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Policy Measures to Reduce Nitrogen Emissions from Agriculture

An Assessment based on a Consistent Farm Group Model

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Policy measures to reduce nitrogen emissions from agriculture – an assessment based on a consistent farm group model

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Abstract

A farm group model (FGM) has been developed aiming to narrow the gaps between farm specific and sector consistent policy impact analysis. The model system consists of a consistent aggregation scheme, procedures to determine consistent input-output tables and a non-linear optimisation system. The FGM is used to assess the impacts of policy measures (levies and quotas on mineral nitrogen fertiliser and the nitrogen surplus) to control nitrogen emissions from agriculture at a reduction level of about one third compared to the reference situation. Policy measures controlling mineral nitrogen fertiliser in first place reduce cereal production, while policies controlling the nitrogen surplus lead to a strong decline of pig meat production. A quota on nitrogen surplus leads to an equal level of nitrogen surplus in all farm groups. Policies oriented to control mineral nitrogen input in the first place have negative income effects on groups with a low share of livestock production, while measure in conbination with the nitrogen surplus may lead to a strong decline of income in farm groups with an intensive animal husbandry.

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1 Introduction

In agri-environmental policy global policy measures as well as command and control instruments are used. The latter ones are often specified with regard to farm structural characteristics or sources of pollution. Due to the symptom of dispersed sources of nitrogen emissions a rather dis-aggregated assessment is necessary to cover all aspects of source and level of pollution as well as the damage potentials.

With regard to agricultural and agri-environmental policy assessment a farm group model has been developed following a bottom-up approach (JACOBS, 1998; SCHLEEF, 1998). It is based on homogeneous farm groups covering the major part of the agricultural sector in former Western Germany. Homogeneous farm groups can be built with regard to policies to be assessed. Models are specified referring to farm structural characteristics and in consistency to the underlying farm accounting data. Additional activities of farm adaptations due to policy interventions are included in the model.

Principles of the farm group model and its main features are described briefly. The model is used to assess levies and quotas on mineral nitrogen fertiliser input or nitrogen surpluses. Impacts on crop and livestock production, farm income and nitrogen surpluses are shown for farm groups deviating by orientation of production and pollution level.

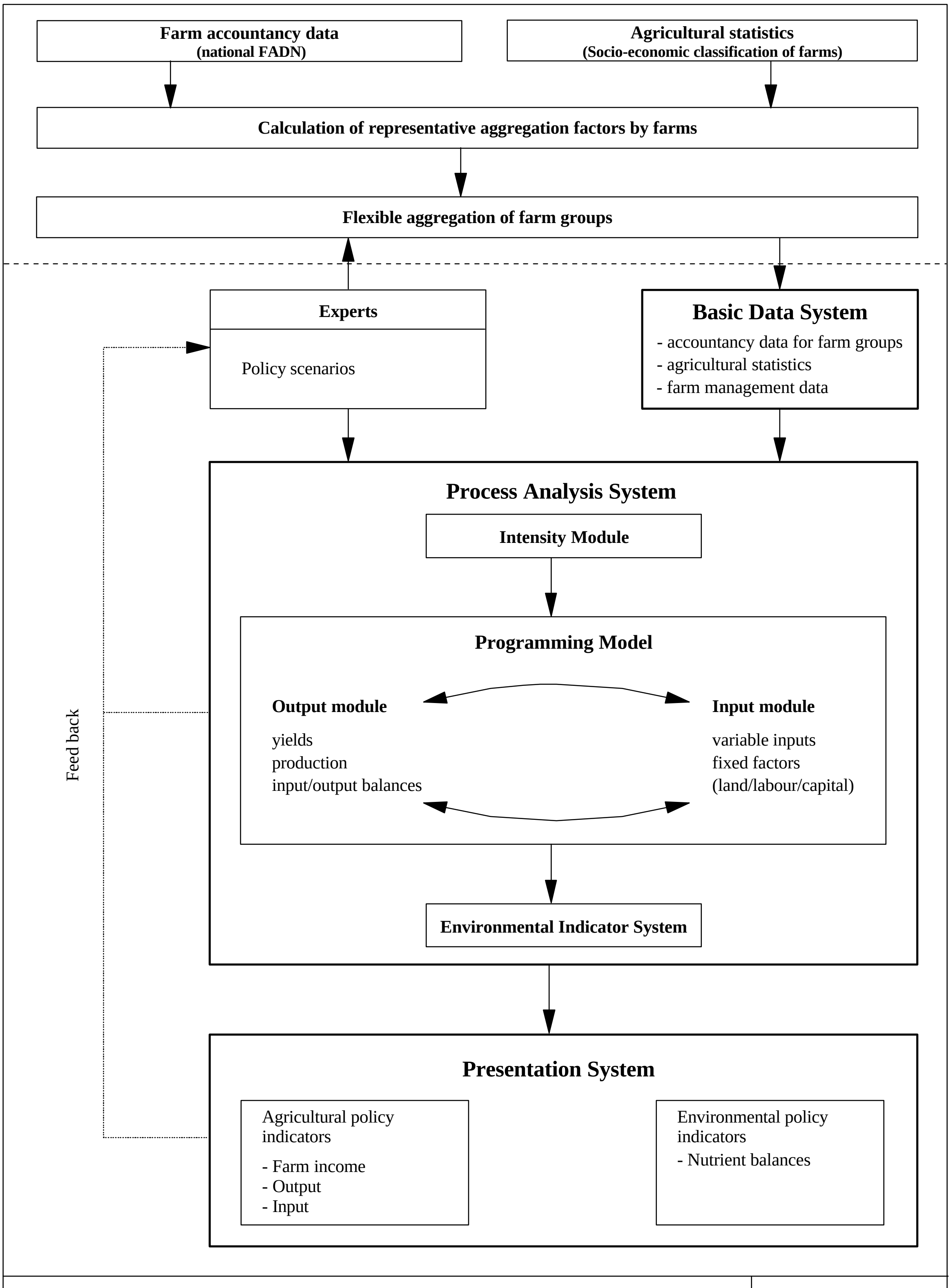
2 Conception and features of the Farm Group Model

