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A case study for Switzerland

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Implications of risk attitude and climate change for optimal grassland management – A Case Study for Switzerland

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Abstract

We present a bio-economic model by combining a process-based grassland simulation model with an economic decision model that accounts for income risks and yield quality. The model is used to examine optimal nitrogen (N) application rates in a grass-clover system in Switzerland under current and future climatic conditions. Results for present-day climatic conditions suggest that increasing nitrogen inputs has positive effects on yields but also leads to higher yield variability, yield distributions more skewed to the left and therefore higher downside risks. As a result, accounting for farmers' risk aversion in solving the optimization problem leads to lower optimal N inputs. Simulations with a climate change scenario that predicts higher temperatures throughout the year and lower rainfall amounts during the growing season indicate higher yields, increasing yield variability, and changes in yield quality. By allowing herbage prices to vary as a function of yield quality we find overall lower optimal N inputs and more marked effects of risk aversion on optimal N levels under climate change than under present conditions. However, disregarding yield quality in solving the optimization problem gives higher optimal N inputs under future conditions.

Keywords

Grassland production, bio-economic modeling, downside risks, risk aversion, optimal management, climate change

Introduction

Climate change is expected to affect grassland production in various ways, with consequences for future food supply and land use (*e.g*. Soussana and Lüscher 2007). To investigate the impact of (changes in) environmental conditions and management practices on grassland systems, a wide range of process-based biophysical models has been developed (*e.g.* Schapendonk *et al.* 1998; Peters 2011; Soussana *et al.* 2012). Studies relying on such models, however, cannot properly address the economic aspects of grassland management, in spite of their important role for the choice of optimal management options at the farm scale. To take into account both the agronomic and as well as the economic perspective, biophysical models have to be extended to include economic information and assumptions on farmers' behaviour.

The need for integrated assessments has thus motivated the development and use of combined bio-economic modelling solutions (*e.g.* Berentsen *et al.* 2000; Herrero *et al.* 1999), in which farmers' goal function is typically formulated as a profit maximization problem. This framework has been extended in recent years by recognizing that also risk perception and risk management are crucial elements of farmers' decision making process (*e.g.* Louhichi *et al.* 2010; Janssen *et al.* 2010; Finger *et al.* 2010). Yet, up to now risk has often been represented exclusively in terms of the second moment of the yield or income distribution, *i.e.* standard deviation or variance. By making this restriction, the models overlook the fact that decision makers also aim to reduce downside risks, *i.e.* avoid extremely low outcomes (*e.g.* Moschini and Hennessy 2000). The reason is that years with exceptionally low profits have the potential to significantly affect the economic viability of a farm (*e.g.* Koundouri *et al.* 2006; Torkamani and Shajari 2008). In the case of herbage production, downside risks have been shown to be particularly important (Torrell et al, 2010).

Paying attention to a possible asymmetry in the distribution of yields is important also for examining the relationship between nitrogen (N) inputs and grass production. In fact, even though the application of N fertilizers improves the average productivity of the sward, higher fertilization intensity is often found to lead to more variable yield levels, more negatively skewed (*i.e.* left tailed) yield distributions, and ultimately higher (downside) risks. In practice, a risk-averse decision maker would account for these negative effects by reducing the N inputs.

With climate change potentially leading to a higher incidence of extreme events (e.g. Calanca 2007), consideration of downside risks is even more important in the context of climate change impact assessments. So far, however, the problem of integrating downside risk aversion in bio-economic models has been tackled only in a few studies (Holden and Shiferaw 2004; Holden et al. 2004; Finger 2013;

Briner and Finger 2013, Finger and Calanca, 2011). The goal of our study was to integrate downside risks in a bio-economic model and examine the implications of risk aversion for optimal nitrogen use in grassland production under current and future climatic conditions. For illustrative purposes, we present a case study from Switzerland, a country where grasslands represent about 71% of the total agricultural acreage and where cattle meat and dairy production account for 35% of the total monetary output of the agricultural sector (SBV 2011). To this aim we extended an earlier framework (Finger *et al.* 2010) by (a) combining a process-based grassland simulation model with an economic decision model that accounts for farmers' risk aversion, and (b) allowing for considering yield quality aspects in solving the optimization problem.

