An economic assessment of drought effects on three grassland systems in Switzerland

Journal Article

Author(s):
Finger, Robert; Gilgen, Anna K.; Prechsl, Ulrich E.; Buchmann, Nina

Publication date:
2013-04

Permanent link:
https://doi.org/10.3929/ethz-b-000063002

Originally published in:
Regional Environmental Change 13(2), https://doi.org/10.1007/s10113-012-0346-x

Citation for the original published paper:

Finger, R., Gilgen A., Prechsl, U., Buchmann, N. (2013). An economic assessment of drought effects on three grassland systems in Switzerland. Regional Environmental Change 13(2) 365-374. DOI: 10.1007/s10113-012-0346-x

An economic assessment of drought effects on three grassland systems in Switzerland

Key-Words: drought, grassland, weeds, yield, economic costs and benefits

Abstract

This paper analyzes the economic impacts of summer drought on Swiss grassland production. We combine field trial data from drought experiments in three different grasslands in Switzerland with site-specific information on economic costs and benefits. The analysis focuses on the economic implications of drought effects on grassland yields as well as grassland composition. In agreement with earlier studies, we found rather heterogeneous yield effects of drought on Swiss grassland systems, with significantly reduced yields as a response to drought at the lowland and sub-alpine sites, but increased yields at the wetter pre-alpine site. Relative yield losses were highest at the sub-alpine site (with annual yield losses of up to 37%). However, because income from grassland production at extensive sites relies to a large extent on ecological direct payments, even large yield losses had only limited implications in terms of relative profit reductions. In contrast, negative drought impacts at the most productive, intensively managed lowland site were dominant, with average annual drought-induced profit margin reductions of about 28%. This is furthermore emphasized if analyzing the farm-level perspective of drought impacts. Combining site-specific effects at the farm-level, we found that in particular farms with high shares of lowland grassland sites suffer from summer droughts in terms of farm-level fodder production and profit margins. Moreover, our results showed that the higher competitiveness of weeds (broad-leaved dock) under drought conditions will require increasing attention on weed control measures in future grassland

production systems. Taking into account that the risk of drought occurrence is expected to increase in the coming years, additional instruments to cope with drought risks in fodder production and finally farmers' income have to be developed.

1 Introduction

Changes in climatic conditions in Europe are projected to include increasing temperatures and decreasing amounts of summer precipitation (Christensen et al. 2007; Frei et al. 2006). In line with these effects, the probability of summer drought occurrence is expected to increase in the next decades (e.g. Calanca, 2007; Sheffield and Wood, 2008). However, summer droughts are not only an expected phenomenon under future climate, but are already a problem under current climatic conditions. In 2003, a summer drought and heat wave hit large parts of Europe (Schär et al. 2004), which is expected to be 'a shape of things to come' in the future (Beniston 2004). The 2003 drought led to remarkably large losses in plant productivity across Europe (Ciais et al. 2005; EEA 2005; Smit et al. 2008). Consequently, such drought events are increasingly expected to affect agricultural production (Fuhrer et al. 2006; Hopkins and Del Prado 2007, Brown et al. 2011).

The drought sensitivity of grasslands is of outmost importance because, in Europe at large, grasslands cover one third of the total agricultural area and are the backbone for dairy farming and animal husbandry. Furthermore, grasslands provide additional ecosystem services ranging from erosion control to landscape esthetics for tourism (Smit et al. 2008; Millennium Ecosystem Assessment 2005; Quétier et al. 2010; Lamarque et al. 2011). In Switzerland, meadows and pastures cover 744000 ha which represent about 71% of the total agricultural acreage (SBV 2011).

To analyze the effects of drought occurrence on grassland productivity and composition, experimental research has been conducted (see Bloor et al. 2010; Gilgen and Buchmann 2009 for overviews of current literature). These studies, relying on drought simulations, mainly focused on an assessment of drought impacts on plant physiology, vegetation performance and grassland composition. However, to transform this knowledge into expected implications of summer drought conditions for farmers' income, an economic assessment that takes cost and benefit information into account is required, supplementing the existing ecological assessments. Against this background, our paper investigates the economic effects of summer droughts on grassland production under heterogeneous production conditions. More specifically, we assess the impact of summer droughts on farmers' income for three different grassland sites, representing a typical three-stage grassland farming system in Switzerland. We use long-term field trial data to address three aspects of drought impacts important from the farmer's perspective: First, the farmers' income losses; second, changes in grassland composition (i.e. species) relevant for its fodder value; and third, increased weed occurrence as a consequence of drought, crucial for management costs and the monetary value of grassland production.

2 Study Sites and Experimental Setup

The field trials took place between 2005 and 2010 at three agricultural research stations of ETH Zurich (Switzerland): Chamau (8°24′38″E, 47°12′37″N) representing the lowland region, Früebüel (8°32′16″E, 47°6′57″N) located on a pre-alpine mountain, and Alp Weissenstein (9°47′25″E, 46°34′59″N) representing grassland production at the sub-alpine level (Table 1).

< Table 1. Characteristics of the three study sites. >

The three study sites represent contrasting climatic conditions and production systems: artificial vs. permanent grasslands, intensive vs. extensive management, wet pre-alpine (Früebüel) vs. dry sub-alpine (Alp Weissenstein) climate, lowland- vs. mountain-agriculture (Table 1). The differences across these three study sites reflect the actual heterogeneity of Swiss agricultural production.

Starting field trials with regard to annual biomass production in 2006, seven rain shelters were installed at Chamau, six at Früebüel and five shelters at Alp Weissenstein. In 2010, the number of shelters was reduced to six at the Chamau site. The shelters (3 x 3.5 m area and >2 m at the highest point) were covered with transparent plastic foils in spring and summer for a period of 50-88 days (depending on site and year), starting between May and July (site dependent). The rainfall exclusion aimed to simulate a rather extreme drought, reducing annual rainfall by about 30% (see Gilgen and Buchmann 2009 for detailed descriptions and set-up dates). The simulated drought conditions, based on current climate projections for Switzerland, mimic extreme climatic conditions under current climate regimes (e.g. as observed in the year 2003), but are in particular expected to occur more frequently within the next decades (cp. e.g. Beniston 2004, Frei et al. 2006; Calanca 2007). All measurements were taken on a core area of 2 m^2 in the middle of the shelters to minimize border effects such as possible soil moisture gradients. The same number of untreated control plots was established next to the shelters, receiving ambient rainfall.

