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Research article

Calculating N fertilizer doses for oil-seed rape using plant and soil data

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Abstract – We evaluated the economic and environmental interests of a balance-sheet method recently developed for calculating N fertilizer doses for oil-seed rape. The evaluation was performed using simple models of yield, grain oil content, and residual soil mineral nitrogen responses to applied N. The models were fitted to 53 fertilizer trials carried out in France between 1993 and 1999. The results show that the use of the balance-sheet method decreases the variability of farmers' income, increases grain quality, and decreases the risk of water pollution by nitrate.

decision rule / fertilization / grain oil content / nitrogen balance / oil-seed rape

1. INTRODUCTION

The amount of nitrogen fertilizer applied to oil-seed rape (*Brassica napus* L.) has an influence on farmers' income, on the environment, and on grain quality. Low nitrogen doses may induce a loss of income for farmers, whereas excessive amounts of applied nitrogen may increase the risk of water pollution by nitrate and decrease grain oil content [8]. Nitrogen fertilizer doses applied to oil-seed rape are usually determined by farmers independently of plant and soil characteristics. A method has been recently developed by French agronomists to adjust nitrogen doses for oil-seed rape to plant and soil measurements [5]. This method is based on a simple nitrogen balance quite similar to the balance defined for corn by Stanford [6]. The balance inputs are soil depth, mineral soil nitrogen at the end of winter and plant biomass at the end of winter, and the output is a recommended nitrogen dose. The soil depth is used to estimate a target yield. The values of mineral soil nitrogen and of plant biomass at the end of winter are used to estimate the amount of nitrogen supplied by the soil to the crop. The inputs of the balance are measured before the date of nitrogen application. The aim of this study is to evaluate the economic and environmental interests of using the nitrogen balance [5] compared with the application of a fixed amount of nitrogen fertilizer on oil-seed rape fields. Two versions of the nitrogen balance are considered successively.

2. MATERIALS AND METHODS

2.1. Data

The evaluation was performed with a data set including 53 fertilizer trials carried out in France between 1993 and 1999. Each trial consists of 4 to 8 different nitrogen fertilizer doses in the range 0–300 kg·ha^{-1}. Common oil-seed rape varieties were used. Yield, grain oil content and residual soil mineral nitrogen at harvest were measured for each nitrogen treatment and the inputs of the nitrogen balance were measured for each trial. See [4] for more detail about experimental methods.

The data set was used to evaluate three decision rules for calculating nitrogen doses. The first decision rule simply consists of applying a fixed amount of nitrogen fertilizer, 180 kg·ha^{-1} in all fields. This is a standard practice among French farmers [1]. This decision rule is further referred to as FIXED-DOSE. The second decision rule consists of using the full version of the nitrogen balance [5]. In this case, the recommended nitrogen doses vary from field to field and are calculated in function of soil depth, mineral soil nitrogen at the end of winter, and plant biomass at the end of winter. This decision rule is further referred to as FULL-BALANCE. The last decision rule consists of calculating nitrogen doses from a simplified version of the nitrogen balance that does not take into account soil mineral nitrogen at the end of winter. This nitrogen balance, further referred to as SIMPLE-BALANCE, only includes two input variables, namely soil depth and plant biomass at the end of winter. SIMPLE-BALANCE does not require any soil analysis but may lead to less accurate nitrogen recommendations than FULL-BALANCE. The two nitrogen balances were used to calculate nitrogen fertilizer recommendations for the 53 trials.

2.2. Evaluation of the decision rules

The decision rules were evaluated for four criteria; namely, yield, farmer's gross margin, grain oil content and residual soil mineral nitrogen at harvest. The gross margin is calculated from yield as $p\,y(d) - c\,d$ where d is the nitrogen dose (kg·ha^{-1}), $y(d)$ is

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the yield ($t{\cdot}ha^{-1}$) obtained when dose d is applied, p is the grain price ($euro{\cdot}t^{-1}$) and c is the fertilizer price ($euro{\cdot}kg^{-1}$). c is set to 0.46 $euros{\cdot}kg^{-1}$. p is fixed to 190 and 230 $euros{\cdot}t^{-1}$ successively. The values of the criteria were estimated for each one of the 53 experimental trials by using the method described by Bullock and Bullock [2] and extended by Makowski et al. [3]. The general principle is to fit models describing the responses to applied nitrogen trial by trial. The fitted models are then used to estimate the values of the criteria for the 53 trials in function of the nitrogen doses recommended by the decision rules.

