Fertilization: trade-offs between manure abatement and plant productivity

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Abstract— **In 2005, 30% of the Flemish farms faced a manure excess, while at aggregated level still 9.7% of the emission rights were unused. This means that, despite the various possibilities, Flemish farmers do not succeed in an effective exchange of manure between farms. In current paper is shown how inorganic fertilizer use influences the use and exchange of organic nitrogen. Because of the mutual interdependency between organic and inorganic nitrogen emission rights (or quota), inorganic nitrogen use limits the emission rights for organic nitrogen. Utilisation of these emission rights are analysed as a trade-offs choice between plant productivity (use of inorganic nitrogen) and manure disposal, as the major abatement alternative of manure production. Farmers still prefer inorganic fertilizers because of their effect on plant productivity and income. However, by changing the quota rent of organic nitrogen, the fertilization behaviour can be influenced. A higher quota rent of organic nitrogen would increase the use of manure. This trade-off behaviour seriously influences effectiveness of policies. When the objective is to lower the total nitrogen use, a mere reduction of organic quota can partially be counteracted by a higher inorganic nitrogen use. When the objective is to better spread the manure, increasing the quota rent for deficit farms will increase their acceptance of manure.**

Keywords— **manure abatement, nutrient emission rights, Tobit model**

I. INTRODUCTION

Since the 1960s, several West European countries, e.g. The Netherlands, Denmark, France and Belgium, faced a large expansion and intensification process in the livestock production (in particular pigs and poultry). In these regions, the growth in animal number was favoured by the proximity of ports [1]. In Flanders in 2005, for example, 5.789.931 pigs and 26.949.252 units of poultry were reared [2]. An excess of nutrients resulted from the feed compounds trade balance and led to a high pressure on the environment [1]. As a result, surface and groundwater got polluted with nitrogen, because of denitrification, and phosphate leaching into the soil [3]. During 2005, the livestock sector in Flanders produced 157,991,110 kg of nitrogen and 60,111,081 kg of phosphorus. Pig production accounted for 37.1% of the total nitrogen production and 41.9% of the total phosphorus production. The poultry sector accounted for, respectively, 10.6% and 12.9% of the total Flemish nitrogen and phosphorus production [2]. The production of pigs and poultry is mostly concentrated in West Flanders (the westernmost province of Flanders), which borders on the North Sea. The ports of Zeebrugge and Ostend are situated in this province while the port of Ghent is adjacent. In this area, 54% of Flanders pigs and 37.5% of Flanders poultry are reared. Consequently, 40% of the total nitrogen production and 43% of the total phosphorus production is generated in this province.

As a consequence of the Nitrate Directive (91/676/EEC)1, the Flemish region has introduced a manure decree in 1991, which describes how manure should be disposed. A limited amount of manure can be spread on the land according to the type of manure, crop category and land category. With this disposal constraint, the manure decree actually created a system of tradable emission rights [4]. In fact, land entails a right to spread manure and both land and manure are tradable between farms. In this manure exchange system, conceived as system of tradable emission rights, manure is labelled as the emission, whereas the right to spread manure on land is labelled as the emission right [5]. This labelling is justified because manure use, given the imperfect

1. [1] The main purpose of the directive was to protect the waters against pollution caused by nitrates from agricultural sources

incorporation of nutrient inputs into end products, jointly entails a nutrient emission.

Flemish farms can react to the manure legislation as follows:

- the farm adapts its animal production to produce less manure;
- the farm chooses for abatement by obtaining sufficient emission rights or by end-of-pipe solutions such as manure processing.

When regarding manure disposition on land as an abatement measure, manure is considered as a waste product rather then a product which contains valuable nutrients.

On top of the regional concentration of animal production, agricultural development has led to a great differentiation between farms (specialised livestock farms, specialised arable farms and mixed farms) resulting in a concentration of manure production at farm level as well. Despite the various manure exchange possibilities provided in the manure legislation, a lot of farms do not succeed in an effective exchange. The reasons for this have hardly been examined, but [1] give at least one by showing, for the Dutch case, that arable farms consider manure as secondary choice to inorganic fertilizers.

