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Water productivity of poultry production: the influence of different broiler fattening systems

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Abstract

With the expected increase in poultry meat consumption water use will increase as well. The objective of this study is to quantify the effects of fattening systems on the water productivity in broiler chicken production with consideration given to conditions in Germany. Four fattening systems were analyzed in terms of water use for feed production, drinking, cleaning, and the parent stock. The fattening systems differed in intensity, ranging from fast fattening with a fattening period of 30 days and a carcass weight of 1.1 kg to slow fattening with a period up to 46 days and a carcass weight of 2.1 kg. During the fattening period the broiler chicken were fed with performance-linked feed. The water productivity of the feed components varied from 0.4 kg dry mass per m^3 water input for soybean meal to 1.8 kg dry mass per m^3 water input for maize. In all fattening systems the water input for feed production accounted for 90 to 93% of the total water input. The share for the parent stock was 7 to 10%, while drinking and cleaning water accounted for less than 1%. For all fattening systems the water productivity was 0.3 kg carcass weight per m^3 water input, 2.8 MJ food energy per m^3 water input and 57 g food protein per m^3 water input. The shorter fattening period and lower feed demand in the more intensive fattening systems were juxtaposed to the higher carcass weight and higher water productivity of the feed components in the more extensive systems.

Introduction

The world population is growing. It is estimated that in 2050 there will be 9.3 billion people living on the earth (UNDESA 2011). Besides the increasing number of people, diets are changing to include more meat. Meat production is expected to increase by 1.6% per year from 2013 to 2022. Fifty percent of this additional meat is predicted to be poultry such that poultry production will increase by 1.9% per year (OECD 2013). Poultry is a meat type acceptable to all major religious and cultural groups (Steinfeld et al. 2006). In 2022, poultry is projected to account for 37% of global meat supply and to be the world's largest meat sector (OECD 2013). Poultry production in Germany increased from 0.9 million tons in 2003 to 1.4 million tons in 2012 (Statistisches Bundesamt [German Federal Statistical Office] 2013). Sixty percent of German poultry production is generated by broiler chicken (Statistisches Bundesamt [German Federal Statistical Office] 2013). In 2003, 0.5 million tons of broiler meat were produced (Statistisches Bundesamt [German Federal Statistical Office] 2013). In 2012, 0.9 million tons of Germany's total poultry production were accounted for by broiler meat (Statistisches Bundesamt [German Federal

Statistical Office] 2013). This trend is expected to continue through the coming years (OECD 2013).

The increasing consumption of animal products leads to higher pressure on global resources such as land, energy, and water (Pimentel et al. 1997). Agriculture is competing with domestic and industrial uses for water (Postel 2000). In addition, climate changes are expected to increase the pressure on water resources (Gerstengarbe et al. 2003). To meet these challenges of global change, agricultural productivity must be increased.

Studies of the water use in livestock production systems focus mainly on water demand for milk and beef production (Armstrong et al. 2000; Singh and Kishore 2004; Molden et al. 2007; Peden et al. 2007; Haileslassie et al. 2009, 2011; Descheemaeker et al. 2010; Peters et al. 2010; Rockström et al. 2010; Moore et al. 2011; de Boer et al. 2012; Zonderland-Thomassen and Ledgard 2012; Krauß et al. 2015). Renault and Wallander (2000) calculated the water productivity of poultry for Californian conditions. Crop transpiration and soil evaporation were considered to be water input. Renault and Wallander (2000) estimate the water productivity of poultry at 0.244 kg m^{-3} water, the water productivity of meat protein at 33 g m^{-3} water, and the water productivity of food energy in poultry at 1.4 MJ m^{-3} water. Chapagain and Hoekstra (2003) estimate the virtual water content of poultry, including crop transpiration, soil evaporation, service, and drinking water, to be between 0.9 and 4.2 m^3 water kg^{-1} poultry. The world average is estimated at 1.5 m^3 kg^{-1} (Chapagain and Hoekstra 2003). The wide range of water productivity or virtual water content is due to the regions investigated and their climatic conditions, the intensity of production and the sources of water included in the water input.

