Mathematical programming models for agri-environmental policy analysis: A case study from the White Carpathians

Modely matematického programování pro analýzu agroenvironmentálních politik: Případová studie z Bílých Karpat

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Abstract: BEGRAB_PRO.1 – a mathematical programming model for BEef and GRAssland Biodiversity PRoduction Optimisation – elaborated for analysis of organic suckler cow farms in the Protected Landscape Area White Carpathians, the Czech Republic, is presented and applied to the analysis of jointness between several environmental goods. In this way, the paper complements recent studies on jointness between commodities and non-commodities. If these goods are joint in production, agri-environmental payments must be carefully designed because they do not influence only production of the environmental good they are intended for but also the production of other environmental goods. If jointness is negative, any increase in the payment for an environmental good leads to a decrease in production of other environmental goods.

Key words: mathematical programming, jointness, agricultural policy, biodiversity, suckler cows

Abstrakt: V článku představujeme BEGRAB_PRO.1 – model matematického programování pro optimalizaci produkce skotu a biodiverzity – vypracovaný pro analýzu ekologických farem s chovem krav bez tržní produkce mléka v Chráněné krajinné oblasti Bílé Karpaty. Model je ilustrativně aplikován na analýzu produkční vazby mezi několika environmentálními statky. Tímto způsobem článek doplňuje nedávno publikované studie věnované analýze produkčních vazeb mezi zemědělskými výrobky a environmentálními statky. Na základě obdržených výsledků tvrdíme, že, pokud existuje produkční vazba mezi jednotlivými environmentálními statky, platby za agroenvironmentální opatření musí být precizně stanoveny, protože neovlivňují pouze produkci environmentálního statku, pro který jsou určeny, ale také všech ostatních environmentálních statků napojených produkční vazbou. Pokud je tato vazba negativní, zvýšení platby za jeden environmentální statek povede ke snížení produkce ostatních environmentálních statků.

Klíčová slova: matematické programování, produkční vazba, zemědělská politika, biodiverzita, krávy bez tržní produkce mléka

The European model of multifunctional agriculture recognises the value of other agricultural outputs than food and fibre. The Czech Administration adopted this model and is translating it progressively into the national agricultural policy. In this paper, we present BEGRAB_PRO.1 – a mathematical programming model for BEef and GRAssland Biodiversity PRoduction Optimisation – elaborated for the analysis of organic suckler cow farms in the White Carpathians PLA (Protected Landscape Area), the Czech Republic. This model describes the suckler cow farm production system and enables to account not only for beef but also for biodiversity production. Biodiversity production is in the model depicted by a system of technical constraints which represent restrictions and tasks to be respected in order to produce the particular environmental goods. The number of hectares managed in compliance with these prescriptions is used as a benchmark for the quantity of biodiversity produced. Prescriptions from the current agri-environmental measures aiming directly at biodiversity production are applied with the hypothesis that they were properly designed and thus their respect increases the quantity of biodiversity.

The ability of BEGRAB_PRO.1 to help the policy design aiming at promotion of multifunctional agriculture is illustrated by focusing on jointness – one of the two basic characteristics of multifunctionality according to the OECD (2001). Recently, empirical studies appeared on the existence and type of jointness in production of agricultural commodities and non-commodities (Peerlings and Polman 2004 or Havlík et al. 2004). These studies focused on jointness between commodities and non-commodities. The present paper complements the research in this area by adding an analysis of jointness among several non-commodities. For various reasons, governments may desire that a farmer produces more than one environmental good at his farm, e.g. it is preferable that a French farmer involved in a fertilisation control programme does not abandon the maintenance of his hedges. It will be demonstrated that in this case, taking into account jointness among several environmental goods improves understanding of jointness between commodities and non-commodities and is essential for the design of cost efficient agri-environmental policies.

The Czech agri-environmental programme adopted after the EU accession in 2004 provides an excellent opportunity to illustrate our statements. Its instrument, designed directly for grassland biodiversity promotion, is the "Sound Grassland Management" programme. The measures involved in this programme distinguish between pastures and meadows, and it is forbidden to graze grassland put under the meadow measures. The agreements are signed for 5 years and the type of grassland may not be changed from pasture to meadow or *vice versa* during this period. This encourages the development of different plant covers according to the type of the subscribed agreement. The expected outcomes of the programme are thus two environmental goods which can be called "pasture biodiversity" and "meadow biodiversity". The overall biodiversity on the farm level increases if both types are produced. Therefore, it is desirable that both pasture and meadow agreements be subscribed.

MODEL PRESENTATION

White Carpathians PLA is a mountainous area on the border between the Czech and the Slovak Republic. White Carpathians meadows belong to the most species-rich plant associations in Europe (about 70 species of vascular plants per1 m^2) and their importance is given by the total acreage of these meadows, too. Their vegetation is characterised by a huge mosaic of meadow, bordering and forest plant associations and by a rich occurrence of both xerophile and humid species. (Pražan et al. 2002) These meadows are mainly utilised for suckler cow and sheep rearing. The White Carpathians PLA is as a formally designated protected area concerned by special measures involved in the new agri-environmental programme.

BEGRAB_PRO.1 was designed on the basis of interviews on organic farms in the White Carpathians. In 2003, 28 organic farms covering 8 943 ha were interviewed. According to personal communication from IS Kopanice[1], the total number of organic farms in the White Carpathians amounted to 46 and they cultivated 14 668 ha. The analysed sample represented thus 61% of the total in terms of the number of farms as well as in the area covered. Concerning grassland[2], which is of major interest for this study, there are in total 14 579 ha in the White Carpathians PLA, and the interviews covered 5 766 ha of this grassland, 40%.[3]

Model structure

BEGRAB_PRO.1 is a linear annual deterministic farm level mathematical programming model of the well known structure

Maximise

$$GM = \sum_j p_j x_j - \sum_j w_j x_j$$

subject to

$$\sum_j a_{ij} x_j \le b_i \qquad \forall i$$

$$x_j \ge 0 \qquad \forall j$$

where GM is the total gross margin, p_j is the revenue from activity j, x_j is the level of activity j and w_j is the direct cost of activity j. a_{ij} is the input requirement coefficient of activity j for input i, b_i is the quantity of input i at hand. The model is composed of 238 blocks

[1] IS Kopanice (Informační středisko pro rozvoj Moravských Kopanic) advices organic farmers in the region. The authors are grateful to Milan Drgáč and Renata Vaculíková whose help in organising the field research was indispensable for its successful accomplishment.

[2] If not stated otherwise, by "grassland" is meant exclusively the permanent grassland.

[3] The research was partially funded by the grant of the Ministry of Environment VaV 620/11/03.

