Agricultural Systems 214 (2024) 103837

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Sustainable intensification of grass-based beef production systems in alpine regions: How to increase economic efficiency while preserving biodiversity?

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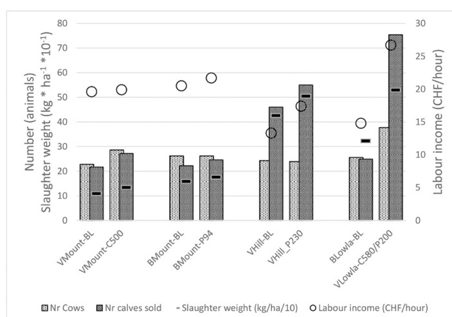
HIGHLIGHTS

- Share of biodiversity areas on farms studied is between 11% and 45%, depending on the productivity potential of the site.
- ·Productivity and profitability can be increased by improving cow efficiency rather than by increasing stocking rate..
- · The less productive mountain farms record more biodiversity, whereby profitability is strongly dependent on direct payments.
- Both profitability and biodiversity can be improved if the system is aligned with the production potential of the site.

GRAPHICAL ABSTRACT

Income follows cow efficiency while maintaining biodiversity



(BL = baseline; reduction cow-liveweight [630kg to 500kg] for veal (VMount) and increasing cow productivity [85% to 94%=0.94 calves/cow] for beef (BMount) in mountain region; increasing cow productivity [190% to 230%=2.3 calves/cow] for veal in hilly region (VHill); increasing cow productivity [97% to 200%=2 calves/cow], reduction cow-liveweight [745kg to 580kg] and changing from beef to veal in lowland region (VLowla).

ARTICLE INFO

Editor: Paul Crosson

Keywords:
Grass-based beef production
Profitability
Productivity
Biodiversity

ABSTRACT

CONTEXT: Beef production on grasslands has multiple positive impacts. In addition to the production of high-quality protein, marginal lands in particular enable high biodiversity and landscape quality. However, this type of production is perceived as less economical than more intensive meat production systems.
OBJECTIVE: The aim of the study is to develop recommendations on how different grass-based production systems can be economically improved without endangering biodiversity.
METHODS: Thirty-five suckler cow farms supplying into two different brand programmes (Natura-Veal: slaughter age at five months; Natura-Beef: slaughter age at 10 months) were grouped into four production systems across two production sites in Switzerland: Natura-Veal, mountain region, extensive (VMount); Natura-Beef, mountain region (BMount); Natura-Veal, hilly region, intensive (VHill) and Natura-Beef, lowlands (BLowla). On the farms, beef production was analysed in detail on the basis of technical production data as well as full cost accounting. The farms were grouped into one model farm (farm type) per production system. On each model farm, optimisation options were simulated and checked for practicability with farmer participation. The optimisation

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https://doi.org/10.1016/j.agsy.2023.103837
Received 13 July 2023; Received in revised form 27 November 2023; Accepted 10 December 2023
Available online 23 December 2023

focused primarily on improving cow efficiency via the sale of more slaughter animals per cow, through lower animal losses, higher fertility or the additional purchase of calves suckled by a nurse cow.
RESULTS AND CONCLUSIONS: Descriptive statistics showed significant positive correlations between stocking rate and land productivity and significant negative correlations between stocking rate/land productivity and the share of biodiversity areas (SBA), confirming previous findings. These relationships were also reflected in the production site of the farms, as mountain farms with lower productivity had a significantly higher SBA, while farms in areas with better grass growth had fewer biodiversity areas but higher productivity. Accordingly, the optimisation options were adapted to the production site under the constraint of a constant stocking rate. In favourable forage-growing areas, further intensification via improving cow efficiency by buying foreign calves led to significant improvements in profitability (VHill and BLowla). In mountain areas, the optimisation potential is lower. Site-adapted, i.e., small-framed and robust, cow types lead to better cow efficiency, which also contributes to good profitability in extensive production with a high biodiversity share, although this is strongly determined by national direct payments (VMount and BMount). Both income and biodiversity can be optimised if cow efficiency is increased and production systems are adapted to the site as closely as possible.
SIGNIFICANCE: The study shows practicable recommendations for sustainable intensification in grass-based meat production systems in the current discussion on maintaining or increasing biodiversity in agriculture.

1. Introduction

A growing world population puts increasing pressure on natural resources and makes it highly challenging to reach the objective of reducing global greenhouse gas emissions. Approximately 25% of meat production is derived from ruminants (OECD/FAO, 2022), most of which is beef produced either intensively in stables or feedlots or extensively on meadows and pastures. Studies have shown that intensive production systems perform better than extensive grass-based systems in terms of environmental impact per product unit (Pelletier et al., 2010; Capper, 2012; Clark and Tilman, 2017; McGee et al., 2022). However, it is often overlooked that extensive beef production systems mostly take place on marginal land (i.e. land that is not suitable for arable farming due to climatic and topographical reasons). There, beef production is not in competition with human food and can even show a better feed conversion than poultry or pork production if only the “feed” edible for humans is taken into account (CAST, 1999; Wilkinson, 2011; Schader et al., 2015; Mottet et al., 2017).

While many studies have focused on the negative environmental impacts of grass-based beef production systems (De Vries and De Boer, 2015; McClelland et al., 2018), fewer studies have focused on their positive effects. On the one hand, grass-based production systems contribute to sustainable food security because they are able to convert these feeds at low opportunity costs into nutrients such as protein and fat that would otherwise be lost to food production (van Zanten et al., 2019). On the other hand, they also provide various ecosystem services, such as biodiversity conservation and enhancement or landscape conservation (Kleijn et al., 2009; Richter et al., 2021; Angerer et al., 2021). The latter also has socioeconomic importance for local communities, especially with regard to tourism (Allan et al., 2015; Huber and Finger, 2020). Even in arable farming regions, raising extensive beef cattle can contribute to soil fertility by building up organic substances, both directly through the manure supply and indirectly through the cultivation (and feeding) of temporary grassland with legumes, which has a positive effect on crop rotation (Van Zanten et al., 2019). Ruminants have also been shown to have – as part of crop-livestock systems – a positive effect on weed control and pest cycle disruption in arable crops (Schut et al., 2021).

With regard to biodiversity conservation, one of the goals of the Convention on Biological Diversity (CBD) is to conserve at least 30% of land areas, especially those with special importance for biodiversity and ecosystem services. The convention also states that agricultural land should be employed with biodiversity-friendly practices, such as sustainable intensification, to ensure the resilience and long-term productivity of agricultural production systems (CBD, 2022, Target 10). Thus, there is a strong public interest in preserving extensively utilised meadows or pastures on marginal land. However, trade-offs may arise, especially between productivity and biodiversity. Concerning profitability, grass-based beef production in Europe has rather poor economics – even in favourable areas such as Ireland (Deblitz, 2010; Hennessy and Moran, 2016). The Organisation for Economic and Cooperation and Development's (OECD) Agricultural Outlook predicts a reduction in suckler cow herds in Europe due to low profitability (OECD/FAO, 2022). Grass-based beef production systems, especially those located in mountain areas, are severely disadvantaged in terms of productivity. Compared to production systems that strongly rely on concentrates, feed production is characterised by both significantly lower nutrient yields per hectare, resulting from the shortened growing season, and by expensive special mechanisation due to the topography and small plot sizes. Thus, the production of roughage on marginal land is usually connected with significantly higher costs, especially if the forage has to be conserved for winter feeding. In Europe, these handicaps are mostly compensated by direct governmental payments with the goal of maintaining production on farms to fulfil overarching societal goals, such as landscape maintenance or biodiversity. Switzerland, as a non-member of European Union, has its own direct payment system, which is characterised by a very differentiated design and, due to its high-cost environment, by a high payment level (FOAG, 2022).

