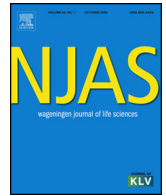




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Research paper

Mismatch between a science-based decision tool and its use: The case of the balance-sheet method for nitrogen fertilization in France

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ABSTRACT

For several decades in France, the balance-sheet method has been recommended and widely used to calculate N fertilizer rates. However, despite the scientific consensus on this method and its adoption as a regulatory tool, high N losses are still frequently occurring, suggesting limits in the implementation of this method. We assumed this consensus might hide discrepancies between some scientific concepts and the ways farmers use methods and tools. We combined a systematic analysis of official reports delivered by groups of experts (Nitrate Groups) from the 20 French regions concerned by the fifth reform of the Nitrate Directive, and interviews with experts, advisors and farmers. We identified principles of the method that reveal discrepancies between the theoretical model and its use, highlighting the gap between scientific concepts and their possible implementation. Here we show three frequent controversies that create uncertainties in calculating N fertilizer rates with the model. 75% of the Nitrate Groups debated about the estimation of the target yield, showing that there is no common understanding of the concept. In practice, farmers tend to fix the target yield as the value they desire more than the average value that can be reached in their fields. Although scientists emphasized the importance of measuring soil mineral content at the end of winter, sampling and uncertain extrapolation of the measurement lead to doubts and uncertainties, weakening the reliability of the N rates estimation. 45% of the interviewed advisors and seven Nitrate Groups put forward limits due to the regulatory implementation of the balance-sheet method, such as the reduced exploration of alternatives adapted to local specificities, or the prevention of an agronomical approach by an administrative one. These controversies among stakeholders showed that despite the rigor of the method and the scientific consensus on it, its implementation creates uncertainties, doubts and errors in the calculated N rates. Despite 40 years of agronomical and technological progress, major points of the method are still obstacles for its use. Considering these discrepancies between the model and its use, we suggest that, instead of persisting in improving incrementally each term of the balance-sheet method, we should switch to the innovative design of a completely new fertilizer calculation method, where users are taken into account from the beginning of the design process.

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1. Introduction

To improve farmer practices, part of an agronomist's activity is focused on the production of models and decision support systems [1]. However, there is often a contrast between the scientific principles of these models and tools and the ways users think or act [2–4]. Reducing the gap between scientific knowledge and prac-

tice is a challenge for the design and implementation of decision support systems, particularly when their use becomes mandatory through regulations [5].

In France, there has been consensus, for several decades, on the use of the balance-sheet method to calculate N fertilizer rates (Table 1), with the aim of reducing nitrate losses from agricultural activities toward groundwater. The balance-sheet method is one of the oldest agronomic science-based decision tools, and has been subject to intense and continuous effort to improve it over the years. The French National Institute for Agronomical Research developed this method about 40 years ago [6,7] to rationalize N fertilizer management, which was, until then, mainly empirical. The model is

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Table 1
Operational presentation of the balance-sheet equation for winter wheat and a variant, the efficiency equation, without organic fertilizer (extract from the Comifer's guidelines [8]).

	(1)Balance-sheet equation for wheat	(2)Efficiency equation
Equation	$X = (Pf - Pi) - (Mh + Mh_p + Mr + Mr_{ci} + Ri + N_{irr} - L - Rf)$ (1)	$X = (Pf - P0)/ANR$ (2)
Signification of the terms	X: N mineral fertilizer Pf: Total Plant N uptake (Pf = target yield (y) × N requirement per unit of production (b)) Pi: Plant N uptake before the end of winter (opening of the balance-sheet) Mh: Net mineralization of soil humus Mh _p : Net mineralization from grassland ploughing Mr: Net mineralization of crop residues Mr _{ci} : Net mineralization of catch crop residues Ri: N soil content at the end of winter (opening of the balance-sheet) N _{irr} : N from irrigation water L: Leached Nitrate after the opening of the balance-sheet Rf: N soil content at harvest (closure of the balance-sheet)	P0: N uptake of a crop without N fertilizer applied ANR: Apparent Nitrogen Recovery of N fertilizer
Practical recommendations for the measurement of the terms of the equation	Ri is measured (in February); the other terms are estimated from simple models whose inputs are available for farmers at the field level.	P0 and ANR are estimated from simple models whose inputs are available for farmers at the field level. These models are parameterized based on networks of non-fertilized plots [7].