Inorganic fertilizers are preferred to manure because the latter has a high non-uniformity of nitrogen content, a relatively high nitrogen loss and thus less nitrogen available for immediate crop uptake [1]. According to [6] inorganic fertilizers are often used because of the direct available nitrogen. Evidence exists that using inorganic fertilizers has a significant positive effect on productivity of most crops. Because of these positive effects, farmers prefer to use inorganic nitrogen. Because of the mutual interdependency between organic and inorganic nitrogen, however, the use of inorganic fertilizers limits the maximum dose of organic nitrogen, and thus the utilisation of emission rights of the latter.

The aim of the study is to examine how the use of inorganic fertilizers can effect the use of organic nitrogen and how the link between both fertilization types can influence the effect of a policy change. For analysing the competition between inorganic fertilizers and manure use, a variable is defined that relates inorganic nitrogen use to remaining free fertilization room for inorganic nitrogen. This allows for an econometric estimation of the drivers for a given trade-off between manure abatement (emission right utilisation) and plant productivity. The study also aims at formulating a more effective regulation than the current major efforts of the Flemish government, which are not yet effective with respect to the Nitrate Directive. In spring 2006, 38.5% of the Flemish measure points exceeded the 50 mg nitrate per litre water standard [7]. The remainder of the paper is organised as follows. First, a short overview is given of the Flemish manure regulation and discussed from an emission right perspective. Section 3 describes the data of observed substitution of inorganic and organic fertilisers and the methodology. In section 4 the results are given and interpreted. The paper ends with a conclusion.

II. MANURE POLICY IN FLANDERS: SYSTEM OF EMISSION QUOTA

Since 2000, the farmer must comply with four different nutrient emission rights: nitrogen from inorganic fertilizers, nitrogen from manure, total nitrogen and phosphorus. In this study, only nitrogen emission rights will be considered because they are the most important problem for water quality. The nitrogen use is restricted by two individual quota (organic and inorganic nitrogen) and one joint quota (total nitrogen). Because the sum of both individual quota is larger than the joint quota, the use of an individual quota can affect the other when the joint quota becomes binding (Fig.1).

To describe the interaction between the three quota, we introduce the concept of free fertilization zone (FFZ). FFZ is the amount of one nitrogen type the farmer can apply without affecting the quota of the other type. FFZ is thus the part of the quotas that can be used without interaction with the other quota. The utilisation of the quota beyond the FFZ affects the possibility to use the quota of the other nitrogen type. A free fertilization zone (FFZ) can be delimitated for both individual quota: a free fertilization zone for organic nitrogen (FFZO) and a free fertilization zone for inorganic nitrogen (FFZI).

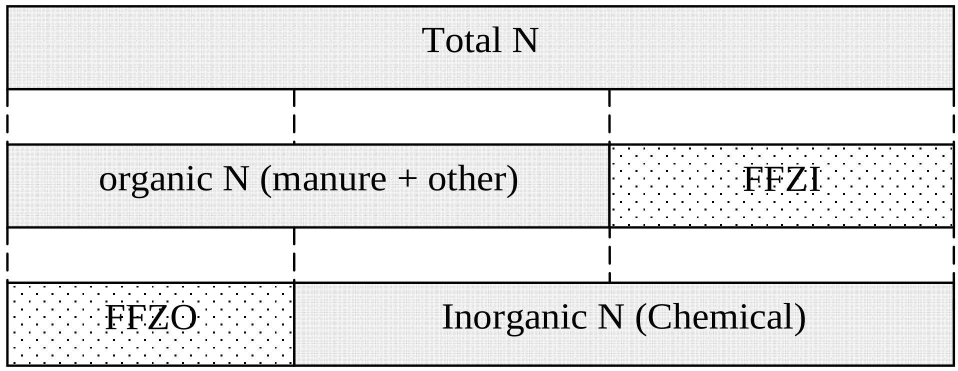

Fig.1 graphical representation of the Flemish emission quota system in the MAPIIbis regulation

Based on the concept of FFZ, the variable 'limitation' (LIM) can describe how much the use of inorganic fertilizers limits the use of manure:

LIM= 'use of inorganic nitrogen' –' free fertilization zone inorganic nitrogen'

In case of a usage of inorganic nitrogen exceeding the FFZI, a positive value of LIM shows how much the use of inorganic nitrogen reduces the available quota of organic nitrogen. A negative value of LIM indicates that the use of inorganic nitrogen does not affect the use of organic nitrogen. Since there is no difference for the farmer for different negative values for LIM, the negative values of the LIM is censored to the single value '0'. The values of FFZ and LIM depend on crops because the manure regulation subdivided crops into four different categories (grassland, corn, low nitrogen crops and other crops) and subsequent different fertilisation norms. The fertilization norms according to these categories in 2003 are given in Table .

