

# **NITROGEN FERTILISATION RECOMMENDATIONS : COULD THEY BE IMPROVED USING STOCHASTICALLY GENERATED CLIMATES IN CONJUNCTION WITH CROP MODELS ?**

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## **ABSTRACT**

Accurate determination of optimal Nitrogen (N) recommendations which ensure maximization of farmer's revenue while minimizing the environmental constraint is maybe among the major challenges in agriculture. Crop models have the potential to deal with such aspects and could thus be used to develop decision support systems. However unknown future weather conditions remains the key point of accurate yield forecast. This paper presents the results of a preliminary study that aims to supply the unknown future with stochastically generated climatic conditions. Coupling the methodology with appropriate decision rules led to a generic decision support system able to guide the N management practices.

**Keywords:** Crop model, Strategic N management, Probability risk assessment

## **INTRODUCTION**

In the context of precision nitrogen (N) management, to ensure that the yield potential could be reached each year, farmers have too often applied quantities of

fertilizers much larger than what was strictly required (Lemaire et al., 2008). However, since 2002, the Belgian Government transposed the European Nitrate Directive 91/676/EEC in the Belgian law under the Sustainable Nitrogen Management in Agriculture Program (PGDA) (Vandenberghe et al., 2011), with the aim to maintain the productivity and the revenue of Belgian's farmers while reducing the environmental impacts of excessive N management strategies.

At the plot level, crop models are powerful tools to assess the impacts of different cropping systems inputs, such as agro-environmental conditions (e.g. soil type, cultivar), management practices (e.g. sowing date, fertilisation), and climatic conditions (e.g. extreme weather sequences) on the crop harvestable organs (Dumont et al. 2014a). They are thus particularly suited to support the decision-making and planning in agriculture (Basso et al., 2011).

However, in a context where increasing frequencies of weather extremes are observed, much effort have been put in recent years to quantify the climatic uncertainty impacting the cropping systems productivity. A feasible approach for evaluating such uncertainty is to quantify the one associated to climatic historical records (Basso et al., 2011) or to stochastic time-series of weather (Dumont et al., 2013; Lawless and Semenov, 2005).

Therefore, a promising approach to study the effect of different N fertilisation practices could be based on the concomitant use of crop models and weather generators. The objective of this preliminary research was to develop such a methodology. Its ability to improve N recommendation was then evaluated with the aim to improve either economic and environmental N-use efficiency.

## **MATERIALS AND METHODS**

### **Nitrogen fertilisation strategies**

In Belgium, the farmers' current N fertilisation practice consists to split a total  $180 \text{ kgN.ha}^{-1}$  application into three equal fractions applied respectively at tillering (Zadoks 23), stem extension (Zadoks 30) and flag-leaf (Zadoks 39) stages.

As long as the final number of grains has not been fixed, the uncertainty linked to climatic variability impacting the final yields remains very high (Dumont et al., 2014a). However, once the number of grains has been put in place, the end-of-season yield is driven mainly by the climatic conditions that influence grain filling, in terms of both carbohydrates and N exportation.

It was therefore decided to impose the first two rates of N applied according to the current Belgian practice (i.e.,  $60 \text{ kgN.ha}^{-1}$ ) applied before anthesis stage. As a strategic approach, different N levels were then simulated for the flag-leaf stage, rising from  $0 \text{ kgN.ha}^{-1}$  to  $100 \text{ kgN.ha}^{-1}$ . This strategy will later be referred to as the 'Modulation-60 treatment' (M60-X). In that way, the N protocol corresponding to the application of  $0 \text{ kgN.ha}^{-1}$  would be called M60-0.

### **Historical records and weather generator**

Data originating from a 31-years (1980-2011) weather station were used in this study. The Ernage station is located only two kilometers from the experimental

site. The database provides all the necessary inputs for the crop model (i.e., solar radiation, wind, precipitation, ambient temperature and relative humidity).

The database was initially analysed using the LARS-Weather Generator (Semenov and Barrow, 1997). Then, a set of synthetic time-series scenarios representative of the climatic conditions in the area were stochastically generated. 300 weather time-series were used to ensure stability in predicted mean grain yield.

### Decision criteria

The economical optimal N fertilizer is the one that maximise the revenue. The marginal net revenue (MNR - Eq. 1) can be computed as a function of the benefits linked to higher yields associated with increasing N practices, and the costs linked to N applications.

$$MNR = (Y_N \cdot G_p) - (N \cdot N_p) \quad \text{Eq. 1}$$

The grain selling price ( $G_p$ ) was fixed at 200 eur.ton<sup>-1</sup> and the fertilizer price ( $N_p$ ) was fixed at 0.3 eur.ton<sup>-1</sup> with a concentration of 27% of N in the fertilizer.

