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Abstract

Biodiversity loss in Europe is caused to a large extent by agricultural intensification. To halt this loss and to support species and habitat types in agricultural areas, agri-environment schemes have been introduced in Europe to compensate farmers for (costly) conservation measures. Currently, agri-environment schemes for grassland in general consider only a few conservation measures with fixed dates and a payment for average opportunity costs, e.g. for later mowing. A systematic approach that calculates farmers` opportunity costs in relation to the timing of grassland use is still lacking. We fill this gap by developing a systematic agri-economic cost assessment approach. Our approach is general enough to be applicable on a large spatial scale but can still sensitively differentiate among different timings. Moreover it is straightforward and time-saving enough to be suitable for implementation in regional scale optimisation procedures. We demonstrate this by applying the systematic cost assessment in the decision support software *DSS-Ecopay* using the example of grassland species and habitats conservation in the German federal state of Saxony.

Keywords

Biodiversity conservation, cost-effectiveness, ecological-economic modelling, agri-environment scheme, grassland, *DSS-Ecopay*

Table of content

Tables

Figures

1 Introduction

Biodiversity loss in Europe is caused to a large extent by agricultural intensification (Benton et al. 2002, Kleijn et al. 2009). To halt this loss and to support species and habitat types in agricultural areas agri-environment schemes have been introduced in Europe (Plieninger et al. 2012). Under such schemes farmers are financially compensated for carrying out biodiversity-enhancing land-use measures (Finn and Ó hUallacháin 2012). However, according to research studies (Kleijn et al. 2011, Kleijn and Sutherland 2003, Marggraf 2003) and farmland biodiversity indicators (Statistisches Bundesamt 2010), the success of existing agri-environment schemes in terms of conservation is mixed at best.

One of the reasons for this failure is, to our knowledge, the lack of approaches and decision support tools which systematically assess the effectiveness and costs of a large set of potential land-use measures on a national or regional scale, despite the growing body of research in this field (Drechsler et al. 2007, Johst et al. 2002, Primdahl et al. 2010; for integrated modelling approaches see also Rossing et al. 2007).

National or regional scale agri-environment schemes are typically designed by first identifying a small number of potential biodiversity-enhancing land-use measures and then calculating the opportunity costs (averaged over the whole area) incurred to farmers if they implement them. Currently, agri-environment schemes in grasslands generally consider only a few measures with a fixed date (e.g. a typical mowing measure is mowing after June 15th) and given loss in energy yield (e.g. for later mowing). Farmers' opportunity costs are calculated for these measures only. However, different species and habitats have different habitat requirements and survival probabilities depending on the timing of measures (cf. Johst et al. subm.). Therefore, all potential grassland use timings should be screened by systematically analysing their impact on species and habitats and their costs. While an ecological model was recently developed by Johst et al. (subm.), a systematic cost assessment for calculating a farmer's income loss is still missing. To fill this gap, this paper presents an approach which can be used to assess spatially and temporally differentiated opportunity costs of farmers for mowing and grazing regimes in a systematic manner.

The development of such an approach is not straightforward. We are confronted with the same challenges identified by Johst et al. (subm.) when they developed a new modelling approach for assessing the ecological impact of grassland measures on species and habitats. These key challenges, which are outlined below, have to be addressed in the development of a systematic approach for cost assessment.

First, a systematic cost assessment approach has to capture a wide variety of spatial differentiations in local conditions like, for example, soil quality and grassland measures potentially available for species and habitats protection, in a common way but also detailed enough to sufficiently consider the differences among them. The latter is particularly important because, in general, agri-environment scheme payments are planned at regional

scale where significant spatial variations may exist. In Germany, for example, the schemes are generally designed at the federal state level (cf. Osterburg 2006).
Second, not only *where* but also *when* a grassland measure is applied is of great importance. A temporal differentiation is important as the timing of grassland use determines the quantity and quality of the harvested grassland yield and its digestibility. For example, late use of grassland in the vegetation period often leads to a lower yield and quality of the grassland compared to earlier land use (e.g. Voigtländer and Jacob 1987) and thus to an income loss to farmers, if they are not compensated (e.g. Bahner 2005). Therefore, assessment of the grassland yield at varying dates in the year is relevant for agri-environment schemes. In contrast to the spatial differentiation of costs of grassland measures, their temporal differentiation has received very little attention.
Finally, if a cost assessment approach is to be implemented in a decision support tool for decision makers, e.g. conservation agencies, it has to be straightforward without losing too much differentiation and detail by assessing the effects of timing of grassland use on farmers' income. This implies that it should not require too much computing time (Ball et al. 2009) and is therefore suitable for optimisation procedures at large spatial scales.
The paper presents a systematic cost assessment solution that meets these challenges. The cost assessment approach is introduced in section 2. Section 2.1 explains the basic framework for assessing the costs of measures followed by a detailed explanation of how our systematic cost assessment approach can differentiate between different locations and timings of grassland uses in section 2.2. We demonstrate how the systematic approach works by inserting data from the German federal state of Saxony using the decision support software *DSS-Ecopay* in which the approach is implemented in section 3. There, we also assess the spatially and temporally differentiated costs of selected mowing and grazing regimes. Section 4 concludes.

2 Approach

2.1 Basic cost assessment framework

The purpose of the cost assessment is to evaluate whether a farmer is willing to implement a specific land-use measure in the context of an agri-environment scheme. The assessment is based on the assumption that a farmer will take part in an agri-environment scheme if he receives a compensation payment p that covers his opportunity costs c for realising the measure m and his transaction costs tc for implementing it (see eq. 1):

$$c_m + tc_m \leq p_m \qquad \text{(eq. 1).}$$

The opportunity costs c reflect the foregone profits of a farmer if he does not use his land in a profit-maximising way but implements a biodiversity-enhancing land-use measure (e.g. in grassland a postponement of the first mowing to protect the nests of meadow birds). We assume that opportunity costs are calculated relative to, and farmers are compensated on the basis of, a specific reference situation, which in grassland is the farmer`s profit maximising mowing or grazing regime in that landscape. Participation in an agri-environment scheme may also lead to transaction costs for the farmer (acquiring information about the scheme, administrative work to fill out forms, etc.) for which he needs to be compensated as well. In this paper we focus on the opportunity costs c of land use and refer the reader interested in transaction costs to the literature (e.g. Mettepenningen et al. 2009).

In more detail, the farmer`s costs c for realising a grassland measure m are:

$$c_m = \left[\left(y_{ref} - y_m\right) \cdot p_f\right] - \left(c_{v,ref} - c_{v,m}\right) - \left[\left(l_{ref} - l_m\right) \cdot p_l\right] \qquad \text{(eq. 2).}$$

The three different terms of eq. 2 have the following meanings.

