Legume-supported cropping systems for Europe

Legume Futures Report 4.4

GHG mitigation costs through legume based agriculture

Compiled by

Benjamin Dequiedt, Vera Eory, Juliette Maire

30 March 2014

Legume-supported cropping systems for Europe (Legume Futures)
is a collaborative research project funded by the European Union through the
7th Framework Programme under grant number 245216 CP-FP
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Legume Futures

Legume-supported cropping systems for Europe (Legume Futures) is an international research project funded by the European Union through the Framework 7 Programme (FP7) under grant agreement number 245216 (FP7-KBBE-2009-3). The Legume Futures research consortium comprises 20 partners in 13 countries.

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Citation

Please cite this report as follows:

Dequiedt, B., Eory, V., Maire, J., Topp,C. F.E., Rees, R. M., Zander,P., Reckling, M., Shlaefke, N. 2014. GHG mitigation costs through legume based agriculture. Legume Futures Report 4.4. Available from www.legumehub.eu

CONTENTS

ABSTRACT

The aim of the research reported here was to assess regional greenhouse gas (GHG) reduction potential due to changing rotations at farm-scale. Rotation data generated for the research reported In Legume Futures report 4.2 from Task 4.2 were used, complemented with nitrous-oxide (N_2O) emissions calculations. This research assessed the GHG abatement cost by using a bottom-up approach, assuming that the farmers are minimizing the abatement cost. Results show aggregated “win-win” abatement potential in the five NUTS2 regions of 11% to 16% of the baseline soil N_2O emissions from arable areas. The total dry matter (DM) production is increases, while the area under cereal production is decreases at this level of GHG abatement.

1 OBJECTIVES

In its latest communication on the climate policy framework, the European Commission set an ambitious target of greenhouse gas (GHG) emissions reduction by 40% below the 1990 level in 2030.[1] This effort follows the recommendations of scientists of the Intergovernmental Experts Group on the Climate Change (IPCC) to contain the average temperature increase below 2°C globally by the end of the century. According to the Annual European Union Greenhouse Gas Inventory, the EU-27 emitted 4,550 Mt CO_2 equivalents in 2011, with the agricultural sector being the second largest emitter, with 461 Mt CO_2 equivalents emissions (10.1 %).[2]

Among the numerous practices suggested to mitigate GHG emissions, one is to increase the cultivation of legumes in crop rotations and on grasslands. Legumes are able to fix nitrogen from the atmosphere, therefore they need no or very little additional nitrogen (N) fertiliser. Additionally, their ability to provide N to the following crop has been demonstrated many times.[3] This effect allows higher yields from succeeding crops at the same fertiliser rate or a reduced fertiliser use for the same yield or a combination of both. Grain and forage legumes are currently grown on 180 M ha worldwide and their extent is expected to increase as the demand for legume production for dietary protein increases.[4] However, the European context is less promising, the use of legumes as grains and forage has declined throughout the EU from 11.3 M ha in 1961 to about 3.4 M ha in 2005.[5]

To assess the GHG abatement cost in the European agriculture via increasing the share of legumes in crop rotations, the marginal abatement cost curves (MACC) analysis was used, which shows the cost of on additional unit of abatement at different level of total emission abatement. MACCs have already been developed to illustrate the economics of climate change mitigation in agriculture. De Cara and Jayet assessed the cost-effectiveness of agricultural mitigation in Europe (2011).[6] The UK government has used

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[1] European Commission, 2014. Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions. A policy framework for climate and energy in the period from 2020 to 2030. Brussels 22.1.2014.
http://ec.europa.eu/clima/policies/2030/docs/com_2014_15_en.pdf

[2] UNFCCC National Inventory Report, 2013

[3] Charles, R., Vullioud, P. 2001. Pois protéagineux et azote dans la rotation. Revue Suisse d'Agriculture 33 (6), 265–270.

[4] Graham PH, Vance C.P. 2003. Legumes: importance and constraints to greater use. Plant Physiol 131:872 – 877

[5] FAOSTAT 2011 data, accessed: January2014 for the year 2011.

[6] De Cara & Jayet, 2011. Marginal abatement costs of greenhouse gas emissions from European agriculture, cost-effectiveness, and the EU Non-ETS burden sharing agreement. Ecological Economics, 70(9), 1680–1690.

MACCs to evaluate climate policy in all sectors of the economy[7], and an agricultural MACC was also developed for France.[8] According to the latter, legumes could reduce GHG emissions by 1.4 Mt CO_2eq, with a mean abatement cost of -52 €/tCO_2eq. However, a detailed analysis of crop rotations suitable for specific farm types has not been undertaken.

This research assesses five NUTS2 regions in Europe, representing a diversity of land types and agroecological zones: Eastern Scotland (UK); Västsverige (Sweden); Brandenburg (Germany); Sud-Muntenia (Romania); Calabria (Italy). These regions are depicted by 13 representative site classes with different soil features, agricultural practices and crops. This information was collected in an agronomic survey that supported research reported in Legume Futures report 4.2.[9] Based on the agronomic practices, that research generated possible rotations for the 13 site classes (in total more than 129 000 potential rotations). Economic data, such as costs, income and labour requirements related to the crops were also collected and crop-specific gross margin (GM) data were generated for the year 2010.

Soil-based nitrous-oxide (N_2O) emissions from crop cultivation were calculated with the IPCC 2006 Tier 1 methodology (Paustian et al. 2006), based on the fertilisation and yield data referred to above. The emissions include direct and indirect N_2O emissions from synthetic N applied, manure N applied and N from crop residues. The average annual GM and N_2O emission of each rotation were calculated as the mean of the annual GM and emissions, respectively. Two agronomic scenarios were examined: yield-increase and N-decrease. The first assumes that the pre-crop effect causes an increase in the following crop's yield with no change in the fertilization practice (yield change data as reprted in Legume Futures report 4.2), while the second assumes that the N fertiliser is reduced by 20% for the following crops with no change in their yield.

The next part of this report describes the methodology used to the data processing and the MACCs creation. The following section presents the results of the MACC model with the abatement cost curves, crop production and crop area evolution. The discussion of the results is presented in the third section.

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[7]MacLeod, M., Moran, D., Eory, V., Rees, R., Barnes, A., Topp, C. F., Ball, B., Hoad, S., Wall, E., McVittie, A., et al. (2010). Developing greenhouse gas marginal abatement cost curves for agricultural emissions from crops and soils in the UK. Agricultural Systems, 103(4), 198–209.

[8]INRA, 2013. Quelle contribution de l'agriculturefrançaise à la reduction des emissions de gaz à effet de serre? Potentield'atténuation et coût de dix actionstechniques. Synthèse du rapport de l'étuderéalisée par l'INRApour le compte de l'ADEME, du MAAF et du MEDDE

[9] Reckling, M., Schläfke, N., Hecker, J.-M., Bachinger, J., Zander, P., Bergkvist, G., Frankow-Lindberg, B., Båth, B., Pristeri, A., Monti, M., Toncea, I., Walker, R., Topp, K., and Watson, C. 2014. Generation and evaluation of legume-supported crop rotations in five case study regions across Europe. Legume Futures Report 4.2. Available from www.legumefutures.de

2 METHODOLOGY

Data description

This research uses the database used in research reported by Reckling et al.[10]. To capture the bio-physical and socio-economic variability of agronomic systems accross Europe, five contrasting NUTS2 regions where selected as case study areas. Crop rotations were generated for each case study region separately. Within the case study regions, a local typology of site classes was formulated. 13 site classes were defined: 5 from Brandenburg, 1 from Sud-Muntenia, 3 from Calabria, 3 from Eastern Scotland and 1 from Västsverige (see Appendix 7 for more details of the site classes). Region-specific crop rotation rules were the basis for generating crop rotations of 3 to 6 years for each case study region. These represent agronomically feasible cropping options for the arable areas, including crops that are currently grown and potential grain and forage legumes.

The crop information we used in included the crop type, preceding crop type, yield, dry matter (DM) content, synthetic and organic fertiliser amount, costs, income and labour requirements, and rotation-specific information on the crop sequence.

The N_2O emissions for each crop were calculated using the IPCC's 2006 Tier 1 methodology[11] (see Appendix 1 for more details). As forage price data were not available in the above database, forage crops' GM was calculated by using external price data. The annual N_2O emissions and GM of each crop rotation were calculated as the average of the rotation.

The frequency of crops presented in rotations in the different site classes (Table 1) does not reflect the statistical crop proportions of the site class, as the possible rotations are generated to represent all agronomically feasible rotations, rather than a representative set of rotations used in the site classes. However, it gives an overview of the crops appearing at different site classes, and gives an indication of the composition of the rotations. For instance, grass appears in 8 out of 18 rotations on Grade 4 sites (Eastern Scotland) – the high GHG emissions and low gross margin of this crop influences these eight rotations and subsequently the MAC curve.

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[10]Reckling, M., Schläfke, N., Hecker, J.-M., Bachinger, J., Zander, P., Bergkvist, G., Frankow-Lindberg, B., Båth, B., Pristeri, A., Monti, M., Toncea, I., Walker, R., Topp, K., and Watson, C. 2014. Generation and evaluation of legume-supported crop rotations in five case study regions across Europe. Legume Futures Report 4.2. Available from www.legumefutures.de

[11] Paustian,K., N.H.Ravindranath, and A.van Amstel (2006) IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme. Eggleston, H. S., Buendia, L., Miwa, K., Ngara, T., and Tanabe, K. Japan, IGES.

Table 1. Crop-frequency in the rotations (for crop abbreviations see Appendix 8, for site class abbreviations see Appendix 7)

Region	**Brandenburg**					**Calabria**			**S-Muntenia**	**Eastern Scotland**			**Västsverige**
Site class	LBG 1	LBG2	LBG3	LBG4	LBG5	irrigated highland	irrigated lowland	rainfed	chernozem	Grade 1&2	Grade 3	Grade 4	clay
No. of rot.	345	2724	902	78	9	14	28	905	137	33852	33890	18	44607
alfalfa	215	1203	443	0	0	3	5	0	0	0	0	0	0
clover	0	0	0	0	0	3	0	13	0	0	0	0	0
combean	0	0	0	0	0	0	0	0	35	0	0	0	0
durum	0	0	0	0	0	0	6	227	0	0	0	0	0
fababea	202	729	0	0	0	0	17	440	0	15345	15345	0	2016
graclov	0	126	109	48	0	0	0	0	0	0	20	10	100
grass	0	0	0	0	0	0	0	0	0	0	18	8	100
linseed	0	0	0	0	0	0	0	0	0	0	0	0	22733
lupin	0	0	248	31	3	9	0	0	0	0	0	0	0
maize_g	0	0	0	0	0	0	0	0	90	0	0	0	0
maize_s	277	1839	637	66	0	0	24	0	0	0	0	0	9629
oatvetc	0	0	0	0	0	0	0	440	0	0	0	0	0
pea	0	909	262	31	0	0	17	440	63	13872	13872	0	19666
peaoat	0	0	0	0	0	0	0	0	0	0	0	0	19667
potato	0	0	0	0	0	14	0	0	0	25098	25098	0	0
ryevetc	0	0	0	0	7	0	0	0	0	0	0	0	0
sbarley	0	1172	440	0	0	0	0	0	0	22648	22669	11	21164
seradel	0	0	0	0	3	0	0	0	0	0	0	0	0
soat	0	1385	480	0	0	0	0	0	0	17261	17282	11	26308
soybean	0	0	0	0	0	0	0	0	35	0	0	0	0
srape	0	0	0	0	0	0	0	0	0	20007	20011	0	14718
sunfl	0	0	0	0	0	0	0	0	28	0	0	0	0
swedes	0	0	0	0	0	0	0	0	0	3141	3143	2	0
swheat	0	0	0	0	0	0	0	0	0	11584	11588	0	18225
tritica	130	986	0	0	0	0	4	307	0	0	0	0	19805
wbarley	125	689	0	0	0	0	6	329	79	14117	14121	0	0
woat	0	0	0	0	0	0	4	307	0	11032	11036	4	0
wrape	30	313	80	0	0	9	0	784	131	3414	3418	0	5646
wrye	228	1607	790	78	9	0	0	0	0	0	0	0	19805
wwheat	157	825	115	0	0	14	5	310	115	15587	15591	0	22623

Scenarios

4 scenarios were considered in the analysis: the combination of two agronomic ('Yield' and 'N-Decrease') and two methodological scenarios (A and B).

Scenario A: Selection of 25 rotations per site class

To assess whether a smaller set of rotations were sufficient to draw conclusions about cost-efficiency, abatement potential and rotation changes, 26 rotations were selected for each site class from the crop rotation database. The selection was made to include the rotations with the most extreme values on 4 metrics: GM, GHG emissions, total yield and share of legumes:

- 5 rotations with the highest GM (€/ha/year)
- 5 rotations with the lowest GHG emissions (tCO_2e/ha/year)
- 5 rotations with the highest total yield (t DM/ha/year)
- 5 rotations with the highest ratios of legume products in the total yield (DM%/year)
- 5 rotations with the highest GM which contain no legumes (€/ha/year)

If there were overlaps between the 5 selections, the number of selected rotations was lower. In addition to these 25 rotations one more rotation was selected to represent the baseline (see in Section 'Baseline') for the particular site class – for some site classes the baseline rotation was already part of the selected rotations.

Scenario B: Inclusion of all the rotations

Here all the possible rotations from Legume Futures Report 4.2 were included in the simulation. A total of 129,793 rotations were available for the 13 site classes, though the number of rotations per site class was very variable, ranging from 9 rotations (LBG5, Brandenburg) to 33,852 rotations (Grade 1&2, Eastern Scotland) (see also Table 1).

Scenario "Yield": Impact of legumes on yield

In this scenario the pre-crop effect of legumes is assumed to result in an increase in the following crop's yield, while the fertilization rate was kept at the same level (this is the assumption used in the research reported in Legume Futures Report 4.2).

Scenario "N-Decrease": Impact of legumes on N application

This scenario assumed that the farmer utilises the pre-crop effect, therefore the N fertilisation was decreased by 20% to obtain the same level of yield as would be obtained without proceeding legumes. This assumption was not assessed in the work reported in Legume Futures Report 4.2. New GM values and N_2O emissions were calculated based on the new yield and new fertiliser use data.

Legume preceding crop effect

For the N-decrease scenario, we assumed that the pre-crop effect allows a 20% reduction in N use while keeping the yield constant. This reduction is based on the UK's Fertiliser Manual[12], which assumes that the soil N supply is 30 kg N/ha higher after peas and beans than after cereals and suggests reducing the N applied accordingly. On average, the total N fertiliser use in these five NUTS2 regions is below 80 kg N/ha[13], therefore the assumed 20% reduction is likely to be underestimating the N_2O savings achievable. For the organic fertiliser field application was reduced by 20% as well, but as this surplus of organic N is assumed to be used on other fields, producing the same amount of N_2O as it would have produced on the original field. However, due to this surplus of organic N applied, the synthetic N use on the other field was reduced by 1/3 of the organic N (assuming an N fertiliser replacement rate of 33%, again, a value in the lower range used in the different European countries[14]). Therefore the total N use reduction effect from the 20% reduction in organic N on field is thus assumed to be 6.66%.

Average land area composition

To define each crop's share of the land area the number of years when the crop is cultivated in the rotation is divided by the overall length of the rotation. For instance, for a 6-yer rotation with 2 years wheat the share of wheat is 33%.

Baseline rotations

The carbon emissions abatement is calculated against a baseline rotation in each site class (Table 2). The baseline rotations were selected based on the share of legumes in the rotation and the GM. First, rotations were selected where the legumes' share was the closest to the proportion of legumes at the national level. In all the five European countries the proportions of legume were below 6%.[15] In the possible rotations the share of legumes was calculated on the basis of the number of years in the rotation that legumes were cultivated. Since the longest rotation was 6 years, the smallest non-zero legume proportion possible was 16.6%, therefore rotations without legumes were selected for baselines. From the set of non-legume rotations the rotation with the highest

[12] Defra, 2011. Fertiliser Manual RB209. Updated 22 April 2013. Tables A-C, p. 91-93. and p. 105-112

[13] Commission staff working document on implementation of Council Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources based on Member State reports for the period 2004-2007 (map on page 18), ec.europa.eu/environment/water/water-nitrates/pdf/swd.pdf.

[14] Webb, J., Sorensen, P., Velthof, G.L., Amon, B., Pinto, M., Rodhe, L., Salomon, E., Hutchings, N., Burczyk, P. and Reid, J. (2010) Study on variation of manure N efficiency throughout Europe - Final report. Report no: ENV.B.1/ETU/2010/0008, DG Environment.

[15] Data for winter rye, rape, barley, maize, wheat, sunflower and soybean from Eurostat (2010), data for faba bean, lupin, oat, pea from FAOSTAT (2011). Accessed: January2014

GM was selected. The baseline rotations are described in Table 2 and diagrams in Appendix 5 show the position of the baseline rotation relative to all the possible rotations in scenario B_N-Decrease.

Table 2. Baseline rotations for the 13 site classes (for crop abbreviations see Appendix 8, for site class abbreviations see Appendix 7)

Region	Site Class	Crop Sequence						GM	Emissions	Yield
		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	€/year/ha	tCO2eq/year/ha	kgDM/year/ha
Brandenburg	LBG1	wrape	wwheat	wbarley				288.30	1.53	5,545
Brandenburg	LBG2	wrape	wwheat	wbarley				161.16	1.41	4,647
Brandenburg	LBG3	wrape	wrye	maize_s	wrye	sbarley		62.14	1.24	5,006
Brandenburg	LBG5	wrye	wrye	wrye	wrye			-174.95	0.44	2,494
Brandenburg	LBG4	wrye	wrye	wrye	wrye			-72.87	0.57	3,526
Calabria	rainfed	wrape	woat	wrape	wbarley			285.00	0.52	2,277
Calabria	Irrigated highland	potato	wrape	wwheat	wrape	wwheat		633.78	0.73	2,733
Calabria	Irrigated lowland	maize_s	wbarley					517.95	1.21	7,525
South-Muntenia	chernozem	sunfl	wwheat	wwheat	wrape	wbarley		246.61	0.97	3,074
Eastern Scotland	Grade_1et2	potato	wwheat	wwheat	wwheat	wwheat	wrape	1525.42	2.17	8,218
Eastern Scotland	Grade_3	potato	wwheat	wwheat	wwheat	wbarley	wrape	1484.32	2.13	8,003
Eastern Scotland	Grade4	grass	grass	grass	sbarley			527.03	2.87	6,190
Västsverige	clay_soil	wwheat	wwheat	wwheat	wwheat	soat		592.89	1.31	3,695

Marginal Abatement Cost Curve

A MACC was generated for each site class and for each scenario (13x4 site-class specific MACCs), for each NUTS2 level x scenario (5x4 MACCs) and an aggregate MACC for the four scenarios (4 MACCs). The rotations were characterized by two metrics: GM and N_2O emissions. The MACC model is based on the assumption that the farmers are profit-maximizing, i.e. their decisions are made on the basis of financial gains. The model is field-based, i.e. for each site class at any given time only one rotation can be applied. Consequently, the farmer chooses the rotation with the lowest marginal abatement cost. The difference in GM per emission unit is calculated for all available rotations as follows:

$$Marginal\ Abatement\ Cost_{r+1} = \frac{Gross\ Margin_{r+1} - Gross\ Margin_{r}}{Emission_{r+1} - \ Emission_{r}}$$

$MarginalAbatementCost_{r+1}$: the additional loss of profit of the additional rotation (r + 1) in € per tCO_2eq. This cost is negative when the additional rotation is more profitable than the baseline.

$GrossMargin_{r+1}$: GM of the additional rotation (€/ha/year)

$GrossMargin_{r}$: GM of the current rotation (€/ha/year)

$Emission_{r+1}$: N_2O emissions of the additional rotation (tCO_2eq/ha/year)

$Emission_{r}$: N_2O emissions of the current rotation (tCO_2eq/ha/year)

Eventually, the selection of rotations starts with the one with the lowest marginal abatement cost and then moves towards those with higher marginal abatement costs. The selection pathway is illustrated for one site class – LBG3 in Brandenburg – in Appendix 6. Graphs of the report present the results for the marginal abatement cost ranging from -300 €/tCO_2eq to +400 €/tCO_2eq.

Along with GHG abatement and the marginal abatement cost, the DM production, the land area covered by cereals, non-legume forages, grain legumes, and legume forages (including grass-legume mixtures) were also calculated.

Extrapolating the results

The site class results were extrapolated to NUTS2 levels based on the share of each site class of the NUTS2 region's arable area (see Appendix 7). The total arable area of the five NUTS2 regions is 4.04 M ha, representing 1.1% of the arable land in the EU-27[16]. For the aggregated results the profit for each region was calculated based on the GM (see Appendix 1).

[16]Eurostat, 2010 data; Accessed: February 2014

Economically efficient cost-effectiveness

The economically efficient cost-effectiveness threshold is approximated by the carbon value used by the UK Government, which is €45 /t CO_2eq (£52 /t CO_2eq) in the non-traded sector in 2010 (central value).[17]

[17] Department of Energy and Climate Change (2009) Carbon Valuation in UK Policy Appraisal: a revised Approach'

3 RESULTS

The aggregated results of the five NUTS2 regions for the four scenarios, up to an abatement cost of 400 €/tCO_2eq, showing the marginal abatement cost, the profit, the total crop, fodder legumes and grain legumes production, and the crop areas, respectively, are illustrated in Figures 1-6. The GHG abatement is associated with financial savings up to 0.4-0.7 Mt CO_2eq for the four scenarios (Figure 1); these "win-win" opportunities result in a strong increase in the total profit from €1.5 billion to €3-3.5 billion (Figure 2). Beyond this point rotations switch toward less profitable rotations, decreasing the total profit. The maximum abatement potential (at €400/t CO_2eq) was 0.9-1.5 Mt CO_2eq (21-30% of the baseline emissions).

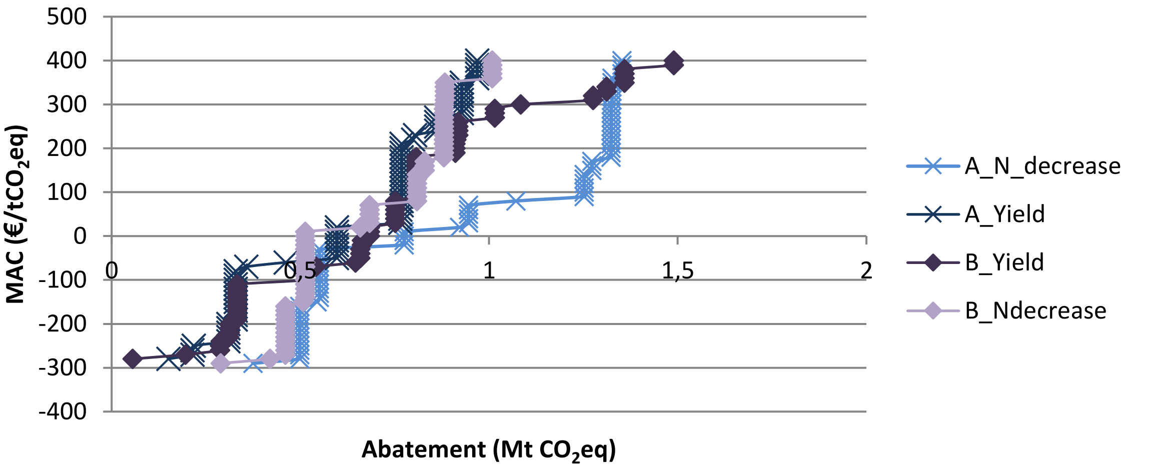


Figure 1. Aggregated MACCs for the 5 NUTS2 regions (for a cost efficiency from -290 €/t CO_2eq to 400 €/ t CO_2eq)

Notes: **A_N-Decrease**: 25 selected rotations per site class; pre-crop effect decreases the N rate, **A_Yield**: 25 selected rotations per site class; pre-crop effect increases the yield, **B_Yield**: all rotations per site class; pre-crop effect increases the yield, **B_N-Decrease**: all rotations per site class; pre-crop effect decreases the N rate.

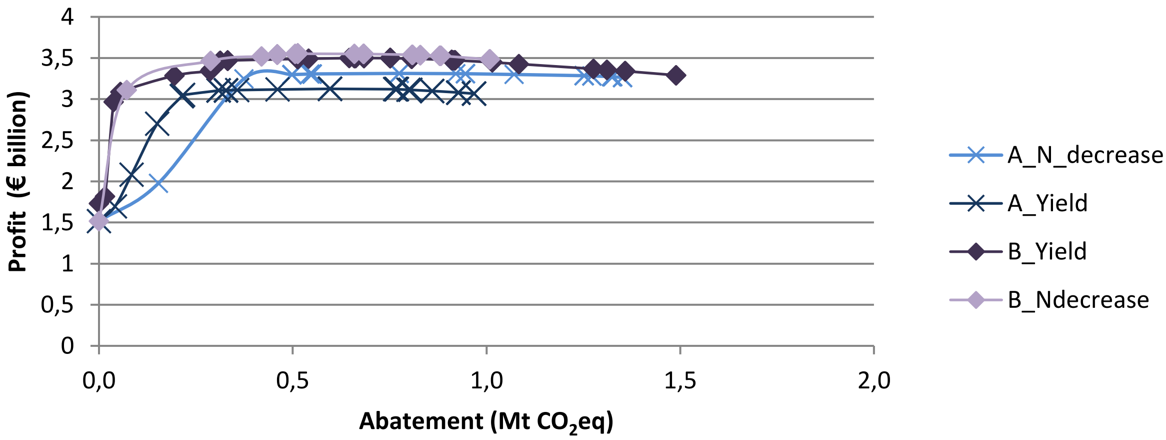


Figure 2. Total profit in the 5 NUTS2 regions

Notes: **A_N-Decrease**: 25 selected rotations per site class; pre-crop effect decreases the N rate, **A_Yield**: 25 selected rotations per site class; pre-crop effect increases the yield, **B_Yield**: all rotations per site class; pre-crop effect increases the yield, **B_N-Decrease**: all rotations per site class; pre-crop effect decreases the N rate.

In all the scenarios the total DM production first increased by around 15% (up to an abatement of 0.3 Mt CO_2eq) and then decreased, but did not fall below the level of the baseline production (16.3-18.4 Mt DM) (Figure 3). The abatement was associated with an increase in grain and fodder legume production, as rotations with lower emissions were introduced. As explained in the methodology section, no baseline rotation in any site class included legumes, so legume production started at zero. When abatement was generated, the fodder legumes production increased to 2.5-3.0 Mt DM (Figure 4). The grain legume production reached a maximum of 1.7-1.9 Mt DM at an abatement of 1 Mt CO_2eq (Figure 5).

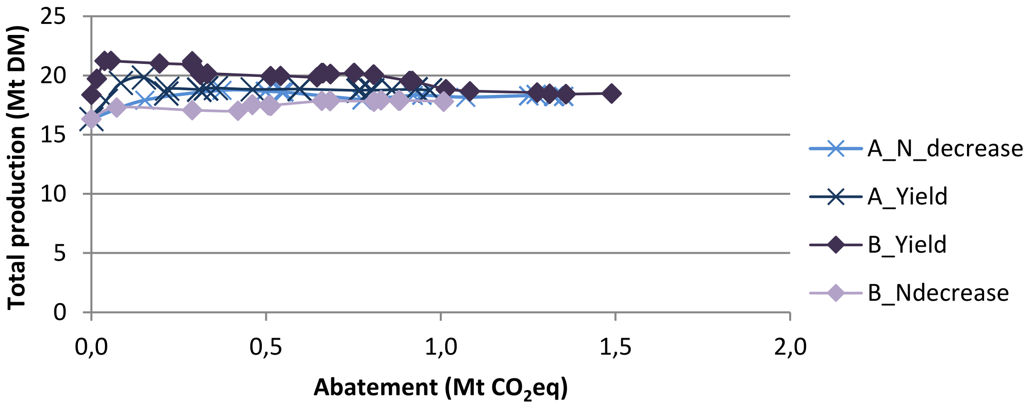


Figure 3. Aggregated total crop production in the 5 NUTS2 regions
Notes: **A_N-Decrease**: 25 selected rotations per site class; pre-crop effect decreases the N rate, **A_Yield**: 25 selected rotations per site class; pre-crop effect increases the yield, **B_Yield**: all rotations per site class; pre-crop effect increases the yield, **B_N-Decrease**: all rotations per site class; pre-crop effect decreases the N rate.

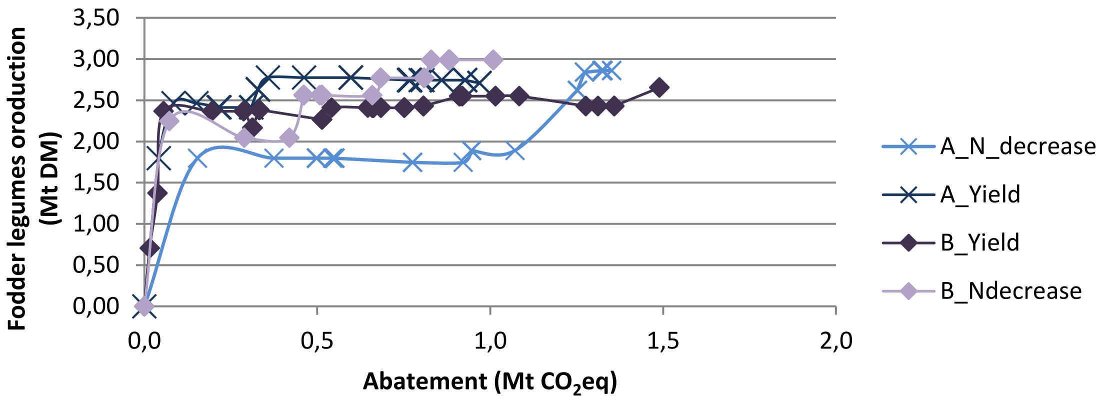


Figure 4. Aggregated fodder legumes production in the 5 NUTS2 regions

Notes: **A_N-Decrease**: 25 selected rotations per site class; pre-crop effect decreases the N rate, **A_Yield**: 25 selected rotations per site class; pre-crop effect increases the yield, **B_Yield**: all rotations per site class; pre-crop effect increases the yield, **B_N-Decrease**: all rotations per site class; pre-crop effect decreases the N rate.