III. MATERIALS AND METHODS

A. Data

The data base has been set up by the Flemish controlling administration: the Flemish land agency (FLA). It contains all variables related to production, transactions, acquisitions and use of nutrients for each Flemish farm individually. The database contains the complete population of 44,796 farms over a period of four years (2002-2005) with a total of 179,764 unbalanced panel observations. For the Tobit regression (see further), only farms with at least 0.5 hectare of land are selected, resulting in a sub sample of 137,987 unbalanced panel observations. Based on the number of hectares per crop category and the corresponding fertilization norms, the three different quotas are calculated. The production of nutrients (including nitrogen) per farm is calculated based on the number of animals per farm and the corresponding excretion norms.

Table 1 The 2003 fertilization norms, in kg/ha (*), according to crop category

Crop category	P_2O_5	Total N	Organic N	In-organic N
Period 1/1/2001 until 31/12/2002				
Grassland	140	450	325	350
corn	120	275	275	150
Low N crops(**)	100	125	125	100
Other crops (***)	110	275	225	200
Period 1/1/2003 until 31/12/2006				
Grassland	130	500	250	350
corn	100	275	250	150
Low N crops	100	125	125	100
Other crops	110	275	200	200

*Only the fertilization norms for the general areas are given. More stringent norms are imposed for vulnerable areas (water, nature and phosphor saturated areas)

**Crops with a low N demand, e.g. onions, chicory, clovers, fruit plantations, flowers,…

***All crops not belonging to one of the 3 other categories, e.g. potatoes, sugar beets, cereals, legumes, …

B. The Tobit model

Given the censored variable 'LIM' a Tobit analysis is appropriate for analysing LIM as dependent variable [8]-[12]. For a more elaborated description of the Tobit model, see e.g. [8][9] The model is specified as:

$$y_{it}^{*} = x_{xt}\beta + \mu_{ti} \quad (1)$$

with

$y_{it} = y_{ti}^{*}$ if $y_{it}^{*} > 0$ and

$y_{it} = 0$ if $y_{it}^{*} \leq 0$

(with y_{it} the limitation of farm *i* in year *t*)

where the residuals, μ_{it} are assumed to be independently and normally distributed. The new random variable, or the latent variable y_{it}^{*} is unobserved if $y_{it}^{*} \leq 0$.

C. Explanatory variables

Obviously, given its direct competition to organic fertilisers in providing crop nutrition, the first set of variables relates to inorganic fertiliser use. In most cases, the farmer applies a given amount of inorganic fertilisers because this provides the plant of immediately available nitrogen[6]. Also [1] indicate that farmers consider inorganic nitrogen superior to organic nitrogen. However, the positive effect of inorganic nitrogen varies among the different crops. Therefore we argue that inorganic nitrogen dose is driven by plant characteristics. This leads to the following main crops categories as explanatory variables: grassland, maize, low nitrogen demanding crops en other crops.

A second variable indicates the change in manure policy and is indicated as 'MAP' (Manure Action Plan) and defined binary (2002=0; 2003-2005=1). This policy change has reduced the quota for organic nitrogen resulting in a higher FFZI. Again we argue that a higher FFZI leads to lower values of LIM.

Next, manure use will be influenced by the local manure pressure. [13] have found that the degree of acceptance[2] varies from almost 100% at manure producing farms to less than 55% at manure accepting farms. We argue that the degree of acceptance can be explained by the theory of quota rent [5][14]. These authors have found that in the case of sugar beet, dairy and manure quota, a higher quota rent leads to a higher degree of quota utilisation. In the case of manure quota, the quota rent can be approximated by the regional manure pressure[3]. A larger manure pressure in the surrounding areas means more costs to discharge the (excess of) manure. Emission rights are fixed locally and, therefore, the manure must be transported over a longer distance before free emission rights can be found. Moreover, more transaction costs are made by searching over longer distance those farms who are willing to accept manure. As a result, in regions with a high manure pressure, under-use of the organic quota leads to higher extra costs, meaning that the quota rent of the quota for organic nitrogen is higher in these regions (because of the higher opportunity costs of not using the quota completely).

