TO BAN OR NOT TO BAN FEBRUARY FERTILIZATION IN HUNGARY?

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Abstract. At present, it is allowed to apply fertilizers starting from 1st of February in Hungary. According to a proposal of the EU this date would be moved to 1st of March. Regarding this issue the following question could be formulated: Does the earlier starter fertilization increase the risk of nitrate leaching significantly? Experimentally, this question could not be answered within the available timeframe. The only scientific tool that is able to handle this problem is a crop simulation model. The 4M crop simulation model was used for answering the above question. The required weather, soil, plant and agrotechnical data were provided for the model using the available Hungarian databases. Three scenarios differing only in the date of the first spring fertilization were compared. According to the results the amount of nitrate leaching does not increase as the date of the first spring fertilization moves from the end of February to the beginning of the month, thus there is no need for extending the fertilization prohibition period. Leaving the prohibition period as it is today will not increase the risk of contaminating the subsurface water reservoirs due to nitrate leaching.
Keywords: *fertilization prohibition period, nitrate leaching, crop model, decision support*

Introduction

Experts of the European Union revise the practical realization of the Nitrate Directive (*91/676/EEC)* in every five years. Based on the collected experiences the EU proposes amendments to the Directive for every member state in order to minimize the nitrate leaching risk of agricultural origin. One of the most recent proposed amendments is the idea of extending the spring fertilization prohibition period. At present, it is allowed to apply fertilizers starting from 1st of February. According to the proposal this date would be moved to 1st of March. Hungarian experts expressed their concerns about the extension of the prohibition period. If the starter fertilization delays one month because of the modified directive it could cause yield loss for the crops sown in the autumn (e.g. barley, wheat, rape) due to the increased nutrient shortage in the early vegetative phase. On the other hand the earlier the fertilizer gets on the soil surface in the spring the higher the possibility might be that a considerable fraction of it leaches out of the root zone due to the usually moist spring weather. It has to be noted that the spring starter fertilizer is applied directly to the soil surface and is not incorporated into the soil. By the time it is applied the root zone is already 10-15 cm deep. Though one can state that is highly unlikely that a portion of the fertilizer applied on the soil surface can go through the continuously deepening root zone without taken up by the plants, someone else can be more aware of the environment protection aspects. The Hungarian experts usually emphasize the yield safety in this matter while EU experts tend to focus on the increasing risk of subsurface water contamination. Regarding this issue the following questions could be formulated: Does the earlier starter fertilization increase the risk of nitrate leaching significantly? Could the initiative to lengthen the fertilization prohibition period be substantiated scientifically?

Experimentally, these questions could be answered only by time-consuming and expensive long-term field trials. Since we do not have years to find the answers by measurements the only remaining scientific tool that is able to handle this problem is a crop simulation model (CSM).

The primary purpose of crop models is to describe the processes of the very complex atmosphere–soil–plant system using mathematical tools (functions, differential equations, etc.) and to simulate them with the help of computers. In the 1970's developments in information technology enabled scientists to create the first crop model software using the accumulated scientific knowledge. Today, there are many well-developed, user friendly crop model software already available such us WOFOST (Boogaard et al., 1998), STICS (Brisson et al., 1998), DSSAT (Jones et al., 2003), CropSyst (Stöckle et al., 2003). During the past two decades crop models have been used in numerous educational and scientific projects (Kovács et al., 1995; Jamieson et al., 1998; Ladányi et al., 2003; Máthéné et al., 2005, Harnos et al., 2006; Fodor, 2006; Kaur, 2008). According to the acquired modelling results CSMs are effective tools in scientific research, education, practical problem exploration and problem solution. They integrate the processes of the crop production, its ecological and technological system of conditions into a functioning simulation model using the achieved scientific results for supporting decision making on every possible level. The presented model application is a nice example how a CSM can support the work of policy makers.

The main objective of the present study is to give a scientifically sound answer for the above formulated question: Does the earlier spring starter fertilization increase the risk of nitrate leaching significantly?