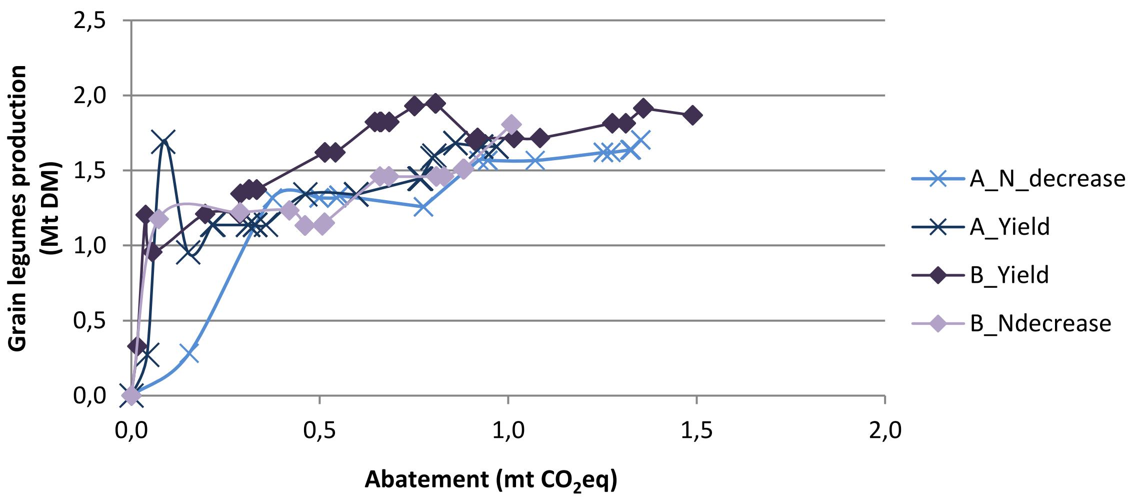
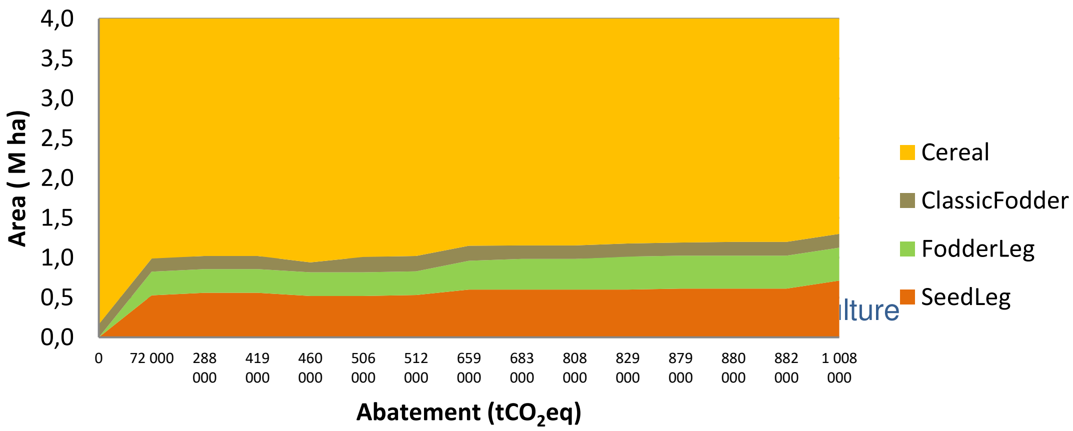


Figure 5. Aggregated grain legumes production in the 5 NUTS2 regions

Notes: **A_N-Decrease**: 25 selected rotations per site class; pre-crop effect decreases the N rate, **A_Yield**: 25 selected rotations per site class; pre-crop effect increases the yield, **B_Yield**: all rotations per site class; pre-crop effect increases the yield, **B_N-Decrease**: all rotations per site class; pre-crop effect decreases the N rate.

The cereal area showed a continuous decrease as it was substituted by grain legumes,



fodder legumes and, to a lesser extent, non-leguminous fodder. Most of this replacement happened with the first rotation changes, up to an abatement of 0.1 Mt CO_2eq (Figure 6). NUTS2 level results on the changes in crop areas can be found in Appendix 3.

Figure 6. Crops areas aggregated for the 5 NUTS2 regions, scenario B_N-decrease (all rotations per site class; pre-crop effect decreases the N rate)

Regional results for the economically efficient cost-effectiveness (€45 €/t CO_2eq) for the B_N-Decrease scenario are illustrated in Tables 3-4. Eastern Scotland offered the highest relative cost-effective abatement: 28% reduction of the baseline soil N_2O emissions (0.62 tCO_2eq/ha/y, (Table 3). The biggest total abatement was achievable in Sud-Muntenia of 328 kt CO_2eq/y, also showing a high relative GHG mitigation of 18%. Brandenburg's and Calabria's cost-effective mitigation potentials were 6% and 7%, respectively, while the potential abatement was lowest in Västsverige (Sweden), with 5 kt CO_2eq/y for the whole region (1% of the baseline). Results for an imaginary 200 ha farm are presented in Table 4.

The GHG abatement was associated with an increase in profit in every region (Table 3). The region with the highest total increase in profit was Sud-Muntenia (€1.4 M), while in relative terms Brandenburg and Sud-Muntenia were associated with very high increases in profits (807% and 305%, respectively), and Västsverige, Calabria and Eastern Scotland showed more moderate profits increases of 33%, 20% and 16%, respectively.

All regions apart from Västsverige showed an increase in the share of legumes, and cereal areas have declined in three regions (Sud-Muntenia, Eastern Scotland and Brandenburg). In Calabria non-leguminous fodder was substituted by both grain legumes and cereals, while in Västsverige non-leguminous fodder was replaced by cereals, with no area increase for legumes. In Eastern Scotland the non-leguminous fodder area also increased alongside the legumes area.

Rotations providing both GHG abatement and financial savings at the same time included both fodder and grain legumes in Brandenburg (grass-clover mix, alfalfa, lupin, pea and faba bean), in Calabria (alfalfa and lupin) and in Eastern Scotland (grass-clover mix and pea), whereas in Sud-Muntenia only grain legumes appear in these rotations (common bean). In Västsverige there were no legumes in the 'win-win' rotations. More detailed results for the scenario B_N-Decrease on the composition of the rotations selected by the MACC model are presented in Appendix 2.

Table 3. Regional results for the baseline and for a cost-effectiveness of €45 /t CO_2eq, scenario B_N-decrease (all rotations per site class; pre-crop effect decreases the N rate)

		Fodder Legumes	Grain Legumes	Classic Fodder	Cereals	Emissions	Abatement		Profit	Crop production	Fodder legumes production	Grain legumes production
		ha	ha	ha	ha	kt CO_2eq/year	t CO_2eq	%	M €/year	kt DM/year	kt DM/year	kt DM/year
Calabria	**Baseline**	0	0	23,841	132,159	114	-	-	61	577	0	0
	45 €/tCO_2eq	0	8,014	0	147,986	107	7	6	73	607	0	17
Sud-Muntenia	**Baseline**	0	0	0	1,859,000	1,796	-	-	458	5,714	0	0
	45 €/tCO_2eq	0	464,750	0	1,394,250	1,468	328	18	1,855	5,855	0	1,035
Eastern Scotland	**Baseline**	0	0	24,091	399,909	931	-	-	604	3,364	0	0
	45 €/tCO_2eq	91,010	65,313	65,313	202,364	667	264	28	703	3,801	209	309
Brandenburg	**Baseline**	0	0	0	1,032,000	1,098	-	-	51	4,545	0	0
	45 €/tCO_2eq	297,185	59,888	101,605	573,322	1,019	80	7	461	5,615	2,562	97
Västsverige	**Baseline**	0	0	115,400	461,600	758	-	-	342	2,132	0	0
	45 €/tCO_2eq	0	0	0	577,000	753	5	1	456	1,982	0	0
Total	***Baseline***	***0***	***0***	***163,332***	***3,884,668***	***4,697***	-	-	***1,516***	***16,332***	***0***	***0***
	45 €/tCO_2eq	***388,196***	***597,965***	***166,918***	***2,894,922***	***4,014***	***683***	***15***	***3,549***	***17,861***	***2,771***	***1,459***

Table 4. Results for a 200 ha farm, for the baseline and for a cost-effectiveness of €45 /t CO_2eq, scenario B_N-decrease (all rotations per site class; pre-crop effect decreases the N rate)

		Fodder Legumes	Grain Legumes	Classic Fodder	Cereals	Emissions	Abatement		Profit	Crop production	Fodder legumes production	Grain legumes production
		ha	ha	ha	ha	kt CO_2eq/year	t CO_2eq	%	M €/year	kt DM/year	kt DM/year	kt DM/year
Calabria	Baseline	0	0	31	169	146	-	-	78,085	740	0	0
	45 €/tCO_2eq	0	10	0	190	137	9	6	93,834	779	0	22
Sud-Muntenia	Baseline	0	0	0	2,383	193	-	-	49,322	615	0	0
	45 €/tCO_2eq	0	596	0	1,788	158	35	18	199,562	630	0	111
Eastern Scotland	Baseline	0	0	31	513	439	-	-	284,975	1,587	0	0
	45 €/tCO_2eq	117	84	84	259	315	124	28	331,786	1,793	99	146
Brandenburg	Baseline	0	0	0	1,323	213	-	-	9,849	881	0	0
	45 €/tCO_2eq	381	77	130	735	197	15	7	89,331	1,088	497	19
Västsverige	Baseline	0	0	148	592	263	-	-	118,577	739	0	0
	45 €/tCO_2eq	0	0	0	740	261	2	1	158,187	687	0	0

4 DISCUSSION

Abatement costs in the 5 NUTS2 regions can be compared with results of other studies. This study focuses specifically on legumes to provide information on abatement costs across European regions and the changes in mitigation costs as affected by the size of h GHG abatements. A study by INRA[18] considered using fodder and grain legumes as two options to mitigate agriculture emissions in France. Legumes abatement cost potential was estimated with respect to a change in France farmlands and not according to rotation changes. The abatement potential estimated was 1.4 Mt CO_2eq for a total cost of €-72 M, which equates to an average cost of €-52 /tCO_2eq. The assessment by Moran *et al*[19] of legumes gave a high average abatement cost of €11,710/tCO_2eq (with a per area cost of implementation of €16.8 /ha), having accounted for interactions with other mitigation options which reduce the abatement potential of this option considerably. The current analysis found the average abatement cost to be €-2,061 /tCO_2eq at a marginal abatement cost of €45 /tCO_2eq, – the lowest average abatement cost from legumes among the three studies (see Appendix 10 for more details of this comparison). Most of this increase in the profit is due to the initial changes from the baseline rotations to other, more profitable rotations. These more profitable rotations could not be considered as baseline due to their legume content.

The results suggest that there is significant potential win-win abatement in all five regions, i.e. a potential decrease in GHG emissions with a simultaneous increase in GM. Win-win mitigation opportunities (i.e. negative cost-effectiveness) will always provoke further questions about the assumptions in the calculations. Indeed, why farmers would refuse currently to reduce their GHG emissions whereas it would raise their profit? The most common explanations for the negative cost-effectiveness are that the model does not capture some important cost elements, or the model's estimates are robust, but farmers either do not have information about these opportunities or the assumption about their profit-maximising behaviour does not capture other barriers.

Assumptions about the baseline practices would affect both the abatement and the cost of win-win opportunities. In the case of the current assessment, the choice of the baseline rotations (which were restricted to rotations with no legumes) and the fact that many low-emission leguminous crops are associated with a relatively high GM in the

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[18] INRA, 2013. Quelle contribution de l'agriculturefrançaise à la reduction des emissions de gaz à effet de serre? Potentield'atténuation et coût de dix actionstechniques. Synthèse du rapport de l'étuderéalisée par l'INRApour le compte de l'ADEME, du MAAF et du MEDDE.

[19] MacLeod, M., Moran, D., Eory, V., Rees, R., Barnes, A., Topp, C. F., Ball, B., Hoad, S., Wall, E., McVittie, A., et al. 2010. Developing greenhouse gas marginal abatement cost curves for agricultural emissions from crops and soils in the UK. Agricultural Systems, 103(4), 198–209.

crop database (see Appendix 9) is partly responsible for the win-win opportunities. Though the baseline used in this analysis is underestimating the current practice of legume use, still, the existence of low-emission-and-high-GM rotations – often with leguminous crops – points out that 'real' win-win opportunities might exist.

Another possible negative bias in the costs is that the constraints of farm production are not built in the simulation. The 13 site classes are not farms, i.e. their production system (e.g. livestock or cereals) is not specified. In reality, farmers are constrained by their production system, for example farms with ruminant animals tend to utilise their land area for home-grown fodder, rather than producing crops for export and importing the feed. On the other hand, farms without ruminants have very limited ability to sell fodder, mostly due to the high transportation costs.

Financial, structural, information and behavioural barriers also exist, contributing to the existence of seemingly win-win opportunities. Structural barriers might be hidden in the supply chain of legumes. For instance, legumes need adapted silos that are not currently established in all regions in Europe. Other barriers exist in the diffusion of information in the agricultural sector. Farmers' decision making, including internal factors (cognition and habit), social factors (norms and roles) and the policy environment can also explain the non-current exploitation of these negative costs. Besides, farmers may be exhibiting risk aversion behavior in response to a potentially higher variation in the yield of legumes. Finally, the effect of an increased legume production and a decreased cereal production on the European crop market is not taken into account in this study – these feedback have the potential of increasing the costs.

5 CONCLUSIONS

The analysis presented here demonstrates that increasing the share of legumes in rotations in the five study areas in Europe can bring significant benefits in GHG mitigation, potentially providing financial savings to farmers and increasing the total DM production in these areas. To achieve a cost-effective abatement of 0.7 – 0.9 Mt CO_2eq (13% of the soil N_2O emissions from these land areas), grain legumes and fodder legumes (including grass-legume mixtures) should be cultivated on around 15% and 10% of the arable land areas, replacing overall 25% of the non-leguminous fodder and cereal areas. Though the increased cultivation of legumes would reduce cereal production, it would provide additional proteins both for animal and human consumption, reducing the need for feed protein imports and possibly animal protein consumption (the grain legume production was 1.2-1.8 Mt DM at the cost-efficient abatement, this accounts to 4.9-5.5% of the 34.4 Mt DM/y soybean import to the EU-25[20]). The reduced cereal production would have implications on cereal production elsewhere, potentially resulting in a GHG leakage. The overall impact of such a shift in the place of production needs a life cycle analysis approach.

Currently grain legumes are cultivated on 1.6% the arable area in the EU-27[21] (unfortunately fodder legumes statistics are problematic as data on grass-legume mixtures are hardly collected). Increasing the share of legumes in European fodder production could be promoted through providing better information on the agronomic issues (e.g. agronomic characteristics of clover varieties, nutritional values of legume fodder for animals) via existing advisory schemes and information tools, or through compulsory schemes, especially given that monitoring and enforcement is relatively straightforward and could be built in to existing monitoring activities. Increasing the share of grain legumes might require more adjustments in the whole supply chain, both in infrastructure (e.g. storage) and in demand. One opportunity within the current CAP policy may be provided by use of Ecological Focus Areas to promote legume production. The demand for grain legumes can come if it becomes practical for livestock farmers and feed producers to replace part of the soybean in the feed with peas and beans, and if consumers become more willing to give up part of their livestock-protein consumption for plant-proteins (this aligns well with efforts promoting a shift in consumption towards a more sustainable pattern). All in all, though the increased grain legume production would displace cereals production, but it could reduce the import of animal feed protein, and could contribute to a reduction in meat consumption in Europe.

[20]Sources: Friends of the Earth Netherlands, 2008. Soy consumption for feed and fuel in the European Union. A research paper prepared for Milieudefensie (Friends of the Earth Netherlands) by Profundo Economic Research, The
Netherlands. Country-specific data available from FOE on request.

[21]Eurostat 2010 data. Accessed: February 2014

The results emphasize the importance of legumes in the European agriculture and underpin that a shift for increased legume production is not only beneficial to the climate, but can be made without significant losses for the farmers and without a reduction in agricultural production. Given the complexity of the agricultural supply chain, these changes have to be supported by appropriate policies targeting not only the farmers producing the crops, but consumers and livestock farmers as well.

Appendix 1 – GM and GHG calculations

Gross margin (GM) and profit calculations

The GM of each crop is calculated according to the following equation:

$$Gross\ Margin_{crop} = (Yield\_OS * PriceA + Yield\_OS\_B * PriceB + YieldByProd * PriceByProd) - (TotalVariableCost + OtherServices)$$

Yield_OS: main production yield (kg DM/ha/year) for instance the grain of wheat
Yield_OS_B: second production yield if it is exist (kg DM/ha/year) for instance the wheat straw
YieldByProd: third production yield if it exist (kg DM/ha/year)
Price A: main production price (€/t)
PriceB: second production price (€/t)
PriceByProd: third production price (€/t)
TotalVariableCost: cost of fungicides, pesticides, fertilisers, insecticides, harvest, irrigation, drying and cleaning, machinery and harvesting cost.
OtherServices: includes contraction costs.

The gross margin of the rotation is calculated as follows:

$$Gross\ Margin_{rotation\ i} = \sum_{a}^{number\ of\ crops\ in\ rotation\ i} Gross\ Margin_{crop\ a}$$

The profit is gross margin of the rotation multiplied by the relevant area:

$$Profit_{siteclassj} = 200\ \times Gross\ Margin_{rotation\ i}$$

$$Profit_{regionk} = Area_{regionk} \times \sum_{j}^{numberofsiteclasses\ inregionk} Gross\ Margin_{rotation\ i} \times Representativity\ Coefficient_{site\ class\ j}$$

$$Profit_{5NUTS2regions} = \sum_{k}^{5NUTS2regions} Profit_{regionk}$$

$RepresentativityCoefficient_{siteclassj}$: share of the area of site class j in region k (Appendix 7)
$Area_{regionk}$: utilized agricultural area of region k (Appendix 7)

N_2O emissions

The total of the N_2O emissions of the rotation is calculated according to IPCC 2006 guidelines[22]:

$$N20\ total_{emission_{rotation}} = \mathrm{N20\ indirect}_{\mathrm{emission}_{\mathrm{rotation}}} + \mathrm{N20\ direct}_{\mathrm{emission}_{\mathrm{rotation}}}$$

Direct N_2O emissions

$$\mathrm{N_2O\ direct}_{\mathrm{emission}_{\mathrm{rotation}}} = \sum_{i=0}^{ncrop} \left(\left(Fsn_{crop} + Fon_{crop} + Fcr_{crop} \right) * 0.01 \right) * \left(\frac{44}{228} \right)$$

Fsn = annual amount of synthetic fertiliser N applied to soils, kg.N.yr^{-1}
Fon = annual amount of animal manure, compost, sewage sludge and other organic N additions applied to soils (Note: If including sewage sludge, cross-check with Waste Sector to ensure there is no double counting of N_2Oemissions from the N in sewage sludge), kg.N.yr^{-1}
Fcr: annual amount of N in crop residues (above-ground and below-ground), including N-fixing crops, and from forage/pasture renewal, returned to soils, kg.N.yr^{-1}

$$\mathrm{Fcr} = \sum (\mathrm{crop} * \mathrm{Cf} * \mathrm{Fracrenew} * (\mathrm{Rag} - \mathrm{Nag} * (1 - \mathrm{Fracremove}) + (\mathrm{Rbg} * \mathrm{Nbg})))$$

Crop = harvested annual DM yield for crop, kg d.m. ha-1
Cf = combustion factor (dimensionless)
FracRenew = fraction of total area under cropthat is renewed annually.
RAG) = ratio of above-ground residues DM (AGDM) to harvested yield for crop(Crop), kg d.m.
NAG= N content of above-ground residues for crop, kg N (kg d.m.) -1
FracRemove = fraction of above-ground residues of cropremoved annually for purposes such as feed, bedding and construction, kg N (kg crop-N)-1.
RBG = ratio of below-ground residues to harvested yield for crop, kg d.m. (kg d.m.)-1.
NBG = N content of below-ground residues for crop, kg N (kg d.m.)-1

[22] Paustian,K., N.H.Ravindranath, and A.van Amstel (2006) 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Volume 4: Agriculture, Forestry and Other Land Use. Eggleston, H. S., Buendia, L., Miwa, K., Ngara, T., and Tanabe, K. Japan, IGES.

Indirect N_2O emissions

$$\mathrm{N_2O\ indirect}_{\mathrm{emission}_{\mathrm{rotation}}} = \sum_{i=0}^{ncrop} \mathrm{N_2Oadt}_{\mathrm{crop}_\mathrm{i}} + \mathrm{N_2O}L_{crop_i}$$

N_2Oadt from atmospheric deposition of N volatilised from managed soils
N_2Oadt: annual amount of N_2O–N produced from atmospheric deposition of N volatilised from managed soils, kg N_2O–N yr-1

$$\mathrm{N_2Oadt}_{\mathrm{crop}} = \left((Fsn * 0.1 + Fon * 0.2) * 0.01\right) * \left(\frac{44}{28}\right)$$

N_2OL from N leaching/runoff from managed soils in regions where leaching/runoff occurs
N_2OL–N: annual amount of N_2O–N produced from leaching and runoff of N additions to managed soils in regions where leaching/runoff occurs, kg N_2O–N yr-1

$$\mathrm{N20L}_{\mathrm{crop}} = \left((Fsn + Fon) * 0.3\right) * 0.0075 * \left(\frac{44}{28}\right)$$

Appendix 2 – Rotation Selection according to the mitigation cost efficiency (in the B N-Decrease Scenario)[23]

[23] Crops abbreviations can be found in Appendix 8

In the five Site Classes of Brandenburg - Germany

Crop1	Crop2	Crop 3	Crop 4	Crop 5	Crop 6	Fodder Legumes	Seed Legumes	Classic Fodder	Cereal	GM	Emissions	Yield Dry matter	Yield Legumes	Yield Fodder Legumes	Yield Seed Legumes	Cost Efficiency
						%	%	%	%	Euros /an/ha	tCO2eq /an/ha	kgdm/an/ha	kgdm/an/ha	kgdm/an/ha	kgdm/an/ha	Euros/tCO2eq
LBG1																
wrape	wwheat	wbarley				0	0	0	100	288	1,5	5545	0	0	0	Baseline
wrape	wwheat	wbarley				0	0	0	100	432	1,4	5517	0	0	0	-1671
alfalfa	alfalfa	wwheat	wbarley	wrape	wrye	33	0	0	67	393	1,2	6877	2885	2885	0	145
alfalfa	alfalfa	tritica	fababea	wwheat	wbarley	33	17	0	50	277	0,5	6626	3530	2885	645	175
alfalfa	alfalfa	wbarley	fababea	wwheat	wbarley	33	17	0	50	268	0,5	6626	3530	2885	645	307
LBG2																
wrape	wwheat	wbarley				0	0	0	100	161	1,4	4647	0	0	0	Baseline
graclov	graclov	wrye	maize_s	fababea	soat	33	17	33	17	482	1,4	5972	2580	2200	380	-20235
graclov	graclov	wwheat	maize_s	fababea	soat	33	17	33	17	488	1,4	5681	2580	2200	380	-1012
graclov	graclov	wwheat	maize_s	pea	soat	33	17	33	17	495	1,4	5736	2635	2200	435	-913
graclov	graclov	wwheat	sbarley	wwheat	soat	33	0	17	50	599	1,2	7953	4433	4433	0	-584
graclov	graclov	wwheat	sbarley	pea	soat	33	17	17	33	526	1,0	7523	5007	4433	573	352
alfalfa	alfalfa	wbarley	pea	wwheat	wbarley	33	17	0	50	266	0,5	4799	3337	3165	172	505
graclov	graclov	wrye	pea	wrye	wrye	33	17	0	50	157	0,5	5878	3108	2750	358	9166

Crop1	Crop2	Crop 3	Crop 4	Crop 5	Crop 6	Fodder Legumes	Seed Legumes	Classic Fodder	Cereal	GM	Emissions	Yield Dry matter	Yield Legumes	Yield Fodder Legumes	Yield Seed Legumes	Cost Efficiency
						%	%	%	%	Euros /an/ha	tCO2eq /an/ha	kgdm/an/ha	kgdm/an/ha	kgdm/an/ha	kgdm/an/ha	Euros/tCO2eq
LBG3																
wrape	wrye	maize_s	wrye	sbarley		0	0	0	100	62	1,2	5006	0	0	0	Baseline
alfalfa	alfalfa	maize_s	pea	wrape	wrye	33	17	17	33	223	1,2	6442	3160	2730	430	-48012
graclov	graclov	wrye	sbarley	wwheat	soat	33	0	17	50	592	1,2	4838	2200	2200	0	-11938
graclov	graclov	wwheat	sbarley	wwheat	soat	33	0	17	50	599	1,2	4547	2200	2200	0	-1012
graclov	graclov	wwheat	sbarley	pea	soat	33	17	17	33	526	1,0	4586	2635	2200	435	352
graclov	graclov	wrye	wrye	pea	wrye	33	17	0	50	261	0,6	6061	3108	2750	358	604
graclov	graclov	wrye	wrye	lupin	wrye	33	17	0	50	249	0,5	6003	3051	2750	301	641
graclov	graclov	wrye	wrye	lupin	wrye	33	17	0	50	166	0,5	6003	3051	2750	301	1126
graclov	graclov	wrye	lupin	wrye	wrye	33	17	0	50	149	0,5	5820	3051	2750	301	1586
LBG4																
wrye	wrye	wrye	wrye			0	0	0	100	-73	0,6	3526	0	0	0	Baseline
graclov	graclov	wrye	wrye	pea	wrye	33	17	0	50	261	0,6	5262	2787	2500	287	-24485
graclov	graclov	wrye	wrye	lupin	wrye	33	17	0	50	249	0,5	5233	2758	2500	258	641
graclov	graclov	wrye	wrye	lupin	wrye	33	17	0	50	166	0,5	5233	2758	2500	258	1126
graclov	graclov	wrye	lupin	wrye	wrye	33	17	0	50	149	0,5	5083	2758	2500	258	1586
lupin	wrye	wrye	wrye	wrye		0	20	0	80	-87	0,4	3130	310	0	310	28273
LBG5																
wrye	wrye	wrye	wrye			0	0	0	100	-175	0,4	2494	0	0	0	Baseline
lupin	wrye	wrye	wrye	wrye		0	20	0	80	-161	0,3	2391	258	0	258	-145

In the three Site Classes of Calabria - Italy

Crop1	Crop2	Crop3	Crop4	Crop5	Fodder Legumes	Seed Legumes	Classic Fodder	Cereal	GM	Emissions	Yield Dry matter	Yield Legumes	Yield Fodder Legumes	Yield Seed Legumes	Cost Efficiency
					%	%	%	%	euros/an/ha	tCO2eq/an/ha	kgdm/an/ha	kgdm/an/ha	kgdm/an/ha	kgdm/an/ha	Euros/tCO2eq
rainfed															
wrape	woat	wrape	wbarley		0	0	25	75	285	0,52	2277	0	0	0	Baseline
wrape	tritica	wrape	tritica		0	0	0	100	381	0,52	2428	0	0	0	-36908
wrape	wwheat	wrape	wbarley		0	0	0	100	395	0,51	2578	0	0	0	-1651
wrape	wbarley	wrape	wbarley		0	0	0	100	404	0,48	2643	0	0	0	-293
pea	wbarley	pea	wbarley		0	50	0	50	179	0,24	2021	516	0	516	917
irrigated_lowland															
maize_s	wbarley				0	0	0	100	518	1,21	7525	0	0	0	Baseline
alfalfa	alfalfa	alfalfa	durum	wbarley	60	0	0	40	215	0,58	6714	5596	5596	0	479
irrigated_highland															
potato	wrape	wwheat	wrape	wwheat	0	0	0	100	634	0,73	2733	0	0	0	Baseline
potato	lupin	wwheat	lupin	wwheat	40	0	60	40	681	0,58	2489	860	0	860	-327
potato	lupin	wrape	lupin	wwheat	40	0	60	40	635	0,56	2393	860	0	860	1945

In the three Site Classes of Eastern Scotland – United Kingdom

Crop1	Crop2	Crop3	Crop4	Crop5	Crop6	Fodder Legumes	Seed Legumes	Classic Fodder	Cereal	GM	Emissions	Yield Dry matter	Yield Legumes	Yield Fodder Legumes	Yield Seed Legumes	Cost Efficiency
						%	%	%	%	euros/an/ha	tCO2eq/an/ha	kgdm/an/ha	kgdm/an/ha	kgdm/an/ha	kgdm/an/ha	Euros/tCO2eq
Grade 1&2																
potato	wwheat	wwheat	wwheat	wwheat	wrape	0,0	0,0	0,0	100,0	1525	2,17	8218	0	0	0	Baseline
potato	wwheat	wwheat	wwheat	wrape	wwheat	0,0	0,0	0,0	100,0	1732	2,05	8070	0	0	0	-1691
potato	wwheat	wwheat	wwheat	wrape	woat	0,0	0,0	16,7	83,3	1750	1,93	7942	0	0	0	-157
potato	wwheat	woat	pea	swedes	swheat	0,0	16,7	16,7	66,7	1743	1,55	9045	788	0	788	19
potato	sbarley	woat	pea	swedes	swheat	0,0	16,7	16,7	66,7	1685	1,41	8687	788	0	788	404
potato	sbarley	woat	pea	swedes	sbarley	0,0	16,7	16,7	66,7	1643	1,32	8615	788	0	788	462
potato	sbarley	woat	pea	swedes	soat	0,0	16,7	33,3	50,0	1632	1,30	8483	788	0	788	493
potato	srape	woat	soat	pea	woat	0,0	16,7	50,0	33,3	1530	1,16	6740	788	0	788	732
potato	soat	soat	pea	srape	woat	0,0	16,7	50,0	33,3	1443	1,11	6378	788	0	788	1842
potato	soat	soat	pea	srape	soat	0,0	16,7	50,0	33,3	1356	1,06	6015	788	0	788	1842
potato	soat	srape	soat	pea	soat	0,0	16,7	50,0	33,3	1303	1,04	5936	788	0	788	1968
potato	soat	pea	soat	srape	soat	0,0	16,7	50,0	33,3	796	0,79	4909	788	0	788	2033
pea	soat	srape	soat	soat	soat	0,0	16,7	66,7	16,7	337	0,77	3556	573	0	573	28225

