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# Partial budgeting for acquiring and operating a ground-based optical crop sensor for variable rate nitrogen application

## Teilkostenrechnung für die Anschaffung und den Betrieb eines bodenbasierten optischen Pflanzensensors für die variable Stickstoffausbringung

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### Summary

Optical crop sensors for variable rate nitrogen application (VRNA) are described as an optimal solution to increase yield while minimizing fertilizer costs, although their operation and acquisition costs could be high. In this study, a partial budgeting approach was used to assess the net income of buying and operating a crop sensor for VRNA for optimizing fertilizer application to winter wheat. Two VRNA scenarios – stimulus, where crops with lower yield expectations received more fertilizer, and compensatory, where crops with higher yield expectations received less fertilizer – were assessed and compared to a conventional way of fertilizer application. Both scenarios showed negative results. The stimulus scenario showed a yearly negative change in income of −227.3 €/ha/year on 25 ha of fertilized area and −38.9 €/ha/year on 250 ha of fertilized area. In the case of the compensatory scenario, a yearly change in income of −271.8 €/ha/year on 25 ha of fertilized area and −83.3 €/ha/year on 250 ha of fertilized area was achieved. Results also showed that bigger farms had lower losses than smaller farms due to the economy of scale. Farmers may opt for sharing or leasing the use of the crop sensor to reduce costs.

**Keywords:** partial budgeting, variable rate crop sensor, precision agriculture, economic assessment, digitalization

### Zusammenfassung

Optische Pflanzensensoren für die variable Stickstoffausbringung (VRNA) werden als optimale Lösung zur Steigerung des Ertrags bei gleichzeitiger Minimierung der Düngerkosten betrachtet, obwohl ihr Betrieb und ihre Anschaffungskosten hoch sein können. In dieser Studie wurde eine Teilkostenrechnung durchgeführt, um das Nettoeinkommen beim Kauf eines Pflanzensensors für die VRNA zur Optimierung der Düngung von Winterweizen zu bewerten. Zwei VRNA-Szenarien – Stimulus, in welchem Pflanzen mit niedrigeren Ertragserwartungen mehr Dünger erhielten, und kompensatorisch, in dem Pflanzen mit höheren Ertragserwartungen weniger Dünger erhielten – wurden bewertet und mit einer konventionellen Düngemethode verglichen. In den zwei zu bewertenden Szenarien wurden negative Ergebnisse erzielt. Das erste Szenario mit geringerer Ertragsminderung aber höherem Düngereinsatz zeigte eine jährliche Gewinnänderung von −227,3 €/ha/Jahr bei 25 Hektar (ha) gedüngter Fläche und −38,9 €/ha/Jahr bei 250 ha. Das zweite Szenario mit höheren Ertragseinbußen aber geringerem Düngereinsatz zeigte eine jährliche Gewinnänderung von −271,8 €/ha/Jahr bei 25 ha gedüngter Fläche und −83,3 €/ha/Jahr bei 250 ha. Die Ergebnisse zeigen, dass größere Betriebe im Gegensatz zu kleineren aufgrund von Skaleneffekten geringere Verluste haben. Um Kosten zu sparen, können Erntesensoren von Landwirten geteilt oder geleast werden.

**Schlagwörter:** Teilkostenrechnung, variable Stickstoffausbringung, Präzisionslandwirtschaft, wirtschaftliche Bewertung, Digitalisierung

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## 1. Introduction

In light of the current trends of an exponential increase in human population and the challenge to feed 9 billion people by the middle of the century (Godfray et al., 2010), the agricultural sector has been shifting the way of cultivating crops. Digital agriculture is reinforcing this transition of having more sustainable food systems by using technology to optimize resources while increasing crop yields and reducing environmental impacts. A common concept of digital agriculture is precision agriculture (PA); PA is a management practice that makes use of sensors to respond to the temporal and spatial necessities of crops (Zhang, 2015). Optical sensors have been used to respond to these crop necessities, especially for varying the rate of nitrogen (N) requirements. Varying the rate of N application alters the amount of available nitrogen (N) in the soil, affecting the N and carbon (C) soil dynamics, and thus direct and indirect soil N emissions (WRI, 2020). The purpose of using Optical sensors for variable rate nitrogen application (VRNA) is to optimize the use of fertilizer, increase profits, and reduce nitrogen leaching and related soil emissions.

