Welfare, environmental impact and economy of broiler chicken production

An overview of the lessons learned from the Greenwell project

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Background

Chicken is the most eaten type of meat worldwide. For decades, broiler production has been characterized by increasing feed efficiency through genetic improvement, more precisely tailored feed compositions, better housing conditions and more professional broiler farmers. As a result, a modern broiler chicken only needs one and a half kilograms of feed for every kilo of growth, and has become ready for slaughter in an ever shorter time.

However, this development (fast growth and high feed efficiency) also had important downsides. In the Netherlands, but also elsewhere in Europe, criticism grew in particular about the ever-increasing growth rate of broilers, which was detrimental in various ways to their welfare and health, and that of their parents (broiler breeders). The economically driven focus on the size of the breast fillet led to chickens with increasingly difficulty to move, especially in the last weeks of their life. The rapid growth also made the chickens more vulnerable to diseases, requiring more frequent antibiotics, and more susceptible to heart and circulatory disorders and leg problems. The legally permitted stocking densities further limit the broilers' freedom of movement and the extent to which they can perform their natural behaviour, and increase the risk of footpad lesions and hock dermatitis.

In the Netherlands, from the beginning of this millennium this criticism led to the idea of working with slower growing broiler chickens. One of the first concepts that brought that idea to the market was Volwaard. A slower-growing broiler chicken that was kept at a considerably lower stocking density and with a covered outdoor area. The resulting higher costs were covered by a higher selling price on the shelf. The concept formed the basis of the criteria for the free-range chicken with the Beter Leven quality mark 1 star (BL1*) from the Dutch Society for the Protection of Animals.

Since then, keeping slower-growing chickens has become a growing trend in the Netherlands, largely due to continuous public pressure from NGOs such as Wakker Dier. From 2013, the large supermarket chains introduced so-called intermediate segments between conventional and free-range chickens with BL1*, with a growth and stocking density in between the two, and at the same time decided to no longer sell conventional chicken meat from the beginning of 2016. In 2021, the Dutch supermarkets also decided to switch completely to fresh chicken with the one-star Beter Leven Keurmerk (BL1*) from the Dutch Society for the Protection of Animals in the course of 2023.
The trend towards slower-growing broiler chickens has not been limited to the Netherlands only. There is also a growing market for chicken meat produced with higher welfare standards in other parts of Western Europe. One example is the European Chicken Commitment (ECC), which is also known as the Better Chicken Commitment (BCC).

Greenwell: connecting welfare, environment and economy

However, the focus on better welfare for broilers in the aforementioned trend raises pressing questions about the consequences of sustainability in other areas, in particular the ecological footprint. The regular broiler has a relatively low environmental footprint (CO_2-eq, land use, biodiversity, minerals, water), because for decades genetic selection has mainly focused on improving the growth and feed efficiency of the broiler. With the 'supermarket concepts' and the Beter Leven Keurmerk 1 star broiler, a higher level of animal welfare and animal health is, almost without exception, accompanied by a higher environmental footprint (Ellen et al., 2012; Leinonen et al., 2012). That is also understandable, because the various concepts have been developed with an eye to animal welfare and animal health, without taking into account the environmental impact. For example, a longer living animal will inevitably also need more feed. The ingredients for this feed have to be grown, transported and processed, which requires scarce raw materials that we could also use for something else. Think in particular of land, fertilizers and energy. So, with slower growing broilers, are we trading environment for welfare, and is this trade-off inevitable? And conversely, is the efficient feed conversion of faster-growing broilers by definition linked to less welfare? Is this contradiction really set in stone?

In the Greenwell project, we tackled these questions in the period from 2017 to 2022, together with a group of leading companies in the poultry sector, and with financial support from the TopSector Agri & Food. Greenwell is a contraction of 'Greening animal welfare in the broiler chain'. An important motivation for the project was the increasing demand in the international market for the retail and food industry for demonstrably better performance on multiple aspects of sustainability, including climate impact, antibiotic use, animal health and animal welfare.

Within Greenwell we have broadly done four things. We first developed models to determine the performance in terms of animal welfare, environment and economy of various broiler concepts. With those models in themselves, we have already contributed to internationally accepted standards for routinely determining environmental and welfare performance in broiler chains. We then also applied those models based on data from the companies involved – in particular the data from thousands of flocks on individual farms and on the slaughter line. We had sufficient data for three separate production types: regular production with a fast-growing broiler (here after also referred to as the regular broiler), a variant of the Kip van Morgen (KvM) and the free-range broiler with a star on the Beter Leven quality mark. (BL1*). Originally, we also wanted to include organic broilers in the comparison, but there were too few Dutch flocks, no routinely registered welfare data, and too few origin data of feed raw materials to make a proper comparison. This approach was unique because the models involved the entire chain from parent animals to slaughter for both animal welfare and the environment, and because a lot of data from many different flocks were used. Secondly, we looked at whether we could feed broilers with low-quality residual flows with a lower environmental footprint, and whether slower-growers are also better suited for this than regular broilers with a faster growth rate. Third, we investigated the influence of breed, growth rate and stocking density on welfare and health in different combinations. And finally, we combined those findings into a simple model to discuss the pros and cons of different possible concepts with (for example) supermarket buyers.

The results of this are all described in separate reports, papers and internal notes. In this review paper, we highlight a number of key points that we have learned.