A farm group model (FGM) was built up to assess policy impacts at a rather dis-aggregated level and to allow the aggregation of results at regional or sector level (JACOBS, 1998; SCHLEEF, 1998). Price policy measures or other policy instruments linked to regional or farm structural characteristics as well as adjusting possibilities at farm level can be specified in detail.

The structure of the FGM closely relates to the regionally differentiated sector model RAUMIS, which was developed at Bonn University and is now also implemented at the FAL (HENRICHSMEYER et. al., 1996). Programming modules of the RAUMIS system are used to allow the best harmonisation of both models. The FGM is part of the system of complementary models of the FAL being used for quantitative policy assessment (ISERMEYER, 1996).

The structure of the FGM and the data flow is illustrated in Figure 1. In the first step consistent **aggregation** factors of individual farms included in the national farm accounting system (FADN) are calculated. Homogeneous farm groups can be built up with regard to specific selection criteria being of special interest for the underlying question. Within the **basic data system**, data from different sources is used to derive complete input-output-tables of agricultural production. By the help of the **process analysis system** future developments of agricultural production, input use, farm income and environmental indicators in different farm groups can be simulated under alternative policy scenarios. The **presentation system** allows to transform the output of the optimisation model into clearly arranged graphs and tables, which can be discussed with policy makers and experts afterwards. If necessary, assumptions can be modified gradually. The conception of the FGM allows to integrate expert knowledge of different disciplines and to satisfy the actual information demand of policy makers (HENRICHSMEYER, 1994, p. 186). The FGM is a partial supply model, which at the present state of development can depict most of the Western German agricultural sector in a consistent way.

Figure 1: The Farm Group Model



Source: SCHLEEF (1998, p. 15)

FAL-BW
SCHLEEF (1997)

2.1 Calculation of consistent aggregation factors

An important data base is farm accounting data of the national FADN. Consistent aggregation factors with regard to land use, livestock production and income of farms included in the data base are calculated (see Figure 1). This step is necessary, because up to now only a simplified free aggregation scheme, aiming at a correct representation of farm income, is used to provide information for the annual report on agriculture (Agrarbericht). These ‘simple’ aggregation factors are determined with regard to socio-economic classification criteria and standard farm income, but they are not representative with respect to physical figures as e. g. land use, livestock production and the use of other factors. For an assessment of policies to reduce nitrogen emissions in agriculture a correct representation of land use and livestock production in different farm groups is of special importance, because these parameters have a high influence on the level of the nitrogen surplus (SCHLEEF and KLEINHANSS, 1997). Furthermore, a correct representation of the production basis of different farm groups allows a direct comparison between aggregated results of the FGM and RAUMIS results. Such information can be used as input for higher aggregated market models in the framework of the system of complementary models used at the FAL.