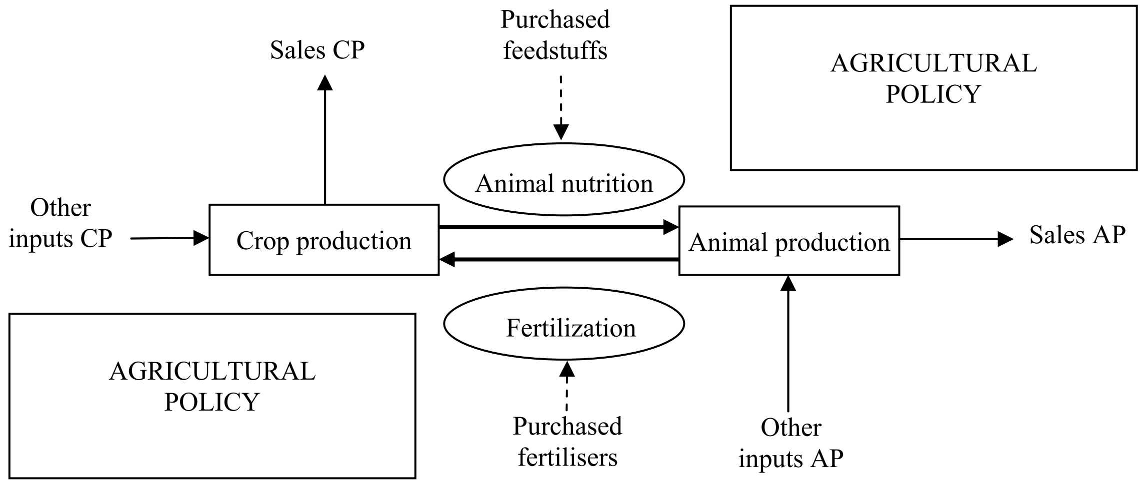

Figure 1. Suckler cow farming system

of equations (25 675 single equations) and 116 blocks of variables (64 020 single continuous variables and 26 binary variables). The model is written in GAMS and solved using the CPLEX solver. Let us present it here in a literary form.

The farming system represented in BEGRAB_PRO.1 is schematically depicted in Figure 1. There are two subsystems: crop production and animal production. These subsystems are linked to each other through the animal nutrition module, which strives to connect nutritional requirements of animals with the produced feedstuffs, and through fertilisation, which relates fertiliser requirements of the particular crops with manure production. The system is open and so there are both purchases of inputs and sales of outputs. A specificity of the suckler cow organic farm system is that internal linkages are fortified at the expense of linkages to exterior. The system performance is to an important extent determined by the agricultural policy. In what follows the particular system elements are presented as they are formulated in the model.

Animal production

The modelled farm is specialized in suckler cow production. In order to ensure a sufficient flexibility of the model, 33 animal activities were introduced differentiating the animals according to their sex, age, breeding intensity and other aspects. The basis of the herd is constituted by middle sized cows weighing 600 kg. Cows calve by 15th March. According to the results obtained by our research, the number of weaned calves per 1 cow was set at 0.90. Calves are weaned at the age of 7 months, by 15th October. The restocking rate was set at 15%. Cows with a dead calf are culled by 30th April, before the beginning of the pasture season; remaining culled cows are sold after weaning, by 15th October. Replacement heifers come exclusively from own breeding.

It is supposed that one half of the weaned calves are females and another half males. A single breeding strategy is considered for females before weaning. After weaning, the farmer can decide how many heifers to sell and how to breed the remaining ones. Two breeding strategies are considered: 1) standard – this breeding strategy leads to young cows calving for the first time at 24 months, 2) extensive – resulting in young cows calving at 36 months. During the breeding, farmer can sell the supplementary heifers at 9 or 12 months. This results in 5 sale categories of heifers. All animal sale categories are described in Table A1 in the Annexe.

Concerning males, the farmer decides about their breeding strategy for the first time already at the age of 3 months. The breeding before weaning is pasture-based for both strategies but the daily gains and thus nutritional requirements differ. After weaning, males can be sold or held for further feeding. Further feeding can be pursued according to three different intensities and while the average daily gains are not dependent on the preceding pasture breeding intensity, the weights are, and thus the animals must be differentiated also with respect to the preceding pasture breeding intensity. After leaving the pasture, by 31th October, bulls are kept in the barn till not sold. In all, 15 sale categories are included for bulls.

Crop production

Crop production on the analysed farms was grassland based. Only 10% of land involved in the research was constituted by arable land. Specialisation in forage crop production was nearly complete. The average farm size was 319 ha. The model represents a farm cultivating 300 ha constituted by 261 ha of grassland and 39 ha of arable land. (This proportion was the average for farms having at least some arable land.) The model can choose to convert the available arable land into grassland but the inverse is not allowed.

Each hectare of grassland can be cultivated according to one of the 25 basic management strategies. First distinction is made between fertilised grasslands (100 kg of nitrogen/ha/year) and non-fertilised grasslands. Management is further differentiated according to harvesting strategies. Grassland is cut once or twice a year and it is or is not grazed afterwards, or it is used exclusively as a pasture. The forage is conserved as hay or silage. Yields are characterized by three parameters: dry matter yield, energy and gross protein contents. The overall dry matter yield was differentiated according to the grassland type (meadows x pastures), fertilisation and the date of the first cut. The energy and gross protein contents were similarly differentiated taking into account the evolution of these parameters during the year. The numerical parameters were estimated using data from Buchgraber et al. (1998), Hejduk (2000) and Straka (1999). 16 basic management strategies are described in Table A2 in the Annexe (management strategies differing from those presented only by the fact that there is no grazing of hay meadows are omitted in the Table). The basic management strategies are further differentiated in order to distinguish the grassland subscribed under the particular agri-environmental agreements. Thus in total 54 grassland activities are depicted in the model.

Arable land management is not directly linked with the grassland biodiversity production and is in the model represented only schematically. Research results indicate that more than one half of the arable land was cultivated with cereals, their most important representatives were winter wheat and oats, another third of the arable land was cultivated with green fodder, mainly clover-grass mixtures. Only these three crops are considered in the model. Fertilisation corresponds to the average encountered level (67 kg nitrogen per ha/year). Each cereal represents a single production activity with yields determined on the basis of the collected data. Clover-grass mixtures are represented by 6 different activities differentiated with respect to harvesting strategies. Clover-grass dry matter yields and energy and gross protein parameters are calculated as for the grassland production. Rotation constraints determine that clover grass mixtures must be preceded by oats, and that cereals should not remain on the same field for more than two successive years, which is one of the constraints imposed on organic farms by the legislation.

Animal nutrition

Available feedstuffs can be divided into four groups: produced grassland forage, produced arable land forage, purchased forage and milk. Concerning produced grassland forage, the three major types – pasture, hay and silage – are further differentiated according to the harvesting period and grassland fertilisation in order to express qualitative differences among the various options. In total 20 different types of produced grassland forage are represented. For the arable land forage, two subgroups can be distinguished: clover-grass mixtures and cereals. Clover grass forage is differentiated in a similar way as the grassland forage, 7 types are distinguished. Only 4 types of forage can be obtained from cereals: wheat and oats grain and straw. Surplus grain can be sold. Straw and grain can be also purchased but no other purchases are available. The last feedstuff accounted for is milk. Milk is available for each calf in the quantity corresponding to an average daily yield of 8 kg per cow respecting the lactation curve. In total, 34 feedstuffs are represented.