However, achieving societal goals is not the only issue. From both macroeconomic and farm management perspectives, a certain level of production efficiency must also be achieved. This “sustainable intensification” basically implies a site-specific optimisation of production potential while ensuring ecosystem services (Pretty, 1997; Baumont et al., 2014). This seems challenging insofar as studies from Ireland have shown that an increase in cattle stocking rate and thus an increase in output per hectare is a major driver of profitability (Fales et al., 1995; Crosson et al., 2014; Taylor et al., 2017b) but has a negative effect on biodiversity (Marriott et al., 2004; Foley et al., 2005; Van Rensburg and Mulugeta, 2016). Nevertheless, even with a high stocking rate, the environmental impacts of food production on grasslands are still lower than those on arable land (Baumont et al., 2020).

Many farm-level investigations of grass-based beef production systems have been presented in the literature. Some studies focus on economic aspects and rely either on detailed empirical analyses (Syrucek et al., 2017; Taylor et al., 2017a, 2017b) or on modelling approaches (Wetlesen et al., 2020a; Kvapilik et al., 2021). Other studies have focused on the environmental and, especially, biodiversity effects of grass-based beef production (Van Rensburg and Mulugeta, 2016; Angerer et al., 2021; McGee et al., 2022). The present study addresses the following research question: What is the relationship between farm size, productivity and biodiversity on suckler cow farms and which site-specific production optimisations can be implemented to improve productivity and profitability while ensuring a certain level of biodiversity? Our work relies on the assumption that the stocking rate and biodiversity provision are oppositely related in grass-based production systems, which implies that optimisation must occur without a stocking rate increase. To answer the research question, individual farm data from 35 farms on production techniques and economics are obtained. The farm data were typified into model farms according to production orientation and altitude and simulated according to the research question. To the best of our knowledge, no comparable study has analysed the various beef production systems in the Alpine region in such detail under consideration of multifunctional aspects.

1.1. Production systems

In Switzerland, approximately 70% of agricultural land consists of grasslands (Agristat, 2021). Accordingly, milk and meat production plays a dominant role (Mack and Huber, 2017). As in other European countries, in the last 20 years, the number of dairy cows has declined due to the increase in milk yield per cow and year, while the number of suckler cows has more than tripled (Agristat, 2021). Systems based on suckler cow husbandry differ according to slaughter age and intensity, which mostly depend on the region (Gazzarin and Jan, 2022).

In general, the quality of roughage in Switzerland is of a high standard due to a suitable climate, heavy soils and good forage management, which ensures high-quality forage grasses and a high proportion of clover (Hofstetter et al., 2014). The pastures are managed on a rotational basis and the paddocks are frequently mown. In addition to the usual silage production, hay is produced, which is usually dried in the barn by ventilation. Thus, with the usual rainfall in the pre-alpine region, grass is used intensively during vegetation season by harvesting it around once a month, either by grazing or by mowing, which ensures high quality at an early stage of growth. This practice results in a balanced forage nutritional composition, allowing for the low use of concentrates (Kirwan et al., 2007).

According to regular surveys on the expectations of the Swiss population regarding agriculture, animal-friendly farming is constantly given the highest priority (FOAG, 2022). As a response to increasing consumer concerns about conventional veal production, characterised by high levels of antibiotic use, a major retailer is running an exclusive programme of veal from calves slaughtered at approximately five months of age (Natura-Veal, slaughter weight of 100–140 kg). The system allows the calf to suckle its mother and can also be intensively operated by buying additional calves from dairy farms. These additional calves are also raised by the cow, either starting from the beginning of its lactation or after five months, once its own calf has been sold. In another more widespread program by the same major retailer, the offspring are slaughtered directly after weaning at approximately 10 months of age (Natura-Beef, carcass weight of 150–250 kg). In this way, separation after weaning in the stable and on the pasture can be omitted. To a lesser extent, there is also an internationally more widespread finishing system, in which the offspring are separately finished and slaughtered between 16 and 24 months, depending on the feeding intensity, which is often boosted with maize silage and concentrated feed.

More than half of the Swiss suckler cow farms are organised in the association “Beef Cattle Switzerland”, and most of them supply the Natura-Veal or Natura-Beef programs, for which this association has an exclusive contract with the retailer. The different production systems are also differentiated in terms of price. The price for Natura-Beef is approximately 5–7%, and the price for Natura-Veal is even greater than 50% above the price for animals that are fattened separately in other programs up to a higher slaughter age, whereby consumer demand for Natura-Veal cannot yet be entirely met with the existing supply.

In parallel to suckler cow farming, there exists another beef farming system, namely extensive pasture fattening with female cattle and steers. Weaned young cattle from dairy farms are usually acquired at the age of 5 to 12 months and finished for a further 10 months, similar to the previously mentioned finishing system based on suckler cows.

To achieve good carcass quality, suitable breeds must also be selected for the respective production systems. Accordingly, for programs with slaughter ages of 5 or 10 months, rather early-maturing bulls (Angus and Limousin) are selected that are well suited for grazing. Depending on the intensity (especially in the intensive form of Natura-Veal production), greater importance is attached to milk yield. Hence, the mother often originates from a beef-dairy cross, with dairy genetics from Brown Swiss or Red Holstein, or is even a pure dual-purpose breed (Original Brown cattle, Original Simmentaler and Tyrolean Grey cattle). If the quality of the grassland is rather weak, the choice of a bull with good fat cover is particularly important.

2. Materials and methods

2.1. Data

For our research, we collected data from 35 suckler cow farms in central and northeastern Switzerland. The investigated region includes both extensively used grasslands in higher mountain areas (800–1400 m above sea level) and intensively used grassland areas in lowland or hilly areas (500–800 m.a.s.l.) with high yield potential.

The population of farms investigated in this work encompasses all farms that (i) are members of “Beef Cattle Switzerland” and (ii) have a beef cattle herd size of at least 18 livestock units (LUs). This limit was set to exclude hobby farms. Four farm groups were identified, each representing a production system: Natura-Veal, mountain region, extensive (VMount), Natura-Beef, mountain region (BMount), Natura-Veal, hilly region, intensive (VHill) and Natura-Beef, lowlands (BLowla), for which a sample of 6, 14, 6 and 9 farms, respectively, was selected. The selection occurred either via cantonal extension services or via public calls to participate in the investigation.