(1) Yield revenue proxy, $c_f = \left(y_{ref} - y_m\right) \cdot p_f$ (eq. 2a)

First, a change in the revenue from the market product of the field has to be considered. While on arable land, e.g., the harvested wheat or rape can be sold directly on the market, this usually does not hold for grassland with its grass yield. Instead, the market revenue here is an indirect one, as it is generated by the feeding of the grass to livestock (fresh, as silage or hay). Thus the market revenue depends on the type and structure of the farm, i.e. whether the farmer increases his revenues by e.g. dairy farming, suckler cow husbandry or fattening. The data needed for the assessment of the grassland market revenue is farm specific and requires complex calculations. In practice, the compensation payment for agri-environment measures is therefore determined by a simplified calculation shown by the first term in equation 2, $\left(y_{ref} - y_m\right) \cdot p_f$.

The net energy grassland yield y_m after the implementation of a measure m (e.g. the mowing at a later time than in the reference situation) is subtracted from the net energy grassland yield y_{ref} for the profit-maximising reference situation ref. Typically, the energy yield is given in MJ NEL/ha (mega joule net energy lactation values per hectare). Net energy lactation is a measuring unit of the energy density of fodder in reference to the milk yield. We also use MJ NEL/ha for our calculations. For beef cows and heifers the energy yield instead is measured as metabolised energy (ME). In these cases, we transfer MJ ME-values into MJ NEL ones. The net energy difference in MJ NEL/ha is finally valued via the purchase of concentrated feed with p_f = price of concentrated feed per MJ NEL. This leads to the costs of concentrated feed, c_f, and thus to a value expressed in monetary units which approximately reflects the change in the quality and quantity of the yield due to an implemented measure in grassland.

(2) Variable costs, $c_v = \left(c_{v,ref} - c_{v,m}\right)$ (eq. 2b)

The second term in equation 2 refers to the variable costs c_v. Total variable costs include costs of seeds, pest management and fertilisation, variable costs of machines and costs of silage. Costs of seeds, pest management and fertilisation consist of the particular input quantity multiplied with the market price of the input. Variable costs of machines are calculated by considering each machine type used, its service time, fuel price and maintenance costs.

The variable costs of the reference situation $c_{v,ref}$ as well as the variable costs $c_{v,m}$ after the implementation of a measure m, e.g. one cut less than in the reference situation, are calculated in €/ha. The difference in variable costs shows cost savings or expenses that have to be subtracted from the yield-difference (see eq. 2).

(3) Labour costs, $c_l = \left(l_{ref} - l_m\right) \cdot p_l$ (eq. 2c)

Implementing a biodiversity-enhancing land-use measure may lead to changes in the time a farmer devotes to grassland management. We follow the approach of some German federal states and consider changes in these labour costs additionally to the variable costs when calculating payments for agri-environment measures (e.g. SMUL 2007). Therefore, the last term in equation 2 considers the labour time the farmer himself needed to invest in grassland management in the reference situation ref and with the implementation of measure *m*. The labour time of the farmer in the reference situation l_{ref} and the labour time after the implementation of a measure l_m are subtracted and multiplied by the price of labour time p_l in €/hour. Again, the labour costs show cost savings or costs that have to be subtracted from the yield-difference (see eq. 2).

2.2 Systematic cost assessment approach for grassland measures

The basic objective of an advanced economic cost assessment is to systematically quantify the effect of the *timing* of grassland use on the opportunity costs of farmers. Given the data at hand, such an approach needs to be *general* and flexible but at the same time detailed enough to adequately reflect the effects of timing of grassland uses. Starting from the basic cost assessment (eq. 2) we develop a systematic approach which is able to assess the cost as a function of the timing of grassland uses to meet the challenges described above. Whereas the price of concentrated feed, variable costs and labour costs are in general independent of the timing of grassland uses and therefore a grassland measure, the grassland yield is strongly dependent on it. Thus, we add time *t* in the first term of equation 2. Fig. 1 shows the basic scheme of the developed systematic approach.

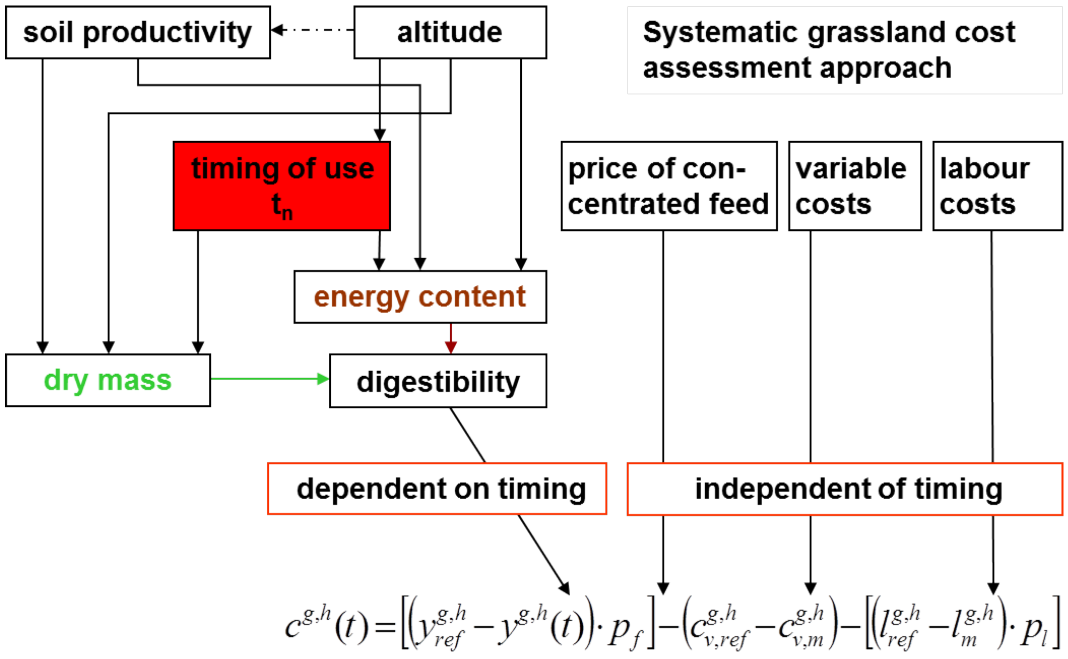

Fig. 1: Scheme of the systematic cost assessment approach for grassland measures which is able to assess the costs of a measure as a function of the timing of its grassland uses. The novelty of this approach compared to the basic cost assessment framework (eq. 2) consists in introducing time-dependence in the grassland yield $y^{g,h}(t)$ reflecting that the timing t of a grassland use strongly impacts this yield and the resulting costs $c^{g,h}(t)$. The superscript g denotes the spatial variation given by values for soil productivity and h the altitude of the considered area. The price of concentrated feed, variable costs and labour costs, however, is in general independent of the timing of the measure.

The grassland yield is influenced by soil productivity and altitude. A shift in specific land-use dates for mowing or grazing has effects on the quantity (dry matter, DM), quality (energy concentration, EC) and thus digestibility ($D(EC)$) of the grassland yield, $y^{g,h}(t)$ (cf. Fig. 1). The sum of each yield of the potential uses n gives the total yield of the farmer summarised in equation 3:

$$y^{g,h}(t)=\sum_n DM_n^{g,h}(t_n)\cdot EC(t_n)\cdot D(EC(t_n)),\ n\in\{1,2,3\} \qquad \text{(eq. 3).}$$

In the following we explain each term of equation 3 in detail. We first describe the overall development of grassland yields y during a year**.** The dry matter at different timings of use $DM_n^{g,h}(t_n)$ is described, followed by changes in energy concentration $EC(t_n)$ and digestibility $D(EC(t_n))$ for varying times of grassland use. Closing, we summarise the effect of these timings of uses on grassland yield $y^{g,h}(t)$.