Annual above-ground biomass production (hereafter referred to as yield) was measured in the years 2006 and 2007 as well as in 2009 and 2010. The year 2005 was used to validate the methodology, but was not considered in our analysis because data was not available for the full growing season. In the year 2008, plots and basic measurements were maintained at Chamau and Früebüel. The original plots at Alp Weissenstein and Chamau had to be abandoned after some years due to heavy damage due to mice infestation, thus new plots were established in 2009 and 2010, respectively.

Dates of biomass harvests mimicked the local management. Samples were taken by using two fixed harvest frames within the plots (two subsamples of 0.1 m^2 each), using a sward height of approximately 7 cm (according to local practice). The harvested biomass was separated into plant species or plant functional types (i.e., N_2 fixing legumes, forbs and grasses), before it was oven-dried at 60°C for about one week and its dry weight quantified.

Weeds were originally not a major problem at any of the sites. However, after a serious infestation of broad-leaved dock (*Rumex obtusifolius* L.) at Chamau in 2006, this species was eradicated in 2007. During the field trial, no fertilizer was applied nor grazing allowed. Nevertheless, plant nutrient contents remained at almost constant levels over time, supported by constant yield levels at the sites. Thus, the management intensities at the three sites were retained during the course of this study. Most importantly, all treatments (e.g. harvesting, weed control) were uniform among control and treatment plots, enabling the direct comparison between both groups. Note that the analysis presented here extends earlier agroecological papers about these experiments (Gilgen and Buchmann 2009; Gilgen et al. 2010) by taking a longer time horizon into account and, most importantly, by focusing on the economic interpretation of field trial results.

3 Methodology and Economic Analysis

The analysis is based on biomass measurements from four years: 2006, 2007, 2009 and 2010. The year 2009 for Alp Weissenstein was not used because the re-establishment of plots (cp. section 2) led to incomparable yield levels. As individual plots (i.e. the locations at the site) have been changed between some experimental years, no plot-specific but site-specific (consisting of several plots) analysis is presented.

In a first step, annual yields were calculated for each plot. For each study site and year, median grassland yields with and without treatment were compared with each other, using bootstrapped confidence intervals based on the Yuen-Welch test (Yuen 1974), i.e. by testing for equality of trimmed means. Bootstrap inference was based on 1999 bootstrap samples where both treatment and control samples are generated by sampling with replacement. In order to assess the general effect of the drought treatment, i.e., over all four years, a Kruskal-Wallis test (a non-parametric analysis of variance) was used. These testing strategies have been selected in favor of other alternatives (e.g. Analysis of (Co)Variance, Regression Analysis) because they do not rely on distributional assumptions and are robust against outliers within the samples (see Finger 2012 for details).

In a second step, yield observations were combined with information on economic costs and benefits. To ensure general inference from our analysis, we assumed average values for costs and benefits from plots with similar production conditions in Switzerland, taken from profit margin calculations for Swiss agriculture (AGRIDEA and FiBL 2010). Thus, the assumed costs are representative for the investigated grassland production systems. Financial benefits from grassland production in Switzerland consist of (governmental) direct payments and the price received for the yield produced. Since forage yields are usually used differently at the three sites (e.g., as silage, hay or for grazing), we had to choose a single unit to compare the different systems. Thus, all grassland yield is assumed to be sold as hay for a price of 300 CHF t^{-1} (AGRIDEA and FiBL 2010). This single price can also be interpreted as the price farmers have to pay to buy additional fodder if the own production does not meet on-farm demand. Direct payments consist of general direct payments as well as ecological direct payments. All farms in Switzerland have to fulfill cross-compliance obligations to receive general direct payments (e.g., area-based payments, see El Benni and Lehmann 2010 for details). These cross-compliance obligations, which apply for both extensive and intensive producers, comprise ecological compensation areas, balanced nutrient budgets, targeted applications of agro-chemicals, soil protection and regulated crop rotations. In addition, low-intensive and extensive production systems such as at Früebüel and Alp Weissenstein are subject to specific ecological programs, which qualify for additional ecological direct payments (BLW, 2009). In particular, extensive production means that no fertilizer is used, herbicides can only be applied on specific parts of the field with weed pressure, and cuts have to be made in specific time windows. Low-intensive production has similar criteria as extensive production but allows the use of organic fertilizer with a total annual nitrogen application below 30 kg N ha^{-1} (see BLW 2009 for details).

< Table 2. Assumptions on costs and benefits in the three grassland production systems. >

Costs in grassland production comprise costs for fertilizer and herbicides, insurance and machinery use. Obviously, costs increase with level of intensity and thus annual total costs differ considerably among the three sites, ranging from about 300 CHF ha^{-1} in the extensive to 1200 CHF ha^{-1} in the intensive production system (Table 2). Costs and benefits were calculated for each plot and year, leading to so-called profit margins that consider all directly attributable costs. We do not account for non-attributable costs (e.g. overhead costs that are necessary to run the farm enterprise) in our analysis. Median profit margins and the dispersion measure MAD (median of absolute deviations from the sample median), which is corrected with a constant (1.4826) to ensure consistency with estimates for the standard deviation, are presented for each study site and treatment group. Statistical inference is based on bootstrapped Yuen-Welch as well as Kruskal-Wallis tests.