Welfare, economic and environmental performance

<u>Welfare</u>: The various broiler concepts perform on average as expected: the regular broilers have a lower level of welfare than the broilers in KvM or BL1*, and BL1* scores better than the intermediate segment KvM (de Jong et al., 2022). But because we used data from many different farms and flocks, we also discovered that there is a large variation within each concept. And especially if only the animal-based indicators (welfare indicators measured on the animal itself) were included in the total welfare score. A variation that indicates that both the top of the regular and the KvM segment perform better than the average of BL1* (*Figure 1*). It was also possible to identify farms within regular and KvM that consistently performed better or worse than average. In other words: the specific farm and the specific farmer have a major influence on the actual result. Farmer management skills matter.
An interesting finding was that within BL1* the variation in welfare score was smaller than within the other systems, and that within BL1* almost no consistently good or bad farms could be identified – the farms showed a relatively small variation in welfare score around the median. This could suggest that broilers in BL1* are better able to cope with variation in management, i.e., a more robust system. It should be noted that there were fewer BL1* flocks in the dataset than flocks from the other systems and we should therefore be cautious about this conclusion (although the number of flocks within BL1* was also large, i.e. 1889 flocks, versus 5683 for regular and 5936 for KvM).

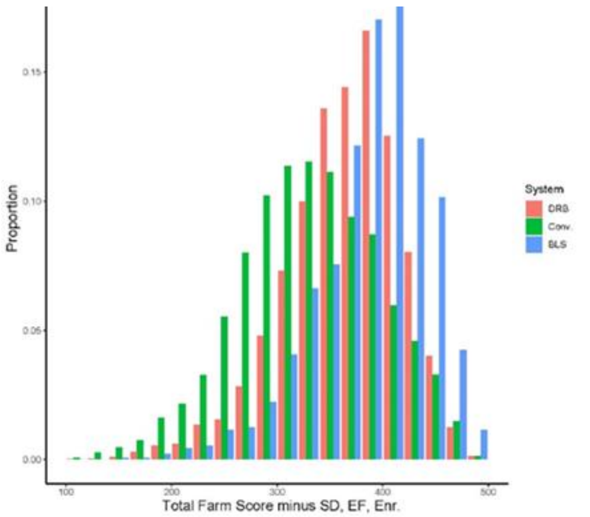


Figure 1: Distribution of the total welfare score per broiler concept, calculated on the basis of the sum of the scores of five individual animal-related welfare characteristics (footpad lesions, hock dermatitis, breast irritation, mortality and scratches/injuries). Green indicates the score distribution for the regular production system, red for Kip van Morgen, and blue for Beter Leven 1 star. A higher score means a better animal welfare score.

<u>Economy</u>: Economically speaking, stocking density, growth rate and feed conversion are the most important factors for the cost price structure. Based on the situation in 2017 (technical results and prices), the production cost per kg live weight of the Kip van Morgen is 20% higher and that of BL1* is 44% higher than conventional (Van Horne, 2020). The main cost items that are higher are feed (higher feed conversion), housing (lower stocking density) and labor (lower stocking density and longer growth period). The costs in the chain are also calculated in the report. The production cost for a kg of breast fillet is respectively 38% and 78% higher for the KvM and BL1* concepts. The lower carcass and breast fillet yield for the concepts play a major role in this. For the situation in 2017, the yield prices for the broiler farmer were collected and the income was calculated. This showed that in the end a comparable income was achieved for the broiler farmer with the three farming systems, because a higher price is paid by the consumer. The higher costs are offset by the higher selling price. The calculation model developed was frequently used in the later phase of the Greenwell project to make calculations at current prices and to add other concept variants.

<u>Environment</u>: In a so-called life cycle analysis (LCA) (Mostert et al., 2022a, Mostert et al., 2022b) a large part of the broiler chain was involved, from the rearing of the parent stock up to and including the broiler farm. The analysis looked at land use and greenhouse gas emissions, among other things. With regard to land use, the results were as expected because the regular broiler needs less feed. The regular broiler required less land than the intermediate (KvM) segment and the BL1*, namely 3.58 m^2/kg LW, compared to 3.99 for the intermediate segment and 4.32 for BL1*. The outcome of greenhouse gases (carbon footprint, expressed in CO_2-eq) associated with the production of broilers was surprising: one kilogram of BL1* can lead to a 3% lower emission of CO_2-eq per kilogram of live weight (LW), i.e. 3.55 kg, then the regular chicken (3.65 kg CO_2-eq/kg LW) and the intermediate (KvM) segment (3.98 kg CO_2-eq/kg LW). Surprising, because a BL1* chicken does need more feed than a regular chicken.

The largest contribution to the total emissions comes from the cultivation and production of raw materials for feed. The change in land use that can be associated with this contributes for more than half of this. Soy is an important part of broiler feed. The origin of that soy has a major impact on the emissions resulting from land use change. If soy is grown on fields that were removed from nature no more than 20 years ago (e.g. the tropical forest in the Amazon), this change of land use counts heavily in the calculation of the carbon footprint, according to generally accepted agreements, because a lot of emissions are released when tropical forest is cut down.

However, the feed of BL1* chickens currently contains less protein and therefore less soy than the feed of regular broilers or those in the intermediate segment. Both the slower growth of the chicken and the current economic optimization of the diets play a role in this.

If the heavy influence of land use change is reduced, for example by getting soy from North America, the equation will be different. In that case, regular broilers have a 23% lower CO2 footprint (1.37 kg CO_2-eq/kg LW) than BLK1* broiler chickens (1.79 kg CO_2-eq/kg LW).

So the country of origin of soy makes a big difference to the calculated climate impact of a broiler. BLK1* chickens need more feed, but depending on the origin of the soy, they can actually be more climate-friendly. At the same time, we know that the current feed formulas for broilers are optimized for economic return in every concept. In case of other criteria playing a more prominent role (such as the carbon footprint), other choices can very well be made. The larger proportion of soy in the diet of regular broilers is therefore not inevitable. This study therefore points to the chance of removing more than half of the climate impact with both regular and slower-growing chickens by using alternatives to soy that do not involve land use change.