Animal feed requirements can be expressed in the programming model in two different ways. The first one, adopted for example by Veysset et al. (2005), consists in the calculation of the daily rations according to the nutritional needs of animals outside the model and in introducing them afterwards into the model. The second approach consists in calculating the daily rations directly in the model. We implement the second approach. Nutritional requirements are controlled by means of three parameters: dry matter, energy and gross protein. These parameters were retained also by Rawlins and Bernardo (1991) and with some adjustments by Meek and Kilpatrick (1991) and others. The year is divided into 6 periods: 2 winter periods and 4 summer periods. (The four summer periods correspond to the pasture season, which lasts from April 1 to October 31.) Nutritional requirements for each animal and each day were determined after the standards by Petrikovič and Sommer (2001). Nutritional requirements are controlled mainly by the minima and maxima on the dry matter, energy and protein uptake, and by the minima and maxima on energy concentration.

The basic feeding module is complemented by legal restrictions imposed on organic farms. These restrictions determine the acceptable percentage of conventional feedstuffs in daily (25%) and yearly (10%) rations for each animal (we consider that the purchased forage comes from conventional farms), and the minimal percentage of the roughage in daily rations (60%).

Fertilisation

No fertiliser purchases are allowed and thus the needs and production of fertilisers constitute a direct linkage between the animal and crop production. Two types of fertilisers are produced by animals in the barn: manure and stale. Each field and grassland management strategy is parameterised by nitrogen requirements. The model controls that nitrogen requirements do not exceed the nitrogen production.

Agricultural policy

Agricultural policies can be considered as a frame of the farming system because the numerous prescriptions conditioning attribution of one or another payment determine to a large extent farmer's behaviour. Due to agricultural policy changes following the Czech Republic EU accession in May 2004, two distinct policy frameworks are to be depicted in the model: the policy framework of year 2002, the year for which the data was collected and which is to be used for the calibration and validation of the model, and the 2004 agricultural policy, the one suitable for the up to date analysis. As the application presented in this paper concerns the 2004 policies, we will focus on this part of the model here.

The following non agri-environmental policies are considered: SAPS (Single Area Payment Scheme), LFA (Less Favoured Areas) payment and TOP UPs for the arable land, suckler cows and cattle. If eligibility for a payment is conditioned by respect of some restrictions, the pertinent restrictions are depicted in the model and it is decided during the optimisation whether to follow the restrictions and to receive the payment, or to ignore them and give up the payment. Such eligibility constraints are modelled using binary variables.

Two agri-environmental programmes are accounted for: "organic farming" and "sound grassland management". As the model is supposed to represent an organic farm, organic farming prescriptions are exogenously imposed. These prescriptions concern basically fertilisation and animal feeding as mentioned above but also the stocking density. The "Sound Grassland Management" (SGM) programme constitutes the basis for biodiversity production and thus represents an essential part of the model.

The SGM is a whole farm programme. There are two general prescriptions conditioning access to this programme: minimum stocking density of 0.2 livestock units (LU) per ha of grassland and maximum average arable land fertilisation of 170 kg of nitrogen/ha per year. More specific prescriptions are then formulated in 6 pre-defined agreements. As it is a whole farm programme, all the permanent grassland should be subscribed under one or another of these agreements. The agreements are divided into two groups, the first one concerns meadows (meadows are defined for the SGM as exclusively mowed grassland with prohibition of pasture) and the second one concerns pastures (pastures can be mowed but must be also grazed at least once a year). Each group contains one general agreement, which can be subscribed by all farms willing to comply with the prescriptions, and supplementary agreements which can be subscribed only by farms in the formally designated protected areas like the White Carpathians PLA.

In total, four "Meadow SGM" agreements are proposed. The general one limits the nitrogen fertilisation to the average of 40 kg/ha/year, it demands that meadows are cut at least twice a year, and imposes the first cut before July 15. The first supplementary agreement demands, besides the basic conditions, that fertilisation is completely excluded. The second supplementary agreement retains the zero fertilisation prescription and adds postponing of the first cut after July 15. These three agreements are depicted in the model. The third supplementary agreement demands not mowing of strips of 6 to 12 meters large for the first cut and mowing them next in the second cut. We suppose that the main cost induced by adopting this management is linked to organisational difficulties of harvesting but we are not able to estimate it in an appropriate way, therefore this agreement is not incorporated in the model.

Concerning the "Pasture SGM", only two agreements are proposed. Prescriptions involved in these agreements contain both restrictions and additional tasks. Restrictions contain mainly nitrogen fertilisation and the instantaneous stocking density limits, obligatory mowing of refusals after each pasture cycle represents an additional task. The general agreement limits the nitrogen fertilisation to the average maximum of 40 kg/ha/year, and the instantaneous stocking density is to be between 0.5 LU/ha and 1.0 LU/ha during the pasture season. The supplementary agreement excludes nitrogen application and limits the instantaneous stocking density to 0.4–0.8 LU/ha. Both agreements are precisely modelled. The control of the instantaneous stocking density, which is always a delicate task, is carried out by indexing the pasture consumed in each period with respect to the management agreement applied on the grassland it comes from and with respect to the animal which ration the pasture enters in. This makes it possible to literally track each animal and to find out on which piece of grassland it was during which day.

Objective function

As stated above, the model objective is maximisation of the gross margin which is defined as the difference between the total income

$$\text{TIN} = \sum_j p_j x_j$$

and the total direct costs

$$\text{TDC} = \sum_j w_j x_j$$

These items can be decomposed in the following way

$$TIN = SA + SC + SAP + SAEP$$

$$TDC = DCAP + DCCP$$

Sales of animals (SA) represent the unique market income from animal production of a suckler cow farm. As there are no available statistics on farmer prices, especially for store animals, averages for different sex and age categories from the data obtained from farmers for the year 2002 were applied to parameterise the objective function. Sales of crops (SC) are constituted by sales of surplus forage. Prices for these products were introduced on the basis of the Czech Statistical Office data for the season 2002–2003. Parameters for subsidies from agricultural non agri-environmental policies (SAP) and agri-environmental programmes (SAEP) were introduced directly from the corresponding legislation.