Subsequently, we aim to address drought impacts at the farm- instead of the field-level. This is motivated by the fact that several farms in Switzerland have grassland production taking place in different production zones. Thus, the three production sites are considered to belong to a single farm enterprise. The pre-alpine and sub-alpine sites are typically used for summer grazing in summer and mid-summer, respectively, while the lowland site is the backbone of fodder production. We use Swiss census data of 2009 (BLW 2012) consisting of data for 52389 farms to identify farms with grassland production in all production zones (i.e. valley, hill and mountain zones). This selection criterion led to a sample of 11091 farms (i.e. 21% of all farms), with an average (total) grassland acreage of 18.91 ha. Based on these selected farms, we derived three typical distributions of grassland acreage across production zones assuming identical total grassland acreage of 18.91 ha. The first exemplary farm type represents the average distribution of grassland acreage across production zones: 5.54 ha at the lowland site, 5.95 ha at the pre-alpine site and 7.42 ha at the sub-alpine site. The second exemplary farm type is rather focused on lowland production with a distribution of 12.22 ha at the lowland site, 2.98 ha at the pre-alpine site and 3.71 ha at the sub-alpine site. Finally, we consider a farm with a higher share of grassland acreage in the mountain zone, comprising grassland acreages at the lowland site of 2.77 ha, 2.98 ha at the pre-alpine site and 13.61 ha at the sub-alpine site. Subsequently, site-specific drought impacts on yields and profit margins are combined at the farm-level for these three typical farm types. More specifically, grassland acreages in the lowland, hill and mountain zone are associated with results for Chamau, Früebüel and Alp Weissenstein, respectively. To derive total production and gross margins at the farm level, median values (over all years) from the three sites are considered and aggregated using the different area distributions described above.

Impacts of climatic extreme events on fodder values are a further point of economic importance. In highly-intensive grass-clover grassland systems, the species composition (i.e. the fraction of grass and clover) is important because it determines the nutritive value of the grassland yield. In particular, clover increases the palatability (and thus total forage intake), but high clover fractions might also lead to excess nitrogen and can negatively affect animal health (Schubiger and Lehmann 1994). More specifically, Lehmann et al. (1981) and Schubiger and Lehmann (1994) recommended that clover fractions for optimal animal feeding should be in the range of 30–50% for productive grasslands in Switzerland (see e.g. van Dorland et al. 2007, for further discussions on optimal grass/clover mixtures). Because clover is only present to a significant extent at the site Chamau (i.e., the artificial grass-legume mixture), the clover-related analysis focused on this single site. Two aspects were considered: First, we investigated if drought decreases/increases the clover content. Differences between the two treatment groups in these probabilities and in the clover contents were assessed using the bootstrapped Yuen Welch and Kruskal-Wallis tests described above. Second, we estimated drought-induced changes in the probabilities that the clover content would fall within the 'optimal' window of 30-50%. The effect of the drought treatment on this binary variable (in- or outside this range) was tested using a logistic regression with a dummy variable for the treatment as explanatory variable. If the latter variable had a significant effect, a treatment effect on clover content was concluded. To test for an overall drought treatment effect, all observations (i.e. over all years) were used and dummy variables for the four years were included, in addition to the drought treatment dummy in the logistic regression.

Finally, as a proof-of-concept, we assessed and quantified the impact of the drought treatment on weed occurrence. In particular, broad-leaved dock, one of the most troublesome weeds in temperate grassland and crop systems in Central Europe, became important at the site Chamau in 2006 (Gilgen et al. 2010). The weed reduces quality and quantity of yields and is thus removed either manually or chemically (see Gilgen et al. 2010; Stilmant et al. 2007, for further references). However, once broad-leaved dock is present in a field, it is very difficult to control (Poetsch 2001; Cavers and Harper 1964; Zaller 2004). Thus, first, the occurrence probability was estimated and compared among treatments, indicating the probability that (costly) measures become necessary to prohibit the weed broad-leaved dock spreading even further under conditions favorable for this species. The effect of the drought treatment on this binary variable (weed present or not) was tested using logistic regressions for single years and the entire period (as described above for the clover content). Second, also the broad-leaved dock biomass, i.e. the strength of infestation, was analyzed. To quantify the damage from broad-leaved dock, the forgone revenue was calculated using the hay price equivalent used above because this fraction of biomass produced is not usable for animal feeding. This represents a rather simplified assessment of damages because in practice the loss due to non-usable biomass may be not linearly increasing with the biomass of broad-leaved dock, for instance, due to the fact that it may be eaten to some extend (and can have some nutritional value) if occurring in low concentrations but will be troublesome for animal nutrition and processing of grassland yields if occurring in larger concentrations (see e.g. Hejduk and Doležal 2004; Harrington et al. 2006, for further discussions). Furthermore, the financial loss would be very likely larger due to the labor intensive plant protection and the cost for machines and/or pesticides. Again, the bootstrapped Yuen Welch and Kruskal-Wallis tests were used to test for significant differences between the two treatment groups.

4 Results

For Chamau and Alp Weissenstein, the drought treatment reduced yields and profit margins in all years. Highest absolute yield losses were in the range of 3.53 t ha^{-1} (Chamau in 2007; -27%, Table 3), while the highest relative yield losses were observed at the Alp Weissenstein site in 2007 with -37% (1.85 t ha^{-1}). Though significant differences in yields and profit margins were not found for all individual years, the overall (i.e. over all years) negative drought effect for the sites Chamau and Alp Weissenstein was significant at the 5% level. Thus, these two sites did clearly suffer from drought events causing reduced grassland productivity. In contrast, for Früebüel, the drought effects were not significant; yields and profit margins actually tended to be higher under drought conditions compared to the control in all years. This clearly indicated that the reduction of summer rainfall can also have positive effects on grassland yields if the production site usually faces high soil moisture, e.g., due to about 1600 mm precipitation as measured at Früebüel. Thus, drought impacts are expected to be spatially very heterogeneous across Swiss grassland production sites, depending on site-specific weather and soil conditions.