There is also international discussion about how the climate effect of land use change should be included, regardless of the actual origin. As long as the global demand for soy far exceeds the supply of soy grown without deforestation, the total climate effect due to the choice of soy from a different origin is small.

Different diets for lower footprint

If we put the current economic optimization aside for a moment, it is interesting to see how chickens of different breeds can deal with feeds with lower protein contents, or with a higher share of other by-products (such as rape and sunflower seed meal). Due to their lower economic value, such products will count less heavily in the footprints as calculated by an LCA.

Together with our colleagues from AFSG, we first identified which by-products are less suitable for human consumption and could therefore potentially be used as an ingredient in broiler diets. The project partners then made a selection from this long list. The selection is shown in the text box on the right.
Because soy in the current diet has such a strong influence on the footprint, it was decided to conduct further research into by-products that could replace that soy component. Due to the wide availability, rapeseed meal and sunflower seed meal were subsequently chosen.

We then carried out two different trials, with fascinating results. In a first (unpublished) pilot, the effect of diets with a higher proportion of by-products on the feed intake and growth of regular chickens and chickens of a slower-growing breed was examined. The feed intake of both the regular and slower-growing breed on the diet with a higher proportion of by-products was higher than predicted from the start (*Figure 2*). The higher crude fiber content of the feed therefore did not inhibit feed intake. In addition it turned out that, contrary to expectations, the regular broiler did better in terms of feed conversion with diets with a higher proportion of by-products than the slower-growing chicken (*Figure 3*). The experiments surprised us because it turned out that we could go much further in adjusting the diets than previously expected, and could therefore include more by-products. This is an indication that there is room for new optima with a lower footprint, regardless of breed or growth rate. It should be noted that in practice feed raw materials have a great variability in quality, and certainly in case of by-products their composition and digestion coefficients are not always known. It would therefore be wise to repeat this trial.

Selection of potentially applicable by-products

- Egg shells from hatchery
- Grass
- Rape seed/sunflower seed expeller, rape seed/sunflower seed meal, solvent extracted
- Insects as enrichment
- Insects to turn low-value residual flows into highly digestible proteins
- Poultry fat
- Processed animal proteins (PAPs)
- By-products from the food industry
- Vegetable waste
- Brewer's grains
- Duckweed

This lower footprint must not, of course, be at the expense of welfare and health. That is why we also looked at a number of welfare aspects with different diets. The results did not indicate that welfare is negatively influenced by the choice of a diet with a higher proportion of rape/sunflower seed meal.
The reason that these combinations are not yet widely used is due to the way diets are currently optimized, namely on costs. Other optimisations, like the ones in this trial, in which welfare and the environment improve, currently lead to higher costs.

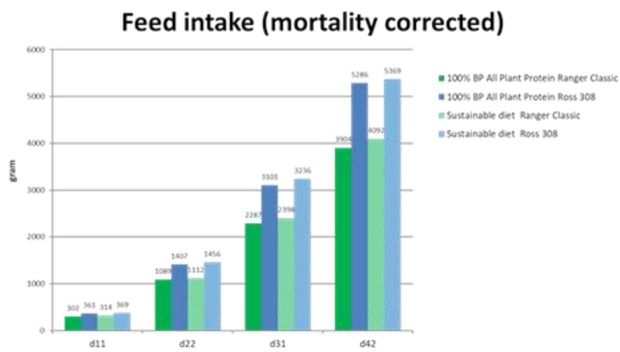


Figure 2: Feed intake for regular (blue) and slower-growing (green) broilers on days 11, 22, 31 and 42. Light blue and light green refer to a specially formulated feed with a higher proportion of rapeseed meal and sunflower seed meal. Dark blue and dark green refer to a 100% balanced protein feed, as prescribed for that breed.

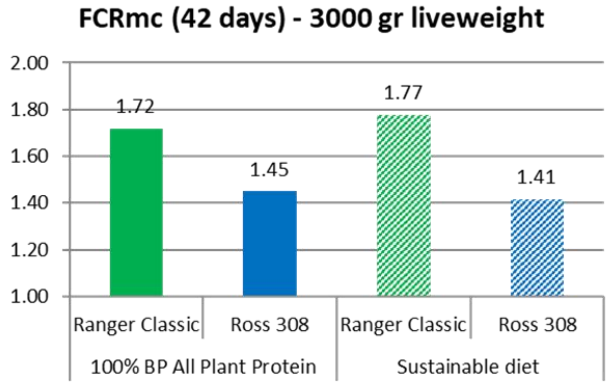


Figure 3: Feed conversion rate (FCR) of regular (blue) and slower growing (green) broilers for a 100% balanced protein feed, as prescribed for that breed (left; dark green and dark blue), and a specially formulated feed with a higher proportion of by-products (right; light green and light blue). FCR is determined for each breed at 42 days.

Stocking density, growth rate and welfare

Finally, we also looked at whether a lower stocking density has a different effect on welfare in a fast- and slower-growing breed, and what effect on welfare is visible when you reduce the growth rate of three breeds by feeding a feed with a lower protein content. For all welfare traits (example in *Figure 4*) and some behaviors (*Figure 5*), a faster and slower-growing broiler breed show an equal response to a reduction in stocking density, i.e. an equal improvement with a reduction in stocking density, and this is generally a linear effect (Van der Eijk et al., 2022, Van der Eijk et al., 2023). Only for footpad lesions there was an interaction between breed and stocking density, with regular, fast-growing chickens showing a stronger response to a reduction in stocking density than slower-growing chickens (*Figure 6*). Of course there are differences in level for most welfare traits, with a slower-growing breed generally having a better level of welfare at a certain stocking density. The conclusion from this trial is that a lower stocking density and a slower growth rate also have a positive effect on welfare separately from each other, and that the greatest welfare gain is achieved with a combination of both factors.