Materials and methods

The 4M crop simulation model (Fodor et al., 2002; Máthéné et al., 2005; Fodor, 2006) has been used in the study. 4M is a daily-step, deterministic (not stochastic) model whose functioning (computation) is determined by the numerical characteristics (parameters) of the atmosphere–soil–plants system. Besides the data that describe the physical, chemical and biological profile of the system, it is also necessary to set its initial, boundary and constraint conditions in the input file of the model. The parameters regulate the functions and equations of the model: the development and growth of plants or the heat, water and nutrient balance of the soil. The initial conditions are the measured system variables at the beginning of the simulation run such as the water or nutrient content of the soil. The boundary conditions are primarily the daily meteorological data such as the global radiation, temperature and precipitation. The constraint conditions cover the numerical expressions of the human activities such as data about planting, harvest, fertilization or irrigation. A short description about the functioning of 4M is provided in Fodor and Pásztor (2010). The following input data were used during the simulations.

Weather data

Artificial but realistic weather data series for the 1951-2100 period was created for the 4M model using the ARPEGE global circulation model (Déqué et al., 1998) combined with the ALADIN-Climate regional climate model (Bubnova et al., 1995; Wang et al., 2011). Regarding the most relevant climatic characteristics (annual precipitation amount, average temperature, etc) for the 1961-1990 reference period, there are no significant differences between the synthetic data and the data observed in Hungary. Based on the available generated temperature and precipitation data the daily global solar radiation values were estimated using the S-shape method (Fodor and Mika, 2011). *Fig. 1* summarizes the most important climatic characteristics of the weather data used in the study. According to the used climate change scenario the atmospheric CO_2 concentration raised from 315 to 720 ppm with a moderate exponential character in the 1951-2100 period. The monthly precipitation amounts will prospectively change considerably only in July, August and September compared to the present situation: there will be 30-40 % less rain in these months around 2100 due to climate change. The monthly average temperatures are expected to rise with 1.5 – 4 °C by the end of the investigated period. The months of the summer half year will be prospectively 3 °C warmer at the end of the century than at present.

