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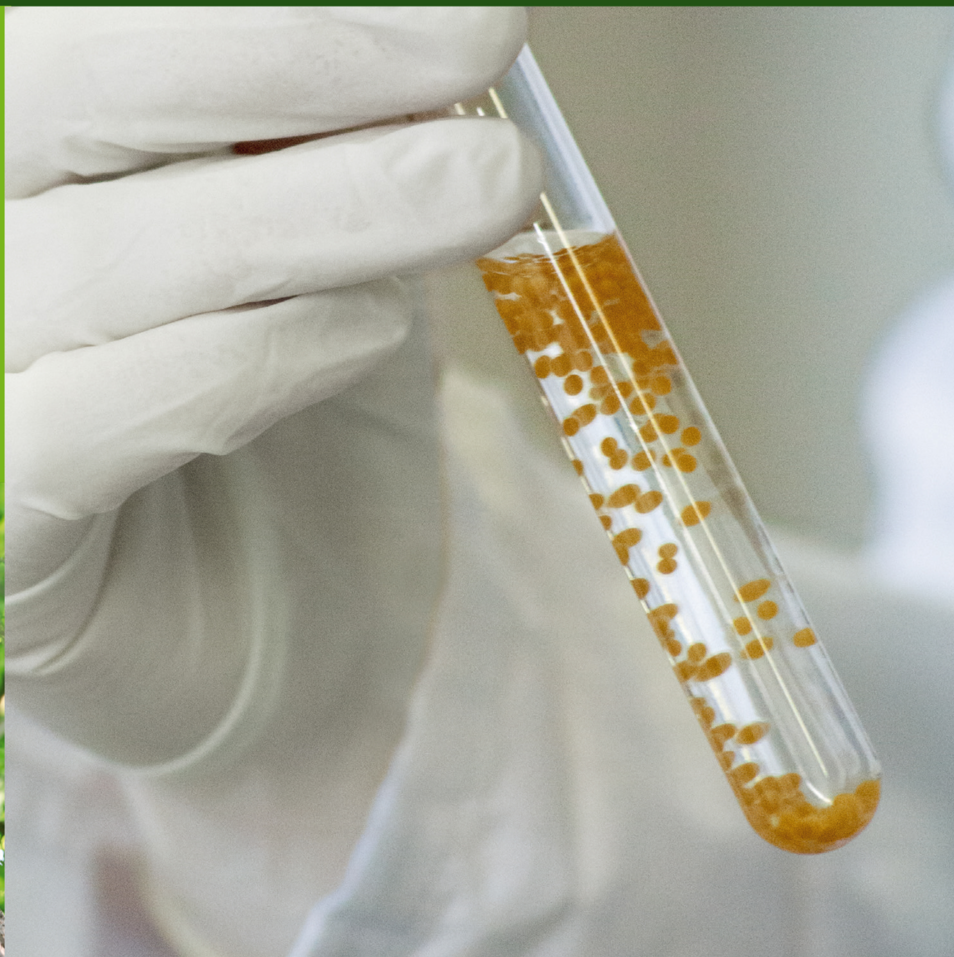

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Content

Effects of three genotypes and two roughages in organic heavy pig production for dry fermented sausage manufacture

1. Performance, carcass quality, and economic aspects

Anja Schwalm*, Christina Well*, Ralf Bussemas* and Friedrich Weißmann*

Abstract

Castrated heavy pigs of >160 kg live weight are used for traditional pork specialties (e.g. dry fermented sausages) due to the required fat quantity and quality. Today, most organic production systems use modern hybrids (Hy) with often insufficient fat features. The use of endangered breeds with high body fat synthesis capacity, e.g. Saddleback (Sa), could be an alternative with the additional benefit of maintaining biodiversity.

This study with a total of 132 castrates analysed the effects of three different genotypes (Sa, Piétrain*Sa (PiSa), Hy) and two different roughage sources (grass-clover silage, straw) on performance, carcass-, meat-, fat-, product-quality (dry fermented sausage), and economic aspects. The present paper deals with performance (PF), carcass quality (CQ), and economic aspects (EA). It is found that PF and CQ are both influenced significantly by the genotype but not by the roughage source. Hy showed the best and Sa the poorest PF (e.g. 804 g vs. 634 g daily weight gain). Concerning CQ, Sa showed the fattest and Hy the leanest carcass (e.g. 1 : 1.36 vs. 1 : 0.49 lean to fat ratio). Concerning EA, Sa generated only about 60 % of the surplus of the revenues over feed and piglet costs compared to Hy. PiSa always ranked in the middle.

It can be concluded that under organic farming conditions Sa and PiSa seem to be suitable for heavy pig production to produce premium segment pork specialities in the form of dry fermented sausages due to performance and carcass quality traits. But as long as the payout price is not adapted to carcass quality or the suitability for processing, in particular the fattening of Sa will not be interesting from an economic point of view.

Keywords: *heavy pig, saddleback, performance, carcass quality, economics*

Zusammenfassung

Effekt unterschiedlicher Genotypen und Raufutter in der ökologischen Mast schwerer Schweine zur Rohwurstherstellung

1. Mastleistung, Schlachtkörperqualität und Wirtschaftlichkeit

Zur Herstellung langgereifter Rohwurst werden Kastraten >160 kg Lebendmasse wegen der benötigten Fettmenge und -qualität genutzt. Zur Mast kommen vor allem moderne Hybriden (Hy), bei denen beides oftmals unzureichend ausfällt. Alte gefährdete Rassen, z.B. Sattelschweine (Sa), mit einer hohen *de-novo* Fettsynthesekapazität könnten eine Alternative darstellen und damit zu deren Erhaltung beitragen.

Es wurden die Effekte von drei Genotypen (Sa, Piétrain*Sa(PiSa), Hy) und zwei Raufuttern (Kleegrassilage, Stroh) auf Mastleistung (ML), Schlachtkörper (SQ)-, Fleisch-, Fett- und Wurstqualität sowie Wirtschaftlichkeit (W) überprüft. Dieser Artikel präsentiert die Ergebnisse zu ML, SQ und W. Der Genotyp jedoch nicht das Raufutter beeinflussten ML und SQ signifikant. Hy zeigte gegenüber Sa die beste ML (804 g vs. 634 g tägl. Zunahme) und bei SQ die geringste Verfettung (1 : 1,36 vs. 1 : 0,49 Fleisch : Fett-Verhältnis). Bezüglich W erreichte Sa nur 60 % des Überschusses über die Ferkel-Futter-Kosten von Hy. Bei sämtlichen Kriterien lagen die Ergebnisse von PiSa zwischen Hy und Sa.

Hinsichtlich der Fettquantitäten scheinen Sa und PiSa für die Rohwurstherstellung am besten geeignet zu sein. Jedoch ist die Mast von Sa in Reinzucht ökonomisch uninteressant, solange der Auszahlungspreis nicht an deren geeignete Schlachtkörperqualität für die Weiterverarbeitung angepasst wird.

Schlüsselworte: *Schwere Schweine, Sattelschwein, Mastleistung, Schlachtkörperqualität, Wirtschaftlichkeit*

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1 Introduction

Heavy pigs (castrated males, 150 to 160 kg live weight) are used for the production of traditional, regional pork specialties (e.g. dry fermented sausages or ham) in several regions of Europe. In this high body weight class, the meat quality, the amount and the quality of fat (e.g. firm, oxidation resistant) are sufficient for the processing of traditional pork products to ensure improved product quality. First and foremost the quality of lean meat and the consistence of the fatty tissue have to be considered (Burgstaller et al., 1992; Bellof and Burgstaller, 1992; Girard et al., 1989; Haase, 2013).

Today, most of the heavy pig production systems use modern pig hybrids/genotypes which are characterized by a high body protein synthesis capacity (Bellof and Burgstaller, 1992), because breeding strategies have been aimed at increasing the lean meat to fat ratio in pigs during recent decades (Hadorn et al., 2008). For the production of traditional pork products such as dry fermented sausages, fat level and quality (Fischer et al., 2006) and meat quality (Bellof and Burgstaller, 1992) are often unsatisfactory.

It is commonly recognized that local pig breeds represent a valuable genetic reserve for typical products or for recovering some properties of meat and fat, currently lost because of severe selective programs (Fortina et al., 2005). Traditional breeds are known to have lower protein synthesis capacity and higher carcass fat yields. This results in a sufficient quantity and quality of fat with a high amount of saturated fatty acids which is favourable for raw sausage production. Finally, this is due to intensive *de-novo* fat-synthesis (Nürnberg et al., 1998). Therefore, the use of traditional breeds (e.g. German or Angeln Saddleback) could be an alternative for the production of traditional, regional pork specialties. Additionally, the use of an old endangered breed might bring marketing advantages and may provide an economically suitable strategy for the conservation of endangered breeds.

The crossbreeding of unimproved breeds with Duroc or Piétrain is known to improve average daily weight gain, feed conversion ratio and lean meat content (Legault et al., 1996). In heavy pig production, this might be advantageous in order to improve performance and carcass traits compared to the purebred, resulting in effective fattening and an economic benefit.

It is well known that old breeds such as Saddlebacks have the potential to produce organoleptically preferable meat. But due to the serious disadvantages in growth and carcass quality, the use of this breed is limited to regional niche production (Paulke et al., 2011). German or Angeln Saddleback pigs produce a very high fatty tissue percentage with an improved meat quality. The fat quality measured by the fatty acid composition of the longissimus muscle in the Saddlebacks was favourable as to oxidative stability because of the high saturated fatty acid content. The high intramuscular fat content and the fatty acid composition resulted in advantages for sensory evaluation and processing conditions (Nürnberg et al., 1997).

The traditional breeds may be especially suitable for outdoor or extensive fattening. In these extensive systems, the use of green fodder as part of the feeding ration might be an option to minimize feeding costs. Additionally, in organic agriculture, the use of roughage, also for monogastric animals, is obligatory (EC 889/2008). Green fodder is known to increase PUFA content and leads to softer fat in the carcass. But for raw sausage production, firm fat with high oxidative stability is needed (Nürnberg et al., 1997).

Against this background, three genotypes (extensive = Saddleback (Sa), semi-intensive = Piétrain*Saddleback (PiSa), intensive = modern hybrid line (Hy)) were slaughtered at about 160 kg live weight. Each genotype was fed with grass-clover silage or straw as roughage source. The aim was to analyze their suitability for the production of the regionally significant pork product dry fermented sausage. Under organic farming conditions, the performance and carcass quality, the meat, fat and product (dry fermented sausages) quality, and economic aspects were quantified. The study refers to work package 3.3.1 (effects of, and interactions between pig genotype and dietary regimes on carcass, meat and processing quality characteristics – experimental approach) within the EU co-funded FP7 research project "Low Input Breeds" – LIB (www.lowinputbreeds.org).

The present paper deals with performance traits, carcass quality, and economic aspects. A second paper (Schwalm et al., 2013) deals with aspects of meat, fat and product (dry fermented sausage) quality.

2 Material and methods

2.1 Animals & keeping

The study was performed at the certified organic experimental pig facility of the Thünen-Institute of Organic Farming in Trenthorst (Germany) using two runs in 2010/2011 (n = 69 animals) and 2011/2012 (n = 65 animals).

A total of 134 barrows of three different genotypes with different classifications of the breeding intensity concerning body protein synthesis capacity were used: Saddleback (Sa) – extensive; Piétrain*Sa (PiSa) – semi-intensive; modern Hybrid (Piétrain*Duroc)*(German Large White*German Landrace) (Hy) – intensive. Each group of genotypes originated from several litters (Sa = 12, PiSa = 10, Hy = 10). Terminal sires in PiSa (Pi) and hybrids (PiDu) were used via artificial insemination and Pi was of MHS-gen-sanitized nn-type.

Each of the three genotypes was fed two different roughage sources: grass-clover silage and straw.

The resulting six treatments were evaluated for selected traits of performance and of carcass quality.

Only barrows were used due to German Best Practice because female oestrus cycle is seen as contraindicated for dry fermented sausage production. This is due to specific hormonal metabolism conditions and the consequently non-free choice of the slaughtering date (Euen, 2013). This is in contrast to Calvo et al. (2010) who did not find significant differences in various meat quality traits.

Due to the loss of two animals, 132 heavy pigs remained for analysis. The distribution of genotypes, animal number and group number is shown in Table 1.

Table 1

Distribution of genotype, roughage source, animal and group numbers

Genotype	Hy [1]		PiSa [2]		Sa [3]	
Roughage source	gcs [4]	straw	gcs	straw	gcs	straw
Groups (n)	2	2	2	2	3	2
Animals (n)	22	22	21	21	27	21

[1] Modern Hybrid

[2] Piétrain * Saddleback

[3] Saddleback

[4] grass-clover silage

Animal housing was in accordance with organic farming regulations (EC 889/2008). The stocking rate was 10 to 11 animals per pen (group) with an animal : feeding place ratio of 1 : 1. Indoor area was 1.5 m² per animal, outdoor area (concrete solid floor) 1.2 m² per animal. Straw was used as litter in both compartments (indoor, outdoor). All fatteners were individually identified.

The pelletized concentrates consisted of feed ingredients of 100 % organic origin. The grower diet contained 52.5 % cereals, 30 % grain legumes, 15 % oilcake and 2.5 % mineral premix with 13.2 MJ Metabolizable Energy (ME)/kg (CV 1.8 %) and a Lysin-ME-ratio of 0.83 (CV 10.4 %). It was fed up to a live weight of around 70 kg. The following finisher diet consisted of 55.5 % cereals, 38 % grain legumes, 4.5 % oilcake and 2 % mineral premix with 12.2 MJ ME/kg (CV 1.6 %) and a Lysin-ME-ratio of 0.67 (CV 13.1 %). No further diet optimization was done with respect to essential amino acids for the grower and finisher diets (for more detailed information see Schwalm et al., 2013, second communication). Both diets were given *semi-ad libitum*. The daily allotted feed was based on a live weight-dependent feeding curve, with a daily feed rest < 1 kg per pen and repast. A mobile feeder with an integrated electronic scale (Vliebo, Netherlands) was used for concentrate offer.

The roughage (grass-clover silage, straw) was offered separately in one rack per pen. The grass-clover silage (dry matter (DM): 31.7 % (CV 11.7 %); XP: 15.9 % in DM (CV 6.6 %); XF: 22.8 % in DM (CV 13.9 %)) was given daily with an average of 0.9 kg fresh matter per day and animal. A higher offer was not considered due to considerably increasing waste. As it was not possible to measure the real feed intake, the amounts of grass-clover silage mentioned are the amounts offered to but not consumed by the pigs. A special straw consumption was not observed. Straw was wasted and racks were refilled when depleted; no further quantitative recordings and qualitative analyses were carried out.

2.2 Data collection & analyses

The fattening period started at an average initial live weight of 26.2 kg (CV 24 %) and animals were slaughtered with a mean live weight of 164.1 kg (CV 3 %). When animals reached a live weight > 159 kg, they were slaughtered the following week in a small family abattoir after a resting period of 45 min and electrical stunning.

Data collection of performance and carcass traits followed basically the federal standard of German testing stations (ZDS, 2007). Feed consumption (daily quantity of concentrate and roughage feed, without reweighing the feeding rest) and feed conversion ratio (only concentrates) were calculated as group average for the whole fattening, the grower and the finisher period. The data concerning live weight development and carcass traits were recorded individually.

The pigs were weighed at the beginning and the end of the trial with the last weighing on the day of slaughtering. Additionally, there were intermediate weighing every four weeks and weekly weighing prior to slaughter. The daily weight gain of each animal was calculated for the whole fattening, the grower, and the finisher period.

Dressing percentage was calculated from warm carcass weight and final live weight. One day after slaughter, muscle and fat area and five different fat thicknesses (for location details see Table 4) were measured, using the chilled carcass half according to the federal standard of German testing stations (ZDS, 2007). Fat thicknesses were measured using a manual calliper, muscle and fat areas were measured by standardised photography and subsequent electronically based planimetry (Matthäus® SCAN-STAR K). Lean meat content was calculated using the "Bonner Formula" (ZDS, 2007).

The carcass half was dissected into the main valuable cuts following the in-house-economic cut methodology of the abattoir (for details see Table 5). Cuts were weighed and are expressed as a percentage of cold carcass side (= (warm carcass weight – 2 % cooling loss)/2) (ZDS, 2007)).

Economic performance is expressed as surplus of the revenues over feed and piglet costs. The used prices are real prices within the trial period. The payout price of 3.27 Euro/kg carcass weight (Table 6) is used for all carcasses because in German heavy pig production the payout price is independent from carcass classification; it is based on Tegut® (Euen, 2013), one of the most important organic food retailers in Germany. The other prices are real prices paid by the Institute of Organic Farming (piglets, concentrates) or communicated by Löser (2013) (grass-clover silage, 30 % dry matter).

2.3 Statistics

Statistical data analyses was carried out with the General Linear Model (Proc GLM, SAS software package version 9.2), considering run, genotype, roughage source and the interaction genotype*roughage source as fixed effects.

For the feed consumption and feed conversion ratio during the whole fattening and the grower period, the average initial live weight (per group) was included in the model as a covariate. Likewise for feed consumption and feed conversion ratio in the fattening period, the average live weight at the beginning of the fattening period (per group) was used as a covariate. For the individually recorded performance traits, the initial live weight (expressed as the difference from the genotype average) was considered as covariate. For the carcass quality traits, the slaughter weight (expressed as the difference from the genotype average) was used as covariate. The parameters including the slaughter weight (e.g. dressing percentage and cuts as percentage of the slaughter weight) were calculated without covariates.

The LSQ-means were statistically compared using the Tukey-Kramer-Test (significance level $p < 0.05$).

3 Results

The parameters concerning performance and carcass quality were significantly influenced by the genotype, whereas the roughage source had no effect (except fat area, see Table 2). No interaction between genotype and roughage source could be found (except in the daily weight gain in the finisher period). Therefore, the selected results of performance and carcass quality are presented as shown in the output format of the following result Tables 3 to 5.

Table 3 illustrates selected characteristics of the growth performance. As expected, Saddlebacks showed lower (-23 %) daily weight gains in the fattening period (in the grower period as well as in the finisher period) resulting in a longer fattening period (+22 % respectively +47.6 days) compared to the modern hybrid line. The daily feed amount given to the three genotypes showed no significant differences – according to the trial design. This leads to a worse feed conversion ratio in the fattening period (+21 %) for the Saddlebacks compared to the modern hybrid line with likewise significant differences in the grower period. In the finisher period, however, the feed conversion ratio was only different by trend. The results of the PiSa always ranked in the middle.

Concerning the carcass quality parameters shown in Table 4, the Saddlebacks had lower dressing percentages than the crossbreeds. Also, the Saddlebacks had obvious higher back fat thicknesses in all measured points. For example, the Fat thickness B of the Saddlebacks was about 2.3 times larger than that of the Hybrids, and about 1.6 times larger than that of the crossbreeds. A 33 % smaller muscle area of the Saddlebacks together with a nearly doubled fat area resulted in a wider lean to fat ratio by the factor 2.8 compared to the Hybrids. The lean to fat ratio clearly shows the lower lean meat amount of the Saddlebacks compared to the modern Hybrid. This is also demonstrated by the lean meat content, calculated by the Bonner Formula (even if the absolute values cannot be used in this high weight class because the formula is only valid till 105 kg carcass weight). The results of the PiSa always ranked in the middle.

The high fat synthesis of the Saddlebacks is also obvious in the cut weights (Table 5). For the Saddlebacks, the fatty joints such as neck, belly, and head with cheek had a higher impact on the carcass half weight compared to the Hybids.

Table 2
Significance levels of fixed effects on growth performance and carcass quality traits

	r^2 (%)	Run (1^{st}, 2^{nd})	Genotype (Hy, PiSa, Sa[1])	Roughage (gcs[2], straw)	G*R interaction
Performance traits					
Daily feed intake[3] in the					
– grower period	75	ns	ns	ns	ns
– finisher period	53	ns	ns	ns	ns
– whole period	42	ns	ns	ns	ns
Feed conversion ratio[3] (only concentrate)					
– grower period	94	ns	**	ns	ns
– finisher period	77	ns	ns	ns	ns
– whole period	89	ns	*	ns	ns
Daily weight gain in the					
– grower period	41	ns	***	ns	ns
– finisher period	46	ns	***	ns	ns
– whole period	53	ns	***	ns	ns
Days on test	59	*	***	ns	ns
Carcass traits					
Carcass weight, warm	7	ns	ns	ns	ns
Dressing percentage	10	ns	*	ns	ns
Back fat thickness					
– hind	52	ns	***	ns	ns
– mid	63	**	***	ns	ns
– fore	80	ns	***	ns	ns
Lateral fat thickness	67	ns	***	ns	ns
Fat size B	83	ns	***	ns	ns
Muscle area	81	ns	***	ns	*
Fat area	81	ns	***	*	ns
Lean-fat-ratio	82	ns	***	ns	ns
Lean meat content	85	*	***	ns	ns
Cuts					
Neck	8	ns	*	ns	ns
Belly	19	ns	**	ns	*
Loin with back fat	17	ns	***	ns	ns
Shoulder	16	ns	*	ns	ns
Leg without foot	37	ns	***	ns	ns
Head with cheek	34	ns	***	ns	ns
Feet	14	ns	***	ns	ns

ns: not significant, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

[1] Hy = modern Hybrid, PiSa = Piétrain*Saddleback, Sa = Saddleback

[2] gcs = grass-clover silage

[3] feed intake and feed conversion ratio calculated for group (pen)

The lean joints such as leg (ham) and shoulder were significantly smaller in Saddlebacks compared to the hybrid line. The cuts of the PiSa crossbreeds always ranked at medium level between the other two genotypes.

Table 3

Selected characteristics of growth performance by genotype and roughage source of heavy pigs (LSQM)

	Genotype[1]			Roughage	
	Hy	PiSa	Sa	gcs[2]	straw
Number of animals (pens) [n]	44 (4)	42 (4)	46 (5)	70 (7)	62 (6)
Days on test	173.6[c]	199.9[b]	221.3[a]	195.7	200.9
Daily feed intake[3] [kg/animal] in the					
– grower period	2.30	2.30	2.05	2.31	2.12
– finisher period	3.06	3.11	3.30	3.21	3.11
– whole period	2.79	2.83	2.92	2.88	2.81
Feed conversion ratio[3] [kg feed (only concentrate) / kg live weight gain] in the					
– grower period	2.91[b]	3.02[b]	3.58[a]	3.14	3.20
– finisher period	3.87	4.55	4.88	4.39	4.48
– whole period	3.64[b]	4.01[ab]	4.42[a]	4.00	4.04
Daily weight gain [g/animal] in the					
– grower period	804[a]	752[a]	551[b]	724	681
– finisher period	818[a]	691[b]	650[b]	721	718
– whole period	804[a]	707[b]	634[c]	719	711

[a, b, c] LSQM with different letters within a row differ significantly between the genotypes for $p < 0.05$ (Tukey-Kramer-Test)

[1] Hy = modern Hybrid, PiSa = Piétrain*Saddleback, Sa = Saddleback

[2] gcs = grass-clover-silage

[3] feed intake and feed conversion ratio calculated in groups (pen)

Table 4

Selected characteristics of carcass quality traits by genotype and roughage source of heavy pigs (LSQM)

	Genotype[1]			Roughage	
	Hy	PiSa	Sa	gcs[2]	straw
Carcass weight, warm [kg]	129.5	128.9	126.7	128.0	128.7
Dressing percentage [%]	78.2[ab]	78.9[a]	77.5[b]	78.1	78.4
Back fat thickness [cm]					
– fore (thickest location at withers)	4.8[c]	5.8[b]	6.4[a]	5.6	5.8
– mid (thinnest location above *M. long. dorsi*)	2.6[c]	3.6[b]	4.3[a]	3.5	3.5
– hind (thinnest location above *M. glut. med.*)	2.1[c]	3.2[b]	4.6[a]	3.3	3.3
Lateral fat thickness (ventral end of *M. lat. dorsi*, 13th rib) [cm]	4.2[c]	4.9[b]	6.1[a]	5.1	5.1
Fat thickness B (thinnest location lateral *M. long. dorsi*, 13th rib) [cm]	1.9[c]	2.8[b]	4.3[a]	3.0	3.1
Muscle area (*M. long. dorsi*, 13th rib) [cm^2]	58.19[a]	52.57[b]	39.22[c]	50.41	49.58
Fat area (*M. long. dorsi*, 13th rib) [cm^2]	28.21[c]	39.01[b]	52.25[a]	38.70[y]	40.95[x]
Lean to fat ratio [fat area / muscle area]	0.49[c]	0.75[b]	1.36[a]	0.85	0.89
Lean meat content [%]	53.4a[a]	42.2[b]	33.3[c]	44.5	43.4

[a, b, c] LSQM with different letters within a row differ significantly between the genotypes for $p < 0.05$ (Tukey-Kramer-Test)

[x, y] LSQM with different letters within a row differ significantly between the roughage sources for $p < 0.05$ (Tukey-Kramer-Test)

[1] Hy = modern Hybrid, PiSa = Piétrain*Saddleback, Sa = Saddleback

[2] gcs = grass-clover silage

Table 5
Amount of selected cuts of the cold carcass half by genotype and roughage source of heavy pigs (LSQM)

	Genotype[1]			Roughage	
	Hy	PiSa	Sa	gcs[2]	straw
Neck [%]	9.80[b]	10.04[b]	10.45[a]	10.09	10.11
Belly [%]	17.32[b]	17.30[b]	18.03[a]	17.52	17.58
Cutlet loin with tenderloin and back fat [%]	18.06[b]	18.18[b]	19.30[a]	18.55	18.48
Shoulder [%]	17.19[a]	16.88[ab]	16.50[b]	16.97	16.74
Leg without foot [%]	28.14[a]	27.57[b]	26.33[c]	27.37	27.32
Head with cheek [%]	8.16[b]	8.38[b]	9.06[a]	8.43	8.63
Feet [%]	2.48[a]	2.27[b]	2.43[a]	2.39	2.39

[a, b, c] LSQM with different letters within a row differ significantly between the genotypes for $p < 0.05$ (Tukey-Kramer-Test)

[1] Hy = modern Hybrid, PiSa = Piétrain*Saddleback, Sa = Saddleback

[2] gcs = grass-clover silage

Table 6
Economic performance (without value added taxes)

	Hy[1]	PiSa[1]	Sa[1]
Final live weight [kg/animal]	165.0	165.0	165.0
Dressing percentage [%]	78.5	78.5	77.8
Carcass weight [kg/animal]	129.5	129.5	128.4
Payout price[2] [€/kg carcass weight]	3.27	3.27	3.27
Revenues [€/animal]	**423.47**	**423.47**	**419.87**
Piglet costs[2] (organic) [€/animal]	**110.00**	**110.00**	**110.00**
Live weight gain, standardised [kg/animal]	140	140	140
Feed-conversion-ratio, 1:	3.6	4.0	4.4
Amount of concentrates [kg/animal]	504	560	616
Concentrate price[2] (100% organic origin) [€/100kg]	39.00	39.00	39.00
Feed costs I (concentrates) [€/animal]	**196.56**	**218.40**	**240.24**
Surplus I [€/animal]	**116.91**	**95.07**	**69.63**
Grass-clover silage, fresh (31.7% dry matter) [kg/animal]	156	180	199
Grass-clover silage price[2] (30% dry matter, 100% organic origin) [€/100kg]	3.15	3.15	3.15
Feed costs II (grass-clover silage) [€/animal]	**4.91**	**5.67**	**6.27**
Surplus II [€/animal]	**112.00**	**89.40**	**63.36**

[1] Hy = modern Hybrid, PiSa = Piétrain*Saddleback, Sa = Saddleback

[2] Real prices during the trial period

Economic performance is shown in Table 6 as surplus of the revenues over the feed and piglet costs of the three genotypes. It is calculated for a standardised animal with a live weight of 165 kg using the trial data and the mean values of the respective prices during the trial period. It can be seen that Saddlebacks will generate surpluses of only about 60 % of the Hybrids. Again, PiSa crossbreeds have an intermediate position. The costs of an additional feeding of grass-clover silage were minimal. The amount of silage was 0.9 kg per day and animal. Due to the longest fattening period (Table 3), the Saddlebacks had the highest silage costs.

4 Discussion

There were no differences in performance and carcass quality parameters between pigs offered concentrate and straw or concentrate and additional grass-clover silage, except for the fat area (Table 2). This is in agreement with many studies which found that the intake of grass/clover silage (i) was very low and (ii) contributed to the energy supply of the pigs only to a small degree (Bellof et al., 1998; Kelly et al., 2007; Hagmüller et al., 2008). Especially, when cereal-based concentrates were available *ad libitum*, the voluntary intake of grass-glover silage was minimal (Bellof et al., 1998; Kelly et al., 2007). If concentrates are restricted, higher intakes of silage can be reached (Bellof et al., 1998). In our study, the amount of grass-clover silage given was recorded per pen, but the intake of the silage was not evaluated. But despite a restrictive offer, it was obvious that the consumption was low due to significant waste of grass-clover silage in the pen (results not presented). It is likely that the low intake was due to the nearly *ad libitum* concentrate offer during the trial. Therefore, the performance and carcass quality parameters were not noteworthy influenced by the roughage source. According to Kelly et al. (2007), there was no evidence of greater intake or utilisation of forages by the traditional breeds in our study.

The daily weight gain of the used breeds was fairly high (Table 3). In particular, the Hybrids showed very high daily weight gains and an improved feed conversion ratio with a narrow lean to fat ratio. This confirms the high body protein synthesis capacity in live weights above 120 kg, especially for the modern hybrid line. This is in accordance with Fischer et al. (2006). In their study, daily weight gains of heavy pigs were only 30 g lower compared to pigs slaughtered at 110 kg. Bellof and Burgstaller (1992) could even observe a further increase of the daily weight gains above 100 kg live weight for some crossbreeds (Du*DL, Pi*(Du*DL)).

In this trial under organic farming conditions, the daily weight gains were slightly below the daily weight gains of heavy pigs in conventional farming systems (729 to 894 g), reported in literature (Kuhn et al., 1994; Burgstaller and Jatsch, 1994; Fischer et al., 2006). But the performance traits must be seen in the context of the used breeds or crossbreeds (Bellof, Burgstaller, 1992; Fortina et al., 2005; Franci et al., 2003). Thus, the comparison of the exact values is difficult. Löser (2006) considers a daily weight gain of 650 g achievable for the production of heavy pigs under organic management conditions.

Due to the higher fat synthesis in heavy pigs, the feed conversion ratio gets worse, so that barrows need 3.1 kg feed per kg live weight gain (Fischer et al., 2006). According to Burgstaller et al. (1992), an *ad libitum* concentrate feeding leads to a feed conversion index of 3.65. This is in accordance with Kuhn et al. (1994). The authors could show that 1 kg body weight gain was reached by 3.35 to 3.99 kg feed, depending on the feeding regime. This shows that the feed conversion ratio of the Hybrids and PiSa crossbreeds was within the range reported in literature (Table 3).

In the fattening for conventional slaughter weights, German or Angeln Saddleback pigs have a worse feed conversion ratio (3.8) compared to improved breeds such as Piétrain (2.7) (Steinberg et al.,1998). This is also obvious in heavy pig production with a body weight of 160 kg. As expected, the daily weight gain of Saddlebacks was lower compared to Hybrids and PiSa crossbreeds, and the feed conversion ratio was worse (Table 3). The lower growth rate of unimproved breeds confirms the results found in other European pig breeds used for heavy pig production (Franci et al., 2003; Serra et al., 1998; Legault et al., 1996).

The conversion of feed into lean tissue growth is markedly more efficient than into adipose tissue. As a consequence, the fatter animals of unimproved breeds such as Saddlebacks result in a worse feed conversion ratio. But both parameters for Saddlebacks were within the range or even better when compared to other extensive breeds used for heavy pig production; for example Limousin pigs and Gascon in France (Legault et al., 1996) or Casertana and Mora Romagnola in Italy (Fortina et al., 2005). The feed conversion indexes for the two Italian breeds fed with a commercial concentrate diet (ca. 50 to 160 kg live weight) were 4.2 and 4.3 and the daily weight gains (up to a live weight of 160 kg) were 524 g and 451 g, respectively (Fortina et al., 2005).

The crossbreed between Piétrain and Saddleback (PiSa) showed significantly improved performance traits compared to the purebred Saddlebacks (Table 3). This confirms the results of Legault et al. (1996) that crossbreeding unimproved breeds with Duroc or Piétrain results in a significant improvement of average daily weight gain and of feed conversion ratio.

In face of the high slaughter weight, the modern hybrid line showed only a moderate fat synthesis. Mean fat size B (thinnest location 13th rib) was only 1.9 cm (Table 4). This is in accordance with Fischer et al. (2006). In this study, Pi*DL crossbreeds with a final live weight of 160 kg only reached a fat size B of about 2 cm. The authors assumed that such fat sizes indicate fat quantities which are not sufficient for the production of dry fermented sausages. In our study, the PiSa crossbreeds and Saddlebacks reached considerable higher fat sizes in all measured points, indicating higher fat yields (Table 4). This leads to the conclusion that these breeds are more suitable for the production of dry fermented sausages with respect to the quantity of fat. The higher fatness of Saddleback pigs confirms again the strong adipogenetic ability of the unimproved breeds (Labroue et al., 2000; Franci et al., 2003). Crossbreeds between improved and unimproved breeds show intermediate values concerning the back fat with respect to parental breeds (Franci et al., 2003). This becomes evident in the fat sizes of our PiSa crossbreeds which always ranked in the middle between Saddlebacks and Hybrids (Table 4).

The important impact of the genotype is confirmed by Bellof and Burgstaller (1992). The authors observed lean to fat ratios between 1 : 0.48 and 1 : 0.63 in heavy barrows (160 kg live weight) of a large variety of genotypes. This is in accordance with Fischer et al. (2006) and with the modern hybrid line in the present paper. In our trial – as expected, the Saddlebacks had excessive higher lean to fat ratios due to the high body fat synthesis of this unimproved breed. PiSa ranked between Saddlebacks and Hybrids (Table 4). This confirms the results of Legault et al. (1996) that crossbreeding unimproved breeds with Duroc or Piétrain results in a significant improvement of lean meat content.

A number of studies have found little effect of slaughter weight on primal cut distribution (Cisneros et al., 1996; Martin et al., 1980; Fischer et al., 2006). When data are expressed as a percentage of side weight, loin and belly increase while shoulder and ham decrease with increasing slaughter weight, but only within small ranges (Martin et al., 1980). Fischer et al. (2006) could not observe serious changes in cut proportions when live weight at slaughter was increased up to 160 kg, except for the back fat. But the authors emphasized that this result has been only proven for the used breed (Pi*German Landrace).

The comparison of the exact values of the cuts (Table 5) with data of literature is difficult due to the different cut procedures used. But the high fat synthesis of the Saddlebacks is also obvious in the cut weights expressed as percent of the carcass half. In the Saddlebacks, the fatty joints such as neck, belly and head with cheek had a higher impact on the carcass half weight compared to the Hybrids.

The amount of cuts significantly differed between the breeds, but the absolute differences are relatively small (Table 5). There was no opportunity to dissect the cuts into fat and lean tissue. Hence, only the gross weight was evaluated. But it can be assumed that the Saddlebacks have a higher fat content in the cuts compared to PiSa crossbreeds and Hybrids.