A non-linear programming model has been built up to derive consistent aggregation factors (JACOBS, 1998). All sample farms of the FADN are classified with regard to their affiliation to Federal States, farming types and standard farm income classes. Sample farms fulfilling the same classification criteria are grouped together within separate optimisation models. Data from the structural survey of the Federal Statistical Office provides information on the total number of farms belonging to a particular group, the aggregated area of land use (differentiated by UAA, permanent grassland, cereals, other marketable crops and sugar beet) and the total number of livestock (differentiated by dairy cows, pigs, layers and fattening poultry). Aggregation factors of the existing FADN are used as starting points. During the optimisation process the ‘free-aggregation factors’ are changed in a way that land use data and livestock numbers, known from the Federal Statistical Office, are reached.

According to Merz (1983) the optimisation problem is formulated in the following way:

$$(1)\quad Z = \sum_{j=1}^{n} a_j * \log \frac{a_j}{b_j} = \min! \qquad 0 < a_j < n,\ 0 < b_j < n,\ \sum_j a_j = \sum_j b_j = n,$$
$$b_j * u \geq a_j \geq b_j * l,\ u > 1,\ 0 < l < 1$$

where a_j = consistent aggregation factor of farm j $(j = 1, \dots, k)$,
b_j = predetermined aggregation factor of farm j,
k = number of sample farms,
n = total number of farms,
u = factor to determine upper deviation limit of aggregation factors,
l = factor to determine lower deviation limit of aggregation factors;

under the restrictions:

$$(2)\quad S * a \geq r * x,\ S * a \leq r * y$$

where $S_{(m,k)}$ = (s_{ij}) matrix of farm specific characteristics i $(i = 1, \dots, m)$,
a = $(a_1, \dots, a_k)$ vector of consistent aggregation factors,
r = $(r_1, \dots, r_m)$ vector of the sum of farm specific characteristics of the total number of farms from the Federal Statistical Office,
x = $(x_1, \dots, x_m)$ vector of factors to allow some deviation from the information of the Federal Statistical Office (lower limit),
y = $(y_1, \dots, y_m)$ vector of factors to allow some deviation from the information of the Federal Statistical Office (upper limit).

Individual ranges (vector *x* and *y*) assigned to each restriction ensure the practical feasibility of the adjusting model. An upper and a lower deviation limit prohibit that an adjusted aggregation factor becomes zero, which would lead to a neglection of the characteristics of a particular sample farm. When the restrictions of the model are fulfilled, adjusted aggregation factors can be used to estimate land use data and livestock numbers for the total of farms correctly. The new aggregation factors are used as weighting factors to build up farm groups and to aggregate results up to sector level.

At present, this system can only be used for Western Germany because of data availability. Due to the fact that farms with a standard farm income of less than 5000 DM and farms being organised as e. g. commercial enterprises are excluded from the data network, the existing FGM can only represent the major part of the agricultural sector in Western Germany.

2.2 Generation of consistent matrix coefficients

The core of the FGM is built by a standard optimisation matrix, which contains 27 activities of crop and 15 activities of livestock production. In the base situation the extent of different agricultural production activities as well as physical yields are available directly form accounting data of farm groups. The use of intermediate products, e. g. heifers, calves and piglets within a particular farm group is estimated by the help of simple balance calculations.

The estimation of the use of input factors like fertiliser, feed, machinery etc. proceeds in two steps. The first one is strictly normative. Based on information from farm management handbooks the use of input factors of each production activity is determined either in relation to yields (e. g. input of feed or fertiliser) or in relation to structural characteristics (e. g. use of machinery). In a second step these normative input coefficients are adjusted according to corresponding accounts of farm accounting data for each farm group. The adjusted input-output-coefficients allow to calculate farm income in consistency with the accounting data. Farm income is the relevant income indicator to be optimised by the policy simulation model.

2.3 Generation of a consistent base situation

Although input-output-tables of agricultural production are derived very carefully, miss-specifications of matrix coefficients might occur and not all relevant restrictions or production options might be considered correctly by the model. If such a model would be optimised with a linear objective function, it is likely that the result differs from information given by the accounting data. Therefore a positive quadratic programming model is used.

In a first step a base year optimisation, using a linear objective function, is conducted. To ensure that the result of the optimisation process reflects the actual situation, the extent of activities is fixed by bounds. The dual solution of this model will usually show positive or negative shadow prices for the activities. Using some mathematical transformations these shadow prices are used to derive a quadratic objective function (HOWITT, 1996). The same matrix, being optimised with a quadratic objective function, delivers the correct base year result without bounds on activities (JACOBS, 1998, pp. 182).