The economic analysis of VRNA technology, as any other novel technology, is of great relevance since profitable technologies tend to be more widely adopted and their environmental and social benefits can be shortly achieved (Lowenberg-DeBoer et al., 2020). Several studies have assessed the economic implications of using optical crop sensors for VRNA; however, the debate of profitability is always an open question since various studies show different results (Schimmelpfennig, 2016). A literature review performed by Colaço and Bramley (2018) revealed that losses range from 30 $/ha to incomes of 70 $/ha in all of the 58 evaluated studies, with an average income of 30 $/ha. According to the authors, most of the studies ignored additional costs related to the PA technology and calculated simple partial gross margins. In Germany, Meyer-Aurich et al. (2008), Zarco-Tejada et al. (2014), and Meyer-Aurich et al. (2010) have shown that VRNA incomes could range from 10 to 25 €/ha, depending on the sensor and the size of the farm. They concluded that farms bigger than 250 ha can obtain more economic benefits. In another review by Diacono et al. (2013), results showed that sensor-based N management is not always profitable because different factors may influence the rate of fertilizer application; it was concluded that profits could range from 5 to 60 $/ha. The discrepancy between sensor-based VRNA economic studies reflects the heterogeneity of factors and different situations affecting farm's profits. As stated by Karatay and Meyer-Aurich (2020), some profitability reports predict low economic returns or even insolvency to cover the initial investment of implementing PA technologies, such as the use of crop sensors. The initial costs included and associated with the acquisition and operation of PA technologies are a common factor regarding this discrepancy. The high initial investment costs vary between studies, since not all of them reported the same costs. Therefore, farmers need to be aware of these extra costs, in addition to the price of acquiring the sensor. As a requirement to implement PA technologies, sometimes it is necessary to gather accurate site-specific crop and soil description data such as crop biomass indices, water holding capacity, drainage conditions, expected precipitation, and so on (Pedersen et al., 2020). Accumulating these data is crucial and costly; procedures such as soil grid sampling and normalized difference vegetation index (NDVI) crop site maps need to be completed with site-specific crop and soil data. Data processing costs include software and hardware, the opportunity costs of developing site-specific management schemes, and the learning/training opportunity costs to operate this software and hardware (Meyer-Aurich et al., 2008). Costs associated with the acquisition of additional equipment and their related depreciation, taxes, insurances, and maintenance are also part of the considerable PA technology investment. Cash flows and net income of farmers may be disrupted by adding all of these additional expenses. For the above-mentioned reason, the aim of this study is to perform a financial evaluation of buying and operating a ground-based optical crop sensor for VRNA. This evaluation may be used as a reference for farmers to have a comprehensive idea of the costs involved and to decide whether or not to invest in this type of technology.

## 2. Methods

### 2.1. Case study

The financial evaluation presented in this paper is based on a field experiment executed between October 2019 and July 2020 at the experimental farm of the University of Natural Resources and Life Sciences, Vienna, which is located in Groß-Enzersdorf, east of Vienna (48°11'28.3"N, 16°33'39.5"E). It is located in the Marchfeld plain, an important crop production region in the northwestern part of the Pannonian Basin. The aim of the experiment was to assess the efficacy of a ground-based optical crop sensor mounted

on a tractor in terms of fertilizer savings and yield increasing in a winter wheat (*Triticum aestivum* L.) field. The evaluated sensor was a CropXplorer (CNH Industrial Österreich GmbH, St. Valentin, Österreich) crop sensor manufactured by Fritzmeier (2020). Figure 1 shows the sensor mounted on a tractor used in the field study. A one-time fertilizer application was performed on April 17, 2020, applying calcium ammonium nitrate (CAN) with 27% N content (Schwaiger, 2021). The execution of fertilizer application was done based on two different scenarios: stimulus and compensatory. In the stimulus scenario, crops with lower yield expectations received more fertilizer and in the compensatory scenario, crops with more yield expectations received less fertilizer. The scenarios were compared to a conventional way of fertilizer application, where fertilizer is applied as business as usual without any sort of precision farming technology involved. Table 1 shows the description of scenarios. The stimulus and compensatory scenarios used the sensor for fertilization based on the original experimental design presented by Schwaiger (2021). Therefore, these two scenarios were chosen to be assessed. An additional third scenario to be evaluated in this study has been generated from the average of the stimulus and compensatory results.