The trial shows that for both the Ross 308 and the Ranger Classic, with a lower stocking density, the final weight is higher and the feed conversion is slightly lower. This means a higher economic result per chicken at a lower stocking density. For the poultry farmer, however, the economic result per square meter of house per year is important. With a lower stocking density, the costs for housing and labor, among other things, are higher per chicken.

According to the test results, the stocking density of 36 and 42 kg per m^2 gives the highest economic result for the Ross 308. With the Ranger Classic, the economic result is clearly the highest with a stocking density of 42 kg per m^2.

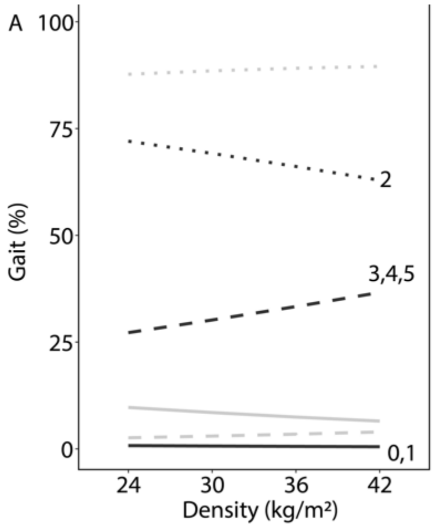


Figure 4: Response to a decrease in stocking density on animal welfare, here for locomotion quality (gait score), for Ross 308 (black lines) and Ranger Classic (slower growing, gray lines). Locomotion quality is scored on a scale of 0 to 5, with 0 being the best and 5 being the worst. Scores 0 and 1 (good quality of locomotion) and 3 and above (moderate to severe locomotion problems) are combined. Score 0, 4 and 5 did not or hardly occur. The figure shows that with decreasing stocking density from 42 to 24 kg/m^2, the quality of locomotion increases, which is particularly visible in a shift from the percentage of chickens with a score of 3 and higher to a higher percentage of chickens with a score of 2 (light locomotion problems) for Ross 308 chickens and – somewhat less clearly – a similar response plus an increase in the percentage of chickens in classes 0 and 1 (no locomotion problems) for Ranger Classic.

Calculation of welfare scores based on the results of the tests

For both the trial on the effect of a reduction in stocking density on welfare in a fast- and slower-growing breed, and the trial on the effect of growth rate on welfare in three breeds, the welfare scores were calculated on the basis of the welfare model developed within Greenwell. Due to the different trial conditions (e.g., stocking density), the results should **only be compared within one trial**. Because the scores for behaviour in particular are still missing in the welfare model, the total score does not provide a complete picture of welfare under the various circumstances.

Table A shows, based on the five welfare indicators, an increasing (better) total score with a decreasing stocking density. At the same stocking density, the slower-growing breed scores a lot higher (better) than the fast-growing broiler breed.

Table A: Welfare scores for the separate indicators as well as the total score for the five welfare indicators, shown per combination of breed and stocking density. The score varies between 0 (bad) and 100 (excellent).

Breed	Stocking density (kg/m^2)	Mortality	Hock burn	Footpad dermatitis	Gait score	Injuries	Total score
Ross 308	42	73	83	20	16	26	217
	36	70	84	29	19	35	237
	30	64	98	51	20	44	277
	24	78	98	71	21	74	341
Ranger Classic	42	85	93	72	66	67	383
	36	83	90	79	66	95	414
	30	82	99	88	78	89	437
	24	81	96	90	75	98	440

Table B shows, based on these five characteristics, an increasing (better) score for each breed with a reduction in the balanced protein content. The two slower-growing breeds have a better total score than the fast-growing breed at the same protein content.

Table B: Welfare scores for the individual welfare indicators as well as the total score for five welfare indicators, presented per combination of breed and growth rate.The score varies between 0 (bad) and 100 (excellent).

Breed	Balanced protein (%)	Mortality	Hock burn	Footpad dermatitis	Gait score	Injuries	Total score
Ross 308	100	51	31	5	2	98	187
	90	72	38	11	4	100	225
	80	74	34	15	7	95	226
Ranger Classic	100	82	29	11	2	100	224
	90	80	27	14	7	100	228
	80	91	40	25	7	97	261
Hubbard JA757	100	83	37	11	6	100	23
	90	83	40	14	6	100	244
	80	85	40	19	10	100	254

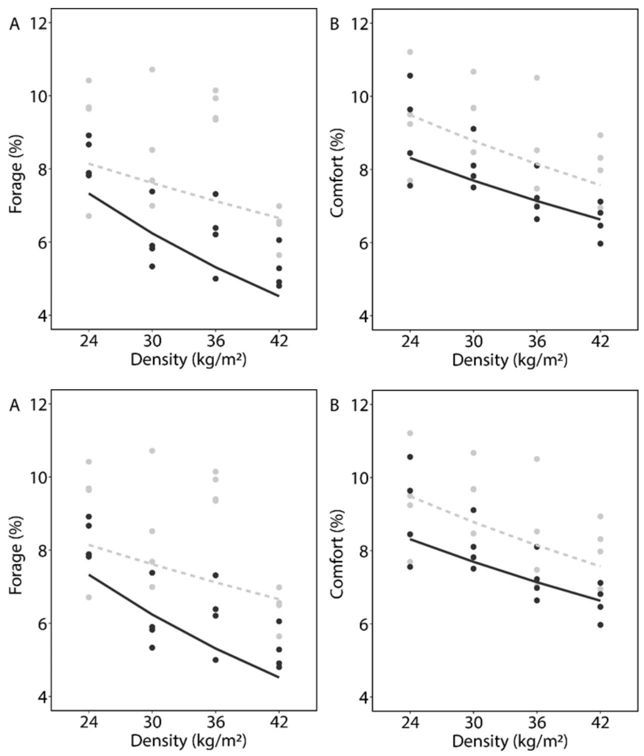


Figure 5: Response of Ross 308 chickens (black line/dots) and Ranger Classic chickens (slower growing breed; gray line/dots) to a reduction in stocking density from 42 kg to 24 kg/m^2 for the foraging (forage) behaviors; left) and comfort behaviors (preening, dust bathing; right). With a reduction in stocking density, the time spent on these behaviors increases linearly.