Furthermore, in the Wallonia region of Belgium, since the PGDA, a survey system has been developed to control N leaching. Taxes, that take the form of a reduction of the public financial assistance for farmers', are applied if the total amount of N remaining in the 0-90 cm soil profile (soil N content [SNC] kgN.ha<sup>-1</sup>) is superior to a given threshold. For the purpose of this study, the most stringent requirements of the directive were considered, *i.e.* a maximum tax of 120 €·ha<sup>-1</sup> is levied if the SNC is superior to 40 kgN.ha<sup>-1</sup>.

$$ENR = MNR - Taxes \quad \text{Eq. 2}$$

$$Taxes = \begin{cases} 0 \text{ eur.ha}^{-1} & \text{if } SNC < 40 \text{ kgN.ha}^{-1} \\ 120 \text{ eur.ha}^{-1} & \text{if } SNC \geq 40 \text{ kgN.ha}^{-1} \end{cases} \quad \text{Eq. 3}$$

This criteria will be later referred as the Environmental-friendly Net Revenue (ENR).

### Crop model

The soil-crop model STICS was used in this study. A wide literature can be found concerning the STICS model formalisms and the way it simulates the yields (Brisson et al., 2003; Brisson et al., 2009). The STICS model requires daily weather climatic inputs, namely minimum and maximum temperatures, total radiation and total rainfall. In the case of more complex formalisms about potential evapotranspiration calculation, the wind speed and vapour pressure are needed.

The STICS model parameterisation, involving calibration and validation, was performed on a four years database presented in the 'Original data' section, using the DREAM Bayesian parameters sampling algorithm (Dumont et al., 2014b).

The contrasted years in terms of climate and yields were used to parameterise the crop water and thermal stresses dependence.

### Original data

Field experiments were carried out to measure the crop response (*Triticum aestivum* L.) under temperate climatic conditions (Belgium) in the Hesbaye region (classic loamy soil). A complete randomised block design was used to evaluate the crop growth under fertilisation levels ranging from 0 to 240 kgN.ha<sup>-1</sup> applied in two or three fractions. The trials were conducted between 2008 and 2012.

Regular biomass growth references measurements (LAI, total biomass, grain yield and protein content) as well as soil N content measurements (NO<sub>3</sub><sup>-</sup> and NH<sub>4</sub><sup>+</sup>) were performed over the growing seasons.

## RESULTS AND DISCUSSIONS

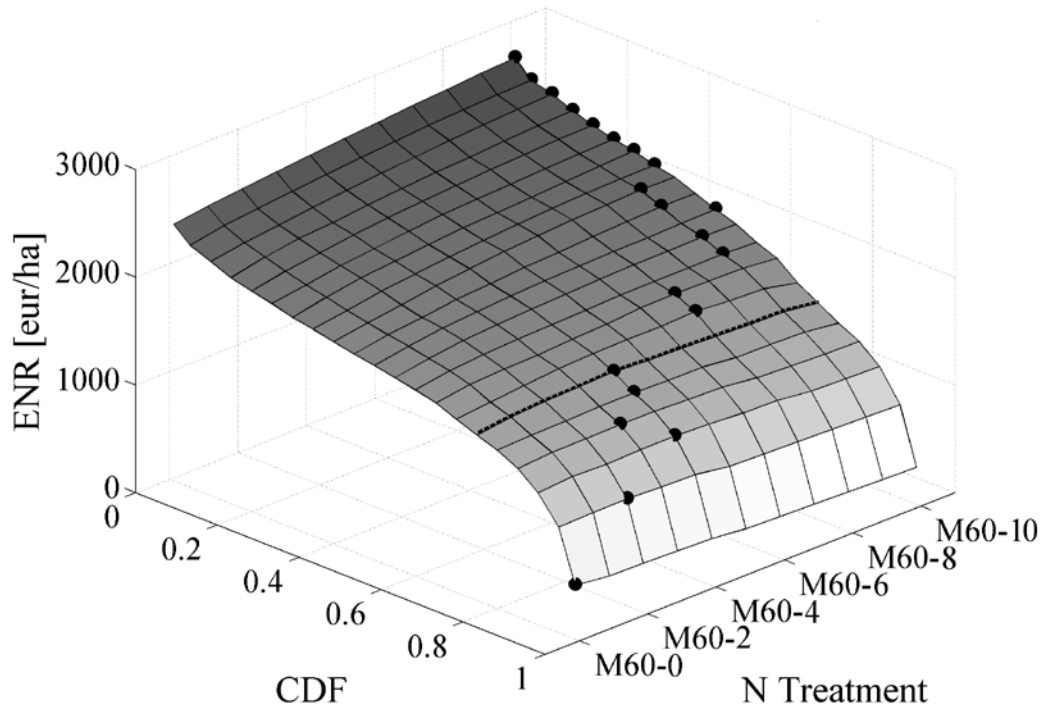
### Environmental-friendly Net Revenue simulations