Finally, a farm-depending variable is defined, indicating its status of manure offering or manure demanding agent. Farms that produce more organic nitrogen than their emission rights (surplus farms), will utilize their quota for organic nitrogen as much as possible (so that the excess of manure is as small as possible), resulting in a smaller limitation. Because of imperfect market conditions, the incentive of deficit farms to keep their quota of organic nitrogen maximal is lower. Because surplus farms can be expected to react more heavily on changing manure pressure, an interaction term with local manure pressure is added. , i.e. a higher manure pressure causes higher costs for surplus farms. Variables used in the Tobit regression are summarized in Table 2.

The Tobit regression model then becomes:

$$LIM_{it}=C_{it}+ \beta 1\ grassland_{it} + \beta 2\ corn_{it} + \beta 3\ sugar\_beet_{it} + \beta 4\ LowN_{it} + \beta 5\ other_{it} + \beta 6\ manure\_pressure_{it} + \beta 7\ surplus\_farm_{it}+ \beta 8\ MAP_{it} + \beta 9\ surplus\_farm_{it}*manure\_pressure_{it} +\mu_{it} \quad (2)$$

IV. RESULTS AND DISCUSSION

Table 3 and Table 4 show the data that characterises the manure problem in Flanders.

2. [2] Degree of acceptance : share of manure actually applied to a specific crop cultivated in a specific field from the theoretical amount of applied manure which maximizes crop yield [15]

3. [3] The regional manure pressure is the dual variable of a linear normative programming model which describes the transport behaviour with fully exploitation of the emission rights of organic nitrogen [16]

Table 2 Variables used in the Tobit model

Variable	definition	mean
limitation	('use of inorganic nitrogen' –'free fertilization zone inorganic nitrogen')/ha	6.689
Grassland	Share of grassland at the farm	0.452
Maize	Share of maize at the farm	0.202
LowN	Share of low N crops at the farm	0.047
Other	Share of hectares of other crops at the farm	0.175
Manure pressure	Proxy of manure pressure in the region of the farm	0.846
Surplus farm	More production of organic nitrogen than emission rights No=0; Yes=1	0.234
MAP	Change in manure policy: 2002=0; 2003-2005=1	0.799

At aggregated level and with full utilization of the emission rights for organic nitrogen, Flanders would not face a manure problem, e.g. in 2005 9.7% of the total emission rights for organic nitrogen were not filled up (Table 3). But as some farmers choose to not fully use their emission rights for organic N, many manure producing farms cannot find enough disposal rights. Therefore, almost 30% of the Flemish farms had a manure surplus in 2005. On the other hand, almost 12% of the Flemish farms applied more inorganic fertilizers than their FFZI (Table 4). At aggregated level, the FFZI exceeded more than 3 million kg N. This is 14% of the total surplus of organic N in Flanders.

The interaction mechanism supports the need for a detailed analysis of the possible contribution of inorganic fertiliser use to the problem. As explained earlier, the impact of inorganic fertiliser on the available organic manure quota is best described by the variable LIM. Table 5 shows the results of a Tobit regression of the impact of farm characteristics and policy on the 'limitation'-behaviour.

The magnitudes of the estimated coefficients from a Tobit model cannot be interpreted directly as slope coefficients (change in share with a unit change in an explanatory variable), however, their signs, significance and relative importance can be interpreted directly [17][18].

The results confirm the hypothesis that the increasing quota rent of organic manure stimulates the utilisation of the organic manure quota leading to a lower limitation of the organic quota. This can be clearly seen when comparing Fig. 2 and Fig. 3.

Fig. 2 gives the regional manure pressure for each Flemish municipality while Fig. 3 gives the share of the organic quota that is limited by the use of inorganic fertilizers. Looking at both figures it is clear that the higher the manure pressure is (i.e. the further away from an area with free emission rights) the less the limitations will be.

The results also confirm the hypothesis that farms with an organic manure surplus make a significantly different trade-off between organic and inorganic manure. When more organic nitrogen is produced on the farm compared to the volume that can be disposed on the farm land (surplus_farm =1), the limitation is smaller.