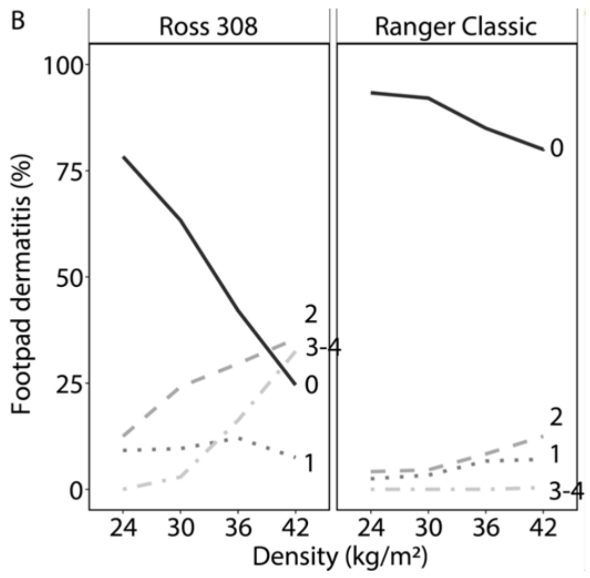


Figure 6: Response of Ross 308 chickens (left) and Ranger Classic chickens (slower growing, right) to a reduction in stocking density from 42 to 24 kg/m^2 for footpad lesions. Footpad lesions are scored on a scale of 0 to 4, where 0 means no lesions and 4 means very severe and large lesions. In both breeds it can be clearly seen that the number of chickens without lesions increases with reduction in stocking density, with this increase being larger for Ross 308 than for Ranger Classic.

A second trial investigated the effect of diet with a three levels of balanced protein content (100%, 90% and 80%) on animal welfare, economy and environmental impact in three breeds: Ross 308 (fast-growing), and Ranger Classic and Hubbard JA757 (both slower-growing). We wanted to see whether a reduction in growth rate by reducing the balanced protein content in the feed would lead to an improvement in animal welfare. In other words: could a fast-growing breed with feed with a diet with less protein achieve the same level of welfare as a slower-growing breed with a diet with a higher protein level?

Table 1: Growth rates (in g/day) up to a slaughter weight of 2.8 kg of three breeds at different percentages of balanced protein in the feed.

	Percentage balanced protein		
Breed	100%	90%	80%
Ross 308	64,7	61,3	55,3
Ranger Classic	54,4	52,8	49,8
Hubbard JA757	49,9	48,8	45,8

First of all, we can see in *Table 1* that the growth rate of a breed can be controlled with the percentage of balanced protein. For example, the daily gain of a Ross 308 chicken with 80% balanced protein is close to that of a Ranger Classic with 100% balanced protein, and a Ranger Classic with 80% balanced protein has the same daily gain as a Hubbard JA757 with 100% balanced protein.

Subsequently, the data show that a diet with a lower balanced protein content within the breed leads to an improvement in welfare (see *Figure 7* for an example of the footpad lesion score and the gait score of the different breeds and diets). Interestingly, especially for the gait score, the best effects are achieved with the 80% diets, while for example Ross 308 80% and Ranger Classic 100% have an approximately equal growth rate. The largest positive effects on animal welfare are achieved with the 80% diet in the slower growing breeds, where the lowest growth rates have been found. Growth rate – controlled by adjusting the balanced protein content in the diet, independent of the breed – can therefore certainly contribute to animal welfare, but this trial also shows that the best effect can be found with the slowest growth, so the combination of a slower growing breed and the least protein-rich feed. In terms of behaviour, an interesting finding is that when the breeds have an equal growth rate, there is no difference in behaviour.

In addition, especially in the behavioral tests (fear behaviour, play behaviour), a lower balanced protein percentage in the feed seems to have the greatest positive effect on the behavior of Ross 308, while the other breeds show a smaller or no response to a lower balanced protein content.

This trial has also been evaluated economically. The calculations are based on the technical results as shown in *Table 2*.

For all experimental groups the stocking density was 14 animals per m^2. The same price for a day-old chicken has been used in the calculations for breeds. Based on the prices of animal feed raw materials in the period September 2020 – August 2021, the feed price has been calculated for the starter, grower 1, grower 2 and finisher diet at a balanced protein level of 100, 90 and 80%. For the final diet the feed price was 39.7, 38.3 and 37.0 Euro per 100 kg respectively. *Table 3* shows the economic results.

Table 2: Technical results of the trial with three breeds and three levels of balanced protein.

