ausgewiesenen Konzentrationen (Meyer, 2008).

[7] Die Simulation bis zu einem bcs nahe Null stellt keine Empfehlung für die praktische Fütterung dar, sondern dient der Bewertung von Extremen. Der völligen Ausschöpfung der "letzten" körperlichen Reserven mit all ihren Risiken steht ein Leistungszuwachs von nur noch 400 kg gegenüber.

ist, wird der zugehörige Leistungszuwachs von nur 400 kg Milch mit deutlich überhöhtem Aufwand erzeugt. Erneut wird deutlich, dass dieser Bereich keinesfalls mit linearen Aufwands- und Ertragsrelationen kalkuliert werden darf, wie es die GfE (2001) empfiehlt.

Insgesamt fiele die Milchleistung um 1.500 bis 2.000 kg höher aus, würde die Fähigkeit der Kuh genutzt, Körpersubstanz in Leistung umzuwandeln. Da den Risiken für Gesundheit und Reproduktion erhebliche Leistungspotentiale gegenüberstehen, sollen die wichtigsten Faktoren dieser Beziehung zwischen zusätzlicher Leistung und Bereitstellung von Körpersubstanz analysiert und diskutiert werden.

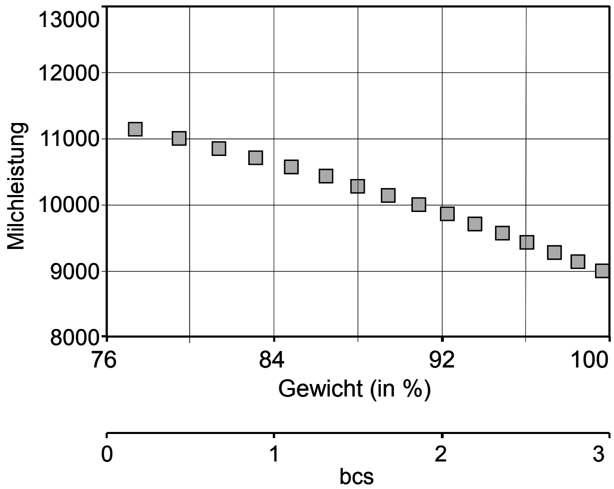

Abbildung 6:

Leistungsentwicklung bei Energiefreisetzung durch Abbau von Körpersubstanz

3.1 Verlauf der Laktationsfunktion

Die Höhe der Tagesleistung im Ablauf der Laktation unterscheidet sich von Kuh zu Kuh. Daher werden für eine Kuh mit 675 kg Gewicht, 25 kg Gewichtszuwachs und einer Jahresleistung von 9.000 kg Milch drei Typen der Laktationsfunktion[8] unterschieden:

Steil: Der Leistungsanstieg nach dem Kalben ist sehr hoch und das Nährstoffdefizit erreicht binnen weniger Wochen mehr als 30 kg Milchäquivalent pro Tag. Danach fällt die Leistung ebenso schnell wieder ab, nicht zuletzt, weil der Abbau von Körpersubstanz schon weit fort geschritten ist.

Flach: Die Tagesleistung steigt allmählich, erreicht nach rd. 3 Monaten ihr Maximum und nimmt dann langsam ab. Die höchste Tagesleistung bleibt 10 bis 20 kg unter derjenigen bei steiler Laktationsfunktion, die Jahresleistung ist jedoch um mehr als 1.500 kg höher.

Mittel: Die Tagesleistung liegt zwischen den beiden zuvor genannten Varianten, sie entspricht der von Olteanacu (1980) sowie der vom NRC (2001) entwickelten Funktion.

Zunächst zeigt Abbildung 7, dass bei gegebener Futterbasis und auch sonst gleichen Voraussetzungen eine Kuh mit flacher Laktationsfunktion, also hoher Persistenz, die höchste Jahresleistung erreichen kann. Je steiler die Leistung in den ersten Wochen der Laktation ansteigt (und später dann entsprechend schnell wieder abfällt), umso ungünstiger fallen die täglichen Aufwands- und Ertragsrelationen aus, die insgesamt eine geringere Gesamtleistung bedeuten.

Bei einem steilen Verlauf der Laktationsfunktion erreicht die Kuh mit den oben genannten Kennzahlen eine Jahresleistung von gut 8.000 kg Milch, wird keine Körpermasse für Milch mobilisiert. Wird der Abbau von 8 % der Körpermasse zugelassen, lässt sich die Jahresleistung um rd. 800 kg steigern. Der nächste Schritt, also der Abbau weiterer 8 % Körpersubstanz, bringt einen weiteren Anstieg, der jedoch nur noch 600 kg ausmacht. Der Einsatz von 16 % Körpersubstanz ermöglicht bei steilem Verlauf der Laktationsfunktion ein Leistungsplus von rd. 1.400 kg Milch. Bei flacher Laktationsfunktion ergibt sich für den Einsatz von 16 % Körpersubstanz eine Mehrleistung von fast 2.000 kg Milch, also ein um 600 kg höherer Zuwachs im Vergleich zur steilen Kurve.

Befindet sich die Laktationsfunktion auf dem mittleren Niveau, erreicht der Leistungszuwachs fast 1.700 kg, wenn der bcs von 3 bis auf den Wert 1 absinkt. Die Berechnungen zeigen deutliche Vorteile für Kühe mit flacher oder mittlerer Laktation, also höherer Persistenz.

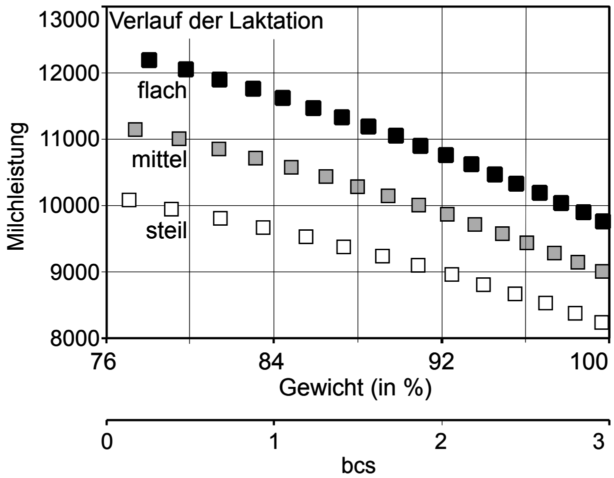

Abbildung 7:

Leistungsentwicklung bei Energiefreisetzung durch Abbau von Körpersubstanz bei unterschiedlichem Verlauf der Laktationskurve

[8] Eine grafische Darstellung und die zugehörige detaillierte Beschreibung der Laktationsfunktionen liefert die Bedienungsanleitung zum SMP (Walter, 2008 a)

3.2 Dauer der Zwischenkalbezeit

Ein Kalb je Jahr, also eine Zwischenkalbezeit (ZKZ) von 365 Tagen, gilt gegenwärtig als eine der Zielgrößen für die erfolgreiche Milchproduktion. Die Betriebe müssen sich im Mittel mit 380 bis 400 Tagen zufrieden[9] geben, nicht wenige Betriebe weisen mehr als 400 Tage auf. Es entsteht daher die Frage, wie die Dauer der ZKZ den Einsatz von Körpersubstanz zur Leistungssteigerung beeinflusst.

In Abbildung 8 wird für eine ZKZ von jeweils 360, 380, 400, 420 und 440 Tagen dargestellt, welche Leistung bei einem bcs von 3 erreicht wird, wenn zunächst keine körperlichen Reserven eingesetzt werden (jeweils rechtes Symbol in Abbildung 7). Mit zunehmender Umwandlung von Körpersubstanz in Leistung kann eine höhere Laktationsleistung erzielt werden. Die Ergebnisse für die ZKZ von 360 Tagen entsprechen denen aus den Abbildungen 6 und 7 (jeweils der mittlere Verlauf der Laktation). Die maximal erzielbare Milchleistung ohne Umwandlung beträgt 9.000 kg und steigt auf 10.500 kg durch einen Körpersubstanzabbau von 16 %, entsprechend einem bcs von nur noch 1. Wird die ZKZ von 440 Tagen dagegengestellt, so erreicht die Kuh 14.000 kg Milch ohne das Einschmelzen von Körpersubstanz. Die Leistung steigt auf fast 18.500 kg Milch, wenn die Kuh 16 % ihres Gewichts mobilisiert.

Abbildung 8 enthält für das Niveau der maximal erzielbaren Milchleistung zwei wichtige Informationen:

- Längere Zwischenkalbezeiten führen zu höheren Leistungen.
- Der Effekt der Umwandlung von Körpersubstanz in Milchleistung ermöglicht wesentlich größere Leistungszuwächse bei längerer ZKZ.

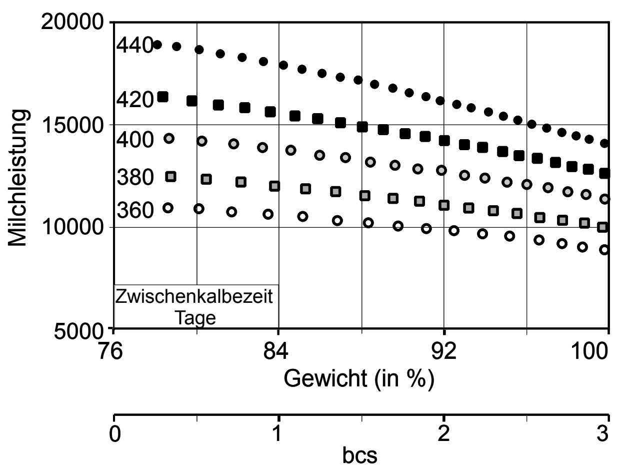

Abbildung 8:

Leistungsentwicklung bei Energiefreisetzung durch Abbau von Körpersubstanz bei unterschiedlicher Dauer der Zwischenkalbezeit

Höhere Leistungen bei längerer ZKZ lassen sich wie folgt erklären:

- Bei einer ZKZ von 360 Tagen sind 60 Tage Güstzeit zu kalkulieren und das entspricht 16,67 %, dagegen macht die gleiche Trockenstehphase bei 440 Tagen ZKZ nur 13,64 % aus.
- Die anteiligen Zeiten mit geringeren bzw. reduzierten Futteraufnahmen (Laktationsbeginn, Trächtigkeit) nehmen ebenfalls ab, so dass absolut und relativ mehr Energie und Nährstoffe für Leistung zur Verfügung stehen.
- Die "modernen HF - Blutlinien" weisen eine große Persistenz auf und halten über lange Zeiträume eine hohe Tagesleistung, wenn die Futterversorgung ausreicht (Rotz et al., 2005; Grossman et al., 2003).

Mit zunehmender ZKZ steigen die Milchleistungen deutlich, wenn Körperreserven in Milchleistung umgewandelt werden. Da die Milchleistungen bei den längeren ZKZ durch die Transformation von Gewicht in Leistung überproportional ansteigen, ist die Frage nach der optimalen Dauer der ZKZ neu zu stellen. Da für die Wirtschaftlichkeit der Milchproduktion alle Einnahmen und Kosten zu berücksichtigen sind, wie der Wert des Kalbes, die Unterschiede bei den anteiligen Aufzuchtkosten etc., liefert die hier dargestellte Leistungsentwicklung den ersten Hinweis auf eine sich ändernde Bewertung der Dauer der ZKZ.

3.3 Gewicht der Kuh

Die Umwandlung von Körpersubstanz in Leistung erweist sich als ein probates Mittel zur Steigerung der Leistung, dementsprechend kommt dem Lebendgewicht der Kühe, also der für diese Umwandlung zur Verfügung stehenden Körpersubstanz, große Bedeutung zu. Das Gewicht der Kühe unterscheidet sich deutlich, einmal zwischen den Rassen und zusätzlich zwischen den Individuen der gleichen Rasse. Mittels Simulation wird die Bedeutung des Lebendgewichts analysiert, die Ergebnisse stellt Abbildung 9 dar.

Die Simulation beginnt für die Kuh sofort nach dem Kalben, jeweils mit einem bcs von 3, also einem ausgewogenen Futterzustand (Abbildung 9, rechter Rand). Zunächst wird deutlich, dass Lebendgewicht und Leistung positiv korreliert sind (Brade, 2005; Durbal, 2001; NRC, 2001). Werden 16 % der Körpersubstanz in Leistung transformiert, also ein bcs von 1 erreicht, dann erzielt die Kuh mit einem Ausgangsgewicht von 575 kg einen Leistungszuwachs von 1.500 kg, mit 675 kg fast 1.750 kg und mit 775 kg sogar rd. 2.000 kg Leistungszuwachs aus Körpersubstanz. Ein um 100 kg höheres Gewicht ermöglicht eine zusätzliche Leistungssteigerung von 250 kg.

9 Vergleiche Rinderreport der Landwirtschaftskammer Schleswig - Holstein.

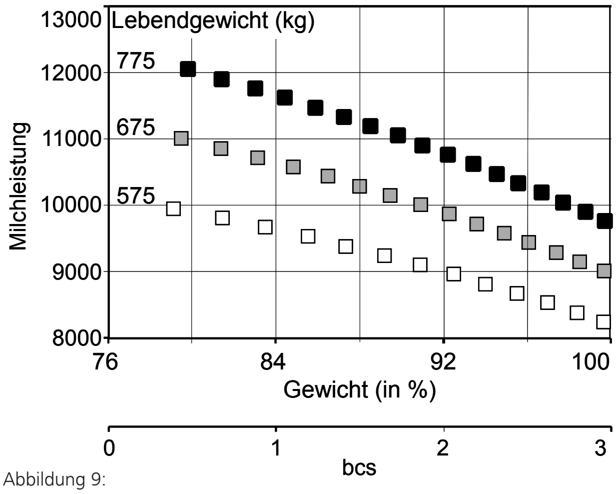

Abbildung 9:

Leistungsentwicklung bei Energiefreisetzung durch Abbau von Körpersubstanz bei unterschiedlichem Lebendgewicht der Kuh

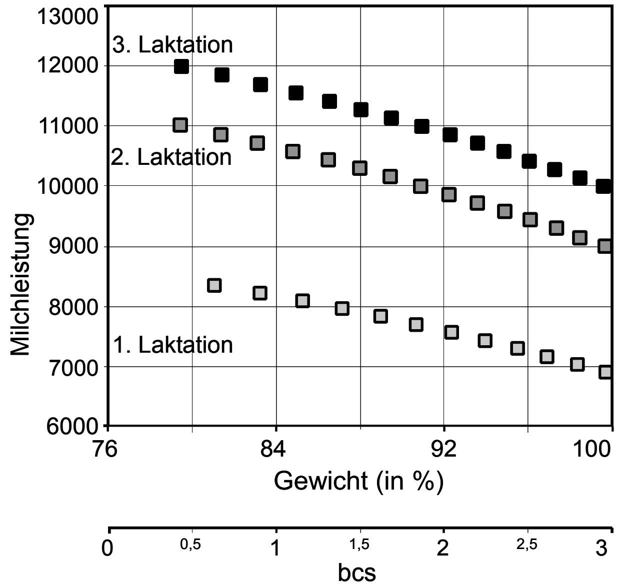

Abbildung 10:

Leistungsentwicklung bei Energiefreisetzung durch Abbau von Körpersubstanz für Kühe in 1., 2. und 3. Laktation

Aus diesen Ergebnissen kann geschlossen werden, dass die Züchtung größerer und schwererer Kühe eine Option der Leistungssteigerung darstellt. In den letzten Dekaden war eine Entwicklung zu größeren und schwereren Kühen festzustellen. Bei der Planung und Konzeption neuer Ställe sollte berücksichtigt werden, dass dieser Trend sich nicht zuletzt wegen der höheren Leistung und der ermittelten gewichtsbedingten Leistungszuwächse auch in Zukunft fortsetzen könnte.

3.4 Alter bzw. Zahl der Kalbungen

Während sich die Bewertung des Gewichts der Kühe vergleichsweise einfach aus den Vorgaben des NRC (2001) ableiten lässt, erfordert die Analyse des Alters (hier die Zahl der Kalbungen) ein differenzierteres Vorgehen. Erstkalbinnen sind noch nicht ausgewachsen, das gilt speziell für ein geringes Erstkalbealter. Da sie ihr Endgewicht noch nicht erreicht haben, steht für den Abbau weniger Körpersubstanz zur Verfügung, so dass zusätzlich je nach Erstkalbealter ein Wachstum mit einer Gewichtszunahme von 8 % bis 12 % zum Erreichen des Endgewichts zu berücksichtigen ist.

Abbildung 10 weist die höchstmöglichen Leistungen der Erstkalbinnen und älteren Kühe für ein unterschiedliches Ausmaß der Umwandlung von Körpersubstanz in Milchleistung aus. Die Resultate für die Kuh in 2. Laktation sind identisch mit denen aus Abbildung 9 bei 675 kg, denen aus Abbildung 8 mit 360 Tagen ZKZ und denen aus Abbildung 7 bei mittlerer Laktationsfunktion. Nach der dritten Kalbung ließe sich eine um 1.000 kg höhere Milchleistung und ein um knapp 200 kg höherer Leistungszuwachs erzielen, wenn 16 % der Körpersubstanz für die Milchproduktion mobilisiert werden, also die Kuh einem bcs von nur noch 1 zuzuordnen wäre.

Für die Kuh in erster Laktation wird hier ein Erstkalbealter von nur 26 Monaten unterstellt. Sie erreicht in der Ausgangssituation (bcs 3) mit knapp 7.000 kg eine deutlich geringere Leistung. Aber auch der Leistungszuwachs fällt im Vergleich zu den älteren Kühen um fast ein Drittel niedriger aus. Die Ursache liegt zunächst im geringeren Gewicht der jungen Kuh (vergleiche Abbildung 9), daneben aber auch in dem zusätzlichen Bedarf für Wachstum. Das SMP unterstellt in Anlehnung an die vom NRC (2001) entwickelten Grundsätze ein kontinuierliches Wachstum, so dass weniger Körpersubstanz für Leistung verfügbar gemacht und dafür in Wachstum umgewidmet wird.

Die in Abbildung 10 dargestellten vergleichsweise geringeren Leistungszuwächse der Kuh in erster Laktation ergeben sich aus dem hier unterstellten frühen EKA und damit dem großen Wachstumsbedarf. Bei höherem EKA mindern sich die Unterschiede zu den älteren Kühen in dem Maße wie sich die Gewichte zur Zeit der Kalbung annähern.

Bei der Bewertung der Eignung von Erstkalbenden sind diese Sachverhalte und Beziehungen zu berücksichtigen, um eine korrekte Leistungseinschätzung vornehmen zu können.