Crop1	Crop2	Crop3	Crop4	Crop5	Crop6	Fodder Legumes	Seed Legumes	Classic Fodder	Cereal	GM	Emissions	Yield Dry matter	Yield Legumes	Yield Fodder Legumes	Yield Seed Legumes	Cost Efficiency
						%	%	%	%	euros/an/ha	tCO2eq/an/ha	kgdm/an/ha	kgdm/an/ha	kgdm/an/ha	kgdm/an/ha	Euros/tCO2eq
Grade_3																
potato	wwheat	wwheat	wwheat	wbarley	wrape	0	0	0	100	1484	2,13	8003	0	0	0	Baseline
potato	wwheat	wwheat	wwheat	wrape	wwheat	0	0	0	100	1732	2,05	8106	0	0	0	-3068
potato	wwheat	wwheat	wwheat	wrape	woat	0	0	17	83	1750	1,93	7963	0	0	0	-157
potato	wwheat	woat	pea	swedes	swheat	0	17	17	67	1743	1,55	8920	788	0	788	19
potato	sbarley	woat	pea	swedes	swheat	0	17	17	67	1685	1,41	8562	788	0	788	404
potato	sbarley	woat	pea	swedes	sbarley	0	17	17	67	1643	1,32	8490	788	0	788	462
potato	sbarley	woat	pea	swedes	soat	0	17	33	50	1632	1,30	8347	788	0	788	493
potato	srape	woat	soat	pea	woat	0	17	50	33	1530	1,16	6517	788	0	788	732
potato	soat	soat	pea	srape	woat	0	17	50	33	1443	1,11	6158	788	0	788	1842
potato	soat	soat	pea	srape	soat	0	17	50	33	1356	1,06	5800	788	0	788	1842
potato	soat	srape	soat	pea	soat	0	17	50	33	1303	1,04	5796	788	0	788	1968
potato	soat	pea	soat	srape	soat	0	17	50	33	796	0,79	4953	788	0	788	2033
pea	soat	srape	soat	soat	soat	0	17	67	17	337	0,77	3600	573	0	573	28225
Grade_4																
grass	grass	grass	sbarley			0	0	75	25	527	2,87	6190	0	0	0	Baseline
grass	grass	grass	sbarley			0	0	75	25	648	2,56	8998	0	0	0	-397
graclov	graclov	graclov	swedes	sbarley		80	0	0	20	631	1,81	8998	6510	6510	0	23
graclov	graclov	graclov	swedes	soat		80	0	20	0	627	1,79	8919	6510	6510	0	213
graclov	graclov	graclov	soat	soat		60	0	40	0	491	1,71	7641	6510	6510	0	1615

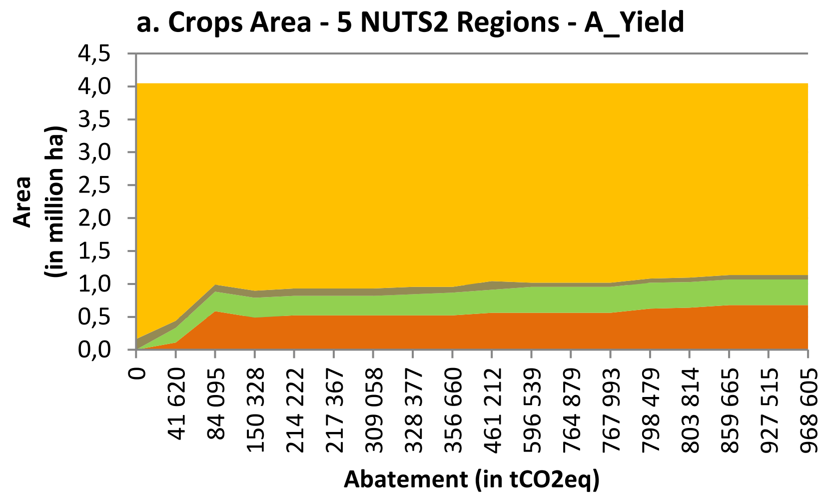
In the Site Classe of Muntenia - Romania

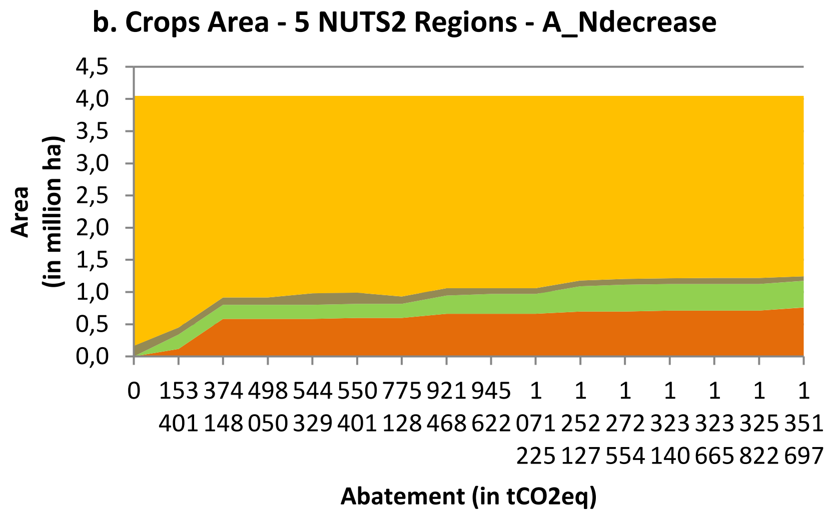
Crop1	Crop2	Crop3	Crop4	Crop5	Crop6	Fodder Legumes	Seed Legumes	Classic Fodder	Cereal	GM	Emissions	Yield Dry matter	Yield Legumes	Yield Fodder Legumes	Yield Seed Legumes	Cost Efficiency
						%	%	%	%	Euros /an/ha	tCO2eq/an/ha	kgdm/an/ha	kgdm/an/ha	kgdm/an/ha	kgdm/an/ha	Euros/tCO2eq
chernozem																
sunfl	wwheat	wwheat	wrape	wbarley		0	0	0	100	246,61	0,97	3074	0	0	0	Baseline
combean	combean	wbarley	wrape	wwheat	wwheat	0	20	0	80	856,21	0,97	2901	446	0	446	-640957
combean	combean	wbarley	wrape	wwheat		0	25	0	75	970,45	0,86	3129	557	0	557	-1051
combean	combean	maize_g	wwheat	wrape		0	25	0	75	997,81	0,79	3150	557	0	557	-410
combean	combean	maize_g	wbarley	wrape		0	25	0	75	994,86	0,79	3708	557	0	557	610
combean	combean	wbarley	sunfl	wwheat	wrape	0	20	0	80	732,12	0,70	3517	446	0	446	3217
soybean	soybean	wbarley	sunfl	wwheat	wrape	0	20	0	80	360,92	0,68	3744	430	0	430	19149
pea	pea	wrape	wbarley	sunfl	wwheat	0	20	0	80	311,18	0,68	3800	602	0	602	30882

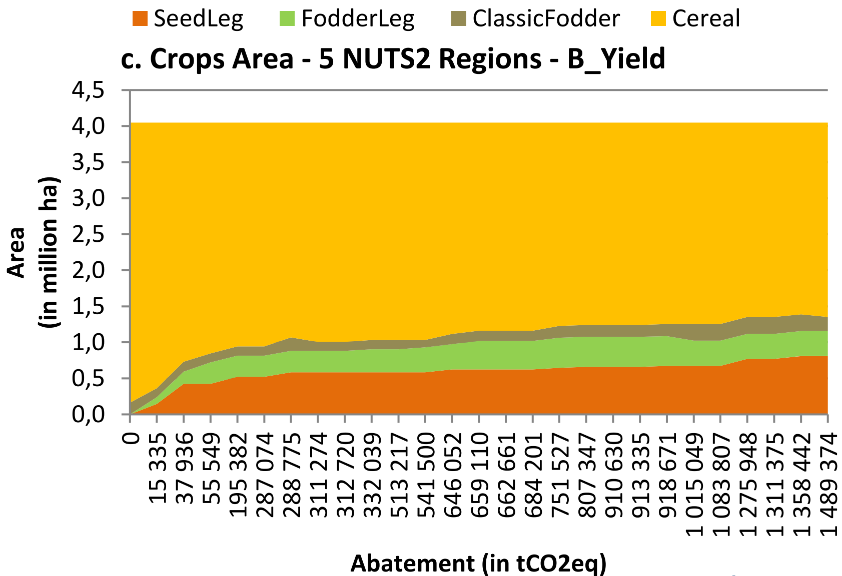
In the Site Class of Västsverige - Sweden

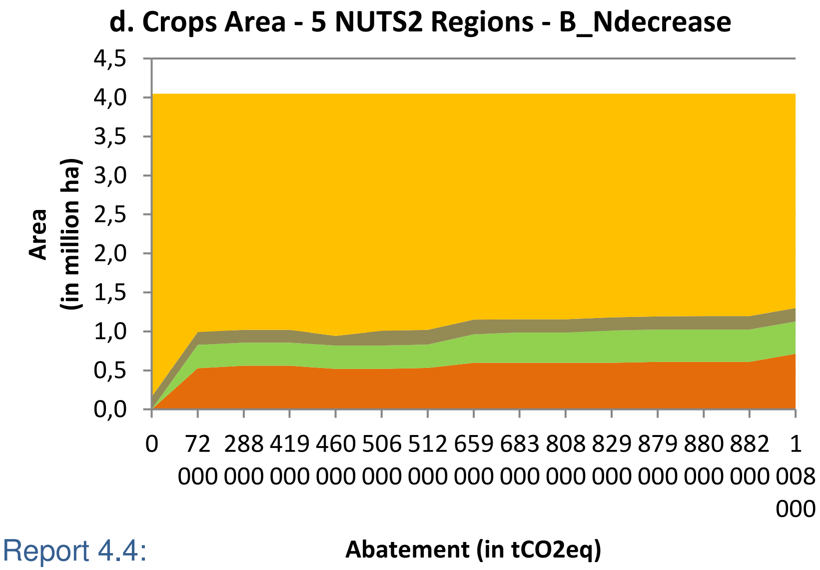
Crop1	Crop2	Crop3	Crop4	Crop5	Crop6	Fodder Legumes	Seed Legumes	Classic Fodder	Cereal	GM	Emissions	Yield Dry matter	Yield Legumes	Yield Fodder Legumes	Yield Seed Legumes	Cost Efficiency
						%	%	%	%	euros/an/ha	tCO2eq/an/ha	kgdm/an/ha	kgdm/an/ha	kgdm/an/ha	kgdm/an/ha	Euros/tCO2eq
clay_soil																
wwheat	wwheat	wwheat	wwheat	soat		0	0	20	80	593	1,31	3695	0	0	0	Baseline
wrape	wwheat	wwheat	wwheat	sbarley		0	0	0	100	791	1,30	3436	0	0	0	-22657
wrape	wwheat	linseed	wwheat	sbarley		0	0	0	100	774	1,09	3360	0	0	0	76
pea	wwheat	sbarley	sbarley	linseed	wwheat	0	17	0	83	609	0,83	3308	435	0	435	650
pea	wwheat	sbarley	sbarley	linseed	sbarley	0	17	0	83	549	0,76	3196	435	0	435	814
pea	sbarley	sbarley	linseed	wwheat	sbarley	0	17	0	83	549	0,76	3196	435	0	435	814
pea	sbarley	sbarley	sbarley	linseed	sbarley	0	17	0	83	489	0,68	3084	435	0	435	814
pea	sbarley	linseed	sbarley	sbarley	sbarley	0	17	0	83	489	0,68	3084	435	0	435	814
pea	soat	sbarley	sbarley	linseed	soat	0	17	33	50	465	0,66	3305	435	0	435	821
pea	soat	linseed	soat	sbarley	sbarley	0	17	33	50	465	0,66	3305	435	0	435	821
fababea	soat	sbarley	linseed	soat		0	20	40	40	426	0,61	3179	456	0	456	908
fababea	soat	linseed	soat	sbarley		0	20	40	40	426	0,61	3179	456	0	456	908
fababea	soat	soat	linseed	soat		0	20	60	20	383	0,59	3137	456	0	456	1672
fababea	soat	linseed	soat	soat		0	20	60	20	383	0,59	3137	456	0	456	1672
srape	soat	linseed	soat	fababea		0	20	40	40	379	0,59	2812	456	0	456	2806
srape	soat	fababea	soat	linseed		0	20	40	40	379	0,59	2812	456	0	456	2806

Appendix 3 – Aggregated crop areas in the 5 NUTS 2 regions in the four different scenarios

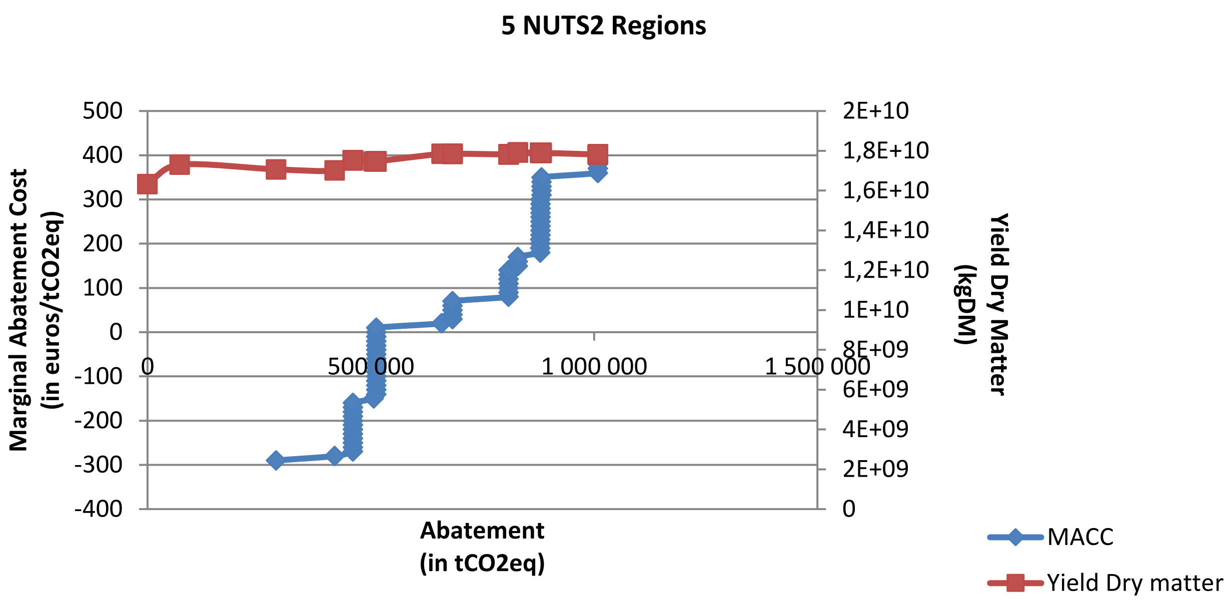


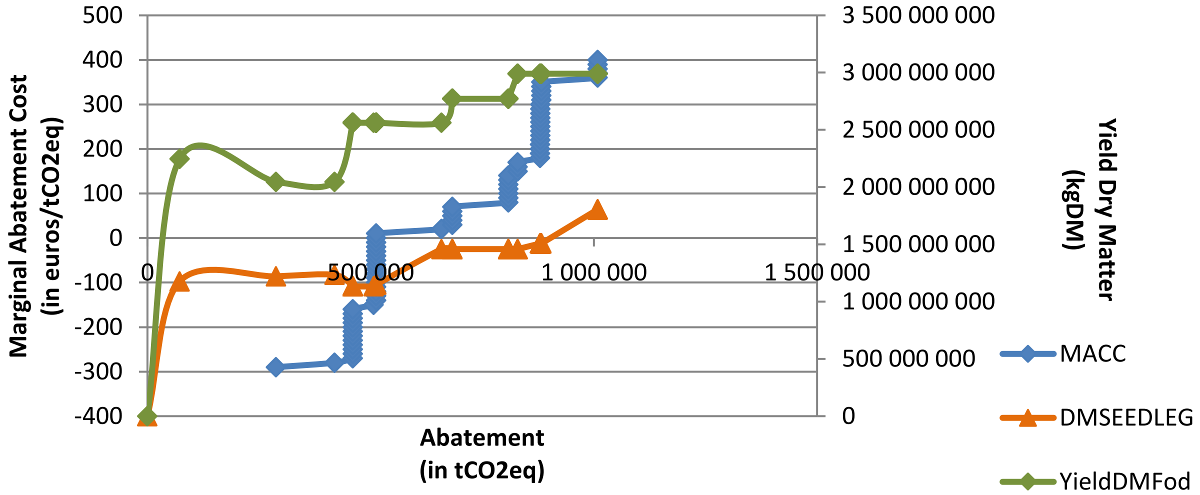


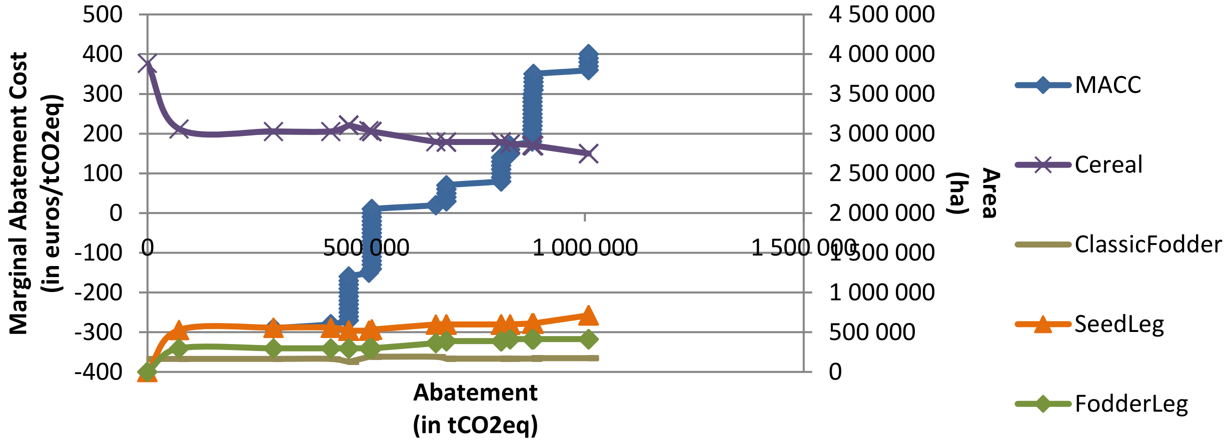




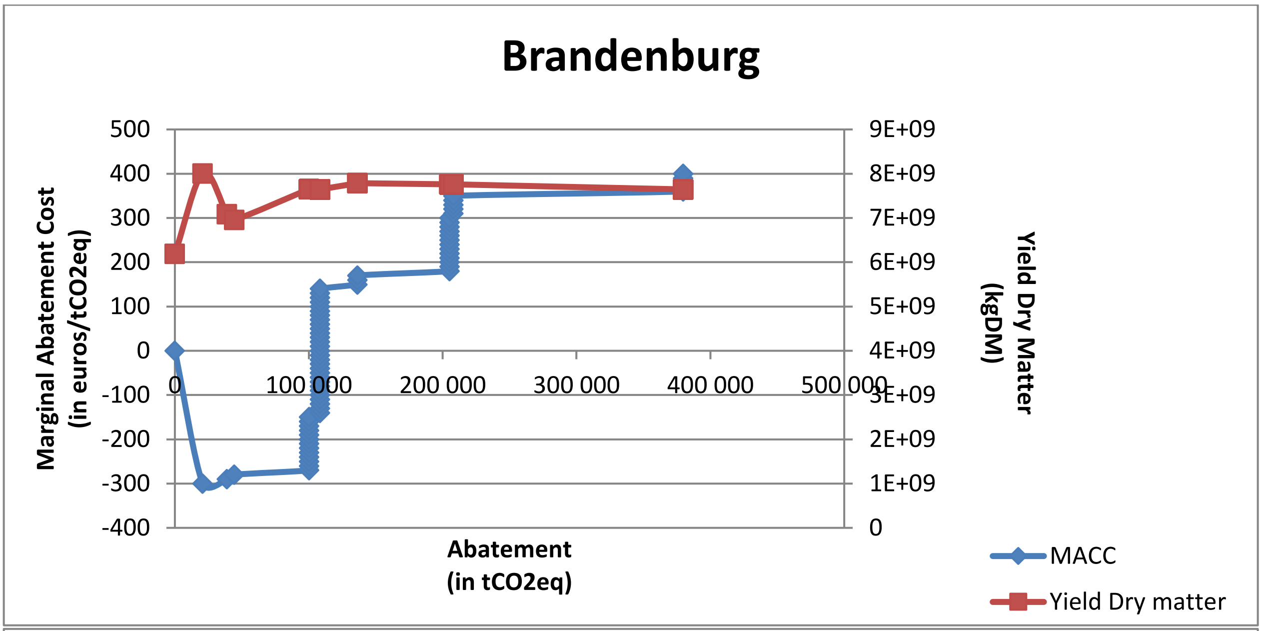
Appendix 4 – MACC, DM production and land area results for the B_N-Decrease scenario aggregated for the 5 NUTS2 regions, for the 5 NUTS2 regions individually, and for the 13 individual site classes

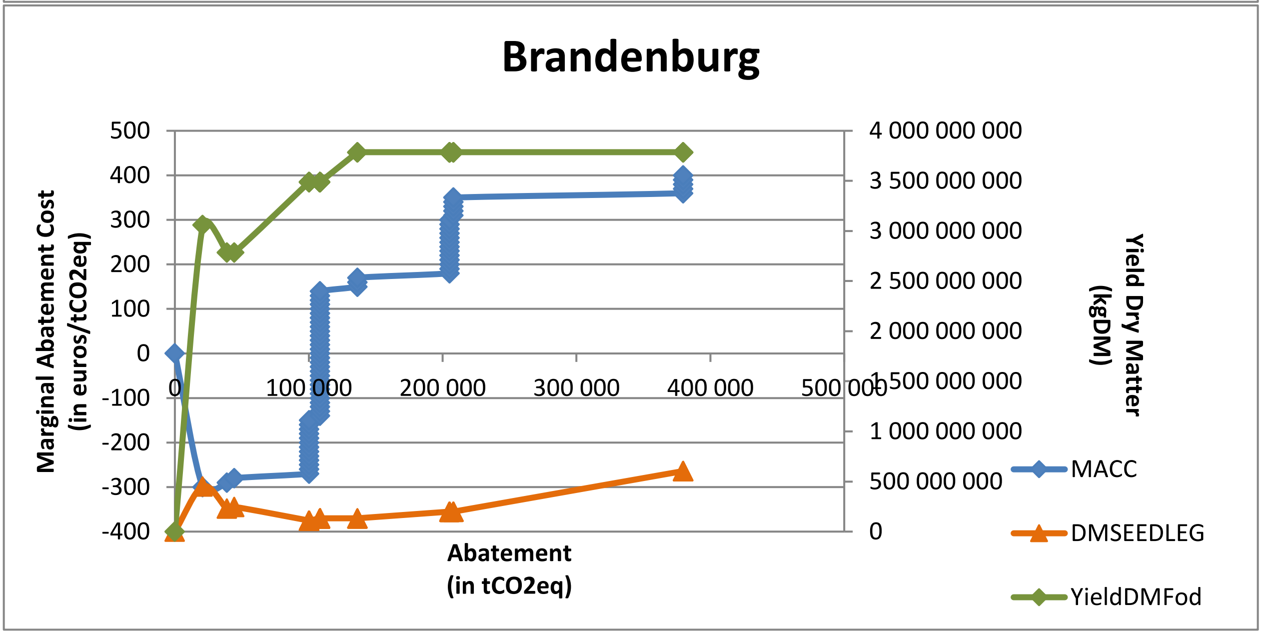

5 NUTS2 Regions
Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
500 000
1 000 000
1 500 000
2E+10
1,8E+10
1,6E+10
1,4E+10
1,2E+10
1E+10
8E+09
6E+09
4E+09
2E+09
0
Yield Dry Matter (kgDM)
Abatement (in tCO2eq)
MACC
Yield Dry matter

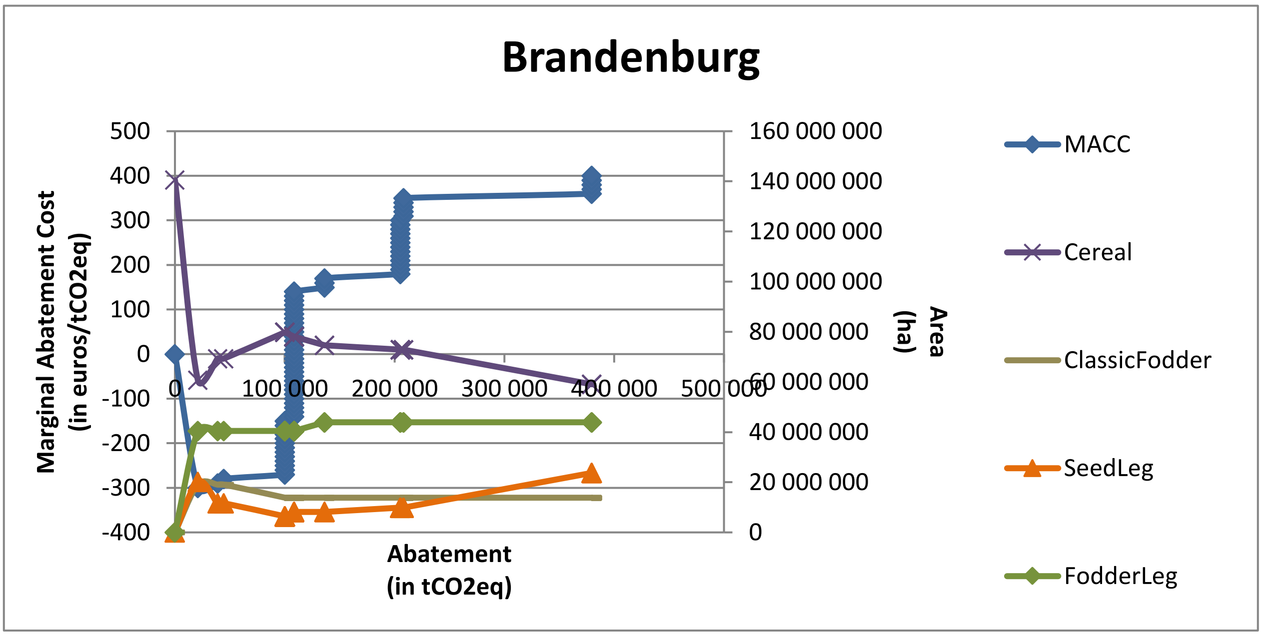

Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
500 000
1 000 000
1 500 000
3 500 000 000
3 000 000 000
2 500 000 000
2 000 000 000
1 500 000 000
1 000 000 000
500 000 000
0
Yield Dry Matter (kgDM)
Abatement (in tCO2eq)
MACC
DMSEEDLEG
YieldDMFod


Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
500 000
1 000 000
1 500 000
4 500 000
4 000 000
3 500 000
3 000 000
2 500 000
2 000 000
1 500 000
1 000 000
500 000
0
Area (ha)
Abatement (in tCO2eq)
MACC
Cereal
ClassicFodder
SeedLeg
FodderLeg