The aim of this study is to quantify the water productivity of poultry production under commercial conditions in Germany and to investigate the influence of different broiler fattening systems. A highly water-productive poultry production system is outlined.

Material and Methods

System boundaries and data

The water productivity of poultry production is analyzed from cradle to farm-gate. The system includes the broiler chicken and the parent stock. The water demand for feed supply, drinking and cleaning was considered here. The indirect water demand for the production of N-fertilizer, supply of diesel and electricity, and the construction of farm buildings was not considered, since this was assumed to be negligible as is reported for milk production (de Boer et al. 2012; Döring et al. 2013).

The most common production and keeping systems in Germany according to the German Agricultural Society (Berk 2008) were investigated. Data on animals per square meter, fattening duration, feed conversion, final weight, and idle time were taken from Berk (2008). Diets were developed according to Jeroch et al. (1999). North-East Germany is considered as the feed production region. Data on feed production conditions were taken from Kraatz (2012).

Fattening systems

Broiler chicken

Various broiler fattening systems are established in Germany. The most common and predominant systems are fast fattening, intermediate fattening, and slow fattening (Berk 2008) (Table 1). A combined system of fast and intermediate fattening is known as splitting fattening. The duration of fattening, the live weight at the end of the fattening, and the carcass weight increase from fast-fattening to slow fattening, while the feed conversion ratio and the stock density decrease (Table 1) (Berk 2008). The live weight of the animals rises with increasing fattening duration from 1.6 kg in 30 days to 3.0 kg in 46 days. The feed

Table 1. Broiler fattening systems according to Berk (2008).

Fattening system	Animals per barn[1]	Fattening period [d]	Final weight [kg]	Carcass weight [kg]	Feed conversion ratio [kg live weight kg^{-1} feed]
Fast fattening	39,900	30	1.6	1.1	0.625
Intermediate fattening	31,000	37	2.1	1.5	0.581
Splitting-fattening total	39,900				
Young[2]	8,900	30	1.6	1.1	0.625
Old[2]	31,000	37	2.1	1.5	0.581
Slow-fattening total	31,000				
Female young[2]	9,300	39	2.0	1.4	0.556
Female old[2]	6,200	46	2.3	1.6	0.556
Male	15,500	46	3.0	2.1	0.556

[1] Barn size of 1700 m^2.

[2] Seven days difference in age of slaughtering between the young and the old animals.

conversion ratio, as ratio of live weight to feed intake, decreases with an increase in fattening duration. All systems are considered under equal conditions with a barn area of 1,700 m^2 and in the keeping of the parent stock. A barn with an area of 1,700 m^2 can accommodate nearly 40,000 broiler chicken, which is a legal limitation for the assessment of environmental effects (Keßler 2012).

The female and male broiler chicken were taken into the barn together in the fast-fattening system and the intermediate-fattening system. The entire stock is removed from the barn on reaching the target live weight.

In the slow-fattening system the males and females are housed separately because of the different daily weight gain. Sixty percent of the females are removed from the barn after 39 days. This gives the remaining females and males more space. One week later they are removed from the barn too.

In the splitting-fattening system 39,900 broiler chicken are taken into the barn as in the fast-fattening system. After 30 days, 22% of the animals are removed from the barn. The remaining 31,000 animals are removed from the barn 1 week later. This procedure is necessary to meet the keeping regulations of a maximum live weight of the animals of 35 kg per square meter of barn.

Parent stock

A standard parent stock is considered uniformly for all fattening systems. The barn of the parent stock has an area of 1,700 m^2 and is equipped like that for laying hens (Mtileni et al. 2007). The barn houses 8,500 females and 850 males (Mtileni et al. 2007). Each hen generates 150 broiler chicken in 64 weeks (Jiang et al. 1998).