For the production of traditional regional pork specialties like dry fermented sausages (e.g. Ahle Wurscht®), the whole carcass (exclusive tenderloin) of heavy pigs is used (Haase, 2013). The back fat and the fat of the shoulder are preferred for the production of dried products because these fatty parts have the best characteristics for processing (Euen, 2013). Especially the amount and the quality of the back fat are essential for the production. In modern hybrid lines, the back fat is often not sufficient in quantity and quality (Fischer et al., 2006; Euen, 2013). It can be assumed that the use of Saddlebacks or of crossbreds with Pi for heavy pig production could lead to a sufficient quantity of fat needed for traditional dry products.

The surplus of the revenues over the feed and piglet costs is used to characterize economic performance (Table 6). It is a simple but meaningful figure because more than 90 % of the allocable variable costs in pig fattening are due to feed and piglet costs (Rasmussen, 2004). In the present study, the remaining variable costs (e.g. veterinarian, electricity …) can be considered as equal between the treatments and therefore as negligible. The prices used for calculation necessarily have snapshot character. But the difference between the treatments is of interest but not the absolute level.

The poor ranking of the Saddlebacks is mainly (i) due to impaired feed conversion (Table 3) with higher feed consumption (Table 6) and (ii) due to lower dressing rate with lower carcass weight (Table 4). A further aggravating fact is the longer fattening period of the Saddlebacks, resulting in fewer fattening runs per year and reducing the benefit per fattening place. Roughage costs per animal are minimal (Table 6). In Germany, straw is little accepted as roughage source. The feeding of grass-clover silage had no benefits concerning performance and carcass quality traits in heavy pig production under nearly *ad libitum* concentrate feeding but increased production costs (Table 6). If concentrates are more restricted, than the use of grass-clover silage might have a higher potential (Bellof et al., 1998).

The calculation of Löser (2006) uses key data of the branch evaluation of 2003/2004 for the fattening of heavy pigs in organic farming. In this study, only a payout price of 2.50 Euro/kg carcass weight was reached but with lower feed and piglet costs as compared to 2013. In our study, the revenues minus feed and piglet costs were 69.63 to 116.97 Euro (Table 6) according to the breeds used. This is considerably lower compared to Löser (2006) with 161.00 Euro. This is mainly due to the clearly lower costs for concentrates (22 Euro/100 kg). As a conclusion, the piglet and feed costs are essential for the economic performance also in the production of heavy pigs. This is already proven for the usual organic pork market with final live weights of about 115 to 120 kg (Wucherpfennig, 2010). In heavy pig production today, the payout price is not influenced by fat quantity and quality or other carcass quality criteria which guarantee the suitability for the respective pork products. Hence, the worse feed conversion ratio of the Saddlebacks could not be compensated and the economic benefit is lower compared to PiSa crossbreeds and Hybrids.

The economic benefit of endangered pig breeds may be considerably improved if crossbreeding schemes are used (Chainetr et al., 2002; Legault et al., 1996; Franci et al., 2003). Crossbreeding of the German or Angeln Saddlebacks is suggested for special marketing programs. This is due to the expected improvement of performance and carcass traits and the corresponding economic benefit (Golze et al., 2013; Pfeiffer 2002; Leenhouwer and Merks, 2013; Weißmann, 2013). These crossbreeding schemes could be adapted to ecological production niches or designed for specific quality products (Chainetr et al., 2002). In our study, the higher economic benefit of the crossbreed PiSa confirms these proposals due to the lower feeding costs (Table 6). An alternative would be that the payout price for the Saddleback and its crossbreeds is adapted to honour the higher quantity of fat, the possibly better meat and fat quality and the possibly better suitability for processing concerning the production of traditional pork specialities. But so far this approach seems to be unrealistic.

5 Conclusions

Under organic farming conditions, Saddlebacks and PiSa crossbreeds seem to be suitable for heavy pig production to produce premium segment pork specialities in the form of dry fermented sausages concerning performance and carcass quality. The low protein level coupled with a high *de-novo* fat synthesis can provide sufficient fat quantities at a final live weight of about 160 kg.

But as long as the payout price is not adapted to carcass quality or the suitability for processing, the fattening of Saddlebacks is not interesting from an economic point of view. Against the background of a sufficient fat quantity when exceeding 2 cm of fat measurement B, Saddlebacks would be more economically competitive if they are slaughtered significantly below 160 kg live weight. But for this strategy more information concerning fatty tissue development is needed to identify the optimal final live weight.

The crossbreeding of Saddlebacks with Piétrain results in improved performance, carcass quality, and economics. This might be a practicable way for the surviving of old, endangered breeds.

Even though the market of heavy pig production is a niche market, under the condition that the animals are used economically, a valuable contribution to the maintenance of old threatened pig breeds could be achieved under the motto "Protect them by eating them".

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7 Disclaimer

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Effects of three genotypes and two roughages in organic heavy pig production for dry fermented sausage manufacture

2. Meat quality, fatty acid pattern, and product quality

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Abstract

Castrated heavy pigs of > 160 kg body weight are used for dry fermented sausage manufacture due to the required fat quantity and quality. Today, most organic production systems use modern hybrids (Hy) with often insufficient fat features. The use of endangered breeds with high body fat synthesis capacity like Saddlebacks (Sa) could be an alternative with an additional benefit as to maintaining biodiversity.

This study with a total of 132 castrates analysed the effects of three genotypes (Sa, Piétrain*Sa (PiSa), Hy) and two roughage sources (grass-clover silage, straw) on performance, carcass-, meat-, fat-, product-quality, and economic aspects. The present paper deals with meat quality (MQ), fatty acid pattern (FAP), and product quality of dry fermented sausage (PQ). MQ and FAP are both influenced significantly by the genotype but not to a noteworthy extent by the roughage source. Regarding MQ, all genotypes were well suited. Concerning FAP, critical poly-unsaturated fatty acid content of back fat required for the production of dry fermented sausages was exceeded by Hy (15.9 %) whereas Sa was best suited with the lowest mean content (11.9 %) under the trial's particular feeding conditions. This suitability of the raw material for the production of dry fermented sausages can also be seen in PQ of the end-product: Sa sausages tend to have the best PQ whereas Hy tend to have the lowest PQ. PiSa always ranked in the middle for nearly all analysed criteria of MQ, FAP and PQ.

Considering the good results of performance, carcass quality and economics of PiSa (1st communication), crossbreeding of Sa with a modern sire line seems to be the best way to ensure the survival of an old endangered pig breed via value creation by producing a premium pork speciality like dry fermented sausage.

Keywords: *Heavy pigs, Saddleback, meat quality, fatty acid pattern, product quality, dry sausage*

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Zusammenfassung

Effekt unterschiedlicher Genotypen und Raufutter in der ökologischen Mast schwerer Schweine zur Rohwurstherstellung

2. Fleischqualität, Fettsäurenmuster und Wurstqualität

Zur Herstellung langgereifter Rohwurst werden kastrierte schwere Schweine wegen der benötigten Fettmenge und -qualität genutzt; vor allem moderne Hybride (Hy) mit oftmals unzureichenden Fettkriterien. Alte Rassen, z.B. Sattelschweine (Sa), mit ihrer hohen *de-novo* Fettsynthesekapazität könnten eine Alternative sein mit gleichzeitigem Beitrag zu deren Erhaltung.

Es wurden die Effekte dreier Genotypen (Sa, Piétrain*Sa(PiSa), Hy) und zweier Raufutter (Kleegrassilage, Stroh) auf Mastleistung (ML), Schlachtkörper(SQ)-, Fleisch(FQ)- und Wurstqualität (WQ), Fettsäurenmuster (FSM) sowie Wirtschaftlichkeit (W) überprüft. Dieser Artikel handelt von FQ, FSM und WQ. FQ und FSM wurden vom Genotyp signifikant beeinflusst, vom Raufutter in nicht nennenswertem Umfang. Bei der FQ schnitten sämtliche Genotypen gleichermaßen gut ab. Beim FSM im Rückenspeck hatte Hy den höchsten (15,9 %) und Sa den niedrigsten (11,9 %) Polyensäurengehalt. Sa zeigte tendenziell die beste WQ, Hy tendenziell die schlechteste. PiSa nahm bei fast sämtlichen Kriterien eine mittlere Stellung ein.

Zusammen mit den guten Ergebnissen von PiSa bei ML, SQ und W (erste Mitteilung) wird geschlussfolgert, dass die Einkreuzung eines modernen Endstufenebers am besten geeignet scheint, alte bedrohte Rassen mit Hilfe der Wertschöpfung im Premiumsegment (z.B. Rohwurst) zu erhalten.

Keywords: *Schwere Schweine, Sattelschwein, Fleischqualität, Fettsäurenmuster, Produktqualität, Langgereifte Rohwurst*

1 Introduction

In some regions of Europe heavy pigs slaughtered at about 160 kg live weight are used for the production of traditional pork products such as dry fermented sausages. Most heavy pig production systems – also in organic agriculture – currently use modern pig genotypes which are characterized by a high body protein synthesis capacity, since pig breeding programmes aimed for „lean meat" are desired by the fresh pork sector. Specific feeding regimes can increase fat levels in modern genotypes, but the amount and quality of fat of heavy pigs are often unsatisfactory with respect to the needs of processors of specific traditional pork products such as dry fermented sausages (Bellof and Burgstaller, 1992; Fischer et al., 2006a).

In this context the most important fat parameters are the consistency and the oxidative stability. Both parameters are mainly influenced by the fatty acid composition. In general a higher amount of unsaturated fatty acids leads to a softer fat with a higher susceptibility for oxidation (Bee, 2004). For optimal processing quality concerning consistency and oxidative stability recommendations have been formulated, limiting the poly-unsaturated fatty acid content (PUFA) of the back fat to a maximum of 12 to 15 % (Warnants et al., 1996; Scheeder et al., 2001; Bee, 2004; Fischer et al., 2006b). The PUFA content in back fat depends on slaughter weight, genotype, feeding and on environmental factors. But in brief: Regardless of the genetic type or life weight class, an increase in body own fat synthesis is associated with an increase in saturated and monounsaturated fatty acids and a remarkable reduction in polyunsaturated fatty acid content (Lo Fiego et al., 2005).

Traditional breeds (e.g. German Saddleback) are known to have lower protein synthesis capacity and higher carcass fat yields. This leads to a sufficient quantity and quality of fat with a high amount of saturated fatty acids due to intensive *de-novo* fat synthesis (Nürnberg et al., 1998) which is favourable for dry fermented sausage production. The German Saddleback pigs produce a very high fatty tissue percentage with a good meat quality. The high intramuscular fat content and its favourable fatty acid composition have advantages as to sensory evaluation and processing conditions (Nürnberg et al., 1997).

Nevertheless old breeds have disadvantages concerning performance and carcass traits which might be improved by crossbreeding with an improved breed such as Piétrain (Legault et al., 1996). Crossbreeding of Saddlebacks is suggested for special marketing programs to improve performance and carcass traits and economic benefit (Pfeiffer, 2002; Golze et al., 2013; Leenhouwer and Merks, 2013; Weißmann, 2013). The use of traditional breeds (e.g. Saddleback) and/or the crossbreeds between traditional and modern genotypes could therefore be an alternative for the production of traditional, regional pork specialties and may provide an economically suitable strategy for the conservation of traditional breeds.

As already mentioned above, the feeding regimen influences meat, fat and consequently product quality of dry fermented sausages, beside the choice of the genotype. In this context the obligatory use of roughage in organic pig feeding (EC 834/2007) is of interest. In Germany, straw as roughage source is controversially discussed, whereas the positive image of grass-clover silage is of common consensus. But in the case of dry fermented sausage production the preferable use of grass-clover silage – contrary to straw – is not unproblematic. It could be shown that such a practice increases the levels of poly-unsaturated fatty acids and softens the texture of pork fat which contradicts dry fermented sausage production (Burgstaller et al., 1992; Warnants et al., 1996).

Against this background three genotypes (extensive = Saddleback (Sa), semi-intensive = Piétrain*Saddleback (PiSa), intensive = modern hybrid line (Hy)), always with grass-clover silage or straw as roughage source, were slaughtered at > 160 kg live weight. The aim was to analyze their suitability for the production of the regionally significant pork product dry fermented sausage. Under organic farming conditions the performance and carcass quality, the meat, fat and product (dry fermented sausages) quality and economic parameters were quantified. It refers to work package 3.3.1 (Effects of, and interactions between, pig genotype and dietary regimes on carcass, meat and processing quality characteristics – experimental approach) within the EU co-funded FP7 research project "Low Input Breeds" – LIB (www.lowinputbreeds.org).

The present paper deals with (i) meat quality, (ii) fatty acid pattern and (iii) product quality of dry fermented sausages produced of them.

A first communication (Schwalm et al., 2013) was concerned with performance, carcass quality and economics of heavy pig production. It could be shown that the old purebred Saddleback and its crossbreed with Piétrain are suitable for dry fermented sausage production as concerns performance and carcass quality (mainly in terms of fat amount), whereas heavy pig production with purebred Saddlebacks is too expensive due to the very high costs of the concentrate feeding mainly due to their poor conversion ratio of feed into body mass.

2 Material and methods

2.1 Animals, keeping and sausage production

Using two runs (2010/2011 and 2011/2012) a total of 132 barrows of three different genotypes with different classifications of the breeding intensity concerning body protein synthesis capacity (Saddleback (Sa): extensive; Piétrain*Sa (PiSa): semi-intensive; modern Hybrid – (Piétrain*Duroc)* (German Large White*German Landrace) (Hy): intensive) combined with two different roughage sources (grass-clover silage (gcs), straw (str)) was divided into six treatments ((i) Sa/gcs (n = 25), (ii) Sa/str (n = 21), (iii) PiSa/gcs (n = 21), (iv) PiSa/str (n = 21), (v) Hy/gcs (n = 22) and (vi) Hy/str (n = 22)) and used for evaluating meat quality, fatty acid pattern and product quality (of dry fermented sausage); for detailed information see Schwalm et al. (2013).

Animal housing was in accordance with organic farming regulations (EC 889/2008); for detailed information see Schwalm et al. (2013). A pen was always linked with genotypes and roughage source of only one treatment.

The concentrates were pelletized and consisted of feed ingredients of 100 % organic origin. The composition of the grower and of the finishing diet is shown in Table 1. Both concentrates were only optimized for energy and the first limiting amino acid Lysin by the diet formula. Neither the grower diet nor the finisher diet were analysed for fatty acid composition. Both diets were given *semi-ad libitum* following a live weight-dependent feeding curve with a feeding rest < 1 kg per pen and repast.

Table 1

Characterization of the concentrate diets (mean value (standard deviation))

Analysed probes	n	Grower period 6	Finisher period 6
Winter barley	%	27.0	33.5
Triticale	%	25.5	22.0
Field peas	%	15.0	25.0
Field beans	%	15.0	13.0
Soya oilcake	%	9.0	- -
Sunflower oilcake	%	6.0	4.5
Mineral premix	%	2.5	2.0
Sum	%	100	100
Metabolizable energy, ME	MJ/kg	13.2 (0.24)	12.2 (0.20)
Crude protein	g/kg	180.0 (18.05)	151.0 (15.25)
Lysin	g/kg	10.9 (0.96)	8.2 (0.80)
Lysin-ME-ratio		0.83 (0.09)	0.67 (0.09)

Grass-clover silage and straw were offered in one separate rack per pen. The grass-clover silage is characterized by 31.7 % dry matter (DM) (CV 11.7 %), 15.9 % XP in DM (CV 6.6 %) and 22.8 % XF in DM (CV 13.9 %). It was offered daily with an average of 0.9 kg fresh matter per day and animal; a higher amount resulted in an even higher waste. Due to the impossibility of measuring real feed intake, the amounts of grass-clover silage mentioned are the amounts offered to but not consumed by the pigs. A special straw consumption was not observed. Straw was refilled when the racks were depleted; no further quantitative recordings and qualitative analyses were carried out. Both roughages were not analysed for fatty acid composition.

The fattening period started at an average initial live weight of 26.2 kg (CV 24 %) and the animals were slaughtered with a mean live weight of 164.1 kg (CV 3 %); for further information see Schwalm et al. (2013).

One day after slaughter a defined meat part (silverside including eye round, about 1,5 kg) and about 500 g back fat of every second pig per treatment were removed from the right carcass half and were stored at -20 °C for sausage production, until all animals of the respective run were slaughtered.

The sausages were made at MRI Kulmbach, Germany. Only back fat and meat of the experimental animals were used. All sausages were manufactured using the same technology, ingredients and formulation, which was

- 75 % lean meat (silverside including eye round)
- 25 % fat (back fat)
- 26 g/kg nitrite curing salt
- 5 g/kg spices (white pepper, coriander, cardamom, nutmeg, paprika, ginger)
- 2 g/kg sugar
- 0.5 g/kg starter culture
- 0.3 g/kg sodium ascorbat

The back fat, meat and ingredients mixture was packed into Naturin Därme 50/60 and left for five weeks in a ripening cabinet. The sausages were fermented according to the following ripening protocol:

time	temperature [°C]	relative humidity [%]	smoke
6 h	22	--	--
48 h	20	90	--
3 h	20	90	+
24 h	20	90	--
96 h	20	88	--
3 h	20	88	+
until five weeks	15	85	--

After ripening, the final product was vacuum-packed and stored at 12 °C for two month.

2.2 Data collection and analyses

Meat quality

Data collection and analyses concerning meat quality followed the guideline for on-station testing of growth performance, carcass quality and meat quality of the German Board for Performance Testing and Estimation of Breeding Value of the pig (ZDS, 2007). Always the left carcass half of all animals was used.

The physical meat quality traits pH-value, pH_{24}, (Knick pH-meter), electrical conductivity, EC_{24}, (Matthäus LF-star), meat color (Minolta CR-300, L*a*b*) were recorded 24 hours after slaughtering for loin and ham. Samples of drip loss were gained by a circular cutter (2.7 cm diameter, 2.9 cm depth) for loin (medial and lateral sample) and ham (one sample) 24 h after slaughtering and stored in a refrigerator at 8 °C for 24 h in special drip loss collectors (Fa. Sarstedt). Drip loss was recorded for the time span 24 h to 48 h post mortem (in case of loin as average of medial and lateral values). For detailed locations see Table 3.

Intramuscular fat content of the *Musculus longissimus dorsi* (13^{th} rib) was determined by MRI Kulmbach, using Near-Infrared-Transmission Spectroscopy (FoodScan, Foss, Rellingen, Germany). IMF-reference values used for the calibration ranged from 0.58 % to 8.74 % (thus, the analyzed samples were within the range of the calibration). To verify the estimation results of the FoodScan, 15 % of the samples were additionally analysed by a modified method according to § 64 in the German code of law for food and animal feed (LFGB, 2011). Fat was extracted with petroleum benzene in the Soxhlet-system 810 of BÜCHI Labortechnik GmbH (Essen, Germany) without prior HCl-digestion. Error and coefficient of determination for the 15 % re-analysed samples were SEP = 0.14 and $R^2 = 0.98$, respectively. 40 samples were analyzed by Soxhlet extraction only, because the amount per sample was too small to be measured with the FoodScan.

Fatty acid pattern

Fatty acids were determined by MRI Kulmbach for (i) subcutaneous back fat (outer layer without rind) adjacent to *Musculus longissimus dorsi* (13th rib), for (ii) ham fat (fat cover without rind above *Musculus semimembranosus*), and for (iii) intramuscular fat of the *Musculus longissimus dorsi* (13th rib) of the left carcass half of all animals. Fatty acids were analysed by gas chromatography (GC) using a Hewlett Packard 6890 series system with a J&W Scientific DB-23 capillary column (60 m x 0.25 mm, i.d. 0.25 µm; Agilent Technologies, Inc., US) and a flame ionisation detector. Sample preparation was performed as described by Schulte and Weber (1989). In brief, back fat samples were homogenized and melted with butylated hydroxytoluol. For transesterification from fatty acids to methyl esters, an aliquot of the liquid fat was mixed with toluol and trimethylsulfonium hydroxide (TMSH). Fat content of muscle tissue was extracted with a mixture of methanol and dichlormethane and then transesterified with TMSH. Then, the sample was injected into the GC system. GC conditions were as follows: injection temperature was 250 °C; carrier gas was Hydrogen, 1.3 ml/min, 1,710 split; column temperature program, 80 °C (5 min), up to 190 °C (rate 2 °C/min), up to 220 °C (1 °C/min), 220 °C (15 min); detector temperature 250 °C. For chromatogram evaluation the Chemsation Software (Agilent Technologies, Inc., US) was used. Calculation of fatty acids was based on the peak area of detected fatty acids (area percentage). Fatty acid concentrations < 0.5 % are not recorded.

Product quality of dry fermented sausage

During ripening (days of sampling: day 0 (subsequent to manufacturing), each week, end of ripening (week 5)) (i) pH and (ii) water activity (a_w) were analysed. The pH was determined electrometrically using a pH-meter 625 Climatic (Fa. Knick). Water activity was determined using an AWK-10 hygrometer (Fa. Nagy). For pH and a_w average values of three replicate measurements were used. The weight loss during ripening was calculated. One sausage per run, treatment and sampling time was used to measure the criteria. Data are presented only for the day subsequent to manufacturing and the end of ripening.

The color and the consistency were measured in ten not neighbouring slices at the end of ripening (five weeks subsequent to manufacturing). The color of the sausage was assessed with the L*a*b*-system using a Minolta Chroma-Meter CR-300 (Fa. Minolta). The consistency of the sausage was measured instrumentally two times per slice with the Instron 1140 (Fa. Instron). The samples used were 10 mm high, of 12.3 mm diameter, with a compression of 76 % at a temperature of 20 °C. One sausage per run, treatment and sampling time was used to measure the criteria.

The fat, protein, water, ash and connective tissue contents were determined according to the German standard of § 64 LFGB methods (LFGB, 2011) at the end of ripening. One sausage per run and treatment was used.

The fatty acid patterns of the sausages were only evaluated at the end of ripening for samples of the first run. In case of Hy, only the straw feeding based variant was available. The fatty acid determination followed the method mentioned above. One sausage per treatment was used.

The peroxide index and the acid value were evaluated according to the German standard of DGF-Einheitsmethoden – Abteilung C (DGF, 2011). TBARS (2-thiobarbituric acid reactive substance) measurements were done according to Botsoglou et al. (1994), and the TBARS values were expressed as milligrams of malonaldehyde per kg of sample. The three parameters of fat stability were evaluated at the end of ripening and after two months of storage. One sausage per run, treatment and sampling time was used to measure the criteria.

The whole product quality analyses were done by the MRI Kulmbach.

2.3 Statistics

Data analyses of meat quality criteria and fatty acid pattern were carried out with the General Linear Model (Proc GLM, SAS software package version 9.2), considering run, genotype, roughage source and the interaction genotype*roughage source as fixed effects. For the intramuscular fat content and the fatty acid composition the slaughter weight (expressed as the difference from the genotype average) was included in the model as a covariate. The remaining meat quality parameters were calculated without covariates. The LSQ-means were statistically compared using the Tukey-Kramer-Test (significance level $p < 0.05$).

For the criteria of product quality of dry fermented sausages only a descriptive statistic (including medium and standard deviation) was performed as the data structure was not sufficient for ANOVA (compare "M&M", "Product quality of dry fermented sausage").

3 Results

The significances of the effects of the statistical model on meat quality and fatty acid pattern are summarised in Table 2. Most meat quality parameters and all fatty acid patterns are influenced by the genotype, whereas the roughage source has only a significant effect on pH_{24} and the fatty acid pattern of the back fat. The significant effect of the run on electrical conductivity, on intramuscular fat content and on fatty acid pattern mainly of the back fat cannot be explained. Due to the negligible genotype*roughage interaction the selected results of meat quality and fatty acid pattern are presented as shown in the output format of the following result tables 3 to 6.

Meat quality traits are shown in Table 3. The electrical conductivity 24 hours p.m. does not differ between genotypes or roughages. The pH_{24} in the *Musculus longissimus dorsi (M.l.d.)* as well as in the *Musculus semimembranosus (M.s.)* are slightly lower in the PiSa compared to the other two genotypes. Interestingly the pH_{24} of the grass-clover silage fed pigs is higher in both examined muscles *(M. l. d., M. s.)*. The *M. l. d.* of the PiSa seems to be redder (a*-value) and yellower (b*-value) compared to Sa and Hy, whereas the *M. s.* of the Hy is lighter (L*-value) and yellower (b*-value) compared to PiSa and Sa. The Sa have considerably lower drip losses of *M. l. d.* and *M. s.* The values reached only 72 % and 73 %, respectively, for M.l.d. of PiSa and Hy. Additionally, the intramuscular fat content of the *M. l. d.* of the Sa is nearly 20 % higher compared to PiSa, whereas differences in the IMF of Sa and Hy are not significant.

Fatty acid pattern of back fat is shown in Table 4. Saddlebacks have significantly the highest saturated fatty acid content and significantly the lowest poly-unsaturated fatty acid content whereas Hy behave in exactly the opposite way. PiSa takes an intermediate position. Roughage consumption (contrary to sole straw offer) results in significantly lower concentrations of mono-unsaturated (due to oleic acid) and significantly higher concentrations of poly-unsaturated fatty acids (due to linoleic acid and linolenic acid) in back fat. But the differences (-1.5 % for MUFA and +3.5 % for PUFA) are very small.

Fatty acid patterns of ham fat and intramuscular fat are shown in Table 5. Due to the minor relevance of ham fat and

Table 2

Significance levels of fixed effects on meat and fat quality traits

	r^2 (%)	Run (1^{st}, 2^{nd})	Genotype [1] (Hy, PiSa, Sa)	Roughage (gcs^2, straw)	G*R interaction
Electr. conductivity24 (loin)	20	***	ns	ns	ns
Electr. conductivity24 (ham)	33	***	ns	ns	ns
pH_{24} (loin)	22	ns	***	**	ns
pH_{24} (ham)	19	ns	***	**	ns
L* (loin)	4	ns	ns	ns	ns
a* (loin)	21	ns	***	ns	**
b* (loin)	14	ns	***	ns	ns
L* (ham)	7	ns	*	ns	ns
a* (ham)	2	ns	ns	ns	ns
b* (ham)	14	ns	**	ns	ns
Drip loss (loin)	19	ns	**	ns	ns
Drip loss (ham)	17	ns	**	ns	*
Intramuscular fat (loin)	19	*	*	ns	ns
Back fat					
– SFA[3]	29	***	***	ns	ns
– MUFA[4]	39	**	***	**	*
– PUFA[5]	66	***	***	**	ns
Ham fat					
– SFA[3]	47	***	***	ns	ns
– MUFA[4]	22	ns	***	ns	ns
– PUFA[5]	14	ns	**	ns	ns
Intramuscular fat					
– SFA[3]	8	ns	*	ns	ns
– MUFA[4]	9	ns	ns	ns	ns
– PUFA[5]	17	ns	***	ns	ns

[1] Hy: modern Hybrid; PiSa: Piétrain*Saddleback; Sa: Saddleback

[2] gcs: grass-clover silage

[3] Saturated Fatty Acids

[4] Mono-Unsaturated Fatty Acids

[5] Poly-Unsaturated Fatty Acids

Table 3

Meat quality traits by genotype and roughage source of heavy pigs (LSQM)

	Genotype [1]			Roughage	
	Hy	PiSa	Sa	gcs[2]	straw
EC_{24}[3], loin (*M. long. dorsi*, 13th/14th rib) [mS/cm]	2.22	2.20	2.05	2.27	2.04
EC_{24}[3], ham (*M. semimembranosus*) [mS/cm]	3.99	3.79	3.77	3.95	3.75
pH_{24}, loin (*M. long. dorsi*, 13th rib)	5.53^{a}	5.47^{b}	5.54^{a}	5.53^{x}	5.49^{y}
pH_{24}, ham (*M. semimembranosus*)	5.58^{a}	5.53^{b}	5.63^{a}	5.60^{x}	5.56^{y}
L*, loin (*M. long. dorsi*, 13th rib)	52.34	52.87	52.95	52.41	53.03
a*, loin (*M. long. dorsi*, 13th rib)	10.01^{b}	11.48^{a}	10.12^{b}	10.41	10.66
b*, loin (*M. long. dorsi*, 13th rib)	6.75^{b}	7.83^{a}	7.29^{ab}	7.18	7.40
L*, ham (*M. semimembranosus*)	41.13^{a}	38.67^{b}	38.40^{b}	39.88	38.93
a*, ham (*M. semimembranosus*)	11.91	12.14	12.09	12.19	11.90
b*, ham (*M. semimembranosus*)	6.40^{a}	5.02^{b}	4.95^{b}	5.78	5.13
Drip loss, loin (*M. long. dorsi*, 14th rib) [%]	6.24^{a}	6.30^{a}	4.56^{b}	5.46	5.93
Drip loss, ham (*M. semimembranosus*) [%]	2.31^{ab}	2.85^{a}	1.75^{b}	2.18	2.43
Intramuscular fat, loin (*M. long. dorsi*, 13th rib) [%]	2.64^{ab}	2.57^{b}	3.11^{a}	2.68	2.87

[1] Hy: modern Hybrid; PiSa: Piétrain*Saddleback; Sa: Saddleback

[2] gcs: grass-clover silage

[3] Electrical conductivity

[a, b] Different indices within row indicate significant differences for genotype (Tukey-Kramer-Test, $p < 0.05$)

[x, y] Different indices within row indicate significant differences for roughage (Tukey-Kramer-Test, $p < 0.05$)

Table 4

Fatty acid pattern (%) of subcutaneous back fat (outer layer, *M. long. dorsi*, 13th rib) by genotype and roughage source of heavy pigs (LSQM)

	Genotype [1]			Roughage	
	Hy	PiSa	Sa	gcs[2]	straw
C14 : 0	1.20^{b}	1.30^{a}	1.31^{a}	1.28	1.27
C16 : 0	21.66c	22.46^{b}	22.96^{a}	22.42	22.30
C18 : 0	12.00^{b}	12.04^{b}	12.55^{a}	12.32	12.07
C16 : 1 cis9	1.93	1.98	1.99	1.95	1.98
C18 : 1 cis9	42.13^{b}	43.24^{a}	43.46^{a}	42.63^{y}	43.25^{x}
C18 : 1 cis11	2.72^{b}	2.81^{ab}	2.85^{a}	2.76	2.83
C20 : 1	1.13^{b}	1.23^{a}	1.19^{ab}	1.17	1.19
C18 : 2n6	12.29^{a}	10.50^{b}	9.37^{c}	10.87^{x}	10.56^{y}
C18 : 3n3	1.30^{a}	1.11^{b}	1.02^{c}	1.21^{x}	1.08^{y}
C20 : 2	0.69^{a}	0.63^{b}	0.55^{c}	0.63	0.62
SFA[3]	35.84^{c}	36.72^{b}	37.79^{a}	36.95	36.62
MUFA[4]	48.63^{b}	49.87^{a}	50.18^{a}	49.18^{y}	49.94^{x}
PUFA[5]	15.38^{a}	13.26^{b}	11.89^{c}	13.74^{x}	13.28^{y}

[1] Hy: modern Hybrid; PiSa: Piétrain*Saddleback; Sa: Saddleback

[2] gcs: grass-clover silage

[3] Saturated Fatty Acids: C14 : 0, C16 : 0, C18 : 0

[4] Mono-Unsaturated Fatty Acids: C16 : 1 cis9, C18 : 1 cis9, C18 : 1 cis11, C20 : 1

[5] Poly-Unsaturated Fatty Acids: C18 : 2n6, C18 : 3n3, C20 : 2

[a, b, c] Different indices within row indicate significant differences for genotype (Tukey-Kramer-Test, $p < 0.05$)

[x, y] Different indices within row indicate significant differences for roughage (Tukey-Kramer-Test, $p < 0.05$)

Table 5
Fatty acid pattern (%) of ham fat and intramuscular fat by genotype and roughage source of heavy pigs (LSQM)

	Genotype [1]			Roughage	
	Hy	PiSa	Sa	gcs[2]	straw
Ham fat (above *M. semimembranosus*)					
– SFA[3]	38.65[a]	37.38[b]	37.62[b]	37.81	37.95
– MUFA[4]	44.95[b]	50.06[a]	52.65[a]	48.26	50.18
– PUFA[5]	11.96[a]	12.31[a]	10.78[b]	11.70	11.67
Intramuscular fat (*M. long. dorsi*, 13[th] rib)					
– SFA[3]	36.42[ab]	36.27[b]	37.07[a]	36.58	36.59
– MUFA[4]	53.87	53.60	54.20	53.73	54.05
– PUFA[5]	9.28[a]	9.64[a]	8.23[b]	9.24	8.86

[1] Hy: modern Hybrid; PiSa: Piétrain*Saddleback; Sa: Saddleback

[2] gcs: grass-clover silage

[3] Saturated Fatty Acids: C14:0, C16:0, C18:0

[4] Mono-Unsaturated Fatty Acids: C16:1 cis9, C18:1 cis9, C18:1 cis11, C20:1

[5] Poly-Unsaturated Fatty Acids: C18:2n6, C18:3n3, C20:2

[a, b] Different indices within row indicate significant differences (Tukey-Kramer-Test, $p < 0.05$)

intramuscular fat for dry fermented sausage manufacturing only the fatty acid groups are presented without the respective single fatty acids. In contrast to back fat, the Hy have significantly higher SFA contents of about 3 % in ham fat compared to the mean SFA content in Sa and PiSa. And again, the Sa have the significantly lowest PUFA content. The mean MUFA content of the Sa and PiSa in ham fat is about 14 % higher than the MUFA content of the Hy. Concerning intramuscular fat, the Sa have the highest SFA and the lowest PUFA content. In contrast to back fat, fatty acid patterns of ham fat and of intramuscular fat do not significantly respond to the different roughage sources.

Product quality traits of dry fermented sausage are shown in Table 6. Due to the data structure the ANOVA procedure was impossible (compare M&M, Product quality of dry fermented sausage & Statistics). Hence, the following results are presented as mean value (mv) and standard deviation (sd) of the two runs for the respective quality traits.

The decline of the pH- and the aw-value during ripening can be seen in Table 5. The sausages of Sa tend to have a slightly higher pH value at the beginning and the end of the ripening compared to the other two genotypes. As expected, the aw-values decrease during ripening and there are no differences between the genotypes in both measured times. L*a*b*-values and weight loss during ripening do not differ noticeably between the genotypes. It seems that the Sa sausages have the firmest consistency compared to the sausages of PiSa and Hy. Roughage source obviously is without effect on the respective physically based product quality traits.

Concerning chemically based quality traits, the sausages of Sa have a considerably higher fat content (about 20 % of Hy) in spite of the same recipe, whereas moisture and protein content are lower compared to Hy sausages. PiSa ranked in the middle. As a result, the fat-protein-ratio is about 40 % higher in Sa than in Hy. But these differences could not be statistically proven due to the small number of batches (Table 6).