Material and Methods

The analysis is carried out in three steps: 1) The process-based grassland model PROGRASS is used to simulate grassland yields[1] and clover content with respect to different levels of nitrogen use under current and future climate conditions. 2) Results of these simulations are used to infer statistical relationships between mean, variance and skewness of grassland yields and nitrogen inputs. 3) These relationships are transferred to an economic optimization model that estimates optimal N levels as a function of risk aversion and forage quality. Hence, the goal function underlying this economic model represents the utility maximization rationale of a risk averse decision maker, whereby herbage prices are allowed to vary depending on clover content as a function of N input.

Simulation of herbage production

We use the PROductive GRASland Simulator (PROGRASS) (Lazzarotto *et al.* 2009) to simulate herbage production at various fertilization intensities and in response to changes in climate. PROGRASS simulates the dynamics of mixtures of perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) accounting for above- and belowground interactions relatively to light interception and the acquisition of soil mineral N. The model requires the specification of weather inputs,

[1] Note that throughout the paper, yield is expressed in tonnes of dry matter.

management options (cutting dates, dates of the fertilizer applications, fertilizer amounts) and initial conditions for above- and belowground biomass, soil organic and mineral N pools and soil moisture content. PROGRASS explicitly considers the effects of elevated CO_2 concentrations on plant dynamics (photosynthesis, stomatal conductance, biological N fixation). Further details concerning the model structure, setup and validation are presented in Lazzarotto *et al.* (2009 and 2010).

To address productive grassland systems typical of the Swiss Plateau, simulations are run for a representative location (Oensingen, 7°44'E, 47°17'N, 450 m a.s.l.). We assume an intensive management with 5 cuts and fertilizer applications per year. We distinguish between 13 different levels of fertilisation, with annual amounts varying from 0 to 600 kg N/ha/y in steps of 50 kg N/ha/y.

To simulate herbage production under future climatic conditions we adopt a climate scenario valid for 2071-2100 developed with the CHRM regional climate model under the assumption of a A2 emission scenarios (Vidale *et al.* 2003). According to Nakicenovic and Swart (2000), "the A2 storyline assumes fertility patterns across regions to converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines".

With respect to the summer months (June to August) the climate change scenario implies a marked increase in temperature (+3.5°C and +5.5°C for daily minimum and maximum temperature, respectively) and a strong reduction of summer rainfall amounts (-35%).Winter precipitation, on the other hand, is projected to increase (+22% as an average for December to March). Atmospheric CO_2 concentrations are set to 700 ppm, which represent almost a doubling of the 370 ppm assumed for the baseline. To provide the necessary inputs for both current and future climatic conditions, 25 years of daily weather data are generated with the LARS-WG stochastic weather generator (e.g. Semenov *et al.* 1998). Combining these 25 years with 13 levels of N-use results in 325 observations for each climate scenario.

Modelling the effects of N input on the moments of the yield distribution

We estimate the effects of N input on the mean, variance and skewness of grassland yields using the moment based approach proposed by Antle (1983). For each of these statistical moments, the performance of different specifications of the functional form is verified on the basis of Wald test (Finger et al. 2010), with the superior being retained for the analysis.

As a result, the effects of N inputs on the expected (*i.e.* average) yield, E(Y(N)) are modelled according to:

(1) $$E(Y(N)) = \alpha_0 + \alpha_1 N^{0.5} + \alpha_2 N$$

Further, variance and skewness of yield distribution are modelled based on the magnitude and type of deviations of actual observations form their expected level, expressed as regression residuals from the production function estimation (Chavas *et al.* 2009) as:

(2) $$\sigma_Y^2 = E[E(Y(N)) - Y(N)]^2 = \beta_0 + \beta_1 N^{0.5}$$

and

(3) $$\sigma_Y^3 = E[E(Y(N)) - Y(N)]^3 = \gamma_0 + \gamma_1 N^{0.5}$$

At each step of the estimation procedure, we use White corrections to account for heteroscedasticity (White 1980).