Total direct costs can be divided into DC of animal production (DCAP) and DC of crop production (DCCP). The items entering the total direct costs here differ slightly from those accounted for in the calculation of *standard gross margins* as recommended by the EUROSTAT therefore we present these items in detail.[4] Animal production direct costs accounted for are: cost of produced feedstuffs and litter, cost of purchased feedstuffs and litter, cost of feeding on the pasture, breeding herd depreciation and "other" direct costs. The cost of produced feedstuffs and litter is not accounted explicitly for; this cost enters the objective function through the cost of crop production. Purchase price of feedstuffs and litters is set equal to the corresponding sale price increased by 10%. The item of the cost of feeding on the pasture represented basically the cost of transport of the conserved forage on the pasture and it was calculated per tonne of the forage. Depreciation of breeding animals enters the objective function through the breeding cost of replacement heifers, which, as mentioned, are all reared from own calves. "Other" direct costs involve the following items: pharmaceuticals and disinfectants, other direct material, other direct costs and services, labour costs and costs of auxiliary activities. These items were evaluated on the basis of the "Survey on the costs of agricultural products in FADN CZ 2002" (FADN – Farm Accountancy Data Framework), carried out under the responsibility of the VÚZE (Research Institute of Agricultural Economics) in Prague.[5]

Crop production direct costs are composed of: produced seeds, purchased seeds, produced fertilisers, fertiliser application and "other" direct costs. Produced seeds enter the objective function indirectly as a reduction of grains available for feeding and sales. Purchase of seeds concerns only clover-grass mixtures production and is evaluated by its purchase price. The cost of produced fertilisers is accounted for through the animal production direct costs and the cost of its application is determined after the Standards by Kavka et al. (2003a). The FADN data are not suitable for evaluation of "other" direct costs of crop production because they are not sufficiently detailed concerning grassland; they distinguish only between meadows and pastures. As our model is primarily concerned with optimisation among various grassland management strategies, these strategies must be properly evaluated. We adopted the approach which consists in specifying all operations carried out on a specific grassland type during the year and in attributing to this type of grassland the "other" direct costs equal to the sum of labour cost, other direct materials and fuel cost relative to these operations after the Standards by Kavka et al. (2003a). The list of activities was determined for currently used strategies on the basis of the research among farmers and complemented when necessary after the Standards by Kavka et al. (2003b). "Other" direct costs for crops on arable land were determined in the same way.

[4] The main difference consists in including the direct labour cost. This approach follows Novák (1999) who argues that this cost should be considered as variable in the case of large farms. Other differences may result from the fact that no official statistics on standard gross margins and their items existed at the time we wrote this paper, and we were forced to approximate them from other sources.

[5] Unfortunately, the cost is distinguished according to the production system, dairy or suckler, only for the animal category "cows" in the FADN CZ. The authors are indebted to Zdeněk Mládek (VÚZE) for his comments, which enabled them to adapt the cost to the suckler cow production system also for other animal categories.

No special cost item in the objective function concerns agri-environmental programmes; if additional activities like refusals cutting are demanded in the programmes, they are involved among the operations belonging to the particular grassland management strategy and enter the objective function through the crop production direct costs. But the agreements involve mainly restrictions on farming activities generating opportunity cost. Opportunity cost is accounted for implicitly.

Model results

Model calibration was carried out using data collected for the year 2002, under the 2002 scenario, where both agricultural and agri-environmental policies were those in force in that year. One calibration parameter was applied, a coefficient determining the permanent grassland yield level. The optimal solution of the calibrated model is reported in summary in the first column of Table 1 and in detail in Table A3 in the Annexe. Concerning land use, the available arable land is utilised as such, no land is converted to grassland. All the grassland is grazed, pure pastures represent 109 ha, 130 ha are cut once for hay, and 22 ha are cut twice for silage. No meadows in the sense specified in the SGM programme are present. The average nitrogen fertilisation is 23 kg/ha/year; all the produced manure is applied. Animal production expressed in the number of livestock units (LU) amounts to 260 LU. 172 cows are present and young animals are sold at the age of 9 months. The bulls rearing strategy corresponds to an intensive one on the pasture and to the moderate one in the barn. The total income amounts to some CZK[6] 4 905 000 constituted by 46% of sales and by 54% of various supports. The total direct costs represented 53% of the total income, leaving the farmer with a gross margin of CZK 2 295 000.

We realized two discrepancies when comparing the model results with the information obtained during the interviews. Firstly, in average one third of the permanent grassland is exclusively cut in reality while all grassland is grazed in the model solution. Regarding the individual data, we can state that the strategy of grazing all the grassland is adopted by 43% of interviewed farms and that farms belonging to this group are often rather small family farms, where the limited land availability plays an important role. Also in the model, the only fixed production factor is

Table 1. Model solution summary for the basic scenarios

		2002[a]	2004[b]	2004B[c]
Structure				
Arable land	ha	39	22	8
Grassland	ha	261	278	292
Livestock	LU	260	226	211
Economics				
Total income	CZK 1 000	4 905	5 634	5 564
Sales	CZK 1 000	2 269	1 896	1 746
Supports	CZK 1 000	2 636	3 738	3 818
Total direct costs	CZK 1 000	2 610	2 263	2 178
Gross margin	CZK 1 000	2 295	3 371	3 386
Environment				
General "SGM meadow" agreement	ha	x	0	0
Supplementary "SGM meadow" agreement: No fertilisation	ha	x	0	0
Supplementary "SGM meadow" agreement: Late cutting	ha	x	0	39
General "SGM pasture" agreement	ha	x	71	88
Supplementary "SGM pasture" agreement: Extensive pasture	ha	x	207	165

[a] 2002 agricultural policy framework, [b] 2004 agricultural policy framework, [c] 2004 agricultural policy framework + "Meadow SGM" payments increased by 30%

[6] 1 EUR = CZK 30

land. Considering other limiting factors like buildings would probably change the results. Another plausible explanation is the fact that all the calvings take place in March in the model while they are rather dispersed in reality, thus the need for conserved forage for the winter is higher. This explains probably also the second deviation consisting in the fact that all the young animals, except replacement heifers, are sold in 9 months. In reality, this sale category was present but it was less important than the category of 6–7 months. Here again the fact that there are no calvings in summer or autumn reduces the need for conserved forage in winter and thus the weaners can be held several weeks longer than usual. These observations should be kept in mind when considering the model results.

For simulations under the 2004 policy framework, the individual suckler cow premium limit was calculated from the solution obtained for year 2002, by multiplying the number of eligible cows by 0.95 (coefficient in force for the LFA zone considered). The limit was set at 139 cows. Under the 2004 policy framework, there is a tendency to reduce arable land in favour of grassland, 17 ha of the available 39 ha are converted to grassland. The nitrogen fertilisation falls in average by 36% so that even not all the produced manure is applied. Another major change is a 13% decrease in the number of LU. This decrease is partially due to a decrease in the number of cows – the individual suckler cow premium limit is not even entirely utilised – and partially due to the extensification of weaner rearing – one third of males is reared already on the pasture according to the standard intensity strategy. The farm extensification under the 2004 policies is also confirmed by a decrease in the proportion of purchased feedstuffs in the feed rations; this portion decreases from 8.6 to 7.9%. In comparison to the year 2002, the total income increases by 15% and the direct costs fall by 13% resulting in a 47% higher gross margin.

Concerning the SGM programme newly introduced in 2004, it turned out not to be very restrictive for the modelled farm. Similarly as in the 2002 year solution, no grassland is utilised as pure meadows in the year 2004, either. Thus the farmer is concerned by the "Pasture SGM" agreements only. The model decides to subscribe 74% of the grassland under the more severe supplementary agreement and 26% under the general one.