Fat stability is characterised by peroxide number, acid value and TBARS (Table 6). All fat stability parameters developed higher values during storage, indicating lower oxidative fat stability, except TBARS in PiSa. After two months of storage at 12 °C the Hy sausages show the highest values and Sa the lowest values in all parameters, the PiSa always rank in the middle. The better fat stability of Sa sausages can be confirmed by the fatty acid composition: Sa sausages have the lowest PUFA concentration (only 70 % of Hy) and the highest SFA concentration (Table 6).

4 Discussion

For the utilisation of heavy pig carcasses for dry fermented sausage production, meat and fat quality is very important; not only regarding nutritive and organoleptic aspects but also from a technological point of view (Russo, 1989; Hadorn et al., 2008).

The PSE and DFD status of the raw meat is one of the most important processing characteristics of meat. The deviations from normal water holding capacity make a proper dry-curing process difficult (Gil et al., 1999). For the pork meat used for salami production the pH_{24} values (exclusion of DFD) should not exceed 6.0 to 6.2 (Bracher and Stoll, 2002) and EC_{24} values should not exceed 6.0 in loin or 9.5 in ham (topside) for exclusion of PSE conditions (Weißmann and Honikel, 1998). In our study (Table 3) the respective values are clearly below and they are in the range of literature data in case of exclusion of DFD (Virgili, Schivazappa, 2002) and of PSE conditions (Westphal, 2002).

Table 6

Mean value (mv) and standard deviation (sd) of selected product quality traits of dry fermented sausage by genotype and roughage source of heavy pigs

	Genotype [1]						Roughage			
	Hy		PiSa		Sa		gcs [2]		straw	
	mv	sd	mv	sd	mv	sd	mv	sd	mv	sd
Physical criteria										
– at the day of manufacturing										
pH	**5.53**	0.03	**5.52**	0.03	**5.60**	0.08	**5.54**	0.06	**5.56**	0.07
aw	**0.95**	0.00	**0.95**	0.00	**0.95**	0.01	**0.95**	0.00	**0.95**	0.01
– at the end of ripening …										
pH	**5.19**	0.11	**5.18**	0.04	**5.38**	0.16	**5.27**	0.14	**5.19**	0.12
aw	**0.89**	0.03	**0.88**	0.02	**0.88**	0.03	**0.88**	0.03	**0.88**	0.02
Weight loss [%]	**37.7**	3.4	**36.6**	1.4	**36.0**	2.6	**36.7**	2.6	**36.9**	2.1
L*	**54.15**	1.33	**53.93**	2.00	**53.25**	2.50	**53.55**	1.99	**54.15**	1.73
a*	**16.34**	2.95	**17.81**	2.41	**18.62**	1.68	**17.80**	2.29	**17.33**	2.70
b*	**10.85**	1.61	**11.08**	1.03	**11.39**	1.40	**11.17**	1.27	**10.99**	1.20
Consistency [N]	**31.0**	9.3	**27.6**	6.6	**42.2**	6.9	**33.2**	11.3	**32.8**	7.0
Chemical criteria										
– at the end of ripening										
Water [%]	**32.3**	2.1	**30.4**	1.9	**28.7**	2.5	**30.5**	2.8	**30.4**	2.0
Crude fat [%]	**35.0**	1.1	**39.1**	3.5	**41.6**	4.5	**38.4**	4.0	**38.9**	4.7
Crude protein [%]	**26.7**	2.7	**24.8**	1.6	**23.1**	3.2	**24.9**	2.6	**24.7**	3.0
Connective tissue [%]	**1.6**	0.2	**1.2**	0.1	**1.4**	0.1	**1.4**	0.3	**1.3**	0.1
Crude Ash [%]	**5.3**	0.6	**5.1**	0.3	**5.0**	0.2	**5.1**	0.3	**5.2**	0.5
SFA [3] [%]	**37.57**	-	**39.21**	0.16	**39.41**	1.07	**38.44**	0.79	**39.75**	0.59
MUFA [4] [%]	**47.61**	-	**49.19**	0.11	**49.63**	0.59	**48.92**	1.23	**49.24**	0.04
PUFA [5] [%]	**14.67**	-	**11.43**	0.28	**10.28**	0.00	**12.19**	2.25	**10.76**	0.67
Peroxide index [milli-equivalent oxygen/kg fat]	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0
Acid value [mg KOH/100g fat]	**13.47**	3.94	**12.02**	3.01	**12.13**	2.66	**11.93**	3.16	**13.32**	2.71
TBA [mg MDA/kg]	**0.127**	0.012	**0.122**	0.023	**0.089**	0.023	**0.109**	0.021	**0.120**	0.032
– at the end of storage (2 month, 12°C)										
Peroxide index [milli-equivalent oxygen/kg fat]	**2.80**	1.51	**1.62**	1.44	**1.09**	1.53	**1.78**	1.54	**1.87**	1.65
Acid value [mg KOH/100g fat]	**21.04**	1.51	**18.29**	1.81	**17.49**	0.82	**18.84**	2.32	**18.93**	1.81
TBA [mg MDA/kg]	**0.137**	0.031	**0.111**	0.032	**0.109**	0.058	**0.119**	0.037	**0.118**	0.046

[1] Hy: modern Hybrid; PiSa: Piétrain*Saddleback; Sa: Saddleback

[2] gcs: grass-clover silage

[3] Saturated Fatty Acids: C14 : 0, C16 : 0, C18 : 0

[4] Mono-Unsaturated Fatty Acids: C16 : 1 cis9, C18 : 1 cis9, C18 : 1 cis11, C20 : 1

[5] Poly-Unsaturated Fatty Acids: C18 : 2n6, C18 : 3n3, C20 : 2

Meat lightness (L*) of the loin remained unaffected by genotype and roughage source (Table 2, Table 3). This confirms the findings of Nürnberg et al. (1997) who could not find differences in meat color (*M. l. d.*) between German Saddlebacks and German Landrace in contrast to Steinberg et al. (1998). This study reported relatively high L* values in Saddlebacks and explained the greater lightness as the effect of a higher IMF content.

In our study, the Sa clearly showed lower drip losses compared to the other two genotypes (Table 3). This is in accordance with Steinberg et al. (1998) and Brandt et al. (2011) but contradicts Nürnberg et al. (1997). However, drip losses of *M. l. d.* are strikingly high in our study. In literature drip losses in heavy pigs are within a wide range from 7.19 % to 8.29 % (Virgili et al., 2003; Lukić et al., 2010) to 1.2 % to 2.3 % (Fischer et al., 2006b; Peinado et al., 2012). These large differences cannot be explained completely. A possible explanation may be the entire procedure of drip loss evaluation, also due to the significant influence of the location (Fischer, 2007). In our study, the overall mean value for medial and lateral drip loss in *M. l. d.* (13^{th} rib) is 4.0 % and 7.4 %, respectively (data not presented). Therefore it is essential, inter alia, on which part of the *M. l. d.* the drip loss is evaluated.

Intramuscular fat content seems to be the best way to separate native pigs from improved ones (Pugliese and Sirtori, 2012). Interestingly the IMF content of Sa and Hy did not differ significantly (Table 3), but in this high weight class both genetics have higher IMF compared to PiSa.

In summary, it can be said that the roughage source was without any noticeable effect on physical and chemical meat quality traits in contrast to the genetic origin. The Sa showed the best meat quality characteristics for use in dried meat products. In literature the crossbreeding of Piétrain with German Saddleback is especially recommended, leading to higher lean meat content without diminishing meat quality (Ehlich, 2005). This could be confirmed by our own meat quality (Table 3) and carcass quality results presented in the first communication (Schwalm et al., 2013). To avoid PSE conditions, MHS-gene-sanitized lines (malignant hyperthermia syndrome) have to be used (Glodek, 1996).

In terms of meat and technological meat quality, fatty acid composition has an outstanding effect on the softness and oxidative stability of fat and meat, as high PUFA levels result in softer fat due to a lower melting point (Wood et al., 2003; Bee, 2004). The ability of unsaturated fatty acids, especially those with two or more double bounds, to rapid oxidation is important to rancidity and to color deterioration (Wood et al., 2003). Higher PUFA and lower pH_{24} are to be regarded as potentially harmful for pork undergoing a long aging because of increased fat susceptibility to rancidity and oiliness and enhanced muscle proteolysis (Virgili and Schivazappa, 2002).

For optimal processing quality concerning consistency and oxidative stability, recommendations have been formulated, limiting the PUFA content of the back fat to a maximum of 12 to 15 % (Kuhn et al., 1995; Warnants et al., 1996; Bee, 2004; Fischer et al., 2006b). In our study, only the Saddlebacks were below 12 % PUFA content in the back fat (mainly used for sausage production) with the Hy showing the highest amount (15.4 %) and PiSa having an intermediate position (Table 4).

Also in the ham fat and in the intramuscular fat, the Saddlebacks have the lowest PUFA concentrations (Table 5). This is in accordance with the studies of Glodek et al. (2004) and Volk et al. (2004). An increase in fat synthesis (due to breed or age) leads to a dilution of PUFA ingested (mainly C18 : 2 and C18:3) by the *de-novo* produced fatty acids (mainly C18 : 1) (Virgili et al., 2003; LoFiego et al., 2005; Fischer et al., 2006b).

Pasture contains relatively high amounts of PUFA which are by a majority from the omega-3 family. Especially linolenic acid content is higher in outdoor reared animals (Andrés et al., 2001). This can lead to technologically undesired carcass fat. This is why feeding of green fodder and/or silage in heavy pigs intended for dry fermented sausage production has to be seen critically (Burgstaller et al., 1992; Johansson et al., 2002). In our study, a slightly lower MUFA and a slightly higher PUFA content in the back fat of the silage fed group could be observed (Table 4), but the values are far below the differences between the genotypes and may not affect the quality of the produced sausages. This seems to be the effect of the small amount of silage offered to the pigs with an average of 0.9 kg grass-silage per animal and day (Schwalm et al., 2013). Concerning the other two fat origins (IMF, ham fat), no significant differences occurred as to the roughage source (Table 5). This is in agreement with the results of Miller et al. (1990) and Warnants et al. (1996), finding a lower dietary PUFA incorporation in IMF compared to back fat.

The pH and aw-values of dry fermented sausages at the beginning and at the end of the ripening period are within normal ranges and show the expected decline during ripening (Table 6). The Sa tend to have slightly higher pH values. This is in accordance with higher pH values at the end of the ripening in dry fermented sausages with higher fat content (Rödel, 1985). The results of Hadorn et al. (2008) indicate that the a_w-value in salami increases with increasing PUFA content. This could not be observed in our study (Table 6) despite the highest PUFA contents in the back fat of the Hy (Table 5), but maybe the differences are too small to cause a change of the a_w-value in the sausage.

Concerning sausage color, there are no clear tendencies between the genotypes or the roughage sources (Table 6). Miller et al. (1993) and Warnants et al. (1998) report that the b*-value (of the L*a*b*-system) is higher for salamis with a higher PUFA level, although the carcass fat showed no yellow discolouration. The results of our study do not confirm this combination (Table 6). In accordance with Caprino et al. (2007), dry fermented sausages of old breeds tend to be redder, represented by the highest a*-value of the Sa.

The higher firmness of the Sa sausages (Table 6) can probably be attributed to the lower PUFA content of the back fat used (Table 4) and of the sausage (Table 6). In the manufacturing of salami/cervelat sausage, an increased number of double bindings results in a soft and greasy consistency of the end product (Houben and Krol, 1980; Warnants et al., 1998; Hadorn et al., 2008).

Concerning the tendencies in the nutrient composition of the sausage (Table 6), the lowest water content is associated with the highest fat content and therefore lowest protein content in the Sa, and vice versa for the Hy; PiSa ranks in the middle. Together with the fat level of the basic material (Schwalm et al., 2013), the presented results make for a conclusive overall picture.

Lipid oxidation is a major quality deteriorative process in muscle foods resulting in a variety of breakdown products which produce off-flavours (Valencia et al., 2008). Especially PUFA are highly sensitive to oxidation (Wood et al., 2003). After 2 months of storage at 12 °C the Sa sausages tend to have the best values in all parameters concerning the oxidative fat stability (peroxide index, acid value, TBARS) (Table 6). The better fat stability of Sa sausages can be confirmed by the fatty acid composition: Sa sausages have the lowest PUFA concentration (only 70 % of Hy) and the highest SFA concentration (Table 6). The lower PUFA content (and therefore better fat stability) of fermented sausages of primitive breeds (Mangaliza, Moravaka) has been shown by Stajić et al. (2011).

TBARS values above 0.5 MDA/kg are considered as critical since they indicate a level of lipid oxidation products resulting in rancid odour and taste (Sheard et al., 2000; Wood et al., 2008). In our dry fermented sausages, TBARS values did not exceed the critical 0.5 MDA-value (Table 6), but rancidity and beginning fat oxidation could be sensorially detected in all sausages after the storage time (comments of the taste panel; data not presented). This is confirmed by the acid values and peroxide indexes, especially at the end of storage.

As a final synopsis, it can be summarised that the results of meat quality and of fatty acid pattern are reflected in the tendencies of the product quality of the dry fermented sausages. Compared to modern hybrids (Hy) and the crossbreed between modern Piétrain and old Saddleback (PiSa) purebred Saddlebacks (Sa) have characteristics of meat quality and chiefly of fatty acid pattern which are more or less optimally suitable for dry fermented sausage production. Meat and fat quality characteristics predestine the Saddlebacks for dry fermented sausage manufacturing. Whereas the genetic origin plays a significant role in dry fermented sausage production, the roughages offered are without practical relevance. But this is only proven for the conditions of our study with an average daily grass-clover supply per pig not exceeding 1 kg.

5 Overall conclusions

It could be shown in the present paper that – from the viewpoint of meat and especially of fat quality – modern hybrids have sub-optimal preconditions for dry fermented sausage production in the range of about 150 to 170 kg live weight at slaughter (under the particular diet composition of our trial), whereas old purebred Saddlebacks are well suited. This is also true for carcass quality: whereas the Saddlebacks have sufficient fat quantities, the modern hybrids represent the lower limit (Schwalm et al., 2013). Performance characteristics are inconsistent. Modern hybrids have the best level of daily weight gain and of feed conversion ratio. On the other hand old Saddlebacks still have a remarkable level of daily weight gain but an inacceptable poor level of feed conversion resulting in very high production costs with a surplus of the revenues over the feed and piglet costs of only 57 % compared to the modern hybrids (Schwalm et al., 2013). Although product quality of dry fermented sausages of Saddleback origin tends to be a little bit higher compared to the modern hybrids, it seems completely unrealistic to achieve selling prices (and sales volumes) which could compensate the strikingly higher production costs of the Saddlebacks; even if the selling arguments of a local breed and a local origin of production could be used. Therefore, it cannot be maintained that the production and merchandising of a pork speciality like dry fermented sausage only based on purebred Saddlebacks is a goal to ensure the survival of endangered purebred old breeds via economically based value creation.

But the use of crossbreeds between old Saddlebacks and a modern terminal sire line like Piétrain is an auspicious alternative (under the strict obedience to use MHS-gene-sanitized lines). The PiSa crossbreeds of our study are characterised by positive manifestations of (i) meat quality, (ii) fatty acid pattern and (iii) product quality as well as (iv) performance, (v) carcass quality and (vi) economics (Schwalm et al., 2013) providing the potential for a sustainable dry fermented sausage production. The necessity of a purebred old pig breed like Saddlebacks as mating partner within this concept opens a promising goal to ensure the survival of purebred Saddlebacks as a typical representative of an old endangered breed.

This consideration need not necessarily remain a pious hope as over the last few years, meat products made of native pigs reared extensively or organically have been met with an ever increasing and renewed interest from customers (Madonia et al., 2007; Maiorano, 2009).

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7 Disclaimer

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Estimate of methane, volatile solids and nitrogen excretion rates of German suckler cows

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Abstract

German beef production is increasingly based on suckler cows. At present, the determination of greenhouse gas and air pollutant emissions from suckler cows are calculated using standard assumptions and IPCC default values. In this work, a national procedure and relevant values are derived from the detailed dairy cow model used in the German agricultural emission inventory. In addition, herd composition data, data concerning animal weights, milk yields and diet composition were collated from literature and evaluated to deduce the excretion rates of volatile solids and nitrogen from which greenhouse gas and air pollutant emissions could be obtained. As a result, suckler cows of the single genotypes found in Germany could be described satisfactorily.

Cow weight, milk yield and feed composition were identified as most important input parameters.

In the inventories, emissions have to be reported as time series. However, time series of important data needed to describe the overall German suckler cow management could not be established, in particular the distribution of genotypes in the national herd. Hence, the characterisation and the resulting excretion rates of the "mean German suckler cow" rely on recent data only. Some of our findings contradict the recommendations given in German standard textbooks, in particular for the milk yield of suckler cows.

Keywords: *methane, volatile solids, nitrogen, excretion, suckler cows, model*

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Zusammenfassung

Schätzung der Ausscheidungsraten von Methan, organischer Trockensubstanz ("volatile solids") und Stickstoff von deutschen Mutterkühen

Die Mutterkuhhaltung ist ein Wirtschaftszweig in der deutschen Rindfleischproduktion, der zunehmend Bedeutung gewinnt. Emissionen von Treibhausgasen und luftverschmutzenden Gasen aus der Mutterkuhhaltung wurden in Deutschland bisher unter Verwendung von Standard-Annahmen (IPCC „default values") beschrieben. In der vorliegenden Arbeit wird die Quantifizierung der für die Emissionen wichtigen Ausscheidungen von Mutterkühen von dem Milchkuh-Modell abgeleitet, das im nationalen Emissionsinventar verwendet wird. Daten zur Herdenzusammensetzung wurden ausgewertet und Literaturdaten zu Tiergewichten und zur Milchleistung sowie zur Fütterung zusammengestellt, um die für die Berechnung der Emissionen wichtigen Ausscheidungsraten von „volatile solids" und Stickstoff bestimmen zu können.

Kuhgewicht, Milchleistung und Futterqualität wurden dabei als die wichtigsten Eingabeparameter identifiziert.

In den Inventaren müssen Emissionen als Zeitreihen berichtet werden. Für wichtige Parameter der deutschen Mutterkuh-Haltung insgesamt, insbesondere die Verteilung der Genotypen, konnten diese nicht im gewünschten Umfang erstellt werden. Daher beschränkt sich die Beschreibung der Ausscheidungsraten der deutschen „mittleren Mutterkuh" auf die Darstellung der gegenwärtigen Situation. Die beschriebenen Ergebnisse widersprechen teilweise den in den gängigen deutschen Handbüchern gemachten Empfehlungen, insbesondere der Milchleistung der Mutterkühe.

Schlüsselwörter: *Methan, volatile solids, Stickstoff, Ausscheidung, Mutterkühe, Modell*

1 Introduction

Cattle are the main source of air pollutants and greenhouse gases in German agriculture. In 2011, about 64 % of the 529 Gg a^{-1} NH_3 emitted from German agriculture originated from the manure management of cattle, and 92 % of agricultural CH_4 emissions from cattle (enteric fermentation and manure management). The share of suckler cows is small but not negligible: 6.4 % of cattle NH_3 emissions and 6.7 % of cattle CH_4 emissions are at present related to suckler cows. They represent about 15 % of the number of dairy cows in Germany (with varying shares, e.g. Bayern: 6.1 %; Brandenburg: 37.3 %, see Lorz, 2010).

Suckler cows produce offspring without producing milk as commodity. As a rule, these animals are kept on marginally profitable grassland areas where the production of beef is coupled to landscape maintenance and preservation (e.g. Weiher, 1994; Bauer et al., 1997; Hochberg, 2007). With decreasing dairy cow numbers and decreasing numbers of births per dairy cow (ADR, 1993 ff), beef production with suckler cow herds is likely to increase to meet the demand. Until now, the various production processes with different genotypes have not been analyzed with respect to their typical emissions of greenhouse gases and air pollutants. Such an attempt presupposes the availability of a set of models describing the whole production line, i.e. suckler cows, heifers for replacement and female and male beef cattle. This has to be performed using a consistent and coherent set of models that reflect animal performance and feed properties.

This work aims at a description of suckler cows excretion and emission rates. The dairy cow model used in the German agricultural emission inventory is adapted to describe the performance and feed data of suckler cows, to enable the derivation of excretion rates of volatile solids (VS) and nitrogen (N). As production characteristics have changed with time, calculations aim at a time series of typical mean excretion rates of German suckler cows. It is not intended to provide a spatial resolution, e.g. for German federal states.

Hence, the approach comprises the following steps:

- Step 1: establishing the suckler cow model by adaptation of the original dairy cow model
- Step 2: identification and provision of input parameters used to run the suckler cow model
- Step 3: sensitivity analysis

The application of the adjusted model to describe typical German suckler cows then presupposes:

- Step 4: establishing the national herd composition (share of different breeds)
- Step 5: identification of relevant national performance data (as time series)
- Step 6: quantification of excretion rates using national input data sets
- Step 7: discussion of representativeness and valuation of uncertainties

2 The suckler cow model

The suckler cow model is derived from the dairy cow model as described in Rösemann et al. (2013; for further details see Dämmgen et al., 2009, 2011) used in the German agricultural emission inventory model GAS-EM. It differs from the dairy cow model in three respects.

(1) Changes in the quantification of maintenance energy requirements

For suckler cows producing beef calves ("Fleischrassen"), the constant $\eta_{\text{nel, m}}$ (see Equation (1)) differs from that for dairy cows; energy requirements are about 20 % less than for dairy cows (Equation 1.4.1 in GfE, 2001; see also Steinwidder and Häusler, 2004):

$$nel_{\text{m}} = \eta_{\text{nel, m}} \cdot w_{\text{unit}} \cdot \left(\frac{w}{w_{\text{unit}}} \right)^{0.75} \qquad (1)$$

where

nel_{m} mean daily net energy required for maintenance (in MJ cow^{-1} d^{-1} NEL)
$\eta_{\text{nel, m}}$ constant
dairy cows: $\eta_{\text{nel, m, dc}} = 0.364$ MJ kg^{-1} d^{-1} NEL
suckler cows: $\eta_{\text{nel, m, sc}} = 0.293$ MJ kg^{-1} d^{-1} NEL
w_{unit} unit value of animal weight (w_{unit} = 1 kg cow^{-1})
w animal weight averaged over lifetime (in kg cow^{-1})

(2) Changes in the calculation of suckler cows' mean live weights and weight gains (see Appendix I).

(3) The use of variable calf birth weights for the quantification of energy requirements related to the development of the conception products (see Appendix II).

3 The input parameters required

The various suckler cow model sub-modules make use of an input data set that differs from the dairy cow model:

- For the assessment of *energy requirements and feed intake rates* the model requires information on live weight, live weight gain, milk yield, milk fat and protein contents, calf weight and number of calves per year.
- As the feed intake rate is also depending on the energy content of the diet, the energy contents of the diet constituents (expressed as NEL and ME contents[1] are needed as well.
- *Methane (CH_4) emissions* from enteric fermentation depend on diet composition. Hence, the crude fibre (CF),

[1] The German valuation system of feed quality differentiates between dairy cows and other cattle. For dairy cows the NEL system is used (NEL: net energy for lactation), for other cattle the ME system (ME: metabolizable energy) is applied in the respective calculations. Hence, both NEL and ME intakes are shown in the following Tables.

nitrogen (N) free extracts (NFE), crude protein (CP) and crude fat (ether extract, EE) contents of the diet have to be taken into account.
- Usually methane emission rates are characterized by the so-called *methane conversion rate* (MCR), i.e. the ratio of the energy equivalent of the methane released to the gross energy (GE) intake. Hence, the GE content of the diet has to be known.
- The quantification of CH_4 *emissions from manure management* according to IPCC (1996, 2006) presupposes the quantification of VS excretion rates. For their calculation feed ash content and digestibility of organic matter are needed.
- N is excreted as *organic N* with faeces and as *total ammoniacal N* (TAN) with urine. In order to estimate their excretion rates, information on feed dry matter intake, feed N content, digestibility of N in feed, overall N contents of both cows and the calves, milk yield and N content of milk protein is required.

4 Sensitivity analysis

The applicability of the model was tested in a sensitivity analysis that was based on data as provided in various German recommendations and textbooks (Bach, 1990; Bauer et al., 1997; Weiß et al., 2005; KTBL, 2006; DLG, 2009; KTBL, 2010) and covers the respective ranges of input parameters found in the literature.

4.1 Default values for the sensitivity analysis

Standard properties for the calculation of energy requirements are:

- mean cow weight 700 kg cow^{-1}
- mean weight gain 0 kg cow^{-1}
- birth rate 1 calf cow^{-1} a^{-1}
- calf birth weight 40 kg $calf^{-1}$
- milk yield 2,500 kg cow^{-1} a^{-1}
- milk fat content 0.040 kg kg^{-1}
- milk protein content 0.034 kg kg^{-1}
- feed quality during grazing 5.5 MJ kg^{-1} NEL in DM
- duration of the grazing period 210 d a^{-1} with 24 h d^{-1}

These properties are varied during the sensitivity analysis.

4.2 Output parameters

The following tables (Tables 2 to 10) list relevant input parameters such as feed intake as well as their variation and the resulting excretion rates as well as common key parameters as output entities. Feed intake is usually characterized by energy (NEL and ME) and dry matter (DM) intake rates. CH_4 is released from enteric fermentation (characterized by MCR) and from manure storage (characterized by B_o and MCF). The latter is governed by the excretion rates of VS. As explained above, emissions of N species from the manure management system, such as NH_3, nitric oxide (NO) and nitrous oxide (N_2O) originate from total N and TAN available in the system. The ratio of TAN excreted to total N excreted is used as an indicator value [2].

In Tables 2 to 10, input data for the standard suckler cow used in the sensitivity analyzes are written in bold figures.

The number of digits given in the tables does not reflect the uncertainty of the respective modelled parameter.

4.3 Variation of animal weights and weight gains

Maintenance energy requirements are governed by **animal weight**. Table 1 depicts the range of mean weights that can be found for German suckler cows (see also Table 12 below).

The effect of the mean cow weight on mean energy requirements and excretion rates

Mean weights differ from the final weights. They depend on the final cow weight and the life-span of the suckler cow. For details see Appendix I. Table 2 expresses the mean weights as percentage of the final weight.

Table 1
The effect of the mean cow weight on mean energy requirements[A] and excretion rates

mean cow weight	kg cow^{-1}	500	600	700	800	900
NEL intake rate	MJ cow^{-1} d^{-1}	46.6	51.8	**56.9**	61.7	66.4
ME intake rate	MJ cow^{-1} d^{-1}	79.5	88.4	**97.0**	105.3	113.4
DM intake rate	kg cow^{-1} d^{-1}	8.5	9.4	**10.3**	11.2	12.1
CH_4 emission (enteric)	kg cow^{-1} a^{-1}	97.2	105.6	**113.6**	121.4	128.9
MCR	MJ MJ^{-1}	0.097	0.095	**0.093**	0.091	0.090
VS excreted	kg cow^{-1} a^{-1}	937	1,043	**1,144**	1,242	1,337
N excreted	kg cow^{-1} a^{-1}	56.4	62.9	**69.2**	75.2	81.0
TAN excreted	kg cow^{-1} a^{-1}	40.9	45.3	**49.5**	53.4	57.2
TAN/N_{excr}	kg kg^{-1}	0.725	0.720	**0.715**	0.711	0.706

[A] The model presupposes that animals are fed according to requirements.

[2] It is customary to derive TAN excretion rates from total N excretion rates using this ratio. It is listed in the emission reporting guidance documents, e.g. EMEP (2009), as a default value.

Table 2
The effect of the duration of the useful life-span on the mean animal weight (expressed as percentage of the cows' final weight)

life-span	a	3	5	7	9
mean weight	% of final weight	91.6	93.0	93.6	93.9

As shown in Table 3, weight gain requires additional energy (and feed) and retains more N.

Table 3
The effect of the mean weight gain on mean energy requirements and excretion rates

mean weight gain	kg cow^{-1} a^{-1}	0	10	20	30
NEL intake rate	MJ cow^{-1} d^{-1}	**56.9**	56.9	57.0	57.1
ME intake rate	MJ cow^{-1} d^{-1}	**97.0**	97.1	97.4	97.5
DM intake rate	kg cow^{-1} d^{-1}	**10.3**	10.4	10.4	10.4
CH_4 emission (enteric)	kg cow^{-1} a^{-1}	**113.6**	113.7	113.9	114.1
MCR	MJ MJ^{-1}	**0.093**	0.093	0.093	0.093
VS excreted	kg cow^{-1} a^{-1}	**1,144**	1,145	1,148	1,150
N excreted	kg cow^{-1} a^{-1}	**69.2**	69.0	68.4	68.0
TAN excreted	kg cow^{-1} a^{-1}	**49.5**	49.1	47.9	47.1
TAN/N_{excr}	kg kg^{-1}	**0.715**	0.712	0.700	0.693

The energy requirements for the growth of the **conception products** vary with the calves' birth weights (see Appendix II). The amount of nitrogen retained is more than compensated by the additional feed intake (Table 4).

4.4 Variation of milk yield and composition

As data from the literature suggest, wide ranges of milk yields and milk fat and protein contents have to be considered. Table 5 illustrates the importance of the knowledge of reliable milk yields. The synthesis of milk fat is an energy-consuming process. This is reflected in Table 6. Changes in milk protein contents have little effect on the energy requirements but do affect the N balance (Table 7).

In this model, the duration of the lactation period has no effect on energy demands or excretion rates, as the annual total of the milk yield is used.

Table 5
The effect of the annual milk yield on mean energy requirements and excretion rates

milk yield	kg calf^{-1}a^{-1}	1,500	2,000	2,500	3,000	3,500
NEL intake rate	MJ cow^{-1} d^{-1}	53.9	55.4	**56.9**	58.3	59.8
ME intake rate	MJ cow^{-1} d^{-1}	92.0	94.5	**97.0**	99.5	102.0
DM intake rate	kg cow^{-1} d^{-1}	9.8	10.1	**10.3**	10.6	10.9
CH_4 emission (enteric)	kg cow^{-1} a^{-1}	108.9	111.3	**113.6**	116.0	118.3
MCR	MJ MJ^{-1}	0.094	0.093	**0.093**	0.092	0.092
VS excreted	kg cow^{-1} a^{-1}	1,085	1,115	**1,144**	1,174	1,203
N excreted	kg cow^{-1} a^{-1}	65.5	67.3	**69.2**	71.0	72.8
TAN excreted	kg cow^{-1} a^{-1}	46.6	48.0	**49.5**	50.9	52.3
TAN/N_{excr}	kg kg^{-1}	0.712	0.713	**0.715**	0.717	0.719

Table 6
The effect of milk fat content on mean energy requirements and excretion rates

milk fat content	kg kg-1	0.035	0.040	0.045	0.050
NEL intake rate	MJ cow^{-1} d^{-1}	56.8	**56.9**	56.9	56.9
ME intake rate	MJ cow^{-1} d^{-1}	97.0	**97.0**	97.0	97.1
DM intake rate	kg cow^{-1} d^{-1}	10.3	**10.3**	10.3	10.4
CH_4 emission (enteric)	kg cow^{-1} a^{-1}	113.6	**113.6**	113.6	113.7
MCR	MJ MJ^{-1}	0.093	**0.093**	0.093	0.093
VS excreted	kg cow^{-1} a^{-1}	1,144	**1,144**	1,144	1,145
N excreted	kg cow^{-1} a^{-1}	69.1	**69.2**	69.2	69.2
TAN excreted	kg cow^{-1} a^{-1}	49.4	**49.5**	49.5	49.5
TAN/N_{excr}	kg kg^{-1}	0.715	**0.715**	0.715	0.715

Table 4
The effect of the calf birth weight on mean energy requirements and excretion rates

calf birth weight	kg calf^{-1}	20	25	30	35	40	45
NEL intake rate	MJ cow^{-1} d^{-1}	55.0	55.5	55.9	56.4	**56.9**	57.3
ME intake rate	MJ cow^{-1} d^{-1}	93.9	94.7	95.4	96.2	**97.0**	97.8
DM intake rate	kg cow^{-1} d^{-1}	10.0	10.1	10.2	10.3	**10.3**	10.4
CH_4 emission (enteric)	kg cow^{-1} a^{-1}	110.7	111.4	112.2	112.9	**113.6**	114.4
MCR	MJ MJ^{-1}	0.093	0.093	0.093	0.093	**0.093**	0.093
VS excreted	kg cow^{-1} a^{-1}	1,107	1,117	1,126	1,135	**1,144**	1,154
N excreted	kg cow^{-1} a^{-1}	67.4	67.9	68.3	68.7	**69.2**	69.6
TAN excreted	kg cow^{-1} a^{-1}	48.2	48.5	48.8	49.2	**49.5**	49.8
TAN/N_{excr}	kg kg^{-1}	0.715	0.715	0.715	0.715	**0.715**	0.715

Table 7

The effect of milk protein content on mean energy requirements and excretion rates

milk protein content	kg kg^{-1}	0.031	0.034	0.037	0.040
NEL intake rate	MJ cow^{-1} d^{-1}	56.8	**56.9**	56.9	56.9
ME intake rate	MJ cow^{-1} d^{-1}	97.0	**97.0**	97.0	97.0
DM intake rate	kg cow^{-1} d^{-1}	10.3	**10.3**	10.3	10.3
CH_4 emission (enteric)	kg cow^{-1} a^{-1}	113.6	**113.6**	113.6	113.6
MCR	MJ MJ^{-1}	0.093	**0.093**	0.093	0.093
VS excreted	kg cow^{-1} a^{-1}	1,144	**1,144**	1,144	1,144
N excreted	kg cow^{-1} a^{-1}	69.2	**69.2**	69.1	69.1
TAN excreted	kg cow^{-1} a^{-1}	49.5	**49.5**	49.5	49.4
TAN/N_{excr}	kg kg^{-1}	0.715	**0.715**	0.715	0.715

4.5 Variation of energy contents of pasture

Feed quality varies considerably. We have chosen different pasture types that are typical for German suckler cow production. Pastures with NEL contents of about 5.2 MJ kg^{-1} can be found in extensive systems but NEL contents of 6.3 MJ kg^{-1} are considered typical for dairy cows. The mean pasture quality is taken to be 5.5 MJ kg^{-1} (LFZ Raumberg-Gumpenstein, 2011; Bauer and Grabner, 2012). Details of the feed composition assumed are shown in Table 8.

Grass silage and barley are fed when the cows are housed. A constant ratio of 90 to 10 % fresh matter (or about 96 to 4 % of DM, in accordance with the proposal in Weiß et al., 2005) is fed. The winter diet fed has about the same nutritional value as the standard grass feed used in our calculations (pasture grass 3). Hence the amounts fed can be related to the duration of grazing.

The resulting DM and NE intake and excretion rates are collated in Table 9.