The Economic Model

To integrate farmers' preferences on mean, variance and skewness of gross margins, the maximization of certainty equivalents is used as goal function for solving the non-linear static optimization problem. Here, gross margin is defined as revenue minus the operational costs of grassland production (details are presented at the end of this section), whereas the certainty equivalent is defined as the sure amount of money that is rated by the farmer identically as the (volatile) gross margin . Denoting the risk premium, the loss of utility due to the presence of risk, by RP and the expected gross margin by $E(\pi)$the certainty equivalent CE is given by:

(4) $CE = E(\pi) - RP$

As in Di Falco and Chavas (2009), we define the (approximate) risk premium as:

(5) $RP = \frac{1}{2} r_2 \sigma_\pi{}^2 + \frac{1}{6} r_3 \sigma_\pi{}^3$

where σ_π^2 and σ_π^3 are the variance and (unstandardized) skewness of gross margins and r_2 and r_3 characterize the decision maker's aversion against variance and (negative) skewness. Following Chavas *et al.* (2009), we base our analysis on a power utility function $U=(1-\tau)^{-1}\pi^{1-\tau}$.With r_2 and r_3 being defined as -U''/U' and -U'''/U', respectively, where a prime denotes a derivative with respect to π, this choice implies $r_2=\tau/\pi$ and $r_3=-(\tau^2+\tau)/\pi^2$. Thus, we assume absolute risk aversion to increase for expected gross margins approaching zero. Important for the purpose of our paper, equation (5) shows that both higher variance and more negative skewness (i.e. a higher downside risk) of gross margins increase the risk premium, i.e. reduces farmer's CE.

To investigate the role of risk aversion on optimal nitrogen use decision, we follow Finger (2013) and investigate optimal input use for 4 different scenarios. With τ being either 0, 1, 2 or 3 taken to represent a gradient from zero to moderate (downside) risk aversion these are: $r_2 = 0, \frac{1}{\pi}, \frac{2}{\pi}$ and $\frac{3}{\pi}$ and $r_3 = 0, -\frac{2}{\pi^2}, -\frac{6}{\pi^2}$ and $-\frac{12}{\pi^2}$.

Specification of gross margins and output prices

To enable the maximization of certainty equivalents, we transform information on yields and nitrogen use into gross margins accounting for revenues, costs and direct payments (Table 1). We assume yield to be sold as (ground dried) hay directly from the swath at a price p_Y. The gross margin also accounts for the variable costs consisting of the price of nitrogen p_N and nitrogen application costs *AC*, fixed costs *FC* as well as direct payments *DP* and is thus calculated as follows:

(6) $\pi = p_Y E(Y(N)) - FC + DP - (p_N + AC) N$

We use two scenarios for hay price. In the first, we use the current (average) price of p_Y = 150 CHF t^{-1} (Table 1) which is kept fixed irrespective of herbage quality. In the second price scenario prices are allowed to vary depending on herbage quality by making the following assumptions: a) a 1% higher fraction of clover in a grass/clover mixture leads to a 0.5% increase of the protein content (Buchgraber 2009); b) a 1% increase in the protein content causes a price increase by 1% (adapted from Agrigate 2012); c) a (fixed) price of p_Y = 150 CHF t^{-1} is valid for a protein content of about 15%, the observed protein content of hay samples from the study region (Bracher et al., 2013), or equivalently a minimum clover fraction (CF) of 30% (Lehmann et al. 1981).

Based on these assumptions, a quality adjusted price is calculated for all observations (325 for each combination of climate and price scenario), based on the clover fraction simulated by PROGRASS. Since the clover fraction (and thus protein content) is dependent on the level of nitrogen fertilization this can be converted into a relationship between fertilization level and price, viz:

(7) $p_Y(N) = \delta_0 + \delta_1 N$

Table 1. Assumption on economic parameters.

Item	Assumption	Source
Price for Yield	Price Scenario 1: 150 CHF t^{-1}	Agrigate (2012)
	Price Scenario 2: quality adjusted	
General Direct Payments	1040 CHF ha^{-1}	
Fixed costs:		
Plant Protection	53 CHF ha^{-1}	AGRIDEA and
Insurance	72 CHF ha^{-1}	FiBL (2010),
Mowing, tedding, raking	106 CHF ha^{-1} cut^{-1}	Briner *et al.* (2012)

Variable costs:		
Price of nitrogen fertilizer	2.36 CHF kg^{-1} of nitrogen fertilizer	Briner *et al.* (2012)
Nitrogen application costs	0.04 CHF kg^{-1} of nitrogen fertilizer	
Risk aversion	Sensitivity analysis with $\tau = 0, 1, 2, 3$	

Finally, we combine information on the first three moments of grassland yield distributions estimated from Equations 1-3 with the information on prices, costs and direct payments (Table 1) to derive mean, variance and skewness of gross margins. This eventually leads to the following maximization problem:

$$(8) \qquad max_N(CE) = max_N\{[p_Y\, E(Y(N)) - FC + DP - (p_N+AC)N] - [\tfrac{1}{2}r_2\sigma_Y^2 p_Y^2 + \tfrac{1}{6}r_3\sigma_Y^3 p_Y^3]\}$$

The first part of the right-hand side of the equation represents the expected gross margin, while the second part represents the risk premium.

