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Precision fertilizer management has been proposed to maximize crop yield and reduce nitrate leaching to the surface and groundwater, and has received a considerable research attention. However, the practical implementation of this concept remains limited as the selection of a correct fertilization strategy is still debatable. Little information is available about the comparison of different management scenarios: should more or less nutrients be applied in the zones with lower crop productivity potential. In addition, this article seeks to consider the situations when precision fertilization could have no added value and conventional fertilization management is more favourable. In order to address these research questions, three fields in Flanders were selected. Using soil maps, NDVI time series and maps of electrical conductivity, two management zones with a potentially different crop productivity were identified in each field. In the spring of 2021, field trials with maize were set up. Fertilization scenarios included conventional practice, +20% and -20% of fertilizer dosage compared to conventional practice. At the end of the growing season, the maize yield was quantified for each trial plot and residual nitrate in the soil was measured to assess the potential environmental impact in terms of nitrate leaching after harvest. The field trial results indicate that precision fertilization outperforms the conventional practice in fields with temporally stable management zones. Lower fertilization in the zones with poor productivity potential demonstrated better results in terms of yield and postharvest nitrate in comparison with the higher fertilization scenario. In the fields with interannually inconsistent zones, conventional practice remains the recommended approach.

Keywords.
soil scanner, NDVI, nutrient management, precision fertilization, fertilization scenario.

Should we increase or decrease the fertilization in the zones with the highest crop productivity potential?

Introduction

Over the past decades, numerous studies have been focused on the variable rate application of fertilizers (precision fertilization, site-specific management) on agricultural fields. Such approaches suggest to provide nutrients to plants in an accurate way to achieve a maximal crop efficiency. This topic received a lot of attention because of the possibilities to obtain a higher crop yield (Matějková Š., 2010; Basso, et al., 2016; Molin et al., 2010), which was observed for different climates, cropping systems and soil types. Lower environmental impact as a result of the variable rate applications was also considered in a number of studies. They reported reductions in the postharvest residual nitrate, its further leaching and contamination of the groundwater (Roberts et al., 2010; Hong t al., 2007), and lower emissions of greenhouse gases (Balafoutis, et al., 2017). Moreover, this approach allows to save fertilizers (Jovarauskas et al., 2021), and could contribute to achieving the EU Green Deal goals related to improvement of the soil quality by reducing the nutrient losses by 50% and reduction of fertilizer use by 20% (ec.europa.eu).

Despite the successes of precision fertilization, its practical implementation remains limited. One of the important aspects of site specific fertilizer management which still lacks consensus, is the correct selection of fertilization strategy that should be adopted in the different parts of an agricultural field. For instance, most studies report a higher efficiency in terms of crop yield when nitrogen fertilizer is added in the poor zones (Guerrero & Mouazen, 2021; Zhang, et al., 2021). However, in some cases N appeared not to be the main limiting factor defining the crop growth. Topography, available moisture, plant diseases and other factors could for instance also negatively affect the development of the plants (Tandzi, Mutengwa, 2019). This is confirmed by the findings of Peralta et al. (2015), who observed a limited crop response to N-fertilization in poor zones compared to more productive zones. In a different study, the fertilizer dosage was suggested to be reduced in the less productive dry spots of potato fields (Janssens et al., 2020). Moreover, N fertilization above a certain level may not increase crop yield (Godard, et al., 2008). Therefore, providing more N in the zones with a low productivity potential is not always the best management decision, as the additional N may reduce the N-uptake efficiency, be left unused by the crop and would be prone to leaching out to the ground water (Spiertz, 2009; Muñoz-Huerta et al., 2013). In addition, most scientific reports only describe results for one field, where the benefits of a fertilization strategy are demonstrated within one season. However, no reports were found on studies involving multiple fields within one region which investigated the conditions when variable rate application is beneficial for the farmers. Moreover, it is important to identify the situations when site-specific fertilizer management is not recommended.