Table 3 Figures at aggregated level in Flanders (source: own calculations based on ALF-database)

year	Total emission right of organic N (kg N)	Total use of organic N (kg N)(*)(**)	Not used emission rights organic N (kg N)	Percentage of surplus farms (***) (%)	Surplus of organic N in surplus farms (kg N)
2002	179,676,241	145,560,232	34,116,009	25.8	18,754,737
2003	144,783,638	135,259,729	9,523,909	36.2	23,978,308
2004	144,546,765	133,547,520	10,999,245	31.4	23,208,290
2005	142,596,948	128,720,995	13,875,953	29.3	21,540,764

*the total use of organic N is the sum of the produced manure, the incoming manure and the purchased other organic materials (like compost, etc) reduced by the outgoing manure

** figures about processing the manure at the farm itself are not known

*** farms with an excess of organic nitrogen

Table 4 Figures at aggregated level in Flanders for inorganic nitrogen and the interdependency between organic and inorganic nitrogen (source: own calculations based on ALF-database)

Year	Total use of inorganic N (kg N)	Farms with a positive limitation (%)	Aggregated limitation in Flanders (kg N)	Percentage of limitation of total manure surplus at surplus farms (%)
2002	32,764,073	26.5	8,383,724	44.7
2003	36,712,952	14.2	3,714,374	15.4
2004	36,510,260	14.3	3,865,725	16.6
2005	34,678,991	11.9	3,006,611	14.0

Table 5 Tobit model of limitation per hectare of land

	Coefficient	Std. Error	z-Statistic	Prob.
C(1)	-15.41702	1.682013	-9.165816	0.0000(***)
Grassland	-89.80413	1.973303	-45.50955	0.0000(***)
Corn	-10.15534	2.157982	-4.705941	0.0000(***)
LowN	55.60214	2.415379	23.02005	0.0000(***)
Other	21.51224	2.093373	10.27635	0.0000(***)
MAP	-40.44623	0.719933	-56.18057	0.0000(***)
Manure_pressure	-2.017080	0.053301	-37.84344	0.0000(***)
Surplus_farm	-48.58333	0.969191	-50.12772	0.0000(***)
Surplus_farm*manure_pressure	1.922771	0.143121	13.43463	0.0000(***)
Log-Likelihood function	-166,012			
LLR test against intercept only (8 d.f.)	-19,808 (***)			
Number of observations	137,987			
Mc-Fadden Pseudo R^2	0.056			

*** indicates significance at alpha = 0.001

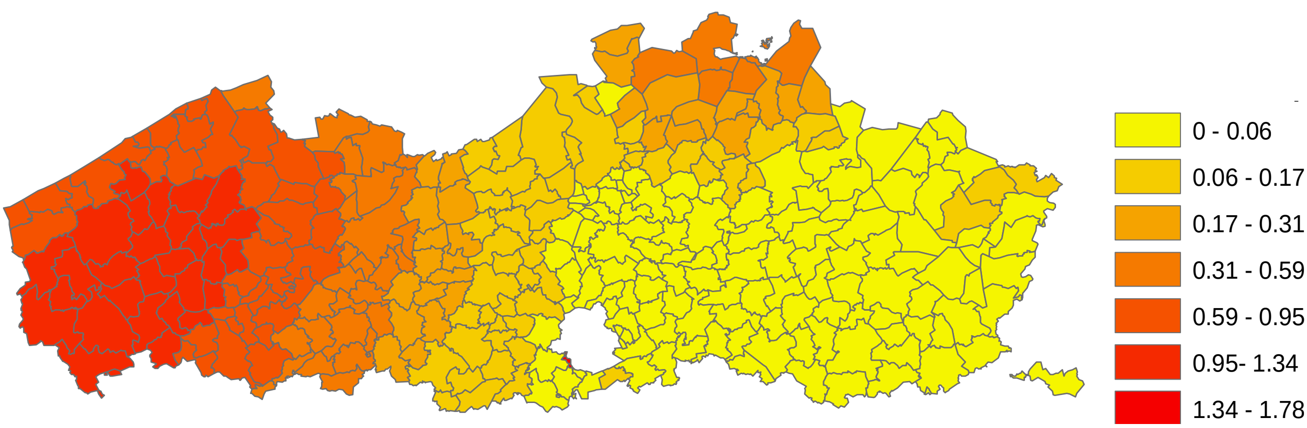

Fig. 2 Regional manure pressure or quota (expressed as the shadow price of quota restriction, in euro/ kg N)