Table 1 indicates that the samples in both regions are quite similar to the sampled population in terms of the number of cows.

For each farm, the accounting data for 2019 were supplemented with records of forage areas (extent and intensity of use, including biodiversity conservation areas), slaughter data and an interview with a farmer. Further data, such as reproduction data and working time, were collected via a questionnaire developed for this purpose.

Production-related operating costs such as supplementary feed, veterinary and pharmaceutical costs or animal purchases, as well as overhead costs consisting of machinery (repairs, depreciation and contractors), fixed assets (buildings, fixed equipment, land and capital), labour (hours) and general farm expenses (administration, electricity, water, insurance, etc.), were recorded. The single-farm results were checked by the farm managers, and if necessary (i.e. if the results were not plausible), the data were verified and corrected where needed. This resulted in a comprehensive dataset that allowed for a detailed analysis but also explained the small sample size due to time-consuming on-farm data collection.

2.2. Study design

To answer our research question, after extensive data acquisition, we conducted a detailed economic and technical analysis of the beef production branches in the selected farms. We carried out a full cost calculation for 2019, including feed production. Using descriptive statistics and individual farm data, the differences among the production systems and the correlations among the variables relevant to the

Table 1
Structural comparison of the sample with the sampled population “Beef Cattle Switzerland”.

Farms	Sample		Sample population*	
	Nr. cows	N	Nr. cows	N
Mountain region	24.8	20	25	1158
Lowland/Hilly region	25.9	15	26.3	1396

* Member-farms of “Beef Cattle Switzerland” with a minimum of 14 cows in 2019 (equivalent to a minimum of 18 LUs).

research question were identified. Next, performance indicators were defined.

To model the optimisation options, a farm type or model farm had to be set up via a homogenisation and aggregation procedure for each farm group representing a production system. The reference situation or baseline of the farm type was compared with the optimisation options using the performance indicators.

3. Method

The accounting data were processed for each farm using the Agri-Perform farm analysis tool (Excel), which enables automatic overhead cost allocation based on observations of more than 4500 Swiss farm branch groups in the farm accountancy data network (FADN; Hoop and Schmid, 2015; Lips, 2017; Gazzarin and Lips, 2018). Using the farm interview, the data could be checked for plausibility by the farm manager so that in the case of unusual cost items, previous accounting years could be included and manual corrections to the overhead cost allocation could be made, if necessary. The aim was to represent a typical business year for beef production on each farm.

The mean values of the relevant variables were compared among the four farm groups with descriptive statistics using individual farm data. Continuous variables were analysed for correlations. Due to a non-existing normal distribution, the Kruskal–Wallis test and non-parametric correlation (Spearman) were applied with the statistics programme STATA.

The next step was to construct a typical farm (model farm) for each of the four farm groups according to the typical farm approach of the International Farm Comparison Network (Hemme et al., 2014). The typical farm should be largely representative of the production system in relation to the respective criteria (slaughter age and region) for the investigated sample population. Starting from the mean value of the farm group, each cost item of the individual farms was examined using local extension services to identify possible outliers. If necessary, the observation was eliminated to make the group more homogeneous. This typification process was a prerequisite for carrying out model simulations that had a degree of general validity for the whole population based on the small samples that were analysed.

Due to different farm-specific situations, the costs of fixed assets were standardised, as they are largely independent of the production system. For this purpose, we used a cost calculation program for farm buildings (Gazzarin and Hilty, 2002). This program enabled us to recalculate the building costs for each farm based on various variables that determined the space requirement. Among these variables are the number of cows, production orientation (slaughter age), region (winter feeding period and building statics) and calving period (space demand for young cattle).

For the cost of capital, 0.83% was assumed to be the average interest rate. This value is based on an initial interest rate of 1.5% with a depreciation period of 15 years (equipment and machinery) to 30 years (buildings) and could be derived from the Excel function PMT (payment based on a fixed interest rate and for a fixed duration). In addition, land costs were standardised based on a uniform 50% share of rented land and region-specific rent (lowlands: Fr. 700.−/ha; hilly region: Fr. 500.−/ha; mountain region: Fr. 300.−/ha).

3.1. Performance indicators

When assessing the performance of the investigated production systems, we distinguished between farm-specific indicators such as production- and biodiversity-related technical performance indicators (land productivity, cow productivity and share of land enrolled in agri-environmental programs for biodiversity) and financial performance indicators (income from beef production).

Land productivity (Formula 1) is calculated from the annual slaughter weight produced in relation to the forage area.

$$P_L = \frac{\sum S_{as}}{F} \tag{1}$$

P_L = land productivity in beef production (kg slaughter weight per ha forage area).

S_{as} = slaughter weights in kg for animals sold (Natura-Veal, Natura-Beef, other beef).

F = forage area for beef production only (ha).

Cow productivity is an additional efficiency indicator (Formula 2) that is defined as the average productivity per cow (per farm) in the number of animals reared and sold per cow and year. Cow productivity considers both the calf (calves) born by a cow and the bought-in calves reared by this cow. Cow productivity can also be expressed as a percentage (%).

$$P_C = \frac{E_p}{E_{tot}} * \frac{365}{I} * L * (1 - F_s) * (1 - F_L) - F_R + C_b * (1 - F_L) \tag{2}$$

P_c = cow productivity = average number of reared and sold animals per cow and year.

E_p = number of productive (pregnant) cows.

E_{tot} = total number of cows.

I = calving interval (number of days between two subsequent calvings).

L = litter size (number of calves per birth).

F_S = factor stillbirths (number of stillbirths per total births).

F_L = factor losses during rearing (number of dead calves per total number of live births or bought-in calves).

F_R = factor replacement rate (one over lifetime per cow).

C_b = bought-in calves per cow.

The share of biodiversity areas (SBA) corresponds to the share of ecological focus areas. It is the share of forage area enrolled in an agri-environmental programme that is aimed at biodiversity conservation (Formula 3) and serves as a simplified (quantitative) indicator of the farm's biodiversity performance, as these areas are subject to certain cultivation regulations: The application of fertilisers and pesticides is not allowed and mowing is required later in the year. The earliest times for mowing in early summer and for grazing in autumn are defined according to altitude.

$$SBA = \frac{B_f}{F} \tag{3}$$

SBA = biodiversity indicator (share of biodiversity areas in Quality 1 or 2 areas per total ha forage area = SBA).

B_f = forage area enrolled in action-oriented payment schemes of the Swiss agri-environmental program for biodiversity conservation (ha).

F = forage area for beef production only (ha).

Profitability is measured via two different income indicators: labour income per hectare and labour income per hour. The labour income is used to remunerate the labour forces, either one's own labour or the labour of employees, after all other costs, such as (variable) operational costs and (fixed) overhead costs, have already been paid. This income is again considered in relation to the available forage area (Formula 4).

$$Inc_f = \frac{\sum R_M + D - (E_{op} + E_m + E_a + E_g)}{F} \tag{4}$$

Inc_f = labour income (CHF per ha).

R_m = market revenues from selling Natura-Veal, Natura-Beef, other beef, cows and surplus roughage.