Breed	Ross 308	Ross 308	Ross 308	Ranger Classic	Ranger Classic	Ranger Classic	Hubbard JA757	Hubbard JA757	Hubbard JA757
Balanced protein (%)	100	90	80	100	90	80	100	90	80
Length rearing period (days)	43	43	48	51	55	58	58	59	62
Final body weight (gr)	2828	2679	2700	2812	2946	2929	2932	2921	2881
Feed conversion rate	1.543	1.595	1.756	1.684	1.794	1.887	1.818	1.854	1.953
Mortality (%)	3.8	2.2	2.0	1.4	1.6	0.7	1.3	1.3	1.2
Growth/bird/day (gram)	64.7	61.3	55.3	54.4	52.8	49.8	49.9	48.8	45.8
Griller (% van live weight)	70.0	68.4	67.2	69.9	69.3	68.8	70.1	69.5	68.6
Breast fillet (% van carcass weight)	34.0	31.9	29.5	32.7	32.0	30.6	31.0	30.0	29.4

Table 3: Economic results of the trial with three breeds and diets with three levels of balanced protein..

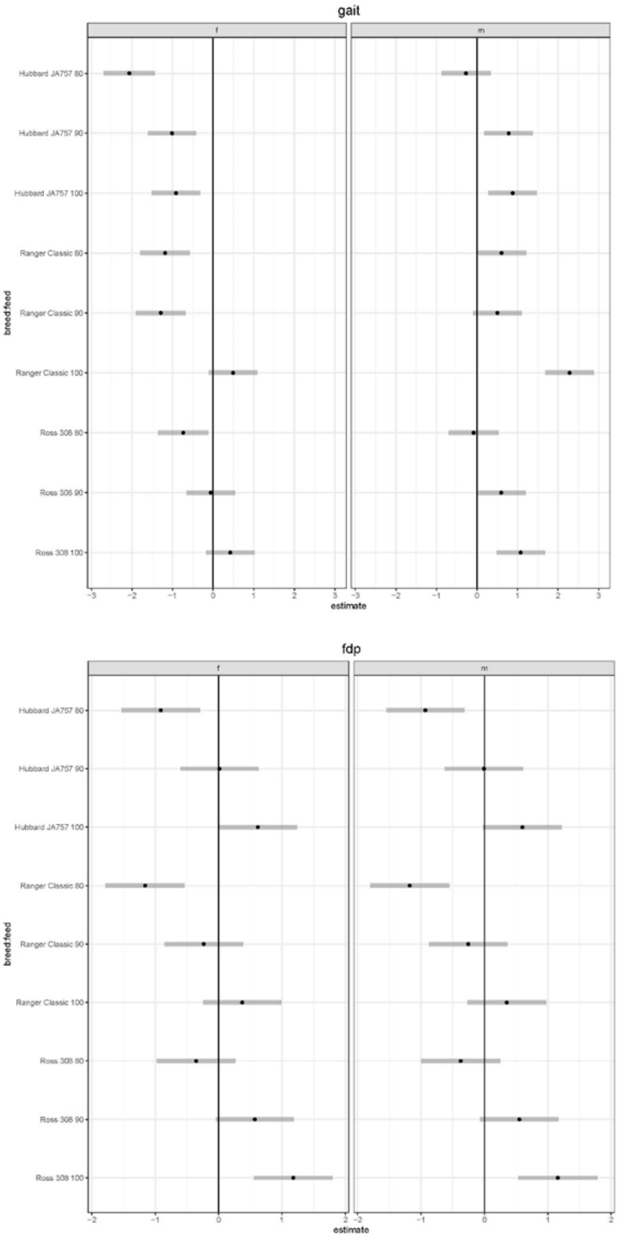
Breed	Ross 308	Ross 308	Ross 308	Ranger Classic	Ranger Classic	Ranger Classic	Hubbard JA757	Hubbard JA757	Hubbard JA757
Balanced protein (%)	100	90	80	100	90	80	100	90	80
Cost price live weight (ct/kg)	100.3	99.9	104.8	106.0	107.4	108.3	111.6	110.9	113.3
index (Ross-100= 100%)	100%	100%	104%	106%	107%	108%	111%	111%	113%
Cost price griller (ct/kg)	176.5	179.2	188.9	184.7	188.1	190.5	192.3	192.9	198.2
index (Ross-100= 100%)	100%	101%	107%	105%	107%	108%	109%	109%	112%
Cost price breast fillet (ct/kg)	370.0	399.7	457.2	408.2	424.8	449.2	448.6	464.7	491.6
index (Ross-100= 100%)	100%	108%	124%	110%	115%	121%	121%	126%	133%

In an intra-breed comparison, the Ross 308 with diet 90% has the lowest cost at farm level. After slaughter, the diet 100% has the lowest cost. Within the Ranger Classic, the diet 100% at every level (farm, griller and breast fillet) gives the lowest costs. In the group with Hubbard JA757, the diet 90% gives the lowest costs at farm level, but after slaughter the cost per kg breast fillet is the lowest with the diet 100%.

It is also possible to compare the combination of breed and balanced protein at the same growth level. The Ross 308 with 80% diet and the Ranger Classic with 100% diet both have a growth per animal per day of approximately 55 grams (see *Table 2*). *Table 3* shows that the farm level cost price for the Ross 308 with diet 80% is slightly lower. After slaughter, the cost price of the Ranger Classic with diet 100% is lower. The Ranger Classic is especially lower in terms of costs per kg fillet. A second comparison is the Ranger Classic with 80% diet and the Hubbard JA757 with diet 100%, both with a growth per animal per day of approximately 50 grams (see *Table 2*). At farm level and after slaughter (griller), the Ranger Classic with diet 80% gives the lowest costs. However, the cost price of both is comparable per kg of breast fillet.

It can be concluded that the Ross 308 with 100% balanced protein has the lowest cost price. The Ross 308 with a lower percentage of balanced protein has a higher cost price in every phase. The cost price per kg of breast fillet in particular clearly increases with 80% balanced protein. If a lower growth level is desired, it is therefore better to choose the Ranger Classic with 100% balanced protein than Ross 308 with 80% balanced protein. This is particularly relevant if the market asks for breast fillets, as is the case in the countries of north-western Europe.