Results and Discussion

Table 2 summarizes the data generated with PROGRASS for current and future climate scenarios. Some general insights can be drawn from these summary statistics. First, nitrogen application increases yields (note that dry matter yields are reported), at a decreasing rate. Second, higher nitrogen applications also induce higher variability of yields (in terms of standard deviation, SD). Third, yields become more negatively skewed (i.e. skewed to the left) with increasing N-application under current climate. Fourth, increasing N levels lead to decreasing clover fraction (Whitehead 1995).

Concerning the relation between N input and clover fraction, data presented in Frame and Newbould (1986) suggest for mixtures of perennial ryegrass and white clover a clover fraction in the herbage varying between 53, 28, 11 and 4% for annual N applications of 0, 120, 240 and 360 kg N ha^{-1}. Similarly, data from the United Kingdom National List Trials, recompiled as well by Frame and Newbould (1986), suggest clover contents declining from 50 to 25%, in average, after application of 200 kg N ha^{-1} yr^{-1}. In light of these numbers, the response of the clover fraction in the herbage to increasing N-level disclosed by our modelling experiments and reported in Table 2 appears to be reasonable, in spite of the fact that PROGRASS likely overestimates the fraction of clover in the herbage (see also Fig. 4 in Lazzarotto et al. 2009)

Apart from this, we find yield levels to be higher and more variable (in terms of SD) under climate change than under current conditions. For the climate change scenario, yield skewness is found to be positive and does not reveal a clear relationship with N inputs. Furthermore, the clover fraction is found to be higher under future climate at N ≤ 200 kg ha^{-1}, but lower for higher annual N applications. This can be explained by CO_2 stimulation of N fixation in clover (Hebeisen et al. 1997) which in PROGRASS is modelled as described in Lazzarotto et al., (2010).

In our output the clover fraction ranges between 10% and 73% and between 9% and 76% under current and future climate, respectively. This implies output prices after adjustment for protein content in the range 144 to 195 CHF t^{-1} and 143 to 197 CHF t^{-1}, respectively.

Table 2. Summary statistics of the data generated with PROGRASS.

	Current climate				**Climate change scenario**			
Nitrogen use (N)	**Mean Yield [t ha^{-1}]**	**SD Yield [t ha^{-1}]**	**Skewness [-]**	**Clover fraction [%]**	**Mean Yield [t ha^{-1}]**	**SD Yield [t ha^{-1}]**	**Skewness [-]**	**Clover fraction [%]**
N ≤100	9.11	1.41	-0.26	50.73	10.82	2.22	0.48	52.29
N > 100 and *N* ≤ 200	11.49	1.49	-0.82	20.76	12.56	2.17	0.51	23.20
N > 200 and *N* ≤ 300	13.78	1.78	-0.98	14.88	14.70	2.40	0.36	14.76
N > 300 and *N* ≤ 400	15.49	2.07	-1.06	13.18	16.72	2.79	0.35	12.53
N > 400 and *N* ≤ 500	16.64	2.31	-1.06	12.72	18.27	3.15	0.39	11.82
N > 500	17.45	2.49	-1.05	12.68	19.42	3.45	0.44	11.88

The implications of increasing N inputs are also reflected in the estimates of the coefficients in equations 1-3 (Table 3), showing a positive but saturating effect of nitrogen on the expected yield level and a positive effect of nitrogen use on the variance of yields. Also, under present climatic conditions higher N inputs are found to lead to a more negatively skewed yield distribution, i.e. to higher downside risks. As seen in Table 3 climate change leads to a higher variance, a higher proportion of yields at the lower tail of the yield distribution and hence a more positive skewness of yields. For our climate change scenario, higher yield variability is primarily related to a higher incidence of extreme climate conditions As increasing N inputs reduces the clover fractions and (in our model) also the protein content of the herbage, we find that increasing N inputs significantly reduces expected herbage prices (Table 3). More specifically, we find that one additional kilogram of nitrogen decreases, on average, the output price by 0.057 and 0.061 CHF t^{-1} under current and future climate, respectively. The steeper response curve under the climate change scenario is due to a stronger sensitivity of the clover fraction to N application.