D = national direct payments (all payments allocated to beef production in CHF).

E_{op} = operational expenses such as feed, veterinary and other variable costs (allocated, in CHF).

E_m = expenses for machinery and contractors, including depreciation (allocated, in CHF).

E_a = expenses for fixed assets (building and equipment, including depreciation), capital and land (allocated, in CHF).

E_g = general farm expenses such as administration, electricity and water (allocated, in CHF).

F = forage area for beef production only (ha).

Labour income per hour (Inc_h) measures income in relation to labour input in the production system. All costs, with the exception of labour costs, were deducted from the total revenues and considered in relation to the labour hours used, resulting in the actual hourly wage. The calculation corresponds to Formula 4, whereby the divisor "hectares" is replaced with the divisor "labour hours".

3.2. Integration of optimisation options in a simulation model

In the last step, the standardised data of the typical farm of each production system were transferred to the farm analysis tool. These four model farms represent the baseline. By linking them directly to an additional simulation model, optimisation options could be calculated and their economic impact could be quantified (Fig. 1). Our model belongs to deterministic farm simulation approaches (Ciaian et al., 2013). It is a production-oriented simulation that is exclusively limited to the farm branch and essentially consists of a herd model with an integrated feed consumption calculation based on data from Morel et al. (2021a, 2021b) and Boessinger et al. (2010). Feed consumption calculation is based on different variables such as live weight and productivity of the cows, fattening period, daily weight increase and calving period, which were determined from either interviews on the farms or the slaughter data.

Starting from an already high standard in Swiss grassland management, on the one hand, optimisation included management interventions that increased the efficiency (productivity) of the suckler cow while maintaining a constant forage area, for example, by increasing the ratio of calves to suckler cows. On the other hand, the economic effect of additional land was calculated for smaller farm types (Table 2). No external roughage should be bought in, with the exception of a performance-adequate adjustment of concentrate use, when the cow is suckling two or three calves. Thus, the stocking rate remains almost constant when the number of cows is reduced accordingly.

Table 2
Optimisation options for different production systems based on conditions in farms with above-average economic results.

Farm type	Option	Description
VMount	C500	Reduction of live weight per cow from 630 to 500 kg, no barn extension and use of existing space capacities
BMount	P85–94	Economic effect of reduced/increased cow productivity by 10% (85% vs. 94%)
VHill	P230	Increasing cow productivity by increasing the number of calves sold per cow (from 190 to 230%)
	Land+	Additional 20% land (rent), no barn extension and use of existing space capacities
BLowla	C580/ P200	Increasing cow efficiency by switching to Natura-Veal intensive: 2 calves sold per cow after 5 Mt. (productivity of 200%), reduction of live weight per cow (745–580 kg) and barn extension

Fig. 1 illustrates the described method. The principle is that, in the first step, the herd and feeding model is adapted to the respective production system (baseline); then, in the second step, variables such as cow productivity or cow weight are changed under constant forage supply, from which the differences in herd structure (number of cows and number of sale animals) are applied to the economic data of the baseline via correction factors. Thus, the higher productivity of cows due to lower losses and better fertility increases the feed demand of young animals. With bought-in calves, the feed requirement of cows increases. In both cases, the number of cows must be reduced accordingly to keep roughage consumption constant. If the live weights of cows are lower, however, the number of cows can be increased due to the cows' lower need for feeding. Such optimisation options are changed in the model under ceteris paribus conditions and have an impact on the outputs and costs.

The definition of the optimisation options and the extent of change in a variable were data-driven. Thus, the above-average individual results for farms within a production system were applied as a guideline for the definition of optimisation options, thus accentuating the strengths of the

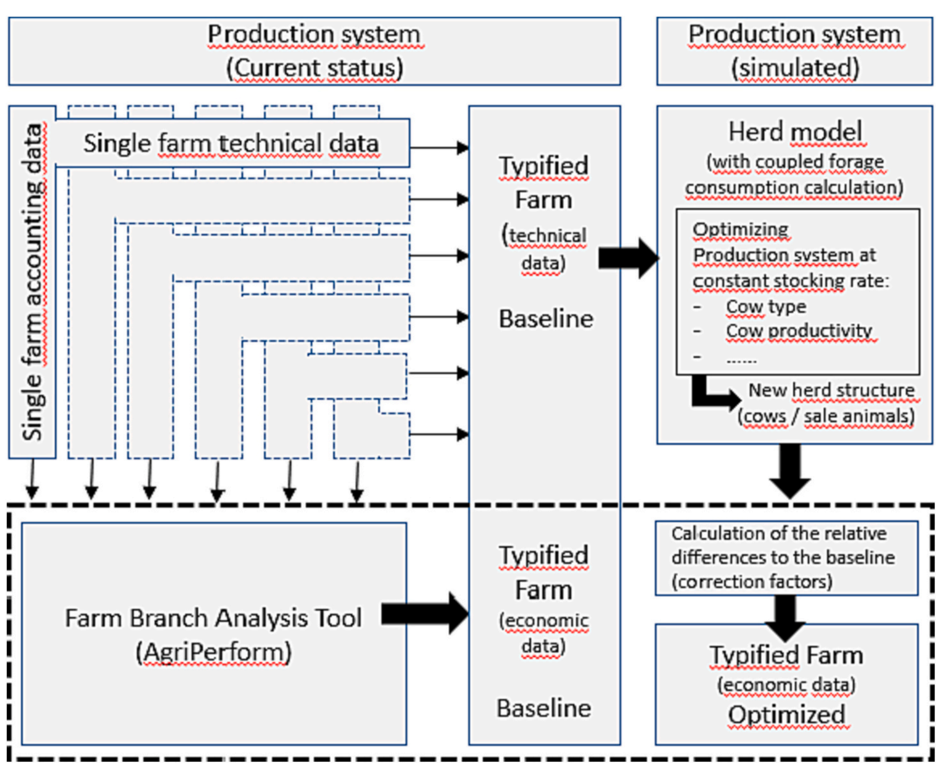

Fig. 1. Model calculation with real accounting data using an extended herd model (economic calculation in the dotted box).

respective production system. This ensured that the measures were realistic. In addition, all results were presented to the participating farms in a workshop and discussed. This participatory approach was intended to ensure that the proposed optimisation options were implementable in practice.

For reasons of simplicity, the official calculation of LUs does not differentiate among the live weights of different cow types, which means that the official stocking rate is distorted if more but lighter cows graze on the same forage area. To avoid confusion, the results do not indicate the stocking rate.

Table 2 shows the detailed specifications of the optimisation options. All economic results from the simulation calculations are comparative-static (i.e. the one-time conversion costs to achieve the intended optimisation status), such as conversion to a different type of cow, are not included.

4. Results

Table 3 presents the correlations among variables such as profitability, productivity and biodiversity performance to be investigated in the context of the research question. In addition to the effect of indicator variables on performance, the forage area, stocking rate (LU suckler cows, including calves, per ha forage area) and share of direct payments in the total revenue (market revenue + direct payments) were also taken into account because these variables have a close relationship to productivity.