Table 9

The effect of feed quality on excretion rates

pasture NEL content	kg cow^{-1} a^{-1}	5.2	5.5	5.8	6.3
NEL intake rate	MJ cow^{-1} d^{-1}	56.9	**56.9**	56.9	56.9
ME intake rate	MJ cow^{-1} d^{-1}	97.5	**97.0**	96.2	92.2
DM intake rate	kg cow^{-1} d^{-1}	10.7	**10.3**	10.0	9.4
CH_4 emission (enteric)	kg cow^{-1} a^{-1}	107.2	**113.6**	98.9	88.3
MCR	MJ MJ^{-1}	0.085	**0.093**	0.084	0.080
VS excreted	kg cow^{-1} a^{-1}	1,306	**1,144**	998	893
N excreted	kg cow^{-1} a^{-1}	66.1	**69.2**	71.9	85.3
TAN excreted	kg cow^{-1} a^{-1}	46.5	**49.5**	52.1	65.2
TAN/N_{excr}	kg kg^{-1}	0.704	**0.715**	0.724	0.765

4.6 Variation of grazing times

In Germany, the duration of the grazing period for suckler cows varies between 190 and 280 d a^{-1} with a mean between 210 and 220 d a^{-1} (Rösemann et al., 2013, data on CD enclosed). The sensitivity analysis makes use of a default value of 210 d a^{-1} and steps of 20 d a^{-1}. The animals are kept outdoors 24 h d^{-1} in any case.

As differences in feed composition between grazing and housing are minor, the changes in excretion rates small (Table 10).

4.7 Summary of findings

It can be seen from the above that cow weight and milk yield have the highest impact on energy intake and excretion rates. Changes in calf birth weights have little influence on excretion rates. Almost no effect can be identified for milk fat and protein contents. Due to the small difference between the energy contents of pasture and silage/barley, the duration of the grazing period has but a small effect on excretion rates.

Hence, as a matter of priority, typical cow weights and milk yields are to be identified for the national emission inventory.

Table 8

Properties of the feed constituents used (DM: dry matter; NEL net energy for lactation; ME: metabolizable energy; CP: crude protein; CF: crude fibre; NFE: nitrogen free extracts; EE: ether extracts - crude fat; Ash: ash content). (Data sources: Beyer et al., 2004; DLG, 2009)

		energy contents [B]			feed constituent contens [B]			
	DM [A] kg kg^{-1}	NEL MJ kg^{-1}	*ME* MJ kg^{-1}	CP kg kg^{-1}	CF kg kg^{-1}	NFE kg kg^{-1}	EE kg kg^{-1}	Ash kg kg^{-1}
pasture grass 1	0.18	6.30	10.00	0.183	0.225	0.425	0.042	0.125
pasture grass 2	0.21	5.80	9.81	0.141	0.272	0.455	0.039	0.093
pasture grass 3	0.25	5.48	9.38	0.118	0.288	0.508	0.026	0.060
pasture grass 4	0.30	5.20	8.97	0.115	0.304	0.473	0.034	0.074
grass silage	0.350	5.24	8.99	0.144	0.272	0.435	0.037	0.112
barley (winter)	0.880	8.08	12.84	0.124	0.057	0.765	0.027	0.027

[A] DM related to fresh matter. [B] All information related to DM.

Table 10

The effect of the duration of the grazing period on mean energy requirements and excretion rates

grazing period	d a^{-1}	170	190	210	230	250	270
NEL intake rate	MJ cow^{-1} d^{-1}	56.3	56.6	**56.9**	57.1	57.4	57.7
ME intake rate	MJ cow^{-1} d^{-1}	95.9	96.5	**97.0**	97.6	98.1	98.7
DM intake rate	kg cow^{-1} d^{-1}	10.2	10.3	**10.3**	10.4	10.5	10.5
CH_4 emission (enteric)	kg cow^{-1} a^{-1}	110.9	112.2	**113.6**	115.0	116.4	117.9
MCR	MJ MJ^{-1}	0.092	0.092	**0.093**	0.093	0.094	0.094
VS excreted	kg cow^{-1} a^{-1}	1,125	1,134	**1,144**	1,154	1,164	1,174
N excreted	kg cow^{-1} a^{-1}	68.4	68.8	**69.2**	69.5	69.9	70.3
TAN excreted	kg cow^{-1} a^{-1}	49.1	49.3	**49.5**	49.6	49.7	49.9
TAN/N_{excr}	kg kg^{-1}	0.718	0.717	**0.715**	0.713	0.711	0.710

Note: The NEL requirements during the cows' dry period are here taken as constant irrespective of the cows' weight. GfE (2001) state that this is related to a live weight of 650 kg cow^{-1}. Bauer and Grabner (2012) apply it to all suckler cows. However, the NEL requirements during the dry period are small compared to the overall annual NEL requirements. This shortcoming will not affect the results.

5 Derivation of input parameters describing the mean German suckler cow

In contrast to dairy cows, where only a few genotypes contribute to the overall milk production, the suckler cow population consists of a high number of genotypes which differ considerably in their properties such as weight and milk yield. For most input parameters used in the model, no official data are available.

An attempt is made to derive a complete and representative set of input parameters to describe the "mean German suckler cow". These are listed at the end of each respective chapter.

5.1 Herd composition

About 40 genotypes are considered in German beef cattle herdbooks[3], 10 of them covering 90 % of the whole population[4]. For these, the Federation of German Cattle Breeders (Arbeitsgemeinschaft Deutscher Rinderzüchter, ADR) provides the number of herdbook cows of beef genotypes ("Herdbuchtiere nach Rassen: Fleischrassen"). Data for the composition of the whole German suckler cow population are available from 2008 onwards (Table 11). It shows that the majority of this population consists of crossbred animals: Many of today's suckler cows are derived from dairy cattle. In northern Germany in particular, they often are the result of (repeated) cross-breeding of Beef-Simmental bulls on black and white dairy cows (Holstein German). In southern Germany, Simmental cows were partly crossed with French beef breeds. Today, most crossbreds show properties of modern Beef-Simmentals. This is partly due to the availability of low-cost Simmental bulls in Germany.

It should be kept in mind that regional herd compositions may deviate considerably from the national mean, see e.g. Roffeis et al. (2006) for Brandenburg.

Table 11

German suckler cows' herd composition (data from ADR, 2009 to 2012)

year	2008 heads	2009 heads	2010 heads	2011 heads	mean share of breed X_{heads}
crossbreds	216,599	224,524	228,402	224,703	0.45
Angus, German	36,292	36,134	35,693	34,567	0.07
Blonde d'Aquitaine	----- [A]	-----	-----	-----	
Charolais	58,655	57,423	55,567	52,511	0.11
Galloway	18,693	17,889	17,675	16,945	0.04
Hereford	-----	-----	-----	-----	
Highland	14,326	14,518	14,826	14,490	0.03
Limousin	62,893	63,290	63,136	61,924	0.13
Simmental	43,839	45,128	45,619	45,765	0.09
Uckermärker	-----	-----	-----	-----	
other	40,270	39,682	39,334	38,914	0.08

[A] no information available

5.2 Typical cow live weights

Table 12 collates cow weights in the early 1990s and in 2010; it is assumed that the latter represent the present situation. Mean weights are calculated as the arithmetic means of the respective lower and upper values. An overall increase can be observed for most genotypes, although this change is

3 For the information provided in (regional) German herdbooks see e.g. RSA (2003) or FVB (2010).

4 For a comprehensive description of the genotypes bred in Germany see Hampel (1995).

doubted by some experts. One potential explanation for increased body weights is that breeding for higher weight gain of the offspring will also result in also higher body mass of their mothers. Improved feeding may be another explanation. In addition, genetic gains have been achieved in the feed conversion rate.

It is obvious that mean weights have increased for some breeds. However, their use as input parameters is coupled to the knowledge of the herd composition, which remains unknown before 2008. Hence the following derivation of the mean German suckler cow is confined to the period after 2008. 2010 is chosen as a reference year.

The weighted mean weight of the national suckler herd (w_m) in 2010 as calculated from the respective share of heads $x_{n,g}$ of a genotype (Table 11) and the mean weight of the genotype w_g (where crossbreds are treated as Simmentals) according to

$$w_m = \sum_g x_{n,g} \cdot w_g \tag{2}$$

and

$$\sum x_{n,g} = 1 \tag{3}$$

amounts to 736 kg cow^{-1}.

It remains unclear whether the dataset in Table 12 refers to mean live weights or slaughter weights. As can be deduced from Table 2, the difference may be reasonable.

Statistics give the live weight at the slaughter house or the carcass weight, from which final live weights can be derived. However, these weights cannot be used directly to derive the mean weights needed for the calculation of ME or NEL requirements for maintenance, as the animals grow considerably during their life-span as suckler cows. Furthermore, their weight oscillates with the reproduction cycles.

Recommendations regarding the productive life-span of suckler cows vary considerably. KTBL (2010) assumed four lactations as base for their economic data set. Weiß et al. (2005) assumed 6 lactations. 7.7 lactations are reported for organic farming in Böttcher (2010). Brändle and Krieg (2008) as well as Bauer et al. (2007) mention 6 to 7 lactations. By definition, suckler cows are called suckler cows after having given birth for the first time. Hence, if one assumes a mean of 6 births per cow, the lifetime of the mean suckler cow comprises 6 lactation periods and 5 births. With a mean life-span as suckler cows of 5 years, the mean annual weight gain is almost 3 % of the final weight.

A detailed procedure to derive suckler cow mean weights from a known weight is described in Appendix I.

A final live weight of 750 kg cow^{-1} is assumed for the mean German suckler cow.

5.3 Typical calf birth weights

Calf birth weights vary with genotype, as Table 13 illustrates. As a rule, heavier cows give birth to heavier calves. It should be noted that the German genotypes may differ considerably from foreign breeds carrying the same names (which may be different genotypes). Consequently, the abundant information provided in the foreign literature was not used for comparisons; we constricted ourselves to data from German genotypes.

A weighted mean calf weight for 2010 was obtained from this data using the same procedure as for suckler cows (Equations (2) and (3)). Then, the mean calf weight relevant to calculate the energy requirements of suckler cows is 35.9 kg calf^{-1}.

A mean calf birth weight of 36 kg calf^{-1} is assumed for the derivation of intake and excretion rates of the mean German suckler cow.

Table 12
Typical lower, upper and average cow weight margins of genotypes in 1990 and 2010.
Sources: Bach (1990) for about 1990 and in Waßmuth et al. (2006) and Fischer et al. (2011)

	typical suckler cow (in kg cow^{-1})					
	lower margin		upper margin		mean[A]	
	1990	2010	1990	2010	1990	2010
Angus, German	550	550	700	700	625	625
Blonde d'Aquitaine	750	850	1,000	950	875	900
Charolais	750	800	900	1,000	825	900
Galloway	450	550	550	550	500	550
Hereford		600		700		650
Highland	400	450	450	550	425	500
Limousin	650	650	750	750	700	700
Simmental	650	700	750	800	700	750
Uckermärker		850		800		850

[A] arithmetic mean of range

Table 13

Typical male and female calf birth weights of genotypes provided in Bach (1990) and ADR (1993) (Table 81) and ADR (2011, Table 5.2, Fleischleistungsprüfung) for about 1990 and 2010, respectively, as well as mean weights (arithmetic mean of the respective male and female calves)

	typical calf birth weights (in kg calf^{-1})					
	male		female		mean	
	1990	2010	1990	2010	1990	2010
Angus, German	550	550	700	700	625	625
Blonde d'Aquitaine	750	850	1,000	950	875	900
Charolais	750	800	900	1,000	825	900
Galloway	450	550	550	550	500	550
Hereford		600		700		650
Highland	400	450	450	550	425	500
Limousin	650	650	750	750	700	700
Simmental	650	700	750	800	700	750
Uckermärker	----- [A]	-----	-----	-----	-----	-----

[A] no information available

A time series of mean calf weights cannot be calculated as the actual herd composition is unknown for most of the time from 1992 onwards. Deriving the composition of the national herd from numbers of herdbook cows would be misleading, as the herdbooks overrepresent the rarer breeds.

5.4 Nitrogen contents of suckler cows and calves

Due to lack of data on the N content of suckler cows and calves, the respective N contents of dairy cows and their calves are used. According to DLG (2005), these amount to 0.0256 kg kg^{-1} N for cows and 0.0296 kg kg^{-1} N for calves.

5.5 Milk yield, milk composition and duration of lactation

Suckler cows give birth to one calf per year. Their milk production is governed by the milk required by their calves. As can be seen from Table 14, these amounts vary to an extent that makes the formation of a mean milk yield impossible. Again, foreign animals of the genotypes bearing identical names may differ with respect to their milk yield as well as to the percentages of milk fat and milk protein.

German recommendations also differ with respect to **mean milk yields**. Bach (1990) mentions 8 months of suckling with an average milk yield of 10 kg cow^{-1} d^{-1}, which sums to about 2,450 kg cow^{-1}. Weiß et al. (2005) assume a milk yield of about 2,500 kg cow^{-1} in 6 to 8 months of lactation. Hampel (1995) substantiates his energy requirement estimates with milk yields between 1,800 and 2,500 kg cow^{-1}. Irrespective of genotype and animal weight, DLG (2009) start from the assumption of about 3,000 kg cow^{-1} for a lactation period of 210 d a^{-1} [5]. However, Steinwidder and Häusler (2004) show (experimental) milk yields between 5 and 10 kg cow^{-1} d^{-1} for various genotypes including crossbreds, which results in a milk yield of about 1,500 kg cow^{-1} a^{-1}.

It has to be kept in mind that milk yields increase with the age of the suckler cow. Petit and Liénard (1988) refer to unpublished results of Ménissier (1987) where the milk yields of the lactations of the second and subsequent calvings exceed those of the first calving by 30 to 50 %. However, the cumulative milk yield for 210 d of lactation never exceeded 1,300 kg cow^{-1} a^{-1}.

With respect to suckler cows' milk yields, literature data and German recommendations disagree to an extent that requires special consideration (see Appendix III).

The information available on milk fat and protein contents is even more sparse. Hence the calculations make use of the respective mean properties of cows' milk, i.e. 41 g kg^{-1} fat and 34 g kg^{-1} protein (see Tables 4.10 and 4.11 in Rösemann et al., 2013), as also suggested in Steinwidder and Häusler (2004).

Weaning occurs between 6 and 10 months of age. A determining factor is the beginning sexual maturity of the calves (males at about 250 kg calf^{-1}, females at about 280 kg calf^{-1}, Steinwidder and Häusler, 2004), i.e. after about 7 months.

Conservative assumptions of a lactation period of 210 d, a milk yield of 1,500 kg cow^{-1} and milk fat and protein contents of 41 and 34 g kg^{-1}, respectively are made here.

5.6 Diet composition and feed properties

It is typical for the suckler cow production line to feed roughage as grass, grass silage or hay only, sometimes combined with small amounts of straw. Energy contents fall below those of the feed used for dairy cows (Bach, 1990; Steinwidder and Häusler, 2004; Häusler et al., 2011; Bauer and Grabner, 2012). Average *NEL* contents are approximately 5.5 MJ kg^{-1} (annual mean). Some barley may be added in winter when the silage quality is insufficient.

5 DLG (2009) extends their table to 12 months. As weaning is proposed to happen after 7 months, the following period is not taken into consideration.

Table 14
Milk yields and milk fat and protein contents – results of a literature survey.

genotype	cow weight kg cow $^{-1}$	milk yield kg cow $^{-1}$ a $^{-1}$	milk fat content g kg $^{-1}$	milk protein content g kg $^{-1}$	source
Angus, German		2,500 - 3,000			Fleischrinderzüchter (undated)
Angus, red	470	1,745			Freetly and Cundiff (1998)
Angus, red		1,164			Scholz et al. (2001)
Angus		1,454			Marston et al. (1992)
Angus			45	33	Sinclear et al. (1998)
Blonde d'Aquitaine	-----	-----	-----	-----	
Charolais		1,350			Petit and Liénard (1988) [A]
Charolais	628	1,520			Petit and Liénard (1988)
Charolais	640	1,630			Petit and Liénard (1988)
Charolais	607	1,250			Petit and Liénard (1988)
Charolais			49	37	Sinclear et al. (1998)
Charolais	about 700	1,656			Murphy et al. (2008)
Charolais		1,596			McGee et al. (2005)
Charolais		1,318			McGee et al. (2005)
Galloway	-----	-----	-----	-----	
Hereford		950			Petit and Liénard (1988)
Hereford	480	1,060			Freetly and Cundiff (1998)
Hereford	594	768	2.59	36.0	McMorris and Wilton (1986)
Hereford		about 1,550			Kress et al. (1996)
Highland	-----	-----	-----	-----	
Limousin		1,130			Petit and Liénard (1988)
Limousin	515	1,160			Petit and Liénard (1988)
Limousin	556	1,210			Petit and Liénard (1988)
Limousin	595	1,250			Petit and Liénard (1988)
Limousin	469	1,080			Petit and Liénard (1988)
Limousin		1,891	43.0	36.5	Scholz et al. (2001)
Limousin	about 600	1,320			Murphy et al. (2008)
Simmental		3,750	40.9	34.9	Scholz et al. (2001)
Simmental	700	1,364	30.9	36.9	McMorris and Wilton (1986)
Simmental		1,724			Marston et al. (1992)
Simmental	543 - 685	3,351	32.0	30.0	Häusler et al. (2011)
Simmental		3,329			Steinwidder et al. (undated)
Uckermärker	-----	-----	-----	-----	

[A] Milk yields in Petit and Liénard are listed in kg cow $^{-1}$ d $^{-1}$ for a lactation period of 6 to 7 months. Here, they were multiplied with 220 d of lactation.

Hence we use pasture grass 3 (5.5 MJ kg $^{-1}$ NEL) and the silage / barley mixture (9 to 1) as described in Table 8.

5.7 Housing and grazing

Statistisches Bundesamt supplied data describing the overall distribution of the grazing management. 24 % of all animals are kept outdoors all year round; 76 % are kept on pasture part of the day, 23.6 h d $^{-1}$ over a grazing period of 227.5 d a $^{-1}$. **This data is used in the suckler cow model.**

6 Resulting energy requirements, feed intake and excretion rates – discussion and conclusions

If the data set described above is input into the suckler cow model, one obtains the results shown in Table 15. This table also allows for a comparison with the data set used in the German agricultural emission inventory (Rösemann et al., 2013, data on CD enclosed).

Table 15
Energy requirements, dry matter intake and excretion rates of the mean German suckler cow

	unit	mean German suckler cow (this work)	German inventory 2010 (Rösemann et al., 2013)
mean weight	kg cow $^{-1}$	750	650
NEL intake rate	MJ cow $^{-1}$ d $^{-1}$	50.7	
ME intake rate	MJ cow $^{-1}$ d $^{-1}$	86.2	98.6
DM intake rate	kg cow $^{-1}$ d $^{-1}$	9.2	9.8
CH_4 emission (enteric)	kg cow $^{-1}$ a $^{-1}$	88.2	76.2
MCR	MJ MJ $^{-1}$	0.089	0.065
VS excreted	kg cow $^{-1}$ a $^{-1}$	987	881
N excreted	kg cow $^{-1}$ a $^{-1}$	57.6	82
TAN excreted	kg cow $^{-1}$ a $^{-1}$	36.9	
TAN/Nexcr	kg kg $^{-1}$	0.641	0.60

The data used in the German emission inventory stem from various standard textbooks, table books and guidance documents for emission inventories. The assumptions with regard to *ME* and DM intake rates as well as the N excretion rates exceed those found in the work at hand; whereas the VS fall below those established in this work.

In the inventory, the CH_4 emission rates from enteric fermentation are calculated using the MCR provided in the IPCC (2006) Guidebook. It can be shown that this MCR underestimates emission rates for low milk yields under German conditions (Dämmgen et al., 2012). The feed quality assumed for suckler cows in the work at hand reflects the fact that suckler cows are mainly kept on marginally profitable grasslands, which produce herbage with low energy and high fibre contents. This also explains the low N excretion rate found in this work. Many pastures do not receive N in the form of fertilizer or manure, so rely on the recycling of the N excreted and the N fixation of legumes to support production. The ratio of TAN to N excreted as used in the present inventory is the default value provided in EMEP (2009). Its application would result in a TAN excretion rate of 49 kg cow $^{-1}$ a $^{-1}$. However, the suckler cow model calculates this ratio from feed properties, which results in a lower TAN excretion rate than in the present German inventory.

The estimates of energy intake obtained in this work are compared with a range of recommendations published in Germany in Table 16. This comparison suffers from an inadequate description of the parameters governing the energy input in the published recommendations. In particular, it is likely that the published recommendations incorporate a safety margin, to ensure that the energy requirements are always fulfilled, despite inter-animal variations in the herd. The high milk yields assumed explain why the energy requirements given in the literature exceed those determined in the work at hand. The values from KTBL (2006, 2010) are closest to the findings in this work but no performance data are included in this publication.

The discussion of the uncertainties of the results obtained for the mean German suckler cow reflects the uncertainties of the suckler cow excretion model and the data.

The dairy cow model from which the suckler cow model was derived passed international review processes within the IPCC and EMEP review processes successfully. Comparisons with measured data are still sparse. However, the CH_4 module derived from Kirchgeßner et al. (1995) illustrates the natural scatter of results from which we estimate an uncertainty of about 10 % (valid input parameters provided).

It remains difficult to address the uncertainties of the output parameters produced in the work at hand, as no uncertainties are available for the input parameters. Only the animal numbers provided by Statistisches Bundesamt can be claimed correct.

If the cow weights are taken to have a range as shown in Table 12, an uncertainty of about 20 % may be deduced for single genotypes. If one assumes an error of 50 kg cow $^{-1}$ for the "mean cow" (i.e. about 7 % of a 750 kg cow) in the estimate of the mean weight, an error of about 4 % results for the excretion rates. Furthermore, it is unclear which type of animal weight is listed (mean weight, weight before slaughtering). The information provided in Table 2 suggests another uncertainty of about 5 %.

As shown in Table 3, weight gains are unlikely to have a significant effect on uncertainties.

Calf weights are recorded from measurements and can be considered accurate, as are the reported weight gains. The derivation of energy requirements for calves, however, relies on data and methods for which uncertainties are unknown. However, Table 4 indicates that errors in the assumption of mean calf birth weights (which will be in the order of a few kg

Table 16
Comparison of modelled energy requirements with published German recommendations (rounded data)

Source	milk yield kg cow $^{-1}$ a $^{-1}$	animal weight kg cow $^{-1}$	energy intake unit	source	this work
Bach (1990)	2,500	650	NEL (GJ cow $^{-1}$ a $^{-1}$)	28	18.5
Weiß et al. (2005)	2,500	650	NEL (MJ cow $^{-1}$ d $^{-1}$)	69	50.7
KTBL (2006)	---	---	GE (GJ cow $^{-1}$ a $^{-1}$)	54	60.0
DLG (2009)	4,000	600 - 750	NEL (MJ cow $^{-1}$ d $^{-1}$)	76	50.7
KTBL (2010)	---	---	*ME* (GJ cow $^{-1}$ a $^{-1}$)	36	31.4

calf $^{-1}$) will not lead to significant errors in the excretion rates of the suckler cows.

The suckler cow model makes use of assumptions on feed quality. As Table 9 shows, a change of the NEL content by 0.1 MJ kg^{-1} (about 2 %) may result in changes of about 5 % for the excretions.

With so many inadequacies in the input parameters, we are unable to rigorously calculate the overall uncertainty of the excretion rates of the mean German suckler cow. We estimate that – given a well characterized set of input data – the model is able to produce plausible results with an uncertainty of less than 20 %.

7 Representativeness of the "mean German suckler cow"

In principle, the suckler cow model can be used to describe single farm situations as long as the set of input parameters can be established satisfactorily. The use of mean values as established above restricts the meaningfulness of resulting excretion and emission rates to the nation as a whole. A higher resolution in space, e.g. the application of the model to single administrative districts, is not allowed.

Appendix I

Determination of mean weights and weight gains of suckler cows

Mean cow weights

Suckler cows are first bulled when they reach about 65 % of the mature cow weights (Bach, 1990; Waßmuth et al., 2006; EBLEX, 2008; Bauer and Grabner, 2012). At their first calving, they have reached about 86 % of their final (mature) cow weights and about 96 % after the birth of their second calves. After the third calf no substantial further weight gain is observed. Cows lose about 10 % of their weight at calving in the form of the calf and afterbirth. This weight is regained in the period by the next calving.

These experimental findings are depicted in the model. Figure A1 illustrates the development of a cow's live weight as considered in this work.

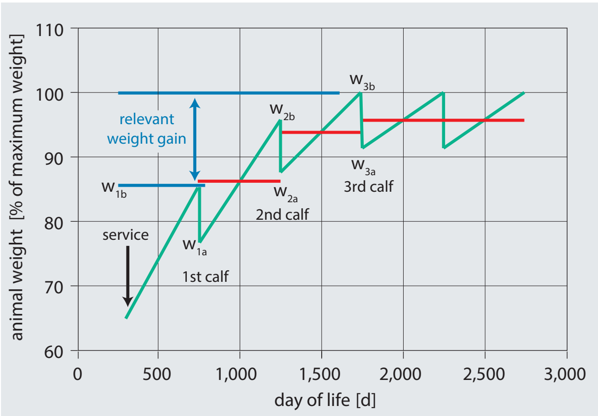

Figure A1
Example live weight development of a suckler cow (green line) (modified after EBLEX, 2008, and related to the German situation using Brade's expert judgement), the annual mean weights (red lines) and the relevant weight gain (blue).

The relevant weight is the mean weight of the animal w_{mean}.

$$w_{\text{mean}} = \left(\frac{w_{1\text{a}} + w_{2\text{b}}}{2} \cdot 1 + \frac{w_{2\text{a}} + w_{3\text{b}}}{2} \cdot 1 + \frac{w_{3\text{a}} + w_{\text{fin}}}{2} \cdot \left(n_{\text{life-span}} - 2 \right) \right) \cdot \frac{1}{n_{\text{life-span}}} \quad \text{(A1)}$$

with

$$w_{1\text{a}} = a \cdot w_{1\text{b}} \quad \text{(A2)}$$
$$w_{1\text{b}} = b \cdot w_{\text{fin}} \quad \text{(A3)}$$
$$w_{2\text{a}} = a \cdot w_{2\text{b}} \quad \text{(A4)}$$
$$w_{2\text{b}} = c \cdot w_{\text{fin}} \quad \text{(A5)}$$
$$w_{3\text{a}} = a \cdot w_{3\text{b}} \quad \text{(A6)}$$
$$w_{3\text{b}} = w_{\text{fin}} \quad \text{(A7)}$$

resulting in

$$w_{\text{mean}} = \left(\frac{a \cdot b \cdot w_{\text{fin}} + c \cdot w_{\text{fin}}}{2} \cdot 1 + \frac{a \cdot c \cdot w_{\text{fin}} + w_{\text{fin}}}{2} \cdot 1 + \frac{a \cdot w_{\text{fin}} + w_{\text{fin}}}{2} \cdot \left(n_{\text{life-span}} - 2 \right) \right) \cdot \frac{1}{n_{\text{life-span}}} \tag{A8}$$

or

$$w_{\text{mean}} = \left(a \cdot b + c + a \cdot c + 1 + [a+1] \cdot \left(n_{\text{life-span}} - 2 \right) \right) \cdot \frac{w_{\text{fin}}}{2\, n_{\text{life-span}}} \tag{A8a}$$

where

w_{mean} relevant mean weight (in kg cow^{-1})
w_{1a} weight immediately after the first calving (in kg cow^{-1})
w_{2b} weight immediately before the second calving (in kg cow^{-1})
w_{2a} weight immediately after the second calving (in kg cow^{-1})
w_{3b} weight immediately before the third calving (in kg cow^{-1})
w_{3a} weight immediately after the third calving (in kg cow^{-1})
w_{fin} final weight at the end of the cow's life (in kg animal^{-1})
$n_{\text{life-span}}$ life-span from first calving to slaughtering (in a)

and

w_{1b} weight immediately before the first calving (in kg cow^{-1})
a constant (a = 0.90 kg kg^{-1}) (see text above)
b constant (b = 0.86 kg kg^{-1})
c constant (c = 0.96 kg kg^{-1})

Mean cow weight gains

The animal subcategory 'suckler cows' comprises females after their first calving. Overall weight gains have to consider comparable weights reflecting the periodic changes due to pregnancy and calving. It is assumed that cows reach their mature weight after the third calving, and that the weight gained after the first calving is about 10 % of the mature weight, that after the second calving is 4 % [6].

As illustrated in Figure A1, the relevant annual weight gain is

$$\Delta w_{\text{mean}} = \left(w_{\text{fin}} - w_{1b} \right) \cdot \beta \cdot \frac{1}{n_{\text{life-span}} \cdot \alpha} = (1-b) \cdot \beta \cdot \frac{w_{\text{fin}}}{n_{\text{life-span}} \cdot \alpha} \tag{A9}$$

where

Δw_{mean} relevant mean weight gain (in g animal^{-1} d^{-1})
w_{fin} mature weight (at the end of the cow's life) (in kg cow^{-1})
w_{1b} start weight immediately before the first calving (in kg cow^{-1})
β mass units conversion factor (β = 1,000 g kg^{-1})
$n_{\text{life-span}}$ life-span from first calving to slaughtering (in a)
α time units conversion factor (α = 365 d a^{-1})
b constant (b = 0.86 kg kg^{-1})

6 This corresponds to Waßmuth et al. (2006) who recommend a weight of about 60 % of the final weight, or about 400 kg cow^{-1} in Bauer et al. (1997).

Appendix II

Derivation of the energy requirements for pregnancy

The energy required to develop conception products are a function of the size of the conception products. For beef cows, the ME requirements for pregnancy (in addition to their maintenance requirements) was expressed as a function of the calf's birth weight by Nicol and Brookes (2007) (Table A1).

Table A1
ME requirements for the development of the conception products according to Nicol and Brookes (2007)

calf birth weight	weeks before calving 12	8	4	0	total
kg calf $^{-1}$		MJ cow $^{-1}$ d $^{-1}$			MJ cow $^{-1}$
30	6	11	20	34	1,700
40	9	15	26	45	2,300
50	11	18	32	55	2,800

GfE (2001) recommend additional ME requirements as shown in Table A2 without mentioning the calf's birth weight.

Table A2
ME requirements for the development of the conception products according to GfE (2001)

weeks before calving 6 to 4		3 to 0		total	
ME	NEL	ME	NEL	ME	NEL
21	13	30	18	1,071	651

The comparison of the data provided in Tables A1 and A2 in Figure A2 suggests that the German calf birth weights should be about 35 to 38 kg calf $^{-1}$, which corresponds with the data used in the German agricultural inventory (36 kg calf $^{-1}$) (Rösemann et al., 2013).

The data set published in GfE (2001) reflects the state of knowledge prior to 1976; it gives just two data points and ignores any requirements in the early stage of the development of the conception products. We therefore prefer to use the more detailed description given in Nicol and Brookes (2007), as there is no principal difference between the metabolisms of beef, dairy and suckler cows.

As shown in Table A1, Nicol and Brookes (2007) also give cumulative additional requirements. Here, the relation between requirements and calf birth weight is linear (Figure A3).

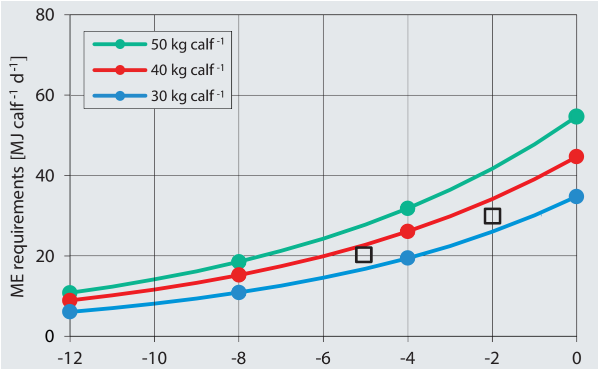

Figure A2
ME requirements for the development of the conception products according to Nicol and Brookes (2007) (lines and markers) and GfE (2001) (squares)

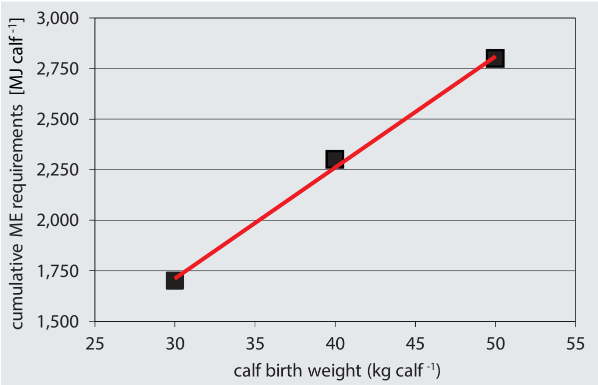

Figure A3
Relation between cumulative ME requirements for the development of the conception products according to Nicol and Brookes (2007) and linear regression

Nicol and Brookes (2007) use ME to characterize the energy requirements. The GfE (2001) data facilitate the conversion of ME requirements to NEL: The fractions deduced from Table A2 for the two time spans are 0.62 and 0.60 MJ MJ $^{-1}$, respectively; the fraction for the entire 6 weeks is 0.61 MJ MJ $^{-1}$. Using this as energy units conversion factor χ, cumulative NEL requirements for the development of the conception products can be calculated in ME units from the regression in Figure A3 as

$$nel_p = \chi \cdot (d \cdot w_{calf} + e) \quad \text{(A10)}$$

where

nel_p cumulative NEL required for the development of the conception products (in MJ animal $^{-1}$ NEL)
χ mean energy units conversion factor (χ = 0.61 MJ MJ $^{-1}$, see text)
d coefficient (d = 55 MJ kg $^{-1}$ ME; slope in Figure A3)
w_{calf} birth weight of calf (in kg calf $^{-1}$)
e constant (e = 66.67 MJ calf $^{-1}$; offset in Figure A3)

Appendix III

Derivation of milk yields from calves' energy requirements

The estimate of milk yields is obviously of key importance for the quantification of emissions from suckler cows. In principle, milk yields can be derived from calves' energy intake rates if the contribution of suckling is known.

Energy requirements

Energy requirements are calculated separately for calves (weight at day 125, w_{125}, of a 125 kg calf^{-1}) and young beef cattle until weaning after seven months (w210).

According to Dämmgen et al. (2013), the ME requirements of calves from birth to a live weight of 125 kg animal^{-1} gained in 18 weeks or 125 days sum to about 3,200 MJ calf^{-1}

The recommendations provided by GfE (2001, Table 1.5.3) and shown in Table A3 are used to describe energy requirements of young beef cattle.

Table A3

ME intake rates of young beef cattle related to animal weights w_{ybc} and weight gains Δw_{ybc} (GfE, 2001)

live weight w_{ybc} kg animal^{-1}	weight gain Δw_{ybc} g animal^{-1} d^{-1}			
	600	700	800	900
150	32.3	34.1	36.0	
200	39.6	42.0	44.3	46.6
250	46.7	49.6	52.6	55.8
300	53.6	57.6	60.8	64.6

Table A3 is converted to a steady function relating ME requirements to animal weights and weight gains of young beef cattle for weights above 100 kg animal^{-1}.

$$ME_{ybc} = \left(f \cdot w_{ybc} + g\right) \cdot \Delta w_{ybc} + \left(h \cdot w_{ybc} + i\right) \quad \text{(A11)}$$

where

ME_{ybc} metabolizable energy required for the life-span of young beef cattle (in MJ animal^{-1} d^{-1})
f coefficient (a = 0.0001202 MJ g kg^{-1})
w_{ybc} live weight (in kg animal^{-1})
g constant (b = 0.000030 MJ g^{-1})
Δw_{ybc} daily weight gain (in g animal^{-1} d^{-1})
h coefficient (h = 0.070502 MJ kg^{-1})
i constant (d = 10.957800 MJ animal^{-1} d^{-1})

The results obtained from the application of this equation match the contents of Table A3 perfectly. Hence, this equation is used to calculate ME requirements for animal weights above 125 kg animal^{-1}.

