WFL Publisher
Science and Technology

Meri-Rastilantie 3 B, FI-00980
Helsinki, Finland
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Journal of Food, Agriculture & Environment Vol.11 (3&4): 1002-1004. 2013
www.world-food.net

Optimisation and risk analysis of greenhouse gas emissions depending on yield and nitrogen rates in rapeseed cultivation

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Received 21 May 2013, accepted 19 October 2013.

Abstract
Attemptation to optimise the N dose (N rate), especially by reducing the amount, brings a specific risk of yield reduction where the agriculture GHG emissions is weighted and measured by CO_2 eq MJ^{-1} FAME. The paper presents an optimisation of agricultural GHG emissions dependant on the size of yield and doses of N, desirability of optimisation, risk analysis for the studied variables as well as estimates for the uncertainty of agricultural GHG emissions, for which a selected optimisation goal was met. It was found that the optimisation of agricultural GHG emissions, with an allocation of rapeseed cake through its impact on crop yields and N doses could lead to a reduction of emissions measured in practice by as much as 2 g CO_2 eq MJ^{-1} FAME. Risk analysis has shown that this can be achieved only through yield increase by up to 7.1% compared to the median of census data. There was no ability to influence the emissions by reducing the dose of N. Agricultural GHG emissions, and a reduction can have a significant impact on the size of their uncertainty.

Key words: FAME, rapeseed, agricultural GHG emissions, optimisation, risk and uncertainty.

Introduction

The obligatory reduction of greenhouse gas (GHG) emissions by 50% in the 2017 (Directive 2009/28/EC)[1] will require improvements in agricultural technology to increase carbon sequestration in soils and fertilisation optimisation in the case of rapeseed production. In previous work, characterisation into the impact for optimal doses of N was done, calculations for the yield response curves = f (N rates), for different ranges of N fertiliser and organic carbon sequestration in soils of agricultural GHG emissions and emission reductions over the life of FAME [2].

The use of fertilisers (with lower GHG emissions rate, caused during their production) in doses of 150 - 180 kg N ha^{-1} will reduce the agricultural emissions respectively by 1.8 and 2.2 g CO_2 eq MJ^{-1} FAME. The optimisation of N doses for practical usage requires a deeper analysis of optimisation including an analysis of risks and uncertainties. In the present study, particular attention was paid on a process to reduce the agricultural emissions of GHG in order to meet the objective optimisation function (desirable optimisation). The optimised data set was accessed by using risk analysis for GHG emissions, yield and N doses. Finally, for the data set, the uncertainty of GHG emissions was estimated. The study goes beyond the methodological requirements laid down in Directive 2009/28/EC for estimating agricultural emissions. However, amendments to the Directive announcing an obligation to take into account iLUC in estimates of GHG emissions from the life cycle of biofuels, tends to seek and use all possible means to reduce emissions in every link of this cycle [3].

The aim of the study was to assess the feasibility of optimised agricultural GHG emissions with an allocation of rapeseed cake by influencing the yield and used N dose as well as an estimation of the manipulation risk and its impact on the uncertainty issue.

Materials and Methods

The study used data from a questionnaire on oilseed farms (3% of the total number of farms engaged in such production) [1]. Agricultural GHG emissions were estimated using the BIOGRACE [4] calculator as total emissions with the allocation of rapeseed cake [2]. For the optimisation of agricultural GHG emissions, Design Optimisation procedures according to a statistical package from Statgraphics were used. The extracted optimised data set (n=227) that complied with an emission target of 20 g CO_2 eq MJ^{-1} FAME was the subject of the risk analysis. It was performed for the best empirical fit distributions, estimated using the @Risk from statistical package Palisade Decision Tools. Those distributions were treated as the output and used in the modelling of random distributions using the Monte Carlo method for 10,000 iterations. The uncertainty of the tested variables in a separate set of optimised data was estimated with a t-factor method of a 95% confidence interval.

Results and Discussion

It was found that the optimum dose of N in rapeseed production for fuel purposes should be in the range of between 150-180 kg N ha^{-1} [2]. The allocation of these doses by using the boundary line approach could not give enough evidence to approve their recommendation in agricultural practice. Therefore, in order to achieve the necessary condition we had to conduct a more comprehensive analysis into the optimisation, risk and uncertainty. The performed optimisation analysis showed that in order to achieve the standard agricultural GHG emission that is required by Directive 2009/28/EC (29 g CO_2 eq MJ^{-1} FAME) or smaller was possible for showed lower yield and N doses (Table 1).

Table 1. Rapeseed yield and nitrogen doses for optimised GHG emission level.