< Table 3. Yield and profit margin effects of drought treatment at three sites. >

The calculated drought effects on profit margins (Table 3) showed that farmers can lose up to 1000 CHF ha^{-1} due to drought events (Chamau in 2007). In relative terms, the highest reductions of profit margins due to such a drought were about 31% (Chamau in 2009 and 2010). On average, the drought treatment induced profit margin losses of 28% at the Chamau site and 12% at the Alp Weissenstein site. An average profit margin increase of 8% was observed for Früebüel. Thus, even though the highest relative yield reductions were observed at the Alp Weissenstein site, relative reductions of profit margins were highest at the site Chamau. In contrast, reductions in profit margins were absent or less pronounced at Früebüel and Alp Weissenstein, respectively. At the intensively managed site Chamau, direct payments did not compensate all costs arising from decreased grassland production under drought conditions (cp. Table 2). In contrast, for the more extensively managed grassland systems, such as Früebüel and Alp Weissenstein, farmers receive additional ecological direct payments while having lower input and machinery costs. In total, the direct payments received are higher than the production costs at these two sites because direct payments compensate for reduced production potentials under ecological production techniques. Thus, the actual reduced grassland production (yield) has lower impacts in economic terms (i.e., to cover costs and generate income) at the more extensive sites, while intensive grassland production requires production to cover its costs and generate income even under drought conditions.

The site-specific drought impacts presented in Table 3 were assessed at the farm-level using three different exemplary farm types with respect to the distribution of grassland acreage across lowland, pre-alpine and sub-alpine production (Table 4). For the average farm (farm type 1), drought treatment causes a reduction of total production of about 9%, while the reduction of profit margins is about 6%. Similar results (reductions of total yield and profit margins of about 8 and 5%, respectively) have been found for the farm type 3 with particular large amount of grassland acreage at the sub-alpine location. In contrast, the exemplary farm with a high share of grassland acreage in lowlands (farm type 2), faces much higher reductions of total grassland production (18%) and profit margins (17%).

Comparing the three exemplary farm types under normal climatic conditions (i.e. in the control group), we find that even though total grassland production differs largely and total grassland acreages are identical across the here considered exemplary farm types, virtually no differences in total gross margins occur. This is due to the fact that smaller productivity in higher altitudes is compensated by higher direct payments. Under drought conditions, however, in particular farms with especially high reliance on lowland production sites suffer from losses in production and gross margins. Even though yield losses in lowland production may – in relative terms – be smaller than in sub-alpine regions, these losses contribute significantly to sharp decreases of grassland production at the farm level, because lowland sites are the backbone of the farm operation in terms of fodder production. As direct payments may not buffer drought induced income reductions to the same extent as in higher altitude production, drought related yield reductions also lead to sharp decreases in total gross margins for farms relying particularly on lowland production. Thus, the farm-level results underline the conclusion that in particular grassland production focused on lowland sites is more vulnerable to summer droughts from a financial point of view.

< Table 4. Drought impacts on total farm-level grassland production and profit margins for three exemplary farm types. >

The clover content (at the Chamau site) was, on average, slightly higher for the drought treatment plots (12%) than for the control plots (5%; Table 5). However, it did not reach the ‘optimal’ window of 30-50% clover fraction in any plot of the control group, whereas on average 18% of the drought treatment plots reached this value. However, no significant differences were found. Although the frequencies of broad-leaved dock occurrence as well as the observed broad-leaved dock biomass did not differ between treatment groups at Chamau (Table 5), in the year 2006, broad-leaved dock dry-matter biomass tended to be higher for the treatment than for the control group, most likely due to a competitive advantage of this weed under drought conditions (Gilgen et al. 2010). The heterogeneity of weed occurrence (and biomass) observed over the years considered is on the one hand caused by differences in weed management (which was the same for control and treatment groups in each year) and on the other hand by overall environmental conditions. On average, an economic burden of about 90 CHF ha^{-1} and year (0.3 t ha^{-1} additional unusable grassland yield times 300 CHF t^{-1}) arose from higher broad-leaved dock competitiveness under drought conditions over all years. However, the economic burden can be as high as 339 CHF ha^{-1} when weed infestation is at its peak, due to less yield being usable for animal feeding. In addition, we expect higher costs for weed control under drought conditions.

< Table 5. Clover and broad-leaved dock contents at the site Chamau. >

5 Discussion

We analyzed the economic impacts of drought on grassland production at three different sites in Switzerland. Drought impact assessment is of particular importance because the frequency of summer drought occurrence is expected to increase in the next decades.

The highest relative yield reductions due to drought conditions were observed at the Alp Weissenstein site. However, relative reductions in the profit margins were highest at the site Chamau, while only small or no reductions in profit margins were observed at Früebüel and Alp Weissenstein. This result is based on the fact that the more extensively managed grassland systems, such as Früebüel and Alp Weissenstein, receive additional ecological direct payments (compensating, for instance, for lower productivity) while having lower input and machinery costs. Thus, the share of the income that is vulnerable to drought conditions, i.e. the actual grassland yield, is small. In contrast, intensive grassland production requires production to cover its costs and generate income - also under drought conditions. For some farmers, direct payments may thus serve as a risk management instrument, i.e. they can prevent profits falling below certain thresholds. This is in line with the findings of Finger and Lehmann (2012) that the increasing level of direct payments has induced decreasing hail insurance adoption rates in Swiss agriculture (see also Finger and Calanca, 2011, for discussions). Thus, increasing drought risks may induce risk averse farmers' to switch to ecological programs to increase the non-risky share of their income.

Considering the effects on species composition, we found clover content to be higher under drought conditions. This is in contrast to model-based results for Swiss grass-clover mixtures which assumed that clover is less tolerant to water stress than grasses (see Lazzarotto et al. 2010 for examples and a literature overview). Frame and Newbold (1986) summarized empirical literature on this issue, and showed that the relationship between rainfall (and drought) and clover competiveness is not straight forward but affected by complex interactions. Also the clover varieties used affect the competitiveness of clover under stress (e.g. Annicchiarico and Proiett 2010). For instance, if some clover varieties have deeper roots and improve soil structure, this could confer an advantage in drought conditions. This also suggests that the use of specific varieties could be an adaptation option for farmers to ensure desired grassland composition even under drought conditions. The use of field trial data is from our point of view a necessary expansion of model-based economic assessments of climate (change) sensitivity of Swiss grassland production (Calanca and Fuhrer 2005; Finger et al. 2010; Lazzarotto et al. 2009; 2010). Though field trial-based analysis has some limitations (see Finger et al. 2010, for a discussion), it has - in contrast to model-based analysis - the key advantage of being based on realistic production and environmental conditions.