3.5 Kondition am Laktationsbeginn

Da die Kuh Körpersubstanz in Leistung umwandeln kann, liegt es nahe, das Tier vor dem Kalben stärker auszufüttern und auf diesem Weg die Leistungssteigerung der nächsten Laktation so intensiv als möglich zu unterstützen. Andererseits gibt es Kühe, die u. a. durch Krankheit in unausgewogener Kondition in die Laktation starten.

Daher wird in Abbildung 11 dargestellt, welche Leistungssteigerungen rechnerisch zu erreichen wären, würde die Kuh mit unterschiedlicher Kondition, also mit einem geringeren oder höheren bcs in die Laktation starten.

Die Kondition bzw. das Über- oder Untergewicht der Kuh am Beginn der Laktation entscheidet über das Ausmaß der in Leistung umwandelbaren Körpersubstanz und damit über die Höhe des Leistungszuwachses. Kühe, die mit dem bcs von 1, also „ausgemergelt" in die Laktation gehen, könnten selbst, wenn sie nochmals 4 % Körpersubstanz (Abbildung 11, Graph unten links) aufbrächten, nur noch 300 bis 400 kg Mehrleistung aus Körpersubstanz erzeugen. Startet die Kuh nach dem Kalben mit einem bcs von 2 und baut ihre Körpersubstanz bis zu einem bcs von 1 (0,5) ab, lässt sich damit ein Leistungszuwachs von 700 (1.000) kg Milch erreichen.

Beginnt die Kuh die Laktation mit einer Kondition gemäß bcs 4 oder 5, dann kann die Körpersubstanzumwandlung rechnerisch 2.700 kg (vom bcs 4 bis 1) oder gar 4.000 kg Milchleistung (vom bcs 5 bis 1) erbringen. Die in den Abbildungen 3 und 4 dargestellten Beziehungen zwischen bcs und Energiegewinn erklären die Progression der in Abbildung 11 dargestellten Leistungszuwächse, die sich theoretisch aus dem Start mit einem deutlich höheren bcs ergeben.

Die Beratung empfiehlt, die Kühe zur Zeit der Kalbung bzw. am Laktationsbeginn entsprechend einem bcs von etwa 3 bis 3,5, maximal bis 4 zu konditionieren, weil

- die Kälber in den letzten Wochen vor der Geburt nicht zu sehr zunehmen sollen, da es die Geburt erschwert,
- die Überfütterung vor dem Kalben den Anstieg der Futteraufnahme danach verzögert und
- fette Kühe zu Beginn der Laktation häufiger von Stoffwechselerkrankungen[10] betroffen sind.

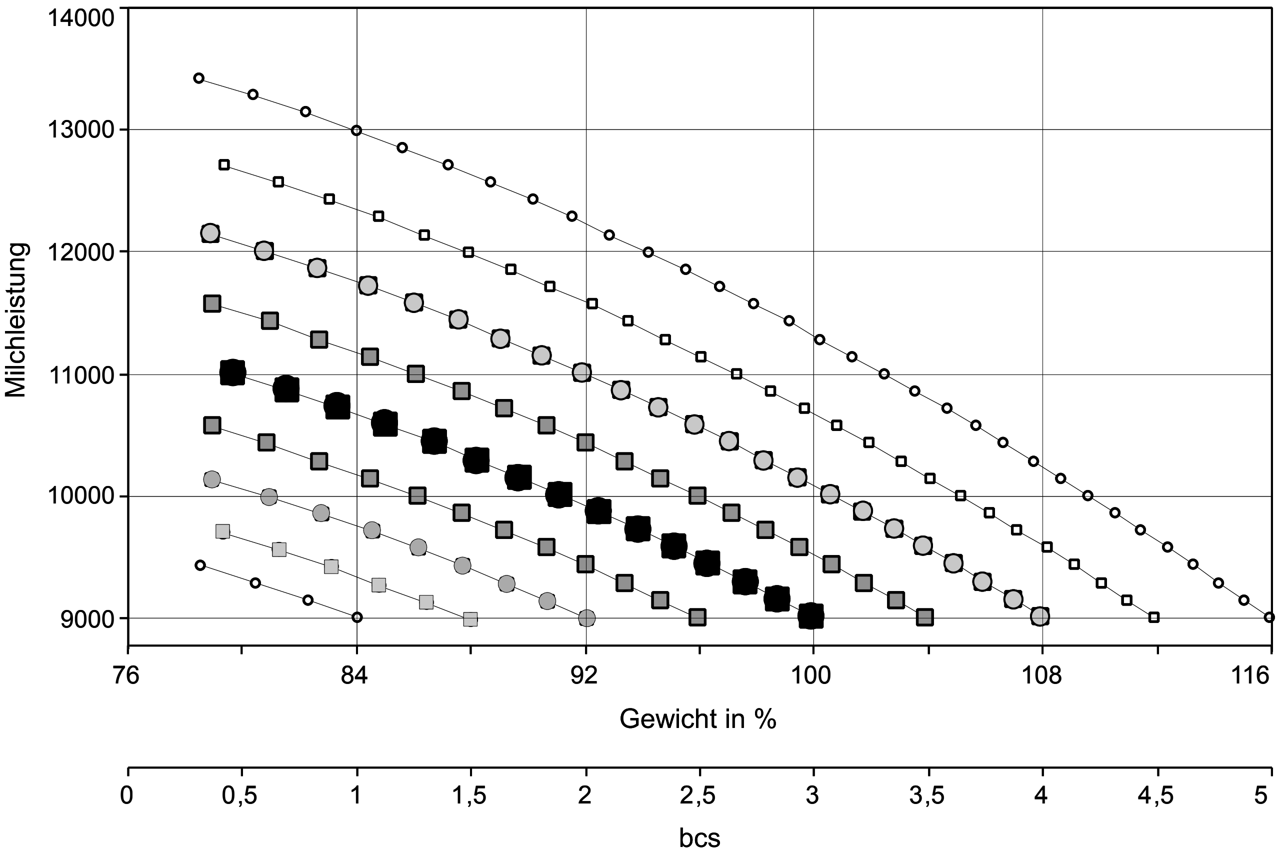

Abbildung 11:

Leistungsentwicklung bei Energiefreisetzung durch Abbau von Körpersubstanz bei unterschiedlichem bcs am Laktationsbeginn

[10] Die Bedeutung von Stoffwechselerkrankungen, Lahmheiten, Mastitis etc. für Futteraufnahme und Leistung bleibt späteren Analysen vorbehalten.

Die Überfütterung bzw. eine „Mastkondition" führen bei Hochleistungskühen zu einer verminderten Futteraufnahme und zu Ketosen, Fettleber, etc. (Drackley, 2005; Staufenbiel, 2005; Evans, 2003; Kaske, 2006; Robinson, 2006). Diese Erkrankungen führen nicht nur zum Leistungseinbruch, sondern haben nicht selten eine erhebliche Reduzierung der Futteraufnahme zur Folge, diese wiederum vergrößern die Energie- und Nährstoffdefizite zusätzlich und verschärfen die Probleme am Beginn der Laktation nochmals.

Der rechnerisch erzielbaren Leistungssteigerung durch Start in die Laktation bei bcs 4 oder 5 steht die von einigen Autoren (Drackley, 2005; Evans, 2003; Kaske, 2006; Robinson, 2006) festgestellte Minderung des Futteraufnahmevermögens verfetteter Kühe gegenüber. Damit steht der Leistungssteigerung durch Umwandlung von mehr Körpersubstanz eine Leistungsminderung durch eine reduzierte Futteraufnahme entgegen. In Tabelle 1 wird das Ergebnis weiterer Kalkulationen dargestellt und nennt den Einfluss reduzierter Futteraufnahmen im ersten Drittel der Laktation auf die Leistung.

Tabelle 1:

Bedeutung der Minderung der Futteraufnahme für die erzielbare Leistung (Kuh mit 675 kg Gewicht, 25 kg Gewichtszuwachs, 2. Laktation, ZKZ 360 Tage)

Berechnung der Futteraufnahme nach	Minderung der Futteraufnahme in den ersten 100 Tagen der Laktation (%)	Bei Minderung der Futteraufnahme noch erzielbare Leistung in % der Ausgangsleistung
NRC (2001)	2,5	98,9
	5,0	97,6
	7,5	96,2
	10,0	94,7
	12,5	93,0
	15,0	91,0
Robinson (2006)	2,5	98,9
	5,0	97,8
	7,5	96,7
	10,0	95,5
	12,5	94,3
	15,0	93,0

Die in Tabelle 1 ermittelten Leistungseinbußen machen die Risiken einer durch Verfettung verursachten Minderung der Futteraufnahme deutlich. Der Leistungserhöhung durch Abbau von zusätzlicher Körpersubstanz bei hohem bcs steht ein ebenso deutlicher Leistungsrückgang bei verminderter Futteraufnahme gegenüber. Da die Literatur nur qualitative aber keine quantitativen Aussagen über das Niveau des bcs und dessen Bedeutung für die Futteraufnahme bietet, lassen sich keine genaueren Abwägungen vornehmen. Die Vorteile eines Starts in die Laktation mit hohem bcs fallen nach Gegenüberstellung mit den hier unterstellten Abnahmen des Futteraufnahmevermögens nur noch sehr gering aus. Die Leistungseinbrüche und die deutlich höheren gesundheitlichen Risiken sprechen somit gegen einen Start mit bcs 5 in die Laktation.

3.5 Dauer der Defizite[11] und mehrperiodischer Ansatz

Die Mobilisierung von Körpersubstanz zur Erzeugung von Milch führt zu erheblichen Gewichtsverlusten und zu einem entsprechenden Absinken des bcs. Dieser Abbau von Körpersubstanz ist wieder auszugleichen, damit die Kuh nicht mit unausgewogener Energie- und Nährstoffbilanz in die nächste Laktation beginnen muss. Defizite aus der vorhergehenden Produktionsperiode mindern das aktuelle Leistungsvermögen, bzw. belasten die in der Hochleistungsphase erneut entstehenden Energie- und Nährstoffungleichgewichte.

Daraus wird deutlich, dass aus methodischer Sicht nicht eine Zwischenkalbezeit allein, sondern die Vorhergehende und die Nachfolgende mit zu berücksichtigen sind. Abbildung 12 zeigt die maximal erzielbaren Milchleistungen, das Entstehen und den Ausgleich der Defizite, die Futteraufnahmen sowie die Gewichtsentwicklung und den zugehörigen bcs für die ersten drei Laktationen.

Neben den allgemein als wichtig angesehenen Zeitpunkten, wie Kalbetermin, Belegen und Trockenstellen, gewinnen in diesem Zusammenhang drei zusätzliche Termine an Bedeutung, bzw. sind in die Liste der kritischen Kennzahlen aufzunehmen:

- Der Tag, an dem die Energiebilanz erstmals ausgeglichen ist, der gleichzeitig den Zeitpunkt des maximalen Energiedefizits und den Wendepunkt in der Entwicklung der Gesamtbilanz darstellt.
- Den Zeitpunkt der erstmals ausgeglichenen Energiebilanz der Zwischenkalbezeit.
- Den 190. Tag der Trächtigkeit, an dem nach NRC (2001) erstmals der Energie- und Nährstoffbedarf des Fötus nennenswerte Bedeutung erlangt und berücksichtigt werden muss.

Abbildung 12 und Tabelle 2 zeigen, dass ab der zweiten Laktation, also bei den älteren Kühen, am 262. bzw. am 255. Tag der Bilanzausgleich erreicht ist.

Bei den Kühen in erster Laktation ist zusätzlich das Wachstum zu berücksichtigen. Aus Abbildung 12 und Tabelle 2 wird deutlich, dass erst am 300. Tag der Laktation, also zeitgleich mit dem Trockenstellen, die Energiebilanz

[11] Die Analyse basiert auf der Zielvorstellung, dass die maximale Leistung erreicht werden soll, um den höchstmöglichen Deckungsbeitrag und Gewinn zu erzielen.

ausgeglichen werden kann. Das Wachstum und die Versorgung des Fötus mussten bis zu diesem Zeitpunkt mit der Leistung, dem Wiederaufbau der Reserven und der Körpersubstanz konkurrieren.

Die zusätzlich in die Analyse einbezogenen Kennzahlen „erstmals ausgeglichene energetische Tagesbilanz" und „erstmals ausgeglichene Energiebilanz der ZKZ" verdeutlichen die Probleme bei der Versorgung der Hochleistungskühe, speziell der Kühe in erster Laktation. Diese Kennzahlen offenbaren die Engpässe der energetischen Versorgung, wenn das Nährstoffdefizit aus dem ersten Laktationsdrittel noch nicht ausgeglichen ist und gleichzeitig die Energie- und Nährstoffansprüche der Reproduktion sowie des Wachstums zu befriedigen sind, wenn also drei Ansprüche um die Energie aus der begrenzten täglichen Futteraufnahme konkurrieren. Die Futteraufnahme wird nach den von NRC (2001) vorgeschlagenen Grundsätzen kalkuliert. Werden die von Gruber (2006) oder Robinson (2006) entwickelten Ansätze zur Bestimmung der Futteraufnahme genutzt, so fällt diese höher aus, weil beide eine positive Beziehung zwischen Grundfutterqualität und Futteraufnahme unterstellen. Wenn diese Schätzer realitätsnäher sind, dann würden die Energiedefizite geringer ausfallen, kürzer andauern als in Tabelle 2 dargestellt und die Kuh weniger belasten.

Weiterhin machen diese Kalkulationen deutlich, dass mit steigendem Leistungsniveau die Dauer der unausgewogenen Energiebilanz immer länger und damit zum "Normalzustand" wird. Dieser Sachverhalt trifft insbesondere für die Milchkühe in erster Laktation zu. Die Kühe der Holstein Frisian Blutlinien, also der auf hohe Milchleistung gezüchteten Rasse, weisen diese genetisch manifestierte Fähigkeit in hohem Maße auf. Sie vermögen den mit diesen lang andauernden Energie- und Nährstoffdefiziten verbundenen Belastungen Stand zu halten. Daher ist das Abrufen und der später notwendige Wiederaufbau von Körpersubstanz ein integraler Bestandteil der Leistung und auch der Leistungssteigerung und sollte von den Milchviehhaltern genutzt werden.

Über 12 % der Milchleistung wird durch Ab- und Wiederaufbau von Körpersubstanz erzeugt (Tabelle 2) und bedeutet für Kühe, dass sie mehr als 70 % einer ZKZ von 360 Tagen in energetisch unausgewogener Kondition produzieren. Erstkalbinnen befinden sich sogar länger als 80 % im Energiedefizit (Tabelle 2).

Damit steigen die Anforderungen derart geforderter Hochleistungskühe an die Haltungsbedingungen und an die Fütterversorgung, so dass nur mit einem ausgefeilten Management eine erfolgreiche Milchproduktion möglich ist.

Tabelle 2:
Ergänzende Kennzahlen zu der Kuh in 1., 2. und 3. Laktation (Abbildung12)

	Kuh in		
	1. Laktation	2. Laktation	3. Laktation
Dauer der ZKZ (Tage)	360	360	360
Dauer der Trächtigkeit (Tage)	280	280	280
Milchleistung (kg / 360 Tage ZKZ)	8375	9920	10575
Maximales Energiedefizit (kg Milch)	1050	1250	1280
in v. H. der Milchleistung	12,5	12,6	12,1
erster Tag mit ausgeglichener energetischer Tagesbilanz	123	110	108
erster Tag mit ausgeglichener energetischer Gesamtbilanz	300	262	255
Defizitäre Phase in v. H. der ZKZ	84	73	71
Gewicht der Kuh am Laktationsbeginn	625	675	700
Wachstum der Kuh (kg)	50	25	0
Gewicht bei maximalem Energiedefizit (kg)	517	566	590
Gesamtgewicht des Fötus (kg)	52	56,5	58
davon Geburtsgewicht des Kalbes (kg)	38	41	43
Gesamtfutteraufnahme (kg TS)	6100	7060	7250
von Kraftfutter (kg TS)	2250	2200	2050

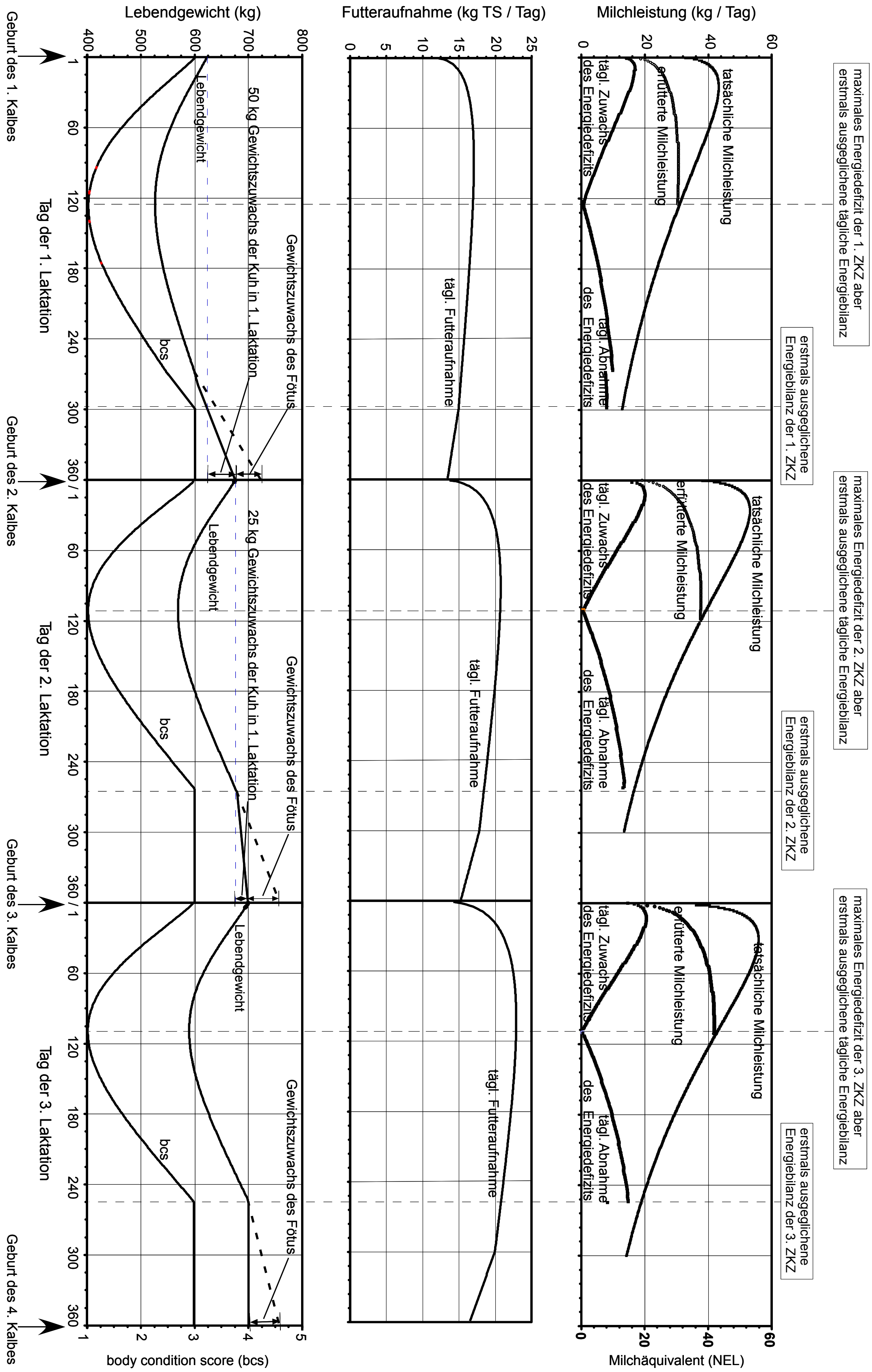

Abbildung 12:

Laktationsfunktionen, Futteraufnahmen, Gewichtsentwicklung und „body condition score“ der ersten drei Laktationsperioden

4 Bewertung und Ausblick

Die Leistungszuwächse in den letzten Jahrzehnten sicherten die Einkommen trotz zunehmend ungünstigeren Preisrelationen. Diese Entwicklungslinien werden sich langfristig nur wenig ändern, so dass Leistungs- und Effizienzsteigerungen auch weiterhin erforderlich sind.