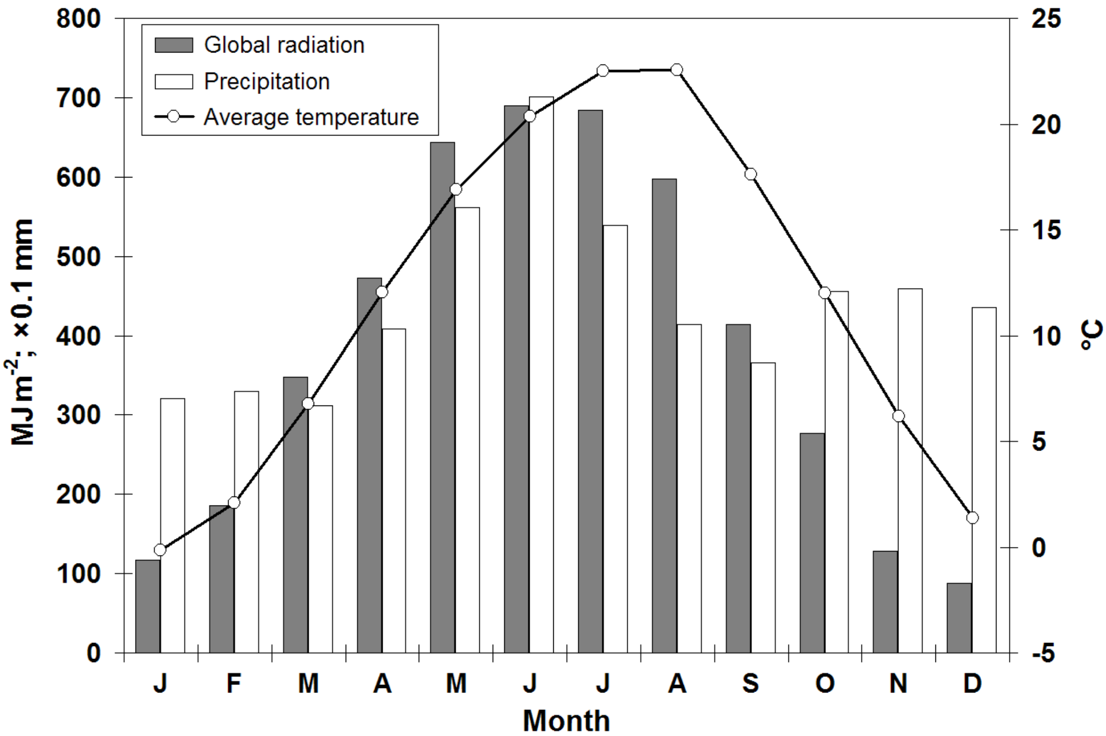

Figure 1. *Average monthly values of the weather data used in the study based on the 150 year long (1951-2100) data series.*

Soil data

Simulations were carried out for the five characteristic soil groups of Hungary. Soil data required by the model were retrieved from the database of RISSAC (Pásztor et al., 2010). The average physical and chemical parameters (bulk density-BD, humus content-

HC, field capacity-FC, wilting point-WP, saturated hydraulic conductivity-Ks and drain constant-DC) of the five soil groups were used during the model runs (*Table 1*).

Table 1. *Soil parameters of the characteristic Hungarian soils used as model inputs in the study*

Soil texture	BD (gcm^{-3})	HC (%)	FC (cm^3cm^{-3})	WP (cm^3cm^{-3})	Ks (cmd^{-1})	DC
Sand	1.55	1.00	0.160	0.030	100	0.5
Sandy loam	1.45	1.65	0.290	0.130	50	0.4
Loam	1.40	2.30	0.340	0.160	10	0.3
Clay loam	1.45	2.60	0.360	0.180	5	0.2
Clay	1.45	3.00	0.400	0.200	1	0.1

Plant data

The approximate values of the plant specific parameters (phenological characteristics, stages, maximum root depth, light use efficiency, specific N content, etc.) were determined based on the pertaining scientific literature. Then, the parameters were fine-tuned in four steps by inverse modelling (Soetaert and Petzoldt, 2010) so that the averages and the variances of the simulated yields were similar to those observed in the 1961-1990 reference period. First the phenological parameters (base temperature and length of phenological stages) were set so that the simulated occurrence of the main phenological stages would be in conformity with the real dates well-known from the literature. In the second step the model should have calculate the potential yields of the crops. This was achieved by adjusting the light use efficiency and the mass – leaf area conversion parameters. Then, in the third step, the effect of the water stress was ‘switched on’ in the model, and thus the parameters of the relationship defining the effect of the waters stress were set so that the model results would be realistic among rain-fed conditions. Finally, the parameters defining the effect of the nitrogen stress were determined.

The development and growth of the plants in *Table 2* were simulated. Although, it is obvious that some of the plant specific parameters did change and will change in the investigated period, all these parameters were considered to be constant during the simulations.

Agrotechnical data

The model input data regarding plant production (planting date, plant density, harvest date, fertilization doses, etc.) were provided according to the common agro-technology of each plant (*Table 2*). It is well-known that the plant production went through an enormous change during the past 60 years. Despite this fact the agrotechnics was postulated to be invariant during the investigated period.

Every crop rotation was simulated on every soil texture in three scenarios that differed only in the date of the first spring fertilization (with grey background in *Table 2*) of the crop sown in the previous autumn. The most relevant outputs (yield, nitrate leaching, etc.) of the model runs were recorded during the simulations. Calculated yields of the simulations where the first spring fertilizer was applied on the 1st of February were compared to those of the other two scenarios (fertilization date: 15/02 and 01/03) with paired t-tests. The annual nitrate leaching amounts as well as the

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distribution of the nitrate leaching rates over the months of the year were investigated depending on the date of the first spring fertilization.