## 2.2. Partial budgeting

The chosen methods to evaluate the financial implications related to the acquisition of the crop sensor for VRNA were partial budgeting and a payback period calculation. Partial budgeting is a tool used by enterprises to assess the financial implications of any possible change on a farm. This tool focuses on adding and reducing income and costs coming from future changes in a systematic way (Sahs and Doye, 2005). The formula given below is used to evaluate the future change in income (Tigner, 2018):

$$\Delta \text{ net income} = (\text{additional income} + \text{reduced costs}) - (\text{additional costs} + \text{reduced income})$$

An advantage of partial budgeting is that only the additional and reduced cash flows are considered without the necessity of doing a complete budget. Table 2 shows the structure (Rabin et al., 2014), together with the costs and income included in this study.

Results on the additional yield and reduced fertilizer application rates coming from the different scenarios were obtained from the VRNA field experiment executed in 2019–2020. The additional fertilizer rate was compared to the conventional way of fertilizer application (Table 3). Crop yields were not only influenced by the fertilizer application rates – the former determined by the sensor's initial calibration –, but weather and soil pedoclimate characteristics also affected them. The average temperature was 10°C and the accumulated precipitation was 478 mm during the period of the experiment. The type of soil of the experimental field is calcareous gray with a pH range between 7.5% and 8% and a clay content of 14% (Schwaiger, 2021).

It is relevant to state that due to technical problems with the crop sensor, the second planned fertilizer application was not performed. Therefore, the amount of applied fertilizer was less than half the common rate used for winter wheat production in the Marchfeld plain, but resulted in high yields nevertheless (cf. Neugschwandtner et al., 2015; Moitzi et al., 2020).

The calibration of the sensor played a crucial role in the losses of grain yield in both scenarios. These losses are directly influenced by the amount of fertilizer and the yield obtained. Despite the losses, statistical significances were not found between the scenarios. The gain or loss of yield and the fertilizer application rates in both scenarios were multiplied with the market price in (€/t) of the milling wheat and the fertilizer costs to obtain values for partial budgeting. The milling wheat market price is based on the protein content of the harvested winter wheat. Laboratory results showed an average protein content of 9.6% in the grain (Schwaiger, 2021). This protein content is below the accepted value for milling wheat (12.5%) at the stock exchange for agricultural products in Austria (Gartner, 2018). Hence, a 12.5% protein content was assumed in the grain for purpose of this

Table 1. Description of the scenarios implemented for VRNA during the field experiment
Tabelle 1. Beschreibung der durchgeführten Szenarien im Feldversuch mit konventioneller und variabler Stickstoffausbringung (VRNA)

| Fertilizer application scenario | Description |
|---|---|
| Stimulus | Crops with lower sensor-determined yield than expected[1] receive higher fertilizer rate |
| Compensatory | Crops with higher sensor-determined yield than expected[1] receive lower fertilizer rate |

[1] Expected yield created on the basis of the isaria's reflectance measurement index (IRMI). This index, created by the sensor's manufacturer, measures the vegetation index of the crop and compares it to the calibration quantity. The calibration value is selected on the basis of an NDVI map and continuously adjusted during the measurements

IRMI, isaria's reflectance measurement index; NDVI, normalized difference vegetation index; VRNA, variable rate nitrogen application