2.4 Scenarios

Environmental policy instruments are assessed in comparison to a reference scenario representing a continuation of 1992 CAP-reform until the year 2005. Structural and technical developments of farms are considered. A description of the main assumptions is given in detail by SCHLEEF (1998, pp. 103) and CYPRIS et al. (1997).

Four different policy measures to reduce nitrogen emissions from agriculture are described. They are formulated rather simple on the basis of a terminology introduced by SCHEELE, ISERMEYER and SCHMITT (1993). Two ‘technological control parameters’ (mineral nitrogen fertiliser and nitrogen surplus) are combined with the ‘policy instruments' levies and farm specific quotas. A levy on mineral nitrogen fertiliser can be addressed to fertiliser producers and traders, who can pass at least a part of their additional costs (the levy) to farmers. The other three measures have to be addressed directly to the farmers. The choice of the 'addressee' implies a nation-wide 'regulation area' under the levy on mineral nitrogen fertiliser and a farm specific 'regulation area' of the other three measures. The incentive to farmers to reduce nitrogen emissions can be controlled by the level of the use of the instruments (dosage).

To allow a better comparison between different measures a dosage is chosen, which leads to a reduction of an average nitrogen surplus for Western Germany of 104 kg/ha in the reference situation to 70 kg/ha under each particular policy measure. According to model results the nitrogen levy amounts to 1.32 DM/kg of mineral nitrogen, the surplus levy to 1.37 DM/kg N-surplus and the nitrogen quota allows a use of 61.3 kg of mineral nitrogen per hectare. Under the surplus quota a N-surplus of only 40.5 kg/ha is allowed to achieve the predetermined goal. The difference between the targeted surplus level of 70 kg/ha and the N-surplus of 40.5 kg/ha allowed under the surplus quota can be explained by the fact, that nitrogen depositions from the atmosphere, amounting roughly to 30 kg/ha on average in Germany, are assumed as irrelevant for the formulation of the policy.

Production functions of different crops (WEINGARTEN, 1996) and cost functions to improve the efficiency of nitrogen use from different types of organic manure (HENRICHSMEYER, WEINGARTEN and STROTMANN, 1992) are included in the model. Furthermore, the combination and the level of production processes can be changed. Transport of liquid manure between different farm groups is not considered by the model.

3 Impacts of policies to reduce nitrogen emissions from agriculture

Impacts of different policy measures on agricultural production, nitrogen surpluses and farm incomes differentiated by farm types and level of nitrogen surpluses in the reference situation are explained. On total, 70 different farm groups are built and optimised separately. Consistent aggregation factors (see chapter 2.1) are used to derive average results shown in Table 1.