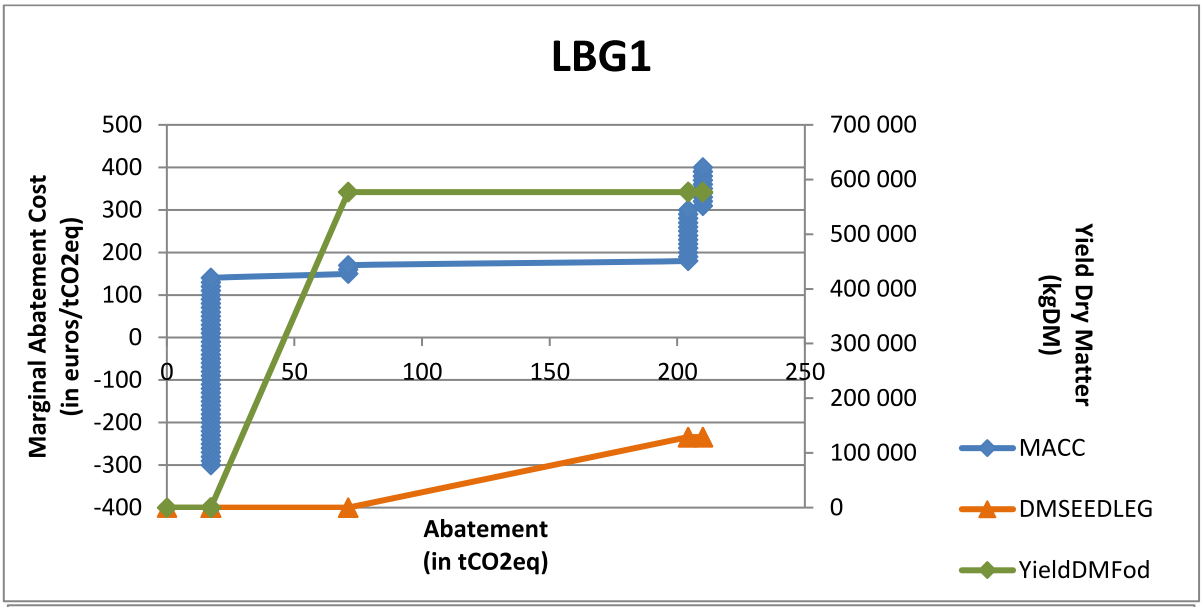
Brandenburg

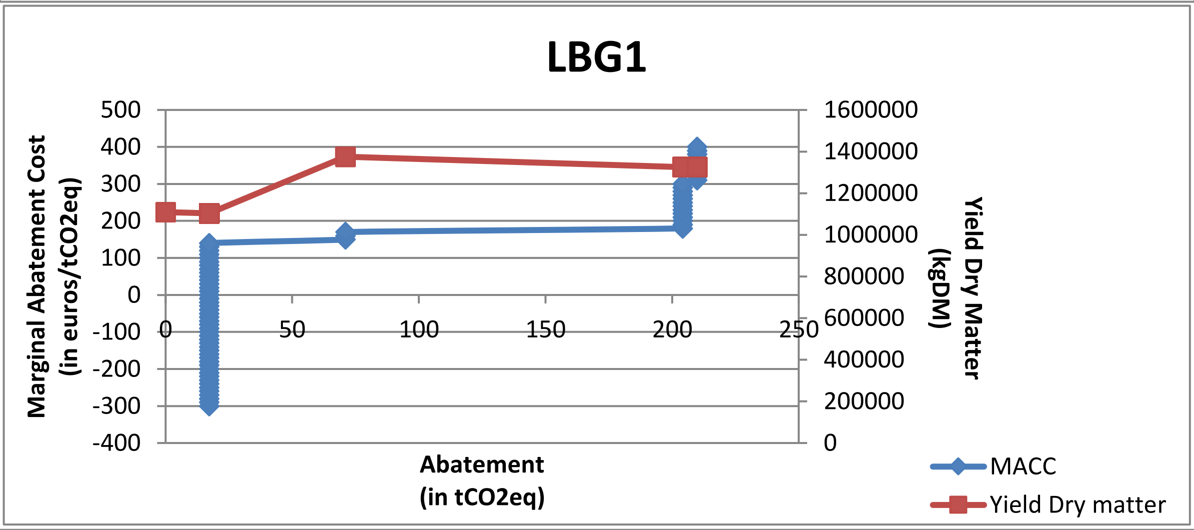


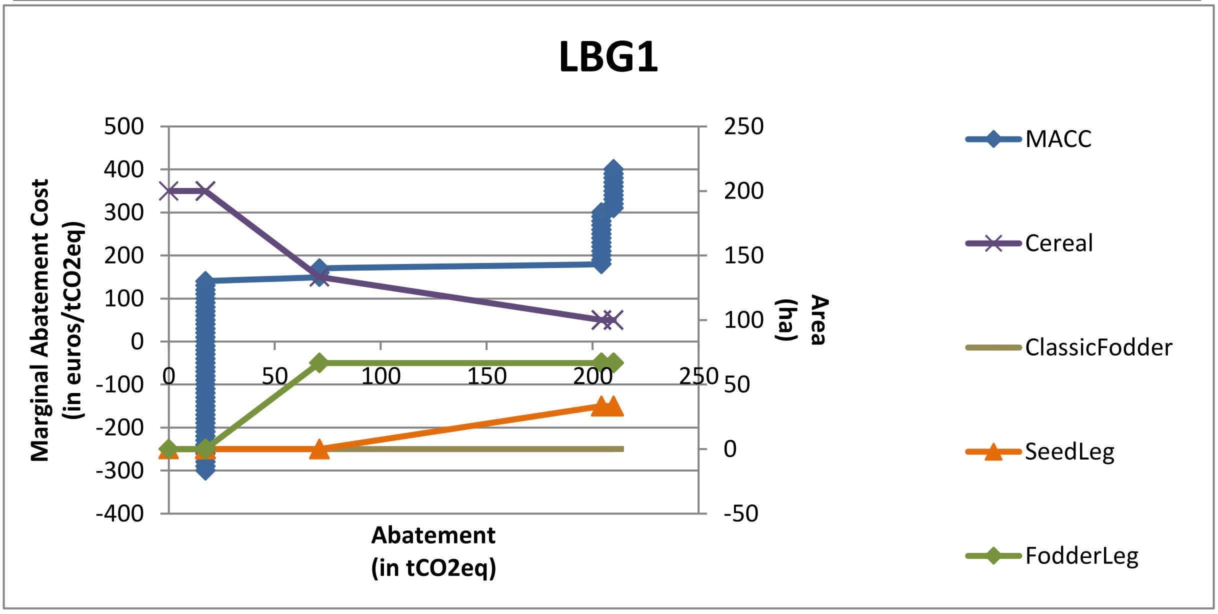


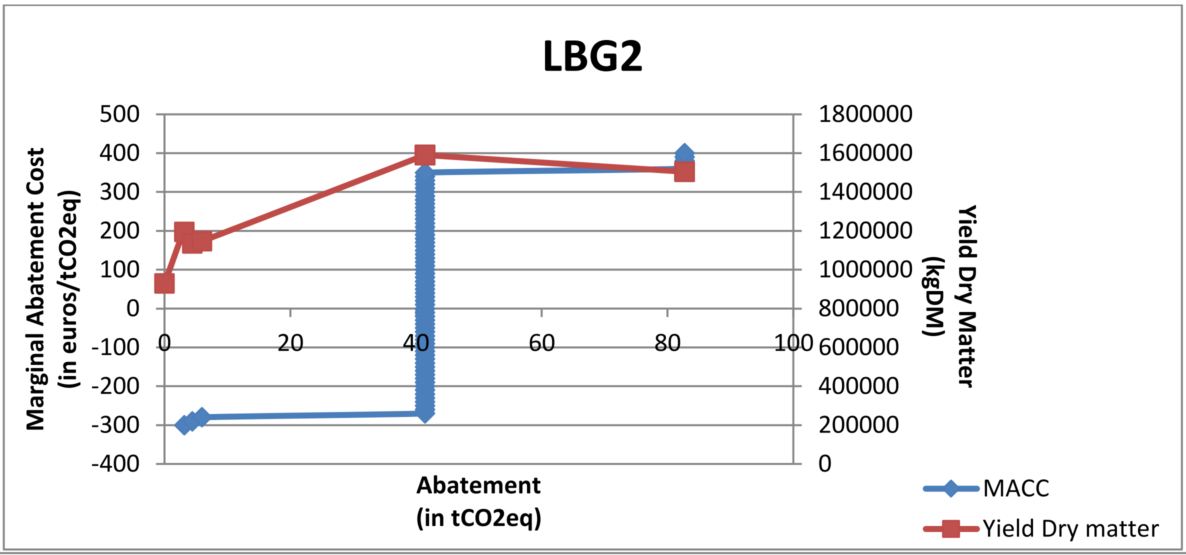


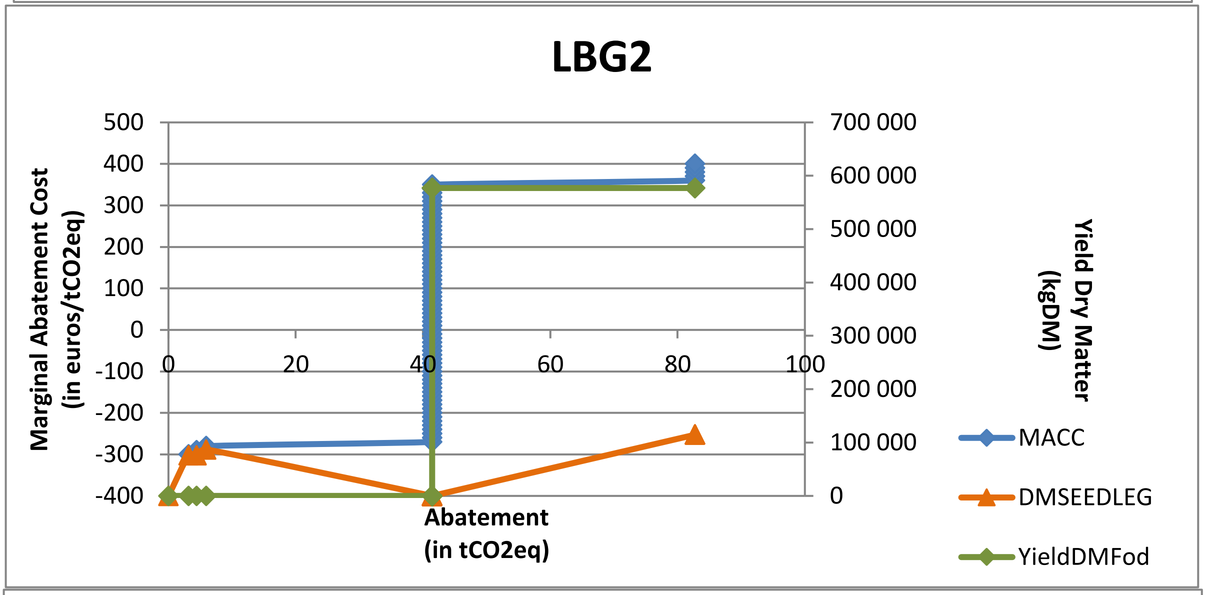
Detail in the site classes of Brandendourg (for 200ha)

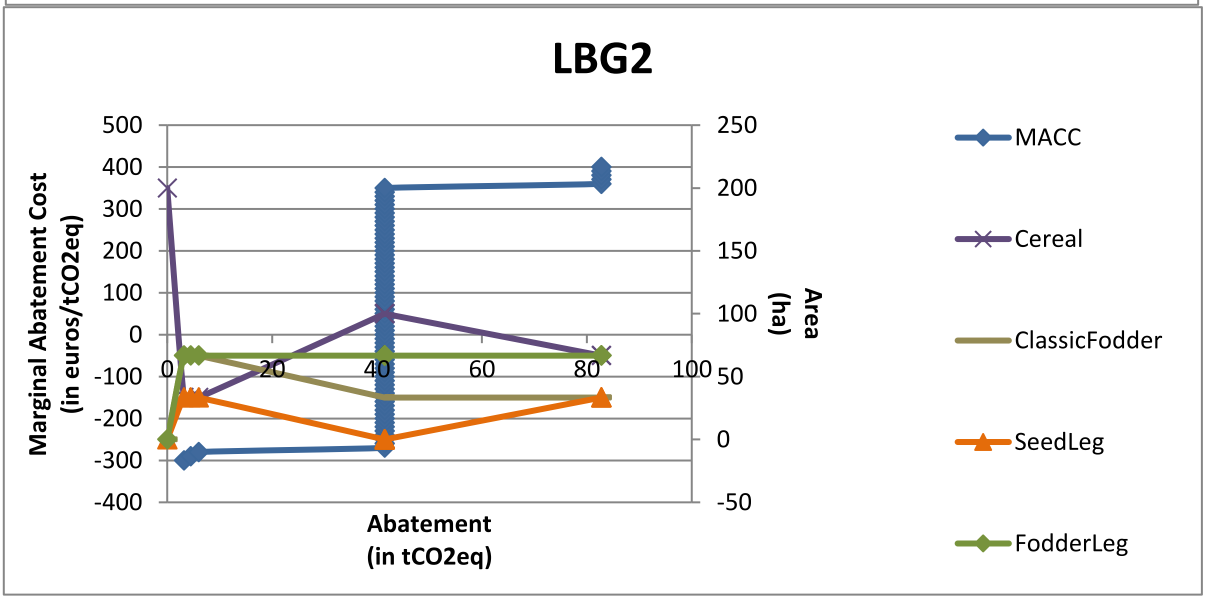


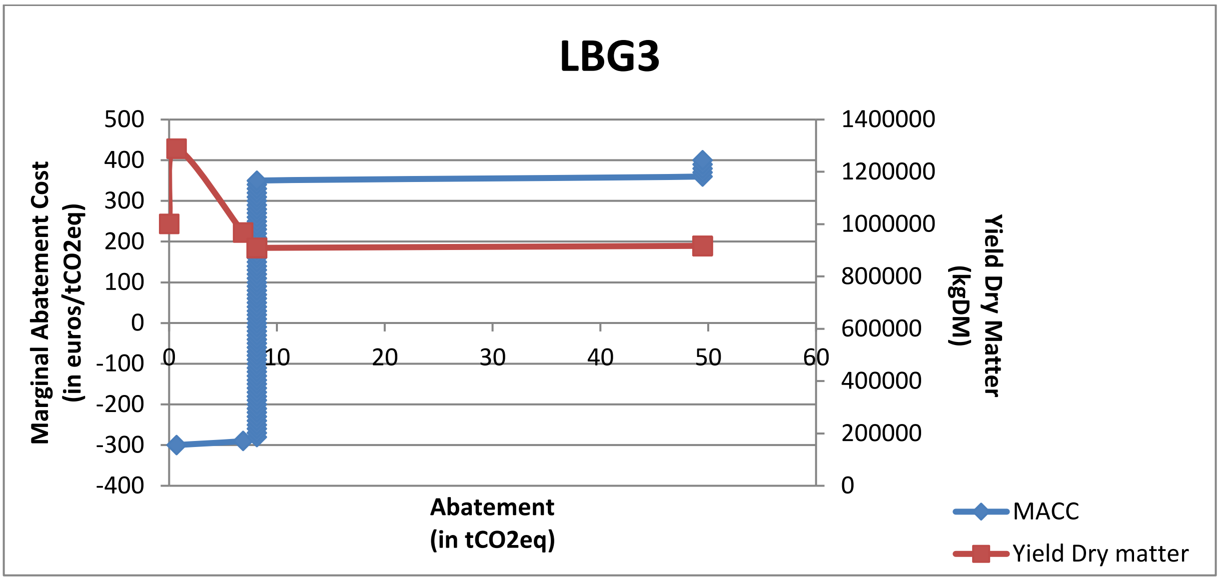


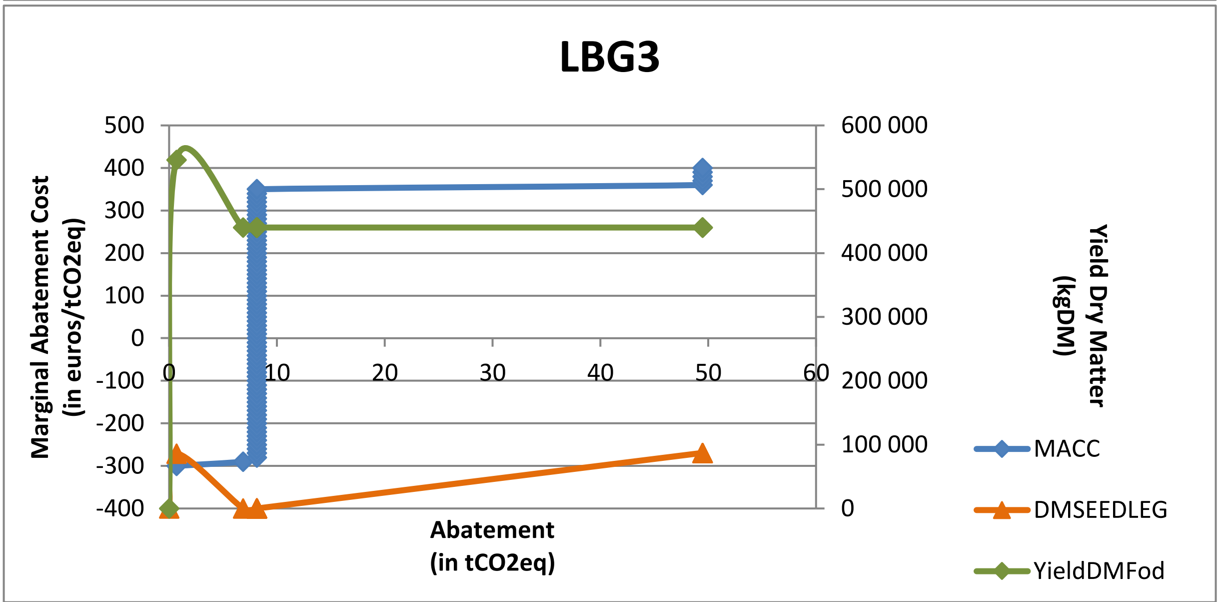


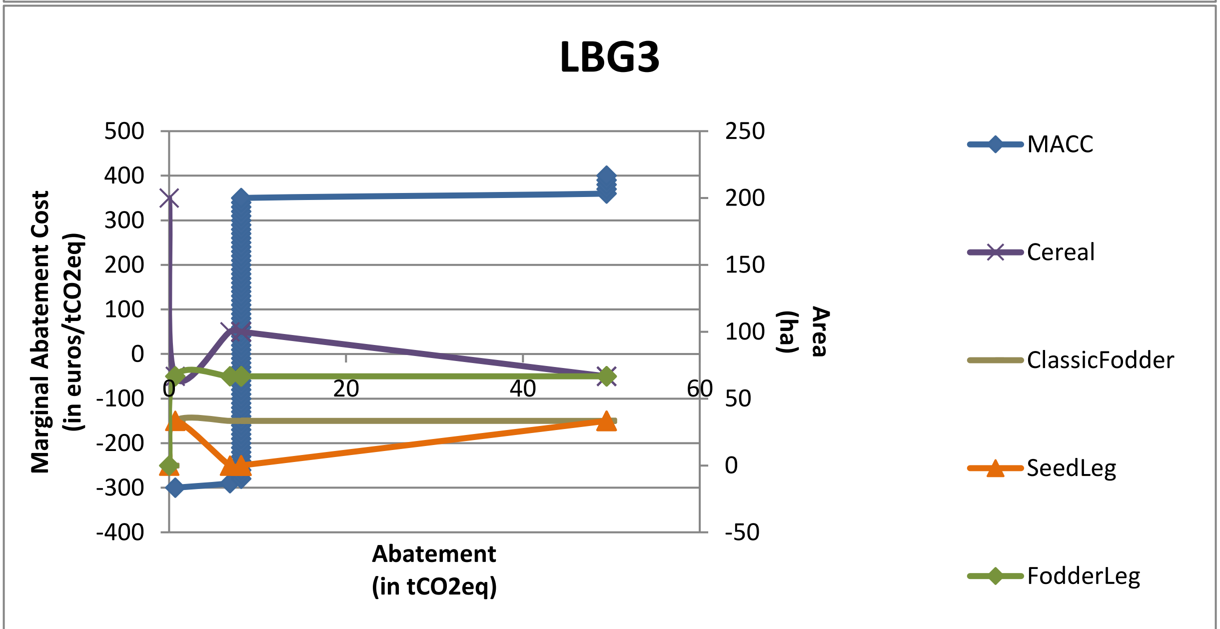

LBG2
Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
20
40
60
80
100
1800000
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
Yield Dry Matter (kgDM)
Abatement (in tCO2eq)
MACC
Yield Dry matter

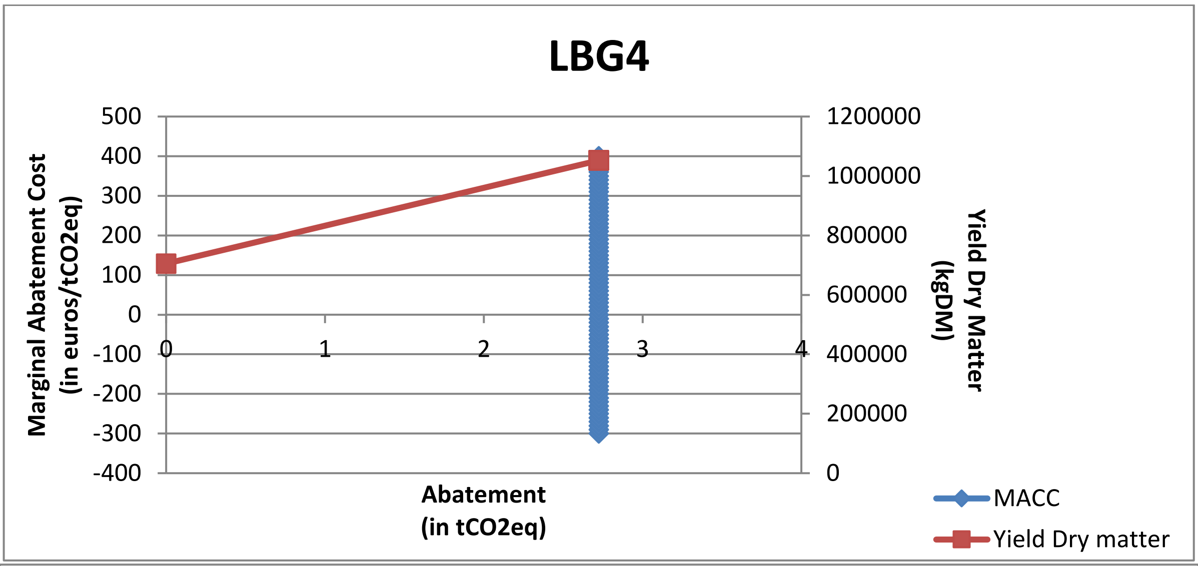

LBG2
Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
20
40
60
80
100
700 000
600 000
500 000
400 000
300 000
200 000
100 000
0
Yield Dry Matter (kgDM)
Abatement (in tCO2eq)
MACC
DMSEEDLEG
YieldDMFod

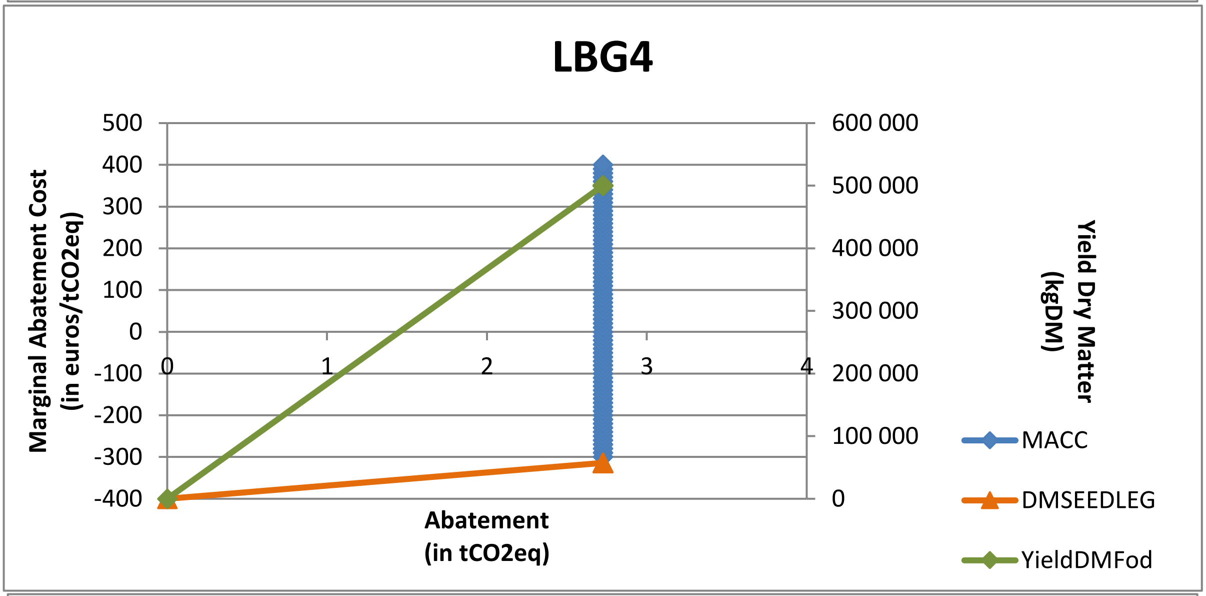

LBG2
Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
20
40
60
80
100
250
200
150
100
50
0
-50
Area (ha)
Abatement (in tCO2eq)
MACC
Cereal
ClassicFodder
SeedLeg
FodderLeg

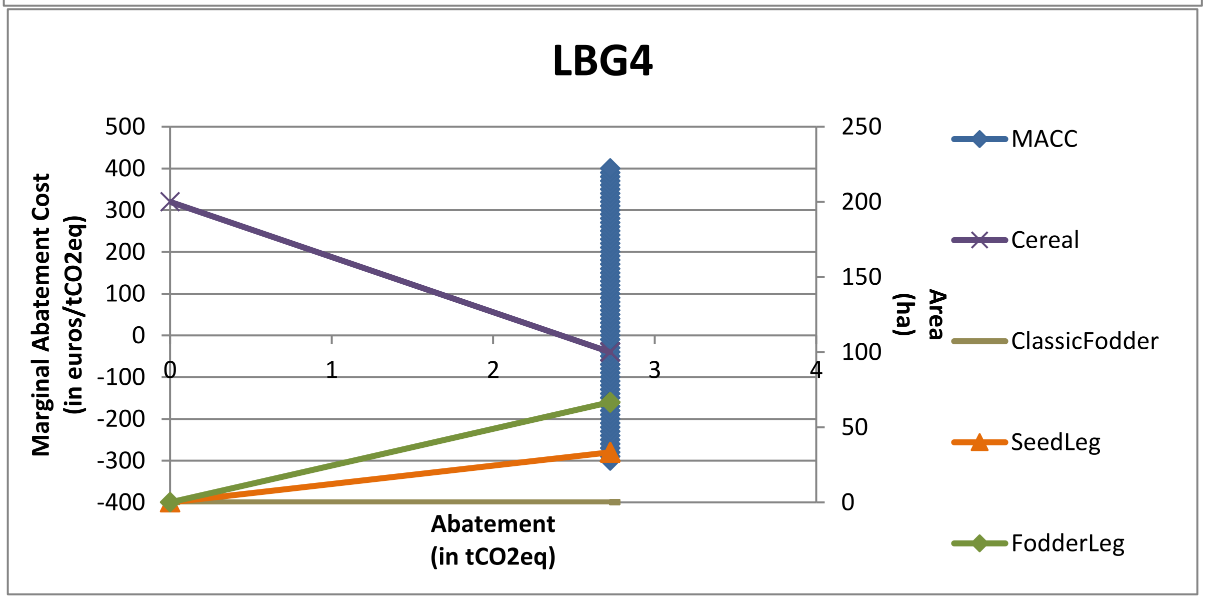

LBG3
Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
10
20
30
40
50
60
1400000
1200000
1000000
800000
600000
400000
200000
0
Yield Dry Matter (kgDM)
Abatement (in tCO2eq)
MACC
Yield Dry matter

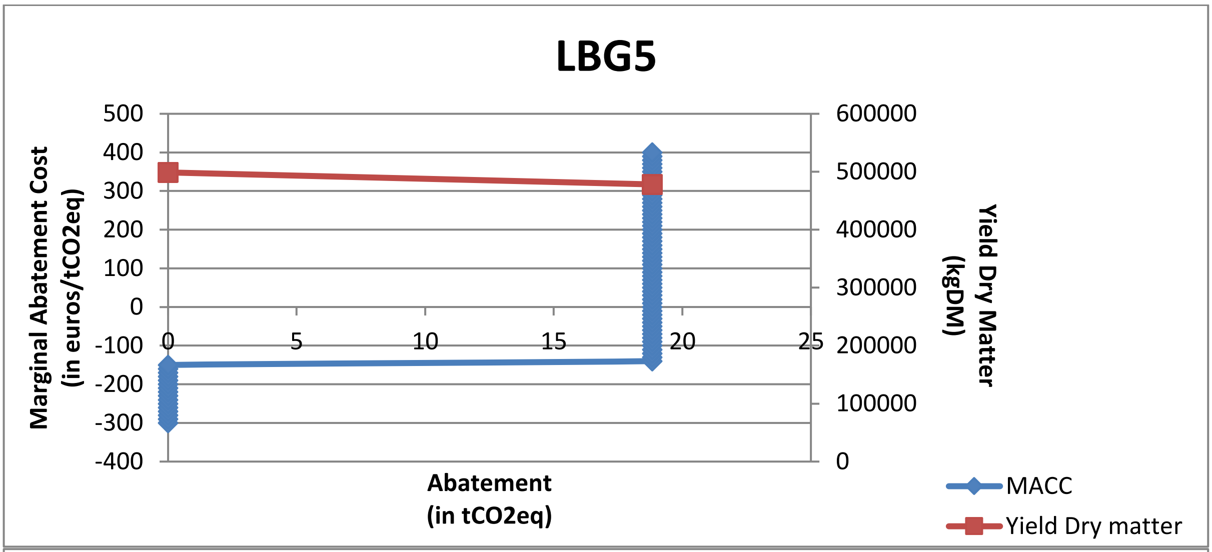

LBG3
Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
10
20
30
40
50
60
600 000
500 000
400 000
300 000
200 000
100 000
0
Yield Dry Matter (kgDM)
Abatement (in tCO2eq)
MACC
DMSEEDLEG
YieldDMFod

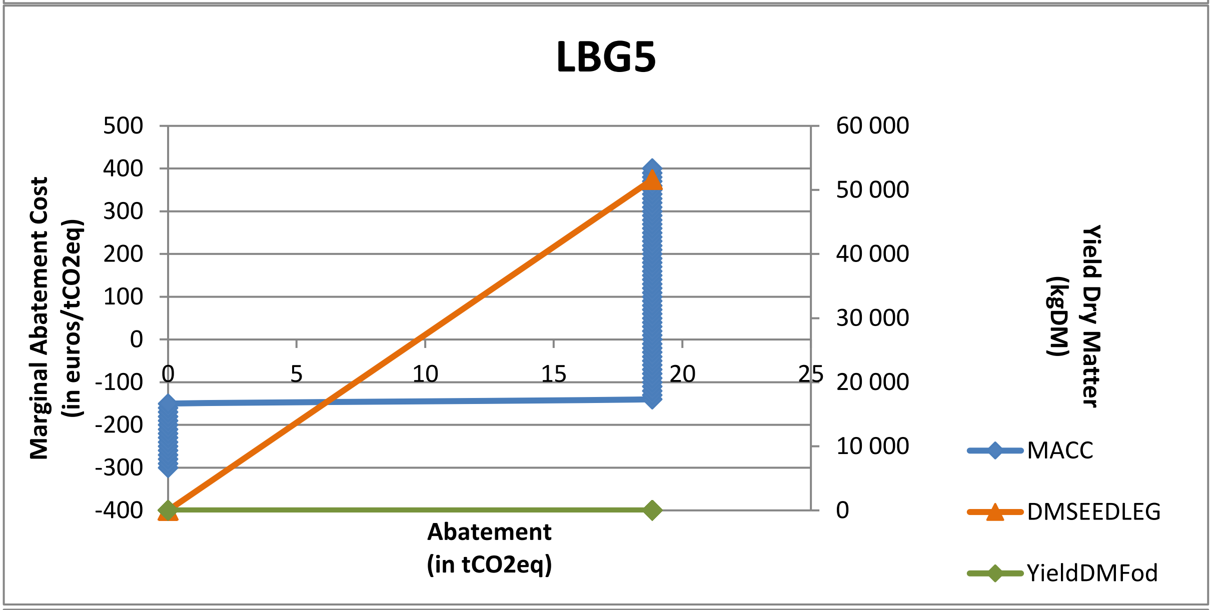

LBG3
Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
20
40
60
250
200
150
100
50
0
-50
Area (ha)
Abatement (in tCO2eq)
MACC
Cereal
ClassicFodder
SeedLeg
FodderLeg