Composition and intake of feed

The composition of the feed for the broiler chicken and the parent stock is shown in Table 2. The ingredients are maize grain, rapeseed meal, rapeseed oil, soybean meal, winter barley, and winter wheat. For the longer-duration fattening, the share of protein-rich components decreases while the share of grain increases (Table 3). Protein-rich feed is fed to the fast-fattening, the intermediate-fattening and the splitting-fattening broiler chicken all the time and to the slow-fattening broiler chicken in the first 25 days (Jeroch et al. 1999). A grain-rich feed is fed to the slow-fattening broiler chicken after 25 days up to the end of fattening (Jeroch et al. 1999) (Table 3). The feed of the parent stock contains 85% grain and only 10% soybean meal (Jeroch et al. 1999) (Table 2). The feed intake of the broiler chicken during the fattening period and of the parent stock during the rearing and laying period is shown in Table 3. A laying hen produces 150 broiler chicken and consumes 60 kg feed during the laying period, so the parent stock consume 400 g feed per broiler chicken (Jiang et al. 1998).

Table 2. Composition of the feed according to Jeroch et al. (1999).

	Feed		
	Protein-rich	Grain-rich	Parent
Feedstuff	Composition in %		
Maize grain	31	26	10
Rapeseed meal	4	5	0
Rapeseed oil	5	5	5
Soybean meal	39	23	10
Winter barley	0	11	15
Winter wheat	21	30	60

Calculation of water productivity

Definition of water productivity

Water productivity is generally defined as the relation of useful output to water input (Seckler et al. 2003). In this study, the output is defined on a mass basis, food energy basis, and food protein basis. The dry matter yield of the crops [kg DM] and the carcass weight of the broiler chicken [kg CW] are defined as the mass basis.

The water productivity of the combined feed was calculated by multiplying the share of the combined feed components (Table 2) by the water productivity of the components (Table 5). The water productivity of the feed WP_{feed} [kg DM m^{-3} $W_{\mathrm{input\text{-}feed}}$] is defined by the *crop yield* [kg DM] related to the water input $W_{\mathrm{input\text{-}feed}}$ [m^3].

Table 3. Feed intake per animal and growing period according to Berk (2008), Jeroch et al. (1999), and Jiang et al. (1998).

	Feed		
	Protein-rich	Grain-rich[1]	Parent
Fattening system	Intake animal^{-1} growing period^{-1} [kg]		
Fast fattening	2.6[2]	–	–
Intermediate fattening	3.6[2]	–	–
Splitting fattening – young	2.6[2]	–	–
Splitting fattening – old	3.6[2]	–	–
Slow fattening – female young	2.0[2,3]	1.6[2,3]	–
Slow fattening – female old	2.0[2,3]	2.1[2,3]	–
Slow fattening – male	2.0[2,3]	3.4[2,3]	–
Parent stock	–	–	60[4]

[1] After 25 days in the slow-fattening system.

[2] Berk (2008).

[3] Jeroch et al. (1999).

[4] Jiang et al. (1998).

$$WP_{\text{feed}} = \text{crop yield}/W_{\text{input-feed}} \quad (1)$$

The water productivity of the poultry meat $WP_{\text{poultry\_meat}}$ [kg CW m^{-3} W_{input}] is defined by the *poultry meat* produced in kg CW per broiler chicken related to the water input W_{input} [m^3].

$$WP_{\text{poultry\_meat}} = \text{poultry meat}/W_{\text{input}} \quad (2)$$

The water productivity of the food energy of poultry meat $WP_{\text{poultry\_energy}}$ [MJ m^{-3} W_{input}] is defined by the *food energy* of poultry meat produced per broiler chicken [MJ] related to the water input W_{input} [m^3]. The food energy content of the carcass is 8.92 MJ kg^{-1} CW (USDA 2013) and the carcass weights are shown in Table 1.

$$WP_{\text{poultry\_energy}} = \text{food energy}/W_{\text{input}} \quad (3)$$

The water productivity of the food protein of poultry meat $WP_{\text{poultry\_protein}}$ [g_{protein} m^{-3} W_{input}] is defined by the *food protein* of poultry meat produced per broiler chicken [g_{protein}] related to the water input W_{input} [m^3]. The food protein content is 183.3 g kg^{-1} CW (USDA 2013) and the carcass weights are shown in Table 1.