Emissions with the allocation rapeseed cake g CO_2 eq MJ^{-1} FAME	Yield kg ha^{-1}	N dose kg ha^{-1}
29	3305	216
26	2951	165
23	3998	207
20	3461	148

The presented records indicate that the relationship between the issue and the independent variables studied is curvilinear. The relationship that describes the regression:

$$E = 41.4 - 0.0191\,Yd + 0.199\,N + 0.00000251\,Yd^2 - 0.0000306\,Yd*N + 0.0000518\,N^2;\ R^2 = 93.2.$$

where:
E - Emission,
Yd - Yield,
N - N rate

The submitted equation is statistically significant (P d≤ 0.05), and the included explanatory variables were not correlated (r <0.5), and therefore could be treated as independent variables. The range of estimated optimal N doses (Table 1) was greater than obtained early by a boundary line approach (150-180 kg N ha^{-1})[1]. Individual independent variables have decreased or increased emissions (Fig. 1).

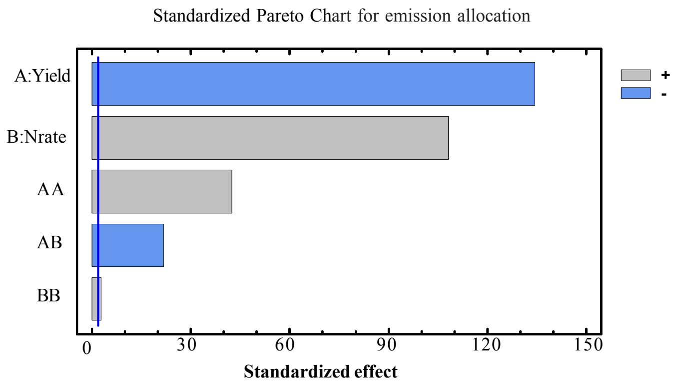

Figure 1. Impact on GHG emissions of the examined independent variables.

The data presented in Table 1 and Fig. 2 give details of the estimated GHG response surface.

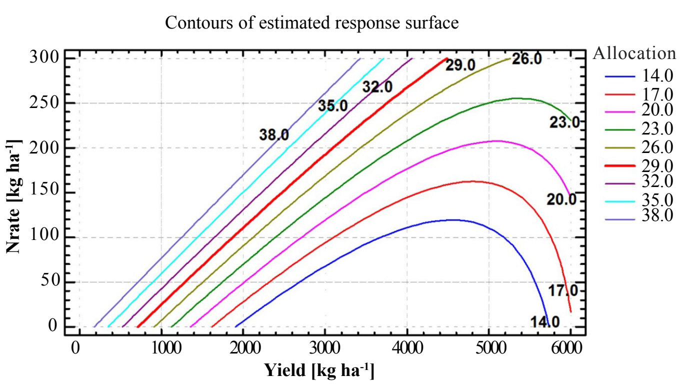

Figure 2. Contours of estimated GHG emission response surface.

This refinement was necessary, because as shown in Table 1 the emission optimisation results for 29 and 26 g of CO_2 eq MJ^{-1} did not add new importance for the practical possibilities in adjusting the N dose in relation to the routinely used doses in the production of rapeseed.

In compliance with the 23 g CO_2 eq MJ^{-1}, in practice it is rather impossible, because a yield of 3998 kg ha^{-1} is only achievable in the upper-pentyl of the yields. Therefore, the probability of achieving it in practice is very low. The utilitarian option that was more of interest was the N dose optimisation for the emission achievement of 20 g CO_2 eq MJ^{-1}, for which would be necessary to increase the yield by 3.6% compared to the median yield and reduce the N dose by 13% compared to the median.

The yields and N dose ranges for the emission standard are in Fig. 2. This option was so interesting that it was subjected to further analysis. From all of the census data (n = 1.218), data was isolated which met the emission optimisation goal (desirability ca 1) (Fig. 3).

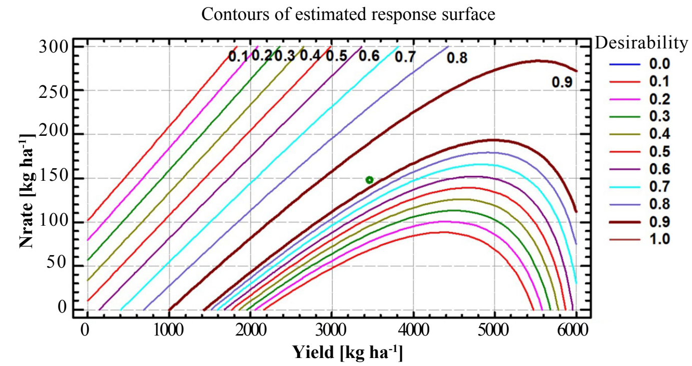

Figure 3. Desirability contours for the optimisation target 20 g CO_2 eq MJ^{-1} (green circle = optimal value).

The desirability values ca 1 indicating that the objective of optimisation to 20 g CO_2 eq MJ^{-1} has been met, observed for 227 households (19% of the total census data) (Table 2).