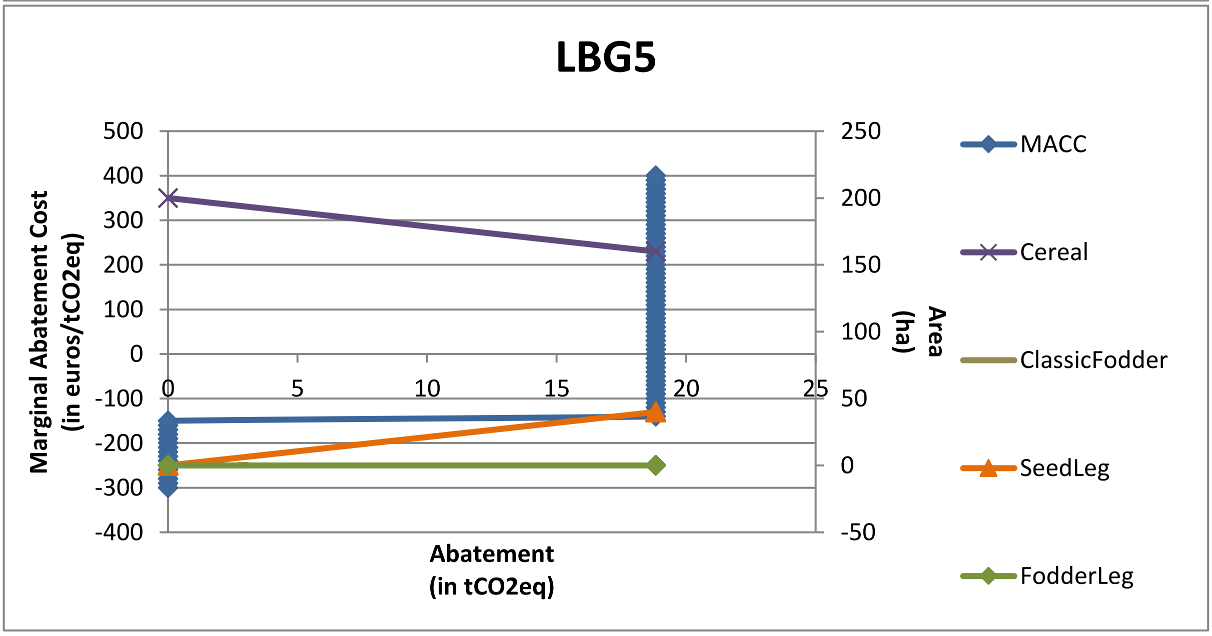

LBG4
Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
1
2
3
4
1200000
1000000
800000
600000
400000
200000
0
Yield Dry Matter (kgDM)
Abatement (in tCO2eq)
MACC
Yield Dry matter


LBG4
Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
1
2
3
4
600 000
500 000
400 000
300 000
200 000
100 000
0
Yield Dry Matter (kgDM)
Abatement (in tCO2eq)
MACC
DMSEEDLEG
YieldDMFod

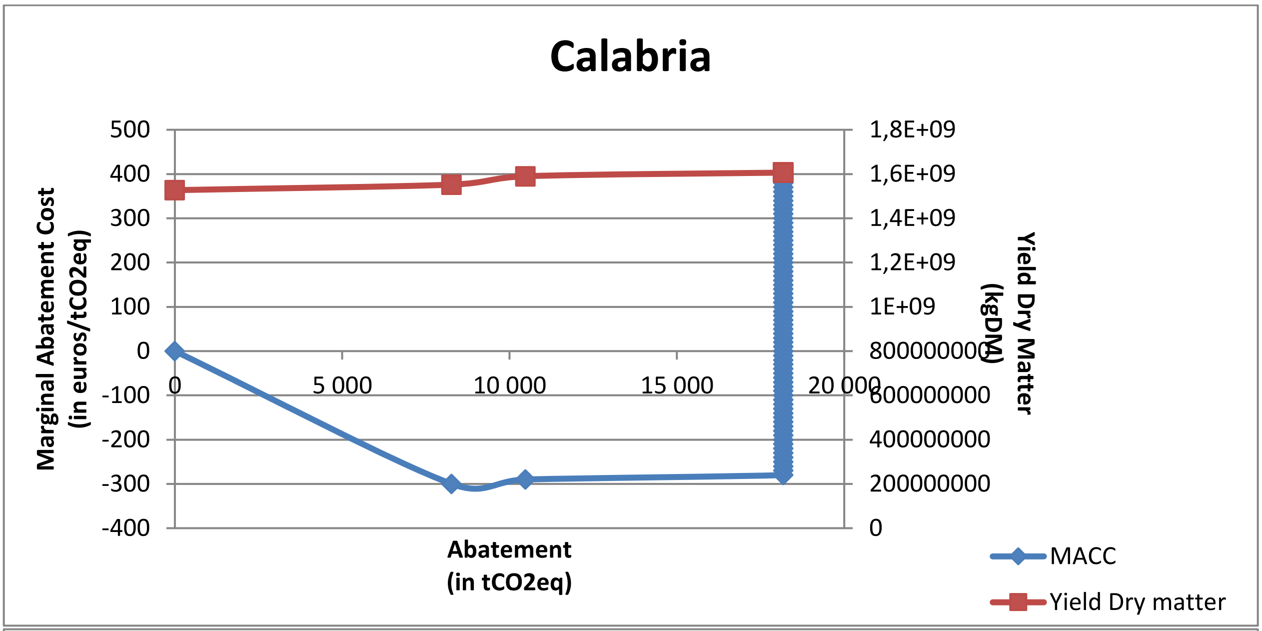

LBG4
Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
1
2
3
4
250
200
150
100
50
0
Area (ha)
Abatement (in tCO2eq)
MACC
Cereal
ClassicFodder
SeedLeg
FodderLeg

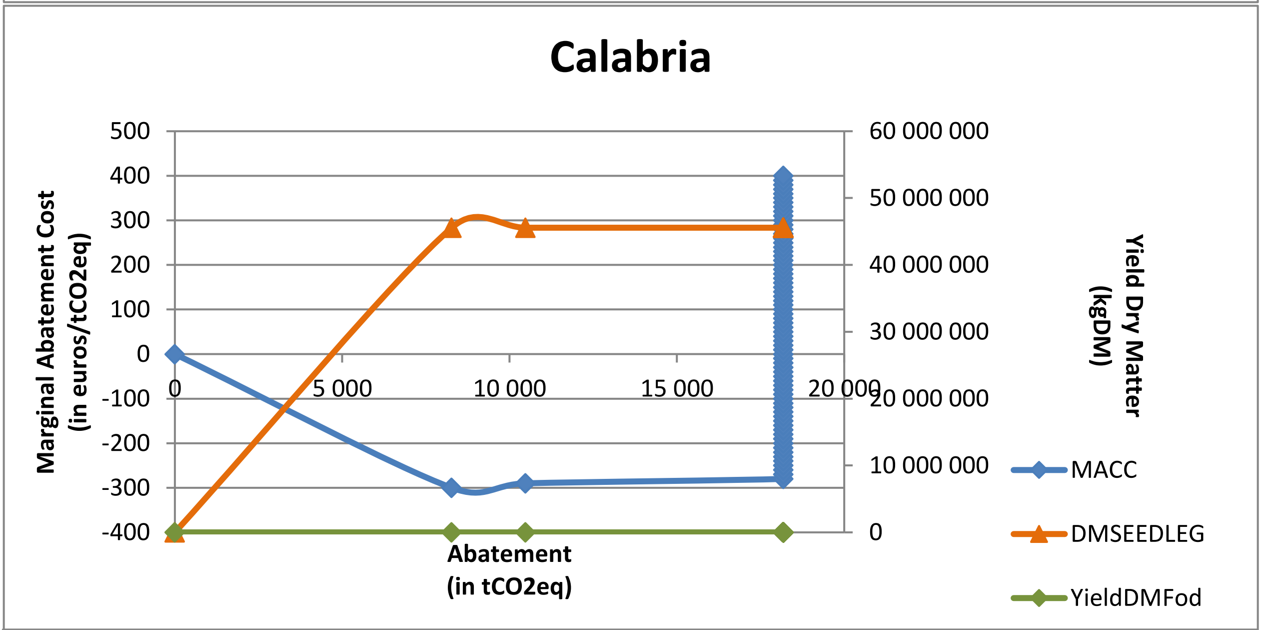

LBG5
Marginal Abatement Cost
(in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
5
10
15
20
25
600000
500000
400000
300000
200000
100000
0
Yield Dry Matter
(kgDM)
Abatement
(in tCO2eq)
MACC
Yield Dry matter

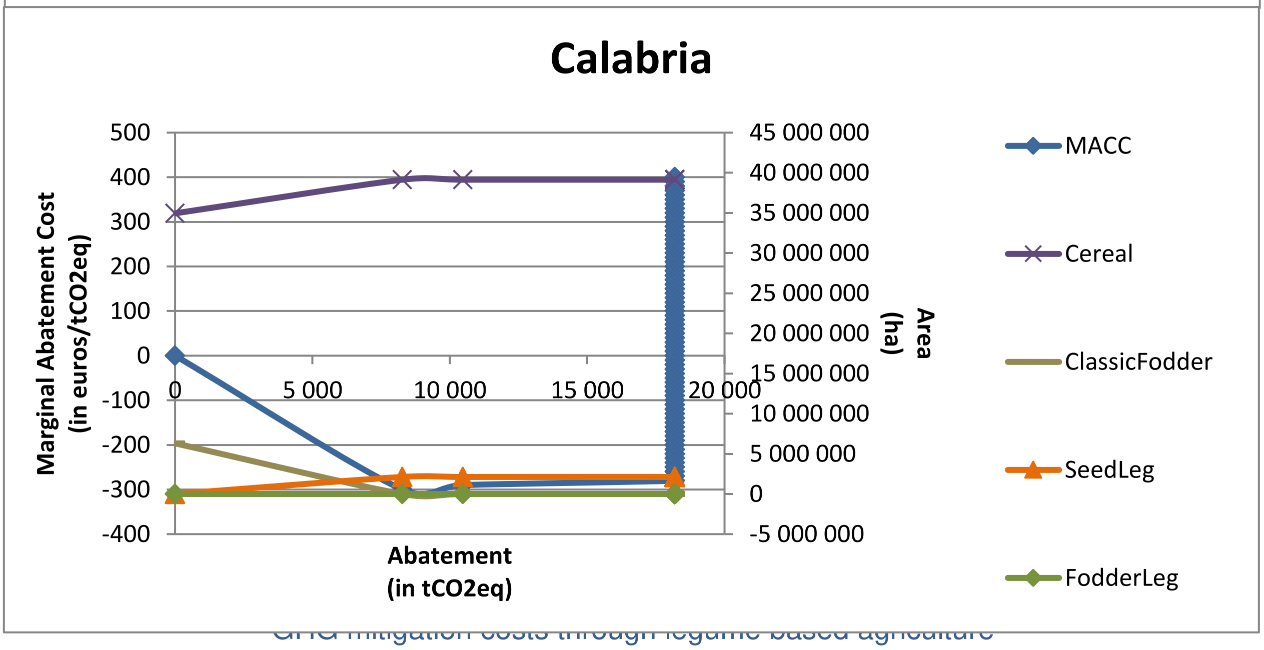

LBG5
Marginal Abatement Cost
(in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
5
10
15
20
25
60 000
50 000
40 000
30 000
20 000
10 000
0
Yield Dry Matter
(kgDM)
Abatement
(in tCO2eq)
MACC
DMSEEDLEG
YieldDMFod


LBG5
Marginal Abatement Cost
(in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
5
10
15
20
25
250
200
150
100
50
0
-50
Area
(ha)
Abatement
(in tCO2eq)
MACC
Cereal
ClassicFodder
SeedLeg
FodderLeg

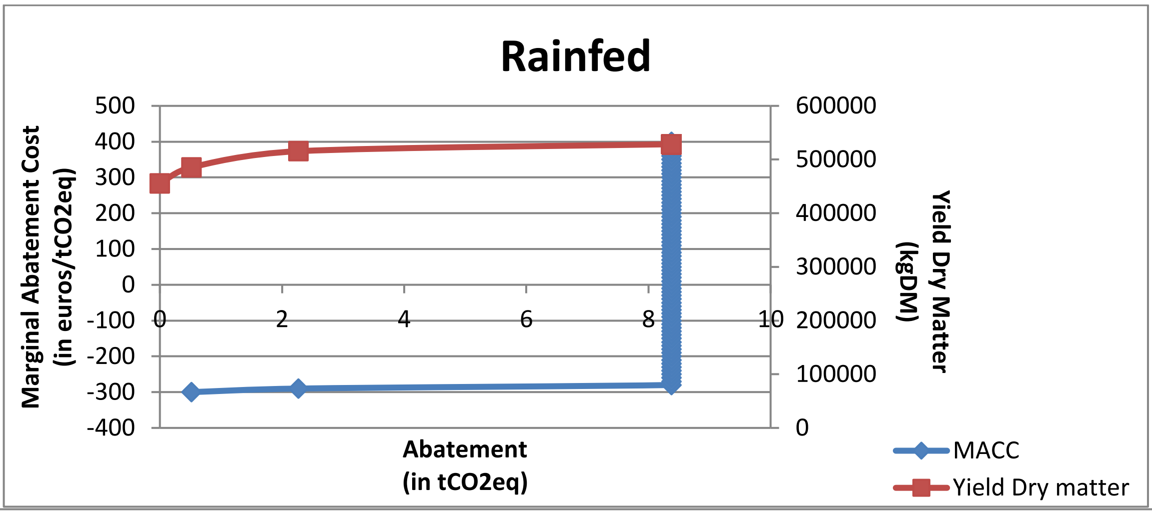
Calabria

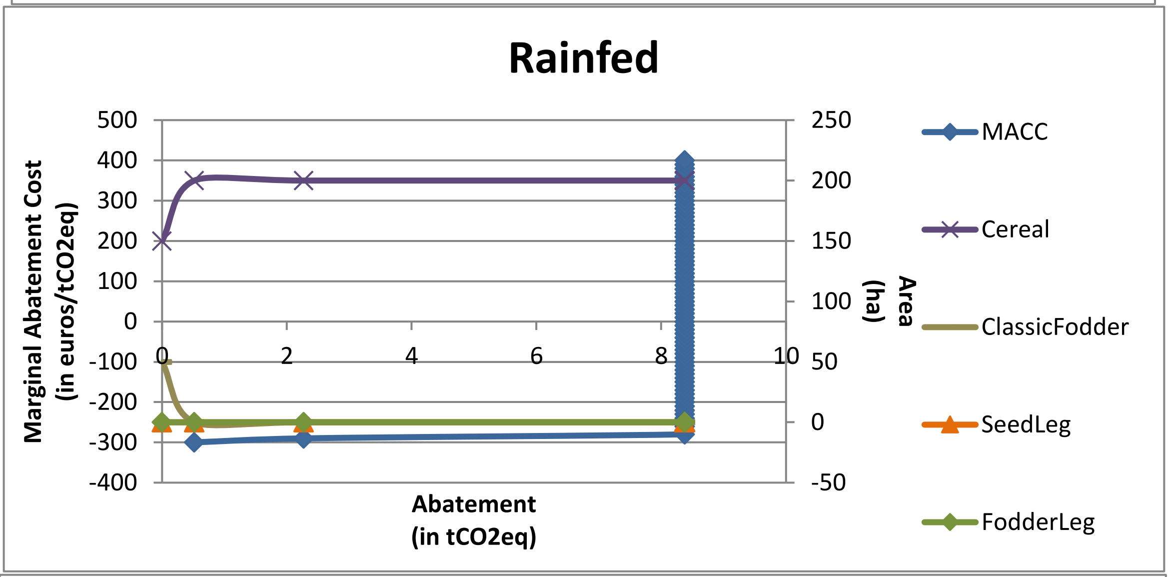

Calabria
Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
5 000
10 000
15 000
20 000
1,8E+09
1,6E+09
1,4E+09
1,2E+09
1E+09
800000000
600000000
400000000
200000000
0
Yield Dry Matter (kgDM)
Abatement (in tCO2eq)
MACC
Yield Dry matter

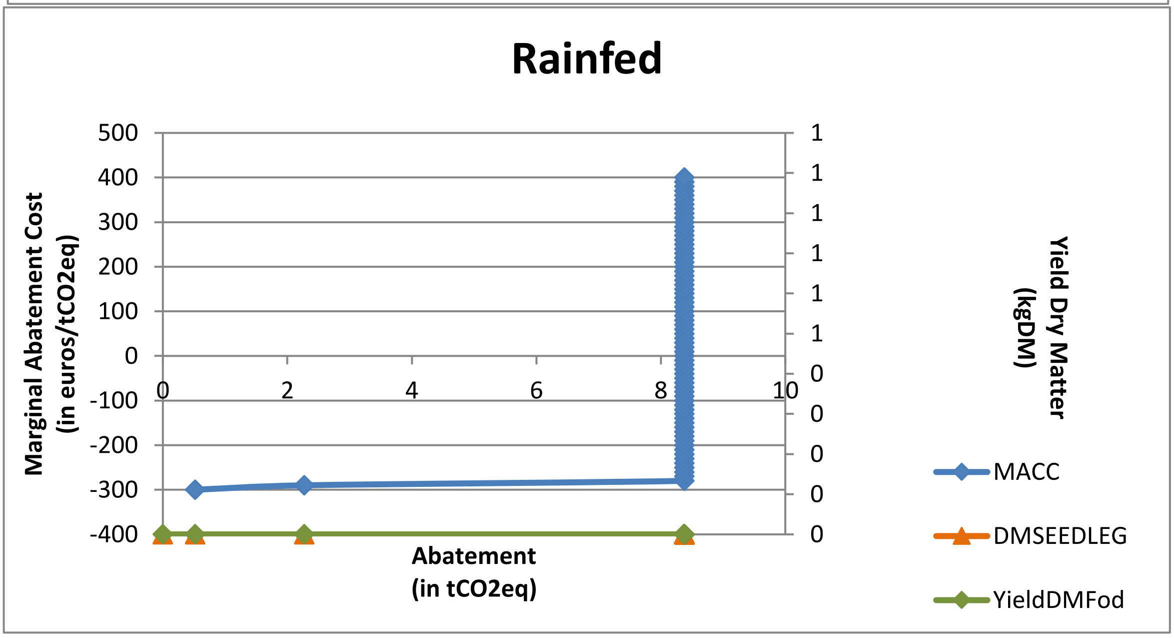

Calabria
Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
5 000
10 000
15 000
20 000
60 000 000
50 000 000
40 000 000
30 000 000
20 000 000
10 000 000
0
Yield Dry Matter (kgDM)
Abatement (in tCO2eq)
MACC
DMSEEDLEG
YieldDMFod

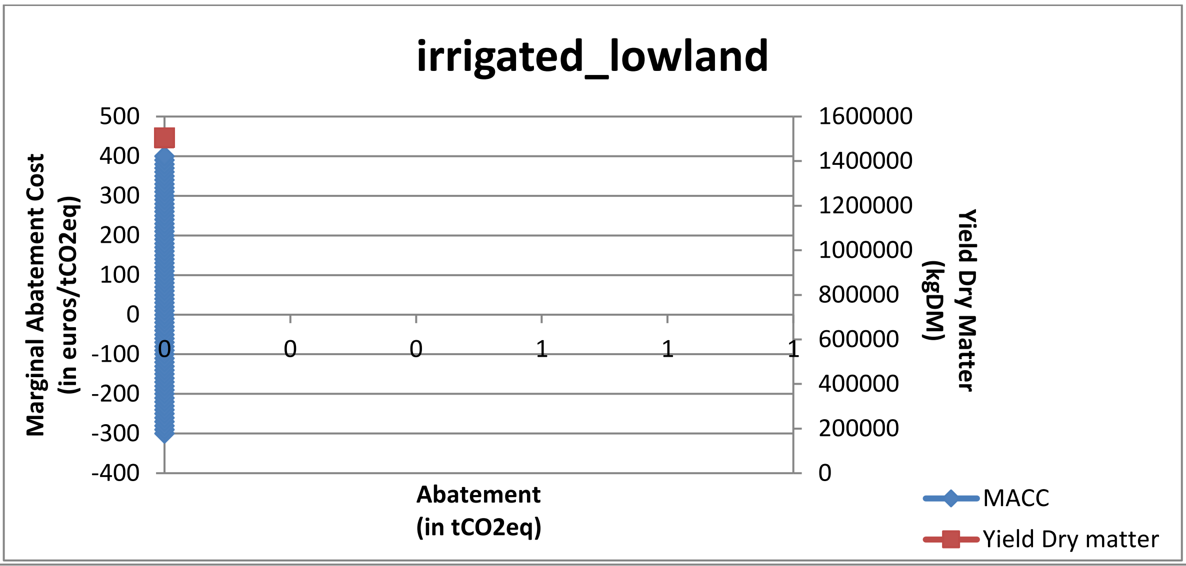

Calabria
Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
5 000
10 000
15 000
20 000
45 000 000
40 000 000
35 000 000
30 000 000
25 000 000
20 000 000
15 000 000
10 000 000
5 000 000
0
-5 000 000
Area (ha)
Abatement (in tCO2eq)
MACC
Cereal
ClassicFodder
SeedLeg
FodderLeg

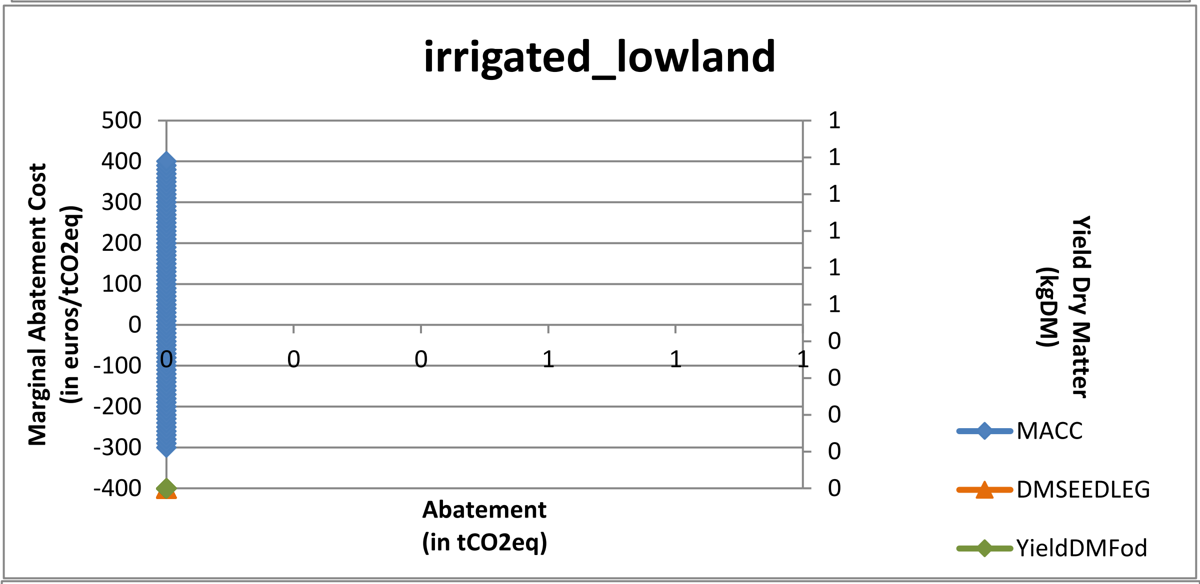
Detail in the site classes of Calabria (for 200ha)

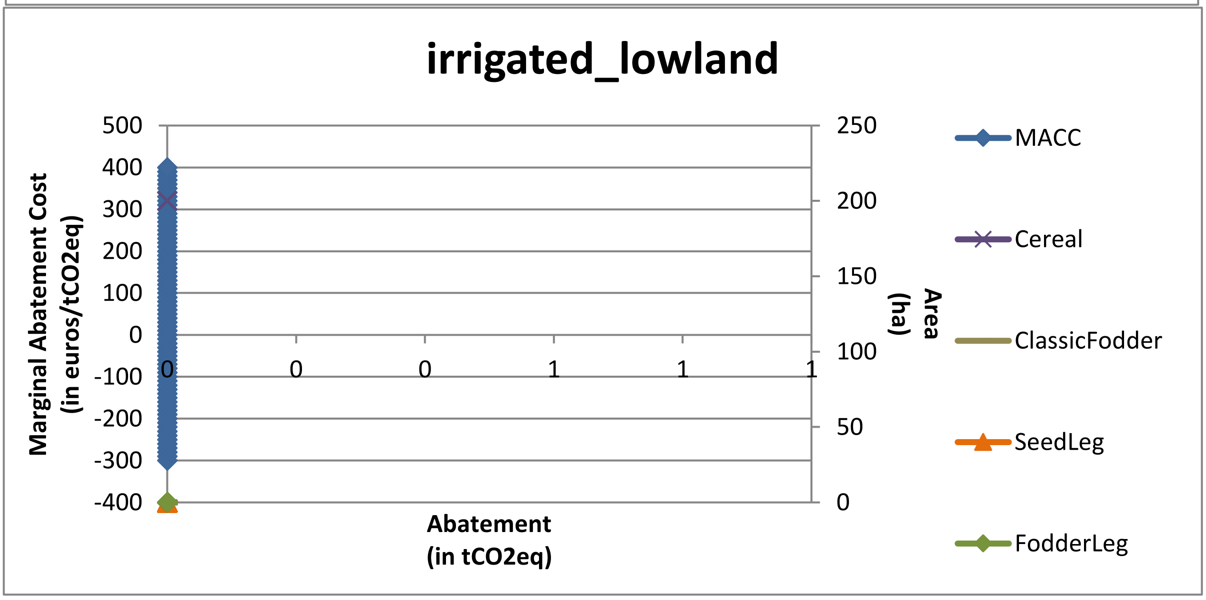


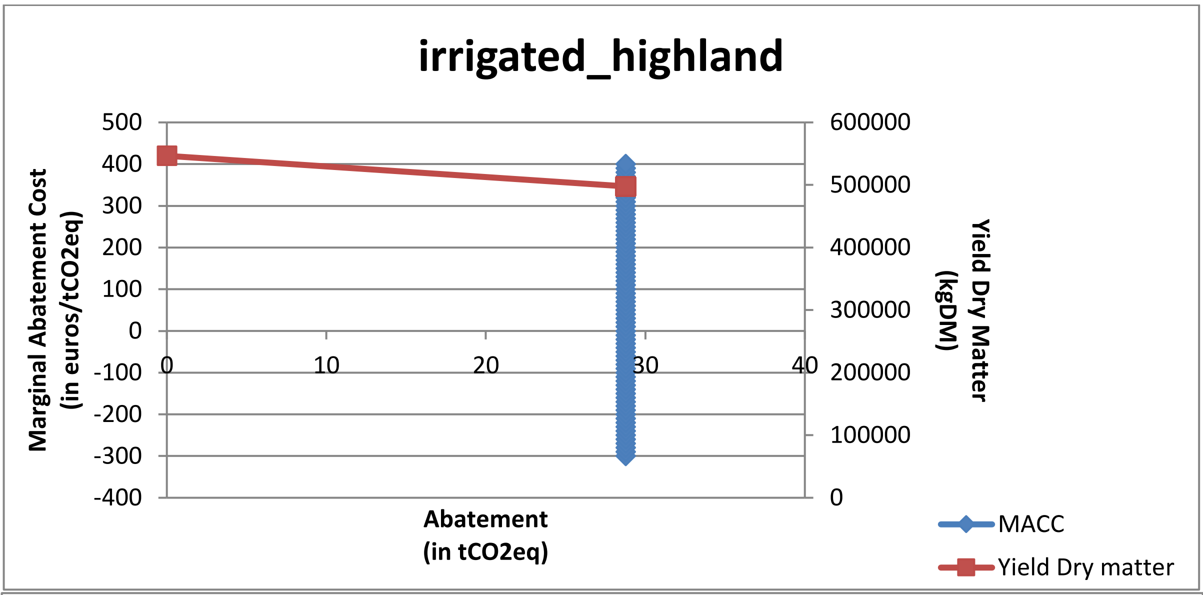


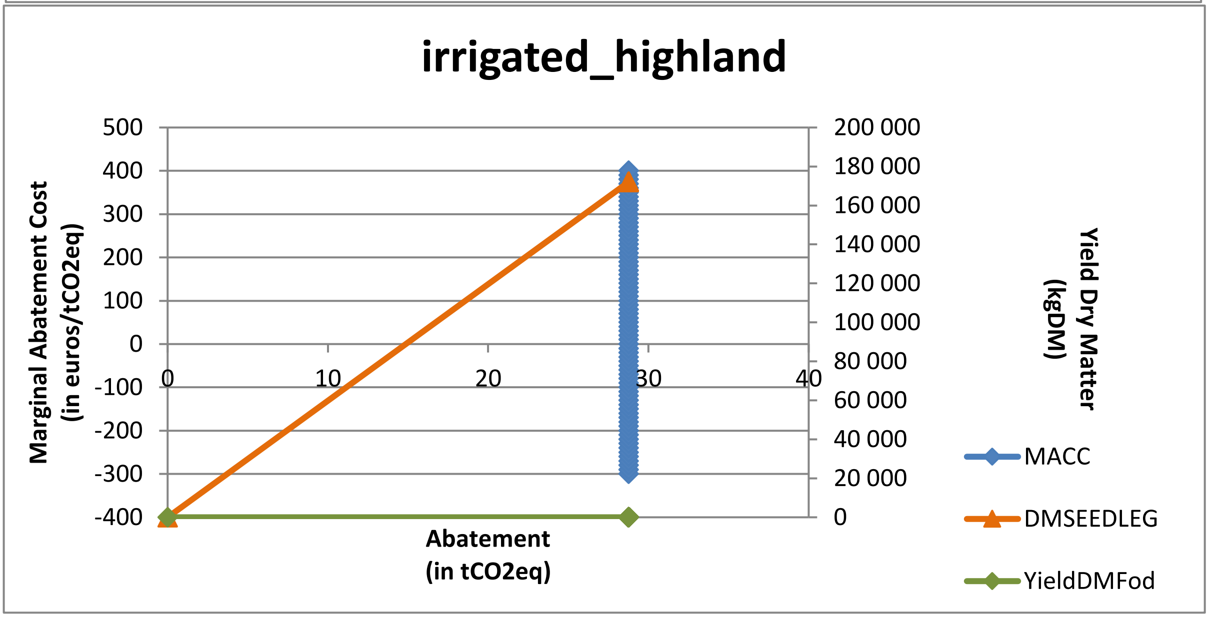


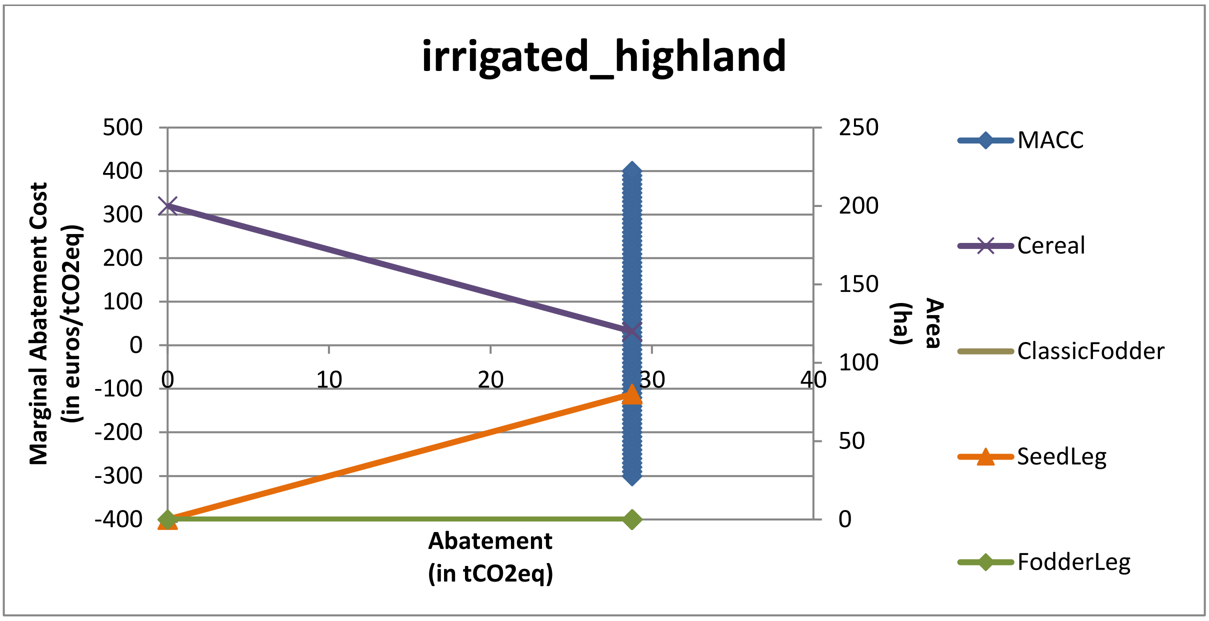

irrigated_lowland
Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
0
0
1
1
1
Abatement (in tCO2eq)
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
Yield Dry Matter (kgDM)
MACC
Yield Dry matter


irrigated_lowland
Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
0
0
1
1
1
Abatement (in tCO2eq)
Yield Dry Matter (kgDM)
MACC
DMSEEDLEG
YieldDMFod