This method requires the definition of a mathematical model for each type of response. Here, several models were considered successively to predict the responses to applied nitrogen of yield, grain oil content and residual soil nitrogen. Three models were considered for yield (linear-plus-plateau, quadratic and quadratic-plus-plateau) [1], one for grain oil content (linear), and two for residual soil mineral nitrogen at harvest (plateau-plus-linear and plateau-plus-quadratic) [3]. The parameters of the different response models were estimated by least squares for each of the 53 trials. To quantify the goodness of fit of the models, the R^2 was calculated for each model and each trial. The resulting R^2 values were then averaged over trials and the models were selected on the basis of the average R^2 values.

3. RESULTS AND DISCUSSION

For yield, the model which gave the highest average R^2 value was the quadratic model ($y = \alpha + \beta d + \gamma d^2$, $R^2 = 0.91$). For residual soil mineral nitrogen, the highest average R^2 value was obtained with the plateau-plus-linear model ($y = R_{MIN}$ if $d < X_{MAX}$ and $y = R_{MIN} + A(d - X_{MAX})$ if $d \geq X_{MAX}$, $R^2 = 0.49$). The average R^2 value obtained with the linear model ($y = \alpha + \beta d$) for grain oil content was equal to 0.80. The relatively low R^2 value obtained for the model of response of residual soil nitrogen is probably due to the significant measurement errors associated with this variable. Comparisons between the fitted models and the data of one trial are shown in Figure 1. The selected models were used to estimate the values of yield, gross margin, grain oil content and residual soil mineral nitrogen at harvest obtained when the nitrogen doses recommended by the decision rules are applied. The farmer's gross margins were then calculated from the estimated yield values. The calculations led to 53 values of yield, gross margin, grain oil content and residual soil nitrogen for each decision rule. These values were summarized by the average, minimal and maximal values (Tab. I).

The nitrogen doses recommended by FULL-BALANCE and SIMPLE-BALANCE are in the ranges 0–220 and 0–210 $kg{\cdot}ha^{-1}$, respectively, and the average values are much lower than 180 $kg{\cdot}ha^{-1}$ (Tab. I). The results of the evaluation show that the average farmer's gross margin is slightly increased when the fertilizer doses are calculated from the nitrogen balances. Compared with the application of a fixed nitrogen dose, the decision rule SIMPLE-BALANCE increases the average gross margin by 16 $euros{\cdot}ha^{-1}$ and 11 $euros{\cdot}ha^{-1}$ for $p = 190$ and $p = 230$ $euros{\cdot}t^{-1}$, respectively. The average gross margins obtained with FULL-BALANCE are smaller than the values obtained with SIMPLE-BALANCE but higher than the average gross margins obtained with FIXED-DOSE. The average yields obtained with FULL-BALANCE and SIMPLE-BALANCE are lower than the value obtained with FIXED-DOSE. This result shows that the economic loss resulting from the application of a fixed nitrogen dose is not due to a yield loss but to the relatively low nitrogen doses calculated by the nitrogen balances. The small difference between the two types of