Table 1: Reference situation and changes under different policy scenarios

		Classification of farms											
farm tpye		average farm	arable farms			cattle & dairy farms			pig & poultry farms		mixed farms		
N-supply from organic manure			low	medium	high	low	medium	high	medium	high	low	medium	high
Grain production													
reference	(t/farm)	117.2	310.7	304.3	273.5	99.9	58.4	35.7	172.4	228.5	124.1	105.4	160.5
levy min. nitrogen	(%)	-11.9	-9.1	-10.6	-13.2	-8.0	-10.3	-28.2	-8.7	-16.2	-7.6	-7.1	-17.0
quota min. nitrogen	(%)	-15.3	-25.2	-21.2	-21.1	-8.3	-3.1	-11.1	-13.9	-9.8	-12.6	-10.4	-12.4
levy N-surplus	(%)	-6.6	-4.5	-6.0	-7.2	-4.7	-5.4	-16.4	-5.9	-10.7	-4.4	-3.7	-8.5
quota N-surplus	(%)	-6.1	-0.3	-4.7	-11.3	-0.1	-1.9	-24.6	-4.3	-19.8	-2.3	-1.9	-16.7
Milk production													
reference	(t/farm)	83.1	6.2	10.5	3.3	47.8	128.2	125.8	0.0	5.0	12.0	22.0	58.0
levy min. nitrogen	(%)	-0.6	-1.7	-1.5	-8.1	-2.0	-0.1	-0.9	-3.4	-7.1	-2.3	-0.1	-1.4
quota min. nitrogen	(%)	-0.2	-0.9	-3.1	-10.6	-0.7	0.0	-0.3	-2.2	-3.2	-2.9	-0.1	-1.1
levy N-surplus	(%)	-3.7	-2.1	-1.3	-8.9	-2.8	-4.2	-3.1	-9.5	-8.9	-4.9	-0.4	-3.1
quota N-surplus	(%)	-3.6	-0.2	-0.9	-12.0	-0.2	-2.5	-5.5	-10.6	-19.0	-3.7	-0.2	-11.6
Pig meat production													
reference	(t/farm)	12.1	1.5	30.1	67.3	0.2	0.5	4.6	10.2	108.9	2.3	6.8	58.0
levy min. nitrogen	(%)	2.6	4.9	3.8	5.4	1.6	6.0	1.7	4.4	2.2	3.0	6.0	1.2
quota min. nitrogen	(%)	3.2	12.3	7.8	9.7	1.7	4.1	1.1	7.6	2.1	6.2	9.5	1.1
levy N-surplus	(%)	-10.2	-11.1	-12.6	-11.4	-4.9	-18.5	-5.0	-8.7	-11.9	-8.4	-15.1	-3.2
quota N-surplus	(%)	-32.3	-2.5	-7.8	-16.2	-0.1	-13.3	-36.5	-5.2	-38.6	-4.2	-11.2	-35.2
Nitrogen surplus													
reference	(kg/ha UAA)	104.3	71.1	107.8	144.2	62.4	84.9	147.9	100.2	228.1	69.9	88.9	173.7
levy min. nitrogen	(%)	-33.0	-43.7	-37.0	-33.9	-37.6	-27.5	-30.3	-32.4	-33.7	-30.2	-29.2	-31.3
quota min. nitrogen	(%)	-32.8	-84.7	-60.3	-50.9	-42.3	-14.5	-14.6	-47.7	-23.9	-48.0	-36.0	-24.8
levy N-surplus	(%)	-33.4	-38.6	-36.6	-35.4	-36.0	-29.7	-31.3	-32.1	-37.3	-28.7	-29.2	-30.4
quota N-surplus	(%)	-32.9	-5.3	-31.2	-50.3	-2.0	-15.6	-51.5	-25.0	-67.4	-13.1	-18.4	-58.1
Farm income													
reference	(DM/farm)	51618	65352	82215	112042	24932	45458	52401	34626	79570	35895	31190	65440
levy min. nitrogen	(%)	-8.2	-18.3	-13.5	-8.5	-13.9	-5.6	-3.0	-13.6	-5.9	-12.9	-10.9	-6.0
quota min. nitrogen	(%)	-3.5	-15.3	-9.9	-3.7	-2.7	0.4	-0.4	-4.9	-1.6	-5.9	-3.4	-1.2
levy N-surplus	(%)	-7.9	-2.8	-7.4	-9.0	-3.4	-7.3	-8.9	-7.8	-17.4	-3.5	-5.9	-13.1
quota N-surplus	(%)	-6.8	0.0	-2.5	-8.0	0.0	-2.2	-9.4	-2.9	-29.0	-0.8	-0.6	-19.9

Source: Own calculations

FAL-BW
SCHLEEF (1998)

3.1 Adjusting processes

A common adjusting process induced by all policy measures being assessed is a more efficient use of nitrogen from organic manure due to investments in additional storage capacities and advanced manure spreading techniques. The use of this adjusting measure is to a high degree depending on farm structural characteristics. Especially in arable farms with a low importance of livestock production the supply of nitrogen from organic manure and hence the possibility to substitute mineral nitrogen fertilisers usually is quite limited.

Furthermore, there is a reduction of production intensity. Levies lead to increasing production costs but leave it to farmers to decide whether to reduce mineral fertiliser input respectively nitrogen surplus or to pay the levy. In contrast to that, quotas prescribe an absolute maxiumum limit, which may not be exceeded. Farms with a high dependency on mineral fertiliser are therefore affected most by the nitrogen quota, while a surplus quota leads to strong impacts on farms with intensive animal husbandry.

3.2 Impacts on production

Referring to the average of all farms there is a strong relation between production decline of different products and the type of technological control parameter. Policies controlling mineral nitrogen input, in the first place reduce cereal production (-11.9 % respectively -15.3 %) and show only little impacts on animal husbandry. Due to the fact that pig manure has a relatively high content of nitrogen there is even a tendency to encourage pig production (+2.6 % respectively +3.2 %). A completely different adjusting pattern can be observed in the case of policies aiming at the control of nitrogen surpluses. Especially pig meat production is reduced significantly under the surplus quota (-32.3 %). It is concentrated in specialised pig & poultry farms, being charcterised by the highest nitrogen surplus in the reference scenario (228.5 kg/ha). Impacts on cereals and milk production are quite limited, because these products are mainly produced in farm groups with moderate or low nitrogen surpluses in the reference situation.