We can state that the 2004 policy framework promotes the multifunctional model of agriculture better than the 2002 policy framework as it leads to a clear diversification from agricultural commodities production to environmental good production, expressed not only by certain extensification but also by changes in the income structure. While the portion of income from animal sales decreased from 44% to 32%, the proportion of income from environmental good production by means of sound grassland management increased from 11% to 20% (here the income from the new SGM programme is compared with the former programme "Sound grassland management through livestock grazing".) But it could perform even better. The overall biodiversity expressed not in terms of the number of species per 1 square metre but in terms of the number of species per farm would be obviously higher if both the "Pasture SGM" and the "Meadow SGM" agreements were subscribed and not only the "Pasture SGM" agreements as it is the case under the 2004 scenario.

One way to motivate the farmer to subscribe a part of grassland under the "Meadow SGM" agreement is to increase the payment level for these agreements holding the payment level for the "Pasture SGM" agreements constant. If the "Meadow SGM" agreement payment level is increased by 30%, scenario 2004B, the model decides to decrease the area involved in the supplementary "Pasture SGM" agreement by 42 ha, from 207 to 165 ha, but at the same time 39 ha are newly subscribed under the "Meadow SGM" agreement aiming at late first cutting, see Table 1. 2004B scenario enhances the overall biodiversity production as the total area of grassland subscribed under the supplementary agreements remains nearly unchanged and production of biodiversity both on pastures and meadows is ensured, but it is probably economically inefficient. In the next section, we will demonstrate this point applying the concept of jointness.

JOINT PRODUCTION OF ONE AGRICULTURAL COMMODITY AND TWO ENVIRONMENTAL GOODS

Let us first briefly summarise the basic concept of jointness and of its types. We adopt the jointness definition proposed by Shumway et al. (1984) stating that if production of outputs i and j is joint, a change in the price of output j will result in a change in the supply of output i. Two major sources of jointness are commonly considered: non-allocable (public) inputs (Baumol et al. (1988)) and allocable fixed inputs. Moschini (1989) summarises the properties of a multiproduct technology joint by a non-allocable input as they were derived by Sakai (1974) and adapts them to the case of jointness by an allocable fixed input:

(1) Multiproduct technology joint by a *non-allocable input* is characterised by weak cost and output supply

complementarities. Thus in this case, the marginal cost of production of an output *i* decreases when the supply of another output *j* increases, and the supply of an output *i* increases when the price of another output *j* increases. In the following text, this type of jointness will be referred to as *positive*.

(2) If the production process is joint by an *allocable fixed input*, the marginal cost of production of an output *i* increases when the supply of another output *j* increases, and the supply of an output *i* decreases when the price of another output *j* increases. This type of jointness will be referred to as *negative*.

Jointness in beef and biodiversity production

When speaking about jointness in the context of multifunctionality, the linkage between agricultural commodities and non-commodities is usually considered. In the case presented here, commodities are represented by beef and two non-commodities are involved: "meadow biodiversity", increasing with the number of hectares subscribed under the supplementary "Meadow SGM" agreement aiming at late cutting, and "pasture biodiversity" increasing with the number of hectares subscribed under the supplementary "Pasture SGM" agreement.[7] One more agreement was subscribed by the model for scenarios presented above, the general "Pasture SGM" agreement, but its outcome will be neglected in the following discussion as it can be considered as maintenance of the status quo rather than production of additional biodiversity. In order to simplify the presentation, the supplementary "Meadow SGM" agreement aiming at late cutting will be called "meadow agreement", the supplementary "Pasture SGM" agreement will be called "pasture agreement", and the general "Pasture SGM" agreement will be called "general pasture agreement".

Sensitivity analysis of the optimal model solution with respect to various beef price levels enables to find whether there is some jointness between the beef and biodiversity production and if so, whether this jointness is positive or negative according to the definitions summarised above. First, we analyse the joint production of beef and "meadow biodiversity", and beef and "pasture biodiversity" separately, by setting to zero the maximum number of hectares under the "pasture agreement" and the "meadow agreement", respectively. Simulations in this section are implemented under the "meadow agreement" payment increased by 30% in comparison to its initial value, as under the scenario 2004B. The results are summarised in Figure 2, the full line indicates the number of hectares subscribed under the "meadow agreement" and the dashed line the number of hectares subscribed under the "pasture agreement". As jointness is analysed separately here, the two lines are outcomes of two separate simulations.

Concerning "meadow biodiversity", its quantity falls when beef prices rise: 234 ha are subscribed under the "meadow agreement" when prices are reduced by 20% in comparison to the 2002 level, but only 63 ha are subscribed when the 2002 price level is increased by 20%. This evolution indicates negative jointness in beef and "meadow biodiversity" production. This is not surprising because postponing of the first cut

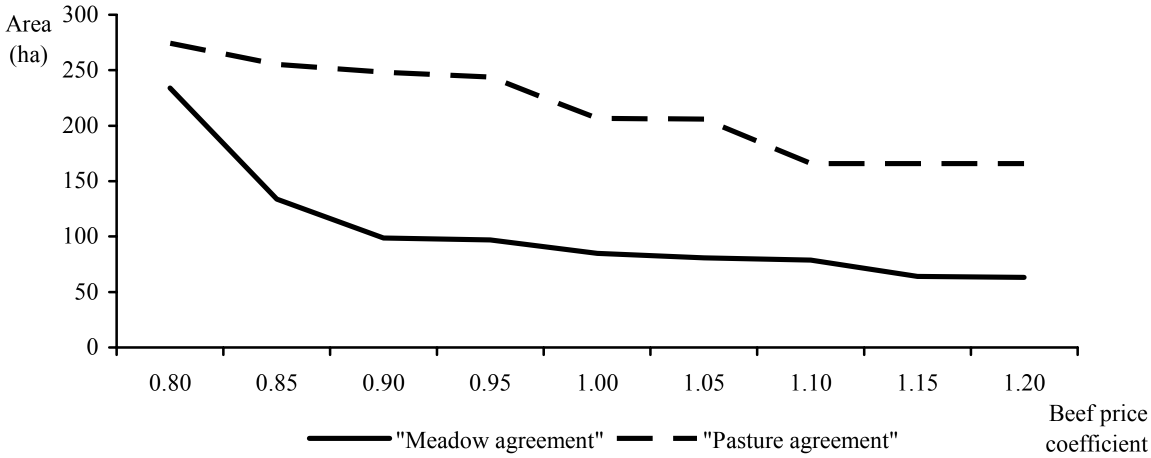

Figure 2. Joint production of beef and two biodiversity types: a separate analysis

[7] In reality, the subscription of grassland under these agreements need not increase the grassland biodiversity – even though the agreements were properly designed – because of the moral hazard. But this problem does not arise in the model which was programmed to act honestly in the sense that if an agreement is subscribed, the prescriptions are followed.