Therefore, the objective of this research is to fill existing knowledge gaps and to assess the yield and environmental response to precision manure management in Flanders (Belgium), a European region with reported over-usage of fertilizers and long-lasting problems of nutrient leaching (VLM, 2020).

Materials and methods

Site description

The field work was conducted on three commercial fields in Flanders (Belgium), planted with silage maize (Fig. 1). Two studied fields were located in the province of Limburg: a 1.04 ha sandy-loam field in Tessenderlo (5° 22' 11.928" E, 51° 15' 49.536" N) and a 2.51 ha sandy field in Lommel (5° 22' 9.3396" E, 51° 15' 45.0252" N). The third field, 7.23 ha sandy-loam field was located in Kortenaken, province of Vlaams-Brabant (5° 2' 10.9932" E, 50° 54' 52.2972" N). The soil and crop measurements were carried out in the growing season of 2021.

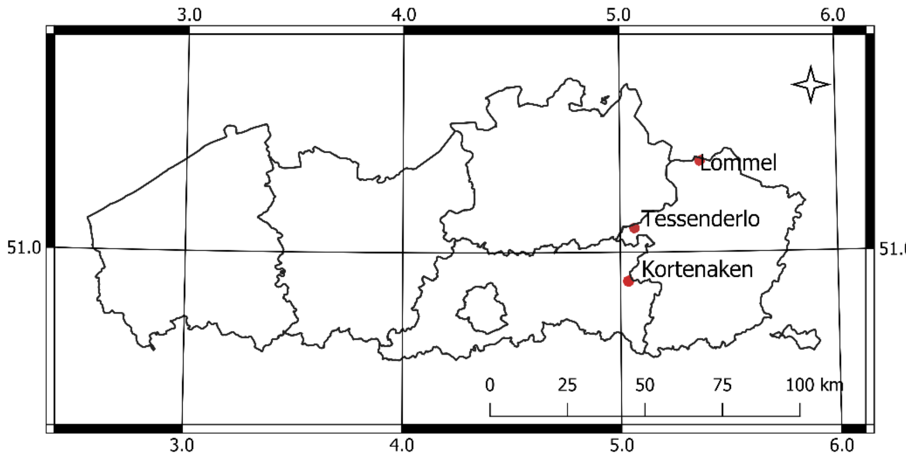

Fig. 1. Location of experimental sites in Flanders (Belgium).

Management zones

Using soil maps, NDVI time series and maps of electrical conductivity, two management zones with a potentially different crop productivity were identified in each field. The maps of electrical conductivity were obtained with a SoilXplorer (AG XTEND) for the layers 0–25 cm (Fig. 2), 15–60 cm, 55–95 cm and 85–115 cm. In addition, Sentinel-2 satellite images were used for calculating NDVI values in the period from 2016 to 2021 (terrascope.be). Calculated vegetation indices were compared with daily precipitation data obtained from the Agri4Cast resource Portal (agri4cast.jrc.ec.europa.eu) to estimate the influence of dry and wet periods on the crop status. Fig. 3-5 indicate the evolution of NDVI values through the growing season in the different zones of each field. This NDVI evolution is shown for the most contrasting years: 2018 as a dry year and 2016 as a wet year in Belgium.