$$WP_{\text{poultry\_protein}} = \text{food protein}/W_{\text{input}} \quad (4)$$

Definition of water input

The water input according to Prochnow et al. (2012) includes the transpiration from precipitation, irrigation water, drinking, and process water in the barn and indirect water. Assigning these components of the water input to the steps of poultry production, the water input W_{input} [m^3] consists of the water input for feed production $W_{\text{input-feed}}$ [m^3], the water supplied by technical means and used in the barn $W_{\text{tech-barn}}$ [m^3], and the water required for replacement of the broiler chicken $W_{\text{input-parent}}$ [m^3], which is part of the indirect water demand in prechains:

$$W_{\text{input}} = W_{\text{input-feed}} + W_{\text{tech-barn}} + W_{\text{input-parent}} \quad (5)$$

$W_{\text{input-feed}}$ [m^3] is the sum of crop transpiration from precipitation $W_{\text{prec-transp}}$ [m^3] and the irrigation water W_{irri} [m^3]. The whole amount of water used for irrigation W_{irri} is taken into account, and not just that part which is transpired by the plants, as the W_{irri} is taken out of the natural cycle (Prochnow et al. 2012).

$$W_{\text{input-feed}} = W_{\text{prec-transp}} + W_{\text{irri}} \quad (6)$$

$W_{\text{tech-barn}}$ [m^3] is the sum of the cleaning water $W_{\text{input-clean}}$ [m^3] and the drinking water of the animals $W_{\text{input-drink}}$ [m^3].

$$W_{\text{tech-barn}} = W_{\text{input-drink}} + W_{\text{input-clean}} \quad (7)$$

$W_{\text{input-parent}}$ [m^3] is the sum of $W_{\text{input-feed-parent}}$ [m^3] and $W_{\text{tech-barn-parent}}$ [m^3].

Calculation of crop transpiration

The water input used for feed production $W_{\text{input-feed}}$ is calculated according to Krauß et al. (2015) and Prochnow et al. (2012). The actual crop transpiration is calculated by using the Leibniz Institute for Agricultural Engineering Potsdam-Bornim (ATB) Modeling Database (Drastig et al. 2013) on a daily basis, considering the region of North-East Germany and including the years 2008, 2009, and 2010. It is based on the Food and Agriculture Organization of the United Nations (FAO) 56 dual crop coefficient method under nonstandard conditions (Allen et al. 1998) and extended with a module to consider crop water stress and interception loss.

The reference evapotranspiration ET_{O} [mm d^{-1}] is calculated with the FAO Penman-Monteith equation (Allen et al. 1998). Multiplying ET_{O} [mm d^{-1}] by the single crop coefficient K_{c} [-] determines the potential evaporation of a crop ET_{c} [mm d^{-1}] (Allen et al. 1998).

$$ET_{\text{c}} = K_{\text{c}} ET_{\text{O}} \quad (8)$$

The crop coefficient K_{c} [-] is separable in the basal crop coefficient for crop transpiration K_{cb} [-] and a coefficient for soil evaporation K_{e} [-]. Under optimal wetting conditions of the soil the potential crop transpiration T_{c} [mm d^{-1}] is calculated by multiplying ET_{O} [mm d^{-1}] by the K_{cb} [-].

$$T_{\text{c}} = K_{\text{cb}} ET_{\text{O}} \quad (9)$$

The potential crop transpiration T_{c} [mm d^{-1}] is multiplied by the transpiration reduction factor K_{s} [-], which is necessary to consider water stress, to calculate the actual crop transpiration from precipitation $T_{\text{act-prec}}$ [mm d^{-1}]. The data for plant available water in the 'BÜK 300' (soil overview map, scale 1:300,000, State Office for Mining, Geology and Resources Brandenburg) are used.

$$T_{\text{act-prec}} = K_{\text{s}} K_{\text{cb}} ET_{\text{O}} \quad (10)$$

The sum of $T_{\text{act-prec}}$ [mm d^{-1}] over day d within the reference period is considered as the actual crop transpiration originated from precipitation $W_{\text{prec-transp}}$ [m^3].