Daraus erwächst die Notwendigkeit die genetisch manifestierte Fähigkeit der Kuh zu nutzen, Körpersubstanz in Milch umzuwidmen. Diese eingesetzte Körpersubstanz gilt es zügig wieder aufzubauen, um die Dauer der defizitären Bilanzen so kurz wie möglich zu halten. Das bedeutet für die Milchproduktion eine Gratwanderung zwischen höherer Leistung und Gesundheitsgefährdung. Weiterhin werden nicht nur die Abkehr von einer auf einzelne Fütterungsabschnitte bezogene Rationsbemessung, sondern auch komplexere Ansätze zur Bestimmung der optimalen Fütterung notwendig. Die Mobilisierung und der Wiederaufbau von Reserven führen in den Bereich komplexer nichtlinearer Aufwands- und Ertragsbeziehungen, die sich nicht mehr mittels einfacher Ansätze durchdringen lassen. Vielmehr sind mehrperiodische Optimierungsansätze in Verbindung mit ganzheitlichen Simulationen erforderlich, um problemadäquate Lösungen zu erzielen.

Eine Milchproduktion mit Tieren, die weit über 10.000 kg Milch geben, lässt sich nur dann noch erfolgreich gestalten, wenn bestmögliche Haltungsbedingungen geschaffen und für die Ernährung von Wiederkäuern optimale Grundfuttermittel erzeugt werden. Die Milchviehhalter werden mit vielen nicht selten widersprüchlichen Forderungen und Empfehlungen der unterschiedlichen Disziplinen (Ökonomie, Ökologie, Veterinärmedizin, Hygiene- und Qualitätsvorschriften, etc.) konfrontiert, die sie nur schwer gegeneinander abwägen und bewerten können, um ein für ihren Betrieb optimales Verfahren erreichen zu können.

Der Abbau und später erforderliche Wiederaufbau von Körpersubstanz ist ein in der Natur manifestiertes Konzept der Leistungssicherung und -steigerung. Milchviehhalter nutzen diese Fähigkeit, um mit hohen Leistungen eine profitable Milchproduktion zu erzielen. Die Ergebnisse der Kalkulationen verdeutlichen, dass ein erheblicher Anteil der Leistungssteigerungen auf die Umwandlung von Körpersubstanz in Milchleistung zurückzuführen ist. Diese Erkenntnisse bedürfen einer Neubewertung der damit verbundenen gesundheitlichen Risiken. Die Milchproduktion mit Hochleistungskühen kann auf diese Transformation nicht verzichten, da es um deren Nutzung bei gleichzeitiger Minimierung der Risiken geht.

Abbildung 12 und Tabelle 2 verdeutlichen, dass Hochleistungskühe über zwei Drittel der ZKZ mit defizitärer energetischer Bilanz produzieren. Daher ist eine verlängerte ZKZ eher eine Reaktion der Kuh um sich mehr Zeit in ausgeglichener Bilanz zu verschaffen. Das wiederum mindert die Belastung und könnte zu einer Neubewertung der Dauer der ZKZ führen.

Je höher die Leistungen steigen und je restriktiver die Anforderungen an die Produktqualität formuliert werden, umso mehr "know how" ist für eine erfolgreiche Milchproduktion erforderlich. Beratung und Wissenschaft sind in Zugzwang und müssen sich der Komplexität von Futterbau und Milchproduktion[12] im betrieblichen Umfeld stellen. Die Empfehlungen der verschiedenen Spezialisten sind miteinander abzustimmen und einer umfassenden Optimierung mit jeweils betriebsspezifischer Zielfunktion zu unterwerfen.

Die Ergebnisse dieser Arbeit machen deutlich, dass die Mobilisierung von Körpersubstanz ein Eckpfeiler für hohe Leistungen darstellt und es gilt diese Fähigkeit zu nutzen, ohne die gesundheitlichen Risiken ansteigen zu lassen.

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Consistent time series of data to model volatile solids and nitrogen excretions of poultry 3a. Broilers. Fattening procedures and animal properties

Hans-Dieter Haenel* and Ulrich Dämmgen**

Summary

Broilers' excretions of nitrogen and carbon relevant to gaseous emissions are depending on animal performance, i.e. on weight and weight gain rates. Weight gains are primarily governed by genetic preposition. However, they also depend on other factors such as feeding, stocking density, diseases, and broiler house indoor climate. In addition, final animal weights are depending on the duration of the fattening period.

Emission reporting for ammonia requires an assessment of excretions with an adequate resolution in space and time. In principle, this is possible. However, in Germany, the data needed for this purpose are not available on a regular basis.

This paper deals with the basics for an improved method to assess excretions by the German broiler production. The new method itself will be presented in a companion paper (Haenel and Dämmgen, 2009).

Keywords: broiler, VS excretion, N excretion, Ammonia, emission inventory

Zusammenfassung

Konsistente Zeitreihen von Daten zur Modellierung der Ausscheidungen von „volatile solids" und Stickstoff bei Geflügel
3a. Masthähnchen und -hühnchen. Mastverfahren und Tiereigenschaften

Die emissionsrelevanten Stickstoff- und Kohlenstoff-Ausscheidungen von Masthähnchen und -hühnchen sind leistungs-, d. h. gewichts- und zuwachsabhängig. Der Gewichtszuwachs wird vorrangig durch genetische Veranlagung bestimmt, hängt aber auch von Faktoren wie Fütterung, Besatzdichte, Erkrankungen und Stallklima ab. Die erreichbaren Tierendgewichte sind überdies eine Funktion der Mastdauer.

Die Berichterstattung für Ammoniak-Emissionen erfordert eine angemessene räumlich und zeitlich differenzierte Beschreibung der Ausscheidungen. Dies ist im Prinzip möglich, scheitert aber daran, dass die benötigten Daten in Deutschland nicht regelmäßig zur Verfügung stehen.

Die vorliegende Arbeit beschreibt die Grundlagen für ein verbessertes Verfahren zur Berechnung der Ausscheidungen bei Masthähnchen und -hühnchen in Deutschland, das in einer ergänzenden Publikation (Haenel und Dämmgen, 2009) vorgestellt wird.

Schlüsselwörter: Masthähnchen, Masthühnchen, Broiler, VS-Ausscheidung, N-Ausscheidung, Ammoniak, Emissionsinventar

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1 Introduction

As highlighted by Steinfeld et al. (2006), agricultural animal production plays an important role in the generation of the anthropogenic greenhouse effect. In addition, the contribution to the emission of gaseous and particulate air pollutants is so important that this sector has to be included in any measures to reduce emissions (BMU, 2006; Dämmgen and Haenel, 2008). A prerequisite to any reduction measures is an adequate description of the emitting processes as well as an assessment of the frequency with which they occur. In Germany, the national emission inventories provided to comply with the reporting obligations within the Framework Convention on Climate Change (UNFCCC, 1997) and the Geneva Protocol on Long Range Transport of Atmospheric Pollutants (UNECE, 2006) serve this purpose. The annual reports describe not only the emissions themselves and the respective process models, but also the emission explaining variables, if possible, as a continuous time series from 1990 onwards.

Emissions from so-called key sources should be assessed with an adequate resolution in time and space. For ammonia, poultry as a whole is considered a key source with respect to the amount emitted. Ammonia has a comparatively short atmospheric lifetime. This again should be reflected by a high resolution of the emission calculations in time and space. In addition, broiler production in Germany has been increasing over time and therefore has to be regarded as a key source with respect to its trend (cf. e. g. ZMP, 1990 to 2006).

Within the calculation procedures depicting emissions from animal production, the adequate assessment of the excretions of carbon and nitrogen compounds is a major prerequisite (Webb et al., 2005). However, due to lack of suitable data and calculation procedures, the emissions from German broiler production have been reported using a comparatively simple method reported in the literature (Dämmgen et al., 2007).

This paper deals with the basics for an improved method to assess excretions by the German broiler production. The new method itself will be described in detail in a companion paper (Haenel and Dämmgen, 2009), which also presents the derivation of the time series of the parameters relevant for emission estimations. The calculations reflect the information provided by both husbandry and animal nutrition. However, the papers aim at a complete description of the processes and data, irrespective of their importance within animal nutrition.

Similar contributions dealing with pullets and laying hens were published recently (Haenel and Dämmgen, 2007a, 2007b).

1 Einleitung

Spätestens seit Steinfeld et al. (2006) ist deutlich, dass die landwirtschaftliche Tierproduktion zu einem großen Anteil am anthropogenen Treibhauseffekt beteiligt ist. Ihre Rolle bei der Emission luftverschmutzender Stoffe ist so erheblich, dass die Landwirtschaft in Minderungsmaßnahmen einbezogen werden muss (BMU, 2006; Dämmgen und Haenel, 2008). Solche Minderungsmaßnahmen setzen voraus, dass die emittierenden Prozesse und ihre Häufigkeit hinreichend gut beschrieben werden können. Hierzu dienen in Deutschland die nationalen Inventare, die gleichzeitig die Erfüllung der internationalen Berichtspflichten im Zusammenhang mit der Klimarahmen-Konvention (UNFCCC, 1997) und dem Genfer Luftreinhalteabkommen (UNECE, 2006) ermöglichen. Die jährlich erstellten Inventarberichte beschreiben neben den Emissionen auch die Prozesse, die sie hervorrufen, und ihre Modellierung und dokumentieren die die Emissionen bestimmenden Variablen als möglichst lückenlose Zeitreihen ab 1990.

Emissionen aus so genannten Hauptquellgruppen sollen mit einer angemessenen zeitlichen und räumlichen Auflösung bestimmt werden. Geflügel insgesamt ist eine Hauptquellgruppe für Ammoniak bezüglich der Höhe der Emissionen. Bei Ammoniak spricht insbesondere die geringe atmosphärische Verweildauer für die feine Auflösung von Emissionsberechnungen. In der Geflügelhaltung in Deutschland stellt die Produktion von Masthähnchen und -hühnchen (Broiler) eine Emissionsquelle mit zunehmender Tendenz dar (vgl. z. B. ZMP, 1990 bis 2006).

Eine wichtige Voraussetzung für die Berechnung von Emissionen aus der Nutztierhaltung ist eine zutreffende Quantifizierung der Ausscheidungen von Kohlenstoff- und Stickstoff-Verbindungen (Webb et al., 2005). Mangels geeigneter Datensätze und Rechenverfahren wurden die Emissionen aus der Masthähnchen-Produktion bisher allerdings nur mit nationalen Mittelwerten (Literaturdaten) nach einem vergleichsweise einfachen Verfahren gerechnet (Dämmgen et al., 2007).

Die vorliegende Arbeit beschreibt die Grundlagen für ein verbessertes Verfahren zur Berechnung der Ausscheidungen bei Masthähnchen und -hühnchen in Deutschland. Darauf aufbauend wird in einer ergänzenden Publikation (Haenel und Dämmgen, 2009) die Ermittlung der Zeitreihen der emissionsrelevanten Parameter beschrieben. Die Berechnungen beruhen auf Erkenntnissen aus Tierhaltung und -ernährung. Dabei steht, unabhängig von der Bedeutung einzelner Teilprozesse für die Tierernährung, die möglichst vollständige Prozess- und Datenbeschreibung im Vordergrund.

Entsprechende Arbeiten zu Junghennen und Legehennen gingen dieser Arbeit voraus (Haenel und Dämmgen, 2007a, 2007b).

2 Fattening procedures and durations

The various broiler production intensities are coined by their respective duration and the final weights obtained. Another important characteristic is the service time between any two fattening periods.

The fattening procedures applied in Germany differ with respect to their duration. Rapid fattening, intermediate fattening, split fattening, extended fattening (both conventional and organic) can be observed. However, rapid fattening and split fattening are dominating. Only in extended fattening are cocks and hens kept separately; in all other cases both genders are fattened together.

The respective typical duration of the fattening process, the numbers of animal rounds per year and the final weights obtained are listed in Table 1.

2 Mastverfahren und Mastdauer

Hähnchen-Mastverfahren werden durch Mastdauer und Tierendgewicht geprägt. Ein weiteres Verfahrensmerkmal ist die für die Reinigung benötigte Zeit zwischen zwei Mastperioden.

Die in Deutschland eingesetzten Mastverfahren gliedern sich in Kurzmast, Mittellangmast, Splittingmast, Langmast und ökologische Langmast. Bevorzugt werden in Deutschland Kurzmast und Splitting-Verfahren. Mit Ausnahme der Langmast, in der Hähne und Hennen getrennt gehalten werden, werden Tiere beider Geschlechter gemeinsam gemästet.

Mastdauer, Reinigungsdauer, Anzahl der Mastdurchgänge pro Jahr und Lebendendgewicht werden nach Mastverfahren getrennt in Tabelle 1 wiedergegeben.

Table 1:

Data characterizing German broiler production procedures

Tabelle 1:

Verfahrenskennwerte zur Hähnchenmast in Deutschland

Fattening procedure	**Sources** (*)	**Characteristics**			
		duration of fattening period d round^{-1}	service period d round^{-1}	animal rounds per year round a^{-1}	final weight g animal^{-1}
rapid fattening (Kurzmast)	1	32 - 34	12.5	8.1	1500
	2	32 - 35			1400 - 1700
	3	33 - 35	12.5	7.9	1500
intermediate fattening (Mittellangmast)	1	38 - 40	13.4	6.7	2000
fatteing for intermediate weights („Mittelschwere Mast“)	2	40 - 42			1700 - 2000
semi-extended fattening („verlängerte Mast“)	3	38 - 42	13.4	7.1	2000
split fattening (Splittingverfahren)					
lot A	1	30 - 32	12.7	7.2	1500
lot A	3	33	12.7		1500
lot B	1	40	12.7	7.2	2200
lot B	3	42	12.7	7.1	1850 - 2000
extended fattening (Langmast)	1	50 - 60	17.6	4.8	2000 – 3000
	2	41 - 51			2000 – 2800
	3	50 - 60	17.6	5.0	2000 - 3000
	4	40 - 45 (hens)			2000 - 2200
	4	50 - 60 (cocks)			2800 - 3300
extended fattening in organic farming (ökologische Langmast)	3	56 - 81	21	4.5	2000 - 3000

(*) Sources: 1: LWK-NW (2006); 2: Sudhop (2008); 3: KTBL (2004), pg. 507; 4: Berk (2005)

The actual duration of fattening procedure is identical with the animal lifespan. It is also the time during which an animal occupies an animal place.

The fattening period is followed by the cleansing period also denoted as service time. The addition of the durations of fattening and cleansing periods yields the duration of the animal round. This can also be treated formally as the product of fattening days and the duration of a day.

Die Mastdauer wird auch als Haltungsdauer oder Lebensdauer bezeichnet. Sie gibt den Zeitraum an, während dessen ein Tier einen Tierplatz besetzt.