Table 2. Partial budgeting structure for the acquisition of the crop sensor for VRNA
Tabelle 2. Teilkostenrechnungsansatz für die Anschaffung des Pflanzensensors für die variable Stickstoffausbringung (VRNA)

| Additional income | Additional costs |
|---|---|
| Yield increased | Equipment costs<br>• Annualized depreciation and interests<br>• Insurance<br>• Repairs and maintenance<br>Information costs<br>• Internet expenses<br>• Annualized mapping expenses<br>Material costs<br>• Fertilizer |
| Reduced costs | Reduced income |
| Fertilizer amount | Yield decreased |
| A. Total additional income and reduced costs | B. Total additional costs and reduced income |
| Δ Net income = A – B | |

VRNA, variable rate nitrogen application

evaluation. The additional costs involved in the acquisition of the crop sensor were separated into three categories: equipment costs, information costs, and material costs.

*Equipment costs:* These costs refer to the acquisition of the crop sensor and the additional machinery that is needed for the correct functionality of the sensor. In this case, an AMAZONE ZA-TS 2000 mounted precision spreader and a laptop are the additional devices required. It is assumed that the farmer already has a non-precision spreader to perform conventional fertilization. In this analysis, the resell salvage value of the non-precision spreader is not considered, although a sensitivity analysis scenario reducing the salvage value of the conventional spreader from the initial investment of the precision spreader is going to be shown. The total costs of these devices are annualized based on the buying costs, salvage value of the equipment, and the real interest rate. It is assumed that a commercial financial institution would finance the acquisition of these devices. Annualized payment ($r$) and the interest rate ($i_r$) were calculated according to Tekin (2010) as follows:

$$r = [C_o - C_n]\,\frac{i_r(1+i_r)^n}{(1+i_r)^n - 1} + C_n * i_r$$

where $r$ is the annual payment (€/year), $C_o$ the purchase price of the equipment (€), $C_n$ the resale value of the equipment (€), $n$ the lifespan of the equipment (years), and $i_r$ is the real interest rate (%).

$$i_r = \frac{i_n - i_g}{1 + i_g}$$

where $i_r$ is the real interest rate (%), $i_n$ the interest rate on loan capital (%), and $i_g$ is the inflation rate (%).

The insurance costs are estimated to be 2% of the value of the machinery. To cover the annual repairs and maintenance costs, 3% of the value of machinery was used (ÖKL, 2019).

*Information costs:* These costs are associated with obtaining site-specific crop and soil data and the methods (software and hardware) to process these data. In this case study, the sensor is initially calibrated based on an NDVI map. Later, the vegetation reflectance measurement index given by the sensor is compared against this initial calibration quantity of the NDVI index. Based on this method, crops with lower/higher sensor-determined vegetation indexes receive higher/lower fertilizer rates. It is not necessary to have any sort of internet connection to operate the sensor; however, it facilitates data transfer and storage to create NDVI maps for further sensor calibration. At the same time, these data can be stored in the cloud, which the sensor's manufacturer offers as a service. In this study, a laptop with access to a wireless network was included in the information costs section. A one-time payment of 75 € to obtain a wireless internet box and the internet monthly fee of 25 €/month (magenta, 2020) were included in these costs.

The creation of NDVI-based soil management zone maps to calibrate the sensor is also optional, although having these maps gives more accurate information about N deficiency in the crops. To create them – NDVI-based soil management zones maps – it is necessary to have access to satellite




Figure 1. Ground-based crop sensor
Abbildung 1. Bodenbasierter optischer Pflanzensensor

Table 3. Fertilizer application rates and yield changes in comparison to the conventional way of fertilizer application
Tabelle 3. Vergleich der Düngerausbringungsraten und Ertragsänderungen des konventionellen und variablen Stickstoffausbringungsszenarios

| Scenario | Fertilizer applied (kg N/ha) | Δ relative to baseline (kg N/ha) | Yield (kg/ha) | Δ relative to baseline (kg/ha) |
|---|---|---|---|---|
| Conventional1 | 56 | – | 6,829 | – |
| Stimulus | 63 | +7 | 6,760 | −69 |
| Compensatory | 44 | −12 | 6,412 | −417 |

[1] The conventional scenario is the baseline for comparison.

images. Precision farming software and/or companies help to determine the management zones and can create yield zoning maps based on NDVI. The yearly satellite mapping software fee is 257 €/year (moneysoft, 2020). The yield zoning map costs are based on the total area to be assessed, 60 € for the first 100 ha and 120 € for more than 100 ha (AgrarCommander, 2020). Although the creation of NDVI-based soil management zone maps is not necessary to utilize the sensor, the potential benefits are augmented by using these maps simultaneously with the sensor. In this study, the costs to create NDVI-based soil management zone maps were included in the information costs. Despite adding the information costs to operate the sensor in this study, a sensitivity analysis scenario without including these costs is presented in the section "Results and discussion."