The reference period is the time between the harvest of the previous crop $d = 1$ and the harvest of the main crop m.

$$W_{\text{prec-transp}} = \sum_{d=1}^{m} T_{\text{act-prec}}(d) \tag{11}$$

Winter rye is chosen as previous crop, as it accounts for 40% of all cereals grown in North-East Germany (MIL 2012). The average harvest is on 1. August. The weather data of the weather stations located in North-East Germany are used for the calculation of crop transpiration. The weather stations are run by the German National Meteorological Service (Deutscher Wetterdienst – DWD). For the years 1971 to 2000 the average temperature was 9.0°C and the average rainfall was 553 mm (DWD 2013). For the balance period 2008, 2009, and 2010 the average temperature was 9.2°C and the average rainfall was 659 mm (DWD 2013). The water productivity of soybeans calculated by Prochnow et al. (2012) for Argentine and Brazilian conditions is taken into account, because 70% of the soybeans fed in Germany were grown in Argentina and Brazil (Statistisches Bundesamt [German Federal Statistical Office] 2010).

Feed production

The feed is produced according to good agricultural practice in terms of seeding, harvesting, and fertilization. Four soil groups are predominant in North-East Germany. The predominant soil characteristics and soil types in soil group 1 are clay, loam, and loamy sand. In soil group 2 loamy sand is predominant. Loamy sand and sandy loam are the dominating soil types in soil group 3. The soil in soil group 4 is characterized by sand and loamy sand. The variability of the soil characteristics lead to differences in the potential yield of the land (Table 4). North-East Germany was divided into 20,000 polygons to combine the soil groups and the soil overview map. Rape seed, winter barley, and winter wheat can be cultivated in all soil groups. Maize for grain can be cultivated in soil group 1, 2, and 3. The data of the crop yield are taken from the State Office for Rural Development, Agriculture and Reorganization of Land (LELF 2010). The seed and harvest dates are considered to be the same in all soil groups. Table 4 shows the dry matter yield of the crops in the four soil groups, the seeding date and the harvesting date. The mean WP_{feed} of a single component of the feed is calculated with the weighted average over the four soil groups within one crop. The water productivity of the combined feed was calculated by multiplying the share of the combined feed components (Table 2) by the water productivity of the components (Table 5).

Table 4. Dry matter yield (LELF 2010), seeding date, and harvesting date (good agricultural practice) of the crops for the soil groups.

Crop	Dry matter yield in t ha^{-1} a^{-1} in soil group 1	2	3	4	Seeding date	Harvesting date
Maize grain	6.9	6.0	5.2	–	20. April	20. October
Winter barley	6.0	5.2	4.1	3.1	15. September	14. July
Winter rapeseed	3.8	3.3	2.7	2.0	25. August	27. July
Winter wheat	6.5	5.4	4.3	3.3	5. October	5. August

Technical water in the barn

Components

The water provided by technical means used in the barn $W_{\text{tech-barn}}$ [m^3] includes the drinking water for the animals, cleaning water for the barn, the hygiene lock, and the washing machine.

Drinking water

The cumulative drinking water demand per broiler chicken ($W_{\text{input-drink-broiler}}$) [m^3] is calculated according to KTBL (2009) as a function of age in weeks x:

$$W_{\text{input-drink-broiler}} = 0.00042x^{1.623} \tag{12}$$

The drinking water demand of the parent stock ($W_{\text{input-drink-parent}}$) is considered at 0.3 L $W_{\text{input-drink-parent}}$ day^{-1} animal^{-1} (KTBL 2009).

Cleaning water

The cleaning water demand ($W_{\text{input-clean}}$) of the barn for the broiler chicken and the parent stock comprises water for soaking, cleaning, and disinfection and amounts to 24.4 L $W_{\text{input-clean}}$ m^{-2} (KTBL 2009). The hygiene lock and the washing machine for the workwear require 50 L $W_{\text{input-clean}}$ day^{-1} (KTBL 2009).