Nach der Ausstallung folgt die Reinigungs- oder Servicezeit. Die Summe aus Haltungsdauer und Reinigungsdauer ergibt die Durchgangsdauer, die sich auch als Produkt von Masttagezahl und der Dauer eines Tages darstellen lässt:

$$\tau_{\mathrm{round}} = \tau_{\mathrm{lifespan}} + \tau_{\mathrm{service}} = \mathrm{k}_{\mathrm{fin}} \cdot \tau_{\mathrm{day}} + \tau_{\mathrm{service}} \qquad (1)$$

where

τ_{round}	duration of round (in d round^{-1})
τ_{lifespan}	span of lifetime within a round (in d round^{-1})
τ_{service}	time needed for cleansing prior to new round (in d round^{-1})
$\mathrm{k}_{\mathrm{fin}}$	number of the final day of fattening period
τ_{day}	time period of one day (τ_{day} = 1 d round^{-1})

The number of animal rounds is derived directly from the duration of animal rounds. The unit for rounds per year is equivalent to the unit of animals per place and year

Aus der Durchgangsdauer folgt unmittelbar die Durchgangszahl, wobei die Einheit für „Durchgang" äquivalent zur Einheit „Tier pro Platz und Jahr" ist:

$$n_{\mathrm{round}} = \frac{\alpha}{\tau_{\mathrm{round}}} \qquad (2)$$

where

n_{round}	number of rounds per year (round a^{-1} = animal place^{-1} a^{-1})
α	time unit conversion factor (α = 365 d a^{-1})
τ_{round}	duration of round (in d round^{-1})

With respect to the needs of Section 4.2, a derivation of the duration of the service period from the duration of the fattening period is required. It can be obtained from the characteristics of the various fattening procedures listed in Table 1, and can be expressed as in equation (3) and Figure 1 using the data as compiled below. Equation (3) is based on the fact that rapid fattening and split fattening prevail in Germany. However, it also takes extended fattening into account. The data points for split and extended fattening are derived for the following conditions:

- split fattening: ratio of cocks to hens 1:1, mean duration of the fattening period (lot A) 38.3 d round^{-1} (from 32 d for 30 % and 41 d round^{-1} for 70 % of the population, lot B), duration of round 53.7 d round^{-1} (from 41 d round^{-1} for the animals with extended fattening plus service period of 12.7 d round^{-1}), resulting in an effective service period of 15.4 d round^{-1} (i.e., difference between a duration of round of 53.7 d round^{-1} and a mean duration of the fattening period of 38.3 d round^{-1})

Für Abschnitt 4.2 wird eine Darstellung der Servicedauer als stetige Funktion der Mastdauer benötigt. Sie lässt sich mit Hilfe der unten aufgeführten Mastverfahren-Kennwerte aus Tabelle 1 ableiten, s. Gleichung (3) und Abbildung 1. Gleichung (3) gründet sich darauf, dass Kurz- und Splittingmast in Deutschland bevorzugt eingesetzt werden, berücksichtigt aber auch die Langmast. Die Mittellangmast wird außer Betracht gelassen. Die Datenpunkte für die Splitting- und die Langmast in Abbildung 1 gelten für folgende Bedingungen:

- Splittingmast: Verhältnis Hähne zu Hennen 1:1, mittlere Mastdauer 38,3 d Durchgang^{-1} (aus 32 d für 30 % – Gruppe A – und 41 d Durchgang^{-1} für 70 % der Tiere – Gruppe B), Durchgangsdauer 53,7 d Durchgang^{-1} (aus 41 d Durchgang^{-1} der länger gemästeten Tiere zuzüglich Reinigungsdauer 12,7 d Durchgang^{-1}), effektive Reinigungsdauer 15,4 d Durchgang^{-1} (Differenz aus Durchgangsdauer 53,7 d Durchgang^{-1} und mittlerer Mastdauer 38,3 d Durchgang^{-1});

- extended fattening: ratio of cocks to hens 1:1, duration of fattening period 56 d round^{-1} for cocks and 42 d round^{-1} for hens, service time in both cases 17.6 d round^{-1}.

Function (3) is constructed in a way that it also includes the service period for extended fattening of cocks, see Figure 1. However, it can only be applied for fattening periods between 30 and 56 d round^{-1}, because for longer periods it yields unrealistic results.

- Langmast: Verhältnis Hähne zu Hennen 1:1, Mastdauer 56 d Durchgang^{-1} für Hähne und 42 d für Hennen, Reinigungsdauer jeweils 17,6 d Durchgang^{-1}.

Die Funktion (3) wurde so gewählt, dass auch für die reine Hähne-Langmast die Reinigungsdauer noch realistisch beschrieben wird (Abbildung 1). Die Funktion ist nur für Mastdauern zwischen rund 30 und 56 Tagen anwendbar. Für längere Mastdauern erbringt sie unbrauchbare Ergebnisse.

$$\tau_{\mathrm{service}} = a_{\mathrm{s}} + b_{\mathrm{s}} \cdot \mathrm{k}_{\mathrm{fin}} + c_{\mathrm{s}} \cdot \mathrm{k}_{\mathrm{fin}}^{2} + d_{\mathrm{s}} \cdot \mathrm{k}_{\mathrm{fin}}^{3} \qquad (3)$$

where

τ_{service}	service time (in d round^{-1})
$\mathrm{k}_{\mathrm{fin}}$	number of the final day of fattening period
a_{s}	constant (a_{s} = -60.914473 d round^{-1})
b_{s}	constant (b_{s} = 4.24917001 d round^{-1})
c_{s}	constant (c_{s} = -0.07646862 d round^{-1})
d_{s}	constant (d_{s} = 0.0004582 d round^{-1})

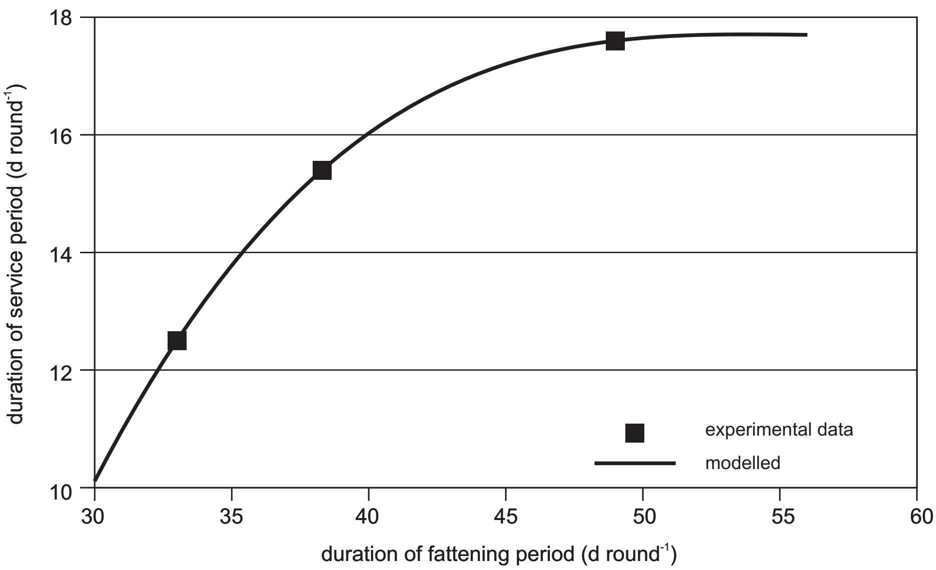

Figure 1:

Parameterization of the duration of the service time as a function of the duration of the fattening period. For details see text.

Abbildung 1:

Parametrisierung der Reinigungsdauer als Funktion der Mastdauer. Details siehe Text.

3 Animal properties

3. 1 Live weights

3.1.1 Start weight

GfE (2000) presupposes a start weight of 42 g animal^{-1}.

In subsequent sections, a number of calculations make use of this value. Thus, a comparison of data obtained within the breeding line and feed contests was made to

3 Tiereigenschaften

3.1 Lebendgewichte

3.1.1 Anfangsgewicht

GfE (2000) geht von einem Anfangsgewicht von 42 g Tier^{-1} aus.

Dieser Wert liegt einer Reihe von Auswertungen in nachfolgenden Abschnitten zugrunde, so dass ein Vergleich mit check whether this assumption is valid (Anonymus, 1997; Anonymus, 2001; Damme, 1994, 1995, 1997; Damme and Rychlik, 2001; Klein, 1991a, 1991b; Lüke et al., 2004; Poteracki, 1991, 1994, 1995, 1996; Poteracki and Adam, 1993a, 1993b; Poteracki et al., 1994; Simon, 2001; Simon and Stegemann, 2005). Figure 2 illustrates the frequency distribution observed (n = 52, bin width 1 g animal^{-1}). The calculated mean is 41.2 g animal^{-1}. There is no trend in the time series. It therefore appears acceptable to use the GfE start weight of 42 g animal^{-1} throughout.

Daten aus Herkunfts- und Futtermittelprüfungen (Anonymus, 1997; Anonymus, 2001; Damme, 1994, 1995, 1997; Damme und Rychlik, 2001; Klein, 1991a, 1991b; Lüke et al., 2004; Potera-cki, 1991, 1994, 1995, 1996; Poteracki und Adam, 1993a, 1993b; Poteracki et al., 1994; Simon, 2001; Simon und Stegemann, 2005) sinnvoll erscheint. Abbildung 2 zeigt die Häufigkeitsverteilung dieser Daten (n = 52, Klassenbreite 1 g Tier^{-1}). Der Mittelwert liegt bei 41,2 g Tier^{-1}. Es existiert kein zeitlicher Trend. Es erscheint daher akzeptabel, den GfE-Wert von 42 g Tier^{-1} als generelles Anfangsgewicht beizubehalten.

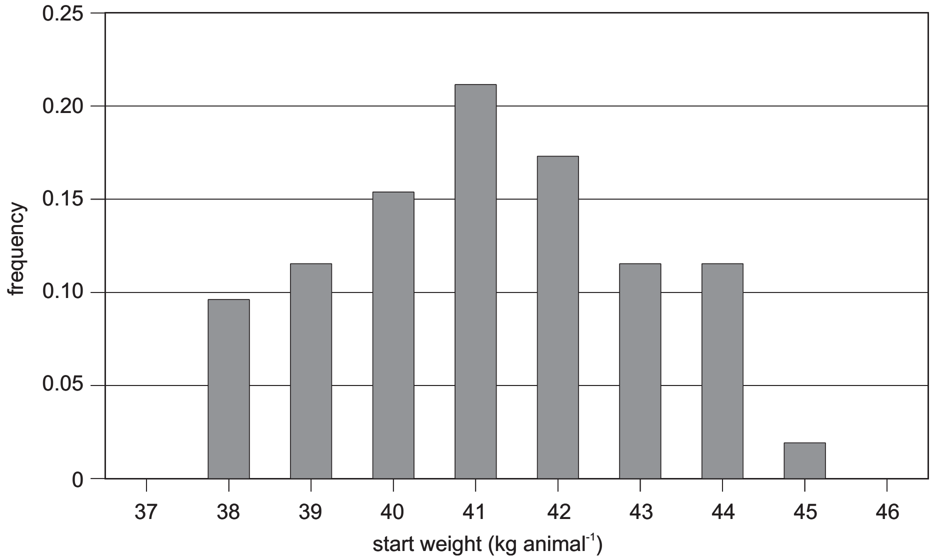

Figure 2:

Frequency distribution of start weights as derived from breeding line and feed contests. For details see text.

Abbildung 2:

Häufigkeitsverteilung der Anfangsgewicht-Daten aus Herkunfts- und Futtermittelprüfungen. Details siehe Text.

3.1.2 Weight gains and final weights according to GfE

Weight gains are mainly determined by genetic predisposition. Other important factors are feeding, stocking density, diseases, as well as indoor climate (LWK-NW, 2006). As data for the latter are not available, their influence on weight gains cannot be ruled out in the context of this paper. Thus we investigate to what extent weight gains can be assessed as a function of lifespan. The changing genetic predisposition is taken into account as weight gain increase since 1990 (cf. Section 3.1.3).

GfE (2000, Table 1.3.2) provides gender specific weight data including gains of the protein and fat contents of the animals. These data are shown in Table 2. GfE (2000) do not report on the year of origin of their data.

3.1.2 Zuwachs und Endgewicht nach GfE

Die Gewichtszunahme wird wesentlich durch die genetische Veranlagung bestimmt. Zusätzliche Einflussfaktoren wie Fütterung, Besatzdichte, Erkrankungen sowie Stallklima (LWK-NW, 2006) werden in der vorliegenden Arbeit mangels Daten nicht berücksichtigt. Im Folgenden wird deshalb angestrebt, die Gewichtszunahme als Funktion der Lebensdauer zu beschreiben. Die genetische Veranlagung wird dabei durch den mittleren Anstieg in den Tiergewichten seit 1990 berücksichtigt (s. Abschnitt 3.1.3).

GfE (2000, Tabelle 1.3.2) gibt – ohne Jahresangabe der Datenerhebung – geschlechtsspezifische Wachstumsdaten einschließlich Proteinzunahme und Fettzunahme als Funktion der Lebensdauer an, Tabelle 2.

Table 2:

Gender specific weight characteristics according to GfE (2000, Table 1.3.2)

Tabelle 2:

Geschlechtsspezifische Wachstumsdaten aus GfE (2000, Tabelle 1.3.2.)

Age	animal weight at the end of week n (w)		mean weekly weight gain ($\Delta w/\Delta t$)		protein gains (feathers only), related to overall weight gain ($\Delta x_{XP, F}$)	protein gains (body except feathers), related to overall weight gain ($\Delta x_{XP, B}$)	fat gains (body including feathers), related to overall weight gain (Δx_F)	
weeks	cocks	hens	cocks	hens	broilers	broilers	cocks	hens
n	10^{-3} kg animal^{-1}		10^{-3} kg animal^{-1} d^{-1}		kg kg^{-1}	kg kg^{-1}	kg kg^{-1}	kg kg^{-1}
1	168	150	18.0	15.4	$1.1 \cdot 10^{-2}$	$14.5 \cdot 10^{-2}$	$11.5 \cdot 10^{-2}$	$11.5 \cdot 10^{-2}$
2	396	364	32.6	30.6	$1.2 \cdot 10^{-2}$	$15.9 \cdot 10^{-2}$	$13.4 \cdot 10^{-2}$	$14.0 \cdot 10^{-2}$
3	754	693	51.1	47.0	$2.6 \cdot 10^{-2}$	$16.1 \cdot 10^{-2}$	$15.9 \cdot 10^{-2}$	$16.5 \cdot 10^{-2}$
4	1226	1109	67.4	59.4	$3.0 \cdot 10^{-2}$	$16.3 \cdot 10^{-2}$	$16.4 \cdot 10^{-2}$	$17.5 \cdot 10^{-2}$
5	1768	1561	77.4	64.6	$3.8 \cdot 10^{-2}$	$16.4 \cdot 10^{-2}$	$16.8 \cdot 10^{-2}$	$18.9 \cdot 10^{-2}$
6	2329	2002	80.1	63.0	$4.3 \cdot 10^{-2}$	$16.4 \cdot 10^{-2}$	$17.2 \cdot 10^{-2}$	$20.1 \cdot 10^{-2}$
7	2867	2399	76.9	56.7	$4.5 \cdot 10^{-2}$	$16.5 \cdot 10^{-2}$	$17.5 \cdot 10^{-2}$	$21.5 \cdot 10^{-2}$
8	3352	2737	69.3	48.3	$4.5 \cdot 10^{-2}$	$16.5 \cdot 10^{-2}$	$17.4 \cdot 10^{-2}$	$23.0 \cdot 10^{-2}$

The gender specific weight gains until day k are defined by equation (4).

The data points described by equation (4) can be converted into the steady function expressed in equation (5) with an $R^2 = 0.9999$ for both genders.

Der geschlechtsabhängige Gewichtszuwachs bis zum k-ten Lebenstag ist durch Gleichung (4) definiert. Gleichung (4) kann mittels Regression approximiert werden. Es ergibt sich mit $R^2 = 0{,}9999$ für beide Geschlechter die Gleichung (5).

$$\Delta w_{\mathrm{i,\,k}} = w_{\mathrm{i,\,k}} - w_{\mathrm{start}} = \sum_{\mathrm{j=1}}^{\mathrm{k}} \Delta t \cdot \left(\frac{\Delta w}{\Delta t}\right)_{\mathrm{i,\,j}} \qquad (4)$$

where

$\Delta w_{\mathrm{i,\,k}}$	gender-related total weight gain until day k of life as function of gender i (in kg animal^{-1})
i	gender index (i = male, female)
k	number of day of life
$w_{\mathrm{i,\,k}}$	gender-related live weight as function of day k of life (in kg animal^{-1})
w_{start}	animal start weight (in kg animal^{-1})
j	running index
Δt	time increment (Δt = 1 d)
$(\Delta w/\Delta t)_{\mathrm{i,\,j}}$	gender-related weight gain per animal and day according to Table 2 (in kg animal^{-1} d^{-1})

$$\Delta w_{\mathrm{i,\,k}} = \beta_{\mathrm{g,\,i}} \cdot \mathrm{k} + \gamma_{\mathrm{g,\,i}} \cdot \mathrm{k}^2 + \delta_{\mathrm{g,\,i}} \cdot \mathrm{k}^3 \qquad (5)$$

where

$\Delta w_{\mathrm{i,\,k}}$	gender-related total weight gain until day k of life (in kg animal^{-1})
i	gender index (i = male, female)
k	number of day of life
$\beta_{\mathrm{g,\,i}}$	constant ($\beta_{\mathrm{g,\,male}}$ = 0.952266·10^{-3} kg animal^{-1}, $\beta_{\mathrm{g,\,female}}$ = 1.321635·10^{-3} kg animal^{-1})
$\gamma_{\mathrm{g,\,i}}$	constant ($\gamma_{\mathrm{g,\,male}}$ = 1.946104·10^{-3} kg animal^{-1}, $\gamma_{\mathrm{g,\,female}}$ = 1.799757·10^{-3} kg animal^{-1})
$\delta_{\mathrm{g,\,i}}$	constant ($\delta_{\mathrm{g,\,male}}$ = -0.016163·10^{-3} kg animal^{-1}, $\delta_{\mathrm{g,\,female}}$ = -0.017214·10^{-3} kg animal^{-1})

Figure 3 shows the curves obtained from the application of equation (5). In the regions visualized by continuous lines, a linear approximation as in equation (6) is possible (cocks: R^2 = 0.9999; hens: R^2 = 0.9991). The subsequent calculations make use of these linear relationships.

Abbildung 3 zeigt die durch Gleichung (5) gegebenen Kurvenverläufe. Im durchgezogenen Bereich ist eine lineare Approximation durch Gleichung (6) möglich (Hähne: R^2 = 0,9999; Hennen: R^2 = 0,9991), wovon im Folgenden Gebrauch gemacht wird.

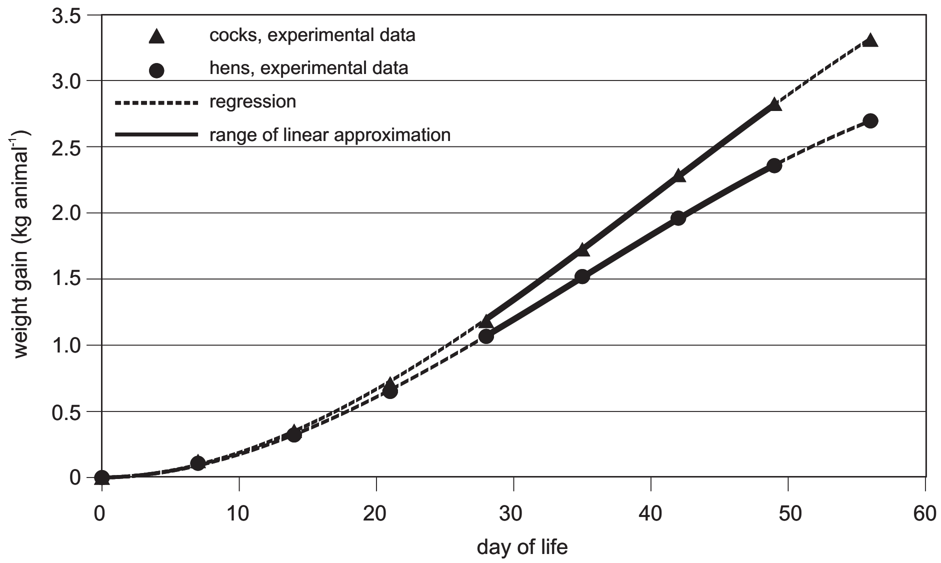

Figure 3:

Weight gain as a function of animal gender and age till week 8, inclusively. Squares and triangles: calculations according to data in GfE (2000), Table 2; dotted lines: regressions functions (equation 5) (cocks and hens: R^2 = 0.9999). Between days 28 and 49, weight gain functions can be approximated linearly (equation 6), continuous lines.