2.2.1 Development of grassland yield y during the time of the year

In spring the growth of grasses and herbs starts and biomass increases. Depending on altitude and temperature it reaches its peak between June and the middle of August (Opitz von Boberfeld 1994). The growth rate of the dry matter DM during the course of the year can be depicted as a steadily growing function with two peaks between June and the middle of August and steadily declining values towards the end of the growing season (see Fig. 2). The total dry matter yield can therefore be assumed as a steadily growing function with a steep slope early in the year and a weak one later on. The energy concentration of the grass decreases over the year (see Fig. 2). But the total dry matter yield increases faster than the energy concentration decreases and thus the total energy yield also increases continuously until the plant dies or the dormancy period begins (Steinhöfel 2002).

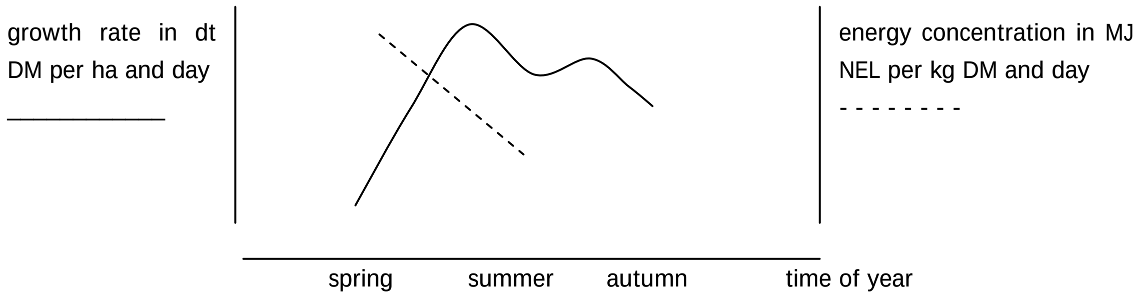

Fig. 2: Schematic representation of the annual growth rate of dry matter yield of grassland in decitons dry matter per ha and day (dt DM per ha and day, solid line) and the energy concentration in mega joule net energy lactation per kg harvestable dry matter (MJ NEL per kg DM and day, dashed line)

Usually, farmers cut the grass when its energy concentration and digestibility are very high and the raw fibre content is still low. This does not correspond with the date of the highest dry matter yield (see Fig. 2). Based on Mährlein (1993b) the second half of May is recommended for the first cut in average years. A first cut at a later date will result in a higher dry matter yield. However, the quality of the forage will be considerably lower. This is due to a reduction of both energy concentration and content of raw proteins as well as an increase in the raw fibre content and a consequent decline in digestibility. The growth rate between two cuts is similar to the annual growth rate curve: after a time of regeneration following the first cut, a strong growth begins followed by a decline in growth (Voigtländer and Jacob 1987), but altogether the growth rate slows down for each further grassland use (cf. Berendonk 2011).

2.2.2 Dry matter yield $DM_n^{g,h}(t_n)$ for varying times of grassland use

For a detailed assessment of costs it would be necessary to take the average yield or growth rate functions for varying grassland types as a basis for the assessment of the grassland dry matter yields at different times of the year. However, it is difficult to identify such functions.

This also holds for the second yield function for the time after the first cut and so on. Such functions require detailed knowledge of vegetation type, site conditions and land management. Since such an approach cannot be put into practice due to insufficient data, the dry matter yield during the course of the year is estimated as follows:

Starting from an average dry matter yield in the reference situation an average effect of a shift in usage (cutting, grazing) dates is defined as a change in dry matter yield in percent of the initial land-use situation (cf. eq. 4). The dry matter yield increases in time (compare development of the DM growth rate in Fig. 2 over the year). Based on information from literature studies (Berendonk 2011, Bergmann 2004, Dahmen 1990, Remmelink et al. 2011) we determined yield changes $\boldsymbol{i}$ (in %) for each time step. Dry matter yield for the first use increases rapidly until the peak of the daily yield growth in summer.

The dry matter yield $DM_n^{g,h}(t_n)$ for each number of grassland use $n \in \{1,2,3\}$ (first, second or third use) of a measure m at soil productivity g and altitude h with timing t_n can be calculated by multiplying the dry matter of the corresponding number of grassland use of the reference situation ref, $DM_{n,ref}^{g,h}$, with the change $\boldsymbol{i}$ of total dry matter yield:

$$DM_n^{g,h}(t_n) = DM_{n,ref}^{g,h} \cdot \left({}^{100+i_{n,m}}\!/_{100} \right) \qquad \text{(eq. 4).}$$

The growth rate slows down for each further grassland use (cf. Berendonk 2011). Therefore, it is assumed that the growth rate for the second use is only 4/5 of the increase of the first use, and the rate for the third use only 3/5, respectively (with $i_2(t_2) = {}^4\!/_5\, i_1(t_1)$, for $i_3(t_3) = {}^3\!/_5\, i_1(t_1)$). The dry matter yields for each use are not summed up to a total dry matter yield because of different energy concentration and digestibility for each use.

2.2.3 Energy concentration $EC(t_n)$ for varying times of grassland use

Feed values (energy concentration) of grasslands can vary strongly depending on the plant-composition and the time of use, e.g. energy concentrations of more than 6.0 MJ NEL/kg DM are achieved on intensively cultivated meadows only, e.g. on meadows with few plant species and an early cutting date (from the beginning until mid-May) (Elsässer and Oppermann 2003). Grassland rich in plant species can show energy concentrations from low to high of 4.3-6.0 MJ NEL/kg DM. Due to their elasticity of use meadows rich in plant species can show medium or high feed quality also at a late date of use, i.e. when the vegetation grows older the feed quality declines much less than on meadows with few plant species dominated by grass (see e.g. Elsässer and Oppermann 2003). Table 1 summarises the feed values of different types of grassland use and growths at various cutting dates in MJ NEL/kg DM according to the German Agricultural Society (DLG 1997).