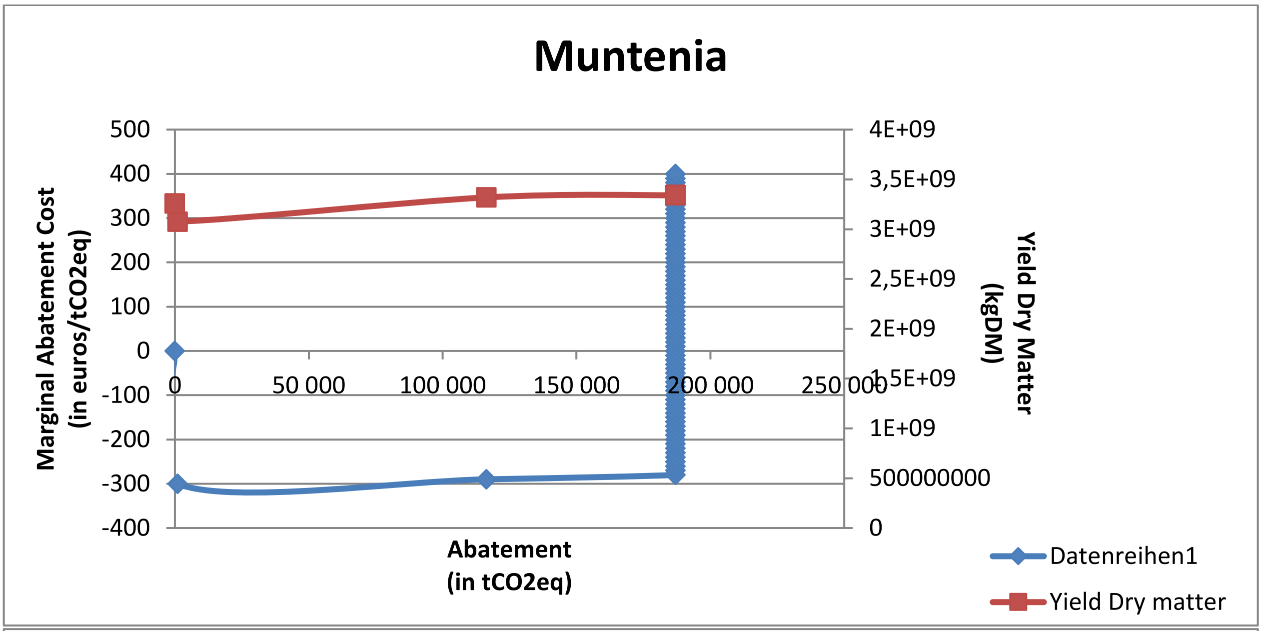

irrigated_lowland
Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
0
0
1
1
1
Abatement (in tCO2eq)
250
200
150
100
50
0
Area (ha)
MACC
Cereal
ClassicFodder
SeedLeg
FodderLeg

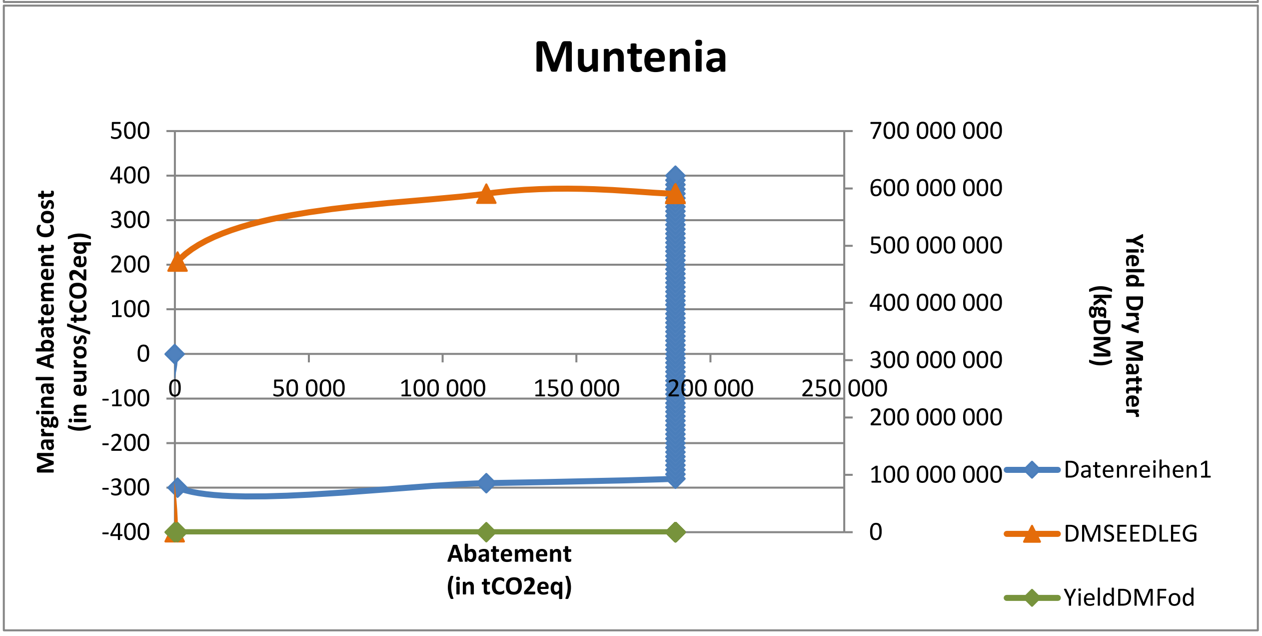

irrigated_highland
Marginal Abatement Cost (in euros/tCO2eq)
Yield Dry Matter (kgDM)
Abatement (in tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
600000
500000
400000
300000
200000
100000
0
0
10
20
30
40
MACC
Yield Dry matter

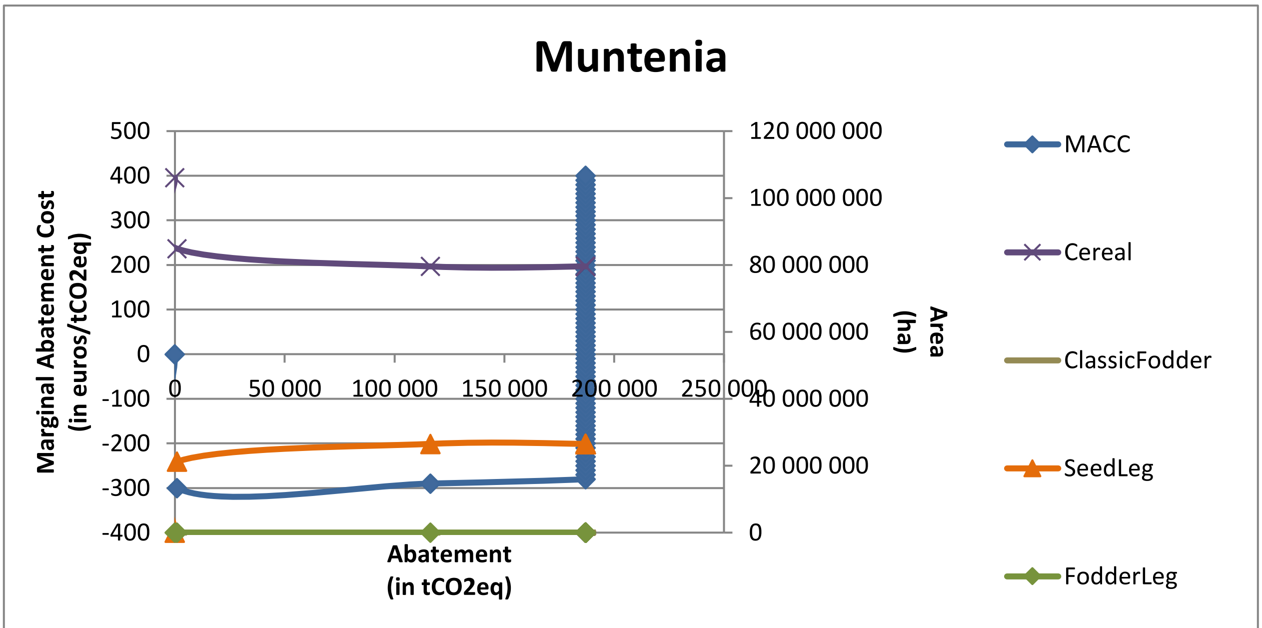

irrigated_highland
Marginal Abatement Cost (in euros/tCO2eq)
Yield Dry Matter (kgDM)
Abatement (in tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
200 000
180 000
160 000
140 000
120 000
100 000
80 000
60 000
40 000
20 000
0
0
10
20
30
40
MACC
DMSEEDLEG
YieldDMFod



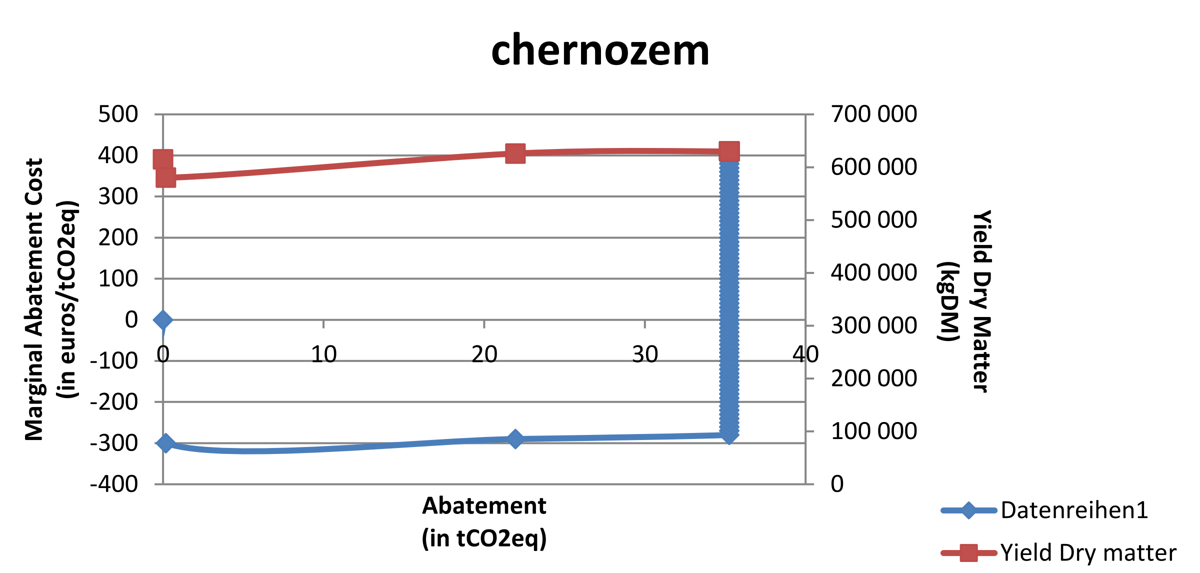
South-Muntenia

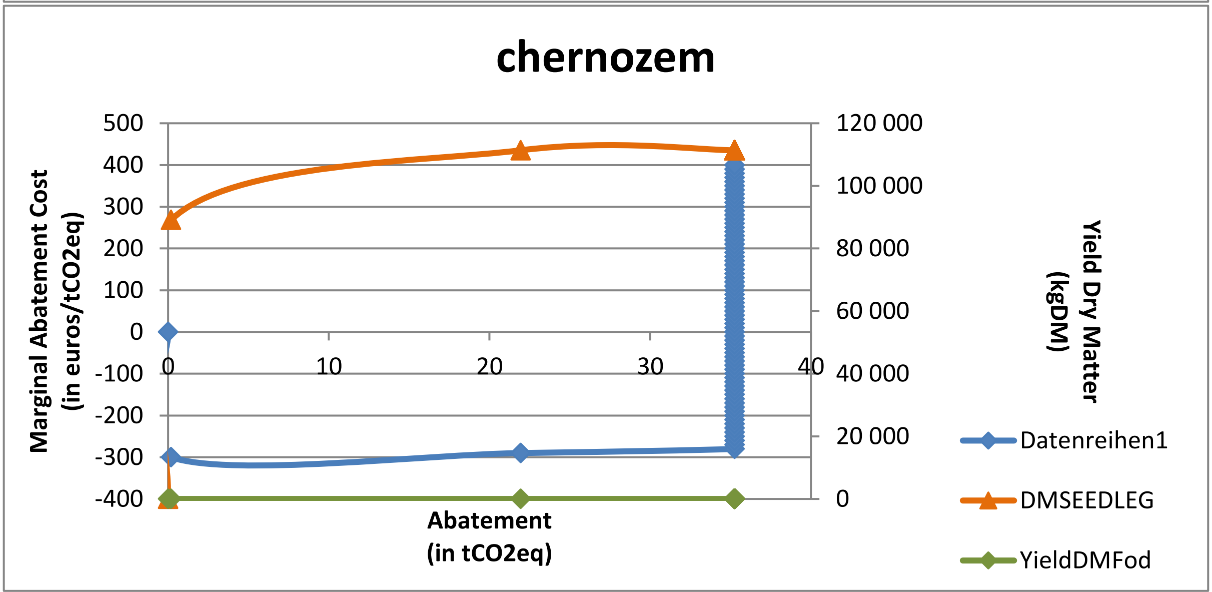

Muntenia
Marginal Abatement Cost
(in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
50 000
100 000
150 000
200 000
250 000
4E+09
3,5E+09
3E+09
2,5E+09
2E+09
1,5E+09
1E+09
500000000
0
Yield Dry Matter
(kgDM)
Abatement
(in tCO2eq)
Datenreihen1
Yield Dry matter

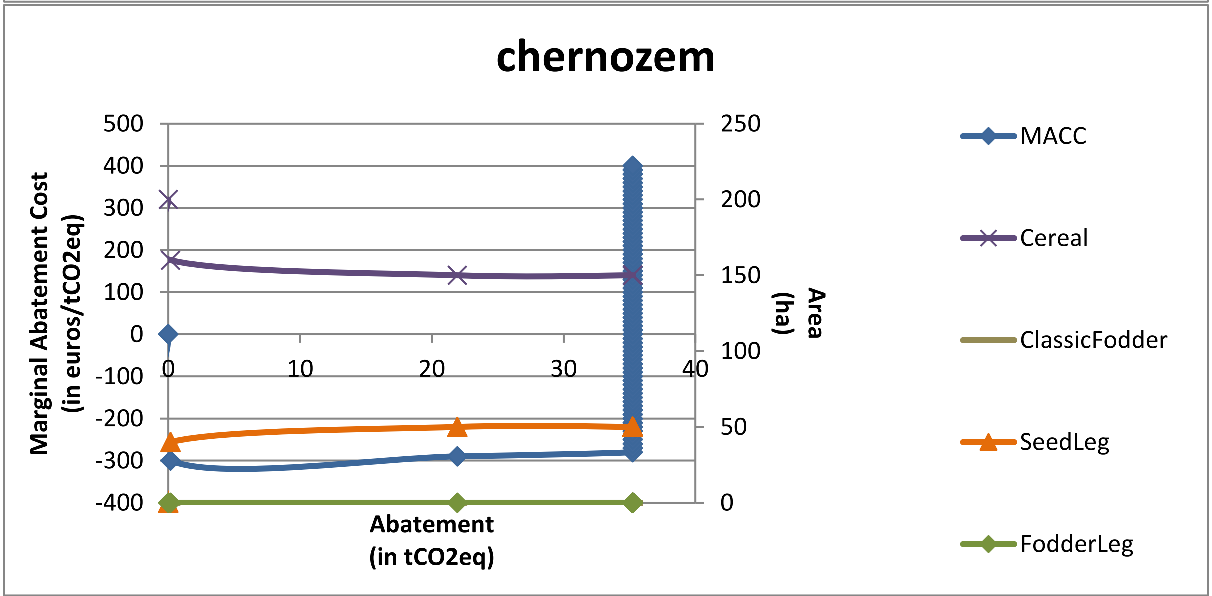

Muntenia
Marginal Abatement Cost
(in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
50 000
100 000
150 000
200 000
250 000
700 000 000
600 000 000
500 000 000
400 000 000
300 000 000
200 000 000
100 000 000
0
Yield Dry Matter
(kgDM)
Abatement
(in tCO2eq)
Datenreihen1
DMSEEDLEG
YieldDMFod

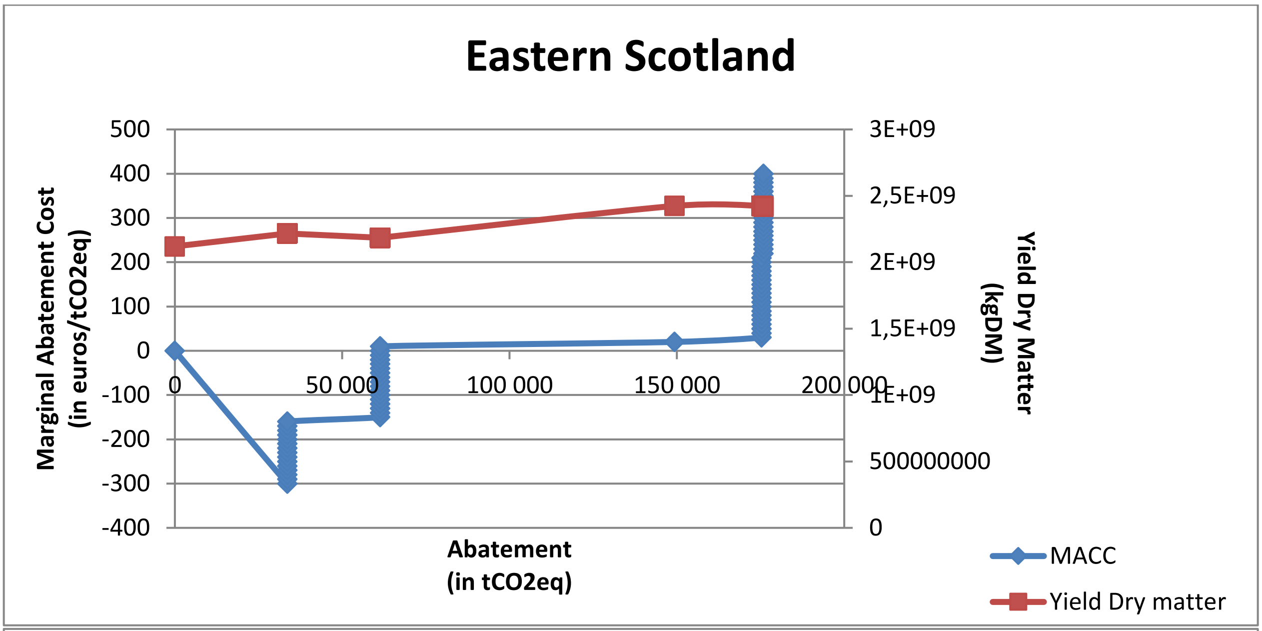

Muntenia
Marginal Abatement Cost
(in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
50 000
100 000
150 000
200 000
250 000
120 000 000
100 000 000
80 000 000
60 000 000
40 000 000
20 000 000
0
Area
(ha)
Abatement
(in tCO2eq)
MACC
Cereal
ClassicFodder
SeedLeg
FodderLeg

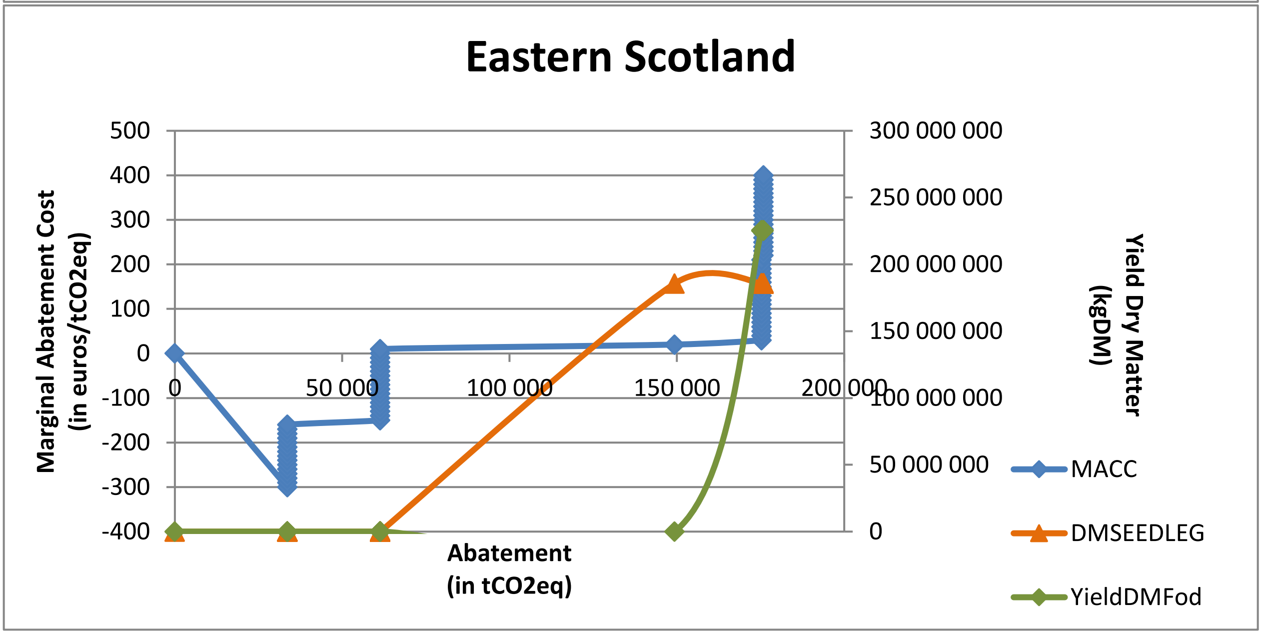
Detail for South-Muntenia Site Class (for 200 ha)

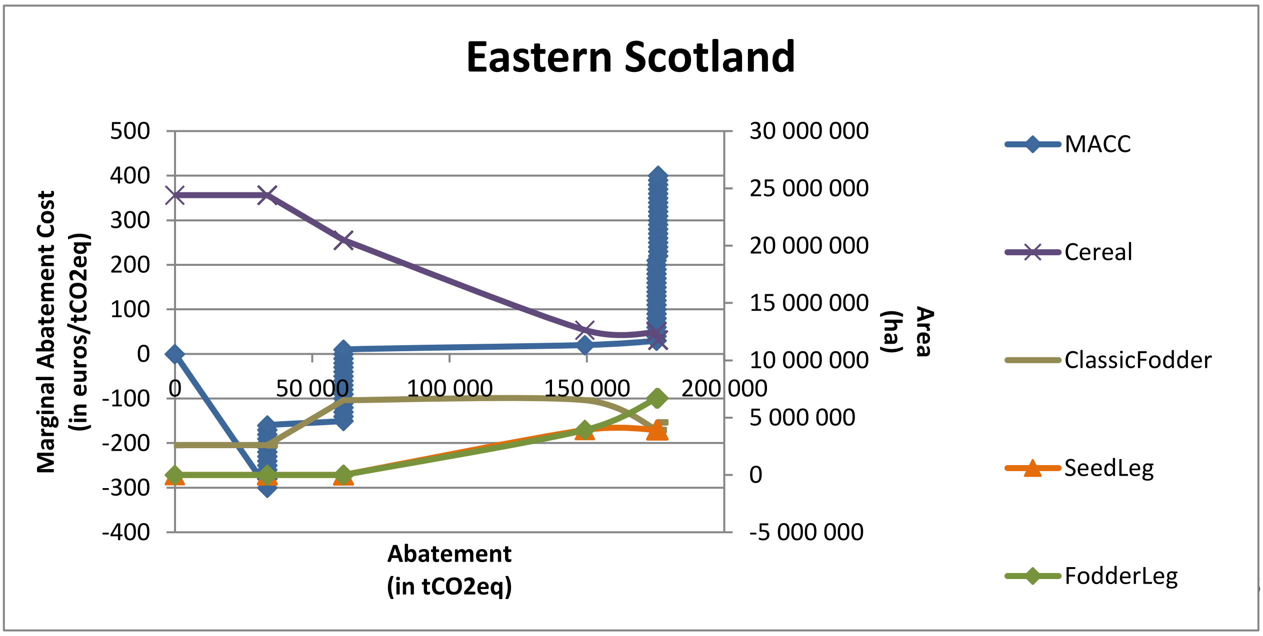




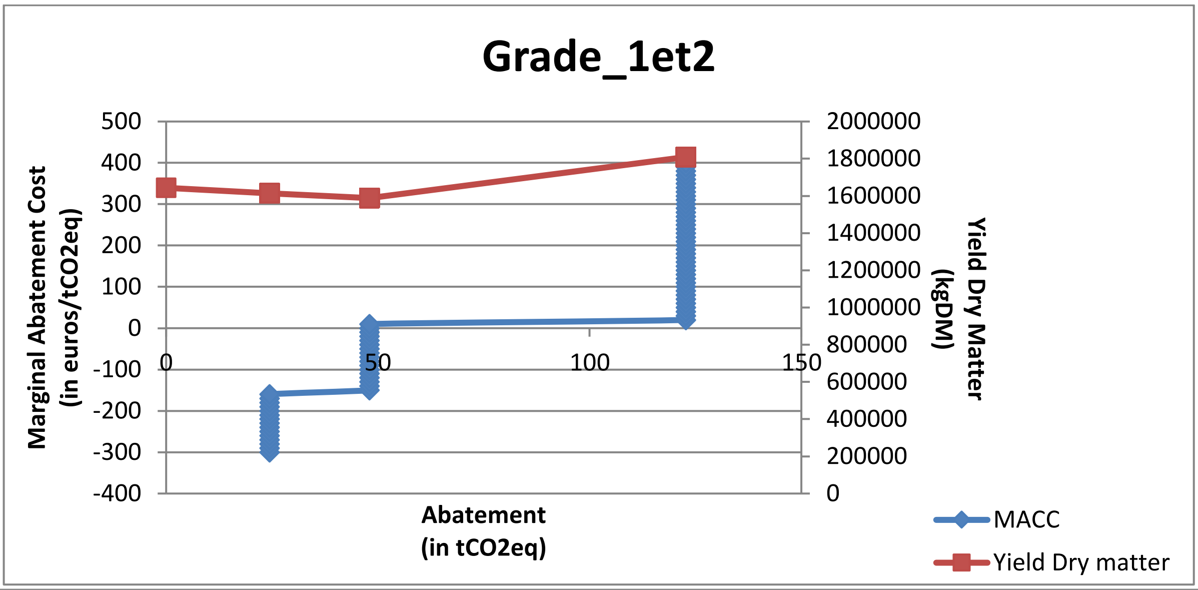


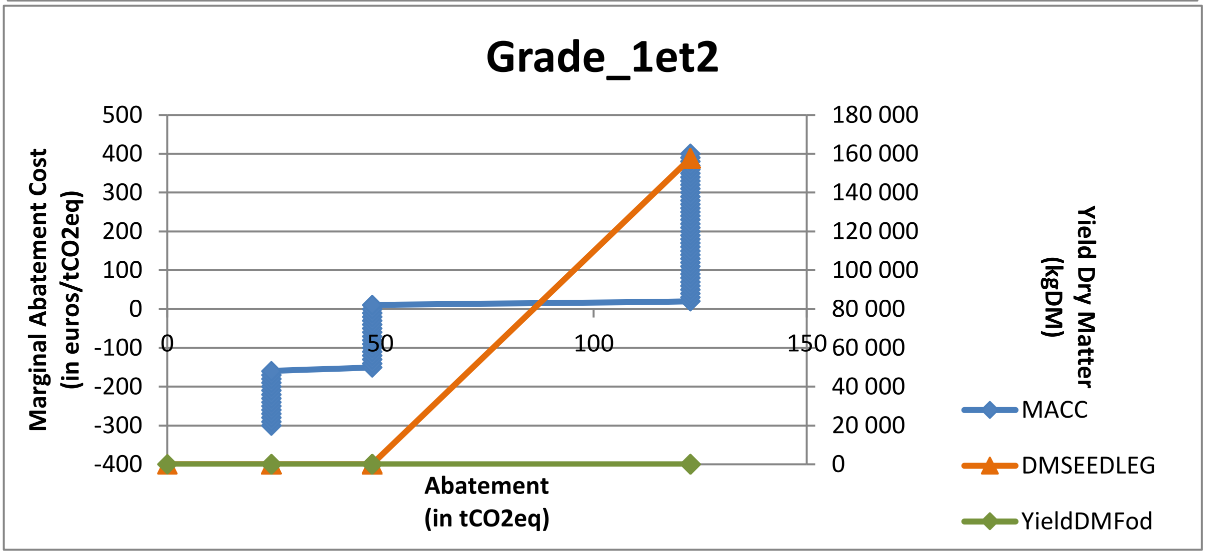

Eastern Scotland
Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
50 000
100 000
150 000
200 000
3E+09
2,5E+09
2E+09
1,5E+09
1E+09
500000000
0
Yield Dry Matter (kgDM)
Abatement (in tCO2eq)
MACC
Yield Dry matter