Abbildung 3:

Von Geschlecht und Lebensalter abhängiger Zuwachs bis zur 8. Woche einschließlich. Punkte: Berechnungen nach GfE (2000)-Daten (Tabelle 2); Linien: Regressionsfunktionen, s. Gleichung (5) (Hähne und Hennen: R^2 = 0,9999). Zwischen Tag 28 and Tag 49 (durchgezogene Linienanteile) ist eine Linearisierung der Zuwachsfunktionen möglich, s. Gleichung (6).

$$\Delta w_{\mathrm{i,\,k,\,lin}} = a_{\mathrm{g,\,i}} + b_{\mathrm{g,\,i}} \cdot \mathrm{k} \tag{6}$$

where

$\Delta w_{\mathrm{i,\,k,\,lin}}$	linearization of total weight gain $\Delta w_{\mathrm{i,\,k}}$ (in kg animal^{-1})
i	gender index (i = male, female)
k	number of day of life
$a_{\mathrm{g,\,i}}$	constant ($a_{\mathrm{g,\,male}} = -1010.7\cdot10^{-3}$ kg animal^{-1}, $a_{\mathrm{g,\,female}} = -645.3\cdot10^{-3}$ kg animal^{-1})
$b_{\mathrm{g,\,i}}$	constant ($b_{\mathrm{g,\,male}} = 78.343\cdot10^{-3}$ kg animal^{-1}, $b_{\mathrm{g,\,female}} = 61.586\cdot10^{-3}$ kg animal^{-1}

The gender specific live weight at the end of the fattening period can be assessed using equation (7). For fattening periods between 28 and 49 days the linear relation expressed in equation (6) can be used.

If one needs a mean for both genders, equation (7) is

Das geschlechtsspezifische Lebendgewicht am Ende einer Mast ergibt sich aus Gleichung (7), wobei für Mastdauern zwischen 28 und 49 Tagen näherungsweise der linearisierte Zuwachs nach Gleichung (6) eingesetzt werden kann.

$$w_{\mathrm{i,\,kfin}} = w_{\mathrm{start}} + \Delta w_{\mathrm{i,\,kfin}} \tag{7}$$

where

$w_{\mathrm{i,\,kfin}}$	gender-related final live weight (in kg animal^{-1})
i	gender index (i = male, female)
w_{start}	animal start weight (in kg animal^{-1})
$\Delta w_{\mathrm{i,\,kfin}}$	gender-related total weight gain during fattening period (in kg animal^{-1})

modified to yield equation (8):
3.1.3 Development of animal weights since 1990

Gemittelt über beide Geschlechter wird Gleichung (7) zu:

$$w_{\text{br, kfin}} = w_{\text{start}} + \Delta w_{\text{br, kfin}} = w_{\text{start}} + x_{\text{male}} \cdot \Delta w_{\text{male, kfin}} + (1 - x_{\text{male}}) \cdot \Delta w_{\text{female, kfin}} \tag{8}$$

where

$w_{\text{br, kfin}}$	average final live weight (in kg animal^{-1})
$\Delta w_{\text{br, kfin}}$	average animal weight gain per place and fattening period (in kg animal^{-1} = kg place^{-1} round^{-1})
w_{start}	animal start weight (in kg animal^{-1})
x_{male}	ratio of male broiler animal numbers to total population
$\Delta w_{\text{male, kfin}}$	total weight gain of a male broiler during fattening period (in kg animal^{-1} = kg place^{-1} round^{-1})
$\Delta w_{\text{female, kfin}}$	total weight gain of a female broiler during fattening period (in kg animal^{-1} = kg place^{-1} round^{-1})

3.1.3 Development of animal weights since 1990

Due to the progress in animal breeding, daily weight gains have increased steadily. This development cannot be reflected in the growth function (5) and (6). Thus, a correction is needed.

The evaluation of breeding line and feed contests (for sources see section 3.1.1) exhibit steadily increasing final weights (cf Figure 4, left). These data are based on the assumption of a uniform start weight of 42 g animal-1. According to the test protocols, these data were obtained from populations with equal shares of cocks and hens.

3.1.3 Tiergewicht-Entwicklung seit 1990

Aufgrund des züchterischen Fortschritts wachsen die täglichen Tiergewichtzunahmen beständig an. Da dies in den Wachstumsfunktionen (5) bzw. (6) nicht enthalten ist, ist eine Korrektur erforderlich.

Abbildung 4 (links) zeigt den zeitlichen Trend anhand von Daten aus Herkunfts- und Futtermittelprüfungen (Quellenangaben s. Abschnitt 3.1.1), wobei ein einheitliches Anfangsgewicht von 42 g pro Tier zugrunde gelegt wurde. Die Daten gelten den Versuchsbeschreibungen zufolge für Populationen mit gleichen Anteilen von Hähnen und Hennen.

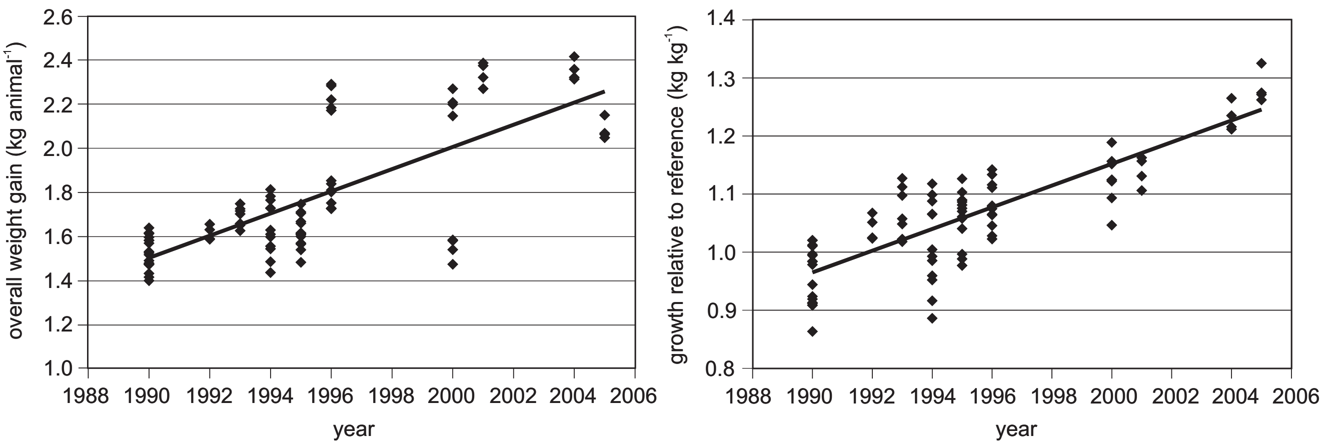

Figure 4:

Left: Absolute overall weight gains exhibit a tendency to increase (experimental data from breeding line and feed contests). Assumed start weight in all cases 0.042 kg animal^{-1}. Right: relative growth rate increases. The regression function defines the growth rate relative to reference, r_g, see equation 9.

Abbildung 4:

Links: Zeitliche Tendenz der Gesamtgewichtszuwächse aus Herkunfts- und Futtermittelprüfungen (Details siehe Text). Annahme in allen Fällen: Anfangsgewicht 0,042 kg Tier^{-1}. Rechts: Zeitliche Entwicklung der normierten Gewichtszunahmen. Die Regressionsfunktion definiert den Zuwachsquotienten r_g, s. Gleichung (9).

The scatter is reduced, when the reported weight gains are normalized using the weight gains as functions of the duration of the fattening period in accordance with GfE (2000) (see Section 3.1.2, equation (5)). The results of this

Die Streuung reduziert sich, wenn die berichteten Zuwächse mit Hilfe der mastdauerabhängigen Zuwächse normiert werden, wie sie sich nach GfE (2000) ergäben, vgl. Abschnitt 3.1.2, Gleichung (5). Abbildung 4 (rechts) procedure are shown in Figure 4, right). A linear trend with a correlation coefficient of 0.7117 was determined for the description with equation (9). This trend defines the growth coefficient r_g (cf Table 3). In accordance with its origin, this coefficient applies to both cocks and hens.

zeigt das Ergebnis, wobei der lineare Trend durch lineare Regression (R^2 = 0,7117) ermittelt wurde, s. Gleichung (9). Der Trend definiert den Zuwachsquotienten r_g (s. auch Tabelle 3), der der Datenherkunft entsprechend einheitlich für Hähne und Hennen gilt.

$$r_g = a_r + b_r \cdot Y \tag{9}$$

where

r_g	growth relative to reference (in kg kg^{-1})
a_r	constant (a_r = -3623.6 kg kg^{-1})
b_r	constant (b_r = 1.8694 kg kg^{-1} a^{-1})
Y	year (four-digit format)

Table 3:
Growth rate relative to reference r_g (in kg kg^{-1}) as calculated using equation (9)
Tabelle 3:
Der mit Gleichung (9) berechnete Zuwachsquotient r_g (in kg kg^{-1})

1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
0.964	0.982	1.001	1.020	1.038	1.057	1.076	1.095	1.113	1.132	1.151	1.169	1.188	1.207	1.225	1.244	

Although there are indications of yet increasing final live weights (Krüger, 2007), weight gain rates for the years from 2006 onwards should not be derived from the long-term trends by extrapolation. Instead, they should be based on reported breeding line and feed contests (reported weight gains normalized using weight gains as in GfE, see Section 3.1.2).

According to Table 3, data provided in GfE (2000) (Table 2), may be valid for 1992. This means that they are likely to be representative of the first half of the 1990ies. Therefore, a correction of the growth function deduced in Section 2.2.1.2 is inevitable: equation (5) has to be substituted by (10), (6) by (11). Strictly speaking, equations (11) and (6) are only valid for fattening periods between 28 and 49 days.

Es gibt Anhaltspunkte für weiterhin steigende Lebendendgewichte (Krüger, 2007). Zuwachsquotienten für die Zeit nach 2005 sollten nicht durch Extrapolation des Trends abgeleitet werden, sondern anhand von Berichten über Herkunfts- und Futtermittelprüfungen (Normierung der berichteten Gewichtszuwächse mit dem Zuwachs nach GfE, s. Abschnitt 3.1.2).

Nach Tabelle 3 träfen die undatierten Hähnchenmastdaten aus GfE (2000) (Tabelle 2) für das Jahr 1992 zu, womit sie allenfalls für die erste Hälfte der 1990er Jahre als repräsentativ angesehen werden können. Eine Korrektur der in Abschnitt 2.2.1.2 abgeleiteten Wachstumsfunktionen ist daher unumgänglich: Gleichung (5) wird zu (10), (6) zu (11), wobei (11) wie (6) streng genommen nur für Mastdauern von 28 bis 49 Tagen gültig ist:

$$\Delta w_{i,k} = r_g \cdot (\beta_{g,i} \cdot k + \gamma_{g,i} \cdot k^2 + \delta_{g,i} \cdot k^3) \tag{10}$$

where

$\Delta w_{i,k}$	gender-related total weight gain until day k of life (in kg animal^{-1})
i	gender index (i = male, female)
k	number of day of life
r_g	growth relative to reference (in kg kg^{-1})
$\beta_{g,i}$	constant ($\beta_{g,male}$ = 0.952266·10^{-3} kg animal^{-1}, $\beta_{g,female}$ = 1.321635·10^{-3} kg animal^{-1})
$\gamma_{g,i}$	constant ($\gamma_{g,male}$ = 1.946104·10^{-3} kg animal^{-1}, $\gamma_{g,female}$ = 1.799757·10^{-3} kg animal^{-1})
$\delta_{g,i}$	constant ($\delta_{g,male}$ = -0.016163·10^{-3} kg animal^{-1}, $\delta_{g,female}$ = -0.017214·10^{-3} kg animal^{-1})

$$\Delta w_{\mathrm{i,\,k,\,lin}} = r_{\mathrm{g}} \cdot (a_{\mathrm{g,\,i}} + b_{\mathrm{g,\,i}} \cdot \mathrm{k}) \tag{11}$$

where

$\Delta w_{\mathrm{i,\,k,\,lin}}$ linearization of total weight gain $\Delta w_{\mathrm{i,\,k}}$ (in kg animal^{-1})
i gender index (i = male, female)
k number of day of life
r_{g} growth relative to reference (in kg kg^{-1})
$a_{\mathrm{g,\,i}}$ constant ($a_{\mathrm{g,\,male}}$ = -1010.7·10^{-3} kg animal^{-1}, $a_{\mathrm{g,\,female}}$ = -645.3·10^{-3} kg animal^{-1})
$b_{\mathrm{g,\,i}}$ constant ($b_{\mathrm{g,\,male}}$ = 78.343·10^{-3} k g animal^{-1}, $b_{\mathrm{g,\,female}}$ = 61.586·10^{-3} kg animal^{-1})

3.2 Cumulative metabolic weight

The metabolic weight is a function of gender and day of life. It is defined by equation (12). Figure 5 illustrates the development with time of the metabolic weight for the GfE data set described in Section 3.1.2 as calculated using equations (4) and (5).

3.2 Kumulatives metabolisches Gewicht

Das von Geschlecht und Lebenstag abhängige metabolische Gewicht ist durch Gleichung (12) definiert. Abbildung 5 zeigt den zeitlichen Verlauf des metabolischen Gewichtes für den in Abschnitt 3.1.2 beschriebenen GfE-Datensatz (berechnet mit Hilfe der Gleichungen (4) und (5)).

$$w_{\mathrm{m,\,i,\,k}} = w_{\mathrm{ref}} \cdot \left(\frac{w_{\mathrm{i,\,k}}}{w_{\mathrm{ref}}}\right)^{0.75} \tag{12}$$

where

$w_{\mathrm{m,\,i,\,k}}$ metabolic animal weight on day k with i = male, female (in kg animal^{-1})
i gender index (i = male, female)
k number of day of life
w_{ref} reference value of animal weight (w_{ref} = 1 kg animal^{-1})

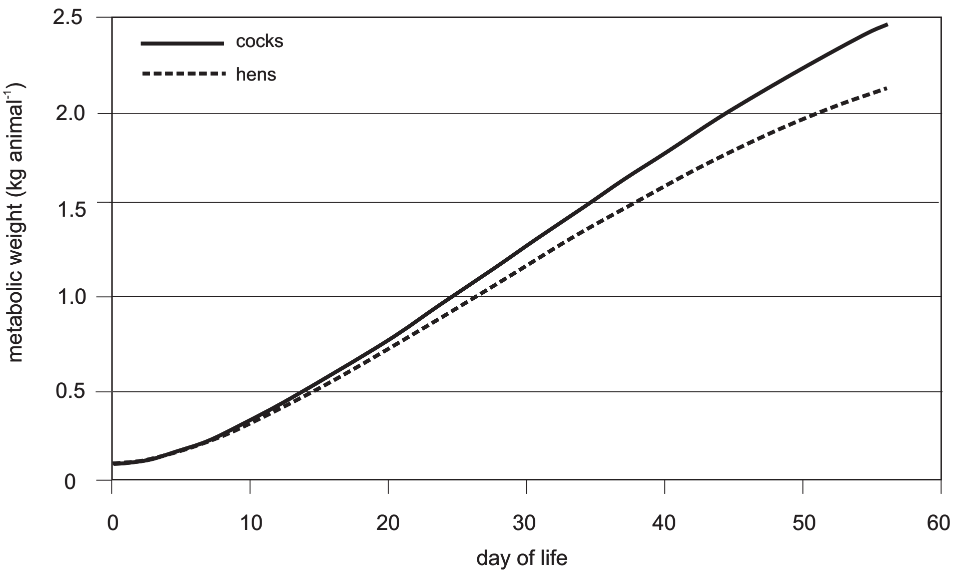

Figure 5:
Exemplary metabolic weight for cocks and hens
Abbildung 5:
Beispielhafter Verlauf des metabolischen Gewichtes für Hahn und Henne

The determination of the metabolizable energy requirements in Section 3.3 presupposes a description of the cumulative metabolic weight ΣW_i, which is equivalent to the areas under the gender specific curves in Figure 5.

In order to simplify the determination, the method described in Haenel and Dämmgen (2007b) is used. Its input parameters are start and final weights as well as a time parameter $\tau_{char, br, i}$:

Für die Ermittlung des Bedarfs an umsetzbarer Energie in Abschnitt 3.3 wird das geschlechtsabhängige kumulative metabolische Gewicht ΣW_i benötigt, das der Fläche unter der geschlechtsspezifischen Kurve in 5 entspricht.

Zur Vereinfachung der Berechnung wird die Vorgehensweise von Haenel und Dämmgen (2007b) aufgegriffen, die als Eingabegrößen lediglich Anfangs- und Endgewicht sowie einen Zeitparameter $\tau_{char, br, i}$ benötigt:

$$\Sigma W_{\mathrm{i}} = w_{\mathrm{ref}} \cdot \left[\tau_{\mathrm{char,\,br,\,i}} \cdot \left(\frac{w_{\mathrm{start}}}{w_{\mathrm{ref}}} \right)^{0.75} + \left(\tau_{\mathrm{lifespan}} - \tau_{\mathrm{char,\,br,\,i}} \right) \cdot \left(\frac{w_{\mathrm{i,\,kfin}}}{w_{\mathrm{ref}}} \right)^{0.75} \right] \quad (13)$$

where

ΣW_i	gender-dependent cumulative metabolic live weight (kg d animal^{-1} round^{-1})
i	gender index (i = male, female)
$\tau_{char, br, i}$	gender-dependent characteristic time scale of growth (in d round^{-1})
w_{start}	animal start weight (in kg animal^{-1})
w_{ref}	reference value of animal weight (w_{ref} = 1 kg animal^{-1})
$\tau_{lifespan}$	duration of fattening period (in d round^{-1})
$w_{i, kfin}$	animal live weight at the end of the round (in kg animal^{-1})

The characteristic time parameter $\tau_{char, br, i}$ needs to be assessed once only. For this purpose, equation (13) is resolved yielding $\tau_{char, br, i}$ and equations (4) and (5) are included. The resulting equation (14) is used to obtain $\tau_{char, br, i}$ as a function of the duration of the fattening period.