This means that the following question can be answered positively: could a fast-growing breed with a diet with less protein achieve the same level of welfare as a slower-growing breed with a diet with a higher protein percentage? Both gait score and footpad lesions are better for Ross 308 at 80% BP compared to Hubbard JA757 at 100% and 90% BP while growth rate is higher and feed efficiency is better. This means that this combination is also better for the environment due to lower land use and CO_2 per kg live weight. Also, Ross 308 at 80% BP is a good example that growth is not a good measure of welfare; after all, they grew faster but had a better welfare score.



Figuur 7: Estimates of effect of breed/feed composition on gait score (top) and footpad lesion score (bottom) for female (left) and male broilers (right). The 0-line shows the average and the gray bar per treatment the variation around it. The more the mean is to the left, the better the score.

The place of broiler farming in our future food system

In a separate (unpublished) study (by Van Kernebeek and Bos) we explored whether it is logical and sensible to keep broilers in a future food system. To feed the now 8 billion people in the world in a sustainable and nutritious way, drastic choices are most likely required regarding which food we produce, and how. The area of fertile agricultural land is decreasing worldwide due to depletion, desiccation and desertification, and at the same time it is important that we have more forests and nature in order to preserve global biodiversity and the storage of carbon in the soil to combat climate change.

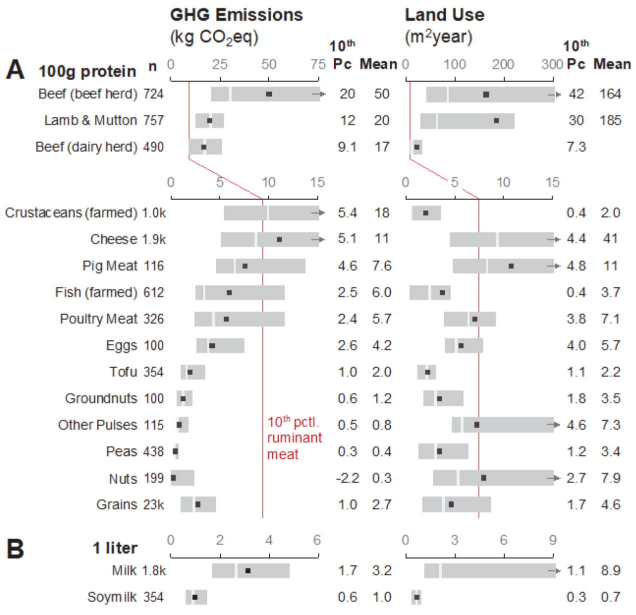
The most drastic step is a complete abandonment of animal production as a food source, as propagated for example (but certainly not exclusively) by Monbiot (2022), due to the large claim that animal husbandry places on agricultural land worldwide for the production of raw materials for feed. We will have to meet our nutritional needs with a plant-based diet, if necessary supplemented with protein production from, for example, advanced fermentation processes. It should be clear: in such a perspective there is no place for broilers at all.

In a food system without livestock farming, however, there is no role for animals that convert by-products, food waste and grass into food for humans. And it is precisely this role that can contribute to the efficient use of land and resources (Van Kernebeek, 2020, Van Hal, 2020, De Boer and Van Ittersum, 2018, Van Zanten, 2016). The importance of this role of animals becomes clear when applying the food system approach, in which all parts of the food system (crop cultivation, animal production, human consumption and recycling) are integrated (Van Zanten, 2016, De Boer and Van Ittersum, 2018, Van Hal , 2020, Van Kernebeek, 2020). These studies show that using animals to convert biomass that is not suitable for human consumption contributes to a more efficient use of land and minerals. And it is thanks to this role of animals that more people can be fed with the limited amount of land and raw materials than if the food system did not have livestock farming (Van Kernebeek, 2020).

From that perspective, animals can play a role in upgrading crops and residual flows that cannot be used directly by humans, such as grass from marginal land or by-products from the food industry. The availability of those crops and residual flows determines the number of animals that still have a desired and functional role in the food system.

Van Zanten (2016) and De Boer and Van Ittersum (2018) estimate that 9-23 grams of the daily protein requirement of Europeans (50-60 grams) could come from animal sources in this way. An optimization study (Van Hal, 2020) subsequently concluded that low-yielding dairy cows and pigs and laying hens were the most suitable animal species for utilizing the soil and residual flows available for animals in Europe. Van Hal et al. (2019) conclude that food waste, by-products and grass are used most land-efficiently by feeding them to animals with a high feed conversion (in their case: laying hens and dairy cows), to animals that are the best in the digestion of specific feeds (especially dairy cows for grass and pigs for food waste), and to animals that could best benefit from low-quality feed because of their low productivity. Van Selm et al. (2022) come to similar conclusions in their study, in which the role of animals is limited to that of converting by-products: broilers cannot compete with, for example, dairy cows and pigs in such a food system. Based on the insight in our Greenwell project that broilers can also handle lower percentages of balanced protein than standard calculations, such optimizations could possibly turn out differently. This requires further investigation.