based on a target yield to estimate crop N requirements and aims at adjusting N fertilizer rate to soil supply to meet these requirements [8]. Soil N supply is estimated through the assessment of soil mineral N content at the end of winter and it takes into account the net mineralization of soil organic matter and applied organic compounds. The use of the model is supposed to reduce N losses to the environment by avoiding fertilizer surpluses [9]. Technical institutes and advisory services have disseminated the method to farmers since 1978 [10]. Since its creation in 1980, the Comifer [French Committee for the Study and Development of Fertilization] has updated the “guidelines for local nitrogen fertilization instructions” to enhance its broad dissemination (Table 1). There have been many efforts to adapt the method and facilitate its use in various situations. For instance, studies carried out in Poitou-Charentes [11] and Lorraine [12] led to modifying the model and providing innovative ways of estimating some terms of the equation, especially the soil mineral N content at the end of winter ([8], see Table 1, Eq. (2)). The balance-sheet method is a rigorous model provided by scientists and accepted by consensus in the entire French agricultural sector. So far, making a provisional nutrient budget at the plot scale, based on the balance-sheet, has been part of the code of good agricultural practices in vulnerable zones in order to decrease nitrate leaching to groundwater: the latest reform of the Nitrate Directive in France put the balance-sheet method to the forefront of regulatory tools to guide and control calculation of N rates.

Our study was based on the hypothesis that, despite the consensus on the balance-sheet method, its implementation may limit the accuracy of the calculation of N rates. As suggested by Lecomte et al. [13] and Cerf et al. [1], studying the way existing methods and tools are used in various situations (it is what they call the “diagnosis of uses”) is helpful in identifying what should be modified to make decision support tools more effective from the user's point of view. In this article, we provide the results of such a diagnosis carried out on the use of the balance-sheet method. On the basis of complementary sources of information, we explored the diversity of use and perception on this agronomic model. We emphasize that existing controversies concerning its parameterization and its use reveal weaknesses in the implementation of the method by users, leading to sources of uncertainty in the calculation of the N fertilizer rates.

2. Material and methods

To investigate discrepancies between the model and the way it is implemented, the diagnosis of its use was based on complementary sources: a systematic analysis of official reports of the Nitrate Groups that aimed at standardizing the implementation of the method at a regional scale, and interviews with users of the method. Just as Vanloqueren and Baret [14] combined different sources to study technology adoption, we used complementary sources to crosscheck qualitative data from different sources and to enhance discrepancies between the science-based model and its use.

2.1. Analysis of the reports of the regional groups of experts on nitrate

From 2012, the balance-sheet method has become a regulatory tool to implement the Nitrate Directive in French territory, which required standardizing the method at a regional scale. This work was led by “Regional Groups of Experts on Nitrate” (Nitrate Groups), created in each of the twenty French regions concerned by the reform of the Nitrate Directive. Each group, bringing together various stakeholders representative of agricultural institutions, was missioned to define the equation of the balance-sheet to be used to calculate N rates over the entire region, and to agree on regional technical references for the equation parameters.

We analyzed reports of Nitrate Groups meetings as well as other deliverables, including prefectural decrees published in 2012 and updated in 2013. All documents were available through decentralized State services. We performed a systematic analysis of all the documents produced by the 20 Nitrate Groups. This analysis offered a large overview of how the model is used in different regions of France. For each group, we reported the proposals made for the equation and each term required for its parameterization on winter wheat. We decided to focus on this crop because the balance-sheet method was first developed and disseminated for winter wheat, and this is the most cultivated arable crop in France. Reports were a relevant source of information because, to produce the regional rules to calculate N rates, each stakeholder justified his choice of parameterization and way of calculating N rates. We thus identified the subjects of debates between experts and then compared the

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