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Economic impacts of variable rate nitrogen fertilization: Input saving and yield increase in cereals.

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Abstract

The purpose of this study is to discuss economic impacts stemming from variable-rate (VR) nitrogen fertilization, one of the main precision agriculture practices. Economic impacts are related to reduced nitrogen use and increased crop yields thanks to a better distribution of inputs, net from possible spatial and temporal uncertainty. The case studies included in the review (N=31) focus on nitrogen fertilization for grain crops, particularly wheat and maize, comparing uniform nitrogen applications versus variable-rate applications for several years in different countries. Findings highlight relevant changes in amounts of nitrogen applied, with the evidence of higher nitrogen efficiency resulting in reduced operating costs, while changes in crop yields are less evident: VR applications and uniform applications substantially reach the same production level, and higher nitrogen use efficiencies are achievable without significantly compromising yields. Overall, net economic impacts are in favour of VR fertilization.

This work can raise farmers' and other stakeholders' knowledge of the actual economic impacts stemming from the adoption of VR fertilization and helps policymakers to understand the economic impact of precision agriculture and the need to foster sustainability-based policies.

Keywords: precision agriculture, variable-rate technology, economic impact, fertilization, nitrogen.

Review Methodology

We searched the Scopus and Web of Science databases (Keyword search terms used: variable rate, site-specific, precision; saving, cost, revenue, profit; nitrogen; cereals, wheat, barley, corn, maize). In addition, new studies were sourced from the selected works through snowballing.

Introduction

A critical issue confronting humankind today is how to meet the growing demand for food in the long term in a sustainable way. In the agricultural sector, widespread adoption of precision agriculture (PA) seems to be a compulsory choice as it can increase the efficiency of farm systems while minimizing environmental impacts [1], especially for large farms [2]. Indeed, the required increase in food production will necessarily rely on a more accurate estimation of crop and soil requirements and improvements in the operation and management of existing plots.

PA is a management strategy that refers to technologies that allow for site-specific and better distribution of agricultural inputs like seeds, fertilizers, pesticides, and water. PA may improve productivity and resources through better management of the spatial and temporal variability in

45 the field compared to conventional agriculture [3,4]. It can lead to economic impacts from input
46 saving and a potential increase in crop yields and, thus, revenues. However, it may also be the
47 case that operating costs diminish to make up for potential yield decreases [5]. In this context, PA
48 adoption can also mitigate potential negative environmental impacts arising from excessive
49 exploitation of agricultural inputs that often characterize conventional agriculture [4].
50 Although the potential benefits that characterize PA technologies are acknowledged in the
51 literature, some perceived risks that slow down their adoption among farmers exist today; in this
52 regard, initial cost and technology complexity are primary issues [3,6]. Novel technologies can
53 entail a high degree of risk for the farmer, especially if their adoption requires a substantial capital
54 investment and the benefits are unclear in advance. Nevertheless, it can open up opportunities for
55 new agricultural business models characterized by an increased share kept by farmers in the food
56 value chains [7].

57 In this study, we have focused on fertilization, a ubiquitous farming activity that in PA can be
58 carried out through variable rate (VR) application systems, also known as site-specific fertilization.
59 This approach is often supported by other monitoring technologies to sense the canopy and by
60 guidance technology that can be automatic. At the operational level, VR technology can be
61 conceptually divided into two sets: the map-based application systems, which are based on
62 historical data collected over time with monitoring technologies, and the real-time sensor-based
63 systems that can adjust the application rates on the go.

64 We aimed to review scientific articles characterized by high methodological rigour describing case-
65 bond applications of VR fertilization and then discuss to which extent these technologies can
66 contribute to increasing economic impacts for farmers. The question that motivated our research
67 is to see whether PA can actually have significant positive impacts on farming performance and if
68 so, raise awareness of these impacts. We also offer policymakers an opportunity to understand
69 PA's positive economic impacts.

70 **Methods**

71 Using VR fertilization technologies can lead to economic benefits through reducing operating costs
72 in the form of fertilizer use reduction and providing improved yields and farm operating revenues.
73 This review focuses on the demonstrated input savings and yield increases from VR fertilization
74 compared to conventional, uniform rate treatments.

75 The review was conducted using a set of study inclusion criteria satisfying quality and
76 transparency requirements following the guidelines provided by Higgins et al. [8]. The inclusion
77 criteria adopted in this review are summarized in Table 1. Two main exclusion criteria were
78 considered: off-topic works and, avoiding double-count of papers, study reviews.