All correlation coefficients are significant. There are strong positive relationships between the share of direct payments and the SBA as well as between land productivity and stocking rate. Furthermore, we find strong negative correlations between stocking rate and forage area, between SBA and stocking rate or land productivity and between land productivity and share of direct payments. With increasing forage area, higher shares of direct payments and biodiversity area as well as higher labour income could be observed.

Fig. 2 illustrates the positive correlation between the extent of the forage area and SBA. Mountain farms have a significantly larger forage area and a significantly higher SBA than farms in hills or lowlands. However, there was no significant correlation between the extent of the forage area and SBA at lower altitudes. There were significant differences among the farm types for both variables (Kruskal–Wallis, $P = 0.001$; $P = 0.0003$).

Fig. 3 illustrates the negative relationship between land productivity and SBA. Here, too, however, the negative relationship was not significant at lower altitudes, which means that with a similar SBA, very different land productivity was achieved.

Table 4 shows the descriptive statistics of the selected farm structure variables for the four farm types considered. Across all farms, the land SBA was 26%, which is close to the envisaged target of the CBD. Differences between the farm types are significant for the variables land area and forage area ($p = 0.001$), SBA ($p = 0.0003$) and stocking rate ($p = 0.0001$). Farms from the mountain region generally have a significantly larger forage area. This finding particularly applies to the VMount farm type, which is located at higher altitudes with poorer forage-growing conditions. Accordingly, this farm type has the lowest stocking rate and the highest SBA – greater than 45%. The farm type from the hill region (VHill) has a significantly smaller forage area, which correspondingly is more intensively applied, resulting in the highest stocking rate and lowest SBA (approximately 11%) among all farm types. Lowland farms (BLowla) have a lower share of forage area in the total agricultural area, which indicates that other relevant farm branches are present. Due to favourable forage-growing conditions, the stocking rate is significantly higher than on the mountain farms, but the farms are managed more extensively than the VHill farm type.

Table A.1 (Appendix) gives an overview of various herd data, such as reproduction data and fattening intensities. The lower calving intervals of the hill and lowland farms are obvious, whereas the mountain farms consistently calve once a year due to the annual summering on alpine pastures. On the hill farm type, more twins tend to be born. The higher use of concentrated feed observed for the hill farm type also reflects the

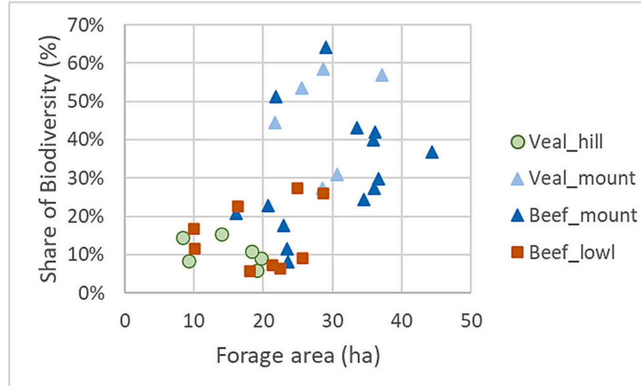

Fig. 2. Relationship between the extent of forage area and its share of biodiversity areas.

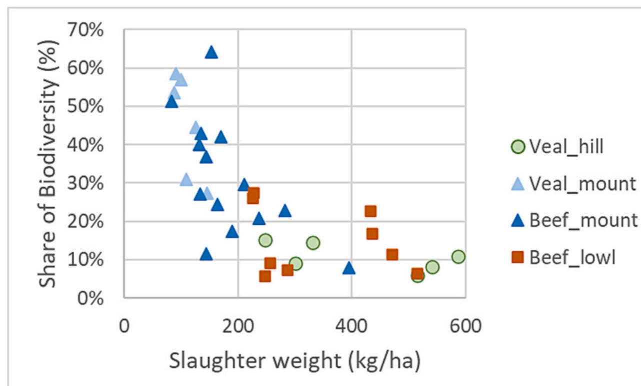

Fig. 3. Relationship between land productivity and land share of biodiversity areas.

Table 3
Correlation coefficients of selected variables ($n = 35$; Spearman, * = 5% significance level).

	Forage area (ha)	*Share of biodiversity*	*Stocking rate*	*Land productivity*	*Profitability*	*Share of direct payments*
Forage area[1]	1.00					
Share of biodiversity areas (SBA)	0.63*	1.00				
Stocking rate	−0.76*	−0.83*	1.00			
Land productivity[2]	−0.68*	−0.83*	0.91*	1.00		
Profitability[3]	0.64*	0.5*	−0.62*	−0.5*	1.00	
Share of direct payments	0.66*	0.8*	−0.85*	−0.9*	0.48*	1.00

[1] For beef production only.
[2] Slaughter weight/ha.
[3] Labour income/h.

Table 4
Structural data of the farm-type groups representing different beef production systems (mean values and standard deviations).

Position	Unit	VMount		BMount		VHill		BLowla	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Land area (total)	ha	31.4	*7.5*	30.9	*7.8*	16	*6.1*	24.9	*8.8*
Forage area (beef only)	Ha	28.7	*5.2*	29.6	*8.2*	14.7	*5.1*	19.7	*6.6*
SBA	%	45.4	*13.4*	31.4	*15.7*	10.7	*3.7*	14.8	*8.7*
Cows	Nr.	22.8	*3.7*	26.2	*6.5*	24.3	*8.9*	25.6	*8.3*
Beef livestock	Units	26.8	*3.8*	33.3	*8.4*	29.8	*12.5*	31.6	*10.2*
Stocking rate[1]	LU/ha	0.95	*0.18*	1.16	*0.25*	2	*0.44*	1.69	*0.47*

[1] Beef LU per ha forage area for beef only.

intensity of production. Lowland farms have the fewest animal losses and the highest slaughter weights, which is attributed to favourable forage-growing conditions.

Table 5 include the results of the model farms with the baseline and the optimisations (columns to the right of the baseline). The first section of the table lists the physical variables that are affected by the optimisation or remain constant depending on the optimisation. The economic effects are shown in the lower section of the table. Detailed calculations are shown in the appendix (Tables A.2–A.5).

The optimisation for the extensive farm type (VMount, Table 5) in unfavourable marginal regions, which consists of a switch to a more lightweight and site-adapted cow, leads to an increase in income per hectare of 16%. The optimisation results in an increase in the number of cows, which causes a higher labour input in winter; consequently, the hourly income remains constant.

The other mountain farm type (BMount) in slightly more favourable forage-growing sites is exemplary for the economic impact of a different cow productivity due to differences in calf losses, conception rates of cows or replacement rates due to a different productive life. A reduction in cow productivity of 10% (0.85 instead of 0.94 calves sold per cow), which in this case corresponds to a loss of 2.4 calves, leads to an income loss of 7% per hectare. The results can also be interpreted in the opposite way because some farms actually had lower cow productivity and can therefore take advantage of this optimisation potential.