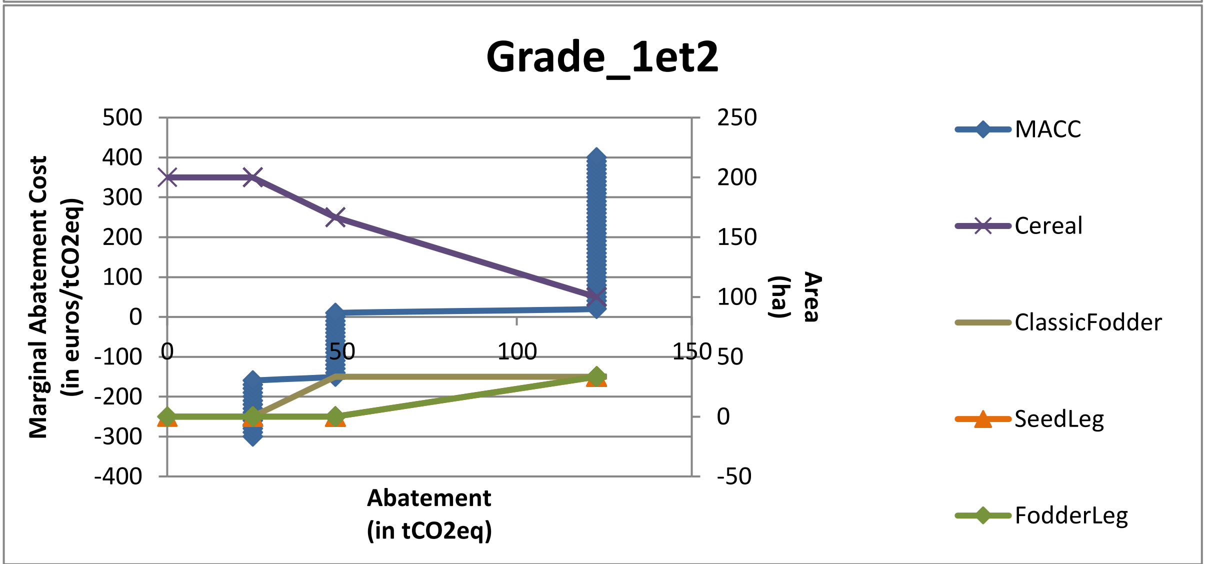

Eastern Scotland
Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
50 000
100 000
150 000
200 000
300 000 000
250 000 000
200 000 000
150 000 000
100 000 000
50 000 000
0
Yield Dry Matter (kgDM)
Abatement (in tCO2eq)
MACC
DMSEEDLEG
YieldDMFod

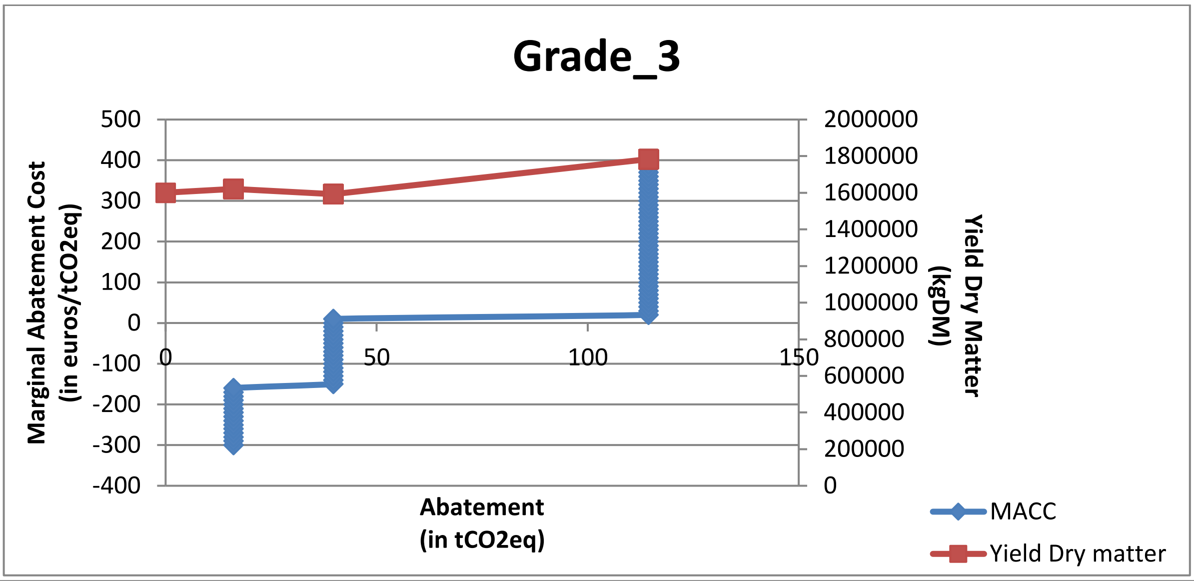

Eastern Scotland
Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
50 000
100 000
150 000
200 000
30 000 000
25 000 000
20 000 000
15 000 000
10 000 000
5 000 000
0
-5 000 000
Area (ha)
Abatement (in tCO2eq)
MACC
Cereal
ClassicFodder
SeedLeg
FodderLeg

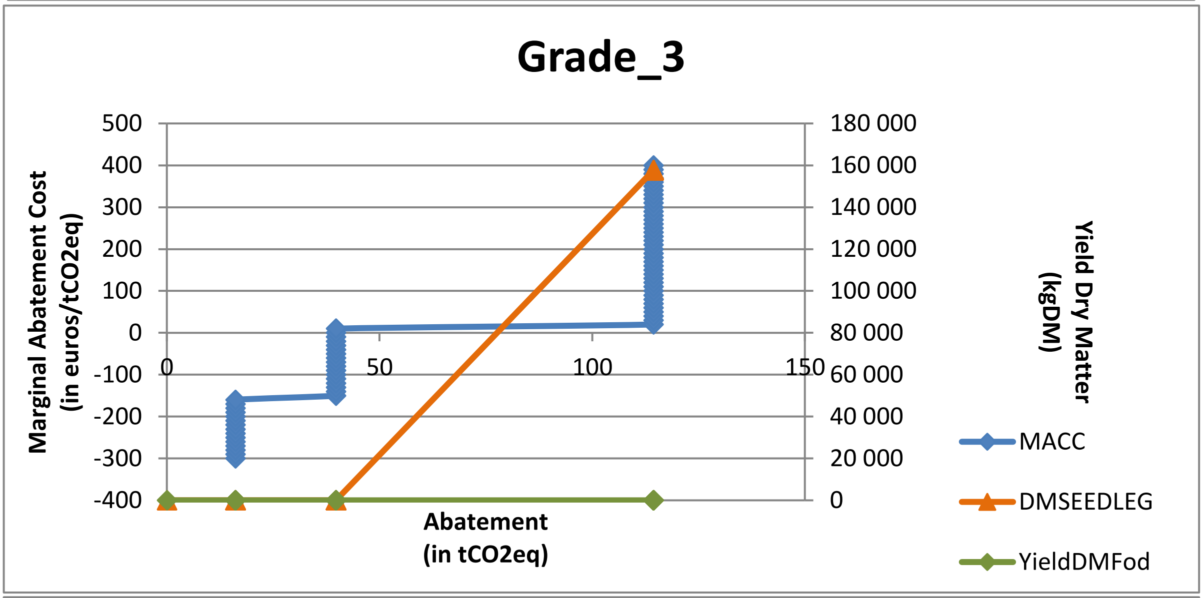
Detail for Eastern Scotland Site Classes (for 200 ha)

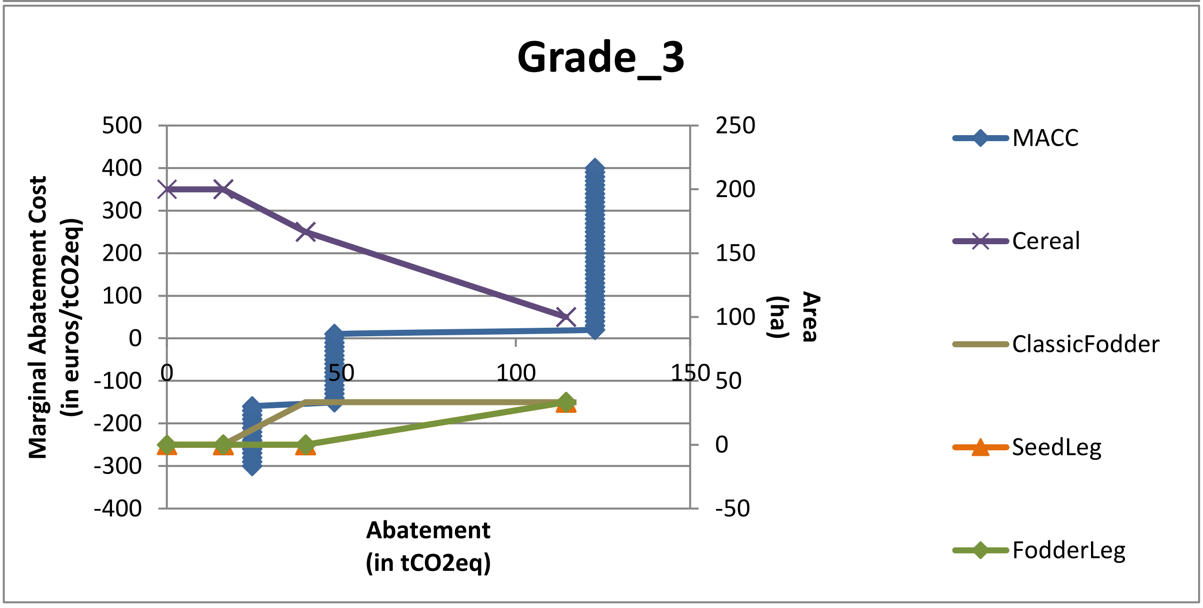


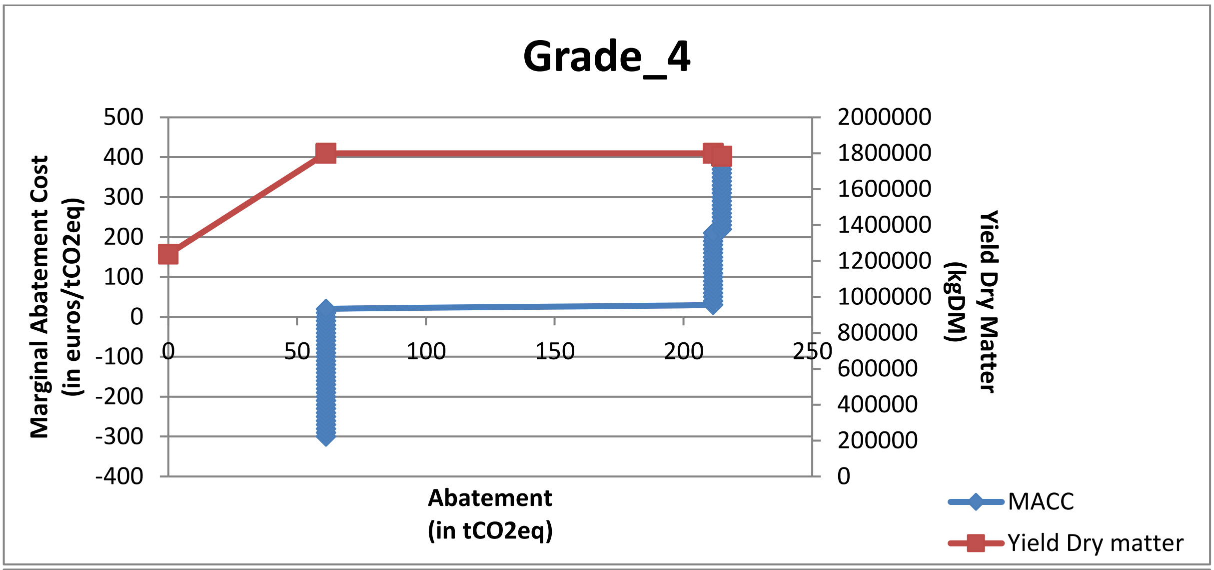


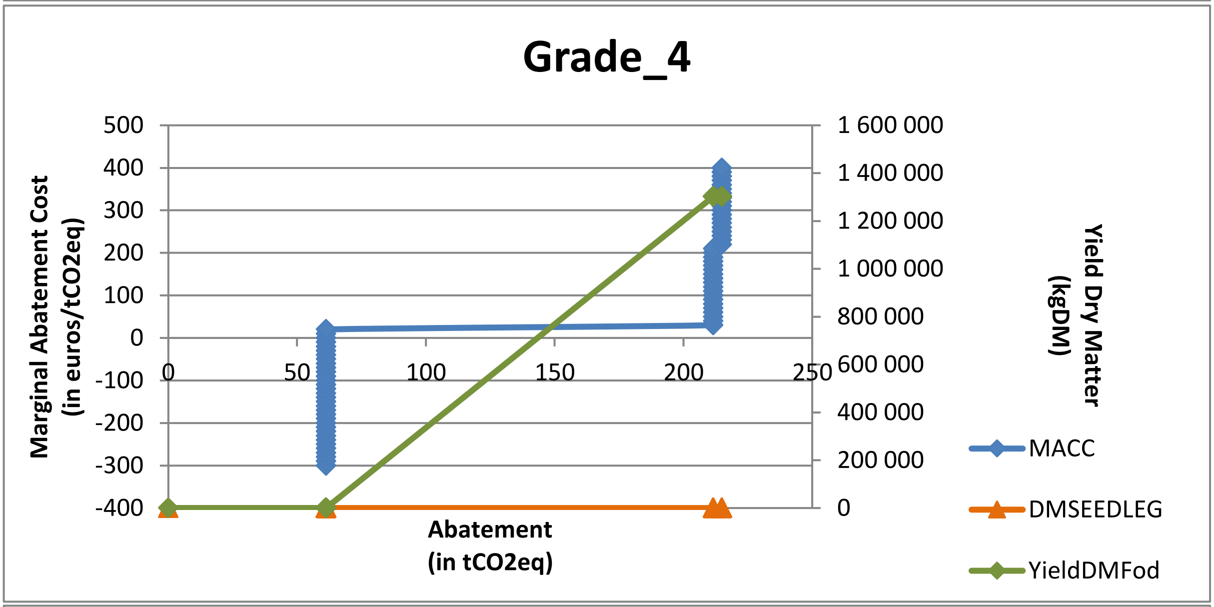


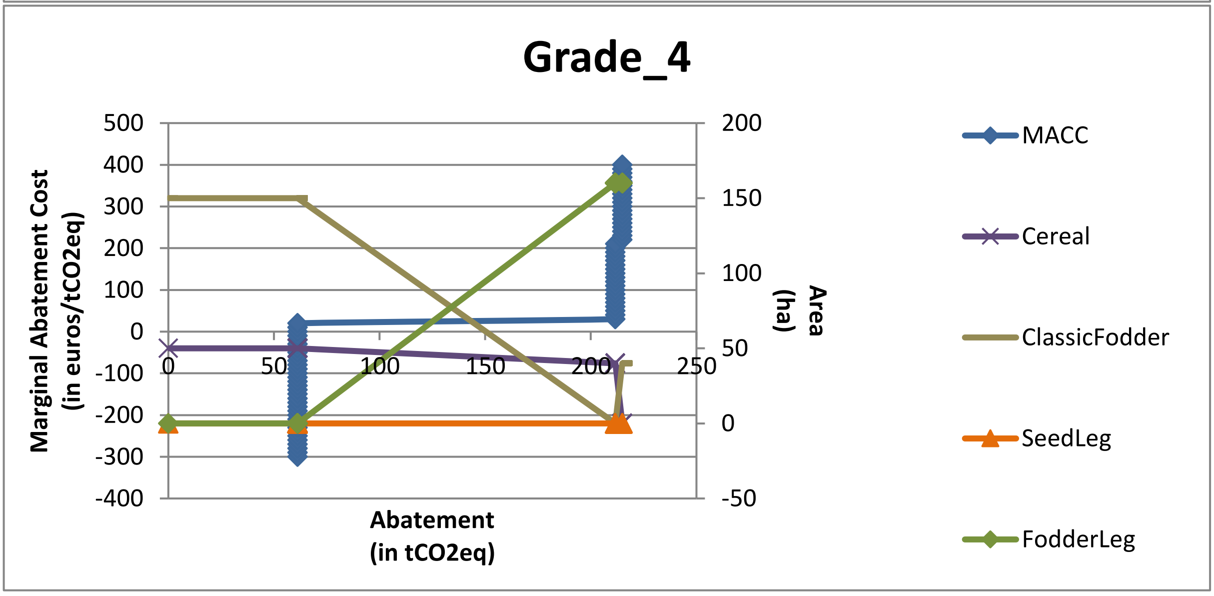

Grade_3
Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
50
100
150
2000000
1800000
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
Yield Dry Matter (kgDM)
Abatement (in tCO2eq)
MACC
Yield Dry matter

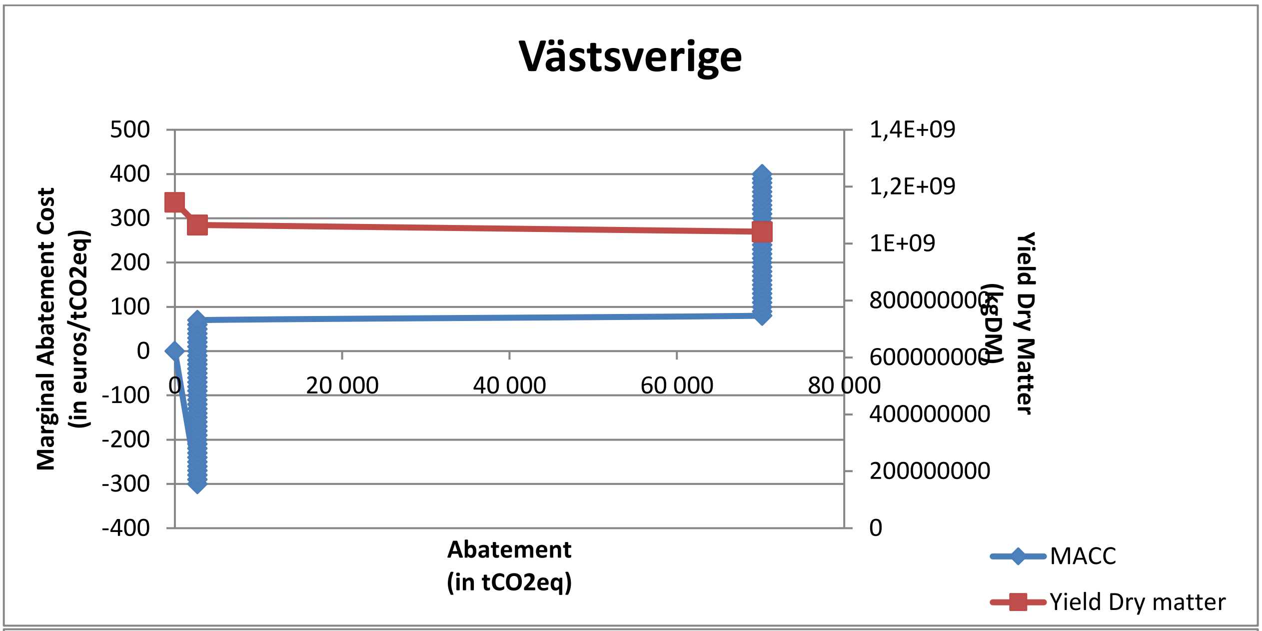

Grade_3
Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
50
100
150
180 000
160 000
140 000
120 000
100 000
80 000
60 000
40 000
20 000
0
Yield Dry Matter (kgDM)
Abatement (in tCO2eq)
MACC
DMSEEDLEG
YieldDMFod

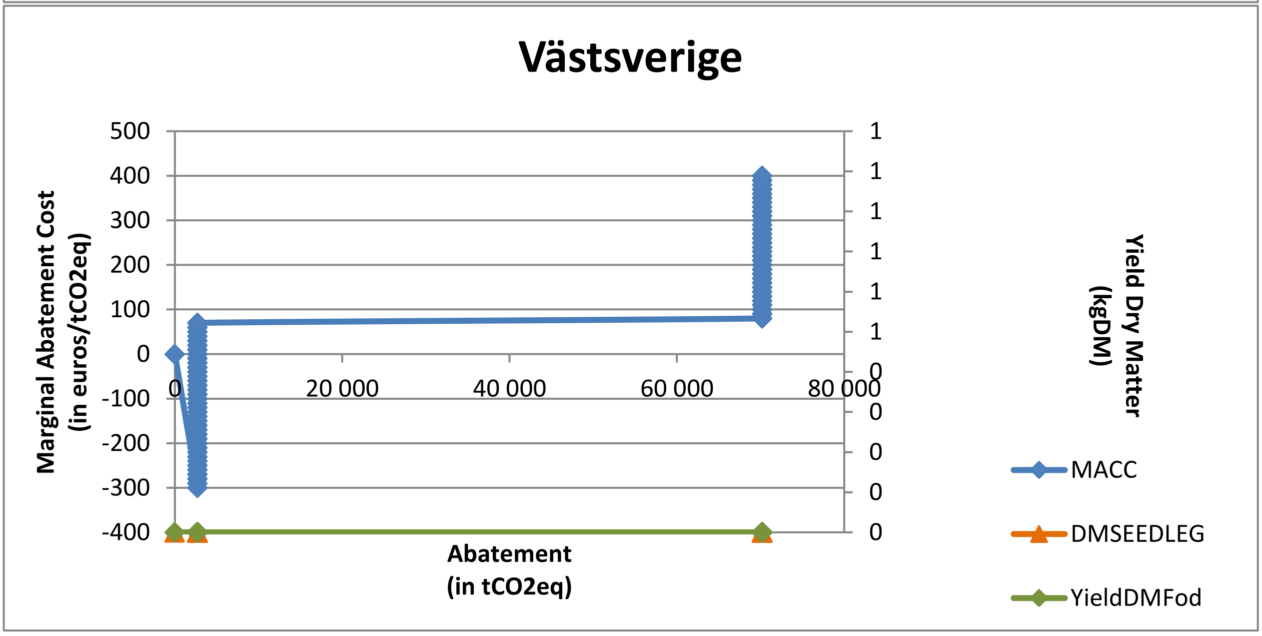

Grade_3
Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
50
100
150
250
200
150
100
50
0
-50
Area (ha)
Abatement (in tCO2eq)
MACC
Cereal
ClassicFodder
SeedLeg
FodderLeg

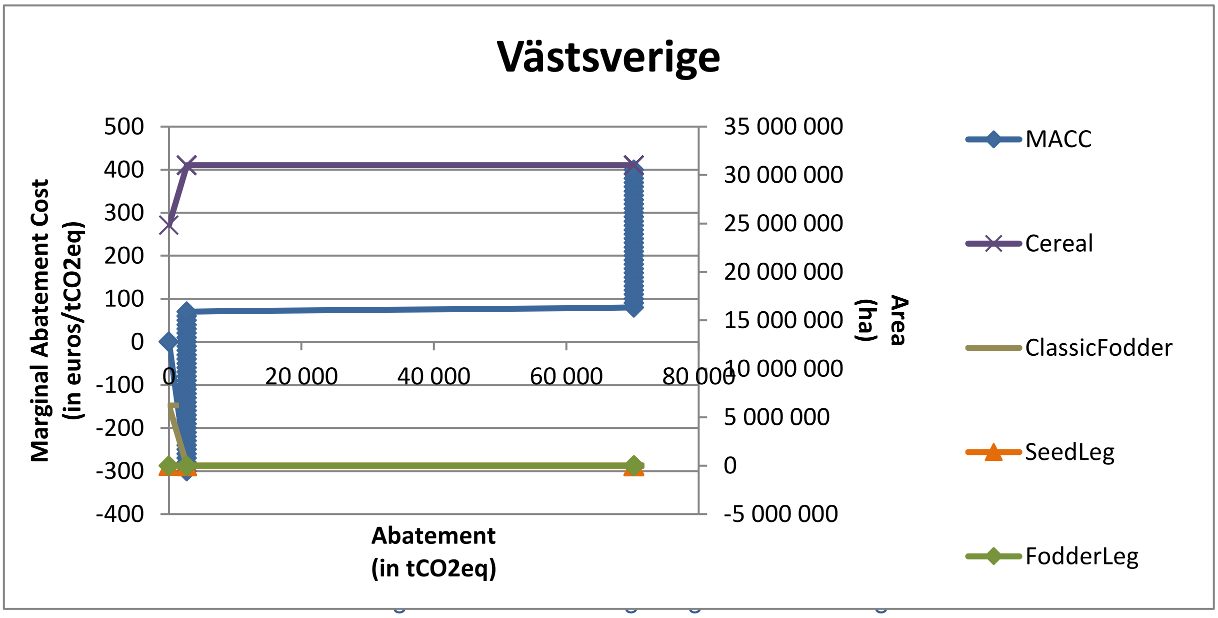

Grade_4
Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
50
100
150
200
250
2000000
1800000
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
Yield Dry Matter (kgDM)
Abatement (in tCO2eq)
MACC
Yield Dry matter

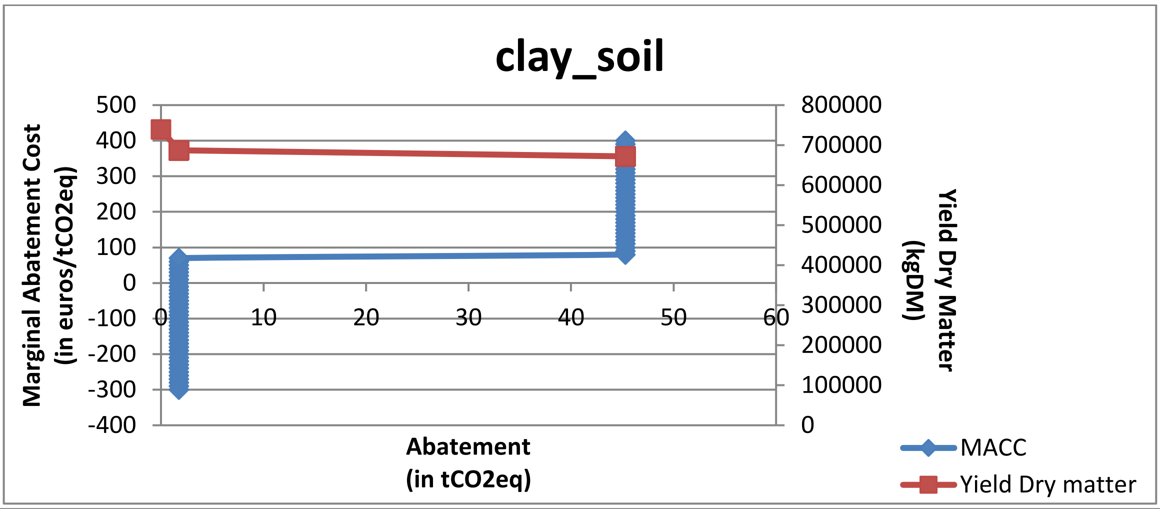

Grade_4
Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
50
100
150
200
250
1 600 000
1 400 000
1 200 000
1 000 000
800 000
600 000
400 000
200 000
0
Yield Dry Matter (kgDM)
Abatement (in tCO2eq)
MACC
DMSEEDLEG
YieldDMFod

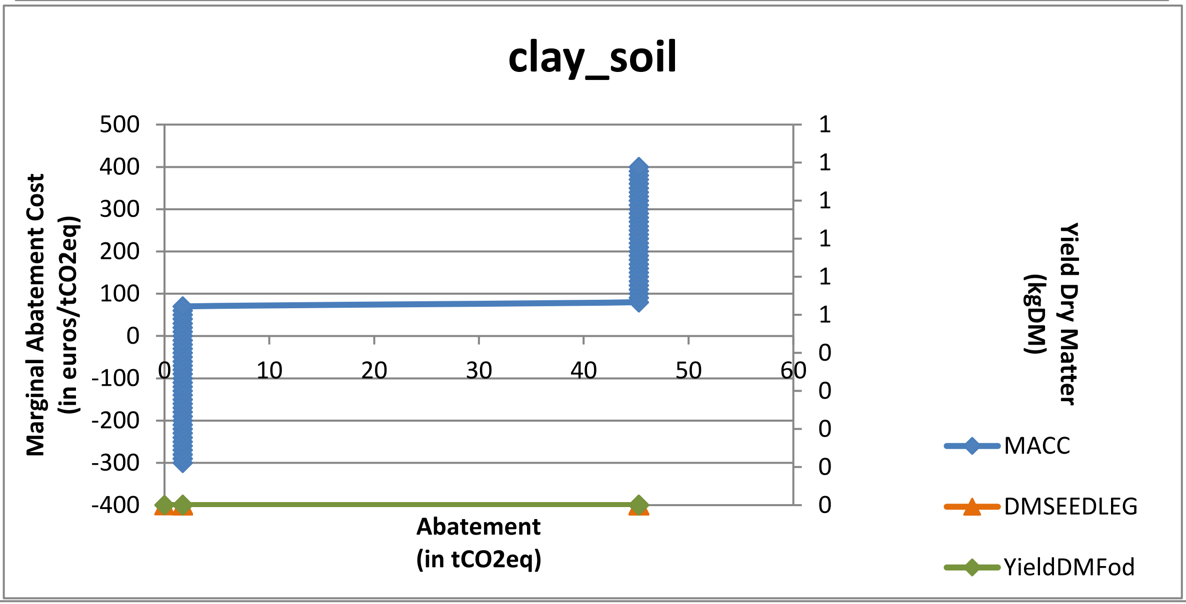

Grade_4
Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
50
100
150
200
250
200
150
100
50
0
-50
Area (ha)
Abatement (in tCO2eq)
MACC
Cereal
ClassicFodder
SeedLeg
FodderLeg