79 In line with the adopted inclusion criteria, the search involved (i) the systematic searching of the
80 online databases Scopus and Web of Science (WoS), and (ii) the use of the "snowballing
81 technique", with new studies sourced from the works referenced in the selected studies.

82 The literature review was based on articles indexed in Scopus in the areas "Agriculture and
83 Biological Sciences" and "Environmental Sciences" and in the WoS area "Agronomy". Several sets
84 of keywords were chosen to obtain a range of research and conference papers to be analyzed,
85 varying the type of economic impact (cost saving, revenue, yield, profit); searches have been
86 performed considering keywords synonyms (variable rate, site-specific). The search query
87 ultimately used was the following:

88 *TITLE-ABS-KEY((variable rate OR site-specific OR precis*) AND (sav* OR cost* OR revenue* OR*
89 *profit*) AND (nitrogen appl*) AND (cereal* OR wheat OR barley OR maize OR corn OR mais))*

90 Following the best practices to perform systematic reviews, including PRISMA mapping [9],
91 collecting eligible works consisted of checking the title, the abstract and the full text according to
92 the inclusion criteria adopted.
93 In total, 250 records were screened; of these, 196 were reviews or considered off-topic and thus
94 excluded; the remaining full-text articles were assessed for eligibility, and 29 papers were
95 excluded because they did not contain enough quantitative data to estimate at least directly or
96 indirectly either the amounts of fertilizer use or the yields at the end of the season. After this
97 screening procedure, 29 articles were finally identified (Figure 1).

98 **Results**

99 We extracted information for our analysis from 29 articles accounting for 31 case studies (2
100 articles contained 2 case studies each, accounting for different crops). Study objectives range from
101 analysing the performance of VR fertilization compared to uniform applications (24 studies) or
102 testing new, integrated VR fertilization technologies (7 studies). In most studies (26), VR
103 fertilization obtained the highest N use efficiency, often below the quantity applied in uniform
104 applications. Yield losses were inexistent or not statistically significant in 19 cases.
105 One interesting finding concerns the 6 studies reporting the worst yield performance (from -2.5%
106 to -4.3%); for these cases, the higher savings in N use ranging between 9.4% and 42.1% allowed to
107 make higher net returns compared to uniform N fertilization, thereby confirming
108 Schimmelpfennig's assumption [3] that yield decreases are more than offset by operating cost
109 decrease. Only 3 studies reported no savings concerning N applications; of these, one study
110 reported an unusual temporal and spatial variability across the years during which the
111 experiments took place, while the other two were conducted in a similar setting for barley and
112 wheat, and proved that uniform applications were the most effective strategy. However, it must
113 be considered that the field experiments reported in these articles were performed between 1998
114 and 2000 with technologies quite different from current state-of-the-art technology.
115 Table 2 shows the characteristics of the studies ordered by descending end year of the
116 experiment. No significant correlation was found between N savings, yields, and crop type. Little
117 significant correlation ($r=0.31$) was found between crop yield and experiment period (considering
118 starting and final years), reflecting world cereal yield increment over the last 30 years. Figure 2
119 and 3 show the statistical distribution of N savings (min -9.6%, max 42.5%, mean 13.6%, median
120 9.4%) and yield increase (min -4.3%, max 6.1%, mean 0.4%, median 0.7%), respectively.

121 **Conclusion**

122 VR fertilization refers to practices and technologies allowing site-specific, optimized distribution of
123 fertilizers. Such input optimization can lead to economic impacts intrinsically related to improved
124 nitrogen use efficiency, which in most cases gives rise to input savings, resulting in a decrease in
125 operating costs. More rarely, it leads to yield increments, resulting in higher revenues.
126 Agriculture is the dominant source of nitrogen pollution, and farm-level decisions are pivotal for
127 improving nitrogen management and use efficiency [39]. In this review, we found consistent
128 evidence that, independently from possible field variability, a higher nitrogen use efficiency is
129 achievable without significantly compromising yields. For these reasons, we expect VR fertilization
130 to receive increased attention from policymakers interested in addressing nitrogen pollution. All
131 that by considering that a reduction of fertilizer use by 20% fostered by the EU Farm to Fork
132 Strategy appears to be possible but still hardly achievable. In this regard, initiatives aimed at
133 increasing the participation of citizens and food system actors are desirable [40,41].

134 The analysis results contribute to the body of knowledge on PA, providing useful information to
135 farmers and policymakers regarding the actual economic impacts resulting from the adoption of
136 VR fertilization systems. Effective policies to incentivize the implementation of PA in ways that
137 achieve their promise of economic and environmental improvement are expected, particularly for
138 small farms that find it hard to spread PA technology investment costs over small surfaces [2, 42].

139

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