*Material costs*: These costs are related to the extra fertilizer applied to the field zones where yield expectations were lower in comparison to other zones. The application rate is based on the scenarios of the VRNA field experiment. In this case, the stimulus scenario required an extra 7 kg N/ha compared to the conventional scenario to compensate for the nutrient deficiency in the zones projecting low yields. This amount was later multiplied by the market price of N in CAN. The price before taxes of CAN was 191 €/t.

A summary of some of the equipment and information precision farming costs are shown in Table 4.

It was not projected to reduce any sort of income by using the crop sensor on the farm. However, based on the yield results of the field experiment, a reduction in income was generated due to technical and environmental factors. For the same reason, a reduction in yield income was added to this partial budget, although this is not the norm. It is important to mention that the additional costs were annualized, therefore a present value (PV) annuity factor was used when calculating the yearly cost. The annuity factor was calculated according to Andrew and Gallagher (2007) as follows:

$$pva = pmt * \frac{1 - (\frac{1}{(1+i)^n})}{i}$$

where *pva* is the PV of annuity (€/year), *pmt* the annual payment cost (€/year), *n* the time period (years), and *i* is the discount rate (%). The financial data utilized at the time of performing this financial analysis is presented in Table 5.

Table 4. Additional precision farming expenses
Tabelle 4. Zusätzliche Ausgaben für die Präzisionslandwirtschaft

| Description | Cost | Reference |
|---|---|---|
| ISARIA crop sensor (€)[1] | 19,393 | Louise (2017) |
| AMAZONE ZA-TS 2000 mounted spreader (€)[2] | 17,735 | Oliver (2018) |
| Laptop (€) | 1,099 | mediamarkt (2020) |
| Internet subscription (€/month) | 25 | magenta (2020) |
| Internet box (€) | 75 | magenta (2020) |
| Satellite mapping software fees (€/year)[3] | 257 | moneysoft (2020) |
| Satellite yield zoning maps (€/year)[4] | 60–120 | AgrarCommander (2020) |

[1] Cost was given in British pounds (17,500 £). The present value cost in Euro was calculated with the following formula: ((cost of sensor in £ × present nominal exchange rate) × CPI in UK)/CPI in Austria
[2] Cost was given in British pounds (15,500 £). The present value cost in Euro was calculated with the following formula: ((Cost of spreader in £ × present nominal exchange rate) × CPI in UK)/CPI in Austria
[3] 20% VAT included. Includes basic software recording and application, one-time installation fee, and XL data package
[4] 20% VAT included. Based on total area to be assessed
CPI, consumer price index; VAT, value added tax

## 2.3. Yield adjustment from other studies for comparison

In addition to the results obtained in the field experiment (Table 3), three additional scenarios are presented, where the benefits of the additional yield of using a sensor are added to the partial budgeting presented here. These scenarios were taken from three field experiments using the same type of ground-based optical crop sensor for VRNA, although the Yara Hydro N was used instead of Fritzmeier sensor in the studies of Link et al. (2002) and Mayfield and Trengove (2009). The additional economic benefits (increase in yield in comparison to a conventional way of fertilizer application) due to the use of the crop sensor in these studies were added to the assessed partial budgeting (Table 6). The amount of nitrogen reduction applied in the mean scenario in this research was used to assess the other three studies;