Table 2. *The relevant agrotechnical data used as model input data in the study. Three scenarios were defined for each rotation with first spring fertilization on 01/02, 15/02 and 01/03.*

Crop rotation	Crop	N fertilization		
		Date, dd/MM	Amount ($kgha^{-1}$)	Depth (cm)
maize – winter wheat	maize	01/04	170	0-25
	winter wheat	05/10	40	0-25
		01/02; 15/02; 01/03	100	soil surface
		25/04	30	soil surface
winter wheat – rape	winter wheat	01/02; 15/02; 01/03	130	soil surface
		25/04	40	soil surface
	rape	10/08	30	0-25
		01/02; 15/02; 01/03	70	soil surface
		20/04	70	soil surface
winter barley – rape	winter barley	10/09	70	0-25
		01/02; 15/02; 01/03	70	soil surface
	rape	10/08	30	0-25
		01/02; 15/02; 01/03	70	soil surface
		20/04	70	soil surface
silage maize – winter barley	silage maize	01/04	150	0-25
	winter barley	10/09	70	0-25
		01/02; 15/02; 01/03	70	soil surface

Results and conclusions

The calculated yield results of the four investigated crop rotations are presented in *Table 3.*

Table 3. *Ca1culated yields averaged over the three investigated scenarios (75 seasons per crop, 1951-2100)*

Crop rotation	Crop	Yield, kg/ha				
		Sand	Sandy loam	Loam	Clay loam	Clay
maize – winter wheat	maize	6863	8605	9157	9138	8568
	winter wheat	6400	7313	7601	7624	7397
winter wheat – rape	winter wheat	6584	7836	8345	8380	8209
	rape	2462	3012	3109	3198	3154
winter barley – rape	winter barley	5890	7449	7967	8012	7835
	rape	2407	2883	2982	3064	3049
s. maize – winter barley	silage maize	22759	27853	29510	29535	28018
	winter barley	5938	7117	7464	7504	7315

Though it was not the focus of this study, it has to be noted that the 30 year moving averages of the calculated yields practically did not change in the 1951-2100 period. It seems that the factors causing yield increase and/or decrease (just to name the two main

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antagonistic factors: increase of CO_2 concentration and decrease of precipitation) may compensate each other in the future. This result is in full conformity with the previous finding of van de Geijn and Goudriaan (1996). On the other hand, approaching 2100, the variations compared to the average yields (SD) increased for all of the investigated plants (from 27% to 35%) indicating the prospected increase of extremes as well as the decrease of yield safety as a consequence of climate change.

The calculated yields of the scenarios with different first spring fertilization dates confirmed the concerns about the yield loss of winter crops due to the increased nutrient shortage in the early vegetative phase. If the prohibition period would have been lengthened with one month the yields of the winter crops would significantly decrease independently of the soil type (*Table 4*).

Table 4. *Calculated winter crop yield losses of two fertilization scenarios compared to those of the 01/02 first spring fertilization scenario for the five investigates soil groups. Asterisks denote the significant differences (α=0.05)*

Soil group	Date of fertilization, dd/MM	
	15/02	01/03
Sand	-29*	-101*
Sandy loam	-15	-57*
Loam	-7	-31*
Clay loam	-8	-33*
Clay	-11	-44*

According to the results presented in *Fig. 2* the amount of nitrate leaching does not increase as the date of the first spring fertilization moves from the end of February to the beginning of the month.