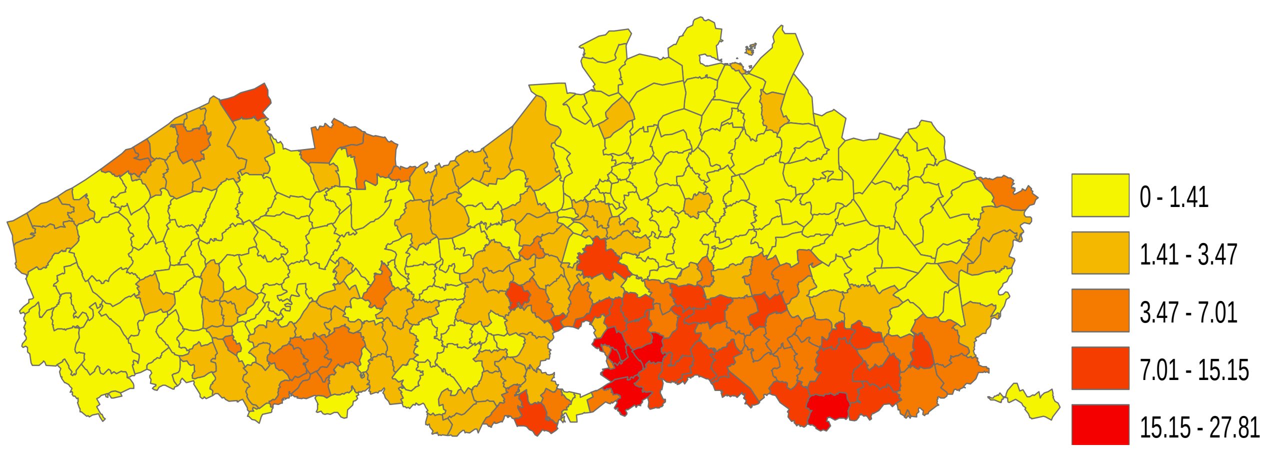

Fig. 3 share of the quota for organic nitrogen that is restricted by the use of inorganic fertilizers (in %)

When, on the other hand, less nitrogen is produced on the farm compared to the volume that can be disposed on the farm, perfect market conditions would imply that the deficit farm would accept manure or sell manure emission rights. However, the results indicate that this perfect market assumption does not hold, probably due to transaction costs.

Finally, the significant interaction term shows that surplus and deficit producers of organic nitrogen react differently on a changing manure pressure in the region. The sign is, however, the opposite of what one at first sight may expect. Surplus farms react less heavily on changing manure pressures than it is the case for deficit farms. Nevertheless growing manure pressure can be expected to lead to higher discharge costs at surplus farms, contrary to deficit farms which do not face these extra costs. The

explanation can be found through looking more closely at the initial farm behaviour at a low manure pressure. To keep the discharge costs as low as possible, even with a low manure pressure, surplus farms will minimize the amount of manure that has to be transported or processed. Therefore the limitation of the organic quota on these farms will be rather small. Because of this already optimal categories with a very limited FFZI will lead to a lower limitation value. Increasing importance of grassland, which has the largest FFZI, in the total farm acreage will behaviour, changing manure pressure has a rather small impact on farm behaviour. However deficit farms do not act in an optimal way by a low manure pressure. A growing manure pressure leads to a higher amount the surplus farms is prepared to pay to farms which are willing to accept manure. Emission rights are becoming more valuable and this can incite deficit farms to dispose more emission rights and therefore to keep the limitation smaller than it is the case at a low manure pressure. Besides the quota rent, other aspects play a role as well. The positive effects of inorganic fertilizers make organic nitrogen inferior to inorganic nitrogen. Farmers will always make use of inorganic fertilizers, even when this use could affect the emission rights of organic nitrogen. This becomes obvious, when looking more closely into the results. If farmers would give preference to organic nitrogen, the use of inorganic fertilizers would be limited by the FFZ of inorganic nitrogen (and thus limitations would be zero). Crop categories with a large FFZI have a negative impact on limitation while a greater share of crop lead to a smaller limitation. The LowN crops have no FFZI.