Results and Discussion

Water productivity of the feed

The water productivity of the feedstuffs is shown in Table 5. Maize grain has the highest water productivity with 1.8 kg dry matter (DM) m^{-3} $W_{\text{input-feed}}$, while the water productivity is lowest for soybean meal with 0.4 kg DM m^{-3} $W_{\text{input-feed}}$ and rapeseed meal with 0.8 kg DM m^{-3} $W_{\text{input-feed}}$. Winter wheat and winter

Table 5. Water input and water productivity of the feedstuffs for the soil groups according to Krauß et al. (2015) (values in brackets are the standard deviation).

	Soil group				
Feedstuff	Mean[1]	1	2	3	4
Water input [m^3 $W_{\text{input-feed}}$ ha^{-1}]					
Maize grain	3,200 (±480)	3,570 (±410)	3,230 (±450)	3,140 (±470)	–
Winter barley	3,030 (±300)	3,090 (±270)	3,040 (±280)	3,020 (±290)	3,040 (±320)
Winter rapeseed	3,360 (±260)	3,340 (±240)	3,340 (±240)	3,350 (±250)	3,370 (±270)
Winter wheat	3,920 (±330)	4,000 (±270)	3,950 (±280)	3,910 (±320)	3,910 (±360)
Water productivity [kg DM m^{-3} $W_{\text{input-feed}}$]					
Maize grain	1.8 (±0.3)	2.0 (±0.3)	1.9 (±0.3)	1.7 (±0.2)	–
Soybean meal[2]	0.4	–	–	–	–
Winter barley	1.3 (±0.3)	2.0 (±0.2)	1.7 (±0.2)	1.4 (±0.1)	1.0 (±0.1)
Winter rapeseed meal	0.8 (±0.2)	1.1 (±0.1)	1.0 (±0.1)	0.8 (±0.1)	0.6 (±0.0)
Winter wheat	1.1 (±0.2)	1.6 (±0.1)	1.4 (±0.1)	1.1 (±0.1)	0.8 (±0.1)

[1] Weighted average.

[2] Prochnow et al. 2012.

barley have a medium water productivity of 1.1 and 1.3 kg DM m^{-3} $W_{\text{input-feed}}$. The water productivity of the feed decreases with a decreasing yield potential of the soil groups, reflected by the increasing share of sand in the soil. The variation of the water productivity between the soil groups was caused by the differing yields, while the transpiration of the plants was similar.

Prochnow et al. (2012) calculated the average water productivity of barley, rapeseed meal, and wheat of a commercial farm in East Germany, obtaining nearly the same results. Barley had a water productivity of 1.4 kg DM m^{-3} $W_{\text{input-feed}}$ with a minimum of 0.8 and a maximum of 1.9. Rapeseed had a water productivity of 0.8 kg DM m^{-3} $W_{\text{input-feed}}$ with a minimum of 0.6 and a maximum of 1.0. Wheat had a water productivity of 1.1 kg DM m^{-3} $W_{\text{input-feed}}$ with a minimum of 0.7 and a maximum of 2.0. The variation between the water productivity of the different fields on the commercial farm was as high as the variation between the soil groups.

The variation between the water productivity of the crops is caused by the different crop yields and crop transpiration. The average water input for maize grain, barley, rapeseed, and wheat is 3,200, 3,030, 3,360, and 3,920 m^3 ha^{-1}, respectively (Table 5). Among the crops regarded, the transpiration of maize grain shows the second lowest value, while its yield is highest. This results in the highest water productivity for maize. By comparison with the winter wheat, the winter barley transpires more than 20% less water, while its yield is only 5% less. Therefore, the water productivity of barley is higher compared with wheat.

The water productivity of the combined feed in the fattening systems is 0.7 kg DM m^{-3} $W_{\text{input-feed}}$ for the protein-rich feed of the fast-fattening broiler chicken, 0.8 kg DM m^{-3} $W_{\text{input-feed}}$ for the grain-rich feed and 1.0 kg DM m^{-3} $W_{\text{input-feed}}$ for the parent feed. The protein-rich feed contains a higher share of protein from soybean meal than the grain-rich feed. The grain-rich feed contains more winter barley and winter wheat. The water productivity of grain is higher than that of soybean meal and so the protein-rich feed has lower water productivity than the grain-rich feed. The parent feed contains only 10% soybean meal and for that reason the water productivity of the parent feed is highest compared with the other feeds.