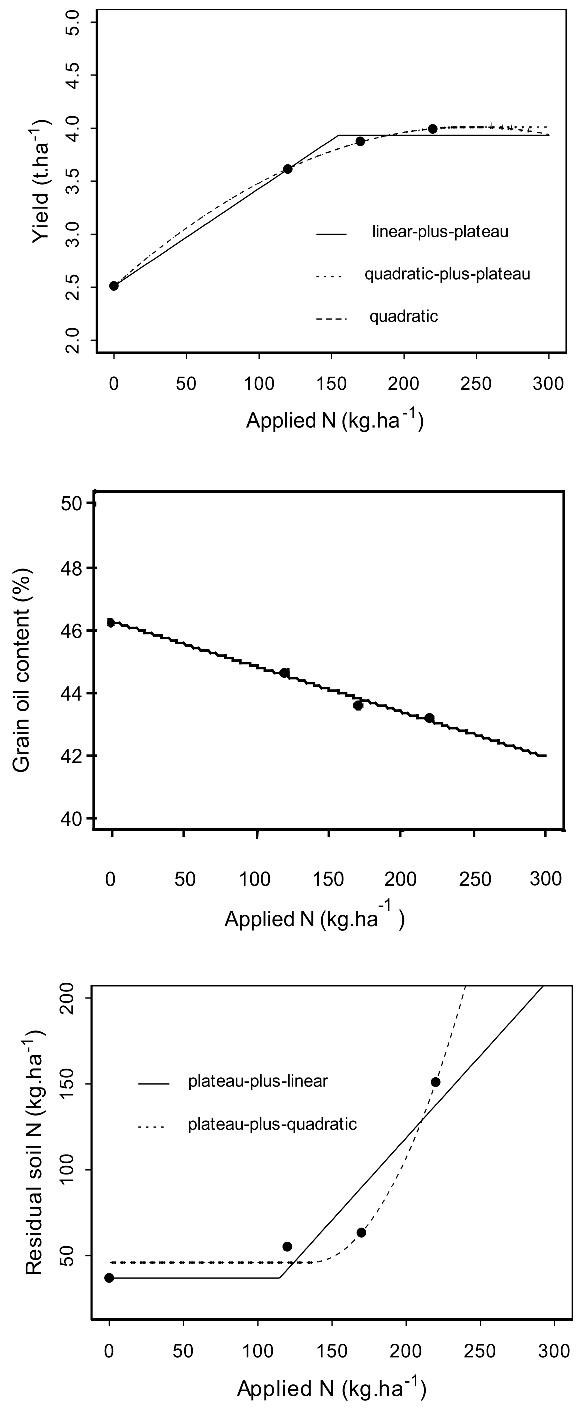

Figure 1. The models of yield, grain oil content and residual soil N at harvest as a function of applied N fitted to the data of one trial.

Table I. Nitrogen doses recommended by three decision rules and results obtained when the recommended doses are applied on 53 fields. Gross margins 1 and 2 are calculated with a grain price set to 190 and 230 euros·t^{-1}, respectively.

		Decision rules		
		FULL-BALANCE	SIMPLE-BALANCE	FIXED-DOSE
Nitrogen dose	min	0	0	180
(kg·ha^{-1})	average	85	84	180
	max	220	210	180
Gross margin 1	min	252	252	4
(euro·ha^{-1})	average	596	600	584
	max	895	997	1189
Gross margin 2	min	303	303	22
(euro·ha^{-1})	average	722	728	717
	max	1080	1203	1443
Yield	min	1.33	1.33	0.46
(t·ha^{-1})	average	3.34	3.37	3.52
	max	4.87	5.45	6.71
Grain oil content	min	38.28	40.1	39.85
(%)	average	43.7	43.7	42.8
	max	46.39	46.39	45.82
Residual soil N	min	6	6	7
at harvest	average	50	50	82
(kg·ha^{-1})	max	193	193	336

nitrogen balance is probably due to the high errors generally associated with the measurements of soil mineral nitrogen [7].

Another result is that the variability of the gross margin across fields is much smaller when the nitrogen doses are calculated with the nitrogen balances. For instance, the values of gross margin 1 obtained with SIMPLE-BALANCE are in the range 252–997 euros·ha^{-1}, whereas the values obtained with FIXED-DOSE range from 4 to 1189 euros·ha^{-1}. The minimal gross margin values obtained with FULL-BALANCE and SIMPLE-BALANCE are always much higher than the minimal values obtained with FIXED-DOSE.

Table I shows that grain oil content is increased on average by 0.9% when the recommendations of the nitrogen balances are applied. Such an increase can be very interesting for collecting firms and agro-industries because the use of grains with high oil content improves the efficiency of the industrial processes. The grain oil contents obtained with the two nitrogen balances are quite similar.

Finally, the results of the evaluation show that the residual soil mineral nitrogen at harvest is decreased by 32 kg·ha^{-1} when nitrogen doses are calculated with the nitrogen balances (Tab. I). Moreover, the residual soil nitrogen never exceeds 193 kg·ha^{-1} with the nitrogen balances, whereas this variable can reach 336 kg·ha^{-1} when the same nitrogen rate is applied in all fields. Consequently, the use of the nitrogen balances can significantly reduce the risk of water pollution by nitrate. This is due to the low nitrogen rates recommended by FULL-BALANCE and SIMPLE-BALANCE. It is worth noting that the estimated values of residual soil nitrogen are relatively inaccurate due to the low R^2 value obtained by fitting the response model to residual soil nitrogen data.

4. CONCLUSION

In conclusion, the evaluation of the three decision rules shows that the use of the nitrogen balance decreases the variability of farmers' income, increases grain quality, and decreases the risk of water pollution by nitrate. No great differences were observed between the full version of the nitrogen balance and a simpler version based only on soil depth and biomass at the end of winter.

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