Nevertheless, we are aware that the experimental setup presented here focused on drought effects and cannot be the only basis for a general climate change impact assessment of Swiss grasslands. Three points are expected to be of particular additional importance:

First, temperature effects and CO_2 fertilization are not considered in our analysis. CO_2 fertilization is often considered an important determinant of grassland productivity and composition under future climate conditions (Finger et al. 2010; Hebeisen et al. 1997). High atmospheric CO_2 concentrations increased short-term grassland yields on average by about 15 to 20% (Soussana and Lüscher 2007), although long-term yield increases were lower. In addition, rising CO_2 concentrations may also increase water use efficiency and thus might reduce drought sensitivity of grassland systems (see Soussana and Lüscher 2007 for a literature overview). Increasing temperatures may have ambiguous effects on grassland production. While temperature levels exceeding certain thresholds may harm productivity levels, longer growing seasons may be beneficial for the farmer (Olesen and Bindi 2002).

Second, drought effects may depend critically on the actual type of use of grasslands. In our experimental setup, all considered grasslands were mown to enable biomass measurements. In reality, however, in particular alpine and pre-alpine grasslands are mainly used for grazing. Because drought impacts on biomass but also indirect effects such as weed infestation may differ across management practices and intensities (e.g. comparing the different pressure on specific species arising from mowing and grazing, see e.g. Bütof et al. 2012, for discussions), next steps of this research should comprise experimental setups allowing mimicking site-specific management practices.

Third, no changes in grassland management were considered. Thus, potential adaptation responses of farmers to increased drought occurrence are not explicitly assessed. We are aware that economic burdens of droughts could be different if such adjustments were considered. For instance, machinery costs would be smaller if fewer cuts would be necessary under drought conditions. We assumed for this study that machinery costs remain constant for small yield reductions, which was motivated by the fact that the number of machinery operations remains constant, no new equipment is purchased, and transport costs (that could be indeed yield dependent) are not considered in our analysis. Furthermore, farmers may use irrigation to deal with the risk of potential drought (or more general: climate) related damage in grassland production (Calanca and Fuhrer 2005), as it is particularly common in dry inner-alpine valleys of Switzerland (Weber and Schild 2007). Alternatively, insurance solutions can assist farmers to cope with risks of yield losses and should thus be considered in a climate change adaptation framework (Finger and Calanca 2011). The financial burden from droughts would be smaller if farmers would adopt such adaptation measures to cope with drought risks. Moreover, our approach to specify costs of droughts using an approach consisting of (constant) opportunity costs for buying fodder has not considered the systemic nature of drought risks. Droughts may affect all farms over a widespread area, reducing the local supply of fodder and could thus cause higher prices of fodder (see e.g. Briner and Finger 2012, for discussions). Taking this potential effect into account, the financial burden from droughts may be higher than indicated by our results.

Thus, in further research, comprehensive experimental evidence should also address such management adaptations and effects on market to allow more realistic modeling of drought and climate change impacts. More general, our economic analysis was focused on drought impact on mean profits. However, we are aware that also its impacts on production risks expressed as standard deviation or skewness should be addressed in future research (e.g. Finger and Calanca 2011). Furthermore, the role of drought risk in whole farm assessments should be further investigated (e.g. Briner and Finger 2012).

6 Conclusion

Linking yield observations with information on economic costs and benefits shows that even though relative yield losses for extensively managed sites in higher altitudes may be large, the economic impact of drought may be smaller at these sites compared to more intensively managed sites. This is due to the fact that farmers using extensive production systems have an additional (financial) buffer from direct payments to cope with extreme climate events. In contrast, small yield losses due to a drought can induce large economic damages for an intensive producer. Along these lines, we found that in particular farms with high shares of lowland production would suffer from droughts due to sharp reductions in farm-level fodder production and profit margins.

Even though the highest yield losses were observed at the extensive sub-alpine site, drought impacts are particularly important at intensive lowland production sites. Thus, adaptation measures aiming to reduce vulnerability of grassland based farms should particularly address lowland production. Furthermore, because droughts might increase the competitiveness of broad-leaved dock, (costs for) weed control could potentially be considerably more important if droughts occur more frequently in the future.

Acknowledgements

The paper is a contribution to the activities of the National Centre of Competence in Research on Climate (NCCR Climate) supported by the Swiss National Science Foundation. We would like to thank Simon Briner for providing information on census data and helpful comments, as well as two anonymous reviewers and the editor for constructive comments and very helpful suggestions.

References

AGRIDEA, FiBL (2010) Deckungsbeiträge 2010. Swiss Association for the Development of Rural Areas (AGRIDEA) and Research Institute for Organic Agriculture (FiBL), Switzerland.

Annicchiarico P, Proiett S (2010) White clover selected for enhanced competitive ability widens the compatibility with grasses and favours the optimization of legume content and forage yield in mown clover-grass mixtures. Grass Forage Sci 65: 318-324

Beniston M. (2004) The 2003 heat wave in Europe: A shape of things to come? An analysis based on Swiss climatological data and model simulations. Geophys Res Lett 31: L02202, doi:10.1029/2003GL018857.

Bloor JMG, Pichon P, Falcimagne R, Leadley P, Soussana J-F (2010) Effects of Warming, Summer Drought, and CO_2 Enrichment on Aboveground Biomass Production, Flowering Phenology, and Community Structure in an Upland Grassland Ecosystem. Ecosystems 13: 888-900.