Table 5. Financial data used for calculations
Tabelle 5. Für Berechnungen verwendete Finanzdaten

| Description | Value | Reference |
|---|---|---|
| Calcium ammonium nitrate (€/t)[1] | 191 | agrarheute (2020) |
| Milling wheat (12% protein [€/t])[2] | 173 | AMA (2020) |
| Diesel (€/l)[3] | 1.00 | globalpetrolprices (2020) |
| Exchange rate (€/£)[4] | 1.10 | x-rates (2020) |
| CPI in the UK[5] | 108.80 | ONS (2020) |
| CPI in Austria[5] | 108.00 | Statistik Austria (2020) |
| Lifespan of sensor (years) | 15 | Assumed |
| Salvage value of sensor (%) | 26 | Edwards (2015) |
| List price of pneumatic spreader (€) | 23,000 | ÖKL (2019) |
| Salvage value of pneumatic spreader (%)[6] | 40 | Edwards (2015) |
| Lifespan of precision spreader (years) | 10 | Assumed |
| Salvage value of precision spreader (%) | 35 | Edwards (2015) |
| Repair and maintenance of sensor (%) | 3 | ÖKL (2019) |
| Lifespan of the laptop (years) | 5 | Assumed |
| Insurance (%) | 2 | ÖKL (2019) |
| Interest rate (%)[7] | 1.76 | ONB (2020) |
| Inflation rate (%)[8] | 1.40 | Statistik Austria (2020) |
| VAT (%) | 20 | PwC (2019) |
| VAT on fertilizers (%) | 13 | OECD (2020) |

[1] September 2020
[2] October 31, 2020
[3] September 29, 2020
[4] September 30, 2020
[5] CPI August 2020
[6] Capacity of spreader 1700 l–15 m
[7] Lending rate – new business to nonfinancial corporations up to 1 million € over 5 years, rate of August 2020
[8] August 2020
CPI, consumer price index; VAT, value added tax

only the amount of yield input was changed. It is important to mention that not only the amount of fertilizer applied, but also other factors, such as climate and soil conditions, play a crucial role in the amount of yield obtained in different studies. However, these factors were not considered in this comparison; just the additional yield obtained by using the crop sensor relative to baseline was considered.

Table 6. Additional studies and their change in yield due to the use of crop sensors for VRNA
Tabelle 6. Zusätzliche Studien und deren Ertragsänderung durch den Einsatz von Pflanzensensoren für VRNA

| Type of crop sensor | Δ yield relative to baseline (t/ha) | Study |
|---|---|---|
| Fritzmeier | 1.25 | Galambošová et al. (2015) |
| Hydro N | 0.16 | Link et al. (2002) |
| Yara Hydro N | 0.04 | Mayfield and Trengove (2009) |

Conventional fertilizer application (constant fertilizer rate without sensor) is the baseline for comparison
VRNA, variable rate nitrogen application

## 3. Results and discussion

### 3.1. Partial budgeting results

The compensatory scenario shows the highest negative change in income (Figure 2). This scenario presents an income of −271.8 €/ha/year on 25 ha of fertilized area and −83.3 €/ha/year on 250 ha of fertilized area. Although this scenario gives the highest amount of fertilizer reduction with −12 kg N/ha, the reduced costs did not cover the additional costs related to the acquisition and operation of the sensor. In addition, the negative amount of yield had a null impact on additional benefits resulting from buying the sensor, since it was the scenario giving a lower yield. On the other hand, the stimulus scenario shows the lowest negative change in income. This scenario presents −227.3 €/ha/year on a 25 ha farm and −38.9 €/ha/year on 250 ha of fertilized area. The stimulus scenario applies an additional amount of fertilizer (+27 kg N/ha), but gives the lowest yield reduction of −69 kg/ha. The third scenario represents the mean of these two strategies, the compensatory and stimulus. A sensitivity analysis of the third scenario was also included in the results. The first sensitivity analysis scenario takes the salvage value of the traditional spreader and reduces this amount to the initial investment of the precision spreader. In this case, the financial losses were −228.4 €/ha/year on 25 ha