Table 3. Coefficient estimates for mean, variance, skewness and price functions.

	Current climate	**Climate change scenario**
a) Expected yield level		
α_0**(**Intercept)	7.89 (39.74)***	9.72 (30.49)***
α_1(N)	0.025 (12.97)***	0.019 (6.89)***
α_2(N^2)	-0.00001 (-4.09)***	-0.0000038 (-0.78)
R^2 and F-test	0.74***	0.59***
b) Yield variance		
β_0 (Intercept)	0.86 (1.86)*	2.81 (3.39)***
β_1 ($N^{0.5}$)	0.009 (3.93)***	0.014 (4.07)***
R^2 and F-test	0.05***	0.06***
c) Yield skewness		
γ_0(Intercept)	1.05 (0.37)	2.75 (0.52)
γ_1 ($N^{0.5}$)	-0.03(-1.80)*	0.02 (0.71)
R^2 and F-test	0.02**	0.001
d) **Adjusted Prices**[1]		
δ_0 (Intercept)	172	173
δ_1 (N)	-0.057***	-0.061***
R^2 and F-test	0.61***	0.66***
Observations	325	325

Statistics in parentheses are t statistics. Single, double and triple asterisks (*) denote statistical significance at the 10%, 5% and 1% level, respectively. [1] Price levels are measured in CHF t^{-1}.

Results of the economic optimization are presented in Table 4. Because increasing N inputs is associated with higher yield variability, we find a sharp reduction of optimal N application levels for increasing levels of risk aversion. Accounting for fodder quality, optimal annual N applications under current climatic conditions are found to range between 170 kg ha^{-1} for risk averse decision makers ($\tau = 3$) and 199 kg ha^{-1} for risk neutral decision makers ($\tau = 0$). For Switzerland, these results are in good agreement with the recommended application (Walther et al. 1994) and observed yield levels (12 to 14.5 t ha^{-1}) match observations made in intensive grassland production (AGRIDEA 2010, AGRIDEA and FIBL, 2010).

In contrast, solutions of the of the optimization problem disregarding quality aspects (right panel of Table 4), indicate optimal N-applications and yield levels that are inconsistent with the empirical data. This suggests that accounting for quality aspects in calculating returns from grassland production is necessary to obtain a representation of management decisions that matches the present situation in Swiss agriculture (Finger et al 2010). Relative changes in optimal N inputs due to risk aversion, however, are similar for both approaches, i.e. with and without quality consideration.

Table 4. Optimal Production Patterns in Present and Future Climate.

	With quality adjusted prices			**Without quality adjusted prices**		
Scenario on climate and risk aversion	**Nitrogen [kg ha^{-1}]**	**Certainty Equivalent [CHF ha^{-1}]**	**Expected Yield [t ha^{-1}]**	**Nitrogen [kg ha^{-1}]**	**Certainty Equivalent [CHF ha^{-1}]**	**Expected Yield [t ha^{-1}]**
Current climate						
Risk neutral: $\tau = 0$	199	1878	12.30	355	1929	14.98
Risk averse: $\tau = 1$	191	1859	12.14	340	1900	14.75
Risk averse: $\tau = 2$	181	1838	11.94	323	1869	14.48
Risk averse: $\tau = 3$	170	1817	11.72	305	1837	14.19
Climate change scenario						
Risk neutral: $\tau = 0$	100	2086	11.62	575	2142	19.61
Risk averse: $\tau = 1$	81	2060	11.27	513	2084	18.66
Risk averse: $\tau = 2$	62	2037	10.91	457	2034	17.79
Risk averse: $\tau = 3$	44	2017	10.57	406	1991	16.96

Solutions of the optimization problem obtained on account of the climate change scenario (lower part of Tab. 4) disclose lower optimal N levels than found under present conditions if herbage prices are allowed to vary depending on yield quality. In fact, under future climatic conditions increasing N inputs have a stronger impact on clover fraction than under current conditions (Table 3), leading to a more substantial reduction of the quality adjusted prices. Also, comparing the results for the current climate and those for the climate change scenario, we find that risk aversion has a stronger impact on optimal levels of nitrogen use in the latter case. For instance, with $\tau = 3$ the reduction of N-use is of about 56% under climate change, as compared to 15% under current climatic conditions.