A more dominant perspective on the environmental sustainability of production processes is the life cycle assessment (LCA). LCAs look at the impact on ecology and consumption of energy and raw materials per production unit (e.g. a kilogram of meat), and are agnostic about the absolute volume that can be produced on earth given available land and raw materials. The advantage of an LCA is that different products and production processes (with the same assumptions) within a product group can be compared, for example on their climate impact. In this project, such a thorough LCA was also carried out for the various broiler concepts (Mostert et al., 2022b), see also above. Although the outcome of an LCA strongly depends on the assumptions that are made, broiler production in almost all LCAs is favorable to very favorable compared to other forms of animal production, but also, for example, that of cheese (see *Figure 8*, copied from Poore and Nemecek (2018)). However, vegetable protein sources such as nuts, legumes and soy products such as tofu are superior. Viewed from an LCA perspective, it is therefore better for the climate to eat chicken than cheese, and much better than beef or lamb. The pig also scores less well ecologically than the chicken, but the extent to which this is strongly dependent on the amount of residual flows that a pig uses according to that analysis.



Figuur 8: Estimated global variation in GHG emissions and Land Use of (A) Protein-rich products. Grains are also shown here given that they contribute 41% of global protein intake, despite lower protein content. (B) Milks. n = farm or regional inventories. Pc and pctl. = percentile. Copied from Fig 1. in Poore and Nemecek (2018).

This corresponds with the most traditional measure of efficiency in livestock farming, the feed conversion. This measure indicates the ratio between the kilos of feed that are needed for the animal to reach a certain weight. A higher feed conversion is considered less efficient than a lower feed conversion. A broiler has a lower feed conversion than a pig and a much lower feed conversion than beef cattle. This remains the case with a slower growing chicken, but the difference becomes slightly smaller. For dairy cattle, this comparison depends on the allocation to milk and meat.

Our conclusion is that it strongly depends on your point of departure whether it makes sense to keep broilers in a future food system. As long as animal production in itself, or its size, is not in question, the broiler chicken is ecologically better than a pig or a beef cattle, expressed in terms of impact per kilogram of product or protein. In the food system approach, the first studies point to a more important role for dairy cows and pigs and a small share of laying hens, while broilers are not necessary. This could possibly turn out differently if the models used calculate with lower percentages of balanced protein in broiler feed.

Conclusions

We started the Greenwell project with the question whether welfare, environment and economy in broiler production could be improved simultaneously. The main conclusions are:

1. Broiler chickens kept according to the BL1* guidelines generally have a better welfare than KvM broilers, which in turn have a better welfare than regular broilers. However, the variation is large: the management skills of the poultry farmer make a big difference, especially with regular chickens and KvM.
2. Welfare and the environment can be significantly and simultaneously improved. The most important factors for this are growth rate, capacity utilization and the choice of raw materials for the feed.
3. Stocking density and growth rate have this effect independently of each other. A fast-growing chicken in a lower stocking density is therefore also a conceivable way to improve welfare, as is a slower-growing chicken at a higher stocking density, but the combination (slower grower + lower stocking density) results in the greatest effect.
4. There are very interesting opportunities in using by-products such as rapeseed and sunflower meal as a (partial) replacement for soy, but also poultry fat, resulting in a lower ecological footprint. And this has no negative consequences for welfare.
5. Production and cultivation of raw materials (and related land use change) and feed conversion are the main drivers of greenhouse gas emissions and land use. The land use change (LUC) that can accompany soy production accounts for more than half of the climate impact of broiler production. This provides for a great opportunity for the sector to further reduce the climate footprint.
6. The soy used in broiler feed often comes from Latin America. Because slower-growing chickens (especially BL1*) are fed much less soy in the current economic optimisations than regular, fast-growing chickens, their climate impact is surprisingly slightly lower than conventional production, despite their longer lifespan and higher feed conversion. However, if the soy is sourced from North America, the climate impact of slower-growing chickens is higher than that of regular chickens.
7. Although slower-growers have better welfare than regular chickens, they do require more land and raw materials per kilogram of product than regular chickens, but still less than beef cattle and most pigs.
8. From an economic point of view, stocking density, growth rate and feed conversion ratio are the most important factors for building up the production costs. Based on normative technical results and prices of input factors, the production costs per kg live weight of the KvM is 20% higher and that of BL1* is 44% higher than the regular chicken.
9. In today's global market, cost is leading. Optimizations for welfare and the environment are currently not competitive on cost price with conventional production. The transition from conventional to Kip van Morgen and (currently) to BL1* in the Netherlands indicates that this calculus can change if the market (the consumer) is prepared to pay more. As the market takes the carbon footprint of production more into account, feed optimization will also turn out differently in practice. In Greenwell we have shown that there is still a lot of room for this in terms of animal performance.
10. There is room for further improvement in every broiler concept, both in terms of the environment and animal welfare. Important factors are stocking density, growth rate and choice of raw materials for feed. In addition, the quality of the management (stockmanship) largely determines whether that potential is actually realized.
11. Sustainability within broiler farming should not be viewed separately from sustainability of the food system as a whole. The principle whereby animals are used to valorise by products, food waste, and grass from marginal land contributes to more efficient food production. In such a system, broilers seem to play a lesser role than dairy cows and pigs.

Perspective/continuation

We finish this Greenwell project with a large amount of new insights, but many questions and development directions remain to be explored further.

1. We have not even tested the limits of what a broiler can eat without a negative effect on welfare or health.
2. What role can the broiler play in a future food system if it only receives (non-humanly consumable) residual flows, or an even lower protein content in the feed?
3. Price-sensitivity of optimizations on CO_2 or land use. What premium is needed in the market to optimize on ecologically better feeds?
4. Relative impact of stocking density versus growth rate on welfare. What has the largest effect, what is the most economically beneficial welfare measure, given a certain minimum welfare standard?

5. Insight into how organic performs against the other systems to have a complete comparison. This is also important because organic production is now stimulated by the EU but we have no clear insight into its performance.
6. Including all production chain phases in animal welfare assessment, which was currently only possible for the broiler phase.
7. A more detailed idea is to find a nice combination in certain forms of feed that simultaneously offer enrichment and a low footprint.

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