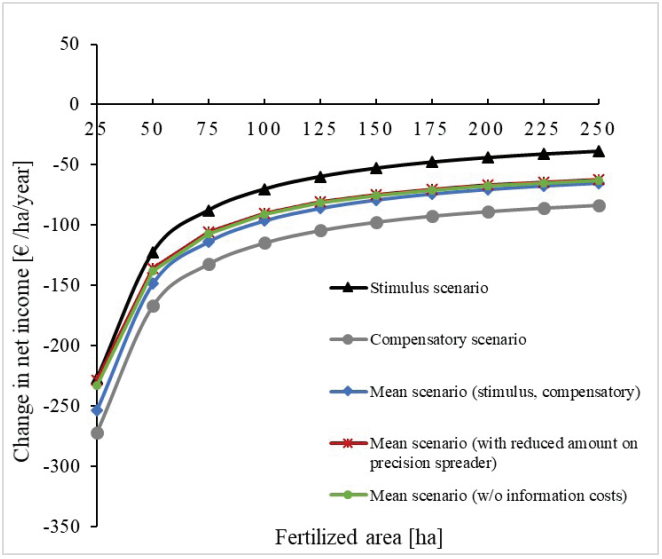



Figure 2. Change in income (€/ha/year) caused by the acquisition and operation of the optical crop sensor for VRNA
VRNA, variable rate nitrogen application
Abbildung 2. Gewinnveränderung (€/ha/Jahr) aufgrund der Anschaffung und Verwendung eines optischen Pflanzensensors für die variable Stickstoffausbringung (VRNA)

of fertilized area and −62.3 €/ha/year on 250 ha of fertilized area. This is around a 10% reduction on 25 ha of fertilized area and 4% reduction on 250 ha of fertilized area, relative to the mean scenario. In the second sensitivity analysis, the information costs were removed from the additional costs in partial budgeting. In this case, an 8% reduction on 25 ha of fertilized area and a 3% reduction on 250 ha of fertilized area relative to the mean scenario were achieved.

The negative results on this partial budgeting may be affected by the external factors disturbing the amount of attained yield in all of the scenarios. Either increasing the yield or reducing the usage of the fertilizer may have the same impact on partial budgeting. The reason for this premise is that the difference between the market price of fertilizer (191 €/t) and milling wheat (173 €/t) at the time of this evaluation was only 18 €/t; this is around 10% higher price of the fertilizer relative to the price of the milling wheat. The crucial element is either the amount of additional yield or the reduction of fertilizer or a combination of both, which could pay off the additional precision farming costs attributed to the sensor. In this case, a negative amount of additional yield carries all the additional precision farming costs to the savings coming from the reduction of fertilizer usage.

Results also show that bigger farms have significantly better results than smaller farms. The additional income gained from the increased yield and reduced costs grows in proportion to the size of the fertilized area. However, farms smaller than 250 ha cannot pay for the additional precision farming costs due to the negative amount of yield obtained in all the scenarios relative to the conventional scenario. These results are similar to the ones obtained by Meyer-Aurich et al. (2008) who reported that farms bigger than 250 ha may obtain greater income. The calculated payback period just to cover the cost of the crop sensor device without including the additional necessary components for its operation is shown in Table 7. The mean of the stimulus and the compensatory scenario was chosen to compute the payback period. The reduced costs due to fertilizing savings were used to calculate the time of repayment because the additional amount of yield was negative in all the scenarios. Results show that 25 ha of fertilized area would need 331 years to cover the cost of the sensor with the fertilizer savings, whereas 250 ha of fertilized area would need 31.1 years.

## 3.2. Comparison of results with other studies

Figure 3 shows a comparison of the partial budgeting results with selected studies (Table 6). It is possible to perceive negative results in the studies of Link et al. (2002) and Mayfield and Trengove (2009), as in both studies, a minimal amount of yield increase occurred due to the use of the sensor, 0.04 t/ha in the study of Mayfield and Trengove (2009) and 0.16 t/ha in the study of Link et al. (2002). The amount of yield increased between conventional and VRNA scenarios in the study of Mayfield and Trengove (2009) was not statistically significant, whereas Link et al. (2002) did not provide results for statistical significance. Galambošová et al. (2015)