In the intensive hill farm type (VHill), both a further intensification from 1.9 to 2.3 calves sold per cow (purchase of 9 additional calves) and an increase in forage area by 20% would result in considerable increases of income per hectare by 33% and 19%, respectively, while hourly income would increase by 31%. This finding is mainly attributed to higher market revenue but a lower increase in costs (Appendix Table A.4).

The greatest potential for optimisation is seen in the lowland farm type (BLowla), where the poorest incomes are found. A switch to Natura-Veal production with a lighter cow type and additional calf acquisition (two calves per cow) results in a 2.5 times higher income per hectare or in an 80% higher hourly income than the baseline.

Fig. 4 summarises the most important results based on the performance indicators. It is evident that an improvement in cow efficiency in the same forage area leads to a higher number of animals for sale, which results in higher productivity per hectare and a higher labour income.

5. Discussion

Based on 35 suckler cow farms under different site conditions in the Swiss Alpine region, detailed technical and financial data were analysed and summarised into four production systems via a standardisation process. In a subsequent step, we investigated the economic impact of different optimisation options aimed at intensifying production while persevering the biodiversity supply of these farms.

The investigated production systems are grass-based to a high extent. The calves remain with their mothers until slaughter (i.e. 5 months [veal] or 10 months [beef]) and are not separately weaned and fattened with feed of higher nutrient density, as is common in other countries. The production system is accordingly rare in the international context, which means that a comparison of the results with other studies on grass-based beef production is limited. In Ireland, there are economic studies of different production systems with different sales weights. These studies indicate that the higher the income, the more slaughter weight is sold per cow, which means that the costs of the cow can be allocated to more "meat" (Crosson and McGee, 2011). However, the price ratios are not comparable to branded production in Switzerland, which targets sensitive consumers who are willing to pay higher prices, which is an important requirement for economic success also in other

Table 5
Optimisation of the production systems in the mountain region (Natura-Veal extensive: VMount; Natura-Beef: BMount), in the hill region (Natura-Veal intensive: VHill) and in the lowlands (Natura-Beef: BLowla); optimisation under the restriction of maintaining the share of biodiversity area in the total forage area.

Position	Unit	VMount Baseline	VMount C500	BMount Baseline	BMount P94-85	VHill Baseline	VHill P230	VHill Land+	BLowla Baseline	BLowla C580/ P200
Forage area	ha	28.7	28.7	29.6	29.6	14.7	14.7	17.6	19.7	19.7
Gross forage yield per ha	t, DM	3.6	3.6	4.4	4.4	8.6	8.6	8.6	10.8	10.8
Bought-in roughage	t, DM	0	0	4	4	8	8	8	5	5
Cows	Nr.	22.8	*28.6*	26.2	26.2	24.3	23.9	29	25.6	37.7
Cow live weight	kg	630	*500*	650	650	570	570	570	745	580
Calves sold from own cows	Nr.	21.7	*27.2*	24.6	22.2	24	23.6	28.6	24.9	36.7
Total calves sold	Nr.	21.7	*27.2*	24.6	22.2	46	55	55	24.9	75.4
Labour input	h/year	3471	3992	3785	3721	2964	3027	3228	2542	3553
Performance indicators										
Land productivity	Kg/ha	109	134	176	159	426	505	422	323	530
Cow-productivity (total)	Calves/ cow	0.95	0.95	0.94	0.85	1.9	2.3	1.9	0.97	2
Labour income per ha	CHF	2373	2763	2777	2584	2680	3585	3188	1904	4822
Labour income per hour	CHF	19.6	19.9	21.7	20.5	13.3	17.4	17.4	14.8	26.7

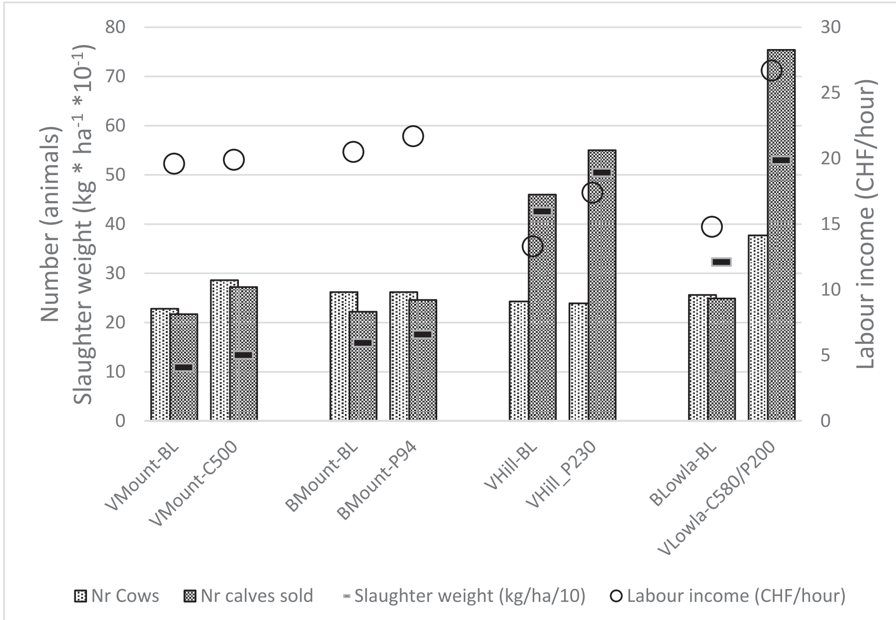

Fig. 4. Income follows cow efficiency while maintaining biodiversity.
(BL = baseline; reduction cow-liveweight [C500] and increasing cow productivity [94%] in mountain region; increasing cow productivity [230%] in hilly region; increasing cow productivity [200%] and reduction cow-liveweight [C580] in lowland region).

countries (Zanon et al., 2023).

5.1. Biodiversity and land productivity

An examination of all farms revealed a distinct positive correlation between the stocking rate and slaughter weight produced per hectare of forage area. In contrast, this productivity was significantly negatively correlated with SBA. This finding is supported by other studies (Marriott et al., 2004; Van Rensburg and Mulugeta, 2016; Mondière et al., 2024).

It must be pointed out that the share of biodiversity areas is not a comprehensive indicator of biodiversity because it does not take quality into account (Knudsen et al., 2017). In fact, the areas on the farms were also graded according to quality (Quality 1 and Quality 2, depending on the number and diversity of plant species and structures for wildlife). Quality 2 generates additional direct payments twice as high if a certain minimum quality is achieved (Mack et al., 2020). The connectivity of habitats is also an important prerequisite for the quality of biodiversity (Correa Ayram et al., 2016). Accordingly, the farms participate in connectivity projects, which, however, depend more on the region than on the management decisions of the farm. In view of the research question, however, only the share of forage area was used as an indicator of biodiversity because it is considered the most important prerequisite and is also economically relevant. In contrast, a comprehensive inclusion of biodiversity quality would have generated a disproportionate effort without significantly influencing the results.