Zur einmaligen Berechnung von $\tau_{char, br, i}$ wird Gleichung (13) nach $\tau_{char, br, i}$ aufgelöst und mit Hilfe von (4) und (5) ausgewertet. Gleichung (14) und Abbildung 6 zeigen das Ergebnis.

$$\tau_{\mathrm{char,br,i}} = a_{\tau,\mathrm{i}} + b_{\tau,\mathrm{i}} \cdot \mathrm{k}_{\mathrm{fin}} + c_{\tau,\mathrm{i}} \cdot \mathrm{k}_{\mathrm{fin}}^{2} \quad (14)$$

where

$\tau_{char, br, i}$	characteristic time scale of growth (in d round^{-1})
i	gender index (i = male, female)
k_{fin}	number of final day of fattening period
$a_{\tau, i}$	constant ($a_{\tau, male}$ = -1.419952 d round^{-1}, $a_{\tau, female}$ = -1.502001 d round^{-1})
$b_{\tau, i}$	constant ($b_{\tau, male}$ = 0.689000 d round^{-1}, $b_{\tau, female}$ = 0.713653 d round^{-1})
$c_{\tau, i}$	constant ($c_{\tau, male}$ = -0.002281 d round^{-1}, $c_{\tau, female}$ = -0.003068 d round^{-1})

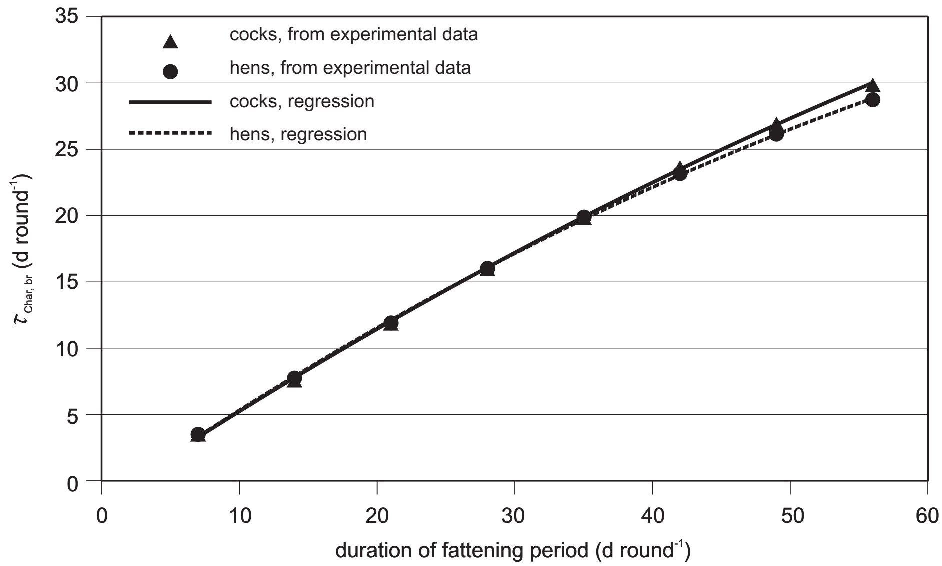

Figure 6:

Characteristic time parameter $\tau_{\mathrm{char,\,br,\,i}}$ as function of fattening period duration and gender. Symbols: values calculated according to GfE (2000), Table 2; lines: respective regression functions (cocks: R^2 = 0.9997; hens: R^2 = 0.9996)

Abbildung 6:

Charakteristischer Zeitparameter $\tau_{\mathrm{char,\,br,\,i}}$ als Funktion von Mastdauer und Geschlecht. Punkte: Berechnungen nach GfE (2000)-Daten (Tabelle 2); Linien: Regressionsfunktionen (Hähne: R^2 = 0,9997; Hennen: R^2 = 0,9996)

3.3 ME requirements

Metabolic energy (ME) requirements comprise the requirements for both maintenance and growth. The overall ME requirements during the fattening period are to be calculated separately for both genders according to:

3.3 ME-Bedarf

Der Bedarf an umsetzbarer Energie (ME) umfasst den Bedarf für Erhaltung und den Bedarf für Zuwachs. Unter Berücksichtigung der Geschlechtsabhängigkeit gilt damit für den während einer Mastperiode pro Tier entstehenden ME-Bedarf:

$$\sum_{\mathrm{j=1}}^{\mathrm{k_{fin}}} \tau_{\mathrm{day}} \cdot ME_{\mathrm{i,\,j}} = \sum_{\mathrm{j=1}}^{\mathrm{k_{fin}}} \tau_{\mathrm{day}} \cdot ME_{\mathrm{m,\,i,\,j}} + \sum_{\mathrm{j=1}}^{\mathrm{k_{fin}}} \tau_{\mathrm{day}} \cdot ME_{\mathrm{g,\,i,\,j}} \tag{15}$$

where

$\Sigma\, \tau_{\mathrm{day}} \cdot ME_{\mathrm{i,\,j}}$	fattening-period total of $ME_{\mathrm{i,\,j}}$ (in MJ animal^{-1} round^{-1} ME)
τ_{day}	time period of one day (τ_{day} = 1 d round^{-1})
$ME_{\mathrm{i,\,j}}$	gender-dependent requirements of total metabolizable energy for day j (in MJ animal^{-1} d^{-1} ME)
i	gender index (i = male, female)
j	index of day
$\mathrm{k_{fin}}$	number of final day of fattening period
$\Sigma\, \tau_{\mathrm{day}} \cdot ME_{\mathrm{m,\,i,\,j}}$	fattening-period total of $ME_{\mathrm{m,\,i,\,j}}$ (in MJ animal^{-1} round^{-1} ME)
$ME_{\mathrm{m,\,i,\,j}}$	gender-dependent metabolizable energy required for maintenance for day j (in MJ animal^{-1} d^{-1} ME)
$\Sigma\, \tau_{\mathrm{day}} \cdot ME_{\mathrm{g,\,i,\,j}}$	fattening-period total of $ME_{\mathrm{g,\,i,\,j}}$ (in MJ animal^{-1} round^{-1} ME)
$ME_{\mathrm{g,\,i,\,j}}$	gender-dependent metabolizable energy consumed for growth for day j (in MJ animal^{-1} d^{-1} ME)

The right hand side terms of (15) equal to

Für die Terme der rechten Seite von (15) gilt:

$$\sum_{j=1}^{k_{fin}} \tau_{day} \cdot ME_{m,i,j} = \eta_{ME,m} \cdot \Sigma W_i \tag{16}$$

where

$\Sigma\, \tau_{day} \cdot ME_{m,\, i, j}$	fattening-period total of $ME_{m,\, i, j}$ (in MJ animal^{-1} round^{-1} ME)
τ_{day}	time period of one day (τ_{day} = 1 d round^{-1})
$ME_{m,\, i, j}$	gender-dependent metabolizable energy required for maintenance for day j (in MJ animal^{-1} d^{-1} ME)
i	gender index (i = male, female)
j	index of day
k_{fin}	number of final day of fattening period
$\eta_{ME,\, m}$	specific metabolizable energy required for daily maintenance ($\eta_{ME,\, m}$ = 0.48 MJ kg^{-1} d^{-1} ME, GfE (2000))
ΣW_i	gender-dependent cumulative metabolic weight (in kg d animal^{-1} round^{-1})

$$\sum_{j=1}^{k_{fin}} \tau_{day} \cdot ME_{g,i,j} = \eta_{ME,g,i} \cdot \tau_{day} \cdot \sum_{j=1}^{k_{fin}} \left(\frac{\Delta w}{\Delta t} \right)_{i,j} \tag{17}$$

where

$\Sigma\, \tau_{day} \cdot ME_{g,\, i, j}$	fattening-period total of $ME_{g,\, i, j}$ (in MJ animal^{-1} round^{-1} ME)
τ_{day}	time period of one day (τ_{day} = 1 d round^{-1})
$ME_{g,\, i, j}$	gender-dependent metabolizable energy consumed for daily growth (in MJ animal^{-1} d^{-1} ME)
i	gender index (i = male, female)
j	index of day
k_{fin}	number of final day of fattening period
$\eta_{ME,\, g,\, i}$	gender-dependent specific metabolizable energy required for growth (in MJ kg^{-1} ME)
$(\Delta w/\Delta t)_{i,\, j}$	gender-related daily weight gain per animal and day according to Table 2 (in kg animal^{-1} d^{-1})

The specific energy requirements for growth, $\eta_{ME,\, g,\, i}$, is a function of the duration of the fattening period. According to GfE (2000), equations (1.3.2) in combination with (1.3.11) lead to

Der spezifische Energiebedarf für Zuwachs, $\eta_{ME,\, g,\, i}$, ist eine Funktion der Mastdauer. Aus der Kombination der Gleichungen (1.3.2) und (1.3.11) in GfE (2000) folgt:

$$\eta_{ME,g,i} = \frac{\alpha_p}{k_p} \cdot P_i + \frac{\alpha_f}{k_f} \cdot F_i \tag{18}$$

where

$\eta_{ME,\, g,\, i}$	gender-dependent specific metabolizable energy required for growth (in MJ kg^{-1} ME)
i	gender index (i = male, female)
a_p	coeffcient (a_p = 23.86 MJ kg^{-1} ME, according to GfE, 2000, equation 1.3.2)
a_f	coeffcient (a_f = 39.77 MJ kg^{-1} ME, according to GfE, 2000, equation 1.3.2)
k_p	coeffcient (k_p = 0.52 MJ MJ^{-1}, according to GfE, 2000, equation 1.3.11)
k_f	coeffcient (k_f = 0.84 MJ MJ^{-1}, according to GfE, 2000, equation 1.3.11)
P_i	ratio of total protein gain to total weight gain during lifespan (in kg kg $^{-1}$)
F_i	ratio of total fat gain to total weight gain during lifespan (in kg kg $^{-1}$)

The relative increase of the amount of protein P_i is obtained by adding daily amounts over all days of the fattening period (crude protein denoted by XP)

Für die relative Proteinzunahme P_i erhält man durch Summenbildung über alle Tage des Mastzeitraums (XP steht für Rohprotein):

$$P_{\mathrm{i}} = \left[\sum_{\mathrm{j}=1}^{\mathrm{k_{fin}}} \left(\frac{\Delta w}{\Delta t} \right)_{\mathrm{i,\,j}} \cdot (\Delta x_{\mathrm{XP,\,F,\,j}} + \Delta x_{\mathrm{XP,\,B,\,j}}) \right] \cdot \left[\sum_{\mathrm{j}=1}^{\mathrm{k_{fin}}} \left(\frac{\Delta w}{\Delta t} \right)_{\mathrm{i,\,j}} \right]^{-1} \qquad (19)$$

where

P_i	ratio of total protein gain to total weight gain during lifetime (in kg kg $^{-1}$)
i	gender index (i = male, female)
j	index of day
k_{fin}	number of final day of fattening period
$(\Delta w/\Delta t)_{i,\,j}$	gender-related daily weight gain per animal and day according to Table 2 (in kg animal^{-1} d^{-1})
$\Delta x_{XP,\,F,\,j}$	gender-related protein gain by feathers according to Table 2 (in kg XP (in kg weight gain)$^{-1}$)
$\Delta x_{XP,\,B,\,j}$	gender-related protein gain in animal body according to Table 2 (in kg XP (in kg weight gain)$^{-1}$)

The input entities required for Equation (19) can be taken directly from the weekly data provided in Table 2 (corresponding to the day j).

By analogy, the relative increase in fat F_i is:

Die in Gleichung (19) eingehenden Größen können direkt aus der dem Tag j entsprechenden Wochenzeile in Tabelle 2 entnommen werden.

Analog erhält man für die relative Fettzunahme F_i:

$$F_{\mathrm{i}} = \left[\sum_{\mathrm{j}=1}^{\mathrm{k_{fin}}} \left(\frac{\Delta w}{\Delta t} \right)_{\mathrm{i,\,j}} \cdot \Delta x_{\mathrm{F,\,i,\,j}} \right] \cdot \left[\sum_{\mathrm{j}=1}^{\mathrm{k_{fin}}} \left(\frac{\Delta w}{\Delta t} \right)_{\mathrm{i,\,j}} \right]^{-1} \qquad (20)$$

where

F_i	ratio of total fat gain to total weight gain during lifespan (in kg kg^{-1})
i	gender index (i = male, female)
j	index of day
k_{fin}	number of final day of fattening period
$(\Delta w/\Delta t)_{i,\,j}$	gender-related daily weight gain per animal and day according to Table 2 (in kg animal^{-1} d^{-1})
$\Delta x_{F,\,i,\,j}$	gender-related fat gain according to Table 2 (in kg fat (in kg weight gain)$^{-1}$)

Figure 7 illustrates the specific energy requirements for growth, $\eta_{ME,\,g,\,i}$, as a function gender and the duration of the feeding period.

Abbildung 7 zeigt den spezifischen Energiebedarf für Zuwachs, $\eta_{ME,\,g,\,i}$, als Funktion von Geschlecht und Mastdauer.

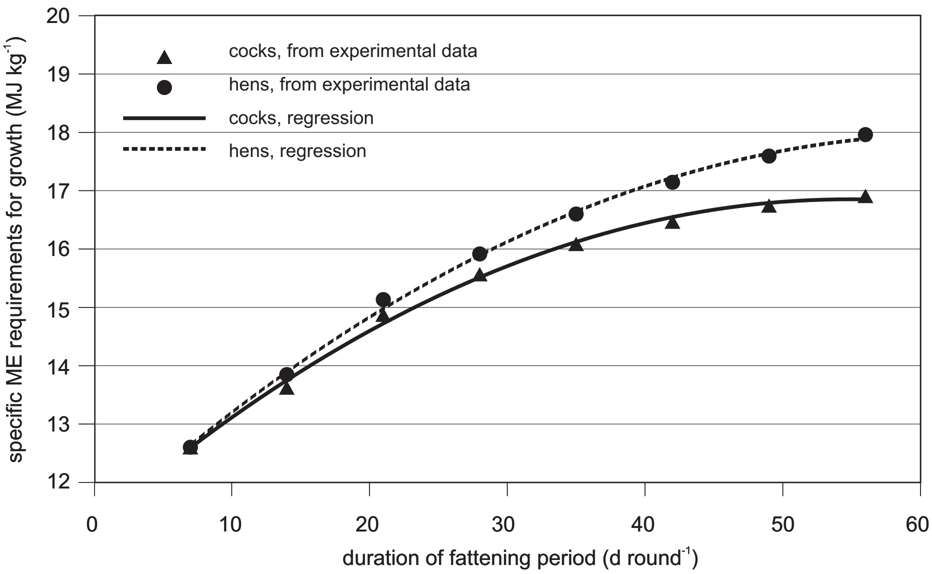

Figure 7:

Mean specific ME requirements for growth (averaged over the whole fattening period). Symbols: results derived from GfE (2000) data as given in Table 2; lines: regression functions as given by equation (21) (cocks: R^2 = 0.9982; hens: R^2 = 0.9968)

Abbildung 7:

Über die Mastdauer gemittelter spezifischer ME-Bedarf für Zuwachs. Punkte: Berechnungen unter Verwendung von GfE (2000)-Daten (s. Tabelle 2); Linien: Regressionsfunktionen (Hähne: R^2 = 0,9982; Hennen: R^2 = 0,9968)

The regression obtained for the relation shown in Figure 7 is as follows:

Die Gleichung für die in Abbildung 7 gezeigte Regression lautet:

$$\eta_{\mathrm{ME,\,g,\,i}} = a_{\eta,\mathrm{i}} + b_{\eta,\mathrm{i}} \cdot \mathrm{k_{fin}} + c_{\eta,\mathrm{i}} \cdot \mathrm{k_{fin}}^2 \tag{21}$$

where

$\eta_{\mathrm{ME,\,g,\,i}}$	gender-dependent specific metabolizable energy required for growth (in MJ kg^{-1} ME)
$\mathrm{k_{fin}}$	number of final day of fattening period
$a_{\eta,\mathrm{i}}$	constant ($a_{\eta,\mathrm{male}}$ = 11.253984 MJ kg^{-1}, $a_{\eta,\mathrm{female}}$ = 11.2224501 MJ kg^{-1})
$b_{\eta,\mathrm{i}}$	constant ($b_{\eta,\mathrm{male}}$ = 0.204377 MJ kg^{-1}, $b_{\eta,\mathrm{female}}$ = 0.214422 MJ kg^{-1})
$c_{\eta,\mathrm{i}}$	constant ($c_{\eta,\mathrm{male}}$ = -0.001865 MJ kg^{-1}, $c_{\eta,\mathrm{female}}$ = -0.001704 MJ kg^{-1})

Averaging the daily metabolic energy requirements over the entire round, one obtains:

Der über einen Durchgang gemittelte Tagesbedarf der metabolisierbaren Energie ergibt sich aus:

$$ME_{\mathrm{br}} = \frac{1}{\tau_{\mathrm{round}}} \cdot \left[x_{\mathrm{male}} \cdot \sum_{\mathrm{j=1}}^{\mathrm{k_{fin}}} \tau_{\mathrm{day}} \cdot ME_{\mathrm{male,\,j}} + (1 - x_{\mathrm{male}}) \cdot \sum_{\mathrm{j=1}}^{\mathrm{k_{fin}}} \tau_{\mathrm{day}} \cdot ME_{\mathrm{female,\,j}} \right] \tag{22}$$

where

ME_{br}	daily metabolizable energy averaged over one round (in MJ $place^{-1}$ d^{-1} ME)
τ_{round}	duration of production cycle (in d $round^{-1}$)
j	index of day
$\mathrm{k_{fin}}$	number of final day of fattening period
x_{male}	ratio of male broiler animal numbers to total population
$ME_{\mathrm{male,\,j}}$	requirements of total metabolizable energy for male broilers on day j (in MJ $animal^{-1}$ d^{-1} ME)
$ME_{\mathrm{female,\,j}}$	requirements of total metabolizable energy for female broilers on day j (in MJ $animal^{-1}$ d^{-1} ME)

GfE (2000) recommends surplus supplies to the ME requirements calculated from (22) to reflect common feeding practice (see Table 1.3.2 in GfE, 2000, footnote 3). This recommendation was checked by calculation of "real" ME intakes using feed ME contents as reported from breeding line and feed contests (all feed ME data as declared by the producers; for data sources see Section 3.1.1). Figure 8 displays these "real" ME intakes over the ME requirements calculated from (22). It seems that Equation (22) tends to slightly overestimate the "real" ME intakes. Thus, in subsequent calculations no surplus supplies are added to the ME requirements obtained by Equation (22). This reflects the proposal made in IPCC (2006), Section 10.2, to derive excretion rates from the energy requirements for adequate feeding.