Disregarding quality aspects, however, leads to different results. Due to the higher productivity and stronger yield responses to nitrogen application, optimal N-levels are substantially higher (e.g. 575 kg/ha for a risk neutral decision maker) under future than under present-day climatic conditions, implying that under the assumption of fixed herbage prices intensification of the production could represent a viable adaptation option.

In summary, our results show that accounting for yield quality in evaluating optimal options for adaptation to climate change may shift the overall strategy from intensification to extensification. This finding is in line with earlier research revealing that magnitude and even sign of climate change impacts can considerably differ depending on the scope of the analysis, with repercussions for the choice of adaptation options (e.g. Falloon and Betts 2010, Reidsma *et al.* 2009).

Limitations

We model optimal management in grassland production using a static approach in which optimal N-application rates are derived at the annual level and the number of cuts is pre-defined. In reality, farmers have the flexibility to adjust fertilization and cutting frequency depending on the current state of the sward and weather conditions. For instance, in Switzerland reducing fertilization intensity and cutting frequency is one of the common strategy adopted by farmers for cope with drought. The static modelling approach used here is not able to capture this flexibility, as opposed to so-called state-contingent approaches (e.g. Adamson et al. 2007). In this sense, our goal was to show with an illustrative example the sensitivity of optimal solution to the definition of the decision problem in bio-economic models.

Another limitation of the current setup is that it does not account for the on-farm use of grassland production but assumes grass to be sold as hay. Even though there are viable markets for hay and other grass silage, in Switzerland the direct on-farm use for feeding animals is much more important in practice. Integration of subsequent steps of on-farm use in the analysis framework would hence be necessary to better capture the context in which farmers actually operate (see e.g. Briner and Finger 2013). In addition, it should be pointed out that changes in risk preferences and environmental conditions could eventually lead to smaller changes in optimal management practices, which clearly has implications for adaptation.

Although we stressed the importance of considering herbage quality in the evaluation of optimal management strategies, in interpreting our results it is important to bear in mind that the grassland model PROGRASS does not include the full range of factors affecting herbage quality. Apart from fertilization, the botanical composition of the sward and herbage quality are affected for instance by over-seeding, adjustments of cutting schedules or, in the case of pastures, grazing intensity. A further drawback is that the model does not offer options for simulating weeds and weed control, which are important in relation to drought (Finger et al. 2013) and could play a more distinct role in the future

The implications of climate change were examined with only one scenario. Even though this scenario is in line with the range of shifts disclosed by a comprehensive assessment of climate change projections for Switzerland (CH2011, 2011), the use of a single realization is clearly insufficient to develop robust assessments. In this respect, the question of the minimal sample size required for estimating the statistical moment of the yield distribution is also of central importance. For our analysis we used 25 years of data for each of the fertilization scenarios. While, this is probably sufficient to estimate yield variance, it is not sufficient to model the skewness of the yield distribution (Lehmann *et al.* 2013).

Summary and conclusions

We found that under current climatic conditions nitrogen fertilization increases grassland productivity but also leads to a higher variance and a more negative skewness of yields, i.e. increased downside risks. Therefore, risk aversion implies lower optimal N inputs because the input is risk increasing. As an example, our analysis indicates that allowing for a moderate risk aversion in solving the optimization problem would results in a 15% reduction in optimal N application rates. This suggests that accounting for risks in bio-economic models is necessary to achieve a realistic representation of farmers' behaviour in bio-economic models. Likewise, we found that accounting for quality differences in grassland yields by using quality adjusted price levels resulted in optimal nitrogen rates that more closely matches actual data than if herbage prices are kept fixed.

Our results show that climate change, *ceteris paribus*, leads to higher grassland yields but also to substantially higher yield variability. Without consideration of herbage quality, higher yield levels under climate change prompt higher N inputs to exploit this potential. Yet optimal nitrogen rates are smaller than under current climate if quality aspects are taken into account. Under climate change, N inputs are further reduced by up to 60% when accounting for the risk aversion of farmers. The increasing relevance of risk considerations in the scenario is understandable in view of the higher production risks called upon by the climate change scenario adopted for the present analysis.

In summary, adaptation responses may depend critically on risk preferences as well as on the consideration of yield quality, suggesting that conclusions on climate change impacts and adaptation are sensitive to the preferences of farmers. Thus, recommendations on adaptation strategies should account for differences among farmers with respect to their goal functions.

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