BLW (2009) Direktzahlungsverordnung. Bundesamt für Landwirtschaft (BLW) – Swiss Federal Office for Agriculture, Bern, Switzerland.

BLW (2012) Agrarinformationssystem AGIS. Bundesamt für Landwirtschaft (BLW) – Swiss Federal Office for Agriculture, Bern, Switzerland.

Briner S, Finger R (2012) Bio-economic modeling of decisions under yield and price risk for suckler cow farms. 123rd EAAE Seminar "Price Volatility and Farm Income Stabilisation", Dublin, February 23rd - 24th, 2012.

Brown I, Poggio L, Gimona A, Castellazzi M (2011) Climate change, drought risk and land capability for agriculture: implications for land use in Scotland. Reg Environ Change 11: 503–518.

Bütof A, von Riedmatten LR, Dormann CF, Scherer-Lorenzen M, Welk E, Bruelheide H (2012) The responses of grassland plants to experimentally simulated climate change depend on land use and region. Global Change Biol 18: 127-137.

Calanca P (2007) Climate change and drought occurrence in the Alpine region: How severe are becoming the extremes? Global Planet Change 57: 151-160.

Calanca P, Fuhrer J (2005) Swiss agriculture in a changing climate: grassland production and its economic value. In: Haurie A, ViguierL (eds) The Coupling of Climate and Economic Dynamics – Essays on Integrated Assessment, Advances in Global Change Research 22, Springer, Dordrecht, NL, pp. 341–353.

Cavers PB, Harper JL (1964) *Rumex obtusifolius* L. and *R. crispus* L. J Ecol 52: 737–766.

Christensen JH, Hewitson B, Busuioc A, Chen A, Gao X, Held I, Jones R, Kolli RK, Kwon W-T, Laprise R, Magaña Rueda V, Mearns L, Menéndez CG, Räisänen J, Rinke A, Sarr A, Whetto P (2007) Regional climate projections. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK, pp. 847–940.

Ciais P, Reichstein M, Viovy N, Granier A, Ogee J, Allard V, Aubinet M, Buchmann N, Bernhofer C, Carrara A, Chevallier F, De Noblet N, Friend AD, Friedlingstein P, Grunwald T, Heinesch B, Keronen P, Knohl A, Krinner G, Loustau D, Manca G, Matteucci G, Miglietta F, Ourcival JM, Papale D, Pilegaard K, Rambal S, Seufert G, Soussana JF, Sanz MJ, Schulze ED, Versala T, Valentini R (2005) Europe-wide reduction in primary productivity caused by the heat and drought in 2003. Nature 437: 529-533.

EEA (2005) Vulnerability and adaptation to climate change in Europe. European Environment Agency (EEA). Technical Report No 7/2005.

El Benni N, Lehmann B (2010) Swiss agricultural policy reform: landscape changes in consequence of national agricultural policy and international competition pressure. In Primdahl J, Swaffield S (eds) Globalisation and Agricultural Landscapes - Change Patterns and Policy trends in Developed Countries. Cambridge University Press, Cambridge, 73-94.

Finger R. (2012) Biases in Farm-level Yield Risk Analysis due to Data Aggregation. Ger J Agric Econ 61: 30-43.

Finger R, Lazzarotto P, Calanca P (2010) Bio-economic assessment of climate change impacts on managed grassland production. Agric Syst 103: 666-674.

Finger R, Calanca P (2011) Risk Management Strategies to Cope with Climate Change in Grassland Production: An Illustrative Case Study for the Swiss Plateau. Region Environ Change 11: 935-949.

Finger R, Lehmann N (2012) The Influence of Direct Payments on Farmers' Hail Insurance Decisions. Agr Econ 43: 341–352.

Frame J, Newbold P (1986) Agronomy of white clover. Adv Agron 40: 1–88.

Frei C, Schöll R, Fukutome S, Schmidli J, Vidale PL (2006) Future change of precipitation extremes in Europe: Intercomparison of scenarios from regional climate models. J Geophys Res Atmos 111: D06105, doi:10.1029/2005JD005965.

Fuhrer J, Beniston M, Fischlin A, Frei C, Goyette S, Jasper K, Pfister C (2006) Climate risks and their impact on agriculture and forests in Switzerland. Clim Change 79: 79-102.

Gilgen AK, Signarbieux C, Feller U, Buchmann N (2010) Competitive advantage of *Rumex obtusifolius* L. might increase in intensively managed temperate grasslands under drier climate. Agric Ecosyst Environ 135: 15–23.

Gilgen AK, Buchmann N (2009) Response of temperate grasslands at different altitudes to simulated summer drought differed but scaled with annual precipitation. Biogeosciences 6: 2525-2539.

Harrington KC, Thatcher A, Kemp PD (2006) Mineral composition and nutritive value of some common pasture weeds. N Z Plant Prot 59: 261–265.

Hebeisen T, Lüscher A, Zanetti S, Fischer BU, Hartwig UA, Frehner M, Hendrey GR, Blum H, Nösberger J (1997) Growth response of *Trifolium repens* L. and *Lolium perenne* L. as monocultures and bi-species mixture to free air CO_2 enrichment and management. Global Change Biol 3: 149–160.

Hejduk S, Doležal P (2004) Nutritive value of broad-leaved dock (*Rumex obtusifolius* L.) and its effect on the quality of grass silages. Czech J Anim Sci 49: 144-150.

Hopkins A, Del Prado A (2007) Implications of climate change for grassland in Europe: impacts, adaptations and mitigation options: a review. Grass Forage Sci 62: 118-126.

Lamarque P, Tappeiner U, Turner C, Steinbacher M, Bardgett RD, Szukics U, Schermer M, Lavorel S (2011) Stakeholder perceptions of grassland ecosystem services in relation to knowledge on soil fertility and biodiversity. Reg Environ Change 11: 791-804.

Lazzarotto P, Calanca P, Fuhrer J (2009) Dynamics of grass-clover mixtures – An analysis of the response to management with the PROductive GRASsland Simulator (PROGRASS). Ecol Model 220: 703-724.