Concerning farm groups with low or medium nitrogen supply from organic manure it can be observed quite often, that a surplus levy leads to a stronger decline of milk or pig meat production than a quota on the surplus (e. g. cattle & dairy farms with low or medium supply of nitrogen from organic manure). According to the formulation of the policy, farmers get the quota for free. As long as the surplus quota might not be sold there will be no competition for scarce quota between farm groups. In contrast to that, farmers have to pay for each kilogramme of nitrogen surplus under the levy. Furthermore, the estimation of consistent input-output-coefficients (see chapter 2.2) shows, that farm groups being specialised in one branch of livestock production (e. g. cattle & dairy or pig & poultry farms with a high supply of nitrogen from organic manure) have the best input-output-relations and therefore can afford to pay high levies or to buy additional quotas if the quota would be marketable.

3.3 Impacts on nitrogen surpluses

On the average of all farms the nitrogen surplus for all policy measures is reduced by about one third. Only a quota on nitrogen surplus leads to an almost equal distribution of nitrogen surpluses in all farm groups. The highest reduction in this policy occurs in pig & poultry farms (-67.4 %) with a high supply of nitrogen from organic manure in the reference scenario. Low reductions of nitrogen surpluses can be observed in farm groups with a low nitrogen supply from organic manure (e. g. in cattle & dairy farms only -2.0 %), because most of farms in this group already fulfil the requirements of this measure in the reference situation. All other measures lead to a more or less unequal distribution of nitrogen surpluses. The highest degree of unevenness in the distribution of nitrogen surpluses is caused by a levy on mineral nitrogen fertiliser, because this policy mainly affects farm groups with a low supply of nitrogen from organic manure.

3.4 Income effects

Regarding the average farm income it is estimated that levies lead to higher income losses than farm specific quotas. The main reason is that the levies have to be paid for the whole amount of mineral nitrogen fertiliser input respectively nitrogen surplus, while the farmers for the first time get quotas for free (see chapter 3.2). If a market for quota will be established the mentioned advantages will decrease in the long term.

A second item to be mentioned is that the levy on mineral nitrogen fertiliser leads to slightly higher income losses than the levy on surpluses. The reverse holds in case of quota policies. An analysis of income losses differentiated by farm group shows that farm groups (e. g. arable farms with a low supply of nitrogene from organic manure) with a high dependency on crop production in the first place suffer from policies oriented to the control of mineral nitrogen fertiliser input (-18.3 % respectively -15.3 % in arable farms with low nitrogen supply from organic manure), while farm groups specialised in livestock production are stronger affected by policies controlling the nitrogen surplus (-17.4 % respectively -29.9 % in pig & poultry farms with a high nitrogen supply from organic manure).

4 Summary

A farm group model has been developed aiming to narrow the gaps between farm specific and sector consistent policy impact analysis. The FGM is used to assess the impacts of levies and quotas on mineral nitrogen fertiliser input and nitrogen surpluses on cereal, milk and pig meat production as well as on nitrogen surpluses and on farm income. Farm accounting data from the national FADN is the most important data source of the FGM. For each sample farm consistent aggregation factors are estimated. Afterwards sample farms are aggregated to farm groups according to farm specific characteristics, which are of special interest for nitrogen policies. Accounting data in combination with information from farm management handbooks is used to derive consistent input-output-tables of agricultural production, which are optimised by a PQP-model and hence used for policy impact analysis.

The impacts of policies to reduce nitrogen emissions from agriculture are simulated and compared to a reference scenario. Policy measures controlling mineral nitrogen fertiliser in the first place reduce cereal production and only show minor impacts on livestock production, while policies controlling the nitrogen surplus lead to a strong decline of pig meat production. A quota on nitrogen surpluses leads to an equal level of nitrogen surpluses in all farm groups. Levies and quotas in combination with mineral nitrogen fertiliser input in the first place reduce nitrogen surpluses in farm groups with low or medium supply of nitrogen from organic manure in the base situation. Farm groups with a high share of intensive livestock production show relatively low income losses under policies aiming at the control of mineral nitrogen fertiliser input. The opposite holds for farm groups with a low importance of livestock production.

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