Table 1: Feed values (energy concentration) of different types of grassland use at various cutting dates in MJ NEL/kg DM according to DLG (1997). The date of ear and panicle emergence (development stages of grass) can differ greatly according to the local conditions

	1^{st} growth MJ NEL/kg DM				2^{nd} growth MJ NEL/kg DM		
type of cultivation	start of ear/panicle	full ear/ panicle	start of flowering	Midterm/end of flowering	< 4 weeks	4-6 weeks	7-9 weeks
Green fodder							
2-3 uses, rich in grass	6,9	6,27	5,88	5,5	6,12	5,95	5,74
2-3 uses, rich in clover and herbs	7,03	6,5	6,18	5,71	6,87	6,25	5,97
	end of June/ start of July	middle/end of July	August	September			> 7 weeks
1-2 uses, late 1^{st} use, rich in grass	5,48	4,92	-	4,02			4,76
1-2 uses, late 1^{st} use, rich in clover and herbs	4,53						
Silage							
2-3 cuts, rich in grass	6.69	5.89	5.76	5.38	5.98	5.68	5.46
2-3 cuts, rich in clover and herbs	6.51	6.41	5.84	5.66	6.28	5.82	5.34
	end of June/ start of July	middle/end of July	August	September			> 7 weeks
1-2 cuts, late 1^{st} cut, rich in grass							3.55
1-2 cuts, late 1^{st} cut, rich in clover and herbs	4.35		3.77	2.5			4.81
Hay							
2-3 cuts, rich in grass		5.32	4.93	4.55	5.71	5.28	4.76
2-3 cuts, rich in clover and herbs		5.54	5.31	4.96	5.67	5.28	4.66
	end of June/ start of July	middle/ end of July	August	September			> 7 weeks
1-2 cuts, late 1^{st} cut, rich in grass	4.85	4.7	4.22				
1-2 cuts, late 1^{st} cut, rich in clover and herbs	5.14	5.07	4.44				5.38

For a specification of the grassland energy concentration at different times of the year the initial reference situation has to be defined. The reference situation is based on the assumption that the first cut for making silage is made around May 15^{th}. According to DLG (1997) the optimal date for a second cut is assumed to be six weeks later, since at this time the combination of dry matter yield and energy concentration reaches its maximum. As explained above, a later cutting date has a negative influence on the energy concentration of the grass for feeding. Since no detailed information on the composition of the fresh matter – e.g. if it is rich in grass or in clover and herbs – is available, the calculations can only lead to an average approximation of the real values. The feed values indicated in Table 1 are used to assess the losses in energy concentration during the course of the year. For example, according to DLG (1997) (cf. Table 1) the values of silage of the first cut in case of a 2-3-cut cultivation start at approximately 6.51 MJ NEL/kg DM and decline to a minimum value of 2.5 MJ NEL/kg DM in September. This is a relative decline of 62%.

We assume a linear decline of the energy concentration of the different grassland uses (cf. Fig. 2, a reference is e.g. Koch et al. 2003) as presented in equation 5. The energy concentration $EC(t_n)$ of a specific number of grassland use $n \in \{1,2,3\}$ (first, second or third use), type of grassland use u (silage, hay, green fodder intensive=>3 uses, green fodder extensive=1-2 uses), spatial variation defined by soil productivity g and altitude h equals the corresponding energy concentration EC in the reference situation with the reference value a_{ref} of energy concentration minus the decline $d_u^{g,h}$ in energy concentration per time delay Δt, whereas $\Delta t = t_{m/n} - t_{ref/n}$, i.e. the timing of grassland use t_n of grassland measure m minus the timing of grassland use t_n in the reference situation, ref.

$$EC_{n,u}(t_n) = EC_{a,n,u}^{g,h} - d_u^{g,h} \cdot \Delta t \qquad \text{(eq. 5).}$$

2.2.4 Digestibility $D(EC(t_n))$ of the grass

With lower energy concentration $EC_{n,u}(t_n)$ the digestibility $D(EC(t_n))$ of the harvested forage for the livestock and thus the fodder quality decrease (cf. 2.2.1). Therefore, the value of the harvested grass for the farmer further decreases with decreasing digestibility (eq. 3). We tested digestibility factors for different timings of grassland use and adapted them in a way that, in general, the total energy yield decreases with an increasing delay in grassland use.

It could also be argued that below a specific energy concentration threshold the quality of the grass is too low to be used for livestock at all. In this case a farmer would lose the total energy yield and his costs for implementing the measure would increase enormously. Whether a farmer is able to use grass with low quality depends on his type of business and livestock. In our analysis we do not consider specific types of farms but general conditions. We assume that, in general, a total loss of the yield does not occur.

2.2.5 Modifications of yield assessment for some types of grassland measures

As shown above, equation 3 gives the total yield of the farmer for shifting grassland use in time. Small modifications are necessary for the grassland measure types seasonal grazing, all-year grazing, mowing strips, and the combination of mowing and seasonal grazing.

Modification for seasonal and all-year grazing

While mowing and its effects are very well studied, grazing schemes are not. There is still a great need for research on the quantitative and qualitative changes in yield considering varying spatial conditions given by soil productivity g and altitude h and different timings t within a year (cf. Mährlein 1997).

For *rotational grazing* the yield calculations of equations 3-5 can be applied. Rotational grazing means that the animals are allowed to graze on the pasture for a quarter-month using the total possible energy yield of the area. It is assumed that the farmer adapts the number of grazing animals to the amount of feed available on the pasture.

For *other grazing schemes* it is possible to assess the effects on yield by comparing the reference grazing performance with the feed conversion by a reduced stocking rate (Mährlein 1993a, 1997 with example calculations) to get the grazing performance not used (equal to the energy yield loss). In more detail, the energy yield of other grazing, ${y_{othergraz}}^{g,h}(t)$, is calculated as the forage needed by livestock given for predefined stocking rates s (in livestock unit (LU)/ha) starting grazing at t and the amount of grazing days z (following Mährlein 1993a, see eq. 6). This approach also requires knowledge of the daily uptake rate r_j of livestock type j per LU/ha.

$$y_{othergraz}^{g,h}(t) = s(t) \cdot r_j \cdot z \qquad \text{(eq. 6).}$$

The difference of $y_{othergraz}^{g,h}(t)$ compared to the given reference energy yield y_{ref} shows the loss caused by the measure due to the change in stocking rate and amount of grazing days. If the grassland yield on the considered area is not sufficient for the uptake rate of the livestock with the chosen stocking rate and grazing time (i.e. the chosen stocking rate is too high), the measure is not permitted for this area.

For all-year grazing we assume an average stocking rate of 0.5 LU/ha as well as the possibility of grazing during 365 days.

Modification for a combination of mowing and seasonal grazing

Sometimes, grassland is mowed in spring to produce silage as forage for the winter season and afterwards the meadow is used for rotational or seasonal grazing. Thus, the energy yield is achieved by two different uses. For the combination of mowing and rotational grazing equations 3-5 are used to calculate the yield after the measure implementation. To calculate the yield for the grazing part for the combination of mowing and seasonal grazing, equation 6 is used. The energy yield gained by a combination of mowing and seasonal grazing is thus calculated by equation 7.

$$y^{g,h}(t) = DM^{g,h}(t_n) \cdot EC\ (t_n) \cdot D(EC(t_n)) + y_{othergraz}^{g,h}(t) \qquad \text{(eq. 7).}$$

The resulting total change in energy yield due to the implementation of a grassland measure m is then calculated by subtracting the total yield for the farmer after the implementation, $y(t_m)$ **(eq. 5-7)**, from the total energy yield of the reference situation y_{ref}.