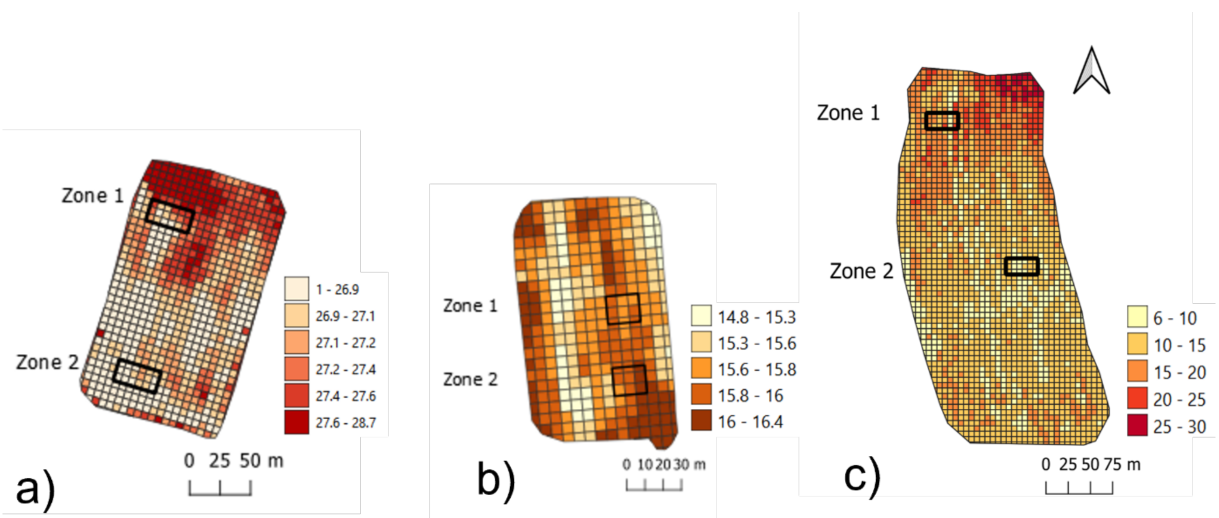

Fig 2. Maps of electrical conductivity (dS/m) at a depth of 0-25 cm with indication of the locations of the management zones in the trial fields in a) Lommel, b) Tessenderlo and c) Kortenaken.

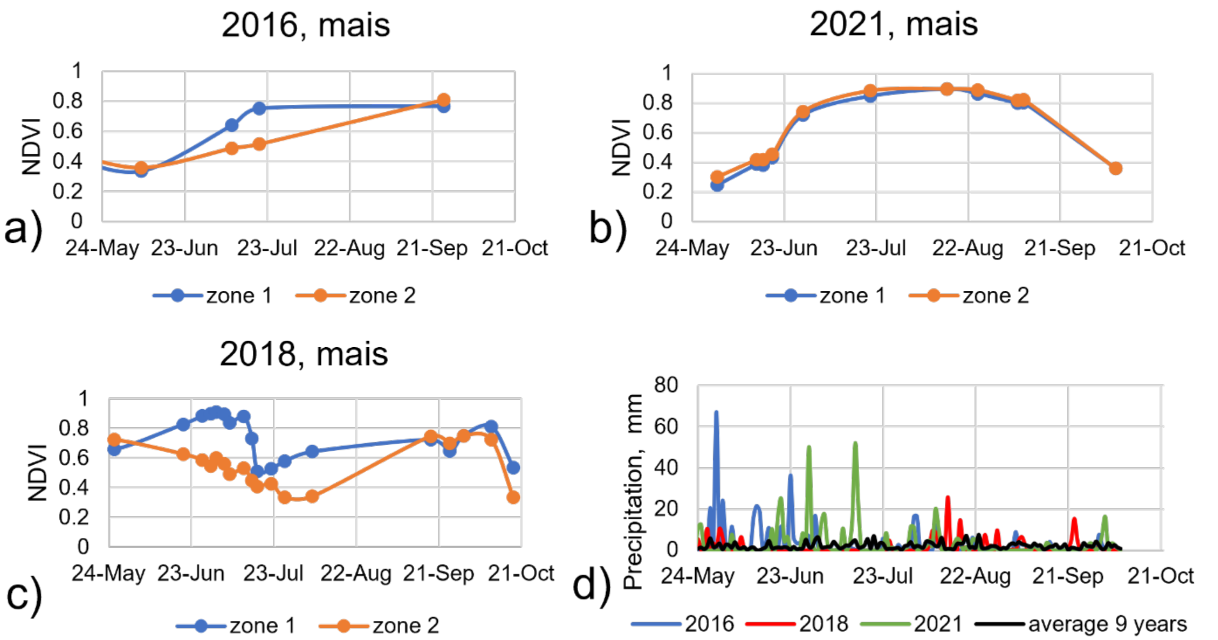

Fig 3. NDVI profiles for the two management zones in Lommel for a) & b) wet years, c) a dry year and d) the corresponding precipitation in these wet and dry years.