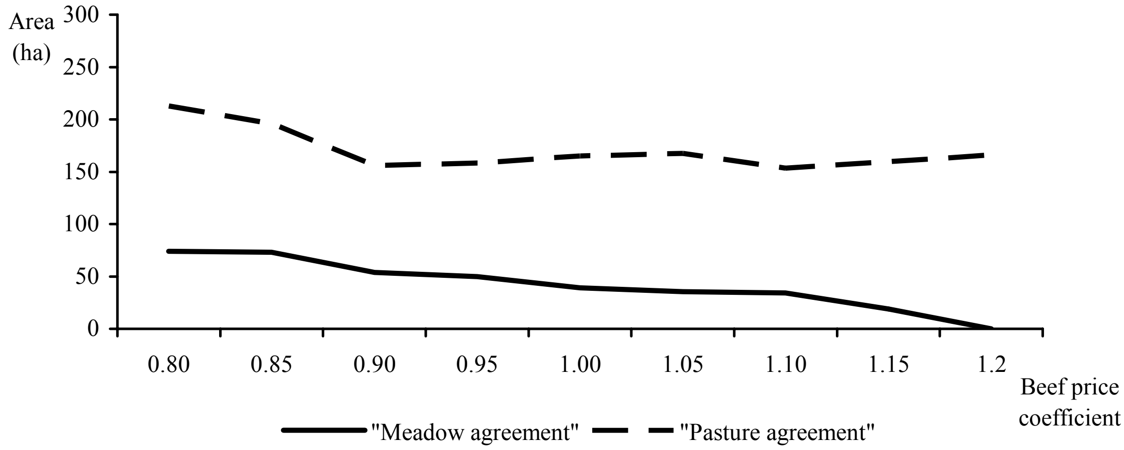

Figure 3. Joint production of beef and two biodiversity types: a simultaneous analysis

reduces the beef production capacity of grassland. As grassland is a relatively fixed factor (supplementary hectares can be obtained only by converting the arable land), its increased need for beef production is to be covered by diverting it from biodiversity production. Grassland is an allocable fixed factor.

The same evolution is observable concerning "pasture biodiversity" production: 274 ha are under the "pasture agreement" when the 2002 price level is decreased by 20%, but only 166 ha are subscribed when the price level is increased by 20%. Thus jointness is negative also for beef and "pasture biodiversity" production. The explanation is similar to the "meadow biodiversity" case. One of the basic constraints in the "pasture agreement" is the restriction concerning the instantaneous stocking density, which should be included between 0.4 and 0.8 LU/ha of pasture. From the solutions depicted in Table 1, it is obvious that the upper limit is binding. Thus subscription of the "pasture agreement" demands lowering of the stocking density, and consequently of beef production.[8]

The difference between the negative jointness in beef and "meadow biodiversity" production, and the negative jointness in beef and "pasture biodiversity" production consists in their intensity. While the quantity of "meadow biodiversity" falls by 73% when beef prices increase from 80% to 120% of the 2002 price level, the "pasture biodiversity" production falls over the same range by 39% only, and the area subscribed under the "pasture agreement" is systematically higher for the same price level than the area subscribed under the "meadow agreement". But this information alone is not sufficient to explain the phenomenon observed in Figure 3: if both supplementary agreements can be subscribed at the same time, the jointness between beef and "meadow biodiversity" remains negative but the sign of the jointness between beef and "pasture biodiversity" is indeterminate. In other words, while the number of hectares subscribed under the "meadow agreement" falls systematically when beef prices rise, the number of hectares subscribed under the "pasture agreement" sometimes falls and sometimes rises when beef prices rise. The answer is proposed by considering jointness in "meadow biodiversity" and "pasture biodiversity" production.

Jointness in "meadow biodiversity" and "pasture biodiversity" production

Let us analyse the presence of jointness among several environmental goods like we usually do it for agricultural commodities and environmental goods. Increasing the payment for the "pasture agreement", in fact the price for "pasture biodiversity", while holding the payment for the "meadow agreement" constant at its initial value leads to: a fall in "meadow biodiversity" production (9 ha are subscribed for the initial "pasture agreement" payment decreased by 30%, 0 ha are subscribed for any higher level of this payment) and to an increase in "pasture biodiversity" production (0 ha are subscribed under the "pasture agreement" for the initial agreement payment reduced by 30% and 285 ha are subscribed for the initial payment increased by 30%). These results are summarised in Figure 4. According to the definitions given, we can state that there is a negative jointness between these two types of biodiversity due to the presence of an allocable fixed factor. Not surprisingly, this fixed factor is once again grassland which must be allocated between pastures and meadows as the two supplementary agreements cannot be subscribed for the same plot.

[8] If the lower limit were binding, jointness would probably be positive.

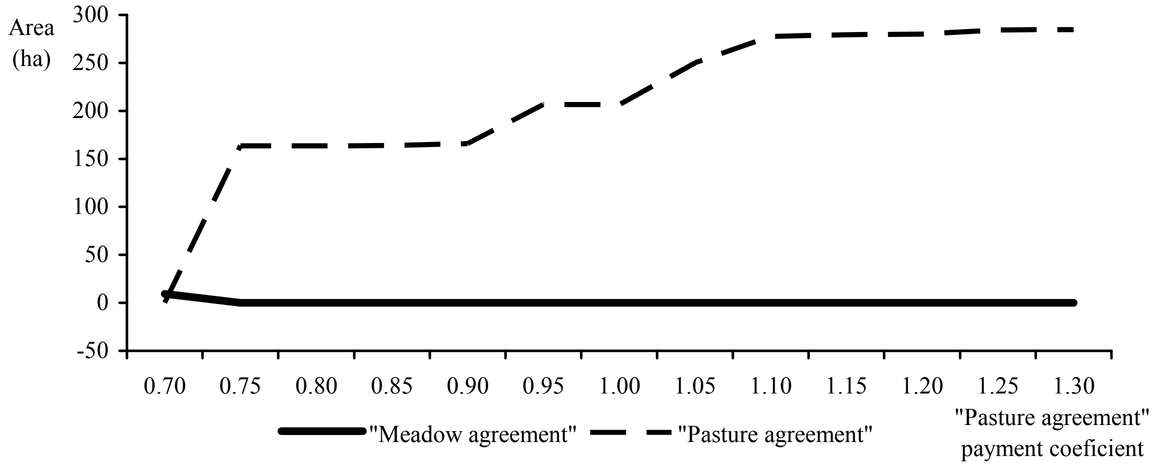

Figure 4. Joint production of "meadow biodiversity" and "pasture biodiversity": an analysis *via* quantities

Figure 4 gave us a clear but rather caricatural information about the type of jointness between "meadow biodiversity" and "pasture biodiversity". A more persuasive demonstration of the negative type of jointness is provided in Figure 5. We stated that negative jointness implies increasing marginal cost of production of an output if the supply of another output increases. In Figure 5, we can observe changes in the number of hectares subscribed under the "pasture agreement" when the payment for this agreement increases and when the area subscribed under the "meadow agreement" is fixed at 39 ha, the value previously obtained under the scenario 2004B. The number of hectares subscribed under the "pasture agreement" increases when the "pasture agreement" payment rises and this increase influences the marginal cost of compliance (MCC) with the "meadow agreement", which rises for the 39th ha from CZK 5 559/ha, if 0 hectares are subscribed under the "pasture agreement", to CZK 8 467 /ha if 256 hectares are subscribed under the "pasture agreement" (an increase by 52%).[9] Thus the negative type of jointness is confirmed also in this way.