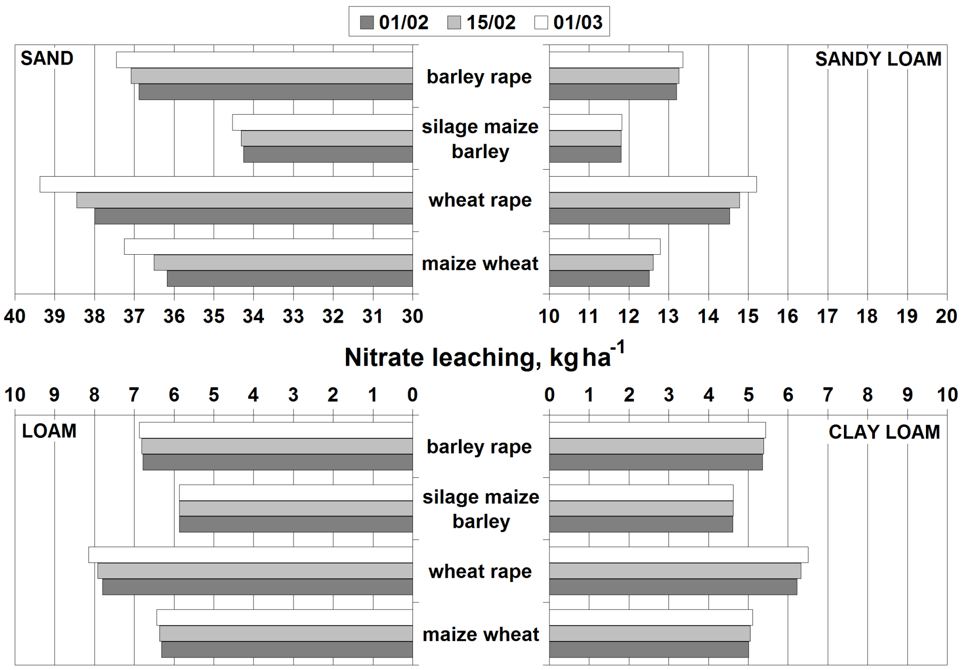

Figure 2. *Annual nitrate leaching rates as a function of the 1st spring fertilization date (dd/MM) of winter crops based on 150 year long simulations (1951-2100)*

The earlier spring fertilization does not cause increased nitrate leaching rates during the spring (*Fig. 3*). On the contrary, the earlier fertilization resulted in lower nitrate leaching rates in every month. During the moistest spring (290 mm precipitation between February and May compared to the average of 160 mm) of the 1951-2100 period, zero kgha^{-1} nitrate left the root zone till the end of June according to the simulations.

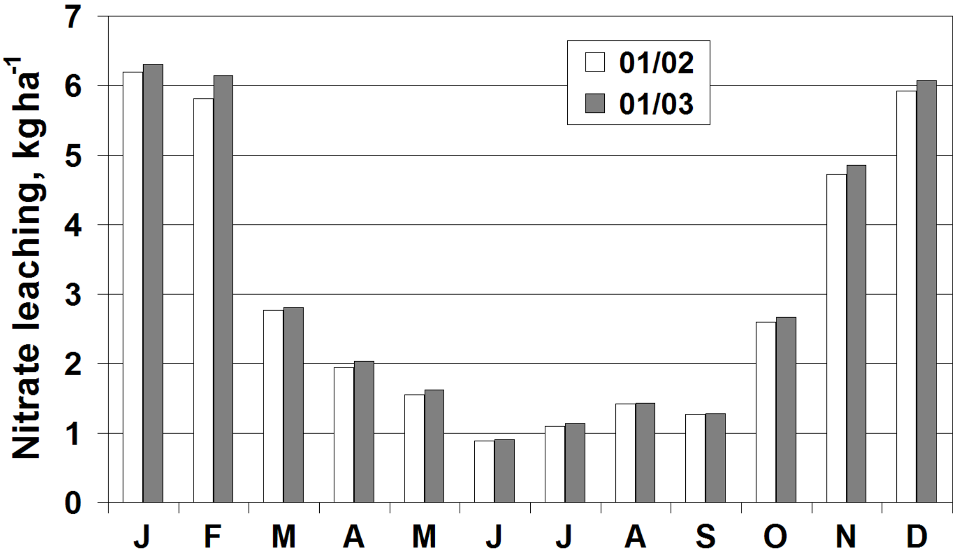

Figure 3. *Monthly nitrate leaching rates as a function of the 1st spring fertilization date (dd/MM) of winter crops based on 150 year long simulations (1951-2100).*

Based on the findings there is no need for extending the fertilization prohibition period by moving its end to 1st of March, in fact it may cause yield loss. Leaving the prohibition period as it is today will not increase the risk of contaminating the subsurface water reservoirs due to nitrate leaching.

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