The differences in terms of land productivity, stocking rate, forage area and SBA among the investigated systems are largely determined by the locations of the farms. Land productivity ranges from approximately 100–500 kg, and SBA ranges from approximately 11–45%, depending on the production system. In this regard, it is crucial to adapt optimisation options to the site (i.e. to strictly define these options in relation to the production systems). The options for the optimisation conducted with a simulation model included neither intensification of the forage area nor an increase in the stocking rate via additional fodder imports. Instead, the options focused on increasing animal efficiency via genetics and animal management.

For mountain farms, a higher stocking rate is simply not an option for both natural reasons and regulatory requirements under direct payments. Rather, unfavourable plots for production are set aside as biodiversity sites because the corresponding biodiversity payments contribute more to income than the costly intensification of fodder cultivation. In addition, the mountain farms analysed in this study have a larger forage area, allowing for scale effects via larger herds and thus lower overhead costs but also a greater scope for biodiversity areas. As a result, farms in such unfavourable forage-growing areas emphasise landscape maintenance and biodiversity conservation, with stocking rates of approximately 1 LU/ha. This finding is reflected in the high share of direct payments of the total revenues: 64% (VMount) and 61% (BMount); that is, these farms are producing landscape and biodiversity with meat as a “by-product”.

Higher productivity is observed on farms in the hilly and lowland regions, with stocking rates of 2 LU/ha and 1.69 LU/ha, respectively, which are comparable to an Irish study, indicating approximately 2 LU (Taylor et al., 2017b). However, these farms also have a significantly lower SBA and it can also be assumed that a more intensive grazing strategy with rotational grazing also tends to reduce biodiversity (Farruggia et al., 2014). It is reasonable to assume that size (forage area) and SBA are also negatively correlated, even if this correlation is not statistically significant for hill and lowland farms, which is most likely attributed to the small sample size (Mack et al., 2020). At least a moderate extension of forage area on the “small and intensive” model farm (F+, VHill) with the highest stocking rate, highest land productivity and lowest SBA will reduce intensification pressure by reducing overhead costs per product unit and should lead to a corresponding increase in labour income. This is particularly the case if existing machines and buildings can be better utilised to capacity.

5.2. Profitability

On mountain farms, the potential for optimisation in the area of production techniques is rather limited. Both the VMount farm type and the BMount farm type achieve comparatively good incomes. This income needs to significantly contribute to household income because there are usually no other available farm opportunities, such as in lowland farms. Despite the high direct payment share, the modelled optimisation options indicate that maintaining good cow productivity and site-adapted lightweight cow types enables a constant or increase in income. To reach a higher income, more labour has to be spent in the case of the optimisation option "lightweight cow types", which can exceed the working capacity depending on the farm.

More favourable forage-growing sites, such as those found in the hills and lowlands, have an increased focus on meat production. A distinction must be made between farms that, for climatic reasons, exclusively operate on grasslands (VHill) and those with arable land and therefore also run other possibly more lucrative branches of the farm (BLowla). Extensive beef production may not be particularly profitable but rather serves as a utiliser of non-arable marginal land and temporary pastures in crop rotation or as a producer of organic fertiliser for arable crops (Van Zanten et al., 2019).

Improving cow productivity by buying calves from dairy farms, which allows more calves to suckle on the cow and be sold after fattening, considerably improves profitability. The increase in cow productivity from 1.9 to 2.3 corresponds to 9 additional calves for the intensive farm type "VHill" and, taking into account the additional labour, results in the same hourly labour income as a 20% increase in forage area.

The optimisation of the farm in the lowlands with an increase in cow productivity is somewhat more spectacular. The extraordinarily high increase in income must be interpreted with certain precautions. Thus, the conversion from rather extensive Natura-Beef production to intensive Natura-Veal production leads to fundamental farm adaptations, with beef production changing from an extensive sideline branch to a main branch. This finding is reflected in the increase in working hours by more than 1000 h per year. Accordingly, this transition is reasonable, especially if the farm operates exclusively on grasslands due to climatic conditions and has few other opportunities. The farm achieves an income comparable to that of well-managed dairy farms with full grazing (Gazzarin et al., 2021). However, this situation applies only under the given price conditions. The prices for Natura-Veal are relatively high due to demand and less slaughter weight, and it cannot be ruled out that this will fundamentally change in the future. It must also be taken into account that the one-time conversion costs are not included in the optimisation.

Nevertheless, this optimisation impressively shows the potential for better use of the suckler cow. With regard to the research question, it is also important to consider that the proposed optimisation option of increased cow productivity does not need to be fully exploited, allowing the creation of additional biodiversity areas as long as income is still higher than that in the baseline situation. Even extensification is an option. Although land productivity will decrease, the decline should be slowed down by increasing milk yield and daily weight gain per animal through more selective feeding and thus a higher nutrient intake (Marriott et al., 2004).

Overall same questions arise in similar fattening production systems based on the offspring of dairy cows. In a Swedish study, economic incentive options for extensive steer fattening systems were modelled to ensure biodiversity through grazing and to compete with intensive bull fattening systems (Holmström et al., 2021). Consistent cost reductions through large herds, simple buildings and/or public payments as well as (higher) brand prices make it possible to equalise or exceed the contribution margin of bull fattening.

5.3. Practicability

An important objective of this study was the active participation of the farms so that their results could be not only checked for plausibility but also incorporated into the formulation of optimisation options. A site-specific approach is appropriate to minimise the trade-offs between biodiversity and food security to a certain extent. Sites with good grass growth should be intensively utilised with a lower SBA, while less productive sites at higher altitudes should follow a higher SBA. This finding is also supported by the observation that it is easier to achieve good-quality biodiversity in unproductive plots, while many desired plant species compete more strongly in sites with naturally heavy and deep soils and disappear more easily, even if the areas are hardly fertilised (Plantureux et al., 2005; Farruggia et al., 2014).

The current direct payment system, which couples payments to land, has a retarding effect on structural change by basically making land more expensive, which explains why optimisation via an extension of the forage area is fundamentally difficult to implement (Varacca et al., 2022). However, extension of the forage area is particularly important for small farms that do not have any alternative sources of income outside of agriculture. However, some small farms in the study generated a large part of their farm income from soil-independent pig or poultry production, which has negative environmental impacts as a result of large nutrient surpluses that can hardly be recycled in intensively farmed regions. Here, an extension of the forage area would fundamentally mitigate the conflict between land productivity and biodiversity by creating more space for biodiversity in addition to higher income by better utilisation of farm capacities (machinery and buildings) and targeted biodiversity payments.

A further key aspect of optimisation is the type of cow. Here, a site-specific approach is necessary. Most suckler cow farms have a history as dairy farms. Accordingly, the often large-framed dairy cow types were crossed with fattening breeds, also to benefit from the heterosis effect (Wetlesen et al., 2020b). Milk yield was still satisfactory, but less attention was paid to live weight, which has an impact on the (non-productive) nutrient demand for maintenance of the animal (Morel et al., 2021a). In contrast to the dairy cow, the suckler cow is associated with higher costs per product unit, as she generates money only from her offspring. Therefore, the cow should use the feed as efficiently as possible, requiring an optimal live weight, which has already been implemented on some farms in the study. It is then also important to allocate the costs of the cow to as much slaughter weight as possible, which, on the one hand, is achieved by a longer finishing period (Crosson and McGee, 2011) but, on the other hand, can also be achieved by additional calves. Here, however, the price ratios are at least as crucial as the weaned carcass weight per cow.