The type of jointness in "meadow biodiversity" and "pasture biodiversity" production together with the previously obtained information on the intensity of jointness between beef and the environmental goods explain the irregular behaviour of "pasture biodiversity" production observed in Figure 3. An increase in beef prices influences "pasture biodiversity" pro-

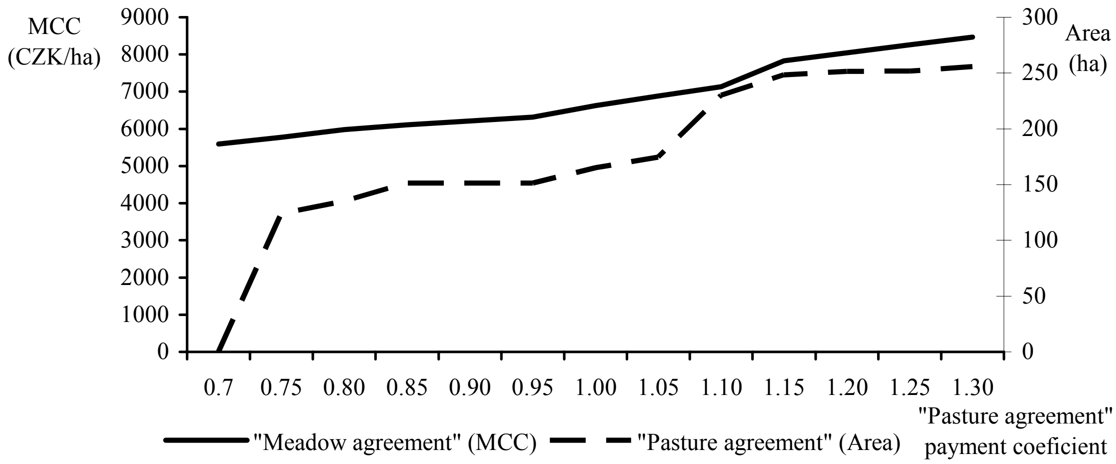

Figure 5. Joint production of "meadow biodiversity" and "pasture biodiversity": an analysis *via* marginal costs

[9] There is a causal link between the number of hectares subscribed under the "pasture agreement" and the MCC of the "meadow agreement". This would be more transparent if the area under "pasture agreement" were graphed on the x-axis, and if the "pasture agreement" payment coefficient were omitted. But we did not want to exclude the information about the "pasture agreement" payment level from the graph.

Table 2. Separate versus simultaneous agri-environmental payment design

	2004B			2004C		
	area	payment	public expenditure	area	payment	public expenditure
	ha	CZK/ha	CZK	ha	CZK/ha	CZK
"Meadow agreement"	39	6 669	260 869	39	5 980	233 216
"Pasture agreement"	165	4 330	714 667	135	3 464	468 087
"General pasture agreement"	88	2 890	254 688	117	2 890	337 973
Total	292	x	1 230 224	291	x	1 039 276

duction by a negative direct and a positive indirect effect going through the "meadow agreement" (the price increase leads to a decrease in the "meadow biodiversity" and thus to a decrease in the marginal cost of "pasture biodiversity" production). Depending on which effect is stronger, the "pasture biodiversity" production falls or increases when beef prices rise. Jointness with beef production is more intensive for "meadow biodiversity", therefore it is the joint beef and "pasture biodiversity" production of which sign the is indeterminate.

The notion not only of the evolution but also of the magnitude of the marginal cost is of interest because if agri-environmental programmes are voluntary and the farmer can decide how much of his land he subscribes under which agreement, he subscribes such an area that the marginal cost of compliance of the last hectare subscribed is equal to the agreement payment. Figure 5 presents a clear demonstration that the subscription of 39 ha, which was obtained under the scenario 2004B by increasing the payment for "meadow agreement" by 30%, can be obtained more cheaply if the increase in the "meadow agreement" payment is accompanied by a reduction of the "pasture agreement" payment.

Table 2 provides a numerical example comparing the results from scenario 2004B with results from a new scenario 2004C. In the new scenario, the "pasture agreement" payment is reduced by 20% and the payment for "meadow agreement" is set equal to the marginal cost of compliance for the 39th ha. The overall public expenditure for the SGM programme falls by CZK 190 948, 29 ha move from the "pasture agreement" to the "general pasture agreement" and 1 ha is converted to arable land. The difference in value of biodiversity produced on the 30 ha withdrawn from the "pasture agreement" would have to be at least CZK 6 365/ha/year in order for the scenario 2004B to be superior to the scenario 2004C. This is not very probable, because regarding the initially proposed payments as an indicator of the biodiversity value, we see that the payment proposed for the "pasture agreement" is CZK 4 330/ha and that the difference between the "pasture agreement" and the "general pasture agreement" is CZK 1 440/ha only.

CONCLUSION

Application of BEGRAB_PRO.1 illustrated that mathematical programming farm level models may provide a valuable insight into the farmer's decision making process concerning production of environmental goods. It was demonstrated that if several environmental goods are at stake, not only jointness between agricultural commodities and the individual environmental goods should be analysed, but also jointness among the environmental goods themselves. If these goods are joint in production, agri-environmental payments must be carefully designed because they do not influence only the production of environmental good they are intended for, but also of other environmental goods. If jointness is negative, any increase in the payment for an environmental good leads to a decrease in production of other goods. Thus an unsatisfactory area involved under one agreement does not necessarily mean that the corresponding payment is too low but maybe other payments are too high.

Jointness in beef and biodiversity production identified in our application was rather negative but this result should be considered with caution. Meadows in the White Carpathians are the result of agricultural activity existing there since the 16th century and their preservation is conditioned by some positive level of this activity. Thus when analysing the simulation results, we should bear in mind that two aspects are not accounted for in the model: grassland heterogeneity and fixed costs. The grassland quality applied in the model is an average one but in reality, the grassland is heterogeneous. Then there is a danger that the high quality land will be over-utilised and the marginal land, often the most valuable one from the biodiversity point of view, will be abandoned. Concerning the long term, it would be important to take into account also fixed costs. If farming were not sufficiently profitable, the old equipment would not be replaced and grassland abandonment could become a problem.

Further developments of the model are possible. BEGRAB_PRO.1 represents an organic farm with only a limited possibility to use purchased inputs, especially feedstuffs. As it can be seen in Table A3, the portion of energy coming from purchased feedstuffs is low for all the scenarios, around 8%. This is caused by legal restrictions imposed on organic farms. It would be interesting to build another model of a conventional farm with larger availability of purchased inputs and to compare both outcomes. In this way, it could be also found out whether organic farms are more or less likely to produce grassland biodiversity as defined here than conventional farms.