$$\Delta y \ = y_{ref} - y(t) \qquad \text{(eq. 8, part of eq. 2).}$$

Modification in equation 2 for the measure mowing strips

Mowing strips have been proposed for the protection of some endangered birds like, e.g. the corncrake, *Crex crex*, and the black-tailed godwit, *Limosa limosa*, (Broyer 2003, Junker et al. 2007, LUA BB 2010, Tyler et al. 1998, personal communication Bellebaum 2008 concerning corncrake in the Lower Oder Valley). If this measure is implemented, strips are left unmown at the beginning of the grassland use. So there is no yield for this part of the field. The strips are finally mowed when the second or third cut is made or at the end of the year (aftermath). However, the energy concentration is low since the grass is overaged and of low digestibility. To what extent the farmer still can use this grass has to be decided for each single case. For reasons of simplification a complete loss of yield is assumed for the strips. The area o of the unmown strips is defined as a percentage of the total grassland area. Thus, the remaining area q of the grassland area equals $q = 100 - o/100$ (cf. eq. 9). $(y_{ref} - y_m)$ in eq. 2 is replaced by.

$$y_{strips}(t) = y_{ref} - q \cdot \sum_n DM_n^{g,h}(t_n) \cdot EC(t_n) \cdot D(EC(t_n)),\ n \in \{1,2,3\} \qquad \text{(eq. 9).}$$

3 Example of use – implementation of the systematic cost assessment approach in the software *DSS-Ecopay*

With the help of the developed approach the timing effect on the costs of grassland use can be considered systematically. We demonstrate the applicability and performance of our approach based on the example of grassland conservation in the German federal state of Saxony. To do so, we implemented our approach in the decision-support software *DSS-Ecopay* (Mewes et al. 2012). The purpose of *DSS-Ecopay* is to provide decision makers such as conservation managers and agricultural administrations with information on the ecological effectiveness and cost-effectiveness of agri-environment schemes in grasslands.

With our cost assessment approach we calculate spatially differentiated costs of possible grassland measures in *DSS-Ecopay*. *DSS-Ecopay* also contains an ecological model that assesses the ecological effects of these grassland measures on species and habitat types (Johst et al. subm.). *DSS-Ecopay* is available free of charge on the internet (www.inf.fu-berlin.de/DSS-Ecopay).

DSS-Ecopay consists of a database and software code. The database contains, in addition to some GIS data (e.g. land-use information on Saxony, information on soil productivity, altitude, etc.) and parameter information needed for the ecological model, the parameter information for the economic cost assessment (parameters defined within the approach (cf. chapter 2), e.g. for the change in dry matter yield with input values for Saxony) as well as the definition of the grassland measures (timing, frequency, stocking rates, fertiliser input).

In the context of this paper, we are interested in the costs of the defined grassland measures. We therefore use the cost assessment approach described in section 2 and combine it with the necessary data (sections 3.1), define a time scale for the systematic consideration of timing of grassland uses t_n (sections 3.2) and combine it with the agri-economic and land-use information for Saxony to calculate $DM_n^{g,h}(t_n)$, $EC(t_n)$, and $D(EC(t_n))$ (sections 3.3-3.5). This allows us to demonstrate the applicability of our approach, and in section 3.6 we show some results for selected mowing and grazing measures for Saxony.

3.1 Data sources for Saxony

We use data from the literature and a database[1] for the calculation of payments for agri-environment schemes provided by the Saxon State Office for the Environment, Agriculture and Geology, LfULG (Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie) (compare e.g. LfULG 2010). Table 2 gives an overview of the common grassland management methods in Saxony which are taken for the reference situations. In the case of mowing, the farmer uses the first cut for making silage, and the second and third cut for making hay. The average gross yield in decitonne fresh matter per hectare (dt FM/ha, 1 dt = 100 kg) for this land use amounts to 325-450 dt FM/ha. Typical cutting dates are mid-May, early July, and mid-August. If the grassland is used for grazing, in line with common practice it is assumed that the indicated stocking capacity leads to a complete consumption of the fresh forage available. For rotational grazing we take the same land-use dates as for mowing. For seasonal grazing, grazing takes place from April to October. In the combination mowing and grazing, the first cut for making silage is mid-May and the subsequent use for grazing starts at the beginning of July. In all reference situations farmers also apply nitrogen fertiliser. The calculation of extensive grassland measures (such as 1-2 cut mowing) is based on the datasets with half level of N-fertilisation and 2 uses from the database for Saxony (cf. Table 2 and footnote 1). In Saxony, costs of 0.0262 €/MJ NEL for concentrated feed are considered for the assessment of the energy yield difference via the purchase of concentrated feed. For example, a loss of 15,000 MJ NEL/ha compared to the reference situation leads to costs of 393 Euro.

Table 2: Relevant grassland production methods in Saxony with gross yields in dt FM/ha for yield level classes low and very high (adapted to LfULG 2010)

production method	Grassland use	gross yield [dt FM/ha] for yield level low and very high	
	Reference situation – intensive cultivation		
meadow	3-cut: 1^{st} cut wilted silage (40% of the yield), $2^{nd}+3^{rd}$ cut hay	325	450
pasture	grazing (stocking capacity 2.5 LU/ha)	360	500
combination of mowing & grazing	1^{st} cut wilted silage (30% of the yield), following/further use: grazing	350	485
	Basis of the calculation for extensive cultivation measures		
meadow	reduced N-fertiliser, 2 cuts: 1^{st} cut wilted silage (40% of the yield), 2^{nd} cut hay	225	325
pasture	reduced N-fertiliser, grazing (stocking capacity 1.5 LU/ha)	250	360
combination of mowing & grazing	reduced N-fertiliser, 1-cut wilted silage (35% of the yield), further use: grazing	240	350

[1] http://www.landwirtschaft.sachsen.de/bpsplan2007/asp/hauptgruppe.asp?id_hg=22&bez_hg=Gr%FCnland-%2DFutternutzung&inten=1&verw=1 (last accessed 4 July 2013)

Further general assumptions for the calculation of the yield (eq. 2a)

- To assess the effect of a complete N-fertilisation ban, we used data on energy yields without N-fertilisation from SMUL (2007). With the help of this information yields of a 2-cut mowing scheme with reduced N-fertilisation can be compared with those of a cultivation without N-fertilisation. It can roughly be deduced that cultivation without fertilisation causes a yield loss of 20% compared to cultivation with reduced N-fertilisation. A more detailed differentiation cannot be made since the data available is insufficient.
- The database for Saxony does not contain yields for 1-cut mowing schemes. We therefore take the first cut of the reference yield of the 2-cut mowing scheme with half N-fertilisation which is used as hay as a basis. The reference quality is adapted to hay corresponding to DLG (1997) (see Table 1).
- In contrast to meadow use, there is no data for rotational grazing indicating which percentage of the grassland yield is obtained by which use. We assume for two uses that each single use comprises approximately 50% of the total yield.
- For grassland production methods the database for Saxony specifies, among others, the gross yield of fresh matter (dt/ha), the net yield of dry matter (dt/ha) and the net energy yield in MJ ME/ha. MJ ME is converted to MJ NEL (cf. section 2.1). The benchmark of LfULG is a fixed conversion factor of 1.65 for fodder energy (MJ ME/1.65 = MJ NEL) (written communication LfULG 2010).
- One must also consider that a higher location above sea level leads to a shorter vegetation period and thus affects the vegetation growth (e.g. Buchgraber 2000). For Saxony, we differentiate between elevations below and above 500 m above sea level. For areas situated higher than 500 m above sea level the growing season and thus the growing of the grass starts two weeks later and ends two weeks earlier than on areas located on a lower level. This also impacts the timing of grassland use which starts later in the year at higher altitudes.
- Last, the gross yields per production method in the database for Saxony are divided into four yield levels (very high, high, medium and low). For a spatial differentiation of costs, we use GIS-data on the local soil productivity given by grassland values (ranging from 8-88, 8= low productivity, 88= very high productivity) on municipality level. We attribute the reference grassland yields for the four yield levels given in the Saxony database to the grassland values in the following way: yield level low=grassland value 34, yield level medium=grassland value 39, yield level high=grassland value 49, yield level very high=grassland value 59. The software interpolates the corresponding yields for all other grassland values.