As the relation of ME requirements with weights and weight gains is linear in both cases, the (slight) extrapolation to higher weight gains seems adequate and was also used in GfE (2001).

Relevant animal weights and weight gains

ADR (1993, and subsequent years) list mature weights and overall weight gains Δw_{total}, for the offspring from herdbook cows that passed performance tests for all years, They also report he weights at day 200, w200, since the year 2000 onwards. The arithmetic means of the weight gains for male and female animals are shown in Table A4.

Table A4 contains gaps for weights at day 200, w_{200}, for Galloway and Highland cattle, for 2000 and 2010. These had to be filled to construct a weighted mean for the overall herd. Missing values were derived by using a mean ratio $x_{\Delta w,\,g}$ between the overall weight gain, $w_{total,\,g}$, and the weight gain at day 200, $w_{200,\,g}$, for each genotype. The arithmetic mean of the values listed in Table A4 for 2000 and 2010, $x_{\Delta w}$*, were used; values for Charolais and 2010 were omitted as dubious.

Table A4

Ratios $x_{\Delta w}$ of weight gains for genotypes g at day 200, Δw_{200}, and overall weight gains, Δw_{total}

	2000			2010			mean
	Δw_{total}	Δw_{200}	$x_{\Delta w,\,g}$	Δw_{total}	Δw_{200}	$x_{\Delta w,\,g}$	$x_{\Delta w,\,g}$*
Angus, German	1,227	988	0.81	1,264	1,010	0.80	0.80
Blonde d'Aquitaine		1,139		1,345	1,255	0.93	0.93
Charolais	1,403	1,154	0.82	1,418	1,422	1.00	0.91
Galloway	777			776			
Hereford	1,236	904	0.73	1,294	1,059	0.82	0.77
Highland	686			578			
Limousin	1,238	1,016	0.82	1,281	1,107	0.86	0.84
Simmental	1,349	1,114	0.83	1,471	1,197	0.81	0.82
Uckermärker				1,485	1,151	0.77	0.77

The resulting weight gains w_{200} for Galloway and Highland cattle are 639 and 520 g animal^{-1} d^{-1}, respectively.

A weighted mean reflecting the herd composition (numbers of herdbook cows in 2010 of the respective genotype as provided in Table 11 were used) can be obtained from this data.

$$X_{\Delta w} = \sum_{g} x_{\Delta w, g} \cdot x_{n, g} \tag{A12}$$

and

$$\sum x_{n, g} = 1 \tag{A13}$$

Calculations yield a mean $X_{\Delta w}$ of 0.82 which happens to be the value obtained for Simmentals.

The relevant mean weights describing the animals between days 125 and 210 were derived from the weight at day 125 (125 kg animal^{-1}) and the weight gained in 85 days as young beef cattle with a weight gain Δw_{200}, the so-called weanlings:

$$w_{wean} = \frac{1}{2} \cdot \left(w_{125} + \left(w_{birth} + (t_{wean} - t_{calf}) \cdot \Delta w_{200} \cdot \beta\right)\right) \tag{A14}$$

where

w_{wean}	relevant mean weight of the weanling for ME requirement calculations (in kg animal^{-1})
w_{125}	final weight of calves (w_{125} = 125 kg animal^{-1})
w_{birth}	birth weight of calves (in kg calf^{-1})
t_{wean}	time of weaning (in d)
t_{calf}	final day of calves' life-span (in d)
Δw_{200}	daily weight gain until day 200 (in g animal^{-1} d^{-1})
β	mass units conversion factor (β = 0.001 kg g^{-1})

Examples of relevant weights and weight gains are listed in Table A5. Again, weighted means for the year 2010 are calculated to be used for the ME assessment using Equation (A11).

Relevant energy requirements of weanlings

The energy requirements of weanlings at day 210 are the total of the respective requirements of calves and young beef cattle:

$$ME_{wean}{}^* = ME_{calf}{}^* + ME_{ybc}{}^* \tag{A15}$$

where

$ME_{wean}{}^*$	ME required for the life-span from birth to weaning (in MJ animal^{-1} ME)
$ME_{calf}{}^*$	ME required for the life-span from birth to day 125 (ME_{calf} = 2,875 MJ animal^{-1} ME)
$ME_{ybc}{}^*$	ME required for the life-span from day 125 to weaning (in MJ animal^{-1} ME)

$ME_{calf}{}^*$ is constant and determined according to Dämmgen et al. (2013). $ME_{ybc}{}^*$ is calculated for the various genotypes using ME_{ybs} generated according to Equation (A11):

$$ME_{ybc}{}^* = ME_{ybc} \cdot \left(t_{wean} - t_{calf}\right) \tag{A16}$$

where

$ME_{ybc}{}^*$	ME required for the life-span from day 125 to weaning (in MJ animal^{-1} ME)
ME_{ybc}	ME required for the life-span of young beef cattle (in MJ animal^{-1} d^{-1})
t_{wean}	time of weaning (in d)
t_{calf}	final day of calves' life-span (in d)

Table A5
Resulting relevant weanling weights w_{wean} and weight gains Δw_{200} for the calculaton of ME

	1992		2000		2010	
	w_{wean}	Δw_{200}	w_{wean}	Δw_{200}	w_{wean}	Δw_{200}
	kg animal^{-1}	g animal^{-1} d^{-1}	kg animal^{-1}	g animal^{-1} d^{-1}	kg animal^{-1}	g animal^{-1} d^{-1}
Angus, German	176	929	183	988	186	1,010
Blonde d'Aquitaine				1,139	215	1,255
Charolais	198	1,088	206	1,154	233	1,422
Galloway	140	628	135	639	144	638
Hereford	175	903	174	904	191	1,059
Highland	134	578	144	564	124	476
Limousin	176	920	187	1,016	198	1,107
Simmental	191	1,043	200	1,114	208	1,197
Uckermärker					203	1,151

Share of milk in calves' diets

Bauer and Grabner (2012) give an estimate of the share in calves' nutrition of ME that is covered by milk. Their information was complemented by the data given in Dämmgen et al. (2013) to provide an example estimate over the whole lactation period.

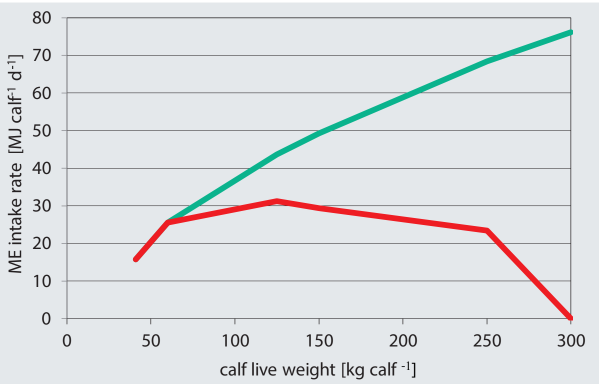

Figure A4

ME intake rate per calf. green: overall ME intake rate; red: ME intake rate as milk

In order to get an overall share the area below the green and red polygons in Figure A4 were calculated. Their ratio, i.e. the fraction of ME intake with milk and the total ME intake is 0.47 MJ MJ $^{-1}$. This value is used for the derivation of milk yields for all genotypes and all years.

The milk required for the feeding of calves is then calculated as

$$Y_{\text{milk}} = \frac{ME_{\text{ybc}}{}^{*} \cdot x_{\text{ME}}}{\eta_{\text{ME, milk}} \cdot \eta_{\text{DM, milk}}} \qquad \text{(A17)}$$

Y_{milk} milk yield required to nourish one calf (in kg cow $^{-1}$)
$ME_{\text{ybc}}{}^{*}$ ME required for the life-span from day 125 to weaning (in MJ animal $^{-1}$ ME)
x_{ME} share of ME attributed to milk (x_{ME} = 0.47 MJ MJ $^{-1}$)
$\eta_{\text{ME, milk}}$ ME content of milk ($\eta_{\text{ME, milk}}$ = 19.19 MJ kg $^{-1}$)
$\eta_{\text{DM milk}}$ dry matter content of milk ($\eta_{\text{DM milk}}$ = 0.123 kg kg $^{-1}$)

Table A6 gives example results.

Table A6

Modelled milk yields for various genotypes

	1995 kg cow $^{-1}$ a $^{-1}$	2000 kg cow $^{-1}$ a $^{-1}$	2010 kg cow $^{-1}$ a $^{-1}$
Angus, German	1,327	1,359	1,377
Blonde d'Aquitaine			1,579
Charolais	1,480	1,502	1,730
Galloway	1,114	1,104	1,128
Hereford	1,309	1,300	1,413
Highland	1,074	1,080	1,036
Limousin	1,338	1,382	1,456
Simmental	1,415	1,464	1,530
Uckermärker			1,492

For 2010, the weighted mean using animal number provided for the shares of single genotypes in the overall population amounts to 1,501 kg cow $^{-1}$ a $^{-1}$. Due to lack of animal numbers, it does not include Blonde d'Aquitaine and Uckermärker.

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Determination of inorganic and organic P dissolved in water and Olsen extracts by inductively coupled plasma optical emission spectroscopy (ICP-OES) and colorimetry

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Abstract

A lab experiment was carried out to investigate the feasibility of calculating soluble ("plant available") organic soil P in water and Olsen extracts from P measurements by ICP-OES and colorimetry. To this aim, mixed solutions of water soluble organic P (sodium phytate) or polyphosphates common in organic soil compounds (sodium polyphosphate and sodium triphosphate pentabasic) with orthophosphate (KH_2PO_4) were produced at different mixing ratios and P was measured by both methods. While ICP-OES was able to determine total dissolved P (with an error of up to about 13 %), as expected only orthophosphate was measured by colorimetry (with an error of up to around 9 %). Thus, it is possible to calculate "non orthophosphate" (organic P and polyphosphates) dissolved in the respective soil extracts with reasonable accuracy. However, some error may occur due to hydrolysis of non-orthophosphate as well as due to the fact that, in real soil extracts, suspended colloidal P and soluble complexes of P with Fe, Al and/or Ca, which are not plant available, may increase total P measured by ICP-OES.

Keywords: *inorganic P, organic P, soil extracts, plant availability, colorimetry, ICP-OES*

Zusammenfassung

Bestimmung von anorganischem und organischem P im Wasser- und Olsenextrakt mittels optischer Emissionsspektroskopie (ICP-OES) und Kolorimetrie

Ein Laborexperiment wurde durchgeführt, um herauszufinden, ob es möglich ist, aus der Messung von P in Wasser und im Olsenextrakt mittels ICP-OES und Kolorimetrie das lösliche organische (pflanzenverfügbare) P zu berechnen. Zu diesem Zweck wurden Mischlösungen aus organischem P (N-Phytat) bzw. Polyphosphaten, die in organischen Bodenverbindungen auftreten (Na-Polyphosphat, pentabasisches Na-Triphosphat), mit Orthophosphat (KH_2PO_4) hergestellt und mit beiden Methoden P darin gemessen. Während mittels ICP-OES das gesamte gelöste P bestimmt werden konnte (mit einem Fehler bis zu maximal 13 %), erfasste die Kolorimetrie erwartungsgemäß nur das Orthophosphat (mit einem Fehler bis zu rund 9 %). Demnach ist es möglich, das in den beiden Bodenextrakten gelöste "Nicht-Orthophosphat" (d. h. organisches P oder Poly-P) mit ausreichender Genauigkeit zu berechnen. Allerdings können Fehler zum einen aufgrund von Hydrolyse der Nicht-Orthophosphate sowie in realen Bodenextrakten auch dadurch entstehen, dass suspendiertes kolloidales P sowie lösliche P-Komplexe mit Fe, Al und /oder Ca das mit ICP-OES gemessene Gesamt-P erhöhen.

Stichwörter: *anorganisches P, organisches P, Bodenextrakte, Pflanzenverfügbarkeit, Colorimetrie, ICP-OES*

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Background and aim of this study

Various extractants are in use to estimate the amount of plant available P in soils. Traditionally, the molybdenum blue method was used to determine the amount of extracted P. This coloring agent only reacts with the inorganic orthophosphate (PO_4) compound. Therefore, it is assumed that organic P dissolved by the applied extractant will not be accounted for by this method of determination. In contrast to this, ICP-OES is thought to measure all P forms present in the soil extract, including organic as well as other inorganic compounds (Mallarino, 2003; Ziadi et al., 2009; Matula, 2010, 2011; Paz-Ferreiro et al., 2012). Therefore, it can be hypothesized that the "organic" P (including non-orthophosphate P-forms common in organic compounds, such as polyphosphates) dissolved by a given extractant may be estimated by subtracting P measured by colorimetry („dissolved inorganic P") from P measured by ICP („total dissolved P"). While this combined methodology is already in use in some research labs, it has not yet been validated as such. The aim of the reported experiment was to validate the underlying assumptions using pure lab grade chemicals at different mixing ratios.

Material and methods

A water soluble organic phosphate (sodium phytate) as well as two water soluble polyphosphates (sodium polyphosphate and sodium triphosphate pentabasic) were each mixed with KH_2PO_4 at different inorganic/"organic" P ratios and dissolved in water and Olsen (bicarbonate) extractant (Olsen et al., 1954) (Table 1).

Table 1

Salt mixtures and mixing ratios used in the experiment

Mix	Inorganic (ortho-P) salt	Organic/poly-P salt	Inorg./org. P (%)
1	KH_2PO_4 [mono potassium phosphate]	$C_6H_{18}O_{24}P_6$ * x Na+ * y H_2O [sodium phytate]	100/0
			75/25
			50/50
			25/75
			0/100
2	KH_2PO_4	$(NaPO_3)_n$ [sodium polyphosphate, 96 %]	100/0
			75/25
			50/50
			25/75
			0/100
3	KH_2PO_4	$Na_5P_3O_{10}$ [sodium triphosphate pentabasic, 98 %]	100/0
			75/25
			50/50
			25/75
			0/100

All compounds used were in the form of lab grade salts. Since Na phytate came in hydrate form and thus no defined P content was declared, the exact P concentration in this salt was determined after digestion in aqua regia and the salt mix prepared based on the analyzed P concentration. Each treatment was done in four repetitions. The resulting solutions were measured by ICP-OES as well as by colorimetry (using the ascorbic acid – ammonium molybdate method based on Murphy & Riley, 1962) and it was calculated how much of the added inorganic and organic/poly-P was detected by the different methods of determination.

Results and Discussion

Tables 2 to 4 show the results for the three different salt mixtures. Using ICP-OES for detection, between 95 to 113 % of the total P amount added to the extract were detected in the three salt mixtures. Apparently, a measuring error of up to 13 % may occur, including errors in sample preparation (determination of P content in salts, dosage/weighing of salt mixtures, dilution of samples) as well as instrumental inaccuracy (which was calculated for ICP-OES to be no larger than 3.6 % based on repeated measurements of matrix adapted standards).

Table 2

Comparison of P in water and Olsen extractant measured by ICP-OES and colorimetry using salt mix 1 (KH_2PO_4 / sodium phytate), expressed as relative share of total added P (% $P_{tot} = P_{measured}$*100/total P added) and of added organic P (% $P_{org} = (P_{measured}$ – added inorganic P)*100/added org P), mean values of 4 repetitions. Significant differences (ANOVA, $p < 0.05$; post hoc test: LSD5) between recovery rate of P_{tot} (^{a}, ^{b}, …) and P_{org} (^{A}, ^{B}, …) and measuring "error" by colorimetry (^{A}, ^{B}, …), respectively, for different mixing ratios are indicated by different letters (tested separately for water and Olsen, respectively).

Ratio inorg/org P		ICP-OES Water	ICP-OES Olsen	Colorimetry Water	Colorimetry Olsen
100/0	% P_{tot}	113.3 ^{a}	104.5 ^{a}	96.4 ^{a}	99.0 ^{a}
	% P_{org}	-	-	-	-
75/25	% P_{tot}	103.6 ^{b}	100.8 ^{b}	77.5 ^{b}	81.4 ^{b}
	% P_{org}	114.5 ^{A}	103.6 ^{A}	0.0 ^{A}	12.8 ^{A}
50/50	% P_{tot}	104.7 ^{b}	102.0 ^{b}	56.0 ^{c}	59.1 ^{c}
	% P_{org}	109.4 ^{B}	104.6 ^{A}	1.8 ^{B}	8.7 ^{B}
25/75	% P_{tot}	105.6 ^{b}	102.3 ^{bc}	32.0 ^{d}	33.7 ^{d}
	% P_{org}	107.5 ^{BC}	103.2 ^{A}	4.1 ^{C}	6.6 ^{C}
0/100	% P_{tot}	105.8 ^{b}	103.8 ^{ac}	5.7 ^{e}	5.5 ^{e}
	% P_{org}	105.8 ^{C}	103.8 ^{A}	5.7 ^{D}	5.5 ^{C}
$LSD_{\alpha = 5\%}$	P_{tot}	6.6	1.7	0.4	0.7
$LSD_{\alpha = 5\%}$	P_{org}	2.0	4.3	0.2	1.1

Table 3

Comparison of P in water and Olsen extractant measured by ICP-OES and colorimetry using salt mix 2 (KH_2PO_4 / $(NaPO_3)_n$), expressed as relative share of total added P (% $P_{tot} = P_{measured}$ * 100/total P added) and of added poly-P (% $P_{poly} = (P_{measured} -$ added inorganic P)*100/added poly-P), mean values of 4 repetitions. Significant differences (ANOVA, $p < 0.05$; post hoc test: LSD5) between recovery rate of P_{tot} (^{a}, ^{b}, …) and P_{poly} (^{A}, ^{B}, …) and measuring "error" by colorimetry (^{A}, ^{B}, …), respectively, for different mixing ratios are indicated by different letters (tested separately for water and Olsen, respectively).

Ratio inorg/org P		ICP-OES Water	ICP-OES Olsen	Colorimetry Water	Colorimetry Olsen
100/0	% P_{tot}	97.3 ^{a}	108.7 ^{a}	96.5 ^{a}	100.2 ^{a}
	% P_{poly}	-	-	-	-
75/25	% P_{tot}	95.9 ^{a}	99.6 ^{b}	73.8 ^{b}	75.6 ^{b}
	% P_{poly}	83.6 ^{A}	98.4 ^{A}	0.0 ^{A}	2.9 ^{A}
50/50	% P_{tot}	95.7 ^{a}	98.2 ^{b}	50.5 ^{c}	53.3 ^{c}
	% P_{poly}	91.3 ^{B}	96.5 ^{A}	1.0 ^{B}	6.6 ^{A}
25/75	% P_{tot}	96.2 ^{a}	98.2 ^{b}	27.2 ^{d}	29.6 ^{d}
	% P_{poly}	95.0 ^{C}	97.6 ^{A}	2.9 ^{C}	6.1 ^{A}
0/100	% P_{tot}	94.9 ^{a}	95.9 ^{c}	3.6 ^{e}	5.6 ^{e}
	% P_{poly}	94.9 ^{C}	95.9 ^{A}	3.6 ^{D}	5.6 ^{A}
$LSD_{\alpha = 5\%}$	P_{tot}	2.3	2.1	0.3	2.3
$LSD_{\alpha = 5\%}$	P_{org}	1.8	4.7	0.3	2.7

Table 4

Comparison of P in water and Olsen extractant measured by ICP-OES and colorimetry using salt mix 3 (KH_2PO_4 / $Na_5P_3O_{10}$), expressed as relative share of total added P (% $P_{tot} = P_{measured}$ * 100/total P added) and of added poly-P (% $P_{poly} = (P_{measured} -$ added inorganic P)*100/added poly-P), mean values of 4 repetitions. Significant differences (ANOVA, $p < 0.05$; post hoc test: LSD5) between recovery rate of P_{tot} (^{a}, ^{b}, …) and P_{poly} (^{A}, ^{B}, …) and measuring "error" by colorimetry (^{A}, ^{B}, …), respectively, for different mixing ratios are indicated by different letters or numbers (tested separately for water and Olsen, respectively).

Ratio inorg/org P		ICP-OES Water	ICP-OES Olsen	Colorimetry Water	Colorimetry Olsen
100/0	% P_{tot}	98.5 ^{a}	110.3 ^{a}	100.3 ^{a}	99.3 ^{a}
	% P_{poly}	-	-	-	-
75/25	% P_{tot}	100.5 ^{a}	100.2 ^{b}	77.0 ^{b}	77.1 ^{b}
	% P_{poly}	102.1 ^{A}	100.8 ^{A}	8.1 ^{A}	8.4 ^{A}
50/50	% P_{tot}	98.8 ^{a}	100.8 ^{b}	52.0 ^{c}	49.7 ^{c}
	% P_{poly}	97.5 ^{A}	101.5 ^{A}	3.9 ^{B}	0.1 ^{B}
25/75	% P_{tot}	98.6 ^{a}	99.6 ^{b}	27.2 ^{d}	26.9 ^{d}
	% P_{poly}	98.2 ^{A}	99.5 ^{A}	3.0 ^{C}	2.5 ^{C}
0/100	% P_{tot}	98.8 ^{a}	98.9 ^{b}	1.8 ^{e}	1.5 ^{e}
	% P_{poly}	98.8 ^{A}	98.9 ^{A}	1.8 ^{D}	1.5 ^{C}
$LSD_{\alpha = 5\%}$	P_{tot}	1.8	3.4	0.5	1.0
$LSD_{\alpha = 5\%}$	P_{org}	8.0	5.1	0.6	1.1

As expected, the amount of P measured by colorimetry came very close to the amount of added inorganic P, while the organic/poly-P remained largely undetected. However, depending on the salt mixture and the extractant used, colorimetry resulted in up to nearly 9 % more P being measured than was added as ortho-P compound (see Table 2: 33.7 % of P_{tot} measured by colorimetry in Olsen solution while only 25 % of the total were added as ortho-P). This error is a little higher than observed by Torres-Dorante et al. (2004), who measured different polyphosphate solutions by colorimetry and found orthophosphate-concentrations in the range of 5 to 6 % of total P. While this might at least partly be attributed to the detection method's inherent inaccuracy, it could also be interpreted as an indication that some of the organic (and poly-) P was transformed into orthophosphate by the acid coloring reagent (which brought the pH of the measured samples down to <1) and therefore detected by colorimetry. This would concur with Matula (2010) and Baldwin (1998) who argued that at pH values below 2, hydrolysis of less stable esters of phosphorus may take place, increasing the amount of assumed inorganic P measured by colorimetry. It is also known from the literature that spontaneous hydrolysis of polyphosphates back into the ortho-P form may occur (Torres-Dorante et al., 2005), with the rate of hydrolysis increasing at decreasing pH (Robertson, 2001). It should be noted, however, that in the study by Baldwin (1998), less than 2 % of the tested tripolyphosphate and inositol hexaphosphate were hydrolysed. The assumption that the degree of hydrolysis by the acid coloring agent is rather limited is also supported in our experiment by some control measurements with ion chromatography (IC), which agreed well with or even exceeded the colorimetric measurements (data not shown here). However, similar to the observations reported by Torres-Dorante et al. (2004), some of the "excess" ortho-P determined in our experiment might also stem from the declared minor impurity of the lab chemicals (see Table 1), which contain small traces of ortho-P.

Conclusion and outlook

Based on the presented results from the lab experiment, the combination of ICP-OES and colorimetry promises to be a valid method for estimating the amount of dissolved organic (and polyphosphate-) P in standard soil P extracts. However, due to hydrolysis of organic P compounds and polyphosphates back into ortho-P, a range of error in the order of up to 13 % must be accounted for. In addition, ICP-OES does not differentiate between dissolved organic P and non-orthophosphate inorganic P compounds dissolved in the solution, so it will not give a precise estimate of organic P. In order to further specify the composition of P compounds in solution, speciation by weak-ion exchange chromatography may be performed (Baldwin, 1998). Nevertheless, measuring total dissolved soil P by ICP-OES may still allow an assessment of potentially plant available soil P, keeping in mind that according to Torres-Dorante et al. (2005), hydrolysis – and thus transformation into a plant available form – of polyphosphates may take as long as 30 days up to a couple of months, depending on the type of compound. A possible limitation of the method's accuracy when using it for real soils, however, is indicated by Pierzynski et al. (2012) who pointed out that soil extracts may contain suspended colloidal (i.e. particle bound) P not removed by filtering, as well as soluble complexes of P with Fe, Al and/or Ca, which are not plant available, but may increase the total P measured by ICP-OES.

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Ergebnisse zur Nettoprimärproduktion von mit biologisch geklärtem Abwasser bewässerten Pappeln und Weiden im Kurzumtrieb

Konrad Lorenz* und Jürgen Müller*

Zusammenfassung

In der Thüringer Ackerebene, einer der trockensten Regionen Deutschlands, wurden unterschiedlich alte Pappeln und Weiden im Kurzumtrieb mit biologisch geklärtem Abwasser bewässert. Schwerpunkt der Untersuchungen war die Ermittlung der Nettoprimärproduktion und des Wachstums von bewässerten und unbewässerten Bestandesflächen. Mit diesen Untersuchungen sollte beispielhaft der Nachweis erbracht werden, dass für die Produktion von Energieholz die Nutzung von Abwasser in trockenen Gebieten ein zusätzliches Wasser- und Nährstoffpotential darstellt. Der Bewässerungsbedarf der Bestände wird mit dem Wasserhaushaltsmodell („Zephyr") ermittelt. In Abhängigkeit von der Witterung, des Bodens und der Pflanzenentwicklung werden der Termin und die Höhe der Zusatzwassergabe berechnet.

Die ersten Ergebnisse zeigen bezüglich der Nettoprimärproduktion positive Bewässerungseffekte. Die bewässerten Individuen weisen eine größere Biomasse, unterteilt in holziger und Blattbiomasse, auf. Die phänologischen Beobachtungen zeigten eine Differenzierung des Blattfalls. So setzte bei den bewässerten Beständen der Blattfall später als bei den unbewässerten ein. Die Zusatzbewässerung hatte auf den Blattaustrieb keinen zeitlichen Effekt.

Schlüsselwörter: *Kurzumtriebsplantagen, Klimawandel, Trockenheit, biologisch geklärtes Abwasser, Waldwachstum, Phänologie*

Summary

Results for net primary production from with biologically treated wastewater irrigated poplars and willows in short rotation coppices

In the lowland of Thuringia, one of the driest regions in Germany, short rotation coppices stocked with poplar and willow clones were watered with biologically clarified wastewater. The focus of the study was the determination of the net primary production and growth of watered and non-watered residuals, respectively. The study aims to provide evidence that, for the production of energy wood, the use of wastewater in dry areas presents an additional water-and nutrient source. The watering demand of stocks is determined by the water balance model („Zephyr"). Depending on weather conditions, soil, and plant development date and amount of additional water transfer are calculated.

The first results show a positive effect of watering regarding net primary production. The watered individuals have a greater biomass, divided into woody and leafy biomass. The phenological observations showed differences in leaf fall occuring later for the watered individuals. However, there was no effect on leaf occurrence with the addition of water.

Keywords: *short rotation coppices, climate change, drought, biologically clarified wastewater, forest growth, phenology*

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1 Einleitung

Ziel des vom BMBF geförderten Verbundprojektes BEST (Bioenergie-Regionen Stärken) ist die Entwicklung von regional angepassten Konzepten zur Biomasseproduktion bezüglich ihrer ökologischen und ökonomischen Auswirkungen. Die Untersuchungen erfolgen in den Beispielregionen Göttinger Land und Thüringer Ackerebene (BERTA). Die Regionen unterscheiden sich in ihren naturräumlichen Gegebenheiten (Witterung, Boden). Die Thüringer Ackerebene gehört zu den trockensten Gebieten Deutschlands. In Dachwig (Thüringen) sind in der Referenzperiode 1961 bis 1990 494 mm Niederschlag (DWD) pro Jahr gefallen, dies sind fast 300 mm weniger als im langjährigen Mittel für Deutschland. Im Zuge des prognostizierten Klimawandels (Kunka 2004) soll sich die Trockenheit in der Thüringer Ackerebene noch verstärken.

Der Untersuchungsschwerpunkt liegt in der Erarbeitung von innovativen Nutzungskonzepten zur Energieholzerzeugung in Kurzumtriebsplantagen (KUP). Ziel des KUP-Anbaus ist die maximale Produktion von Energieholz zur weiteren thermischen Verwertung. Zur Reduzierung des vorhandenen Wasserdefizits wäre der Einsatz von biologisch geklärtem Abwasser für die Bewässerung von KUP eine prüfenswerte Fragestellung. Dadurch ist es möglich, Wasser in der Region zu halten, welches sonst über die Vorfluter in die Flüsse abfließen würde. Damit stehen diese Forschungen in der Region BERTA als Beispiel für die Nutzung von Wasserreserven zur Erzeugung von holziger Biomasse in Wassermangelregionen. Ziel ist es deshalb, die Effekte des Abwassereinsatzes in unterschiedlich alten Pappel- und Weidenbeständen zu untersuchen. Der Schwerpunkt liegt in der Ermittlung der oberirdischen Biomasse auf den bewässerten und unbewässerten Beständen.

Durch steigende Energiekosten stößt der Anbau von schnellwachsenden Baumarten auf ein wachsendes Interesse (Röhricht und Ruscher, 2009). Dem Landwirt wird es durch eine verbesserte Gesetzgebung (EEG) vereinfacht, auf landwirtschaftlich genutzten Flächen schnellwachsende Baumarten anzubauen.

Schnellwachsende Baumarten verbrauchen im Vergleich zu traditionellen Ackerfrüchten mehr Wasser (Lamersdorf und Schulte-Bisping, 2010; Petzold et al., 2009; Dimitriou et al. 2009). Bei nicht ausreichender Wasserversorgung können Zuwachseinbußen entstehen.

2 Material und Methoden

2.1 Untersuchungsgebiet

Die für die Untersuchungen eingerichteten Versuchsflächen „BERTA I“ und „BERTA II“ liegen in der Thüringer Ackerebene, nordwestlich des Ortes Großfahner (Abbildung 1).

In die Untersuchungen wurden zwei Standorte mit jeweils zwei unterschiedlichen Baumarten einbezogen. Die Versuchsflächen „BERTA I“ sind durch eine carbonathaltige Lössfließerde über stark humosem Sediment charakterisiert. Es handelt sich hierbei um eine Braunerde. Anfang April 2011 lag der Grundwasserflurabstand bei ca. 80 cm Bodentiefe. Durch Wasserhaltungsmaßnahmen im Bereich der Bestandesflächen sank der Grundwasserstand ab Herbst 2011 unter 2,8 m (Tiefe des gesetzten Pegels). Bei „BERTA II“ handelt es sich um eine Braunerde-Rendzina. Carbonathaltige, umgelagerte Keuperablagerungen liegen auf tonig kalkhaltigen Ablagerungen (Hartmann, 2014). Auf dem Standort „BERTA II“ liegt keine Grundwasserbeeinflussung vor. Auf beiden Versuchsflächen ist die Bodenart toniger Schluff (Hartmann, 2013). Daraus ergibt sich eine nutzbare Feldkapazität (nFK) von 262 mm („BERTA I“) und 139 mm („BERTA II“) bis 160 cm Bodentiefe.

Abbildung 1
Luftbild der Versuchsflächen „BERTA“ (BioEnergie-Region Thüringer Ackerebene)
(Quelle: Google-Earth)

Das Jahr 2011 war im Vergleich zum langjährigen Mittel ein Trockenjahr. Die ohnehin schon geringen Niederschläge (vgl. Einleitung) liegen im Jahr 2011 mit 399 mm unter den Niederschlagsmengen des langjährigen Mittels. Die Niederschlagshöhe des Jahres 2012 ist ähnlich der des langjährigen Mittels (507 mm). In den Jahren 2011 und 2012 ist nach Abbildung 2 eine Frühjahrstrockenheit festzustellen. Bei höheren Temperaturen sind geringere Niederschläge gefallen. Im Gegensatz zum trockenen Frühjahr ist in beiden Jahren ein feuchterer und wärmerer Sommer als im langjährigen Mittel zu erkennen. Außer im August 2012 sind die Niederschlagsmengen in beiden Jahren höher als im langjährigen Mittel. Im Herbst beider Jahre wird ein Niederschlagsdefizit deutlich. Außer im Oktober 2011 und im November 2012 sind auch im Herbst beider Jahre weniger Niederschläge gefallen als im langjährigen Mittel. Die Durchschnittstemperaturen sind insgesamt leicht erhöht.

Das Untersuchungsgebiet „BERTA I“ ist mit Pappel- und Weidenklonen per Stecklingspflanzung in unterschiedlichen Jahren bepflanzt worden. Japanklon (Pappel) und Tora (Weide) wurden im Jahr 2008 auf „BERTA I“ zu Einzelreihen angepflanzt. Bei einer Dichte von fast 30.000 Individuen pro Hektar (0,75 x 0,45 m) ist der Japanklon sehr dichtstehend. Tora wurde zu ca. 13.500 Individuen pro Hektar (1,67 x 0,45 m) gepflanzt. Das Versuchsflächendesign von „BERTA I“ ist in Abbildung 3 dargestellt.