Annexe

Table A1. Animal sale categories

	Breeding strategy	Live weight (beginning)	Live weight (end)	ADG*
		kg	kg	kg/day
Weaners 7 months				
Females	standard	35	219	0.86
Males	standard	40	235	0.91
Males	intensive	40	293	1.18
Heifers				
Heifers 9 months	standard	219	261	0.69
Heifers 12 months	standard	261	320	0.66
Heifers 9 months	extensive	219	250	0.51
Heifers 12 months	extensive	250	295	0.50
Bulls				
a) after standard pasture				
Bulls 9 months	extensive	235	278	0.70
Bulls 12 months	extensive	278	341	0.70
Bulls 24 months	extensive	341	562	0.61
Bulls 9 months	standard	235	296	1.00
Bulls 18 months	standard	296	542	0.90
Bulls 24 months	standard	542	686	0.80
Bulls 9 months	intensive	235	321	1.41
Bulls 18 months	intensive	321	650	1.20
b) after intensive pasture				
Bulls 9 months	extensive	293	336	0.70
Bulls 12 months	extensive	336	399	0.70
Bulls 24 months	extensive	399	620	0.61
Bulls 9 months	standard	293	354	1.00
Bulls 18 months	standard	354	600	0.90
Bulls 9 months	intensive	293	379	1.41
Bulls 18 months	intensive	379	708	1.20

*Average Daily Gain

Table A2. Forage yields on permanent grassland in terms of disposable dry mater (DM) and energy and gross protein contents

	Fertilised grassland							Non fertilised grassland							Late cutting	
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2
Disposable dry matter (t/ha)																
Hay (1st cut)	2.85		2.85		2.85			2.42		2.42		2.42			2.10	2.10
Hay (2nd cut)	1.31			1.66				0.81			1.03					
Silage (1st cut)		2.73		2.73		2.73			2.43		2.43		2.43			
Silage (2nd cut)		1.68	1.33						1.06	0.82					0.48	
Pasture (01/05–30/06)							1.86							1.41		
Pasture (01/07–14/08)					0.96	1.30	0.96					0.51	0.73	0.73		
Pasture (15/08–14/09)		0.43	0.31		0.21	0.21	0.46					0.16	0.16	0.35		0.41
Pasture (15/09–31/10)	0.32	0.13	0.13	0.40	0.11	0.11	0.22		0.28	0.22	0.20	0.09	0.09	0.17		0.08
Energy (GJ NEL/t DM)																
Hay (1st cut)	5.50		5.50		5.50			5.20		5.20					4.40	4.40
Hay (2nd cut)	5.00			5.00				4.90			4.90					
Silage (1st cut)		5.80		5.80					5.50		5.50					
Silage (2nd cut)		5.30	5.30						5.20	5.20					5.20	
Pasture (01/05–30/06)							6.01							5.81		
Pasture (01/07–14/08)					5.84	5.84	5.84					5.64	5.64	5.64		
Pasture (15/08–14/09)		5.72	5.72		5.72	5.72	5.72					5.44	5.44	5.44		5.54
Pasture (15/09–31/10)	5.70	5.70	5.70	5.70	5.72	5.72	5.72	5.40	5.40	5.40	5.40	5.40	5.40	5.40		5.40
Gross protein (kg/t DM)																
Hay (1st cut)	130		130					110		110		110			90	90
Hay (2nd cut)	120			120				100			100					
Silage (1st cut)		150		150					130		130		130			
Silage (2nd cut)		140	140						120	120					120	
Pasture (01/05–30/06)							171							131		
Pasture (01/07–14/08)					160	160	160					114	114	114		
Pasture (15/08–14/09)		160	160		160	160	160					102	102	102		107
Pasture (15/09–31/10)	160	160	160	160	160	160	160	100	100	100	100	100	100	100		100

Table A3. Detailed model solutions

		2002	2004	2004B	2004C
CROP PRODUCTION					
Arable land	ha	39.00	22.35	7.71	8.93
Wheat	ha	1.20	2.25	2.58	2.29
Oats	ha	18.90	12.66	2.58	3.66
Clover-grass mixtures: 2 cuts silage + grazing	ha	18.90	7.44	2.58	2.98
Grassland	ha	261.00	277.65	292.29	291.07
Non-fertilised: 2 cuts silage + grazing	ha	21.78	0.00	0.00	0.00
Non-fertilised: 1 cut hay + grazing	ha	130.11	151.65	151.02	145.26
Non-fertilised: grazing	ha	67.08	79.98	66.90	60.03
Fertilised: 1 cut hay + grazing	ha	0.00	4.83	0.00	13.06
Fertilised: 1 cut silage + grazing	ha	0.00	0.00	6.21	0.00
Fertilised: grazing	ha	42.03	23.58	29.04	33.72
Late cutting: 1 cut hay + 1 cut silage	ha	0.00	0.00	19.56	19.50
Late cutting: 1 cut hay + grazing	ha	0.00	17.64	0.00	0.00
Late cutting: 1 cut hay	ha	0.00	0.00	19.56	19.50
ANIMAL PRODUCTION					
Livestock	LU	260.19	225.57	210.57	215.49
Cows – total	nb	172.17	149.73	139.50	142.59
Cows – premium eligible	nb	146.34	127.26	118.56	121.20
Sales					
Culled cows	nb	25.83	22.44	20.91	21.39
Heifers 9 months: standard	nb	51.66	44.91	41.85	42.78
Bulls 9 months: standard pasture + standard barn	nb	0.00	23.01	7.68	0.00
Bulls 9 months: intensive pasture + standard barn	nb	77.46	44.37	55.08	64.16
ENVIRONMENT					
Sound grassland management programme					
Supplementary “Meadow SGM” agreement	ha	x	0.00	39.12	39.00
General “Pasture SGM” agreement	ha	x	70.98	88.14	116.95
Supplementary “Pasture SGM” agreement	ha	x	206.67	165.06	135.13
Nitrogen					
Requirements	kg	6 802.83	4 328.49	4 038.69	5 272.70
Production	kg	6 802.83	5 902.47	5 507.31	5 634.19
Feeding					
Portion of energy from purchased feedstuffs	%	8.57	7.85	7.83	8.28
ECONOMICS					
Total income	CZK 1000	4905.27	5633.88	5564.13	5455.66
Animal sales	CZK 1 000	2 162.43	1 813.92	1 729.80	1 790.94
Crop sales	CZK 1 000	106.41	82.17	16.68	23.76
Commodity support	CZK 1 000	1 162.08	1 254.09	1 186.53	1 202.21
LFA payment	CZK 1 000	587.25	999.57	1 052.25	1 047.87
Organic farming support	CZK 1 000	339.00	384.06	348.66	351.60
Sound grassland management support	CZK 1 000	548.10	1 100.04	1 230.24	1 039.28
Total direct costs	CZK 1 000	2 610.15	2 262.54	2 178.18	2 228.96
Purchased feedstuffs	CZK 1 000	106.05	88.29	87.87	93.62
Purchased litter	CZK 1 000	30.72	26.67	24.87	25.45
Feeding on pasture	CZK 1 000	16.14	11.85	11.55	12.38
“Other” direct costs - Animals	CZK 1 000	1 462.02	1 271.49	1 184.58	1 210.85
Fertiliser application	CZK 1 000	61.77	30.30	28.26	45.81
“Other” direct costs - Grassland	CZK 1 000	723.63	727.86	804.21	798.27
“Other” direct costs - Arable land	CZK 1 000	209.82	106.08	36.84	42.57
Gross margin	CZK 1 000	2 295.12	3 371.34	3 385.98	3 226.71

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