Change in variable and labour costs (eq. 2b and 2c)

As for the yield the economic calculations are made in accordance with the existing data and calculations for agri-environment measures in Saxony. Thereby, the agri-economic cost assessment considers the following data from the Saxony planning and assessment database, which is available on the internet[2], and of LfULG (2010): costs of seeds, costs of fertilisation, pest management costs (treatment with herbicide), variable costs of machines, hired labour time, machine rental, costs of making silage, pasture costs such as fences, and the labour costs of the farmer himself.

3.2 Systematic consideration of timing of grassland uses t_n

Our systematic grassland approach considers different dates for grassland uses making up different grassland measures. In principle, this could be done by daily time steps (e.g. mowing on the 1st of June, 2nd of June and so on). However, such a daily time scale would not only result in an enormous number of possible timings but would also need very specific and detailed data, which are not available. We therefore divide the year into 48 consecutively numbered quarter-months (QM) whereby one month contains four quarter months, e.g. the first quarter of January = QM 1, second quarter of January = QM 2. Compared to weeks, the advantage of using quarter-months is that each month has a fixed number of four quarter-months. This definition of the time scale facilitates not only the systematic variation in the timing of grassland use but also provides some flexibility for the farmers in the timing of grassland use within a quarter-month. This seems to be more realistic.

We assume that the first possible grassland use is in QM 19 (mid-May) except for seasonal grazing where the potential grazing period starts in QM 13 (beginning of April). The last quarter-month for a grassland use is QM 40 (end of October). In between these dates any QM can be chosen for the first use. Several intervals between the first and the second use (0, 4, 6, 8 or 10 QM) as well as the second and the third use are taken into account. Because the focus of this paper is on the implementation of time effects of grassland use on costs, we will not present the definition of the grassland measures in detail (parameters other than different timings and frequency are: livestock density, use of N-fertiliser, type of livestock). Altogether, 969 different combinations are considered (cf. Table 3).

Reference situation

For mowing, grassland use with the first cut taking place in the 19th QM (mid-May), the second cut six QMs later (at the end of June), and the third cut six QMs after that (mid-August) represents the average conventional 3-cut reference situation as the usual profit-maximising use in Saxony. The same timing holds for the different uses of rotational grazing and the combination of mowing and rotational grazing.

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[2] The cost data of silage and hay production can be found here: http://www.landwirtschaft.sachsen.de/landwirtschaft/254.htm (last accessed 4 July 2013), >konventionelle Wirtschaftsweise >Produktionsrichtungen >Futterbau >Grünland-Futternutzung, >Wiese >Verfahren >Verfahren detailliert anzeigen >berechnete Maschinenkosten.

Table 3: Overview of the different timings of grassland use differentiated according to kind of grassland use (QM=quarter-month, year divided into 48 consecutively numbered QMs, e.g. QM 19 = third quarter of May)

Kind of grassland use	Timing of grassland use
Mowing	Time of first cut (QM 19-30) Interval from first to second cut (0,4,6,8,10 QM) Interval from second to third cut (0,4,6,8,10 QM); last cut QM 40
	Time of first cut (QM 19-22) Interval from first to second cut also 12, 14, 16 QM
	Only one cut after QM 30, time (QM 31-40)
Mowing strips	Time of first cut (QM 19/20) Interval from first to second cut (0,4,6,8,10 QM) Interval from second to third cut (0,4,6,8,10 QM); last cut QM 40
Grazing	All-year grazing
Seasonal grazing	Start of grazing period (QM 13,15,17,...,29)
Rotational grazing	First time of grazing (QM 19-30) Interval from first to second grazing (0,4,6,8,10 QM) Interval from second to third grazing (0,4,6,8,10 QM); last use QM 40
	Time of grazing (QM 19-22) Interval from first to second grazing also 12, 14, 16 QM
	Only one grazing after QM 30, time (QM 31-40)
Combination of mowing and seasonal grazing	Time of cut (QM 19-28) Interval from cut to grazing (6 QM)
Combination of mowing and rotational grazing	Time of cut (QM 19-30) Interval from cut to grazing (4,6,8,10 QM) Interval from first to second grazing (0,4,6,8,10 QM); last use QM 40
	Time of cut (QM 19-22) Interval from cut to grazing also 12, 14, 16 QM

3.3 Dry matter yield $DM_n^{g,h}(t_n)$ *for Saxony*

Table 4 shows the estimated change i of dry matter yield in % for different timings of up to three grassland uses without any further change in management for Saxony. In the reference situation the first use is in quarter-month 19 and the interval from the first to the second use and from the second to the third use is six quarter-months. If the second or third use is earlier than in the reference situation the dry matter yield is lower, whereas for a later use a growth in dry matter yield can be expected. As growth depends strongly on the local conditions and the production method used, these values are approximations.

Table 4: Estimated change i of dry matter yield in % for different timings of up to three grassland uses without any further change in management. The change is (pre)defined for the uneven quarter-months (QMs). The even quarter-months are calculated by interpolation. The reference situation (general grassland use) marked with grey shading is defined by a first use in QM 19 followed by a second and third use 6 QM after the previous use.

quarter-month (QM) of first use	change *i* of dry matter yield in %
19	0 (reference)
21	48
23	90
25	124
27	150
29	171
31	188
33	201
35	210
37	213
39	215
2nd use: interval to previous use in QM	4/5 of change *i* of 1st use
4	-20
6	0 (reference)
8	38
10	72
12	99
14	120
16	137
3rd use: interval previous use in QM	3/5 of change *i* of 1st use
4	-20
6	0 (reference)
8	29
10	54

3.4 Energy concentration $EC(t_n)$ for Saxony

Using data from Saxony as reference (start) values a_{ref} of energy concentration in the reference situation the following linear functions for four different types of grassland use according to equation 5 and Table 5 are derived:

$$EC_{silage}(t_n) = 652.7 - 27 \cdot \Delta t$$

$$EC_{hay}(t_n) = 555.1 - 11 \cdot \Delta t$$

$$EC_{greenInt}(t_n) = 689.3 - 22 \cdot \Delta t$$

$$EC_{greenExt}(t_n) = 603.9 - 11 \cdot \Delta t$$

Table 5 shows the declines in energy concentration in MJ NEL/dt and percentage according to equation 5 for varying times and different kinds of grassland use. The numbers in Table 5 are approximations, since the development of the yield also strongly depends on local conditions and the details of cultivation.