Water use of the parent stock

The water input for feed production of the parent stock is 0.365 m^3 per broiler chicken. The drinking water and the water used for cleaning the barn of the parent stock is 1 L per broiler chicken. In total 0.366 m^3 water per broiler chicken is used to produce the feed, to provide drinking water and to clean the barn of the parent stock.

Water input, product output and water productivity of the broiler chicken

The water input of the broiler fattening systems is shown in Table 6. The water input for feed production increases with an increasing duration of fattening from 3.2 m^3 animal^{-1} for fast fattening to 6.0 m^3 animal^{-1} for the males in slow fattening. The water input for feed production accounts for 90 to 93% of the whole water input. The water used for the parent stock accounts for 7 to 10% of the water input. The water used for cleaning the barn and for the hygiene lock is 44 m^3 per fattening period and accounts for less than 1% of total water input.

Table 6. Water use, product output, and water productivity of the fattening systems.

		Fattening system									
				Splitting fattening			Slow fattening				
		Fast fattening	Intermediate fattening	Young[2]	Old[2]	Total	Female young[2]	Female old[2]	Male	Total	Parent[1]
Water input											
$W_{\text{input-feed}}$[3]	m^3 $broiler^{-1}$	3.2	4.5	3.2	4.5		4.2	4.7	6.0		0.365
$W_{\text{input-drink}}$	m^3 $broiler^{-1}$	0.004	0.006	0.004	0.006		0.007	0.009	0.009		0.001
$W_{\text{input-parent}}$	m^3 $broiler^{-1}$	0.366	0.366	0.366	0.366		0.366	0.366	0.366		
$W_{\text{input-feed}}$	m^3 $barn^{-1}$	128,509	138,246	28,665	138,246	166,911	38,637	29,007	93,636	161,279	464,933
$W_{\text{input-drink}}$	m^3 $barn^{-1}$	178	194	40	194	234	63	55	138	257	1,382
$W_{\text{input-clean}}$	m^3 $barn^{-1}$	44	44			44				44	65
total W_{input}[4]	m^3 $barn^{-1}$	143,322	149,821			181,780				172,918	466,380
Output											
Animals per barn		39,900	31,000	8,900	31,000	39,900	9,300	6,200	15,500	31,000	9,350
Carcass weight	kg $broiler^{-1}$	1.1	1.5	1.1	1.5		1.4	1.6	2.1		
Mass output	kg CW^5 $barn^{-1}$	44,688	45,570			55,538				55,552	
Food energy content	MJ kg^{-1} CW	8.92	8.92			8.92				8.92	
Food energy output	MJ $barn^{-1}$	398,617	406,484			495,399				495,524	
Food protein content	g_{protein} kg^{-1} CW	183.3	183.3			183.3				183.3	
Food protein output	kg $barn^{-1}$	8,191	8,353			10,180				10,183	
Water productivity											
$WP_{\text{poultry\_meat}}$[6]	kg CW m^{-3} W_{input}	0.3	0.3			0.3				0.3	
$WP_{\text{poultry\_energy}}$[7]	MJ m^{-3} W_{input}	2.8	2.7			2.7				2.9	
$WP_{\text{poultry\_protein}}$[8]	g_{protein} m^{-3} W_{input}	57	56			56				59	

[1] The values per broiler represent the water input per broiler chicken. The values per barn represent the water input of the parent barn.

[2] Seven days difference in age of slaughtering between the young and the old animals (see Table 1).

[3] $W_{\text{input-feed}}$ is calculated by multiplying the water productivity of the combined feed by the feed intake.

[4] Total $W_{\text{input}} = W_{\text{input-feed}} + W_{\text{input-drink}} + W_{\text{input-clean}}$ per barn + ($W_{\text{input-parent}}$ * animals per barn).

[5] CW = carcass weight.

[6] $WP_{\text{poultry\_meat}}$ = total W_{input}/Mass output.