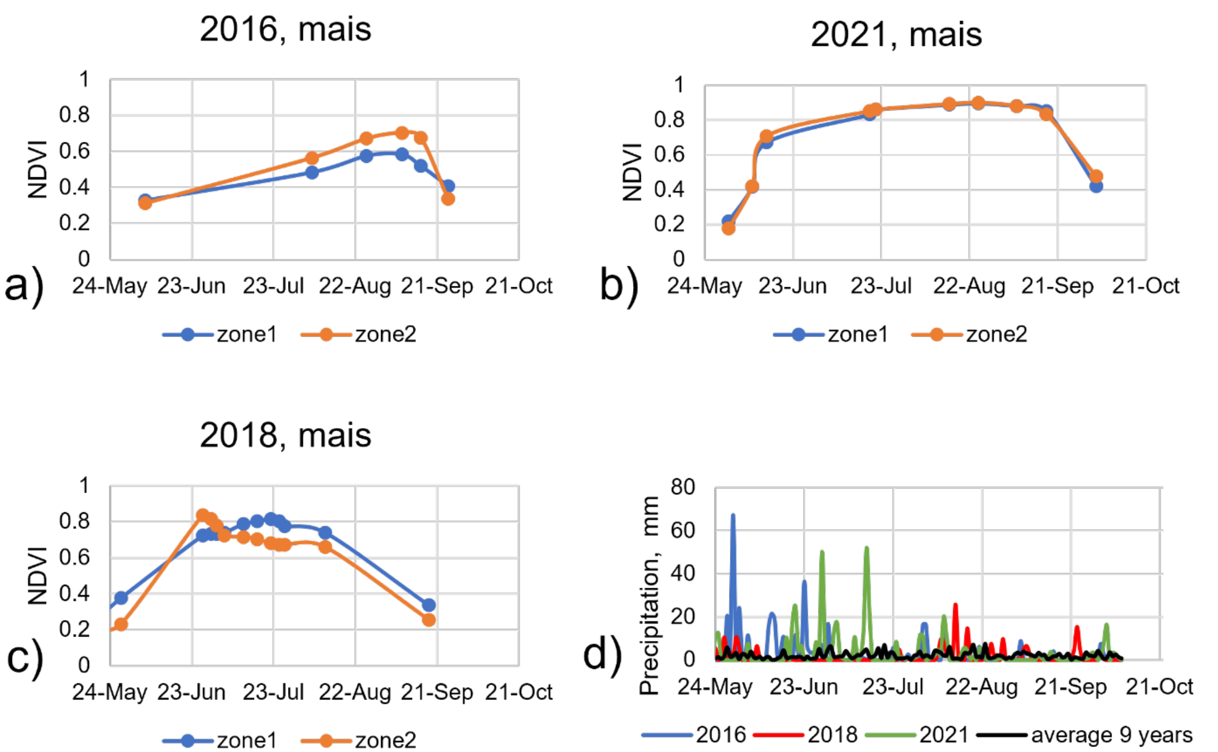

Fig 4. NDVI profiles for the two management zones in Tessenderlo. a) & b) for wet years, c) a dry year and d) the corresponding precipitation in these wet and dry years.