GfE (2000) empfiehlt einen praxisorientierten Zuschlag zu den nach Gleichung (22) berechneten ME-Bedarfswerten, vgl. Fußnote 3 zu Tabelle 1.3.2 in GfE (2000). Zur Überprüfung dieses Vorschlages wurde anhand der deklarierten ME-Futtergehalte, wie sie in Herkunfts- und Futtermittelprüfungen (Quellenangaben s. Abschnitt 3.1.1) berichtet wurden, die „reale" ME-Aufnahme berechnet. Abbildung 8 zeigt das Ergebnis im Vergleich zu den Resultaten aus Gleichung (22). Letztere tendieren eher zu einer leichten Überschätzung des „realen" ME-Bedarfes, weshalb in nachfolgenden Berechnungen auf einen Zuschlag zum Ergebnis von (22) verzichtet wird. Dies entspricht dem Vorschlag von IPCC (2006), Kapitel 10.2, die Berechnung der Ausscheidungen aus dem Energiebedarf für eine bedarfsgerechte Fütterung vorzunehmen.

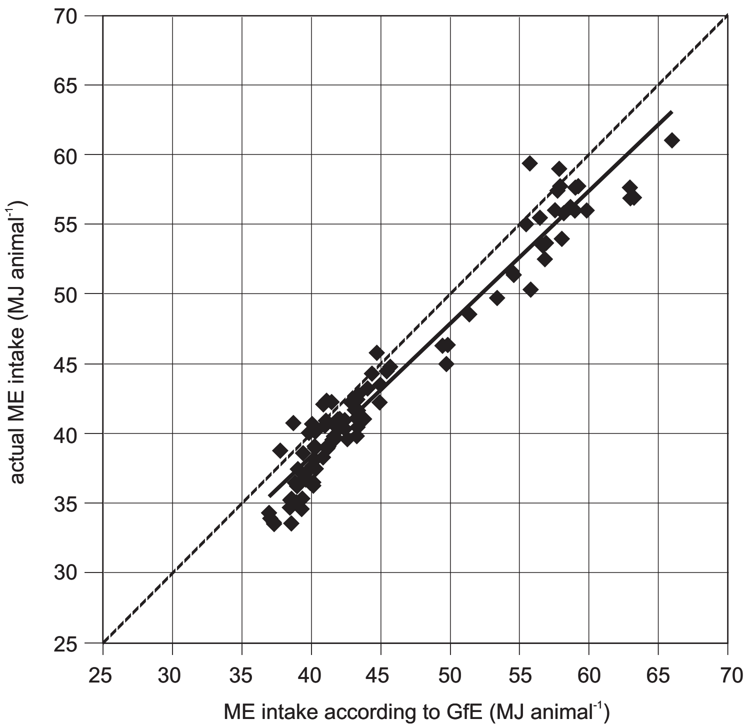

Figure 8:

Comparison of the actual ME intake with the intake calculated according to GfE (2000). Slope of regression with zero intercept: 0.9508 (R^2 = 0.9372). The dashed line is the 1 to 1 line. For details see text.

Abbildung 8:

Vergleich der tatsächlichen ME-Aufnahme mit dem nach GfE (2000) berechneten ME-Bedarf. Steigung der Regressionsgerade durch den Ursprung: 0,9508 (R^2 = 0,9372). Gestrichelt: 1:1-Linie. Details s. Text.

3.4 N balance

The cumulative N balance for the whole fattening period reads as follows:

3.4 N-Bilanz

Für die N-Bilanz eines Tieres über eine gesamte Mastperiode gilt:

$$\sum_{j=1}^{k_{fin}} \tau_{day} \cdot m_{excreted,\,i,\,j} = x_N \cdot \sum_{j=1}^{k_{fin}} \left(\tau_{day} \cdot x_{XP,\,feed,\,j} \cdot m_{feed,\,i,\,j}\right) - x_{N,\,ret,\,i}\left(k_{fin}\right) \cdot \sum_{j=1}^{k_{fin}} \left[\tau_{day} \cdot \left(\frac{\Delta w}{\Delta t}\right)_{i,\,j}\right] \tag{23}$$

where

$\Sigma\, \tau_{day} \cdot m_{excreted,\,i,\,j}$	gender-dependent amount of nitrogen excreted during one round (in kg place^{-1} round^{-1} N = kg animal^{-1} N)
τ_{day}	time period of one day (τ_{day} = 1 d round^{-1})
$m_{excreted,\,i,\,j}$	gender-dependent amount of nitrogen excreted daily (in kg animal^{-1} d^{-1} N)
i	gender index (i = male, female)
j	index of day
k_{fin}	number of final day of fattening period
x_N	nitrogen content of crude protein (x_N = 1/6.25 kg kg^{-1} N)
$x_{XP,\,feed,\,j}$	content of crude protein in feed as function of day j (in kg kg^{-1} XP)
$m_{feed,\,i,\,j}$	daily feed intake during fattening period (in kg animal^{-1} d^{-1})
$x_{N,\,ret,\,i}$ (k_{fin})	gender-dependent specific N retention as function of fattening period duration (in kg kg^{-1} N)
τ_{day}	time period of one day (τ_{day} = 1 d round^{-1})
$(\Delta w/\Delta t)_{i,\,j}$	gender-related daily weight gain per animal and day according to Table 2 (in kg animal^{-1} d^{-1})

Here, the term following the equal sign of equation (23) describes the crude protein intake with feed, the subsequent term the amount of protein retained.

In general, the crude protein content of feeds varies with feeding phases (see Section 2). It is therefore taken into account as a function of the respective day of life.

For adequate feeding reflecting the daily requirements of ME exactly, the amount of feed consumed daily can be calculated according to equation (24).

Der linke Term der rechten Seite von Gleichung (23) beschreibt die Rohprotein-Aufnahme über das Futter, der rechte Term den Rohprotein-Ansatz.

Der Rohproteingehalt des Futters variiert im Allgemeinen mit den Fütterungsphasen (s. Abschnitt 2), weshalb er formal als Funktion des Lebenstages eingeht.

Die tägliche Futtermenge ergibt sich bei bedarfsgerechter, d. h. den tagesspezifischen ME-Bedarf exakt erfüllender Fütterung wie folgt:

$$m_{feed,\,i,\,j} = \frac{ME_{i,\,j}}{\eta_{ME,\,feed,\,j}} \tag{24}$$

where

$m_{feed,\,i,\,j}$	daily feed intake during fattening period (in kg animal^{-1} d^{-1})
$ME_{i,\,j}$	gender-dependent requirements of total metabolizable energy for day j (in MJ animal^{-1} d^{-1} ME)
i	gender index (i = male, female)
j	index of day of life
$\eta_{ME,\,feed,\,j}$	content of metabolizable energy in feed on day j (in MJ kg^{-1} ME)

A value for the specific N retention was published by LfL (2006) (0.035 kg kg^{-1} N). However, this is a mean value used for poultry as a whole. The data provided in GfE (2000) facilitate a differentiated approach resulting in the calculation of a mean depending on the duration of the fattening period:

Für die spezifische N-Retention gibt LfL (2006) einen Wert von 0,035 kg kg^{-1} N an. Dies ist allerdings ein Geflügel-Mittelwert. Einen differenzierteren Ansatz ermöglichen die in Tabelle 2 wiedergegebenen Proteindaten aus GfE (2000). Man erhält damit einen von der Mastdauer abhängigen Mittelwert:

$$x_{\mathrm{N,\,ret,\,i}}\left(\mathrm{k}_{\mathrm{fin}}\right) = x_{\mathrm{N}} \cdot P_{\mathrm{i}} \tag{25}$$

where

$x_{\mathrm{N,\,ret,\,i}}$	lifespan-related gender-dependent specific N retention (in kg kg^{-1} N)
$\mathrm{k}_{\mathrm{fin}}$	number of final day of fattening period
x_{N}	nitrogen content of crude protein (x_{N} = 1/6.25 kg kg^{-1} N)
P_{i}	ratio of total protein gain to total weight gain during fattening period (see eq. 19) (in kg kg^{-1})

In practice, equation (25) yields the same results for cocks and hens, see Figure 9

Die Geschlechtsabhängigkeit von (25) erweist sich als vernachlässigbar, wie Abbildung 9 zeigt.

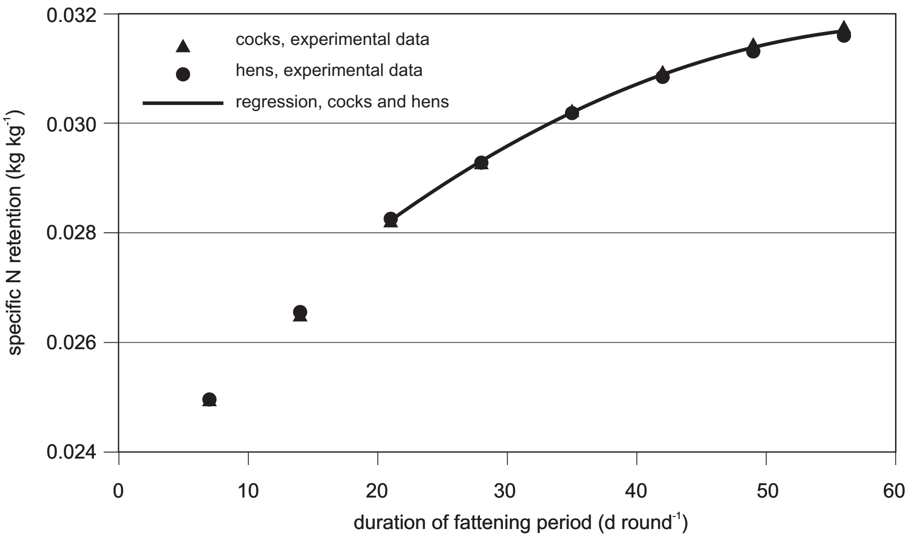

Figure 9:

Specific N retention as function of the duration of the fattening period as well as of gender. Symbols: results calculated from GfE (2000) data as given in Table 2. Regression function as given by Equation (26), R^2 = 0.9981.

Abbildung 9:

Spezifische N-Retention als Funktion von Mastdauer und Geschlecht. Punkte: Berechnungen nach GfE (2000)-Daten (Tabelle 2); Regressionsfunktion nach Gleichung (26) mit R^2 = 0,9981.

If one neglects the irrelevant durations of fattening periods below three weeks as well as the very small differences obtained for cocks and hens, the mean specific N retention can be expressed as a function of the duration of the fattening period by a second order polynomial as in equation (26) (R^2 = 0.9961):

Bleiben die für die Mastpraxis in jedem Fall irrelevanten Mastdauern bis drei Wochen sowie die sehr geringe Geschlechtsabhängigkeit unberücksichtigt, lässt sich die von der Mastdauer abhängige mittlere spezifische N-Retention durch ein Polynom zweiten Grades darstellen (R^2 = 0,9961):

$$x_{\mathrm{N,\,ret,\,male}}\left(\mathrm{k}_{\mathrm{fin}}\right) \approx x_{\mathrm{N,\,ret,\,female}}\left(\mathrm{k}_{\mathrm{fin}}\right) \approx x_{\mathrm{N,\,ret,\,br}}\left(\mathrm{k}_{\mathrm{fin}}\right) = a_{\mathrm{ret}} + b_{\mathrm{ret}} \cdot \mathrm{k}_{\mathrm{fin}} + c_{\mathrm{ret}} \cdot \mathrm{k}_{\mathrm{fin}}^{2} \tag{26}$$

where

$x_{\mathrm{N,\,ret,\,male}}$	lifespan-related specific N retention of male broilers (in kg kg^{-1} N)
$x_{\mathrm{N,\,ret,\,female}}$	lifespan-related specific N retention of female broilers (in kg kg^{-1} N)
$x_{\mathrm{N,\,ret,\,br}}$	gender-averaged specific N retention as function of lifespan (in kg kg^{-1} N)
$\mathrm{k}_{\mathrm{fin}}$	number of final day of fattening period
a_{ret}	constant (a_{ret} = 2.3806·10^{-2} kg kg^{-1} N)
b_{ret}	constant (b_{ret} = 2.5244·10^{-4} kg kg^{-1} N)
c_{ret}	constant (c_{ret} = -1.9964·10^{-6} kg kg^{-1} N)

A shortcoming of equation (26) is the fact that is based on data of the early 1990ies (see Section 3.1.3). However, a potential adjustment of a changing retention as a result of breeding progress is impossible due to the lack of more recent data. As the data obtained using equation (26) fall below those reported by LfL (2006), the results of equation (26) are preferred. This guarantees that the N excretions and thus the emissions are not underestimated.

The mean N excretion per place and day for a population of broilers of both genders is then obtained from equation (27):

Gleichung (26) beruht allerdings auf dem Stand der Broiler-Zucht in der ersten Hälfte der 1990er Jahre (s. Abschnitt 3.1.3). Mangels aktuellerer Daten kann eine mögliche Modifikation der Retention infolge von Zuchtfortschritten nicht berücksichtigt werden. Da die Retention nach (26) niedriger ist, als die nach LfL (2006), werden die Ergebnisse von (26) bevorzugt, um einer Unterschätzung der emissionsrelevanten N-Ausscheidungen vorzubeugen.

Die in einer gemischten Population anfallende mittlere N-Ausscheidung pro Durchgangstag und Platz ergibt sich aus:

$$\sum_{\mathrm{j=1}}^{\mathrm{k_{fin}}} \tau_{\mathrm{day}} \cdot m_{\mathrm{excreted,\,j}} = x_{\mathrm{male}} \cdot \sum_{\mathrm{j=1}}^{\mathrm{k_{fin}}} \left(\tau_{\mathrm{day}} \cdot m_{\mathrm{excreted,\,male,\,j}}\right) + \left(1 - x_{\mathrm{male}}\right) \cdot \sum_{\mathrm{j=1}}^{\mathrm{k_{fin}}} \left(\tau_{\mathrm{day}} \cdot m_{\mathrm{excreted,\,female,\,j}}\right) \tag{27}$$

where

$\Sigma\, \tau_{\mathrm{day}} \cdot m_{\mathrm{excreted,\,j}}$	gender-averaged amount of nitrogen excreted (in kg place^{-1} round^{-1} N = kg animal^{-1} N)
τ_{day}	time period of one day (τ_{day} = 1 d round^{-1})
$m_{\mathrm{excreted,\,j}}$	gender-averaged amount of nitrogen excreted daily (in kg place^{-1} d^{-1} N)
j	index of day
$\mathrm{k_{fin}}$	number of final day of fattening period
x_{male}	fraction of male broiler population (in place place^{-1})
$m_{\mathrm{excreted,\,male,\,j}}$	amount of nitrogen excreted daily by a male broiler (in kg place^{-1} d^{-1} N)
$m_{\mathrm{excreted,\,female,\,j}}$	amount of nitrogen excreted daily by a female broiler (in kg place^{-1} d^{-1} N)

Presupposing feed compositions with respect to ME and XP that are constant with time, the cumulative N excretion amounts to

Daraus folgt unter der Voraussetzung effektiver, d. h. zeitlich konstanter Futtergehalte an ME und XP (s. Abschnitt 2.3.2) zunächst:

$$\begin{aligned}\sum_{\mathrm{j=1}}^{\mathrm{k_{fin}}} \tau_{\mathrm{day}} \cdot m_{\mathrm{excreted,\,j}} = {} & \frac{x_{\mathrm{N}} \cdot x_{\mathrm{XP,\,feed}}}{\eta_{\mathrm{ME,\,feed}}} \cdot \left[x_{\mathrm{male}} \cdot \sum_{\mathrm{j=1}}^{\mathrm{k_{fin}}} \left(\tau_{\mathrm{day}} \cdot ME_{\mathrm{male,\,j}}\right) + \left(1 - x_{\mathrm{male}}\right) \cdot \sum_{\mathrm{j=1}}^{\mathrm{k_{fin}}} \left(\tau_{\mathrm{day}} \cdot ME_{\mathrm{female,\,j}}\right) \right] - \\ & x_{\mathrm{N,\,ret,\,br}}\left(\mathrm{k_{fin}}\right) \cdot \left\{ x_{\mathrm{male}} \cdot \sum_{\mathrm{j=1}}^{\mathrm{k_{fin}}} \left[\tau_{\mathrm{day}} \cdot \left(\frac{\Delta w}{\Delta t}\right)_{\mathrm{male,\,j}} \right] + \left(1 - x_{\mathrm{male}}\right) \cdot \sum_{\mathrm{j=1}}^{\mathrm{k_{fin}}} \left[\tau_{\mathrm{day}} \cdot \left(\frac{\Delta w}{\Delta t}\right)_{\mathrm{female,\,j}} \right] \right\}\end{aligned} \tag{28}$$

where

$\Sigma\, \tau_{\mathrm{day}} \cdot m_{\mathrm{excreted,\,j}}$	gender-averaged amount of nitrogen excreted (in kg place^{-1} round^{-1} N = kg animal^{-1} N)
τ_{day}	time period of one day (τ_{day} = 1 d round^{-1})
$m_{\mathrm{excreted,\,j}}$	gender-averaged amount of nitrogen excreted daily (in kg place^{-1} d^{-1} N)
j	index of day
$\mathrm{k_{fin}}$	number of final day of fattening period
x_{N}	nitrogen content of crude protein (x_{N} = 1/6.25 kg kg^{-1} N)
$x_{\mathrm{XP,\,feed}}$	content of crude protein in feed (in kg kg^{-1} XP)
$\eta_{\mathrm{ME,\,feed}}$	effective content of metabolizable energy in feed (in MJ kg^{-1} ME)
$ME_{\mathrm{male,\,j}}$	total metabolizable energy required by a male broiler on day j of life (in MJ animal^{-1} round^{-1} ME)
$ME_{\mathrm{female,\,j}}$	total metabolizable energy required by a female broiler on day j of life (in MJ animal^{-1} round^{-1} ME)
x_{male}	ratio of male broiler animal numbers to total population
$x_{\mathrm{N,\,ret,\,br}}\,(\mathrm{k_{fin}})$	gender-averaged specific N retention as function of lifespan (in kg kg^{-1} N)
$(\Delta w/\Delta t)_{\mathrm{male,\,j}}$	daily weight gain of a male broiler according to Table 2 (in kg animal^{-1} d^{-1})
$(\Delta w/\Delta t)_{\mathrm{female,\,j}}$	daily weight gain of a female broiler according to Table 2 (in kg animal^{-1} d^{-1})

The left bracket of the right hand side of equation (28) can be substituted by ME_{br} (see equation (22)). The right bracket describes the mean weight gain of a population of cocks and hens, $\Delta w_{br, kfin}$, during one round (see equation (8)). Thus, equation (28) transforms into:

Die linke Klammer auf der rechten Seite von (28) kann durch ME_{br} (s. Gleichung (22)) ausgedrückt werden. Die rechte Klammer repräsentiert den geschlechtsgemittelten Gesamtzuwachs während eines Durchganges, $\Delta w_{br, kfin}$ (s. Gleichung (8)). Damit wird (28) zu:

$$\sum_{j=1}^{k_{fin}} \tau_{day} \cdot m_{excreted, j} = \frac{x_N \cdot x_{XP, feed}}{\eta_{ME, feed}} \cdot \tau_{round} \cdot ME_{br} - x_{N, ret, br}\left(k_{fin}\right) \cdot \Delta w_{br, kfin} \tag{29}$$

where

$\Sigma\, \tau_{day} \cdot m_{excreted, j}$	gender-averaged amount of nitrogen excreted (in kg place^{-1} round^{-1} N = kg animal^{-1} N)
τ_{day}	time period of one day (τ_{day} = 1 d round^{-1})
$m_{excreted, i, j}$	gender-averaged amount of nitrogen excreted daily (in kg place^{-1} d^{-1} N)
j	index of day
k_{fin}	number of final day of fattening period
x_N	nitrogen content of crude protein (x_N = 1/6.25 kg kg^{-1} N)
$x_{XP, feed}$	content of crude protein in feed (in kg kg^{-1} XP)
$\eta_{ME, feed}$	effective content of metabolizable energy in feed (in MJ kg^{-1} ME)
τ_{round}	duration of production cycle (in d round^{-1})
ME_{br}	daily metabolizable energy for average broiler, averaged over one round (in MJ place^{-1} d^{-1} ME)
$x_{N, ret, br}$ (k_{fin})	gender-averaged specific N retention as function of lifespan (in kg kg^{-1} N)
$\Delta w_{br, kfin}$	average animal weight gain per place and fattening period (in kg animal^{-1} = kg place^{-1} round^{-1})

The estimation of mean feed properties as needed in (29) is dealt with in section 4.2.