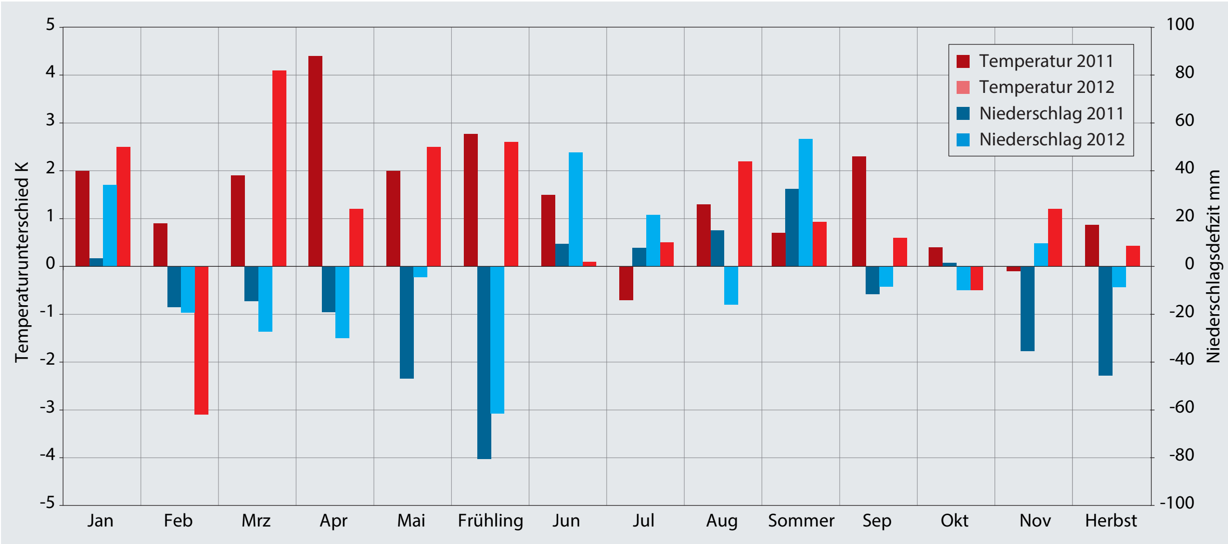


Abbildung 2
Vergleich des Wetters der Jahre 2011 und 2012 mit dem langjährigen Mittel

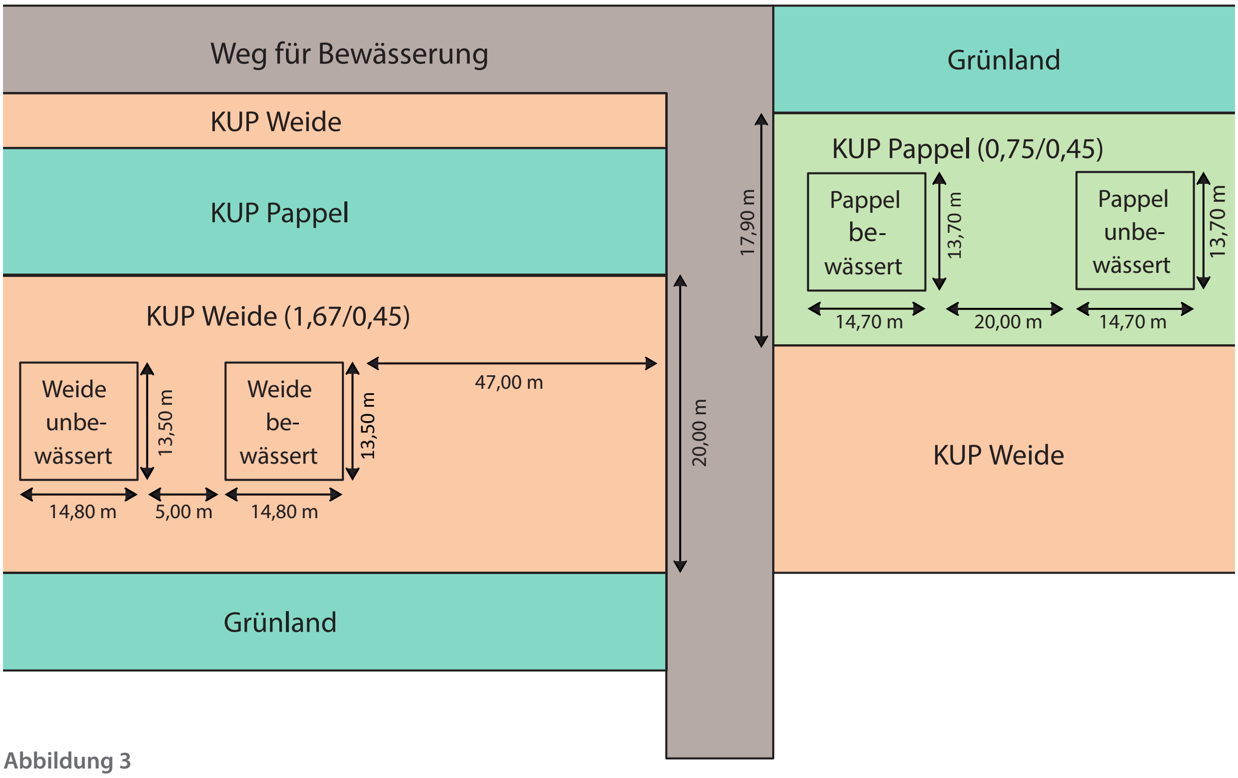


Abbildung 3
Schematische Darstellung der Versuchsfläche „BERTA I"

Im Frühjahr des Jahres 2011 wurden auf „BERTA II" Max 1 (Pappel) und Tordis (Weide) in Doppelreihen gepflanzt. Max 1 weist dabei eine Individuendichte von 9.000 Pflanzen pro Hektar (0,75 x 1,00 x 1,50 m) auf. Tordis wurde in einem engeren Pflanzabstand von 12.000 Pflanzen pro Hektar (0,75 x 0,75 x 1,50 m) durch eine Stecklingspflanzung in den Boden eingebracht. Die bewässerten und unbewässerten Versuchsflächen haben eine Fläche von jeweils 200 m². Das Versuchsflächendesign von „BERTA II" ist in Abbildung 4 dargestellt.

2.2 Instrumentierung der Versuchsflächen

Der Freilandniederschlag wird auf „BERTA I" und „BERTA II" in einem Meter Höhe mit jeweils drei Niederschlagssammlern gemessen. Sie haben eine Oberfläche von 100 cm². Der Kronendurchlass wird auf „BERTA I" mit Hilfe von Niederschlagsrinnen und der Stammabfluss durch Stammabflusskragen gesammelt und gemessen (Abbildung 5). Beide Elemente des Bestandesniederschlages werden einmal monatlich ermittelt (Tabelle 1).

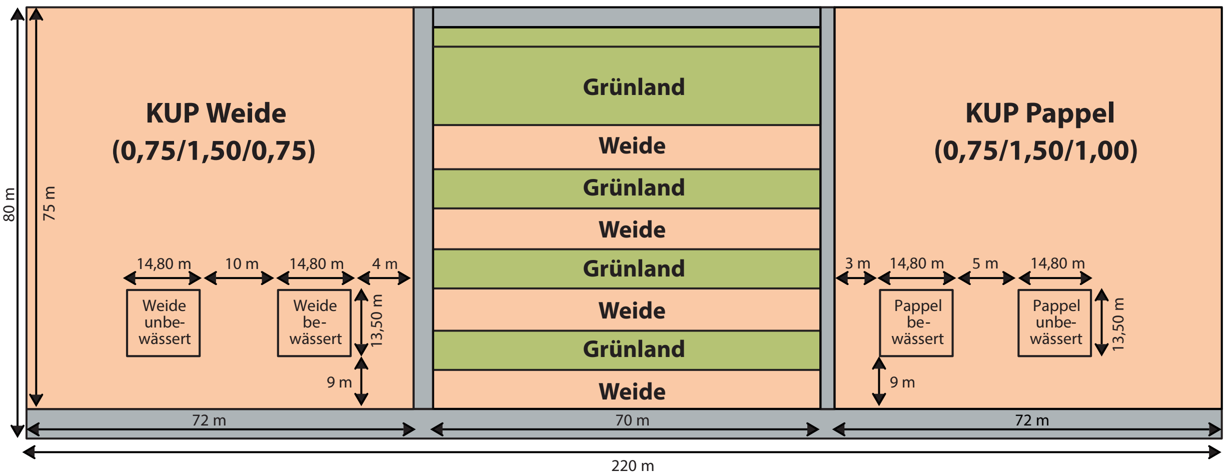


Abbildung 4
Schematische Darstellung der Versuchsfläche „BERTA II“

Abbildung 5
Messung des Bestandesniederschlages mittels Rinnen auf der Versuchsfläche „BERTA I“

Auf „BERTA II“ war es nicht möglich, durch die tiefe Belaubung Niederschlagsrinnen und durch die geringen Stammdurchmesser Stammabflusskragen zu installieren. Es wurden Bodentransekte von Niederschlagssammlern auf den Versuchsflächen installiert. Aus dem Verhältnis zwischen dem Bestandes- und dem Freilandniederschlag lässt sich die Interzeption berechnen.

Die Wirkung der Zusatzbewässerung auf die Stammdurchmesser wird auf den Versuchsflächen von „BERTA I“ kontinuierlich mit Dauerumfangmessbändern (Dendrometer) ermittelt (Tabelle 2). Aus den sich ergebenden Differenzierungen hinsichtlich der Entwicklung der radialen Stammdurchmesser zwischen den bewässerten und unbewässerten Beständen wird auf eine Mehrertragswirkung durch die Abwasserbewässerung geschlossen. Dabei wurden repräsentative Individuen der Kraft´schen Klassen I und II (I: vorherrschend, II: mitherrschend) (Kraft ,1884) ausgewählt. Nach Murach et al. (2008) hängt die Baumhöhe von der Wasserverfügbarkeit ab. Auf den Versuchsparzellen von „BERTA II“ wird deshalb der aus den Bewässerungen entstandene Mehrertrag durch die kontinuierliche Messung der Einzelbaumhöhen an repräsentativen Individuen erfasst (Tabelle 2).

Am Ende jeder Vegetationsperiode wird auf allen Versuchsflächen eine Vollaufnahme bzw. Vollkluppung durchgeführt. Konkret werden dabei auf „BERTA I“ von allen Trieben (Leittrieb + Stockausschlag) die BHD (Brusthöhendurchmesser $d_{1,3}$) ermittelt. Um eine repräsentative Bestandes-Höhenkurve errechnen zu können, wurden zusätzlich ca. 40 Individuen pro Versuchsfläche ausgewählt, bei denen die Einzelbaumhöhe gemessen wurde. Auf „BERTA II“ wird eine Vollaufnahme durchgeführt. Von jedem Stockausschlag und Leittrieb werden der WHD (Wurzeldurchmesser $d_{0,1}$), der BHD und die Einzelbaumhöhe gemessen. Die Bestandes-Höhen-

Tabelle 1
Methoden zur Messung von Wetterdaten

		Erfassungsrhythmus	
Parameter	**Geräte**	**BERTA I**	**BERTA II**
Freilandniederschlag	Niederschlagssammler	3 Niederschlagssammler, nach Niederschlagsereignis	3 Niederschlagssammler, nach Niederschlagsereignis
Kronendurchlass	Niederschlagssammler Niederschlagsrinnen	4 x 2 Niederschlagsrinnen, 1 x pro Monat	4 x 15 Niederschlagssammler, 1 x pro Monat
Stammabfluss	Stammabflusskragen	4 Stammabflusskragen nach Niederschlagsereignis	-----

kurve ergibt sich aus dem Verhältnis zwischen WHD und der Einzelbaumhöhe.

$$h_i = a_1 * e\left(\frac{a_2}{b}\right) + b$$

h_i Einzelbaumhöhe (m)
a_i Regressionskoeffizienten
d Brusthöhendurchmesser ($d_{1,3}$) / Wurzelhalsdurchmesser ($d_{0,1}$) in cm
b Regressionskoeffizient ($d_{1,3}$: $_{1,3}$; $d_{0,1}$: 0,1)

Die Bestandes-Höhenkurve beschreibt nach Gadow (2003) „eine einheitliche bzw. generelle Beziehung zwischen dem Baumdurchmesser [BHD/WHD] und den -höhen [h].“ Die Einzelbaumhöhe wird mit der Michailov-Funktion berechnet. Die Projektion von Einzelbaumhöhen für Bäume, bei denen diese nicht gemessen wurde, ist dadurch möglich. Die Grundflächenmittelhöhe ergibt sich wie folgt:

$$h_m = \frac{\sum (h_i * g_i)}{G}$$

h_m Grundflächenmittelhöhe (m)
h_i Einzelbaumhöhe (m)
g_i Einzelbaumgrundfläche (m^2)
G Bestandesgrundfläche (m^2/ha)

Zur Berechnung der Grundflächenmittelhöhe der Bestände auf „BERTA II“ wird der WHD verwendet. Nicht alle Individuen wiesen 2012 eine Höhe von 1,30 m auf, um dort den Stammdurchmesser (BHD) zu messen. Es führt zu Fehlberechnungen der Einzelbaumhöhe und damit der Grundflächenmittelhöhe, wenn nicht alle Individuen in die Berechnung einbezogen werden. Auf „BERTA I“ wurde der BHD als Berechnungsgrundlage für die Grundflächenmittelhöhe gemessen. Die Auswirkungen eines größeren Wasserangebots auf das Baumwachstum können nach Fischer et al. (2010) für Pappeln und nach Linderson et al. (2007) für Weiden durch die Wassernutzungseffizienz dargestellt werden. Dafür ist es notwendig, einen Wachstumsparameter einer Entwicklung der Wasserverfügbarkeit gegenüber zu stellen. Zur Bewertung der Effizienz des eingesetzten Zusatzwassers wird der berechnete Zuwachs des Stammholzvorrats und der Niederschlag der Vegetationsperioden 2011 und 2012 (01.04. bis 31.10.) und die Bewässerungsmenge genutzt.

$$WE = \frac{(\sum \frac{\Pi}{4} d_{i+1}^2) * h_{m,i+1} \cdot f) - (\sum \frac{\Pi}{4} d_i^2) * h_{m,i} \cdot f)}{((N_F - (N_F * l) + N_B)} \ (in\ V\ fm/m^3)$$

WE Wassereffizienz
d_i Brusthöhendurchmesser ($d_{1,3}$) / Wurzelhalsdurchmesser ($d_{0,1}$) der Einzelbäume im Jahr (m)
$h_{m,i}$ Grundflächenmittelhöhe im Jahr i (m)
f Formzahl (Pappel: 0,45; Weide: 0,60)[1]
N_F Freilandniederschlag der Vegetationsperiode (m^3/ha)

Nach Fischer et al. (2010) und Linderson et al. (2007) wird die Wassernutzungseffizienz in Gramm Biomasse pro Kilogramm Wassermenge angegeben. Die Biomasse konnte von uns nicht jährlich durch die Benutzung der destruktiven Regressionsmethode (Röhle 2009) berechnet werden. Eine Entnahme einer repräsentativen Menge von Individuen zur Ermittlung der Einzelbaumbiomasse hätte zu einer Veränderung der Bestandesstruktur geführt. Die Vergleichbarkeit zwischen den einzelnen Versuchsjahren wäre damit gemindert worden. Somit war es nicht möglich, die gebildete Biomasse pro Hektar zu schätzen. Als Hilfsgröße wurde deshalb der Stammholzvorrat ausgewählt, weil die Berechnung dieser Wachstumsgröße keine Baumentnahme voraussetzt und damit eine Vergleichbarkeit zwischen den einzelnen Versuchsjahren möglich ist.

Auf „BERTA I“ wird mit Hilfe einer repräsentativen Menge an Laubsammlern in vorgegebenen zeitlichen Abständen die Blattmasse gesammelt, bei 105 °C getrocknet, gewogen und auf einen Hektar hochgerechnet (Tabelle 3). „Auf BERTA II“ ist durch die relativ geringe Baumhöhe und Tiefe der Seitenbeastung und dem damit einhergehenden tiefen Kronenansatz eine Installation von Laubsammlern nicht möglich. Es werden

Tabelle 2
Methoden zur Messung von Wetterdaten

		Erfassungsrhythmus	
Parameter	**Geräte**	**BERTA I**	**BERTA II**
Änderung des Stammdurchmessers innerhalb der Vegetationsperiode	Dendrometer	4 x 8 Dendrometer 01.04. – 30.09., 3 x pro Woche	-----
Änderung der Baumhöhe innerhalb der Vegetationsperiode	Teleskop-Höhenmessstange	-----	2 x 10 (Pappel) + 2 x 15 (Weide) Höhenmessbäume 01.04. – 30.09. 2 x pro Woche
Jährlicher Ertrag	Kluppe, Feinkluppe, Teleskop-Höhenmessstange	Vollkluppung, Höhenmessung an repräsentativen Bäumen, nach der Vegetationsperiode	Vollkluppung, Höhenmessung an allen Bäumen, nach der Vegetationsperiode

[1] Formzahlen für Pappel und Weide nach den Daten von Smalian aus Rohe et al. (2009) und Baur (1891)

Tabelle 3
Methoden zur Messung der Blattbiomasse

		Erfassungsrhythmus	
Parameter	**Geräte**	**BERTA I**	**BERTA II**
Blattbiomasse	Laubsammler	4 x 14 Laubsammler (Grundfläche: 0,25 m^2/ Laubsammler) 1 x pro Monat bzw. im Herbst 1 x in 2 Wochen	Blatternte von repräsentativen Bäumen Ende der Vegetationsperiode

Tabelle 4
Methoden der phänologischen Aufnahme

		Erfassungsrhythmus	
Parameter	**Geräte**	**BERTA I**	**BERTA II**
Phänologie	Fotokamera	Blattaustrieb: 01.04. - 15.05. , 3 x pro Woche, Blattfall: 15.07. - 15.11., 3 x pro Woche	Blattaustrieb: 01.04. - 15.05. , 3x pro Woche, Blattfall: 01.08. - 15.11., 3 x pro Woche

an einer repräsentativen Anzahl von Bäumen Ganzbaumernten durchgeführt (Tabelle 3). Zudem werden die Blattoberflächen einer repräsentativen Anzahl von Einzelblättern getrocknet und das Gewicht bestimmt. Außerdem wird die Blattoberfläche ermittelt und das Verhältnis aus Oberfläche und Blattgewicht errechnet. Dadurch ist es möglich, den LAI (Blattflächenindex) zu schätzen.

2.3 *Phänologische Aufnahmen*

Nach Nüske (2012) beschäftigt sich die Phänologie mit periodisch wiederkehrenden Wachstums- und Entwicklungsereignissen. Dabei werden im Rahmen dieses Projektes der Blattaustrieb und der Blattfall beobachtet. Der Blattaustrieb wird im Frühling von Anfang April bis Mitte Mai und der Blattfall von Mitte Juli bis Mitte November beobachtet (Tabelle 4). Drei Mal wöchentlich wird die Phänologie in diesem Zeitraum erfasst.

Die verschiedenen Blattaustriebsstadien werden in sechs Phasen unterteilt (Null bis fünf). Pappeln und Weiden unterscheiden sich sehr deutlich in der Art des Blattaustriebes (Tabelle 5).

Der Blattfall wird mit Hilfe des Belaubungs- und Verfärbungsprozentes aufgenommen. Aus der Kombination von Belaubungs- und dem Verfärbungsprozent wird die photosynthetisch aktive Belaubung (PAB) in Prozent ermittelt:

$$PAB = P_b - (P_b * \frac{P_v}{100})$$

PAB Photosynthetisch aktive Belaubung (%)
P_b Belaubungsprozent (%)
P_v Verfärbungsprozent (%)

Es ist notwendig, die PAB zu berechnen, weil im Jahr 2012 die Weide auf „BERTA II“ noch weit in den Spätherbst gelbbraune Blätter behielt (Belaubungsprozent sehr hoch), die nicht mehr in der Lage waren, Photosynthese zu betreiben. Beispielsweise könnte eine Auffüllung des Bodenwasserspeichers durch die dadurch fehlende Transpiration nicht mehr erklärt werden.

Tabelle 5
Abschätzung des Blattaustriebes bei Pappel und Weide

Stufe	Pappel	Weide
0	– Knospen geschlossen, Winterruhe	– Knospen geschlossen, Winterruhe
1	– Aufbrechen der Knospen – Blatt fängt an, sich zu entfalten – sehr eingeknickt	– Knospen brechen auf – Blatt fängt an, sich zu entfalten – Länge der Blätter < 2 cm
2	– Jungblatt ausgetrieben – stark knittrig – hellgrün	– Längenwachstum der Blätter – buschige Blattanordnung erkennbar – Länge der Blätter 2 - 4 cm
3	– Blatt noch etwas gerollt – hellgrün gefärbt – Blattstiel beginnt sich zu strecken	– deutliche Verbuschung der Blätter erkennbar – Länge der Blätter 4 - 7 cm
4	– Blatt voll ausgebildet – hellgrün gefärbt	– Länge der Blätter 7 - 10 cm
5	– Blätter kräftig grün gefärbt und voll ausgebildet	– Länge der Blätter > 10 cm

Das Verfärbungsprozent als alleinstehendes Merkmal zum Blattfall kann auch nicht mit in die Berechnungen einbezogen werden. Die Weide kann die gelb verfärbten Blätter innerhalb weniger Tage abwerfen. Die am Ast verbleibenden grünen Blätter verfärben sich später. Es kommt somit zu sehr großen Schwankungen, verursacht durch den unregelmäßig verlaufenden Verfärbungsprozess und den Blattfall. Für die Berechnung der PAB werden Belaubungs- und Verfärbungsprozent miteinander kombiniert.

2.4 *Bewässerung*

Um den Bewässerungsbedarf der Kurzumtriebsplantagen zu ermitteln, wird das Wasserhaushaltsmodell „Zephyr“ (Michel, 2009) benutzt. In diesem Modell werden Wetter-, Boden- und Vegetationsdaten verwendet, um das Transpirationsdefizit zu ermitteln. Es wird die aktuelle Wasserverfügbarkeit (prozentualer Anteil der nutzbaren Feldkapazität) für die unterschiedlichen Versuchsflächen aus den Standortsparametern berechnet und daraus Zeitpunkt und Höhe des Zusatzwassereinsatzes abgeleitet. Die Grenze des optimalen Pflanzenwachstums ist bei ≥ 50 % nFK (nutzbare Feldkapazität) festgelegt. Nach DWD (2010) ist ein optimales Pflanzenwachstum bei 50 bis 80 % nFK möglich. Bei einer Unterschreitung von 50 % nFK werden die Versuchsflächen bewässert.

Das biologisch geklärte Abwasser wird durch einen „Tankwagen" in Kombination mit einem Rohrleitungssystem und angeschlossenem Wasserzähler (Wasseruhr) auf die Flächen ausgebracht. Die Abwassergabe innerhalb der Parzelle erfolgt als Furchenbewässerung zwischen den Baumreihen, um ein seitliches Abfließen zu vermeiden und eine gleichmäßige Bewässerung zu ermöglichen (Abbildung 6).

Abbildung 6
Furchenbewässerung mit Abwasser auf der Versuchsfläche „BERTA II"

3 Ergebnisse

3.1 Bewässerung

Die Klimatische Wasserbilanz (KWB) ist ein Indikator für die meteorologische Trockenheit. Sie ist definiert aus der Differenz zwischen Niederschlag und potentieller Evapotranspiration nach Grasreferenzverdunstung (Wendling et al., 1991).

$$KWB = N_F - PET$$

KWB Klimatische Wasserbilanz (mm)
N_F Freilandniederschlag (mm)
PET Potentielle Evapotranspiration (mm)

Wie in Abbildung 7 zu erkennen, ist die kumulierte klimatische Wasserbilanz ohne Zusatzbewässerung in der Vegetationszeit (01.04. bis 31.10.) der Jahre 2011 und 2012 als sehr negativ einzustufen. Im Jahr 2011 war es wegen technologischer Anfangsschwierigkeiten bei der Bewässerung nicht gelungen, die Trockenheit mit der Zusatzbewässerung auszugleichen. Diese Schwierigkeiten konnten 2012 behoben werden, so dass durch eine ausreichende Bewässerung kein Wassermangel für die Pflanzen auftrat.

Die Pappeln und Weiden, die im Jahr 2008 angepflanzt worden sind, erhielten 2011 190 mm Zusatzwasser. 2012 vergrößerte sich die Abwassermenge auf 420 mm. Die neuangepflanzten Pappeln und Weiden erhielten dagegen im Jahr 2011 nur insgesamt 90 mm Zusatzwasser. 2012 verdreifachte sich diese Menge auf 270 mm zusätzliches Abwasser (Tabelle 6).

Tabelle 6
Bewässerungsmenge auf „BERTA" in mm

Versuchsfläche	2011	2012
Pappel BERTA I	104,6	210,9
Weide BERTA I	84,3	210,8
Summe	188,9	421,7
Pappel BERTA II	43,3	134,9
Weide BERTA II	44,4	135,7
Summe	87,7	270,6

Am Beispiel der Entwicklung der prozentualen nFK der Pappeln auf „BERTA I" ist in Abbildung 8 erkennbar, dass sich die Graphen der bewässerten und unbewässerten Pappeln bis Mitte Mai in einem sehr geringen Maß differenzieren. Ab Anfang Juni unterscheiden sich die Kurvenverläufe durch die Ende Mai intensiv durchgeführten Bewässerungsmaßnahmen. Beide Graphen liegen bis zur dritten Julidekade jedoch noch über dem Optimum von 50 % nFK, was eine gute Wasserversorgung darstellt. Im Spätsommer differenzieren sich beide Graphen stärker. Die prozentuale nFK der bewässerten Versuchsfläche befindet sich klar über der Grenze des optimalen Pflanzenwachstums von 50 % nFK. Ab dem 27.07.12 sinkt der Graph der nutzbaren Feldkapazität der unbewässerten Versuchsparzelle deutlich unter das Optimum von 50 % nFK. Für die Weide auf „BERTA I" sind ähnliche Werte berechnet worden.

Auf „BERTA II" konnte durch die doppelte Bewässerungsmenge die Bodenfeuchtigkeit über 50 % nFK gehalten werden. Auf den unbewässerten Versuchsflächen beider Baumarten unterschreitet die nFK am 02.08.12 dauerhaft die Grenze des optimalen Pflanzenwachstums von 50 %.

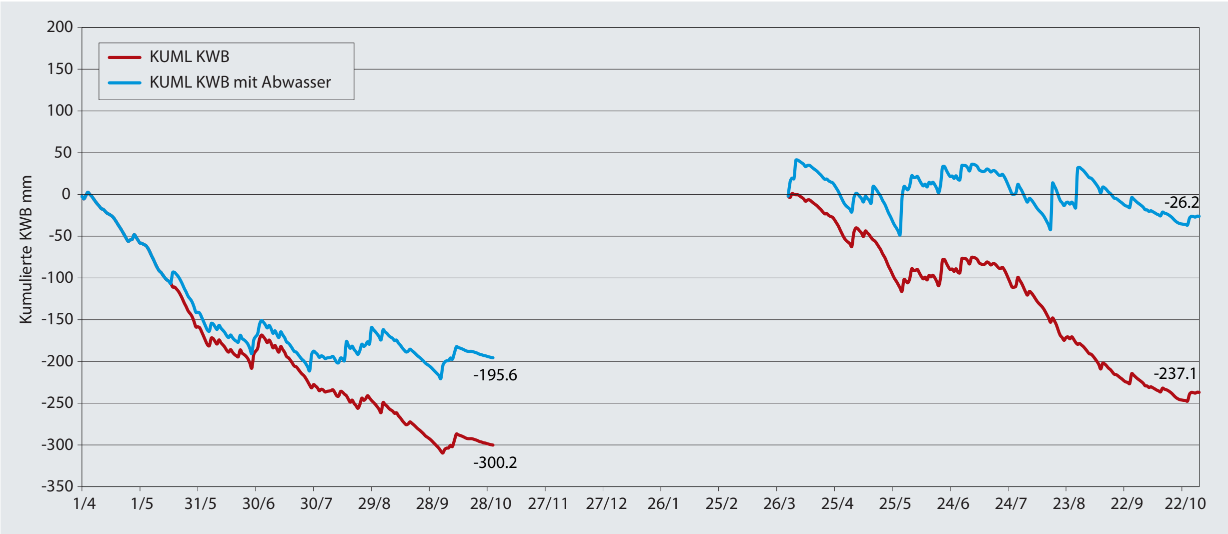


Abbildung 7
Entwicklung der kumulierten Klimatischen Wasserbilanz (KWB) mit und ohne Abwasserbewässerung der Jahre 2011 und 2012 im Bereich BERTA

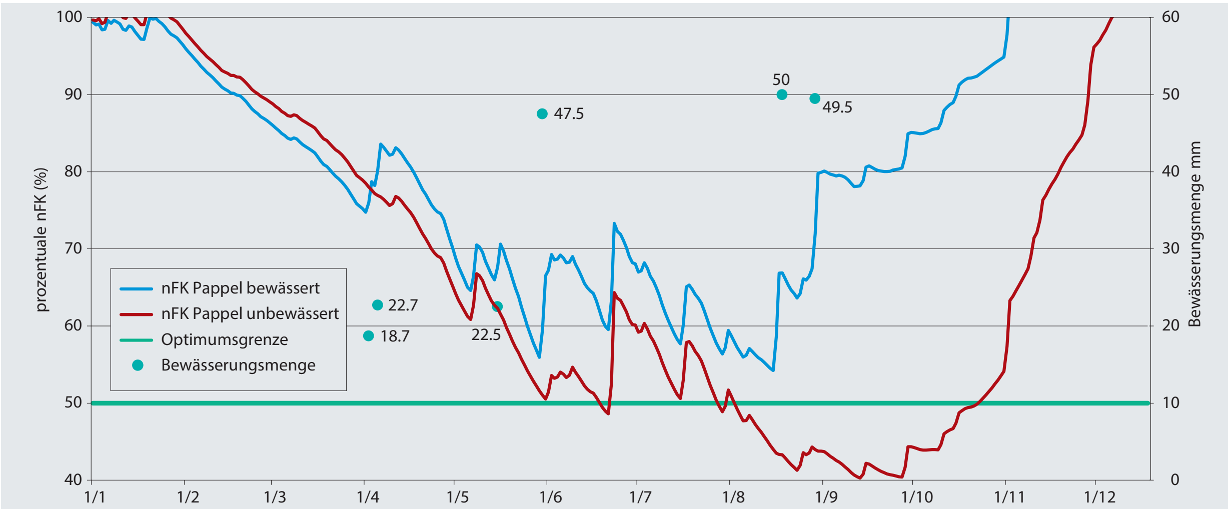


Abbildung 8
Entwicklung der prozentualen nutzbaren Feldkapazität in einer Bodenprofiltiefe von 10 bis 180 cm auf der Versuchsfläche Pappel „BERTA I" 2012

3.2 Belaubung

Nach den Untersuchungen von Kramer (1996) und Hänninen (1990) ist der wesentliche Faktor für den Blattaustrieb die Temperatur. Zudem stellte Peñuelas et al. (2004) fest, dass Niederschläge und Wasserverfügbarkeit maßgeblich die phänologische Entwicklung beeinflussen. Dadurch ist die Phänologie auch zwischen temperatur- und wasserinduziert zu unterscheiden. Der herbstliche Blattfall wird durch niedrigere Temperaturen und der Blattfall innerhalb der Vegetationsperiode durch Wassermangel hervorgerufen.

Nach Abbildung 9 trieben 2012 die Pappeln früher aus als die Weiden. Innerhalb der Baumart ist bei den Pappeln kein Unterschied bezüglich des Blattaustriebes zwischen bewässerten und unbewässerten Individuen zu erkennen. Der Blattaustrieb der Weiden unterscheidet sich gering. Im Zeitraum vom 19.03. bis 14.05.12 liegt nach Abbildung 8 die prozentuale nFK der Pappelparzellen in einem Bereich von 84 bis 65 % (bewässert) und 84 bis 61 % (unbewässert). Die prozentuale nFK der Weide liegt zwischen 86 bis 70 % (bewässert) und 81 bis 61 % (unbewässert). Auf allen Versuchsflächen liegt eine ausreichende Wasserversorgung vor. Durch diese geringen Unterschiede in den Bodenwassermengen weisen bewässerte und unbewässerte Individuen der beiden Baumarten auch einen ähnlich verlaufenden Blattaustrieb auf.

Der Blattfall ist weitaus differenzierter als der Blattaustrieb. Die bewässerten und unbewässerten Weiden verlieren schon bis zum 25.07.12 20 % der gesamten photosynthetisch aktiven Blattmasse (PAB) (Abbildung 10). Die bewässerten Pappeln verlieren nur einen unwesentlichen Anteil der PAB bis zum herbstlichen Blattfall.

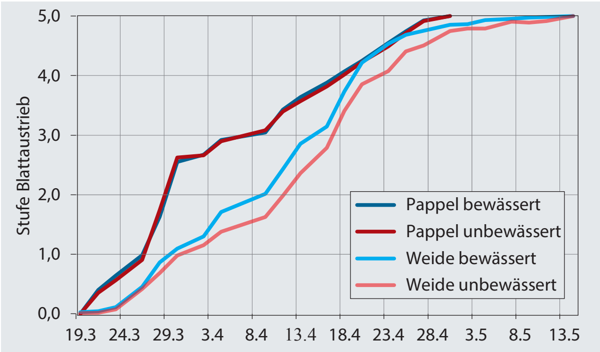


Abbildung 9
Verlauf des Blattaustriebes „BERTA I" 2012

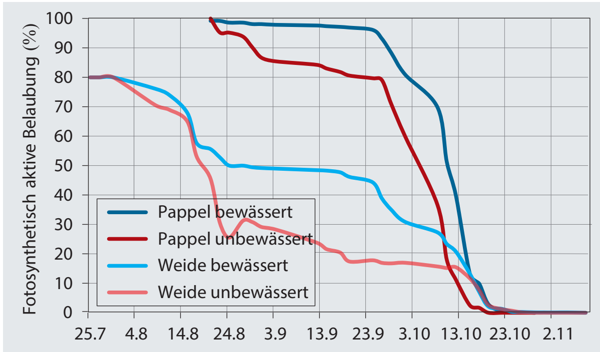


Abbildung 10
Verlauf des Blattfalls „BERTA I" 2012.

Eine Verringerung (20 %) der PAB ist bei der unbewässerten Pappel vom 21.08. bis zum 24.09.12 zu erkennen. Am 20.08. beträgt die prozentuale nFK auf der unbewässerten Pappel-Versuchsfläche noch 42 %, was als Initial des Blattfalls innerhalb der Vegetationsperiode angesehen werden kann. Zum gleichen Zeitpunkt liegt die nFK der bewässerten Pappel bei 65 % und ist als optimal anzusehen. Durch die Unterschiede in der Bodenwasserverfügbarkeit setzt der Blattfall bei der unbewässerten Pappel früher ein als bei der bewässerten. Der intensive herbstliche Blattfall (temperaturinduziert) der bewässerten und unbewässerten Pappeln beginnt in der vierten Septemberdekade. Bei der unbewässerten Pappel endet der Blattfall am 15.10.12, bei der bewässerten am 19.10.12 (Abbildung 10). Das bedeutet, dass der herbstliche Blattfall bei der bewässerten Pappel etwa vier Tage länger dauert als bei der unbewässerten.

Bei der bewässerten und unbewässerten Weide beginnt der herbstliche Blattfall (temperaturinduziert) am 17.08.12 und endet am 19.10.12 (Abbildung 10). Durch den starken Verlust von Blattmasse bei den bewässerten und unbewässerten Weiden vor dem 17.08.12 ist davon auszugehen, dass die Grenze des Optimums der Wasserversorgung höher liegen muss als bei den Pappeln. Die PAB der bewässerten Weide sinkt bis zum 24.08.12 stärker ab als die PAB der bewässerten. Jedoch endet der Blattfall auf beiden Versuchsflächen zum gleichen Datum. Keine Unterschiede sind bei der Dauer des Blattfalls zwischen den bewässerten und unbewässerten Weiden festzustellen. Die PAB der unbewässerten sinkt aber bis zur vierten Augustdekade weitaus stärker ab als bei der bewässerten. Eine sehr starke Minderung der PAB ist bei der bewässerten Weide erst in der dritten Septemberdekade festzustellen.

Insgesamt ist einzuschätzen, dass die bessere Bodenwasserversorgung der bewässerten Pappeln die Verringerung der PAB verzögert. Die unbewässerten Weiden vermindern schneller ihre PAB als die bewässerten, jedoch sind keine Unterschiede in der Gesamtdauer des Blattfalls festzustellen.

Nach Dammann et al. (2010) besteht ein direkter Zusammenhang zwischen der Wasserverfügbarkeit und der gebildeten Blattbiomasse. Bei Wasserstress war an den untersuchten Bäumen eine reduzierte Blattmasse festzustellen.