Intensive farms with lightweight or small-framed cows and additional calves control the carcass quality of the offspring primarily by the fattening bull, while the cow has an upper average milk yield with good health and fertility (Baumont et al., 2014; Delaby et al., 2018). Attaining this yield requires appropriate genetics and additional concentrates to compensate, as well as good grassland management (Peyraud et al., 2010) to ensure that forage production does not come at the expense of biodiversity. For more extensive farms in mountainous regions, it is important that cows have access to all possible forage patches – even in extreme locations – without causing excessive damage to the sloping pastures (Pauler et al., 2020). Here, in addition to lower weight, sure-footedness and health under poor forage conditions play a significant role in reducing costs.

There are still numerous breeds of cows that have adapted over centuries to the harsh conditions in mountain areas (Lampert, 2019; Zanon et al., 2020). Most of them are dual-purpose cows such as Original Brown cattle, Original Simmental, Tarentaise, Tyrolean or Rhaetian Grey cattle (referred to as "Jerseys of the mountains"), which are usually crossed with Limousin genetics to improve carcass quality and benefit from the heterosis effect. Selection of females based on their genetic merit on maternal type traits is also a way to achieve a desired cow type. Cows with above-average maternal traits have fewer calving problems, better fertility, lighter carcasses and lower live weight and are also easier to manage (Twomey et al., 2020).

To grow additional calves, the cows must also be able to tolerate suckling foreign calves, which are mostly found on farms with Original Brown cattle or Grey cattle. A comprehensive study of other breeds regarding tolerance for foreign calves could be interesting.

6. Conclusions

In the alpine region, there are grasslands with different environmental conditions. Accordingly, the farms analysed run very different production systems. Both income and biodiversity areas can be optimised if production is as site-adapted as possible by further accentuating existing production systems. Farms at higher altitudes have an advantage in pursuing the strategy of extensification with the selective designation of biodiversity areas, retaining robust, small-framed cow types. In favourable forage-growing areas at lower altitudes, it makes sense in terms of food security to increase intensity by increasing cow productivity, which also includes the purchase of additional calves. In these areas, efficient, robust and small-framed cow types with higher milk yields and good fertility characteristics can be an important success factor. Such strategies enable a higher income or – if the income could remain constant – even an extension of the biodiversity area. Extension services and agricultural policy should provide appropriate incentives to meet the goal of sustainable intensification in site-appropriate biodiversity areas.

CRediT authorship contribution statement

Christian Gazzarin: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Validation, Writing – original draft, Writing – review & editing. **Pierrick Jan:** Writing – review & editing.

Declaration of Competing Interest

Christian Gazzarin reports financial support was provided by Coop Switzerland. Christian Gazzarin reports financial support was provided by Beef Cattle Switzerland.

Data availability

The data that has been used is confidential.

Acknowledgements

Funding for this study was provided with the participation of Beef Cattle Switzerland and Coop Switzerland. The authors also thank their colleagues at extension offices, the farm managers and their families.

Appendix A

Table A.1
Baseline herd data in four production systems used for model calculation (based on survey data and slaughter records).

Position	Unit	VMount	BMount	VHill	BLowla
Calving interval	Days	365	364	351	357
Pregnancy rate	%	97.8%	97.8%	99.8%	99%
Calves born per cow	Nr	1.041	1.039	1.065	1.032
Stillbirths	%	3.1%	3%	3.3%	3.7%
Rearing losses	%	4.1%	3.2%	4.6%	1.5%
Replacement rate	%	12.1%	10.5%	12%	12.3%
Cow productivity[1]	Nr	0.81	0.85	0.89	0.87
End live weight calves/beef	kg	216	374	224	429
Slaughter weight calves / beef	kg	127	206	132	236
Fattening period	Mt	5.2	10.2	5.2	10.2
Concentrate input per cow	Kg / year	0	50		32

[1] Sold calves per cow, bought-in calves excluded.

Table A.2
Detailed income calculation for the optimisation of the Natura-Veal extensive production system (VMount) – in 1000 CHF.

Position	Baseline	LiveWeight-
Market revenues	62.2	73.8
Direct payments	114.7	116.6
Total revenues	176.9	190.4
Operational costs		
Forage and summering	3.6	3.9
Concentrate	2.2	2.6
Veterinary/medicaments	2.5	2.8
Bought-in animals	9	9.8
Others	8	8.5
Total operational costs	25.3	27.6
Overhead costs		
Machinery	41.4	41.4
Fixed assets	28.6	28.6
Other general expenses	13.5	13.5
Total overhead costs	83.5	83.5
Total costs (excluding labour)	108.8	111.1

Table A.3
Detailed income calculation for the optimisation of the Natura-Beef production system (BMount) – in 1000 CHF.

Position	Baseline	CowProd-10%-
Market revenues	74.7	68.9
Direct payments	119.9	119.8
Total revenues	194.6	188.7
Operational costs:		
Forage and summering	3.5	3.5
Concentrate	2.6	2.5
Veterinary/medicaments	3.4	3.3
Bought-in animals	6.6	6.6
Others	10.4	10.4
Total operational costs	26.5	26.3
Overhead costs		
Machinery	41.1	41.1
Fixed assets	30.1	30.1
Other general expenses	14.7	14.7
Total overhead costs	85.9	85.9
Total costs (excluding labour)	112.4	112.2

Table A.4
Detailed income calculation for the optimisation of the Natura-Veal intensive production system (VHill) in 1000 CHF.

Position	Baseline	Calves/cow+	Land+
Market revenues	112	132.1	132.6
Direct payments	55.1	55.3	62.2
Total revenues	167.1	187.4	194.8
Operational costs:			
Forage and summering	6.1	6.1	7
Concentrate	4.7	5.1	5.3
Veterinary/medicaments	3	3	3.2
Bought-in animals	31	37.5	34.6
Others	9.2	9.3	9.7
Total operational costs	54	61	59.8
Overhead costs			
Machinery	36.1	36.1	39.7
Fixed assets	26.7	26.7	27.3
Other general expenses	10.9	10.9	11.9
Total overhead costs	73.7	73.7	78.9
Total costs (excluding labour)	127.7	134.7	138.7

Table A.5
Detailed income calculation for optimisation of the Natura-Beef production system (BLowla) – in 1000 CHF.

Position	Baseline	VLowla+Int
Market revenues	91.2	196.7
Direct payments	60.8	67.1
Total revenues	152	263.8
Operational costs:		
Forage and summering	7	8.8
Concentrate	2.3	9.6
Veterinary / medicaments	3.8	6.6
Bought-in animals	13.6	42.9
Others	9.5	13.1
Total operational costs	36.2	81
Overhead costs		
Machinery	38.1	38.1
Fixed assets	27.9	34.5
Other general expenses	12.3	15.2
Total overhead costs	78.3	87.8
Total costs (excluding labour)	114.5	168.8

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