Table 5: Assumed linear reduction in energy concentration in MJ NEL/dt and percent for the different kinds and varying times of grassland use for the uneven quarter-months (QM). Second and third use in terms of interval to previous use in QMs. Last use QM 40. (Start values a_{ref} given by data of Saxony).

	Mowing				Grazing			
Start value	1st use of 2 or 3 cuts		1 cut		3 uses		2 uses or 1 use	
a_{ref} MJ NEL/dt	653 – silage		555 – hay		689 – green fodder		604 – green fodder	
1st use in QM			MJ NEL and reduction in quality in %					
19	653	0.0	555	0.0	689	0.0	604	0.0
21	599	8.3	533	4.0	645	6.4	582	3.6
23	545	16.5	511	7.9	601	12.8	560	7.3
25	491	24.8	489	11.9	557	19.1	538	10.9
27	437	33.1	467	15.9	513	25.5	516	14.6
29	383	41.4	445	19.8	469	31.9	494	18.2
31	329	49.6	423	23.8	425	38.3	472	21.9
33	275	57.9	401	27.7	381	44.7	450	25.5
35	221	66.2	379	31.7	337	51.1	428	29.1
37	no entry (2nd/3rd use)		357	35.7	no entry (2nd/3rd use)		406	32.8
39			335	39.6			384	36.4
Start value MJ NEL/dt	555 – hay				604 – green fodder			
2nd use: interval in QMs			MJ NEL and reduction in quality in %					
4	577	-4.0			626	-3.6		
6	555	0.0			604	0.0		
8	533	4.0			582	3.6		
10	511	7.9			560	7.3		
12	489	11.9			538	10.9		
14	467	15.9			516	14.6		
16	445	19.8			494	18.2		
3rd use: interval in QMs			MJ NEL and reduction in quality in %					
4	577	-4.0			626	-3.6		
6	555	0.0			604	0.0		
8	533	4.0			582	3.6		
10	511	7.9			560	7.3		

3.5 Digestibility $D(EC(t_n))$ for Saxony

Table 6 shows the estimated influence of the digestibility onto the different types of grass used: silage, hay and green fodder in Saxony. As described in section 2.2.4, we tested digestibility factors and adapted them in a way that the total energy yield in general decreases with an increasing delay in the grassland use.

Table 6: Estimated influence of digestibility $D(EC(t_n))$ on the different types of grass used: silage, hay and green fodder in Saxony in per cent/100 depending on the reference energy concentration EC

	Digestibility $D(EC(t_n))$ of			
energy concentration EC in MJ NEL/dt	silage	hay	green fodder extensive (1 or 2 uses)	green fodder intensive (3 uses)
670	1.2			1
660	1.1			0.83
650	1			0.78
640	0.92			0.71
630	0.88			0.68
620	0.84	1.2	1.2	0.64
610	0.8	1.2	1.15	0.63
600	0.76	1.2	1	0.59
590	0.72	1.2	0.82	0.58
580	0.68	1.2	0.7	0.57
570	0.64	1.15	0.62	0.56
560	0.6	1.08	0.56	0.55
550	0.56	1	0.56	0.53
540	0.55	0.84	0.52	0.52
530	0.54	0.72	0.49	0.51
520	0.53	0.62	0.47	0.5
510	0.52	0.56	0.45	0.5
500	0.51	0.54	0.44	0.5
490	0.5	0.51	0.43	0.5
480	0.5	0.48	0.42	0.5
470	0.5	0.46	0.41	0.5
460	0.5	0.44	0.4	0.5
450	0.5	0.43	0.4	0.5
440	0.5	0.42	0.4	0.5
430	0.5	0.41	0.4	0.5
420	0.5	0.4	0.4	0.5
410	0.5	0.4	0.4	0.5

3.6 Results and discussion

The systematic approach can assess the opportunity costs for farmers for hundreds of grassland measures (cf. Table 3). We present two examples: one example for mowing regimes (the results for 1-cut mowing) and one for grazing regimes (results for seasonal grazing measures).

Opportunity costs for 1-cut mowing measures

The 1-cut mowing measures allow a farmer to cut his grassland only once a year instead of three times. Also, two types of fertilisation can be distinguished: no N-fertiliser or a reduced amount of N-fertiliser according to the data for Saxony. Fig. 3 shows the minimal, maximal and mean opportunity costs in €/ha of farmers for varying times of the cut for both fertiliser options. The variation in costs is high, e.g. for QM 19 175-580 €/ha (150-535 €/ha), which is caused by the variation in soil productivity. In general, measures on grassland with low soil productivity (=grassland value) are much cheaper than measures on grassland with high soil productivity. It must be considered that for 1-cut mowing measures the spatial variability (y-axis) has a much higher effect on the costs than the temporal one (x-axis). This is because the yield loss from 3-cut to 1-cut and no allowance of N-fertiliser is already very high without an additional change of the 1-cut-time (around 75%). The cost savings in variable costs can only partially outweigh this loss.

Mean opportunity costs for 1-cut mowing measures with reduced N-fertiliser vary from about 300 to 365 €/ha, for measures with no N-fertiliser from about 336 to 390 €/ha. Starting from a cost difference of around 39 €/ha in QM 19 to around 25 €/ha in QM 40, costs for 1-cut mowing measures with reduced N-fertiliser are lower than measures with no N-fertiliser (see section 3.1 for yield difference). Thus, the cost savings of no N-fertiliser cannot outweigh the yield loss.

Finally, one can see that minimal costs in particular decrease visibly after QM 20. This can be explained as follows: In QM 19-20 only lowland grassland is taken into account, because the vegetation period starts two weeks later in the mountainous area. This implies that starting with QM 21 new grassland areas are included whereas the soil productivity in the mountainous area is in general lower than in the lowland area. The slight decrease in costs from QM 19 to QM 20 can be explained by an elasticity of grassland use in extensive grassland (see section 2.2.3).