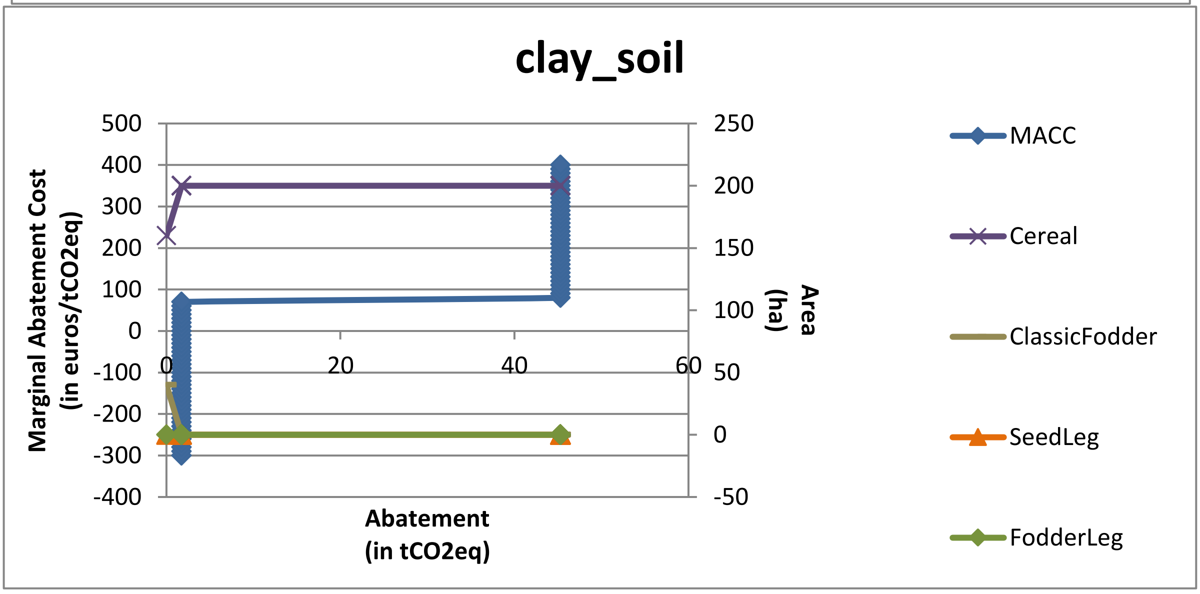

Västsverige
Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
20 000
40 000
60 000
80 000
1,4E+09
1,2E+09
1E+09
800000000
600000000
400000000
200000000
0
Yield Dry Matter (kgDM)
Abatement (in tCO2eq)
MACC
Yield Dry matter


Västsverige
Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
20 000
40 000
60 000
80 000
1
1
1
1
1
1
0
0
0
0
0
Yield Dry Matter (kgDM)
Abatement (in tCO2eq)
MACC
DMSEEDLEG
YieldDMFod

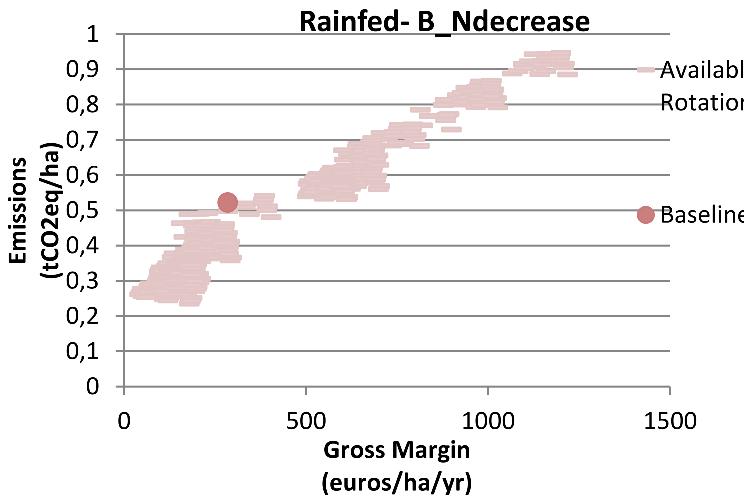

Västsverige
Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
20 000
40 000
60 000
80 000
35 000 000
30 000 000
25 000 000
20 000 000
15 000 000
10 000 000
5 000 000
0
-5 000 000
Area (ha)
Abatement (in tCO2eq)
MACC
Cereal
ClassicFodder
SeedLeg
FodderLeg

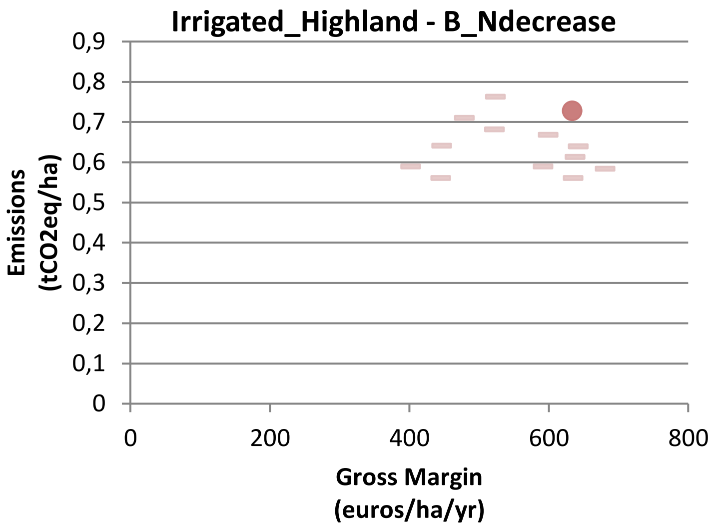

clay_soil
Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
10
20
30
40
50
60
Abatement (in tCO2eq)
Yield Dry Matter (kgDM)
800000
700000
600000
500000
400000
300000
200000
100000
0
MACC
Yield Dry matter

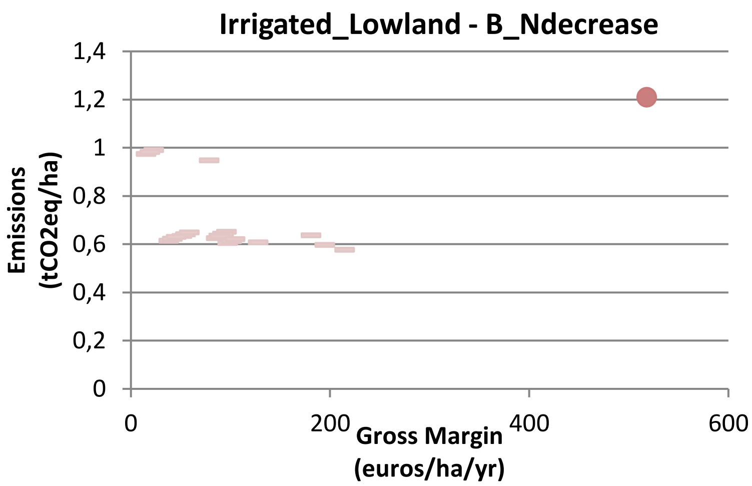

clay_soil
Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
10
20
30
40
50
60
Abatement (in tCO2eq)
Yield Dry Matter (kgDM)
1
1
1
1
1
1
0
0
0
0
0
MACC
DMSEEDLEG
YieldDMFod

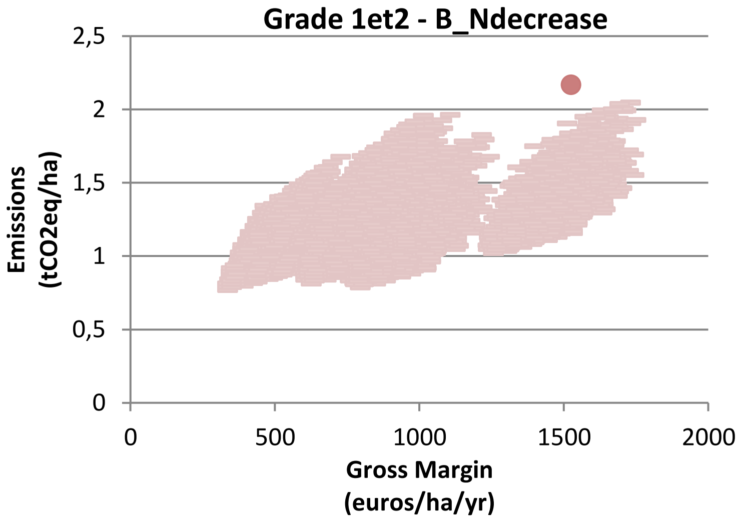

clay_soil
Marginal Abatement Cost (in euros/tCO2eq)
500
400
300
200
100
0
-100
-200
-300
-400
0
20
40
60
Abatement (in tCO2eq)
Area (ha)
250
200
150
100
50
0
-50
MACC
Cereal
ClassicFodder
SeedLeg
FodderLeg

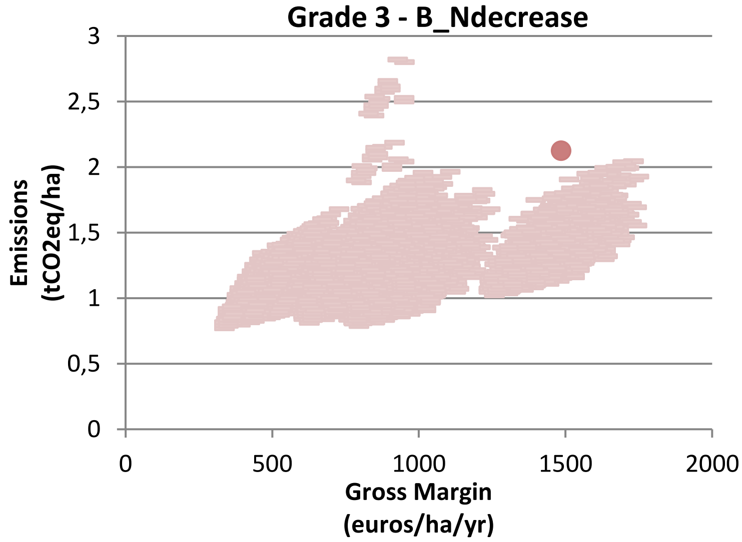
Appendix 5 – GM and GHG emission for each rotation in each site class (B_N-Decrease scenario)

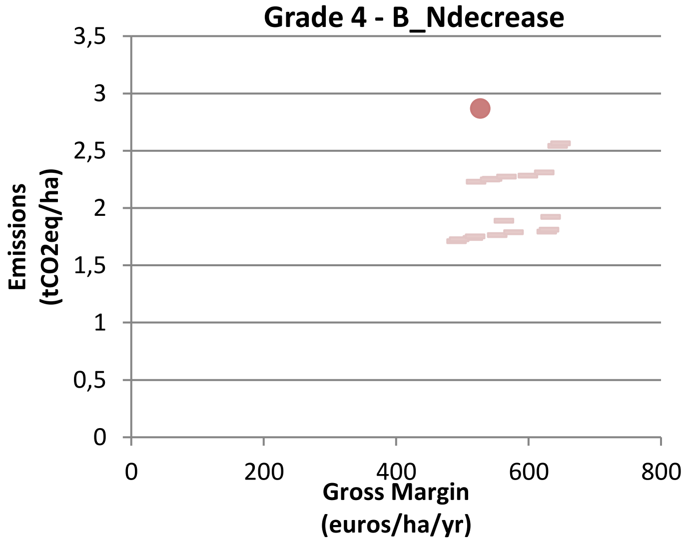


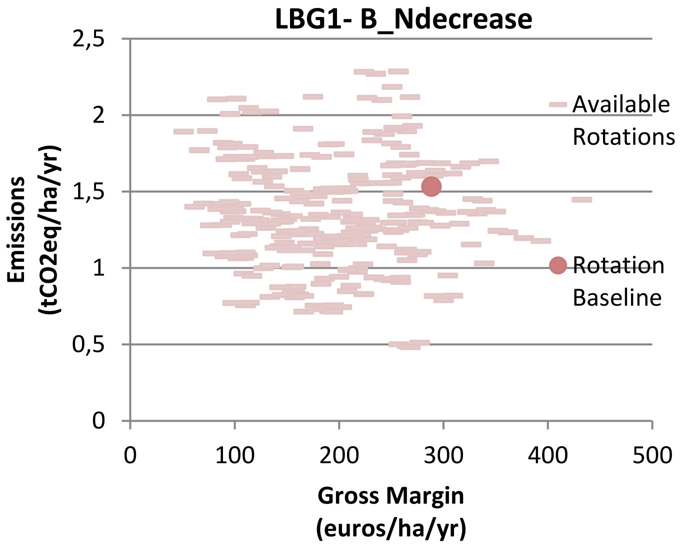


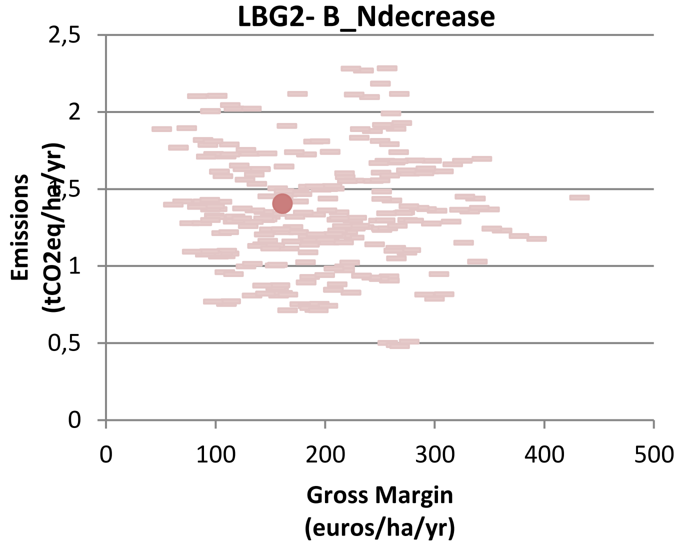


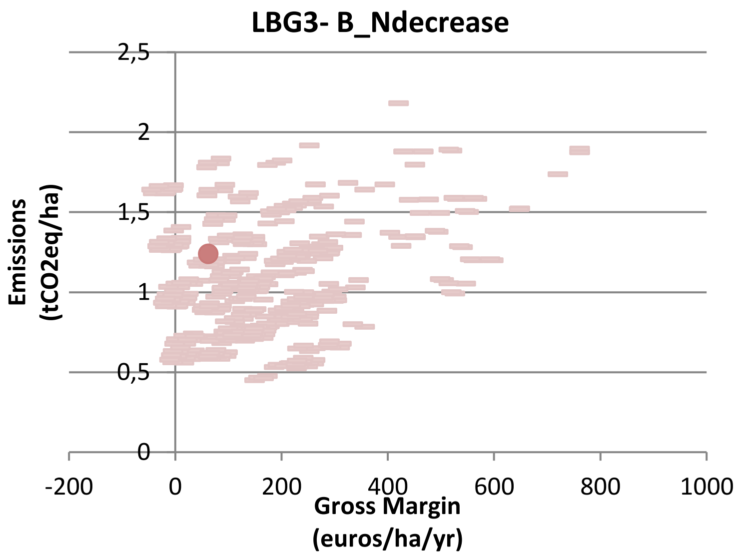


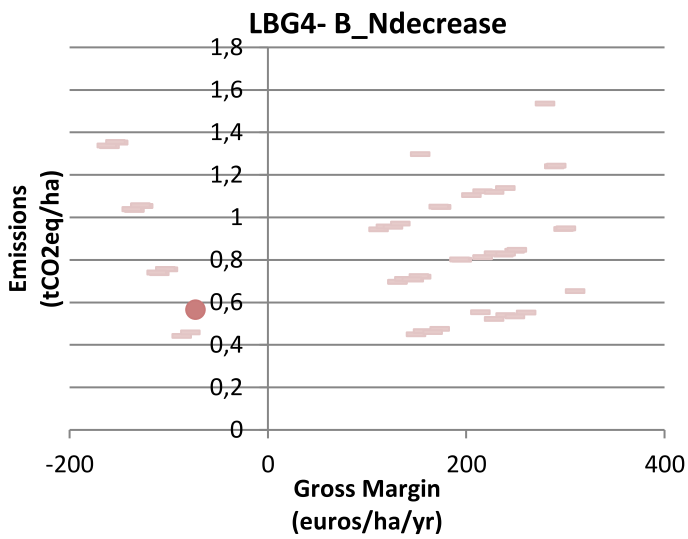


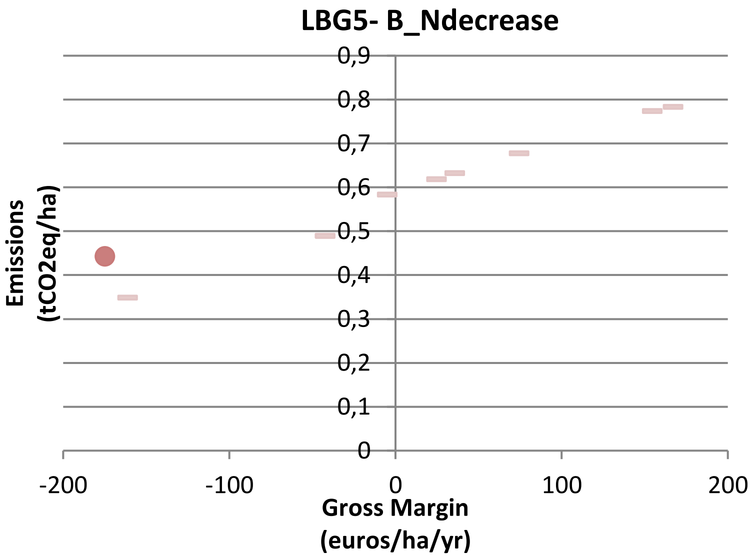


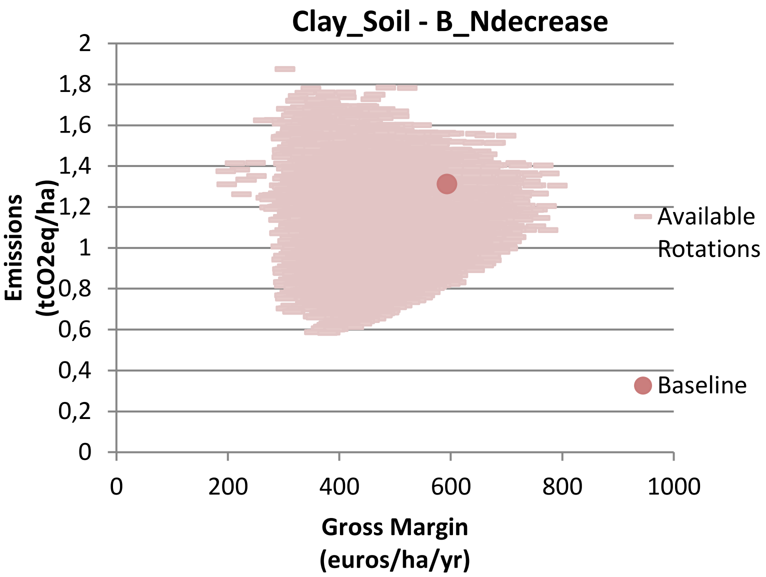

LBG1- B_Ndecrease
Available Rotations
Rotation Baseline
Emissions (tCO2eq/ha/yr)
2,5
2
1,5
1
0,5
0
0
100
200
300
400
500
Gross Margin (euros/ha/yr)

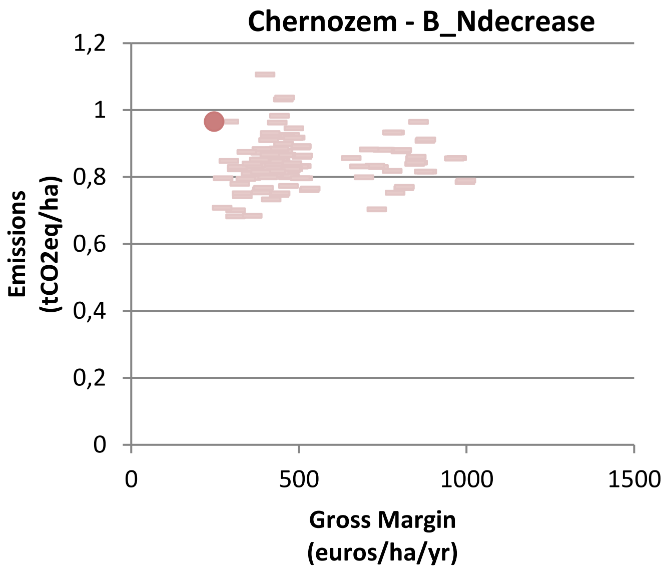

LBG2- B_Ndecrease
Emissions (tCO2eq/ha/yr)
2,5
2
1,5
1
0,5
0
0
100
200
300
400
500
Gross Margin (euros/ha/yr)


LBG3- B_Ndecrease
Emissions (tCO2eq/ha)
2,5
2
1,5
1
0,5
0
-200
0
200
400
600
800
1000
Gross Margin (euros/ha/yr)

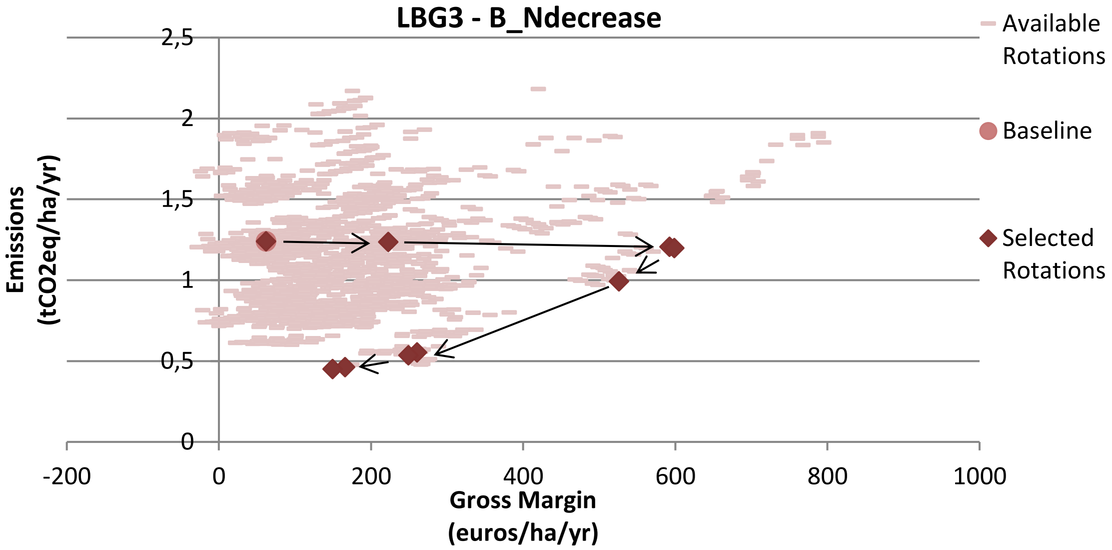

LBG4- B_Ndecrease
Emissions (tCO2eq/ha)
1,8
1,6
1,4
1,2
1
0,8
0,6
0,4
0,2
0
-200
0
200
400
Gross Margin (euros/ha/yr)


LBG5- B_Ndecrease
Emissions (tCO2eq/ha)
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
-200
-100
0
100
200
Gross Margin (euros/ha/yr)


Clay_Soil - B_Ndecrease
Emissions (tCO2eq/ha)
2
1,8
1,6
1,4
1,2
1
0,8
0,6
0,4
0,2
0
0
200
400
600
800
1000
Gross Margin (euros/ha/yr)
Available Rotations
Baseline


Chernozem - B_Ndecrease
Emissions (tCO2eq/ha)
1,2
1
0,8
0,6
0,4
0,2
0
0
500
1000
1500
Gross Margin (euros/ha/yr)

Appendix 6 – Illustration of the selection of rotations to build the MACC (for LBG3 in B_N-Decrease scenario)



The rotations that are selected from all the potential rotations are those which emissions are below the baseline rotation's emissions. To be economically efficient the additional profit of the rotation per emission reduced has to be maximal (or in other words, the marginal abatement cost has to be minimum) compared with the previous selected one. Thus, starting at the baseline point, the selection pathway follows the external boundary of the panel. Finally, it ends at the extreme point of minimum emissions.

Appendix 7 – Site class descriptions

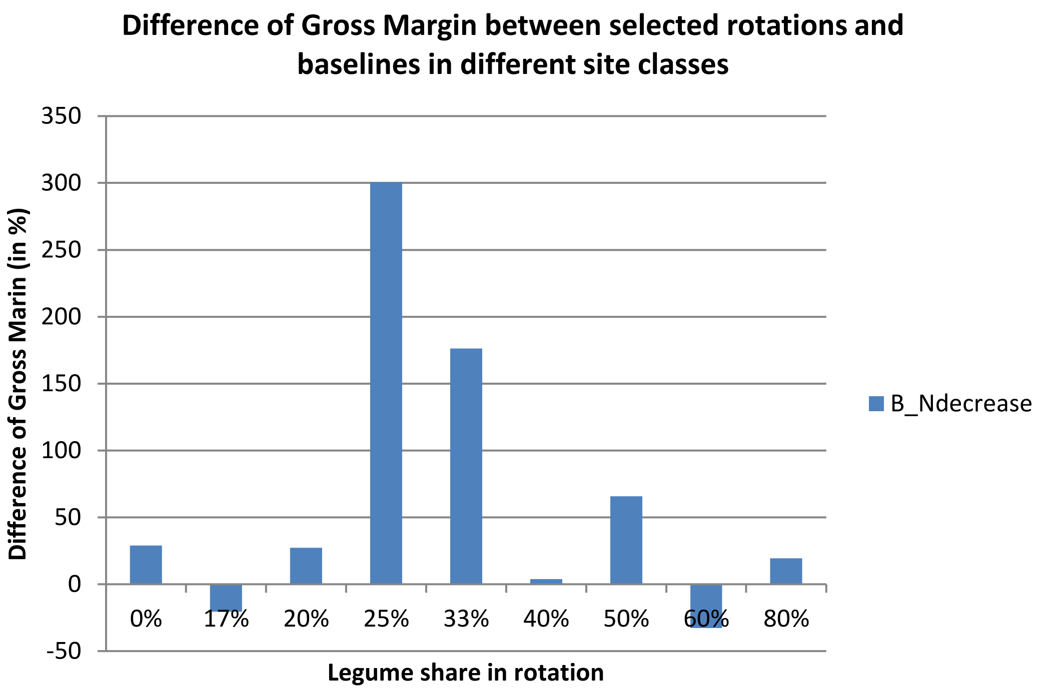
NUTS 2 region	Brandenburg					Calabria			Sud-Muntenia	Eastern Scotland			Vätstsverige
Country	Germany					Italy			Romania	UK			Sweden
Site class	LBG1	LBG2	LBG3	LBG4	LBG5	irrigated highland	irrigated lowland	rainfed	Chernozem	Grade 1&2	Grade 3	Grade 4	claysoil
Soil type	Silty clay loam	Loam	Sandy clay loam	Sandy loam	Loamy sand	Sandy loam	Sandy loam	Loam	Chernozem	Dreghorn	Hobkirk	Yarrow	Silty clay loam
Share of site class from total NUTS2 area (%)	7.4	22.4	36.7	27.3	6.3	12.8	26.0	61.1	100.0	31.8	60.6	7.6	100.0
Area (ha)	75,944	230,952	378,677	281,927	64,500	20,034	40,603	95,363	1,859,000	134,909	256,970	32,121	577,000

Location of the 5 regions in Europe

Appendix 8 – Abbreviation of crops

Abbreviation	Common name	Legume?	TYPE
Seradel	Serradella	yes	Fodder legumes
Wbarley	Winter barley	no	Cereals
SbarleyorSpring barley	Spring barley	no	Cereals
Wrape	Winter rapeseed	no	Cereals
Ryevect/Ryevetc/Rye vetch	Rye-vetch mixture	yes	Fodder legumes
Wrye	Winter rye	no	Cereals
Tritica	Triticale	no	Cereals
Wwheat	Winter wheat	no	Cereals
Swheat	Spring wheat	no	Cereals
Durum	Durum wheat	no	Cereals
Lupin	Lupin	yes	Grain legumes
Soybean	Soy bean	yes	Grain legumes
Fababea	Faba bean	yes	Grain legumes
Alfalfa	Alfalfa	yes	Fodder legumes
Graclov	Grass/cloverley	yes	Fodder legumes
Grass	Grass ley	no	Classic fodder
Peaoat	Pea-oat mixture	yes	Fodder legumes
Soat	Spring oat	no	Classic fodder
Woat	Winter oat	no	Classic fodder
Oatvect/Oat-vetch/ Oatvetc	Oat-vetch mixture	no	Classic fodder
Maize_s/ Silage maize	Maize for silage	no	Classic fodder
Maize_g	Maize for grain	no	Cereals
Linseed	Linseed	no	Cereals
Potato	Potatoes	no	Cereals
Swedes	Swedes	no	Cereals
Combean	Common bean	yes	Grain legumes
Pea	Peas	yes	Grain legumes
Sunfl	Sunflower	no	Cereals
Clover	Clover	yes	Fodder legumes
Sulla	Sulla	yes	Grain legumes
Swede_Fodder	Fodder swedes	no	Classic fodder

Appendix 9 – Difference of Gross Margin between selected rotations and baselines in different site classes



This graph presents the average of differences of gross margin of selected rotations compared with the baseline in the 13 different site classes according to legumes share. We observe that the highest increase of gross margin happens for rotations including 25% of legumes and to a lower extent for rotation including 33% of legumes.

Appendix 10 – Comparison of the results with results on legumes from European MACC studies[24] [25]

		INRA, 2013			Moran et. al, 2010	This study, abatement up to 0 cost-effectiveness (scenario B_N-Decrease)		
	Unit	Grain legumes	Fodder legumes	Total legumes	Total legumes	Grain legumes	Fodder legumes	Total legumes
Geographical scope		France			United Kingdom	5 NUTS2 regions in Europe		
Abatement potential	Mt CO_2eq	0.9	0.5	1.4	0.008	-	-	0.683
Total cost	M €	17	-89	-72	94	-	-	-2,032
Abatement Cost	€/tCO_2eq	19	-185	-52	11,710	-	-	-2,975
Legumes area introduced	ha	877,681	2,822,500	3,700,181	5,572,683	388,196	597,965	986,160
Abatement potential for legumes	t CO_2eq/ha	1.03	0.18	0.38	0.0014	-	-	0.693
Cost per legumes area	€/ha	19.4	-31.5	-19.5	17	-	-	-2,061

24 MacLeod, M., Moran, D., Eory, V., Rees, R., Barnes, A., Topp, C. F., Ball, B., Hoad, S., Wall, E., McVittie, A., et al. (2010). Developing greenhouse gas marginal abatement cost curves for agricultural emissions from crops and soils in the UK. Agricultural Systems, 103(4), 198–209.

25 INRA, 2013. Quelle contribution de l'agriculturefrançaise à la reduction des emissions de gaz à effet de serre? Potentield'atténuation et coût de dix actionstechniques. Synthèse du rapport de l'étuderéalisée par l'INRApour le compte de l'ADEME, du MAAF et du MEDDE.