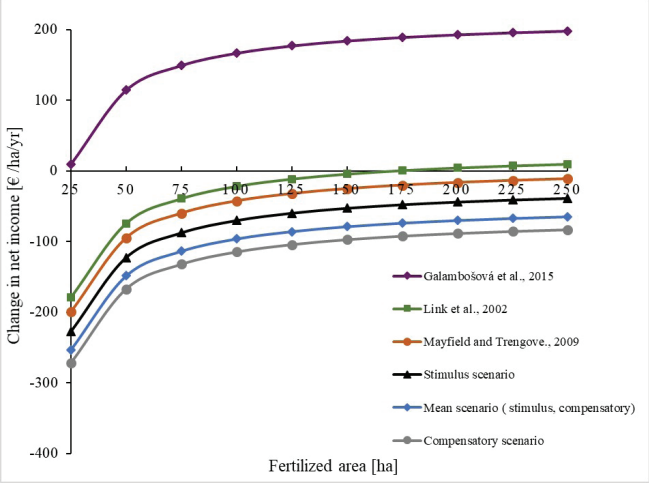



Figure 3. Comparison of scenarios using yield data from other fielded experiments implementing the same or similar crop sensor
Abbildung 3. Szenarienvergleich unter Verwendung von Ertragsdaten aus anderen Feldversuchen bei Einsatz des gleichen oder eines ähnlichen Pflanzensensors

Table 7. Payback period to cover the cost of the crop sensor device using the reduced costs from fertilizing rate application savings
Tabelle 7. Amortisationszeit zur Deckung der Kosten für den Pflanzensensor unter Verwendung der reduzierten Kosten durch die Einsparungen bei der Düngerausbringung

| Payback period (years) | |
|---|---|
| **Fertilized area in ha** | **Mean of stimulus and compensatory scenario** |
| 25 | 331.2 |
| 50 | 165.6 |
| 75 | 110.4 |
| 100 | 82.8 |
| 125 | 66.2 |
| 150 | 55.2 |
| 175 | 47.3 |
| 200 | 41.4 |
| 225 | 36.8 |
| 250 | 33.1 |

presented the highest additional economic benefits among all the studies, as 1.25 t/ha additional yield was obtained in this field experiment by also using the same Fritzmeier crop sensor for VRNA. The reason behind the positive result was the higher doses of fertilizer given to the plants, an average 49 kg N/ha in this study versus around 32 kg N/ha in the study of Mayfield and Trengove (2009), for example. At the same time, Galambošová et al. (2015) combined yield potential maps with the Fritzmeier crop sensor to obtain better results, whereas none of the other studies utilized yield potential maps in their methods. A break-even point on a 24-ha fertilized area could be attained if the additional yield results of Galambošová et al. (2015) were used in the mean of stimulus and compensatory scenario on this research.

## 4. Conclusions

The premise of using optical crop sensors for VRNA is to optimize the use of fertilizer and reduce nitrogen leaching, whereas crop yields and income shall be increased. However, the acquisition of the sensor together with all the additional costs to operate it could be a risky investment since there is not enough evidence of income optimization. Thereby, the aim of this study is to evaluate the net change in income by using a Fritzmeier optical crop sensor for VRNA by performing partial budgeting. Two scenarios were used in the financial evaluation and compared to a conventional scenario: stimulus and compensatory. The stimulus scenario showed a yearly negative change in income of −227.3 €/ha/year on 25 ha of fertilized area and −38.9 €/ha/year on 250 ha of fertilized area. In the case of the compensatory scenario, a yearly change in income of −271.8 €/ha/year on 25 ha of fertilized area and −83.3 €/ha/year change in income on 250 ha of fertilized area had been attained. The negative results were a product of the lower yield increase of the VRNA and the additional costs incurred to operate the sensor. From this financial evaluation, we can establish that variable costs such as the market price of grain and fertilizer have a significant effect on the results. Results also showed that bigger farms are in an advantageous position for using the crop sensor since the additional costs are divided by more hectares. However, this premise also reinforces and promotes the shared use of machinery for multiple farms or the use of service companies offering this type of sensors or any other smart farming machinery to local farmers.

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