Die bewässerten Pappeln und Weiden auf „BERTA I" produzierten im Jahr 2012 mehr Blattbiomasse als die unbewässerten (Abbildung 11). Dabei ist bei der Pappel nur ein leichter Bewässerungseffekt zu erkennen. Die bewässerten Weiden bildeten 23 % mehr Blattmasse als die unbewässerten Individuen aus. Es ist also ein größerer Bewässerungseffekt bzgl. der Entwicklung der Blattmasse bei den Weiden als bei den Pappeln festzustellen.

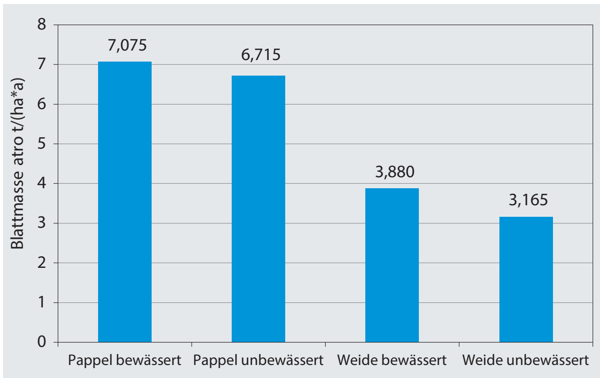


Abbildung 11
Gebildete Blattmasse auf „BERTA I" 2012

Auf den Versuchsparzellen „BERTA II" bildeten die bewässerten Pappeln fast dreimal so viel Blattmasse wie die unbewässerten (Tabelle 7). Die bewässerten Weiden produzierten nur eine etwa doppelt so große Blattmasse wie die unbewässerten.

Tabelle 7
Blattmassen auf „BERTA II" 2012

Versuchsfläche	Blattmasse (t_{atro} / ha *a)
Pappel bewässert	3.86
Pappel unbewässert	1.37
Weide bewässert	0.55
Weide unbewässert	0.27

Der Vergleich zwischen den Versuchsflächen lässt den Schluss zu, dass die jüngeren Bestände („BERTA II“) eine größere Reaktion bezüglich der Blattmassenentwicklung auf eine Zusatzbewässerung zeigen als die älteren („BERTA I“). Beispielsweise bildete die ältere bewässerte Pappel nur 5 % mehr Blattmasse aus als die unbewässerte. Die jüngere bewässerte Pappel weist im gleichen Jahr eine fast dreimal so große Blattmasse auf wie die unbewässerte.

Insgesamt reagieren die jüngeren Bestände durch die Ausbildung einer höheren (relativen) Blattmasse weitaus sensibler auf Bewässerungsmaßnahmen als die älteren.

3.3 Wachstum

Die innerjährliche Änderung des Stammdurchmessers wird an repräsentativen Individuen der Kraft´schen Klassen I und II gemessen. In Abbildung 12 ist eine klare Differenzierung der Entwicklung des Stammdurchmessers zwischen Pappeln und Weiden zu erkennen. Innerhalb der Vegetationsperiode 2012 weisen die Pappeln eine größere Änderung des Stammdurchmessers auf als die Weiden. Bei einem Vergleich zwischen den bewässerten und unbewässerten Beständen bildete jedoch die Weide relativ mehr Stammholz als die Pappel. Die Änderung des Stammdurchmessers der Weide (4,1 mm) ist demnach mehr als doppelt so hoch als bei der Pappel (1,7 mm). Insgesamt wiesen die bewässerten Individuen in der Vegetationsperiode 2012 eine größere Durchmesseränderung auf als die unbewässerten.

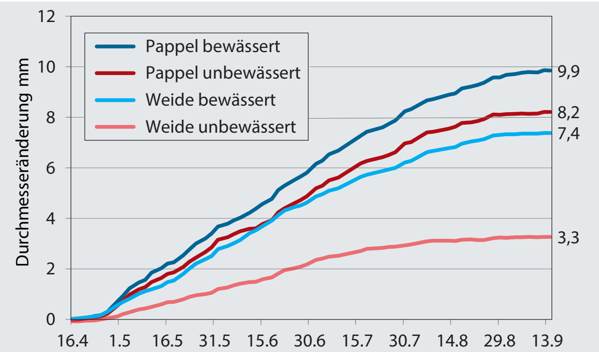


Abbildung 12
Kumulierte Stammdurchmesseränderung an ausgewählten Messbäumen auf „BERTA I“ 2012

Die Höhenänderung der Pappel auf den Versuchsparzellen „BERTA II“ (Abbildung 13) beginnt etwa einen Monat später als der Blattaustrieb (vgl. Abbildung 9). Die Höhenänderung der Weide beginnt wesentlich später (ca. drei Monate) als der Blattaustrieb. Trotz der intensiven Frostschäden der Weide und dem damit verbundenen Absterben des Terminaltriebes können nur sehr geringe Unterschiede zwischen den Baumarten festgestellt werden. Die bewässerten Bäume sind bei beiden Baumarten 65 bis 70 % höher als die unbewässerten. Dies lässt bezüglich der Höhenentwicklung auf einen Bewässerungseffekt und eine ähnliche Sensitivität auf Bewässerungsmaßnahmen schließen.

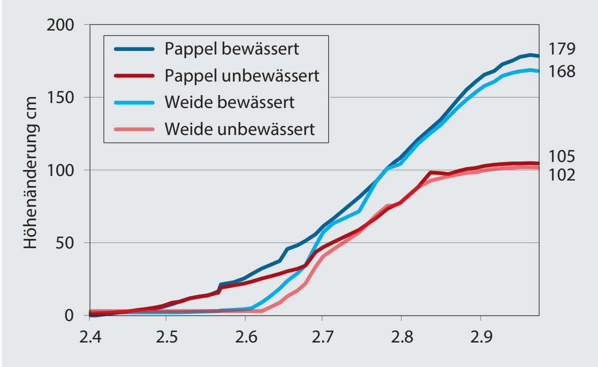


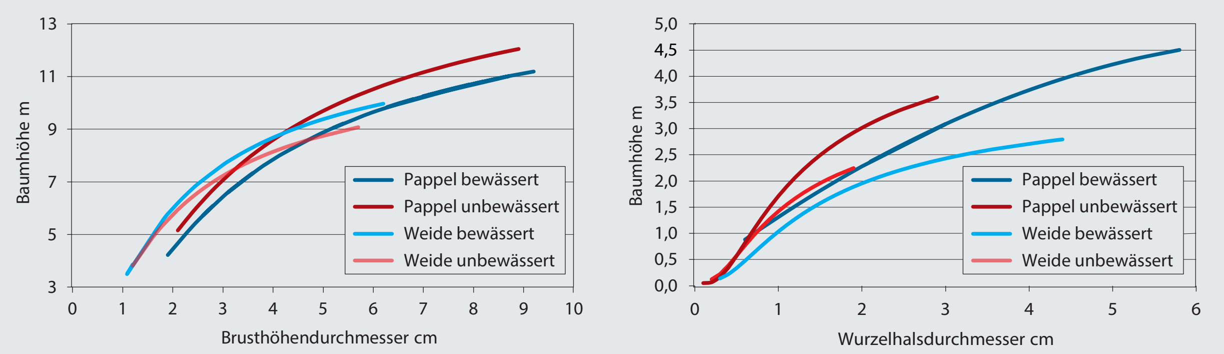
Abbildung 13
Kumulierte Baumhöhenänderung an ausgewählten Messbäumen auf „BERTA II“ 2012

In Abbildung 14 ist zu erkennen, dass die Bestandes-Höhenfunktion aller Baumarten einen ähnlichen Verlauf hat. Bei gleichen BHD weisen alle Baumarten ähnlich große Baumhöhen auf wie die bewässerten. Hinsichtlich der Ausbildung einer größeren Bestandeshöhe bei gleichem BHD kann also keine Bewässerungswirkung festgestellt werden. Bei der Pappel ist dieser Effekt nicht feststellbar. Die bewässerten Pappeln und Weiden auf „BERTA II“ zeigen im Verhältnis zwischen dem Stammdurchmesser und der Baumhöhe einen deutlichen Bewässerungseffekt. Bei gleichem WHD weisen die bewässerten Bestände eine größere Baumhöhe auf als die unbewässerten.

Nach Shinozaki et al. (1964) ist die Blattfläche mit dem Stammdurchmesser korreliert. Eine größere Blattfläche äußert sich in einer höheren Blattmasse. Durch die weitaus höheren Blattmassen (Tabelle 7) der bewässerten Bestände auf „BERTA II“ bildeten die Bäume im Verhältnis mehr Stammbiomasse. Bei den bewässerten Beständen ist von 2011 bis 2012 ein größerer Grundflächenmittelhöhen-Zuwachs als bei den unbewässerten berechnet worden (Tabelle 8). Ein Bewässerungseffekt, der die Baumhöhen beeinflusst, ist erkennbar. Es ist ein größerer relativer Höhenzuwachs bei den jüngeren Beständen festzustellen. Die relativen Stammholzvolumen-Zuwächse sind bei den jüngeren Beständen viel größer als bei den älteren.

In Abbildung 15 ist die Effizienz des Wassereinsatzes in den fünfjährigen Pappeln und Weiden dargestellt. Bei beiden Baumarten ist eine Verringerung der Effizienz (WE) bei zunehmender Niederschlagsmenge (Bestandesniederschlag + Menge an Zusatzbewässerung) zu erkennen. Die Pappel weist bei geringerem Niederschlag im Vergleich zur Weide eine größere WE auf. Die Wassernutzungseffizienz der Weide bleibt im Vergleich zur Pappel relativ konstant. Eine größere WE bei geringen Niederschlägen weist die Pappel im Vergleich zur Weide auf.

Die WE der jungen Pappeln und Weiden zeigen nach Abbildung 16 einen anderen Verlauf. Bei einer Zunahme der Niederschlagsmenge erhöht sie sich bei beiden Baumarten. Die Effizienzsteigerung ist bezüglich der Bildung des Stammholzvorrates bei größeren Niederschlagsmengen bei der Pappel stärker ausgeprägt als bei der Weide (Abbildung 16).



BERTA I	a_1	a_2	R^2
Pappel bewässert	16,583	-3,675	0,9510
Pappel unbewässert	18,612	-4,281	0,9085
Weide bewässert	11,262	-1,673	0,8550
Weide unbewässert	11,190	-1,850	0,9372

BERTA II	a_1	a_2	R^2
Pappel bewässert	5,867	-1,947	0,7538
Pappel unbewässert	3,677	-1,369	0,8924
Weide bewässert	5,291	-1,158	0,8847
Weide unbewässert	3,679	-1,024	0,8493

Abbildung 14
Bestandes-Höhenfunktionen „BERTA I (links) und BERTA II (rechts) 2012

Tabelle 8
Höhenzuwachs und Zuwachs des Stammholzvolumens 2012

	h_m 2011 (m)	Vorrat 2011 (Vfm/ha)	h_m 2012 (m)	Vorrat 2012 (Vfm/ha)	Höhenzuwachs (m)	Zuwachs Vorrat (%)
BERTA I						
Pappel bewässert	9,38	160,733	10,71	222,088	14,2	38,2
Pappel unbewässert	10,31	186,717	11,03	236,430	6,7	26,6
Weide bewässert	7,04	73,450	8,02	116,796	13,9	44,4
Weide unbewässert	6,11	52,160	6,88	76,540	12,6	45,6
BERTA II						
Pappel bewässert	1,19	0,531	3,55	12,204	198,3	2.198,3
Pappel unbewässert	1,01	0,331	2,20	3,998	117,8	1.107,9
Weide bewässert	0,94	0,318	2,33	3,054	147,9	860,4
Weide unbewässert	0,77	0,170	1,37	0,806	77,9	374,1

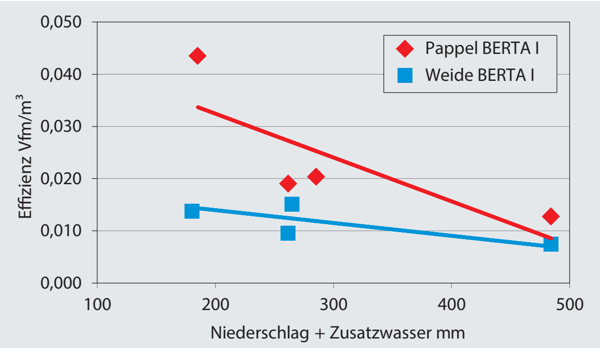


Abbildung 15
Effizienz der Wassernutzung von Pappel und Weide BERTA I

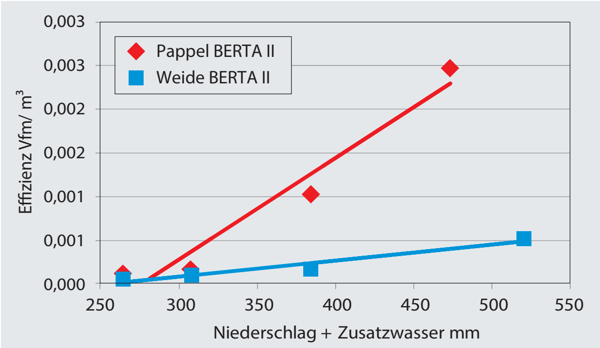


Abbildung 16
Effizienz der Wassernutzung von Pappel und Weide BERTA II

4 Diskussion und Schlussfolgerung

Giovanelli et al. (2007) stellte fest, dass einjährige, bewässerte Pappeln einen größeren Radialzuwachs haben als unbewässerte. Diese Aussage trifft nicht nur auf einjährige Bestände, sondern auch auf mehrjährige bewässerte Pappeln zu. Nach unseren Untersuchungen weisen die bewässerten KUP nach Abbildung 12 einen größeren Radialzuwachs auf als unbewässerte.

Die bewässerten Pappeln und Weiden jeden Alters bildeten auf den untersuchten Flächen größere Grundflächenmittelhöhen-Zuwächse aus als die unbewässerten. Die Untersuchungen von Murach et al. (2008) belegen, dass sich die Baumhöhen von fünf Jahre alten Pappeln und vierjährigen Weiden im Kurzumtrieb bei einer Steigerung des Transpirationswasserangebotes relativ vergrößern. Dies bestätigen die eigenen Untersuchungsergebnisse. Pappeln und Weiden entwickeln bei einer Zunahme des Wasserangebotes auch relativ größere Baumhöhen (Tabelle 8).

Die Ausbildung einer größeren Biomasse bei einer höheren Evapotranspiration stellten Fischer et al. (2010) bei einer siebenjährigen Pappelplantage und Linderson et al. (2007) bei einer dreijährigen Weidenplantage (Tordis) fest. Busch (2009) und Lamersdorf und Schulte-Bisping (2010) stellten eine Zunahme der aktuellen Evapotranspiration bei einer Zunahme des jährlichen Niederschlages bei drei- bis neunjährigen Pappeln und Weiden fest. Das bedeutet, dass sich bei einer höheren Wasserverfügbarkeit durch die steigende Transpiration auch größere Bestandes-Biomassen ausbilden. Nach unseren Ergebnissen sind bei allen Versuchsflächen relativ höhere Biomassen (Stammholzvorrat) bei einer höheren Wasserverfügbarkeit festzustellen, was die Untersuchungen von Linderson et al. (2007) und Fischer et al. (2010) bestätigt.

Zudem stellte Busch (2009) fest, dass drei- bis neunjährige Weiden bei einer Zunahme des jährlichen Niederschlages eine höhere Evapotranspiration haben als gleichaltrige Pappeln und damit im Verhältnis mehr Biomasse bilden. Für die älteren Bestände (BERTA I) trifft dies zu. Die Effizienz der Wassernutzung bei der Weide sinkt bei einer größeren Wasserverfügbarkeit weitaus geringer ab als bei der Pappel. Das bedeutet, dass die Weide bei einem höheren Wasserangebot mit einem relativ stärkeren Biomassezuwachs (Stammholzvorrat) reagiert als die Pappel. Für die jüngeren Bestände (BERTA II) ist dies nicht zutreffend. Die Pappeln weisen eine viel stärkere Erhöhung der Biomasse (relativer Stammholzvorrats-Zuwachs) bei einer Zusatzbewässerung auf als die Weiden. Nach Abbildung 16 kann dies ebenfalls mit der größeren Erhöhung der Wassernutzungseffizienz bei einer steigenden Wasserverfügbarkeit der Pappel im Vergleich zur Weide erklärt werden.

Für einen weiterführenden Vergleich der Nettoprimärproduktion zwischen den einzelnen Beständen wird zum Projektabschluss die Bestandes-Biomasse mit Hilfe der destruktiven Regressionsmethode (Röhle 2009) durchgeführt.

Nach Petzold et al. (2010) ist eine Bewässerung von Pappeln und Weiden im Kurzumtrieb in den ersten zwei Jahren für die Reduktion des Ausfallrisikos sinnvoll, jedoch aber nicht zum Zweck der Ertragssteigerung geeignet. Die Wassernutzungseffizienz verschlechtert sich bei zunehmendem Wasserangebot. Bei einer Bewässerung einer fünfjährigen Pappel und Weide trifft diese Aussage für die eigenen Versuchsflächen zu. Für Pappeln und Weiden in der Etablierungsphase ist eine größere Effizienz der Wassernutzung bei einer Erhöhung der Niederschlagsmenge festzustellen. Nach Murach et al. (2008) weisen Pappeln (vierjährig) und Weiden (dreijährig) einen linearen positiven Verlauf der gebildeten Biomasse bei einer Erhöhung der Wasserverfügbarkeit auf. Das bedeutet, dass die Wassernutzungseffizienz gleich bleibt. Dies kann für die eigenen Versuchsflächen nicht bestätigt werden. Die Effizienz der untersuchten älteren Pappeln und Weiden sinkt bei steigendem Wasserangebot.

Von den Ergebnissen einer größeren Biomasseproduktion bei Zusatzwassergabe der untersuchten KUP´s profitieren lokale Akteure in der BERTA-Region. In der Ortslage Gierstädt werden durch ein Unternehmen Hackschnitzel aus KUP zur Wärmegewinnung genutzt. Bei einer Flächengröße von ca. 6,5 ha (Summe aus Pappel und Weidenfläche BERTA) ist es möglich, aus der gebildeten Holzbiomasse einer Pappel-KUP, die sich im zweiten Anlagejahr der ersten Rotation befindet, ca. 135 MWh[2] (67,5 MWh/Jahr) Wärmeenergie zu produzieren. Nach Aussagen des Unternehmers C. Fleischmann (2013) wird im Unternehmen 1.200 MWh Wärmeenergie pro Jahr produziert. Das bedeutet, dass der Bedarf des Blockheizkraftwerkes in Gierstädt an Biomasse zu 6 % durch die Pappel-KUP mit einer zusätzlichen Abwasserbewässerung gedeckt werden kann. Nach Steinke (2009) weisen KUP in der ersten Rotation die geringsten Erträge auf. Untersuchungen der Wirkung von zusätzlichen Abwassergaben auf die Biomasseerträge von KUP in weiteren Rotationen sind deshalb notwendig.

Die Technik der Zusatzwassergabe mit dem Abwassertransport eines Tankwagens stellt in der jetzigen Form keine betriebswirtschaftlich optimale Lösung dar. Für ein optimales Pflanzenwachstum müssen die festgelegten Grenzen des Bodenwassers eingehalten werden. Durch den größeren Wasserverbrauch von KUP sind im Vergleich von herkömmlichen Ackerkulturen größere Zusatzwassermengen erforderlich. Für eine großflächige Bewässerung wäre es sinnvoll, Speicheranlagen in der Nähe des Bewässerungsortes zu nutzen oder neu anzulegen. Rekonstruierte Feuerlöschteiche bzw. neuangelegte Folienbecken könnten sich für die Abwasserspeicherung anbieten. Die Befüllung der Speicheranlage wird durch einen Tankwagen oder ein vom Klärwerk verlaufendes Rohrleitungssystem durchgeführt. Für eine Bewässerung von 1,7 ha Nutzfläche (BERTA II) mit einer Bewässerungsmenge von 20 mm ist ein Speichervolumen von 340 m^3 erforderlich. Bei einem Bewässerungsturnus von zehn Tagen und einer Zusatzwassergabe von 20 mm pro Turnus im Zeitraum April bis August würden insgesamt ca. 300 mm biologisch geklärtes Abwasser zum Einsatz kommen. Hierzu sind noch weitere Untersuchungen in Zusammenhang mit der Nutzungseffizienz des eingesetzten

[2] Berechnung des Heizwertes von Pappelholz mit einem Wassergehalt von > 50 % (1.525 KWh/fm) nach Hahn und Schardt (2007)

zusätzlichen Abwassers und dem Mehrertrag an Nettoprimärproduktion notwendig.

Für die Wirtschaftlichkeit des Abwassereinsatzes wäre es sinnvoll:

- Die Kosten für den Abwassertransport durch die Anlage von KUP-Flächen in der Nähe der Abwasserkläranlage zu minimieren.
- Vorhandene Speicheranlagen zur Zwischenspeicherung des Abwassers in der Nähe von KUP zu nutzen.

Für die Gewährleistung eines optimalen Pflanzenwachstums ist für die Ermittlung des Zeitpunktes und der Menge der Zusatzwassergabe die Anwendung eines Wasserhaushaltsmodells ratsam. Das erfordert die Bereitstellung von Witterungs-, Boden- und Vegetationsparametern.

5 Danksagung

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Bio-based plastics: status, challenges and trends

Henning Storz* and Klaus-Dieter Vorlop*

Abstract

The increasing concern about diminishing fossil resources and the impacts of the global warming is driving the growth of the new bioeconomy. Bioplastics, thermoplastic biopolymers that are either biodegradable or at least partly bio-based, are one of the fastest growing markets. The average growth rates over the past years have constantly been double-digit. Though the production capacities are small, currently approximately 0.5 % of the global plastics productions, recent market forecasts expect a sharp rise in the upcoming three years. Due to identical property profiles and established recycling processes, the largest growth is expected for partly bio-based conventional plastics, especially for bio-PET.

This development was made possible by numerous innovations in the fields of chemical catalysis, biotechnology, and plastics engineering. It reflects an ongoing change in the bio-plastic industry, which increasingly focuses on the production of durable, bio-based plastics, after years of concentration on biodegradable plastics used for niche applications. But also the markets for bio-based and biodegradable plastics are expected to continue their rapid growth.

This article reviews advances in production processes and material properties of selected bio-based plastics. It focuses on the most important bio-based plastics with established production and commercial applications. It furthermore provides an overview of new applications, and trends, as well as of major producers.

Keywords: *Bio-based plastics, biopolymers, renewable resources, bioeconomy*

Zusammenfassung

Bio-basierte Kunststoffe: Status, Herausforderungen und Trends

Die zunehmende Besorgnis über abnehmende fossile Ressourcen und die Auswirkungen der Klimaerwärmung fördert das Wachstum der Bioökonomie. Der Markt für Biokunststoffe, thermoplastische Biopolymere, die entweder biologisch abbaubar oder wenigstens teilweise bio-basierten Ursprungs sind, ist einer der am schnellsten wachsenden. Obwohl die Produktionskapazitäten von Biokunststoffen gegenwärtig noch klein sind, ca. 0,5 % der globalen Kunststoffproduktion, gehen aktuelle Marktprognosen von einem sprunghaften Anstieg in den kommenden drei Jahren aus. Aufgrund identischer Eigenschaften und etablierter Recyclingprozesse wird das größte Wachstum für bio-basierte konventionelle Kunststoffe wie bio-PET erwartet.

Möglich wurde diese Entwicklung durch Innovationen in den Bereichen der chemischen Katalyse, der Biotechnologie und der Kunststofftechnik. Sie spiegelt einen andauernden Wandel der Kunststoffindustrie wider, die sich zunehmend auf die Produktion nicht bio-abbaubarer Biokunststoffe konzentriert, nachdem der Fokus viele Jahre lang auf biologisch abbaubaren Kunststoffen für Nischenanwendungen lag. Aber auch für die Märkte der bio-abbaubaren Biokunststoffe wird erwartet, dass das schnelle Wachstum ahnält.

Dieser Artikel gibt einen Überblick über ausgewählte bio-basierte Kunststoffe mit Schwerpunkt auf Fortschritten in den Bereichen Produktion und Materialeigenschaften. Er konzentriert sich auf die wichtigsten bio-basierten Kunststoffe mit bereits etablierter Produktion und kommerziellen Anwendungen. Darüber hinaus werden neue Anwendungen, aktuelle Trends und wichtige Produzenten vorgestellt.

Schlüsselwörter: *Bio-basierte Kunststoffe, Biopolymere, Nachwachsende Rohstoffe, Bioökonomie*

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1 Introduction

Steadily growing since 1950, the worldwide production of plastics materials has reached 288 million tons in 2012 (Plastics Europe, 2013). Germany is one of the most important actors on the plastic markets and the biggest manufacturer and processor of plastics in the EU. In 2012, the German plastic industry produced 19.5 million tons of plastics and generated a revenue of 25.1 billion euros (Plastics Europe Deutschland, 2013).

Large amounts of petroleum, approximately 7 % of the global production, are used for the production of plastics (Bozell, 2008). Consequently, today's (renewable) energy debate is also impacting the plastics industry. The challenges are well known and essentially the same that underlie the energy debate. Namely fossil resources, especially petroleum and gas, are of finite availability and have volatile and steadily increasing prices. An additional pressure on decision makers is generated by the growing political and public concern about the environmental impacts related with the increasing utilization of plastics.

Although energy is the primary issue when it comes to the impacts of the depletion of fossil resources, the size of the challenge for the plastic industry is bigger than it might seem. Unlike for the energy issue, there is only one renewable alternative for the production of plastics and bulk chemicals, and that is the use of biomass. The approach of using biomass for the production of plastics is not a new one. The production of the first modern artificial polymer, celluloid, and the vulcanization of rubber, were already sophisticated and quite mature processes at the beginning of the last century. However, in the course of the petrochemical revolution, the markets for plastics based on renewable resources have lost their importance to the petroleum based plastics we are using today.

Though the physical and functional diversity of plastics seems enormous, 64 % of the processed volume is accounted by five commodity plastics, namely polyethylene (PE), polypropylene (PP), poly(vinylchloride) (PVC), poly(styrene) (PS), and poly(ethylene terephthalate) (PET) (Figure 1). The remaining volume is accounted for by other engineering plastics like polyamides and polyurethanes and others. The largest share of the processed volume of plastics is used in the packaging and construction sector, followed by automotive and electronics applications.

Plastics have become an essential part of modern life and offer great economic, ecologic, and social benefits: Examples are functional packagings that reduce food spoilage, lightweight plastic components that lower the fuel consumption of vehicles and aircrafts, and highly efficient insulation foams that enable us to build zero-energy buildings. Except the lack of renewability of their precursors there is nothing wrong with the plastics we are using today.

Thus, changing the raw material base to bio-based feedstocks represents an appealing solution for many in the plastic industry. Accordingly, many companies have outlined the production of bio-based plastics as an objective in the past three decades. The result of the related research activities is a very diverse range of "bioplastics" which make it difficult to define general characteristics. For clarity here a basic definition: A bioplastic is a plastic material that is either bio-based (partially or completely), biodegradable or features both properties. The focus of this review is in bio-based plastics which are necessarily at least partly derived from renewable resources but do not have to be biodegradable.

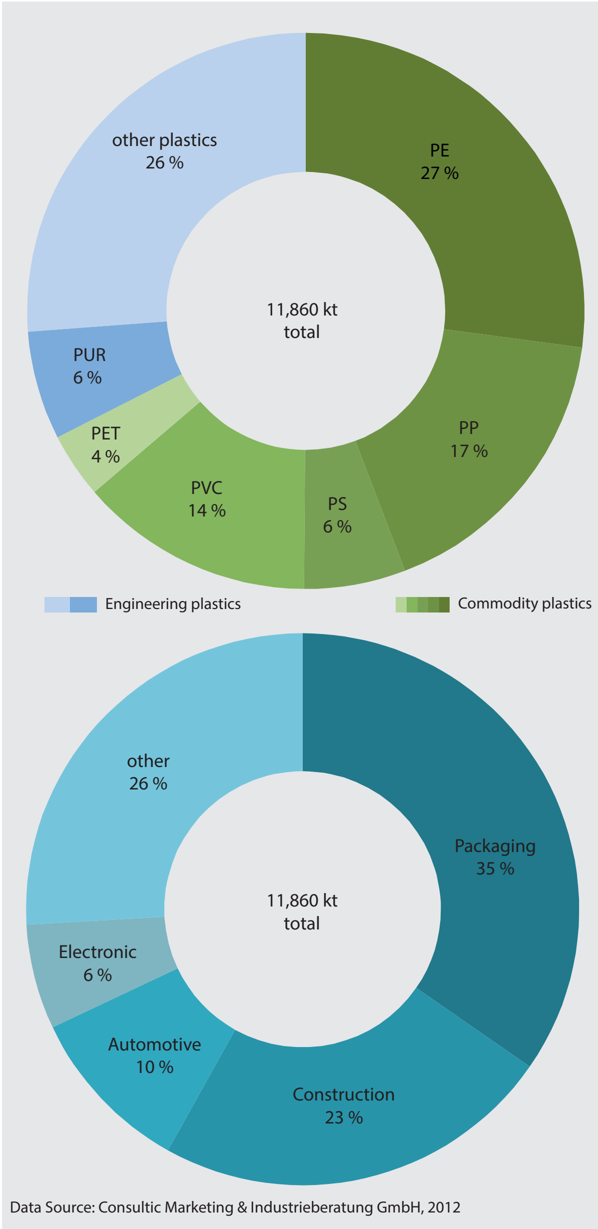

Figure 1
In Germany processed plastics 2011 – above: by type; below: by sector

The first bio-based products introduced to the markets were poly(hydroxyalkanoate) produced by ICI (Great Britain) in the 1980s. Their development was driven by the increasing demand for biodegradable plastics for packaging and agricultural applications. Due to high prices and the lack of essential properties required for main applications, these first products never penetrated important markets. However, the interest in bio-degradable products remained high and the number of applications rapidly grew beyond the originally very limited number of simple packaging applications. Biodegradable products with improved material properties were developed in the 1990s. Some of these were completely petroleum-derived, which gave rise to some irritations among consumers.

In the late 1990s, the interest in bioplastics shifted towards the use of renewable raw materials. In 2001, *NatureWorks LLC* was the *first* company that produced a completely bio-based plastic (poly(lactic acid)) in large quantities (USA, 140 ktpa). Since then, the production of many bio-based plastics has been demonstrated at pilot and demo scale. Some of the products are conventional plastics like PE and PVC, others are partly bio-based (e.g. polyols, polyamides), and some of them are entirely new plastics such as poly(lactic acid). Partly bio-based plastics often require petrochemical monomers that cannot be resembled by bio-based replacements, at least not at a reasonable price. Today's bio-based plastics are sophisticated materials which could technically be a substitute for around 90 % of the plastics we use today (Shen et al., 2010).

At present, however, high price levels and low production capacities of bio-based plastics prevent deeper market penetration. According to a recent forecast, the production capacities of bio-based plastics approximately correspond to 0.5 % of the global plastic production (European Bioplastics, Institute for Bioplastics and Biocomposites, 2013; Plastics Europe, 2013). Though this is a rather small share, numerous commercial successes and ongoing commercializations impressively show the rapidly progressing change in the plastic industry towards bio-based products. If this development continues, bio-based plastics are likely to become an important pillar of the future bio-economy.

This article reviews recent advances in the development, production, and application of a selection of bio-based plastics including novel plastics, like thermoplastic starch and poly(lactic acid), as well bio-based versions of conventional plastics. The key selection criteria for the bio-based plastics discussed, are expected med-term production volumes and usage. Important progress in the development and diversification of material properties of novel bio-based plastics is described and compared with the properties of the conventional plastics they could substitute.

2 Production of bio-based plastics

Bio-based plastics can be obtained via three principal routes (Figure 2). The first approach is by modification of natural polymers while preserving the polymer backbone (mainly) intact. This is the most important approach today, used for the production of starch and cellulose-based plastics and for various other bio-based polymers and fibers used in non-plastic and non-food applications.

The second way comprises a two-step biomass conversion approach starting with the production of bio-based precursors (monomers) by means of biochemical and/or chemical transformation followed by the polymerization of the monomers in the final step (both steps are normally complex and can be divided in several sub-steps). If the monomers obtained are bio-based versions of conventional monomers they are called drop-in (replacements). Conventional plastics produced using drop-in monomers are advantgeous, because they cannot be distinguished, neither structurally nor by performance, from their petrochemical counterparts. Hence, they can readily enter existing processing and recycling systems. A good example is bio-based PE prepared from bio-ethanol derived ethylene.

Bio-based monomers that have new structures or have not been applied to the markets in the past are also used to produce plastics. These "novel" bio-based plastics often have

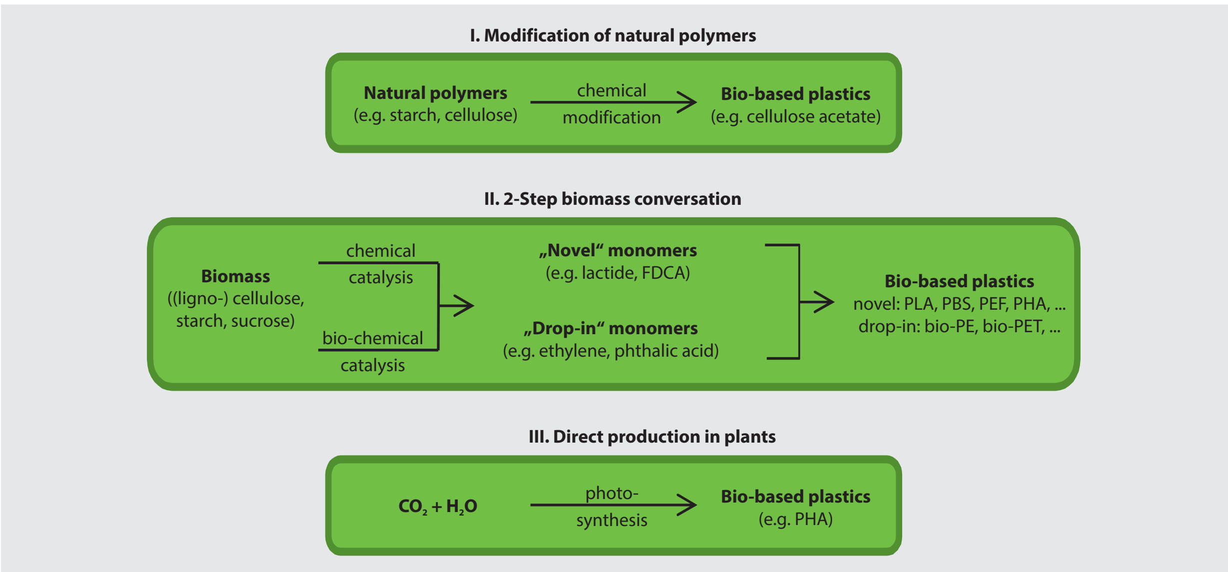

Figure 2
Principal routes to bio-based plastics

different properties. Compared to the standard plastics which they could replace, they often show an improved functionality and thus additional markets and applications. However, in contrast to drop-in plastics, novel bio-based plastics require the development and implementation of new recycling systems.

This second approach to bio-based plastics is constantly gaining importance due to the advancements in the chemical and bio-technological production of monomers.