The statistics comparison shows, that distributions of all studied variables were symmetrical and close to normal. As shown by simulations of possible emission savings is not an optimised set of 9 g CO_2 eq MJ^{-1} (29 - 20), as one would expect, but only 2 g CO_2 eq MJ^{-1} for 50 percentiles of emissions. The value of this could be achieved by increasing yields in lower percentiles of yield. This increase would have to be 26.4% for five percentiles yield and decrease in the direction of the median, reaching 7.1% for 50 percentiles of yield. There was no expediency to maximize yields (yields value similar in 95 percentiles). The possibilities of N dose adjustment were not confirmed because the statistics for dose in both populations were similar. Reported emission savings is the same order as achieved by the selection of the lower ranges of fertiliser GHG emissions generated during their production [1]. Based on previous and present results it can be assumed that the additive effect of the selection of low-emission and moderate N fertiliser increased yields can provide a reduction in agricultural emissions of magnitude 4 g CO_2 eq MJ^{-1} FAME. An increase in rapeseed yield by 7.1% in relation to the median in order to reduce agricultural emissions by 2 g CO_2 eq MJ^{-1} is rather impracticable in view of 2017, since it would require an annual yield growth rate of 1.8%. However, this goal is easy to achieve with a controlled purchase of raw materials for the production of FAME. Comparison of census data and the optimisation of data collection lead to the conclusion that the material purchased should meet the following conditions: 2000-5000 kg ha^{-1} (Me = 3600) and dose 72-161 kg N ha^{-1} (Me = 161). This requirement may involve a more complete knowledge of the yield response curve depending on the dose (Fig. 4) .

In the assessment of the sense for increasing yields, or the introduction of more restrictive rules for raw materials purchase assigned to the production of FAME, important is not only the size of savings in GHG emissions, but also reduction of the uncertainty of the GHG emissions. Therefore, the uncertainty was

Table 2. Risk analysis for GHG emission (g CO_2 eq MJ^{-1}), yield (kg ha^{-1}) and N rates (kg ha^{-1}) for 10,000 iterations of Monte Carlo simulations.

Statistics	Emission		Yield		N rate	
	Census	Optimisation	Census	Optimisation	Census	Optimisation
Mean	24	21	3338	3594	169	162
Median	23	21	3358	3596	169	162
Percentiles						
-5%	16	20	2195	2775	108	116
-50%	23	21	3358	3596	169	161
-95%	36	22	4412	4404	231	208

Table 3. Uncertainty of agricultural GHG emissions in agriculture in the census data set, and in the set after optimisation.

Statistics	Census data	Optimised data
Mean	24.2	21.0
Standard Deviation	6.29	0.81
Count of data	1.218	227
t-factor (95% CI)	1.96	1.96
Uncertainty @ 95% CI	0.357	0.105
% Uncertainty	1.5	0.5

CI-Confidence interval; t-factor-Student t-value; uncertainty @-uncertainty in absolute value.

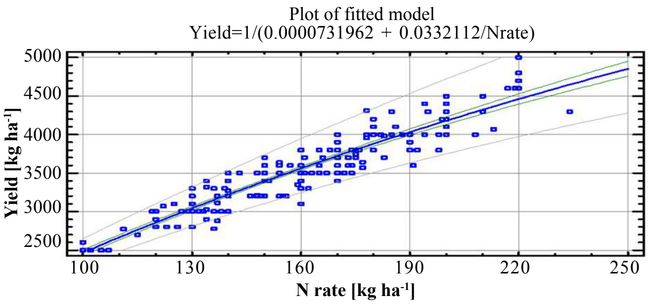

Figure 4. The relationship between yield and the N dose specified in the data set after optimisation (R^2 = 88.6%).

estimated for the whole set and the set after optimisation. The resulting uncertainty varied greatly (Table 3).

Conclusions

The optimisation of agricultural GHG emissions, with allocation of rapeseed cake, through its impacts on crop yields and N dose reduction, can reduce emission in practice by up to 2 g CO_2 eq MJ^{-1} FAME. Risk analysis has shown that this can be achieved only by an increase of yield by 7.1% compared to the median of census data. There was no possibility to influence the GHG emission by a reduction in N dose. The agricultural GHG emission reduction will influence the size of their uncertainty.

Acknowledgements

The studies have been supported by National Science Centre within project N N313 759240.

References

[1]Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. Official Journal of the European Union L **140**(52):16-62.

[2]Borzęcka-Walker, M., Faber, A., Jarosz, Z. and Pudełko, R. 2013. Greenhouse gas emissions from rapeseed cultivation for FAME production in Poland. Journal of Food, Agriculture & Environment **11**(1):1064-1068.

[3]European Commission. 2012. Proposal for a Directive of the European Parliament and of the Council amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on promotion of the use of energy from renewable sources. Com(2012) 595 final, Brussels.

[4]BIOGRACE 2012. Harmonised Calculations of Biofuel Greenhouse Gas Emissions in Europe. Excel Greenhouse gas emission tool. http://www.biograce.net/content/ghgcalculationtools/calculationtool.