[7] $WP_{\text{poultry\_energy}}$ = total W_{input}/Feed energy output.

[8] $WP_{\text{poultry\_protein}}$ = total W_{input}/Feed protein output.

The live weight and the carcass weight of the animals increase with increasing fattening duration and feed intake. The food energy and food protein content of the carcass is given as equal between the fattening systems (Table 6). Hence, the output of food energy and food protein increases with an increasing live weight and carcass weight.

The water productivity of poultry meat is 0.3 kg carcass weight m^{-3} water input in all fattening systems (Table 6). Water productivity in terms of food energy and food protein varies slightly between the fattening systems. The water productivity of food energy in the broiler chicken reared in the intermediate-fattening and splitting-fattening systems is the lowest in this study. The water productivity of food energy in the fast-fattening and the slow-fattening systems is slightly higher than in the other fattening management systems.

Peden et al. (2007) and Singh et al. (2003) also identified the production of feed as the main contributor to water input in animal production. The nearly equal water productivities in the different fattening systems can be explained by the opposing effects of fattening intensity on feed requirement on the one hand and the water productivity of the diets and carcass weight on the other. The broiler chicken with a shorter fattening period has a lower feed demand and a higher feed conversion ratio than animals with a longer fattening period. In fast fattening, the feed conversion ratio is 1.6 kg feed kg^{-1} live weight, and in slow fattening it is 1.8 kg feed kg^{-1} live weight (Berk 2008). The live weight gain of young broiler chicken is mostly generated by the gain in protein. With increasing age the demand for protein related to energy decreases. In fast fattening the animals were fed solely with protein-rich feed, characterized by low water productivity. The lower feed conversion ratio of the animals in slow fattening is compensated by the higher water productivity of the feed, which results in equal water productivity for the poultry meat of all fattening systems.

The water productivity of the poultry meat is 20% higher than that estimated by Renault and Wallander (2000), who – in contrast to this study – included soil evaporation in addition to crop transpiration and excluded the water use in the barn and the water use of the parent stock. Chapagain and Hoekstra (2003) estimated the virtual water content for poultry considering plant transpiration, soil evaporation, and water for drinking and servicing, but excluding the water use of the parent stock. However, calculating the inverse proportion of the virtual water content to have the same unit as the water productivity, the water productivity in this study would be 40% lower than that estimated by Chapagain and Hoekstra (2003) for a system equivalent to fast fattening. The diets of the broiler chicken contained more wheat and maize grain instead of soybean meal (Chapagain and Hoekstra 2003) and are comparable with the parent feed. The average daily gain is 45% lower than in this study. However, the feed conversion ratio is 20% higher. As described before, wheat and maize grain have higher water productivity than soybean meal. The higher feed conversion ratio also increases the water productivity significantly. The longer fattening period increases the drinking and service water demand, which plays a minor part in water input (Singh et al. 2003 and Peden et al. 2007).

In this study, the food energy-related water productivity of the slow-fattening system was 2.9 MJ m^{-3} water (Table 6), which is twice than calculated by Renault and Wallander (2000). The main reason for this difference is the energy content of the carcass, which is 35% higher than that assumed by Renault and Wallander (2000). Assuming an equal energy content results in a water productivity difference of less than 10%. Similarly, the protein-related water productivity is 70% higher than that estimated by Renault and Wallander (2000), since the assumed protein content of poultry meat is 40% higher than that in the study of Renault and Wallander (2000).

The fattening systems investigated do not differ in terms of water productivity. Hence, modifying the intensity of fattening is no approach for increasing the water productivity in broiler production. As at least 90% of the water input originates in feed production, options for increasing the water productivity must be sought in cultivation of the feed crops, optimizing the diets with regard to water-productive crops and a performance-linked amino acid pattern, and improvements in breeding to increase feed conversion ratios.

Conclusions

The major share of the water input in poultry production is caused by feed production. The production intensity of the fattening systems does not affect the water productivity in poultry production. The higher water input in slower fattening systems is compensated by the higher output of mass, food energy, and food protein.

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Conflict of Interest

None declared.

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