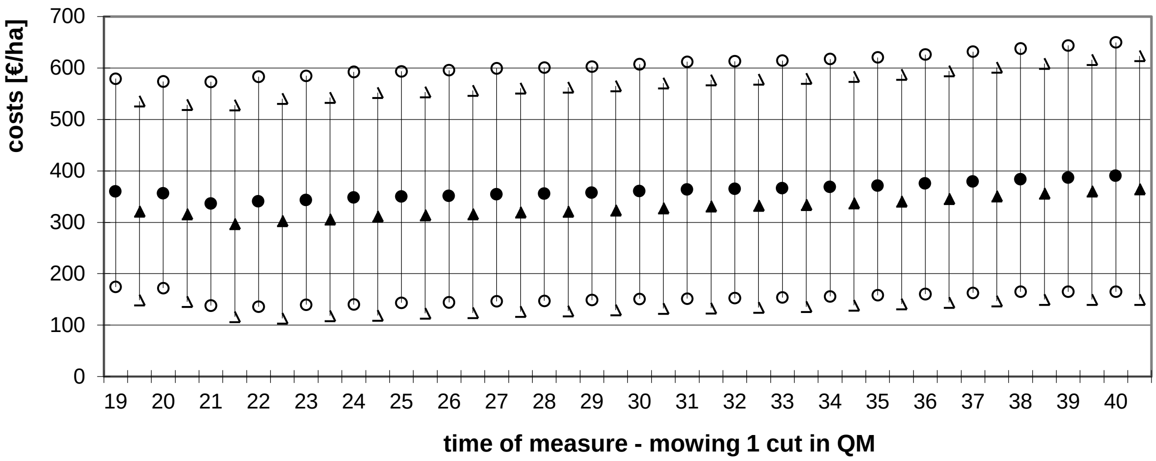

Fig. 3: Minimal, maximal and mean opportunity costs $c^{g,h}(t)$ in €/ha calculated with the systematic approach (eq. 3) plotted against the spatial conditions represented by soil productivity g and altitude h and the timing of grassland use t_n for 1-cut mowing measures. The varying timings of grassland use t_n are given in QMs (quarter-months), circle: no N-fertiliser is allowed, triangle: reduced N-fertiliser. The varying spatial conditions generate spatial variability reflected by the minimum and maximum values at the given timing t_n

Opportunity costs for seasonal grazing measures

Seasonal grazing measures allow grazing of livestock only with some defined stocking rate and grazing period compared to the reference situation. A medium daily uptake rate of 80 MJ NEL/LU is assumed (eq. 6). Fig. 4 shows the minimal, maximal and mean opportunity costs in €/ha of farmers for varying starting points of the grazing period and stocking rates. Clearly, an early start of the grazing period is not at all (i.d. independent of the productivity of the soil) possible with a stocking rate of 3 LU/ha (QM 13-19) due to insufficient fodder (cf. section 2.2.5). Grassland areas which are productive enough to carry enough food are only found after QM 21.

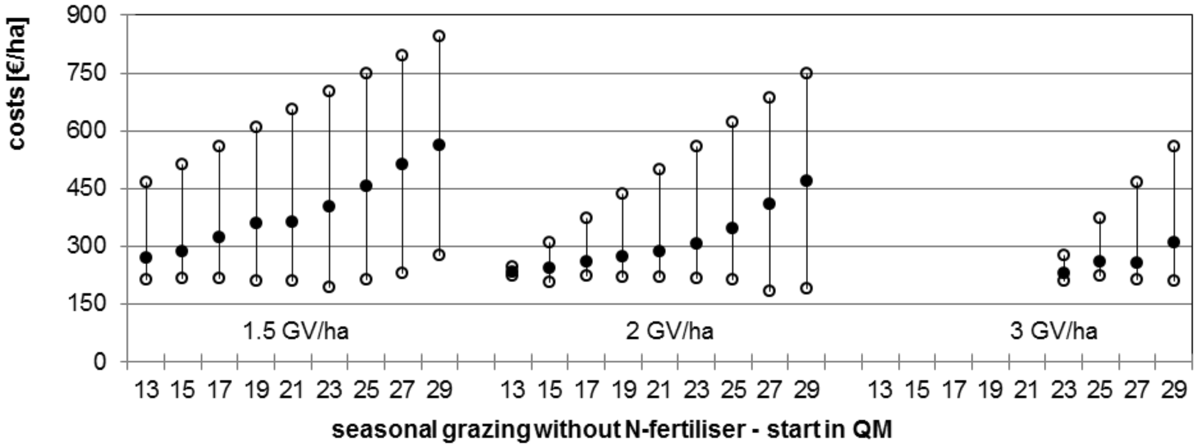

Fig. 4: Minimal, maximal and mean opportunity costs $c^{g,h}(t)$ in €/ha calculated with the systematic approach (eq. 3) plotted against the spatial conditions represented by soil productivity g and altitude h and the timing of grassland use t_n for seasonal grazing measures and different stocking rates. The varying timings of grassland use t_n are given in QMs (quarter-months). The varying spatial conditions generate spatial variability reflected by the minimum and maximum values at given timing t_n

For stocking rates with 1.5 or 2 LU/ha some grassland areas are already productive enough at QM 13. But here too the opportunity costs are influenced by the respective amount of grassland with sufficient productivity for the considered number of livestock by seasonal grazing measures. The cost span between minimal and maximal opportunity costs increases with a later start of grazing because the time span for the livestock to graze the grass of the high productive grassland shortens. This means that an increasing amount of the grassland yield of these areas is not used any more with a later start of the grazing.

The slight dips in minimal and mean costs can be explained by the changing amount of grassland areas which bear sufficient food for the given livestock density. For example mean opportunity costs decrease in QM 21 for 1.5 LU/ha and then increase again. Grassland areas with low productivity do not bear sufficient food for the amount of livestock before QM 21 but only starting from QM 21. Opportunity costs decrease because more grassland areas with low productivity and thus lower opportunity costs are taken in to account. After QM 23 all grassland areas in Saxony bear sufficient food for 1.5 LU/ha. Thus, starting the grazing period later will always lead to an increase in opportunity costs. Finally, as one would expect, farmers` opportunity costs are lower for higher stocking rates because more of the yield can be skimmed.

4 Conclusions

The success of existing agri-environment schemes in terms of conservation is mixed at best and has to be improved. Therefore, modelling procedures and decision support tools are required which can be used to design agri-environment schemes in a way that maximises the conservation output with the given financial resources. To design agri-environment schemes on a large spatial scale and to take into account many different land-use measures, cost assessment approaches are needed which are able to spatially differentiate costs of a high number of alternative measures. Currently, agri-environment schemes for grassland in general consider only a small number of conservation measures with fixed dates and payment based on average opportunity costs.

We present a cost assessment approach for grassland use which is able to systematically assess farmers` opportunity costs for mowing, grazing and a combination of both in a spatially and temporally differentiated manner, i.e. depending not only where a measure is carried out in the landscape but also when it is carried out. Moreover, our approach is straightforward and computer time-saving enough to be suitable for implementation into optimisation procedures at large spatial scales. We demonstrated the practicability of our approach by implementing it in the decision support software *DSS-Ecopay* using the example of grassland species and habitats conservation in the German federal state of Saxony.

The accuracy of the resulting opportunity costs strongly depends on the quality of the data for spatial conditions and on the details of cultivation. When interpreting the results it also has to be taken into account that the use of concentrated feed is limited for nutritional reasons. Furthermore, the possibilities of using cut from extensively cultivated grassland for husbandry are limited, too, depending on the quality of the cut (see e.g. Nitsche and Nitsche 1994). But since conservation managers face the same problems when designing grassland schemes, our approach can help to make the process systematic and more transparent. One great advantage of the use of our approach in *DSS-Ecopay* is its flexibility because changes in the underlying database are easy, when new/better data is available for a comparison of different datasets. Further research is needed to improve the results of the approach concerning growth rate functions and functions of the change in energy concentration of grassland.

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