The third route comprises the production of a polymeric material, which can be used as a plastic without further modification, directly in microorganisms or plants. Because of the progress in genetic engineering and biotechnology which enables to move genes responsible for the production of a polymer like poly(hydroxyalkanoate) (PHA) from bacteria into crops, this route is becoming more feasible. However, as favorable as direct production of bio-based plastics via photosynthesis may seem, as complex are the related environmental and regulatory issues. Although this route has been intensively studied for many years now, no notable quantities of bio-based plastics have been produced accordingly.

2.1 Plastics from natural polymers

Polymers are very common in nature and used in many industrial processes. By the annually produced volume, cellulose, chitin, and lignin are most abundant. Currently, lignin and chitin have no notable commercial applications as plastic materials, but their use as filler for rubber and thermoplastics and as prepolymers is being intensively studied (Chen et al., 2012; Doherty et al., 2011; Hatakeyama H and Hatakeyama T, 2010; Nandanwar et al., 2012; Srinivasa and Tharanathan, 2007).

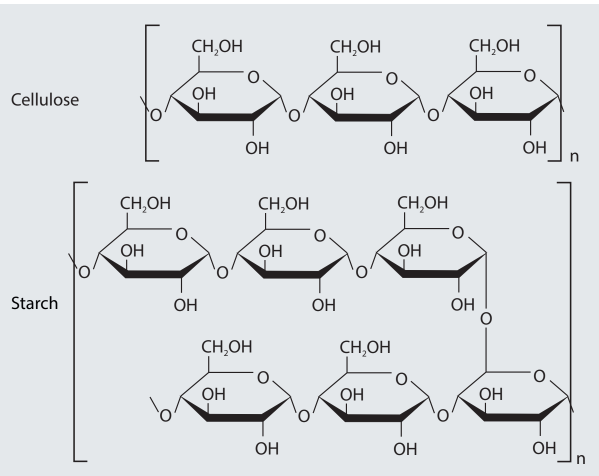

Figure 3
Structure of cellulose and starch

Among the natural polymers, only cellulose and starch are used for the industrial production of bio-based plastics. Their production is in accordance with route I (Figure 2). Though their monomeric building blocks are very similar (Figure 3), they exhibit very different properties. Starch and cellulose have in common that they cannot be processed as a thermoplastic material without prior modification.

2.1.1 Plastics from starch

Starch is a polysaccharide produced by green plants for the storage of energy. Due to its semi-crystalline structure, which undergoes thermal degradation before the melting point is reached, native starch cannot be applied to thermoplastic processing.

A bio-based plastic that is based on starch is thermoplastic starch (TPS). It can be prepared from starch granules by mixing and heating them in the presence of one or more plasticizers, typically water and glycerol, in a process called destructurization. TPS is an attractive bio-based material because starch is cheap, biodegradable, and abundantly available in large volumes. Furthermore, TPS is processable with common equipment. However, TPS is very hydrophilic which renders it unsuitable for applications in humid environments (Liu et al., 2009). This currently limits the applicability of TPS to niche products like fast dissolving dishwasher tabs or adhesive tapes. Several solutions to improve the properties of TPS were developed including the use of less volatile and less water sensitive plasticizers like sorbitol or xylitol and the addition of suitable hydrophobic fillers like lignin (Fang and Hanna, 2000; Kaewtatip and Thongmee, 2013; Li and Huneault, 2011; Rahmat et al., 2009).

Blending TPS and starch with hydrophobic plastics has extended their use as plasctic materials. The hydrophobic component prevents the direct uptake of water and increases the water resistance significantly. Via the variation of the plasticizer content the material properties can be adjusted. Because most hydrophobic polymers are incompatible with starch, the maximum starch content of blends is limited to approximately 25 to 30 %. Higher contents can be achieved by reactive blending in the presence of compatibilizers, which covalently link the components (Kalambur and Rizvi, 2006). Blends with conventional and bio-based polymers have been intensively investigated (Nayak, 2010; van der Burgt et al., 1996; Willett and Shogren, 2002).

Today, various commercial grades are available. Primarily, these are polyester-based blends used for short-lived biodegradable products like bags, packaging films, agricultural mulch films and protection foams. But also non-biodegradable starch-polyolefin blends have been commercialized. Cereplast (USA) offers PE and PP TPS blends that are targeted for long-term applications in automobiles, consumer-goods, and construction. They offer significantly lower carbon footprints than the pure polyolefins. Besides several companies with pilot/demo scale plants (< 10 ktpa) the most important producers of starch plastics are Novamont (Italy, 120 ktpa) and Rodenberg (Netherlands, 47 ktpa).

Though starch based plastics have developed a high market penetration, the production capacities are not expected to grow as fast as expected for other bio-based plastics because many issues exist in using high amounts of starch (> 30 %) without compromising the material properties, even in reactive blends.

2.1.2 Plastics from cellulose

Like starch, cellulose degrades prior to melting. But, because of a high degree of crystallinity, it is more stable than starch and cannot be dissolved or plasticized with common solvents or plasticizers. For the production of a plastic material the cellulose, usually in the form of pulp, has to be chemically modified. The most important thermoplastic cellulose material is cellulose acetate (CA) (Balser et al., 2000). Since it's first commercial production in the early 20th century, CA has been an important plastic material, until it was replaced by less expensive petrochemical plastics. CA is prepared by acetylation of the hydroxyl groups of pulp with acetic anhydride. Depending on the origin of the anhydride CA can be fully or partly bio-based.

The thermal and mechanical properties and the bio-degradation rate of CA, depend on the degree of acetylation (Chandra and Rustgi, 1998). CA is predominantly used for fiber applications (textiles and cigarette filters). Niche plastic-applications include spectacle frames, handles and casings of other high-value products, as well as polarized films, which are used for LCD displays.

The industrial derivatization of pulp is a mature and sophisticated process, which is performed under harsh conditions. Recent research has focused on alternative solvents, such as ionic liquids (Gericke et al., 2012), the expensive recovery of these solvents remains the major drawback of these techniques.

Major producer of cellulosic polymers is Eastman Chemical (USA), further producers are Innovia Films Ltd (UK), and FKuR (Germany). Only a small share of the CA production (800 ktpa) is used for plastics applications. Due to the high price and the niche character of most applications, a significant change of the production capacities cannot be expected in the close future.

2.2 Bio-based polyesters

Polyesters are one of the structurally and functionally most versatile groups of polymeric materials and formed when dicarboxylic acids and di-functional alcohols or hydroxy acid are polymerized. These monomers are quite abundant in nature and can be produced via various fermentative pathways, which were intensively studied and reviewed in the last years (Bechthold et al., 2008; Gandini et al., 2009; van Haveren et al., 2008).

Depending on the utilized monomers and on the process conditions, polyesters with a large spectrum of properties, ranging from stiff to soft, can be prepared. An important feature of many polyesters is their ease of degradation due to the hydrolysis of the ester linkage, which is the reason for their biodegradability. Advances in biotechnology and chemical catalysis have enabled the production of various fully and partly bio-based polyesters. Currently the most important fully bio-based polyester is PLA.

2.2.1 Poly(lactic acid)

PLA plastics are amorphous or semi-crystalline polyesters, that can be produced from the renewable fermentation product lactic acid (LA). The LA molecule has an asymmetric carbon atom and therefore occurs in two forms. L-LA is present in many organisms. The enentiomer D-LA (mirror image of L-LA), however, is very rare in nature (Chahal and Starr, 2000). PLA can be prepared via direct condensation of LA or via ring opening polymerization (ROP) of the cyclic lactic acid dimers, L,L-, D,D-, and D,L-lactide (Lim et al., 2008). The products of both routes are generally referred to as PLA (Figure 4).

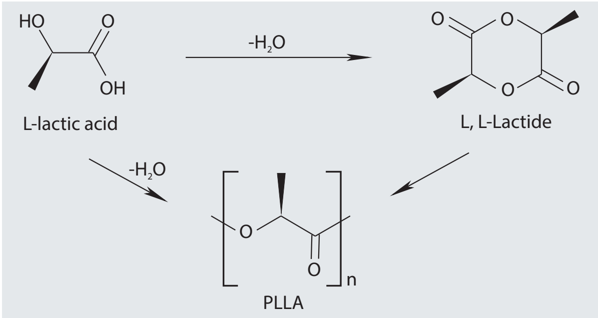

Figure 4
Synthesis of lactide and poly(lactic acid)

According to a commonly adopted and more specific nomenclature, the polycondensation products of LA are called poly(lactic acid), and the products prepared by ROP of lactides are called polylactides.

Besides being biodegradable, a major advantage of PLA is the possibility to process the plastic on common process equipment. The thermal and mechanical properties of PLA properties depend on the ratio and the distribution of L- and D-LA in the polymer chains.

Both, amorphous and semi crystalline PLAs, show a glass transition temperature (Tg) between 50 and 70 °C. Tg is an important parameter. It is defined as the temperature above which the amorphous regions of a plastic change from brittle to rubbery or liquid-like. Accordingly, native PLAs are brittle at room temperature. PLA solely consisting of L-LA blocks is semi-crystalline due to the high structural regularity. The crystalline regions (up to 37 %) provide additional mechanical strength, especially at elevated temperatures (Perego et al., 1996). The melting temperature of the crystals is typically around 180 °C (Lim et al., 2008). An important property of a semi-crystalline thermoplastic is the rate at which it recrystallizes upon cooling from the melt. Fast and spontaneous crystallization is required for many plastic applications with short cycle times (e.g. injection molding). Pure PLLA crystallizes spontaneously, but the rate of crystallization decreases with increasing D-LA content (Saeidlou et al., 2012). Less pure PLLA thus often contains a quasi-amorphous phase and overall shows inferior mechanical properties.

In order to control the PLA crystallinity, several nucleating agents have been investigated. Besides a variety of nanoparticles, talc and nano-clay have proven to be very good nucleating agents for PLA. Below 90 % L-LA content PLLAs remain amorphous (Saeidlou et al., 2012). Because the monomers L-LA and D-LA are enantiomers, PDLA plastics feature the same properties like the corresponding PLLAs.

If both, L-LA and D-LA chain structures are present in a PLA plastic, strong interactions between these complementary structures can cause the formation of a very stable stereo complex. The effect is most pronounced in PLAs that contain equimolar amounts of L- and D-LA, e.g. in 1 : 1 blends of pure PLLA and PDLA (stereo complex PLA (scPLA)). Compared to PLLA, scPLA shows a significantly higher melting temperature of 210 to 240 °C and spontaneous and fast crystallization (Ikada et al., 1987).

Several scPLA production techniques have been developed, including the application of chiral catalysts, melt and solvent blending (Auras et al., 2004; Ovitt and Coates, 2002). Stereocomplex technology significantly improves PLA heat stability and enables to replace PS and PP and other plastics in applications like hot beverage cups and microwave safe packaging. Besides crystallinity control, various plasticization and processing techniques have been investigated in order to overcome the inherent brittleness of PLA (Anderson et al., 2008; Liu and Zhang, 2011). An often observed disadvantage was that improvements in either impact strength or the tensile modulus usually came along with reduction in modulus or tensile strength.

New additives and processing technologies have expanded the number of PLA applications, which today go well beyond the initial scope of biodegradable packagings. They now include many durable applications like bottles, casings of IT-products, cellular phones, films, and textiles (Jamshidian et al., 2010). A bio-materials initiative launched by IBM is currently developing a PLA-ABS blend (30 % PLA) that could replace polycarbonate/acrylonitrile butadiene styrene (PC/ABS), the predominantly used plastic material in IT-products. The remaining technical challenge is to achieve adequate flame retardancy.

Several companies in Belgium, China, Japan, Switzerland, and the Netherlands have installed small PLA productions capacities (several ktpa). NatureWorks LLC remains the world's only large-scale commercial producer of PLA (USA, 140 ktpa). However, the Dutch lactide producer Purac, is providing Lactides (Thailand, 75 ktpa) for PLA production, has started up the world's first D, D-lactide production in 2009 (Spain, 5 ktpa). It is currently used in the production of heat resistant scPLA foam which could be a biodegradeable substitute for expandable polystyrene. Though PLA prices have significantly fallen in the last years, they are still not competitive with commodity plastics. NatureWorks LLC assumes to reach cost parity with PET and PS due to an increased economy of scale by 2015.

2.2.2 Poly(hydroxyalkanoate)

PHAs are a group of naturally occurring, amorphous or semi crystalline polyesters, that are biocompatible and fully biodegradeable (Chen, 2010). PHAs can be produced via bacterial fermentation of renewable feedstocks or in genetically engineered plants according to route II or III (Figure 2) (Braunegg et al., 1998). The generic chemical structure is shown in Figure 5.

More than 150 different PHA monomers, hydroxyalkanoic acids that differ in the length of spacer (X) and type of side group (R), have been identified in PHAs (Steinbüchel and Valentin, 1995). PHA production using microorganisms comprises three basic steps (Suriyamongkol et al., 2007). The fermentation step is usually a two-stage fed batch process, which is followed by a solvent based extraction-precipitation step. After drying, the purified PHA plastic is ready for use. The properties of PHAs strongly depend on their molecular structure and composition. The simplest PHA, poly(3-hydroxybutyrate) (P3HB) is very crystalline (up to 60 %) and shows thermal and mechanical properties that can be compares to PP and PE. However, they show a slow crystallization behavior and the elongation at break, a measure of the flexibility, is two orders of magnitude lower compared to PP (Marchessault and Yu, 2005).

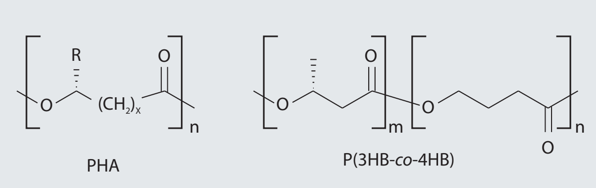

Figure 5
Poly(hydroxyalkanoate) left: generic structure; right: PHA-copolymer

By using mixed cultures, genetically engineered organisms and by varying the carbon sources used in the fermentation process, the final product properties of PHAs can be tailored (Madison and Huisman, 1999). Important progress has been made in fine-tuning the properties of PHA-copolymers comprised of 3-hydroxybutyrate and 3-hydroxyvalerate or 3-hydroxyhexanoate and 4-hydroxybutyrate. They are more flexible than P3HB and can be adjusted to match the property profile of commodity plastics like PP, PE and PET (Laycock et al., 2013; Marchessault and Yu, 2005).

Meredian PHA is currently operating and expanding the world's largest plant (USA, 15 ktpa, 30 ktpa by 2014). Several commercial PHA grades, optimized for a broad range of applications, including injection molded items, films, foams, and fibers, are currently available. According to the manufacturers, PHA production capacities are currently about 35 ktpa. At the current stage of commercialization, the produced grades are mainly used for product development. A project that could have an important impact on the demand for PHAs is a replacement for PC/ABS (50 % PHA) in housings, also investigated by the aforementioned bio-materials initiative.

However, PHA are still among the most expensive biobased plastics. An important cost driver is the energy intensive extraction and purification step, which adversely is also in contradiction with the principles of green chemistry (Koller et al., 2005)

2.2.3 Poly(butylene succinate)

Poly(butylene succinate) (PBS) (Figure 6) is a semi-crystalline, completely biodegradable polyester that is produced by polycondensation of succinic acid and 1,4-butanediol (BDO) (Xu and Guo, 2010).

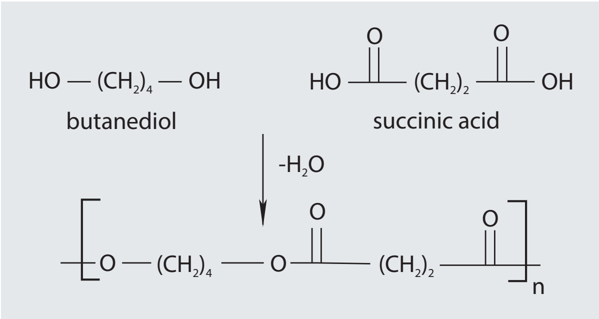

Figure 6
Synthesis of poly(butylene succinate)

Today, PBS is produced in various demo and pilot plants, mainly from petroleum based monomers. The current production capacity is comparatively low (< 20 ktpa). However, bio-based routes to succinic acid and BDO have been extensively investigated (Cheng et al., 2012; Song and Lee, 2006). Several processes have been developed, including the fermentation of carbohydrates using various types of bacteria and fungi. A straight forward route to bio-based BDO is by fermentation of sugars using genetically modified microbes (Yim et al., 2011), demonstarted on a pilot-scale by Genomatica, or via the catalytical hydrogenation of bio-succinic acid (Cukalovic and Stevens, 2008; van Dien, 2013).

PBS is a white thermoplastic material with a low Tg of -45 to -10 °C and a melting point of 90 to 120 °C. It generally features good mechanical properties, similar to those of PE and PP (Hwang et al., 2012). Some flexural and barrier properties, however, are not favorable for some applications (Ray and Okamoto, 2003). In order to adjust these properties PBS is usually blended with other thermoplastics, e.g. TPS or PLA, or comonomers like terephthalic acid or adipic acid are incorporated (Xu and Guo, 2010). The addition of nanofillers like clays or carbon nanotubes has also shown to be an efficient way to improve the material properties (Yang et al., 2007). Since the first commercialization in 1994 further PBS grades, homopolymer, copolymer, and blends with other bio-based plastics, have been commercialized. They can be easily processed with conventional polyolefin equipment. Main applications include packaging films and foams, agricultural mulch films, disposable goods, and fibers (Xu and Guo, 2010).

Due to a lack of availability of bio-based succinic acid and BDO in larger volumes, PBS is currently mainly based on fossil resources. However, the bio-based content is expected to increase, because the production capacities of the constituent bio-based monomers are, according to announcements of several companies and joint ventures (Myriant, Reverdia, Bioamber and BASF, CSM Purac and Genomatica), about to be expanded. The shared objective of these working partnerships is a 100 % bio-based PBS for large volume durable markets such as in the automotive interior parts.

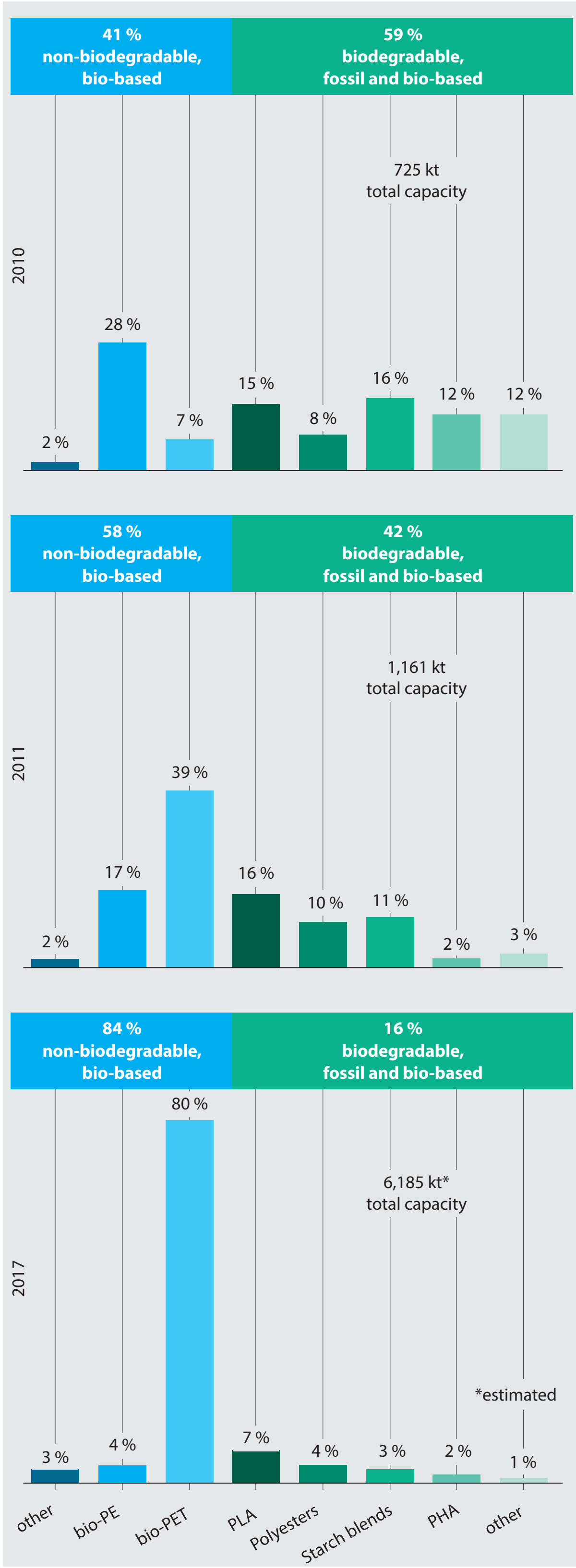

Figure 7
Global production capacity of bioplastics in 2010, 2011 and 2017

2.3 Bio-based conventional plastics

The initial focus of bioplastics was on applications that required biodegradability. Accordingly, the production capacities for durable bio-based plastics have remained comparatively low. However, most of the 'commodity' applications of plastics do not require fast degradability but a bio-based origin is increasingly requested. Recent market studies show that the plastic industry responds to the increased demand with shifting the production towards bio-based conventional plastics that are not biodegradable. Besides the expected rapid increase of the total production capacities to about 6.185 ktpa by 2017, Figure 7 shows the shift of the largest segment from biodegradable plastics (59 % in 2010) towards bio-based non-biodegradable plastics (84 % by 2017) (Data sources: European Bioplastics, Institute for Bioplastics and Biocomposites, 2013; European Bioplastics, Institute for Bioplastics and Biocomposites, 2012; European Bioplastics and University of Applied Sciences and Arts, 2011). Since 2011, the most important bio-based non-biodegradable plastic has been bio-PET, which is expected to grow at an exceptional rate due to the increasing demand for bio-based bottles, and bio-PE. However, though not at the same ratelike the drop-in plastics,also the novel biodegradable plastics PLA and PHA are also expected to grow significantly (nova-Institute GmbH, 2013; European Bioplastics, Institute for Bioplastics and Biocomposites, 2012).

2.3.1 Bio-based polyethylene

By the annual production volume, PE is the most important conventional plastic material. It is extensively used in a wide range of applications especially packaging and construction. Conventional PE is produced by radical polymerization of the petrochemically produced monomer ethylene. Alternatively, bio-based ethylene can be prepared from ethanol. This allows the production of bio-based PE using existing polymerization recators.

Figure 8 shows the reaction scheme of the drop-in approach, which corresponds to route II (Figure 2), starting with the dehydration of ethanol to ethylene and followed by conventional polymerization to PE (Bedia et al., 2011). Via the derivatization of bio-based ethylene, further important bio-based monomers can be obtained (van Haveren et al., 2008). Examples shown are vinylchloride, the precursor of PVC and ethylene glycol, a monomer for used in the production of bio-PET.

Technically, the depicted routes are not essentially new. The bio-based production of plastics and other chemicals had been common processes in Brazil and India in the 1960s and 1970s (World Bank, 1980). For as long as the price for petroleum was low, the production discontinued and the technology stayed economically unattractive. With the rising price level however, the technology has regained interest and many old processes have been reinvestigated recently (Morschbacker, 2009).

The raw material costs represent the most important part of the production costs of bio-PE. Hence, price and availability of the raw materials are the key criterions for siting a bio-PE plant.

Braskem, the first producer of bio-PE, has built its large scale production facility (200 ktpa) in Triunfo (Brazil). It utilizes sugar cane ethanol and started production in late 2010. The produced PE grades target applications in packaging (food and cosmetics), toys, and automotive parts. Against the expectations of many, the first production was sold out very fast, although bio-PE was priced at a premium of about 50 % compared to conventional PE. Packaging converter Tetra Pak recently, announced plans to use bio-PE for the production of its packaging material factories in Brazil. This initial test would increase the renewable content of about 13 billion packages annually produced in Brazil to up to 82 %.

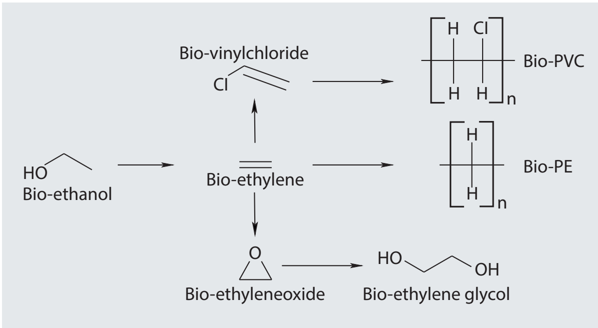

Figure 8
Conversion of ethanol to polyethylene, polyvinylchloride and ethylene glycol

2.3.2 Bio-poly(ethylene terephthalate)

PET is a thermoplastic polyester produced by polycondensation of ethylene glycol (EG) and terephthalic acid (TPA). It is one of the most employed plastics and predominantly used in fiber (textiles) and packaging (bottles and food containers) applications. PET production comprises two steps. The first of these is esterification of TPA with EG, the second is polycondensation, in which PET is formed via a transesterification reaction. High-viscosity PET grades used for bottles or technical yarns are typically produced by chain extension in an additional process step (Rieckmann and Völker, 2004). EG and TPA are typically sourced from petroleum but can alternatively be produced via bio-based routes.

Conventionally, EG is produced via the hydrolysis of ethylene oxide, a product of the catalytical oxidation of ethylene (Figure 8). Provided bio-based ethylene is available, the production of bio-EG is straight forward and can be done in existing plants. As India Glycols demonstrates with its production of bio-EG and other bio-glycols since 1989 (175 ktpa) this route can be technically and economically feasible. The production of bio-based TPA is not as simple. Many processes have been developed and demonstrated at small scale, but none has reached a larger, commercial scale (Dodds and Humphreys, 2013). One of the most advanced processes uses bio-based isobutanol. The related production scheme, depicted in Figure 9, starts with the biotechnological production of isobutanol which is subsequently transformed via isobutylene and paraxylene into bio-TPA via multiple catalytical conversion steps.

The bio-PET used today is partly bio-based, made of bio-based EG and petroleum-derived TPA. Bio-PET has an bio-based carbon content of 20 %. In 2011, the production capacity for bio-based PET reached 620 kt, a 12-fold capacity increase compared to 2010 (Figure 7). Trigger for this sudden and unexpected increase was the great success of the Plant-Bottle, a beverage bottle made of bio-PET, which was introduced by Coca Cola in 2009. Meanwhile other large food manufacturers use the PlantBottle for their products and competitor Pepsi announced to introduce the first fully bio-based bottle, however yet provided only lab-samples of the new bottle.

With the expressed goal of Coca Cola to switch to a fully bio-based bottle by 2020, the bio-PET production capacities are expected to reach 5.000 ktpa by 2016 and to further increase by 2020, (European Bioplastics, Institute for Bioplastics and Biocomposites, 2012; nova-Institute GmbH, 2013). To achieve this goal, Coca Cola cooperates with several renewable chemicals companies and bio-EG plants are being built, e.g. in Taiwan (Greencol, 175 ktpa) or are in planning in Brazil (JBF Industries, 500 ktpa).

The commitment stimulated the development of a bio-based replacement for PET, poly(ethylenefuranoate) (PEF). It can be prepared from EG and 2,5-furandicarboxylic acid (FDCA), a dicarboxylic acid that is structurally comparable with PET. FDCA can be produced from renewable resources. The process, also shown in Figure 9, starts with the conversion of carbohydrates to hydroxymethlyfurfural (HMF). Adjacent catalytical oxidations yield FDCA (Bozell and Petersen, 2010). The last step to PEF is a classical polyesterification of FDCA and EG. Because FDCA and TPA have related structures, bio-based TPA can be prepared from FDCA. The missing two carbon atoms in FDCA can be supplied by bio-ethylene (Figure 9) (Eerhart et al., 2012).

This might, however, not be necessary because PEF and PET compete in performance. Regarding the oxygen, carbon dioxide and water barrier properties PEF might even outperform PET which could reduce food spoilage due to shelf life extension (van Es, 2013). Dutch company Avantium currently operates a FDCA pilot plant (40 tpa) and announced plans to build a commercial-scale plant (40-50 ktpa) by 2015.

3 Challenges and trends

Since the introduction of the first modern bio-based plastics some 30 years ago, the sector is developing very dynamically. Due to the rising price of petroleum and rapid technological advancement, the initially very high price level was lowered significantly. However, todays bio-based plastics still remain too expensive to compete with conventional plastics.

Though, the most important challenge that has to be addressed in the coming years is the further reduction of the production costs. Economies of scale effects are most important to enable competitive price levels. However, because the supply-chains for bio-based products are typically quite long, their up-scaling is challenging, especially because many of the required technologies have not been tested before.

The feedstock selection will be the most important challenge for three reasons: (1) substrate costs typically account for 40-60 % of the total costs of bio-based products (Demain, 2007). (2) the overall yield of the production of bio-based monomers is usually significantly lower than the production of similar petrol based monomers. (3) The simple scale up of the current bio-based plastics production technologies, these usually utilize first-generation feedstocks like sugar cane or corn, are likely to increases the competition of the production of food and bio-based chemicals.

In order to avoid unsustainable demand, research is currently focusing on lignocellulosic biomass and residue streams from agricultural and food production as feedstocks for bio-based chemicals (FitzPatrick et al., 2010). Although the development of these, so called second-generation technologies,

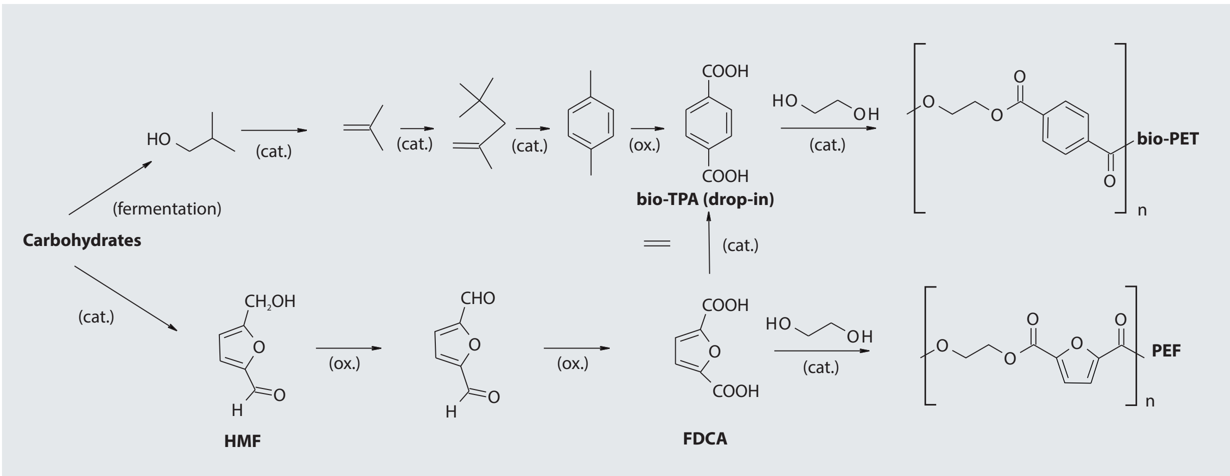

Figure 9
Conversion of sugar to bio-PET and PEF, a novel bio-based plastic that resembles the structure of PET

is progressing, important issues, e.g. the development of efficient lignocellulosic pretreatment, hydrolysis, and downstream technologies, have to be solved (Klein-Marcuschamer et al., 2010). In the meantime, large-scale production capacities are increasingly installed in regions like South America and Asia where low-cost feedstocks, e.g. sugarcane and molasses are available in sufficient quantities. In parallel, new bio-based plastic products and marketing and image campaigns are launched. One of the best indirect results of this trend is the rise of green competition. Bio-PET is nice example for the game-changing impact big players can have on the development of technology, products and markets.

Today's bio-based plastics are predominantly bio-based versions of conventional plastics, mainly PET and PE. By 2016 their share is expected to reach almost 90 %. This imbalance is not surprising because the utilization of drop-in replacements does not require any adjustments to existing polymerization and processing equipment. Although drop-in replacements are extending their lead, it remains difficult to predict whether drop-in replacements or novel plastics will finally come out on top. The success of any approach will depend on the final product cost. Bio-ethanol is currently the most versatile starting material for the production of bio-based conventional plastic. However, because the production of ethylene from sugar based ethanol comprises decarboxylation and dehydration steps, the overall process is not very efficient regarding the use of biomass. In contrast, novel monomers can be produced with significant higher atom efficiency. An example is the biotechnological production of succinic acid in which carbon dioxide can be fixated rather than released as a byproduct (Cheng et al., 2012).

Although novel plastics like PLA and PHA can be processed with standard processing equipment, replacing a conventional plastic with a novel plastic is not a simple task. While the basic physical properties of novel plastics have reached a high level of performance, incompatibilities with conventional additives often impair the property profiles. Though an increasing number of additives are available for novel plastics like PLA and PHA, the additives market for bio-based plastics is small and still lacks solutions for important properties, e.g. the flame retardance. With the expected increase of novel plastic production volume, the market for additive is likely to reach a volume that justifies the development and production of new additives.

Novel plastics increasingly occur in existing recycling systems. Although novel plastics are recyclable and their separation technically feasible, existing recycling facilities are not separating them out because they simply lack the critical volume required for individual reclamation. The problem that arises is that novel plastics are claimed to contaminate and impair the performance of recycled conventional plastics (Cornell, 2007; Soroudi and Jakubowicz, 2013). Because this could force waste management companies to reject batches of otherwise recyclable material, it is increasingly demanded to regulate the use of novel plastics, until the required recycling capabilities are installed area-wide.

4 Conclusions

Societal demands for sustainable production and consumption, and scientific research are leading to a fast commercialization of new applications for bio-based plastics. They are begining to change the way plastics are produced. As a result of the rapid pace of the developments, it is likely that bio-based plastics will be commonly found in commodity applications in the near future.

The increasing number of customers that are willing to pay premium prices for green products, have become an important driver for this development. A recent study showed, that product quality (97 %) and price (87 %) are still influencing the buying behavior of EU citizen more than a the impact of a product on the environment (84 %) (TNS Political & Social network, 2013). While the gap between the impact of price and of the environmental impacts has decreased compared to earlier studies, the increasing number of companies that are going green with their products might change this trend.

To permanently step out of their green niche, bio-based plastics have to be cost-competitive with their conventional counterparts. Given the current price differences of conventional and bio-based plastics and taking into account the current supply situation with renewable resources, one can assume that bio-based and conventional plastics will be used side by side in the forseeable future.

Glossary of Terms	
BDO	1,4-Butanediol
EG	Ethylene glycol
FDCA	2,5-Furandicarboxylic acid
HMF	Hydroxymethylfurfural
ktpa	kilo tons per year
LA	Lactic acid
PBS	Poly(butylene succinate)
PE	Polyethylene
PEF	Poly(ethylenefuranoate)
PET	Poly(ethylene terephthalate)
PHA	Poly(hydroxyalkanoate)
PLA	Poly(lactic acid)
PP	Polypropylene
PS	Poly(styrene)
PUR	Polyurethane
PVC	Poly(vinylchloride)
ROP	Ring opening polymerization
Tg	Glass transition Temperature
TPA	Terephthalic acid
TPS	Thermoplastic starch

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