Lazzarotto P, Calanca P, Semenov M, Fuhrer J (2010) Transient responses to increasing CO_2 and climate change in unfertilized grass–clover mixtures. Clim Res 41: 221–232.

Lehmann J, Zihlmann U, Briner HU (1981) Überlegungen zum Klee-Gras-Anbau. Schweiz Landw Monats 59: 365-378.

Millennium Ecosystem Assessment (2005). Ecosystems and human well-being. Island Press, Washington (DC).

Olesen JE, Bindi M (2002) Consequences of climate change for European agricultural productivity, land use and policy. Eur J Agron 16: 239–262.

Quétier F, Rivoal F, Marty P, De Chazal J, Lavorel S (2010) Social representations of an alpine grassland landscape and socio-political discourses on rural development. Reg Environ Change 10: 119–130.

Pötsch EM (2001) Wissenswertes zur mechanischen und chemischen Ampferbekämpfung. In: 7. Alpenländisches Expertenforum, Gumpenstein, 22.-23. März 2001, Bundesanstalt für alpenländische Landwirtschaft (ed), pp. 75–81.

SBV (2011) Statistische Erhebungen und Schätzungen über Landwirtschaft und Ernährung. Schweizer Bauernverband (SBV, Swiss Farmers' Union), Brugg, Switzerland.

Schär C, Vidale PL, Lüthi D, Frei C, Häberli C, Liniger MA, Appenzeller C (2004) The role of increasing temperature variability in European summer heatwaves. Nature 427: 332-336.

Schubiger FX, Lehmann J (1994) Futterwert unterschiedlich genutzter Klee-Gras-Gemenge. Agrarforschung 1: 167–170.

Sheffield J, Wood EF (2008) Projected changes in drought occurrence under future global warming from multi-model, multi-scenario, IPCC AR4 simulations. Clim Dyn 31: 79–105.

Smit HJ, Metzger MJ, Ewert F (2008) Spatial distribution of grassland productivity and land use in Europe. Agric Syst 98: 208-219.

Soussana J-F, Lüscher A (2007) Temperate grasslands and global atmospheric change: a review. Grass Forage Sci 62: 127–134.

Stilmant D, Knoden D, Bodson B, Luxen P, Herman J, Vrancken C, Losseau C (2007) Broad-leaved dock in grassland farming systems: importance of the problems raised, chemical control and control by alternative methods (in French, summary in English). Fourrages 192: 477–493.

van Dorland HA, Wettstein H-R, Aeschlimann G, Leuenberger H, Kreuzer M (2007) Preference of dairy cows for ryegrass, white clover and red clover, and its effects on nutrient supply and milk quality. Arch Tierernahr 61: 371-389.

Weber M, Schild A (2007) Stand der Bewässerung in der Schweiz - Bericht zur Umfrage 2006. Swiss Federal Office for Agriculture, Bern, Switzerland.

Yuen KK (1974) The two-sample trimmed t for unequal population variances. Biometrika 61: 165-170.

Zaller JG (2004) Ecology and non-chemical control of *Rumex crispus* and *R. obtusifolius* (Polygonaceae): a review. Weed Res 44: 414–432.

Table 1. Characteristics of the three study sites.

	Chamau[1]	**Früebüel**	**Alp Weissenstein**
Elevation in m a.s.l.	393	982	1978
Annual Precipitation Sum in mm	1151	1682	877
Mean Annual Temperature in °C	9.1	6.1	-1.4
Growing Season Length	Mid-April to October	May to mid-October	Mid-June to September
Management Intensity	Intensive (4-6 cuts)	Low-intensive (1-2 cuts)	Extensive (grazing)
Vegetation Type and Dominant Species	Artificial grass-legume mixture: Italian ryegrass (*Lolium multiflorum*), smooth meadow-grass (*Poa pratensis*), white clover (*Trifolium repens*)	Permanent managed pasture: meadow foxtail (*Alopecurus pratensis*), red fescue (*Festuca rubra*), timothy-grass *(Phleum pratense),* sorrel (*Rumex acetosa*)	Permanent alpine pasture: golden oat grass (*Trisetum flavescens*), Alpine cat's tail (*Phleum rhaeticum*), sorrel (*Rumex acetosa*), red clover *(Trifolium pratense)*

Temperature (1961-1990) and precipitation (1971-1990) long-term averages were interpolated from "Atlas der Schweiz 3" Sieber et al. 2011. [1]Further details, historical facts and literature related to these study sites are available at www.chamau.ethz.ch.

Table 2. Assumptions on costs and benefits in the three grassland production systems.

	Chamau	Früebüel	Alp Weissenstein
Revenue			
Yield		Field Trial Data	
Price for Yield (Hay)		300 CHF t^{-1}	
Direct Payments in CHF ha^{-1}			
General Direct Payments	1040	1040	1040
Ecological Direct Payments	0	300*	450**
Costs in CHF ha^{-1}			
Fertilizer Costs	175	98	0
Plant Protection Costs	53	32	0
Insurance[1]	72	72	72
Machinery Costs[2]	867	600	210

Source: AGRIDEA and FiBL (2010). *Low-intensive production. ** Extensive production in mountain area.[1] This insurance comprises damages from hail and other elementary risks such as flooding or storm. A flat rate per hectare insurance premium is paid for grassland, see www.hagel.ch for details. [2] including interest claim.

Table 3. Yield and profit margin effects of drought treatment at three sites.