Fig. 1. presents the 3D response surface of the environmental-friendly net revenue simulations. The cumulative distribution functions (CDF) of the ENR were ranked according to the increasing N practices. The CDF is the immediate expression of the return time of simulated yields or revenues. As an example, when 60-60-0 kgN.ha<sup>-1</sup> were applied, at least 501.2 eur.ha<sup>-1</sup> would be gained 99 years out of 100 (CDF = 0.99). At the same N protocol, they were 50% chances (1 year out of 2) to achieve at least a revenue of 1807 eur.ha<sup>-1</sup>. At the highest N practice, 99 years out of 100 and 1 year out of 2, the revenues would respectively decrease to 346 eur.ha<sup>-1</sup> and increase by 210 eur.ha<sup>-1</sup> (2017 eur.ha<sup>-1</sup>) in comparison with the lowest N practice.

Under the worst climatic conditions, two different effects could impact the revenues. On the one hand, the plant was not properly developed to use correctly high level of N that could be fertilised at flag-leaf stage. Increasing the N practice led thus to increase the costs without improving the benefits (Eq. 1). On the other hand, provided the weather would be characterised by excessive rainfall, the chemical fertilizers would be leached, leading to environmental taxes at the end of the season.

On Fig. 1, for each probability level, the optimal N practice was highlighted by a black dot (•). Our observations showed that the optimal N practices seemed linearly linked to the return time of climatic conditions. Under unfavourable climatic conditions, the optimal N practices, *i.e.* the practices that maximised the ENR, were the lower ones.

According to Basso et al. (2012), a suitable solution would be to select the N application rate that outperforms the others around 75% of the time. This threshold was highlighted by a bold dash line (--) on Fig. 1. At this expected return time, the corresponding optimal practice was the M60-4 protocol, where 40kgN.ha<sup>-1</sup> are applied at the flag-leaf stage.



**Fig. 1.** Environmental-friendly net revenue (ENR) as a function of N fertilisation management and cumulative probability density function (CDF) drawn from 300 synthetic climate scenarios. The dash line (--) represents the ENR reached at a probability level of 75% (3 years out of 4). The dots (•) represents the N treatment producing the optimal ENR under different probability levels (1%, 5%, 10%, ..., 95%, 99%).

Finally, a Wilcoxon test was applied to inter-compare the distributions. The test revealed that the ENR distribution achieved under the M60-4 protocol were statistically equivalent to any other superior fertilisation levels (M60-5 to M60-10). In the same way, the M60-4 protocol was also equivalent to a practice that would consist to apply only 20 kgN.ha<sup>-1</sup> at flag-leaf. This practice should thus be preferred as it decreases the environmental risk.

**Table 1.** Comparison of ENR distributions using a Wilcoxon test. The table presents the *p*-value of the test and the significance level (\*, \*\* or \*\*\*).

Treatment	M60-10	M60-9	M60-8	M60-7	M60-6	M60-5	M60-4	M60-3	M60-2	M60-1
M60-9	0.997									
M60-8	0.880	0.851								
M60-7	0.669	0.673	0.784							
M60-6	0.474	0.430	0.553	0.704						
M60-5	0.240	0.226	0.280	0.395	0.592					
M60-4	0.098	0.072	0.106	0.148	0.278	0.521				
M60-3	0.021*	0.016*	0.020*	0.033*	0.067	0.186	0.440			
M60-2	0.002**	0.001**	0.002**	0.003**	0.007**	0.022*	0.091	0.317		
M60-1	0.000***	0.000***	0.000***	0.000***	0.000***	0.001***	0.003**	0.026*	0.191	
M60-0	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.003**	0.082

## CONCLUSION

A methodology was proposed to analyse the impact on crop yields and farmers' revenues of different N practices under a wide variety of local climate conditions. Overall the global methodology appeared as a full tool to optimise the N practice in a strategic point of view.

In particular, our investigation showed that 3 years out of 4, the N fertilizer rate applied at flag leaf could be decreased by 20 to 40 kgN.ha<sup>-1</sup> in comparison to the current Belgian farmer practice (60-60-60 kgN.ha<sup>-1</sup>).

In conclusion, the potential of using a crop model as a decision tool for improving the economical or environmental N-use efficiency was again demonstrated (Basso et al., 2012). The methodology has furthermore a real potential to stand as a basis to develop tactical decision support system able to optimise N practices in real-time

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