Auf die für (29) benötigten mittleren Futtermittel-Kennwerte geht Abschnitt 4.2 ein.

4 Feed

4.1 Feed characteristics relevant to phase feeding

Usually, each of the fattening procedures mentioned is subdivided into phases reflecting the respective feeding requirements. The first phase comprises the first 10 to 14 days after hatching. Here, a specific chick feed is provided. The next phase is the main phase with fattening feed. As a rule, this phase ends 5 days before slaughtering. In the final phase a special diet is fed whose contents in ME and XP are very similar to the main fattening feed. However, it does not contain coccidio-static agents.

The recommended amounts of the various feeds are to be found e.g. in KTBL (2004). Numerous experiments dealing with the variation of feed constituents have been reported in DGS-Magazin (e.g. Richter and Fischer, 2005).

The breeding line and feed contests used to provide the present paper report manufacturer-declared contents of ME and XP instead of analysed values (Anonymus, 1997; Anonymus, 2001; Damme, 1994, 1995, 1997; Damme and Rychlik, 2001; Klein, 1991a, 1991b; Lüke et al., 2004; Poteracki, 1991, 1994, 1995, 1996; Poteracki and Adam, 1993a, 1993b; Poteracki et al., 1994; Simon, 2001; Simon and Stegemann, 2005). Table 4 presents the trends of the declared feed properties.

4 Fütterung

4.1 Phasenorientierte Futterkennwerte

Üblicherweise wird jedes Mastverfahren in drei Phasen unterteilt, um die Futterinhaltsstoffe dem Bedarf anpassen zu können. Die erste Phase, in der ein spezielles Kükenfutter verabreicht wird, umfasst die ersten 10 bis 14 Tage nach dem Schlüpfen. Die zweite Phase, in der das Mastfutter verfüttert wird, ist die Hauptphase und endet i. d. R. 5 Tage vor dem Schlachttermin. In letzter Phase kommt das kokzidiostatikumfreie Absetzfutter zum Einsatz, das in ME- und XP- Gehalt dem Mastfutter ähnlich ist.

Empfehlungen zur Futterzusammensetzung finden sich in KTBL (2004). Versuche zur Variierung dieser Zusammensetzungen werden u. A. im DGS-Magazin berichtet (z. B. Richter und Fischer, 2005).

Die dieser Arbeit zugrunde liegenden Herkunfts- und Futtermittelprüfungen (Anonymus, 1997; Anonymus, 2001; Damme, 1994, 1995, 1997; Damme und Rychlik, 2001; Klein, 1991a, 1991b; Lüke et al., 2004; Poteracki, 1991, 1994, 1995, 1996; Poteracki und Adam, 1993a, 1993b; Poteracki et al., 1994; Simon, 2001; Simon und Stegemann, 2005) berichten die vom Hersteller deklarierten Werte zu ME- und XP-Gehalt anstelle von analysierten Futtereigenschaften. Die Trends der deklarierten Futtereigenschaften gehen aus Tabelle 4 hervor.

Table 4:

Trends of ME and XP contents in feed according to breeding line and feed contests as declared by feed producers. First figure for 1990, second figure for 2005. For sources see text.

Tabelle 4:

Tendenzen zu ME- und XP-Gehalten im Futter nach Daten aus Herkunfts- und Futtermittelprüfungen (deklarierte Eigenschaften). Erste Angabe für 1990, die zweite für 2005. Quellenangaben s. Text.

type of feed	ME content (MJ kg^{-1})	XP content (kg kg^{-1})
chick feed	12.5 → 12.4	0.230 → 0.225
fattening feed	13.4 → 13.0	0.225 → 0.210
final feed	13.3 → 13.0	0.220 → 0.200

All subsequent considerations and results described make use of the feed characteristics declared by the respective producer.

4.2 Approximation of effective feed characteristics

The knowledge about feed characteristics is a prerequisite for the assessment of N excretions (see Section 3.4). If equation (29) is to be used, mean feed properties have to be known a priori. These averages do not only depend

Im Folgenden beruhen alle Überlegungen und Ergebnisse auf den durch die Hersteller deklarierten Futtereigenschaften.

4.2 Approximation effektiver Futterkennwerte

Futtermittel-Kennwerte sind eine wesentliche Grundlage zur Berechnung der N-Ausscheidung (vgl. Abschnitt 3.4). Soll dazu Gleichung (29) eingesetzt werden, müssen a priori Mittelwerte der Futtermittel-Kennwerte bekannt sein.

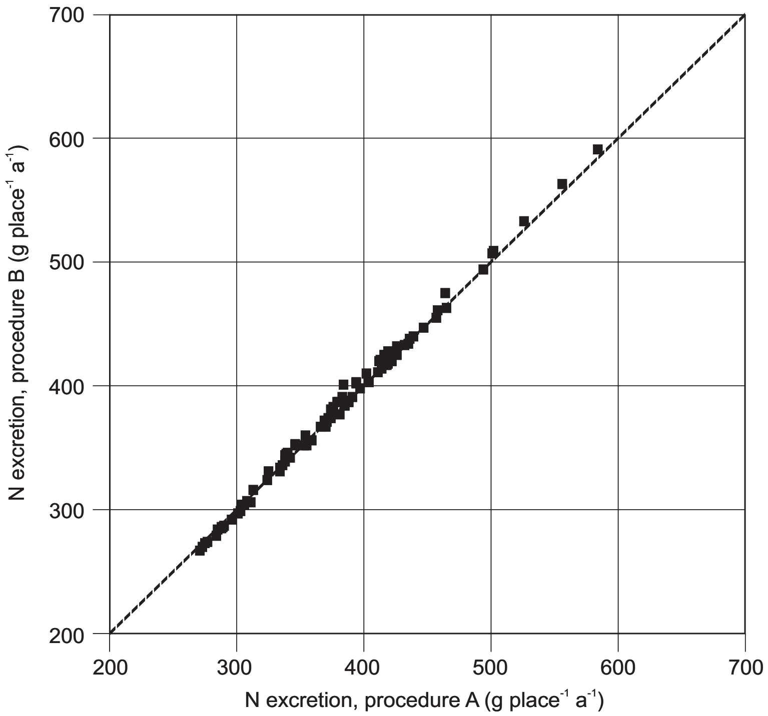

Figure 10:

Comparison of N excretions calculated (A) taking into account lifetime-dependent feeding requirements as well as phase specific feed properties, and (B) with phase-independent feed properties assumed to be identical to the properties of the fattening-phase feed (All feed properties as declared by producers). The dashed line is the 1 to 1 line.

Abbildung 10:

Vergleich berechneter N-Ausscheidungen, wobei die Berechnung zum einen mit phasenspezifischen Futter-Kennwerten (Fall A), zum anderen nur mit den Mastfutter-Kennwerten (Fall B) erfolgte (Alle Futtermerkmale vom Hersteller deklarierte Merkmale). Gestrichelt: 1:1-Linie.

on feed composition but also on the design of the fattening process with respect to the duration of the phases as well as on the feed intake. The latter is also a function of both animal age and performance. As a consequence, effective means would have to be calculated for the whole production process including all parameters. In practice, a simpler approach is preferred that permits the approximation of mean feed properties from known feed properties only. An obvious choice is to simply take the properties of the feed given in the dominating main fattening phase. Figure 10 compares the N excretions based on this simple approximation to those obtained by calculating the whole production process including all parameters.

It is obvious that the properties of the fattening feed can be used to describe N excretions with sufficient accuracy and representativeness for the whole process. Thus they can be used to derive effective feed properties.

Solche Mittelwerte sind allerdings nicht nur eine Funktion der Futterzusammensetzung, sondern werden durch Phasenunterteilung und -dauer sowie durch die von Tieralter und -leistung abhängige Futteraufnahme mitbestimmt. Zur Gewinnung der Mittelwerte der Futtereigenschaften müsste folglich der gesamte Mastprozess durchgerechnet werden. In der Praxis wünschenswert wäre dagegen eine Approximation allein auf Basis der bekannten Futtermitteleigenschaften. Hierzu bieten sich unmittelbar die Daten des Mastfutters an, da dieses in der Fütterung dominiert. Abbildung 10 zeigt einen Vergleich dieses Approximationsansatzes mit der vollständigen Berechnung auf Basis der resultierenden N-Ausscheidung.

Offensichtlich können die Mastfuttereigenschaften hinsichtlich der N-Ausscheidung als hinreichend repräsentativ für die gesamte Fütterung angesehen und somit anstelle der an sich benötigten effektiven Futtereigenschaften verwendet werden.

5 Slaughter yields

Slaughter yields are mainly determined by the respective race or line, to a lesser extent also by keeping and feeding conditions. The range of potential parameters covering keeping and feeding is very wide. Thus, it is improbable that slaughter yields can be assumed to be constant. However, constant yields of 0.73 kg kg^{-1} and 0.74 kg kg^{-1} were proposed by Pingel (1996) and Hahn (2006), respectively.

A look at the data available suggests that there is some correlation between final live weight and slaughter yield. Figure 11 presents data from several test reports (Culioli et al., 1990, see Grashorn, 2000; Damme, 2001; Damme et al., 2005; Grashorn und Brose, 1997, see Grashorn, 2000; Hadorn und Wiedmer, 1998; Soliman et al., 1990; Tiller, 1990; Tüller et al., 1990; Tüller und Velten, 1991). The data points for "hens and cocks" (i.e. data sets originating from the slaughtering of a mixed population) allow for the derivation of a linear trend as described in equation (30). Some data describing hens and cocks separately do not confirm this relation. However, they are mostly restricted to very low and irrelevant weights. Nonetheless, equation (30) will be used in the companion paper (Haenel and Dämmgen, 2009) as part of the pragmatic approach to model durations of animal rounds.

5 Schlachtausbeute

Die Schlachtausbeute wird maßgeblich durch die Eigenschaften der Tierrasse bestimmt, unterliegt aber auch dem Einfluss von Haltungs- und Fütterungsbedingungen. Das weite Spektrum möglicher Einflussfaktoren spricht dagegen, dass der Schlachtausbeutefaktor eine Konstante ist, wie Pingel (1996) und Hahn (2006) sie angeben (0,73 kg kg^{-1} und 0,74 kg kg^{-1}).

Immerhin scheint eine gewisse Korrelation zwischen Tierendgewicht und Schlachtausbeutefaktor zu existieren. Abbildung 11 zeigt entsprechende Daten aus einer Auswahl von Schlachtuntersuchungen (Culioli et al., 1990, zitiert in Grashorn, 2000; Damme, 2001; Damme et al., 2005; Grashorn und Brose, 1997, zitiert in Grashorn, 2000; Hadorn und Wiedmer, 1998; Soliman et al., 1990; Tiller, 1990; Tüller et al., 1990; Tüller und Velten, 1991). Die Datenpunkte „Hähne und Hennen", die Schlachtergebnisse von Hähnen und Hennen zusammenfassen, erlauben die Ableitung eines linearen Trends, s. auch Gleichung (30). Einige Datensätze, die separat für Hähne und Hennen erhoben wurden, bestätigen den Trend nicht, beschränken sich aber im Wesentlichen auf heute nicht mehr übliche niedrige Tiergewichte. Daher geht Gleichung (30) als pragmatischer Ansatz in das in Haenel and Dämmgen (2009) beschriebene Mastdauer-Berechnungsverfahren ein.

$$c_{\mathrm{w,\,br}} = a_{\mathrm{c}} + b_{\mathrm{c}} \cdot w_{\mathrm{br,\,kfin}} \tag{30}$$

where

$c_{\mathrm{w,\,br}}$	ratio of carcass weight to final live weight (in kg kg^{-1})
$w_{\mathrm{br,\,kfin}}$	average final live weight of broilers (in kg animal^{-1})
a_{c}	constant (a_{c} = 0.617494 kg animal^{-1})
b_{c}	constant (b_{c} = 0.039585 kg kg^{-1})

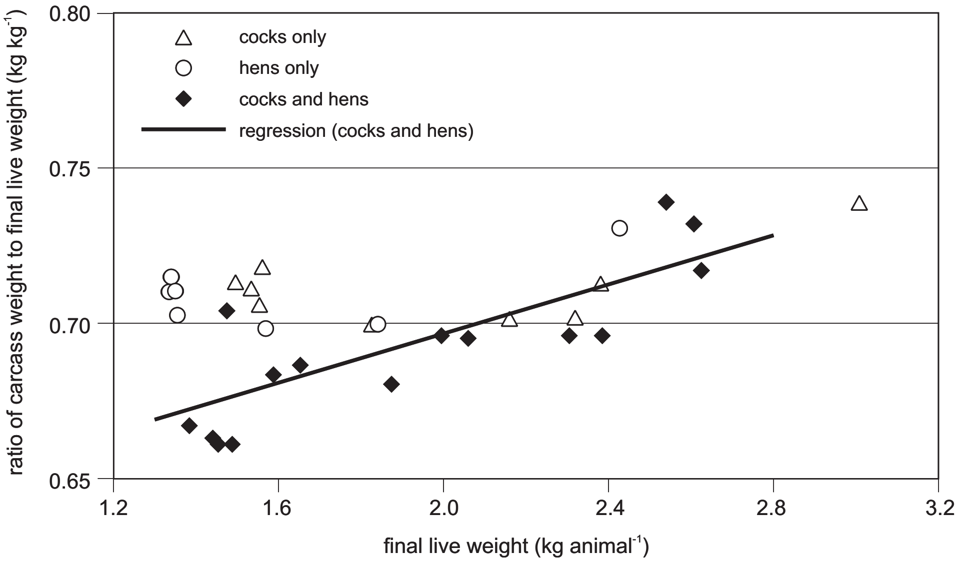

Figure 11:

Slaughter yield as a function of the final live weight. For details see text.

Abbildung 11:

Darstellung von Schlachtausbeute-Faktoren in Abhängigkeit vom Lebendendgewicht. Details siehe Text.

6 Concluding remarks

In the present paper, data on broiler breeding as well as animal properties of broilers could be analysed to yield mathematical formulae. These formulae provide the means to relate excretions per place and year to the progress in broiler breeding (i. e. increasing daily growth rates) as well as to the modifications in broiler rearing (in particular increased fattening periods) and feeding.

In case of a limited data base for the derivation of process descriptions, solutions were selected which make sure that excretions are overestimated rather than underestimated.

For the future it would be preferable to obtain the input data in finer spatial resolution. More information on feed properties would also be desirable.

The equations developed in the present paper will be used in a companion paper (Haenel and Dämmgen, 2009) to derive a model which allows to establish the time series of the parameters relevant for the calculation of emissions from the German broiler husbandry.

7 Acknowledgements

Barbara Amon and Nicholas Hutchings, co-chairs of the Agriculture and Nature Panel, UNECE Task Force on Emission Inventories and Projections, critically reviewed this text for which the authors wish to express their thanks.

6 Schlussbemerkung

In der vorliegenden Arbeit wurden für Masthähnchen und -hühnchen Haltungsparameter und Tiereigenschaften in mathematische Formeln umgesetzt. Diese ermöglichen u. A., den Einfluss züchterischen Fortschritts (d. h. steigender täglicher Gewichtszuwächse) und Veränderungen in der Haltung (insbesondere bei der Mastdauer) und der Fütterung auf die Ausscheidungen pro Platz und Jahr nachzuvollziehen.

In Fällen eingeschränkter Datenverfügbarkeit bei der Ableitung von Prozessbeschreibungen wurden Lösungen gewählt, die eher zu einer Über- als einer Unterschätzung der Ausscheidungen führen.

Für die Zukunft wäre eine feinere räumliche Auflösung der Daten wünschenswert, ebenso wie eine Verdichtung der Futtereigenschaftsdaten.

Die gefundenen Ansätze sollen in einer nachfolgenden Arbeit (Haenel und Dämmgen, 2009) dazu dienen, ein Modell zur Erstellung von Zeitreihen der emissionsrelevanten Parameter in der deutschen Broilerhaltung zu entwickeln.

7 Danksagungen

Barbara Amon und Nicholas Hutchings, die Vorsitzenden des Agriculture and Nature Panel, UNECE Task Force on Emission Inventories and Projections, haben den Text kritisch durchgelesen, wofür Ihnen herzlich gedankt sei.

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