	Median Values (MADs in parentheses) across Plots				
	2006	**2007**	**2009**	**2010**	**Median**
			Chamau		
Yield in dry matter t ha^{-1}					
Control Group	8.35 (3.76)	12.96 (3.11)	8.98 (0.71)	8.33 (1.32)	8.67
Drought Treatment	6.74 (2.13)	9.44 (0.77)	6.46 (0.78)	6.01 (1.74)	6.60
Yields Difference in t ha^{-1} (in %)	-1.61 (-19%) (n.s.)	-3.53 (-27%) (n.s.)	-2.52 (-28%)***	-3.31 (-28%)**	-2.42 (-27%)^{xx}
Profit Margins in CHF ha^{-1}					
Control Group	2257 (1128)	3640 (933)	2446 (212)	2251 (396)	2352
Drought Treatment	1774 (639)	2584 (230)	1690 (234)	1555 (521)	1732
Difference of Profit Margins in CHF ha^{-1} (in %)	-483 (-21%) (n.s.)	-1056 (-29%) (n.s.)	-756 (-31%)***	-696 (-31%)**	-726 (-28%)^{xx}
			Früebüel		
Yield in dry matter t ha^{-1}					
Control Group	5.47 (0.53)	5.74 (2.04)	5.61 (0.97)	6.08 (0.64)	5.68
Drought Treatment	6.16 (2.21)	6.23 (0.79)	6.58 (0.81)	6.48 (0.92)	6.36
Yields Difference in t ha^{-1} (in %)	+0.69 (+13%) (n.s.)	+0.49 (+9%) (n.s.)	+0.97 (+17%) (n.s.)	+0.40 (+7%) (n.s.)	+0.59 (+11%) (n.s.)
Profit Margins in CHF ha^{-1}					
Control Group	2179 (158)	2260 (612)	2221 (290)	2362 (192)	2241
Drought Treatment	2386 (664)	2407 (238)	2512 (243)	2482 (275)	2445
Difference of Profit Margins in CHF ha^{-1} (in %)	+207 (+9%) (n.s.)	+147 (+7%) (n.s.)	+291 (+13%) (n.s.)	+120 (+5%) (n.s.)	+177 (+8%) (n.s.)
			Alp Weissenstein		
Yield in dry matter t ha^{-1}					

Control Group	2.83 (0.08)	5.02 (0.15)	---	2.84 (0.04)	2.84
Drought Treatment	1.98 (0.53)	3.17 (0.79)	---	2.65 (1.22)	2.65
Yields Difference in t ha^{-1} (in %)	-0.85 (-30%)*	-1.85 (-37%)**	---	-0.19 (-7%) (n.s.)	-0.85 (-30%)^{xx}
Profit Margins in CHF ha^{-1}					
Control Group	2057 (63)	2714 (198)	---	2060 (12)	2060
Drought Treatment	1802 (175)	2159 (305)	---	2003 (366)	2003
Difference of Profit Margins in CHF ha^{-1} (in %)	-255 (-12%)**	-555 (-20%)**	---	-57 (-3%) (n.s.)	-255 (-12%) ^{xx}

*, ** and *** denote significant differences (10, 5 and 1% level) between treatment and control groups in a specific year, indicated by a bootstrapped Yuen-Welch test (N=1999). ^{xx} denotes significant general treatment effects (over all years) (at the 5% level) indicated by a Kruskal-Wallis test. Numbers in parentheses are MADs.

Table 4. Drought impacts on total farm-level grassland production and profit margins for three exemplary farm types.

	Grassland production in t yr^{-1}		Profit margins in CHF yr^{-1}	
Farm type*	Control Group	Drought Treatment (relative difference in %)	Control Group	Drought Treatment (relative difference in %)
Exemplary Farm 1	102.90	94.07 (-9%)	41649.23	39005.29 (-6%)
Exemplary Farm 2	133.41	109.44 (-18%)	43062.22	35882.27 (-17%)
Exemplary Farm 3	79.59	73.30 (-8%)	41229.82	39344.57 (-5%)

* A total grassland acreage of 18.91 ha was assumed for all exemplary farms. The distribution across lowland, hill and mountain production zone are as follows (in ha). Exemplary Farm 1 – Average distribution of production areas across zones: 5.54, 5.95, 7.42; Exemplary Farm 2 – Above average lowland production: 12.22, 2.98, 3.71; Exemplary Farm 3 – Above average mountain production: 2.77, 2.98, 13.61. Areas in these zones are associated with results for the Chamau, Früebüel and Alp Weissenstein, respectively. See section 3 for detailed descriptions. Numbers in parentheses are relative differences between drought treatment and the control group (in %).

Table 5. Clover and broad-leaved dock contents at the site Chamau.

	2006	2007	2009	2010	Mean
Clover Content (Mean [range] of all plots)					
Control Group	9% [0-20%]	5% [2-8%]	2% [0-3%]	5% [0-12%]	5%
Drought Treatment	15% [2-35%]	20% [3-50%]	5% [0-9%]	9% [0-34%]	12%
Difference in Clover Content	+6% (n.s.)	+15% (n.s.)	+3% (n.s.)	+4% (n.s.)	+7% (n.s.)
Fraction of Plots with Clover Content between 30% and 50%					
Control Group	0	0	0	0	0
Drought Treatment	0.14 (n.s.)	0.4 (n.s.)	0 (n.s.)	0.17 (n.s.)	0.18 (n.s.)
Fraction of Plots with Broad-leaved Dock					
Control Group	0.86	0.40	0	n.a.	0.42
Drought Treatment	0.86 (n.s.)	0 (n.s.)	0 (n.s.)	n.a.	0.29 (n.s.)
Broad-leaved Dock Biomass (Mean (standard deviation) of all plots)					
Control Group	1.66 (1.96) t ha^{-1}	0.23 (0.49) t ha^{-1}	0 t ha^{-1}	n.a.	0.63
Drought Treatment	2.79 (3.57) t ha^{-1} (n.s.)	0 t ha^{-1} (n.s.)	0 t ha^{-1} (n.s.)	n.a.	0.93 (n.s.)

Drought Effect on Forgone Revenue	-339 CHF ha^{-1}	+69 CHF ha^{-1}	0 CHF ha^{-1}	n.a.	-90 CHF ha^{-1}

Numbers in square brackets and parentheses indicate ranges and standard deviations, respectively. n.s. denotes not significant. Yield values refer to dry matter yields.