An increasing importance of this category will lead to the largest positive effect on limitation. Corn and other crops have an intermediate FFZI, resulting in an intermediate effect on limitation. This indicates that the farmer's behaviour is not influenced by the amount of inorganic nitrogen he can freely dispose without affecting the quota of organic nitrogen. Contrarily, he prefers the optimal use of inorganic nitrogen to the maximum use of organic nitrogen.

In 2003, the manure policy has changed, resulting in more stringent quota for organic nitrogen. This change in policy has led to significant smaller limitations. The more rigid quota for organic nitrogen lead to a larger FFZI. Farmers can apply more inorganic fertilizers without affecting their quota for organic nitrogen. In Table 4 is shown that indeed the use of inorganic fertilizers has increased but the limitation at the same time has decreased. Also the application of organic N has decreased because of the policy change (table 3).

This result weakens the previous statement that optimal use of inorganic nitrogen is superior to the maximum use of organic nitrogen. The farmer makes a trade-off between optimal use of inorganic nitrogen and using as much organic nitrogen as possible. When FFZI is low, the optimal use of inorganic nitrogen lies above the FFZI. If the use of inorganic nitrogen were optimal, the use would not change by changing FFZI. However, when FFZI raises, the optimal use of inorganic nitrogen will increase as well but, as the decreasing LIM values indicate not as much as the FFZI does.

V. CONCLUSIONS

The aim of current paper was to analyse the interaction between both nitrogen types and the impact of the use of inorganic fertilizers on the Flemish manure surplus. The rationale behind this was the ineffective exchange of manure, even with sufficient disposal possibilities at the regional level. By means of a Tobit panel model we have estimated the trade-off made at farm level between maximum utilisation of available organic nitrogen quota for manure abatement and the need to use inorganic nitrogen fertilizer for optimum plant productivity.

Results show that farmers still prefer inorganic nitrogen, which confirm earlier findings of [1] that for farmers the use of inorganic nitrogen is superior to the use of organic nitrogen. In addition to the Feinerman and Komen findings, our results show that the superiority of inorganic nitrogen is driven by maximisation of crop yields but this can be traded off by other economic motivations. Crop yields are positively affected by applying inorganic manure. The intensity of the effect can vary among different crops. Based on the crop characteristics the farmer will set an optimal use of inorganic nitrogen. On the other hand, for the sector as a whole it is important to dispose manure in the most cost-friendly way, meaning to dispose manure as much as possible on the available land (while avoiding processing costs). Because of the imperfect market conditions on the emission rights market, the farmer will base his trade-off choices on farm-level conditions rather than on theoretical regional-level considerations. So, economic conditions at farm level will definitely play a part as well.

The observed inorganic fertilizer use is below the optimal use of inorganic nitrogen. This suboptimal use is due to the trade-off considerations made by farmers. The farmers would increase the amount of inorganic nitrogen if it were possible without affecting the maximum use of organic nitrogen. However, because of the mutual interdependency of both nitrogen types and the value of the organic nitrogen quota, the optimal level is not applied by farmers. This trade-off is significantly influenced by the organic nitrogen quota rent. A higher organic nitrogen quota rent will favour the use of organic nitrogen. If the initially applied level of inorganic nitrogen does not compromise the maximum allowable use of organic nitrogen, nothing will change.

This observed behaviour will influence policies' effectiveness. The Nitrate directive, for example, reduces the organic nitrogen quota. Based on our results, more stringent quota for organic nitrogen then cause a shift to a higher utilisation of inorganic nitrogen at farm level when the quota of total nitrogen or inorganic nitrogen is not adapted accordingly. As long as the optimal level of inorganic nitrogen has not been reached, a one-side reduction of the organic nitrogen quota will therefore be ineffective but also inefficient because of the increased manure disposal costs for the farmers.

Given this trade-off behaviour of farmers, new policy options have to be sought. The farmer's sensitivity to quota rent tempts to increase the quota rent which will lead to a higher utilisation of organic nitrogen. Especially deficit farms will accept more organic nitrogen when quota rent increases. Quota rent for deficit farms increases when transaction costs decreases. Lower transaction costs can lead to an upward shift in demand and supply curve of emission rights resulting in a higher utilisation of these rights. Lowering transactions costs can e.g. be achieved by creating an electronic forum to link demanders and suppliers of emission rights or by lowering transport costs.

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