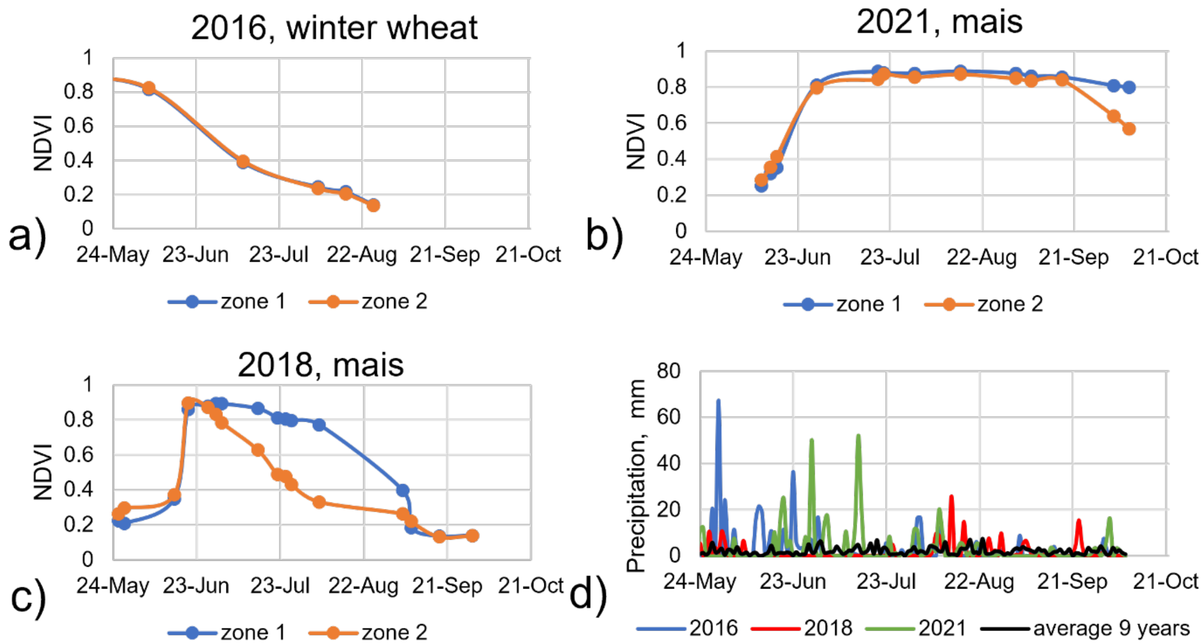

Fig 5. NDVI profiles in the two management zones in Kortenaken. a) & b) wet years, c) a dry year and d) the corresponding precipitation in these wet and dry years.

Field trials and fertilization dosages

In the spring of 2021, field trials were set up in each management zone to investigate the best fertilization scenario. The thresholds defined by the Flemish legislation for manure application were taken into account when defining the fertilization dosages (VLM, 2020). Fertilization scenarios included conventional practice (dosage defined for maize by the Flemish legislation – 128 and 135 kg N/ha depending on the soil type and the region), -20% (102 and 108 kg N/ha) and +20% (154 and 162 kg/ha) of the recommended fertilizer dosage (Table 1). Fertilization treatments were applied in 4 replicates.

Table 1. Dosages of N applied to the management zones defined in the maize fields. The total amount of fertilizer and manure was limited according to the Flemish legislation.

Field	N dosage	N [kg N/ha]
Lommel	Conventional practice	135
	+ 20%	108
	- 20%	162
Tessenderlo	Conventional practice	128
	+ 20%	102
	- 20%	154
Kortenaken	Conventional practice	128
	+ 20%	154
	- 20%	102

At the end of the growing season in September, the maize silage yield was quantified for each trial plot in ton DM/ha. In addition, the residual nitrate (kg nitrate-N/ ha, 0-90 cm depth) was measured in the soil to assess the risk of nitrate leaching after the harvest.

Results

In two studied fields, Lommel and Kortenaken, a clear difference in terms of yield and nitrate residue was observed between the management zones (Fig. 6).

In zone 2 on the field in Lommel, which was hypothesized before planting to have a lower productivity potential, a yield of 21.77 ton DM/ ha was obtained, which was significantly higher than the yield of 17.68 t DM/ha in zone 1 (Fig.6, a). The scenario with the higher fertilizer dosage allowed to increase the yield in zone 1 to 19.92 ton DS/ha, but did not provide a noticeable difference in zone 2. Fertilization with the lower N dosage did not have a significant impact on the amount of available N after the harvest compared to conventional practice (Fig 6, b).

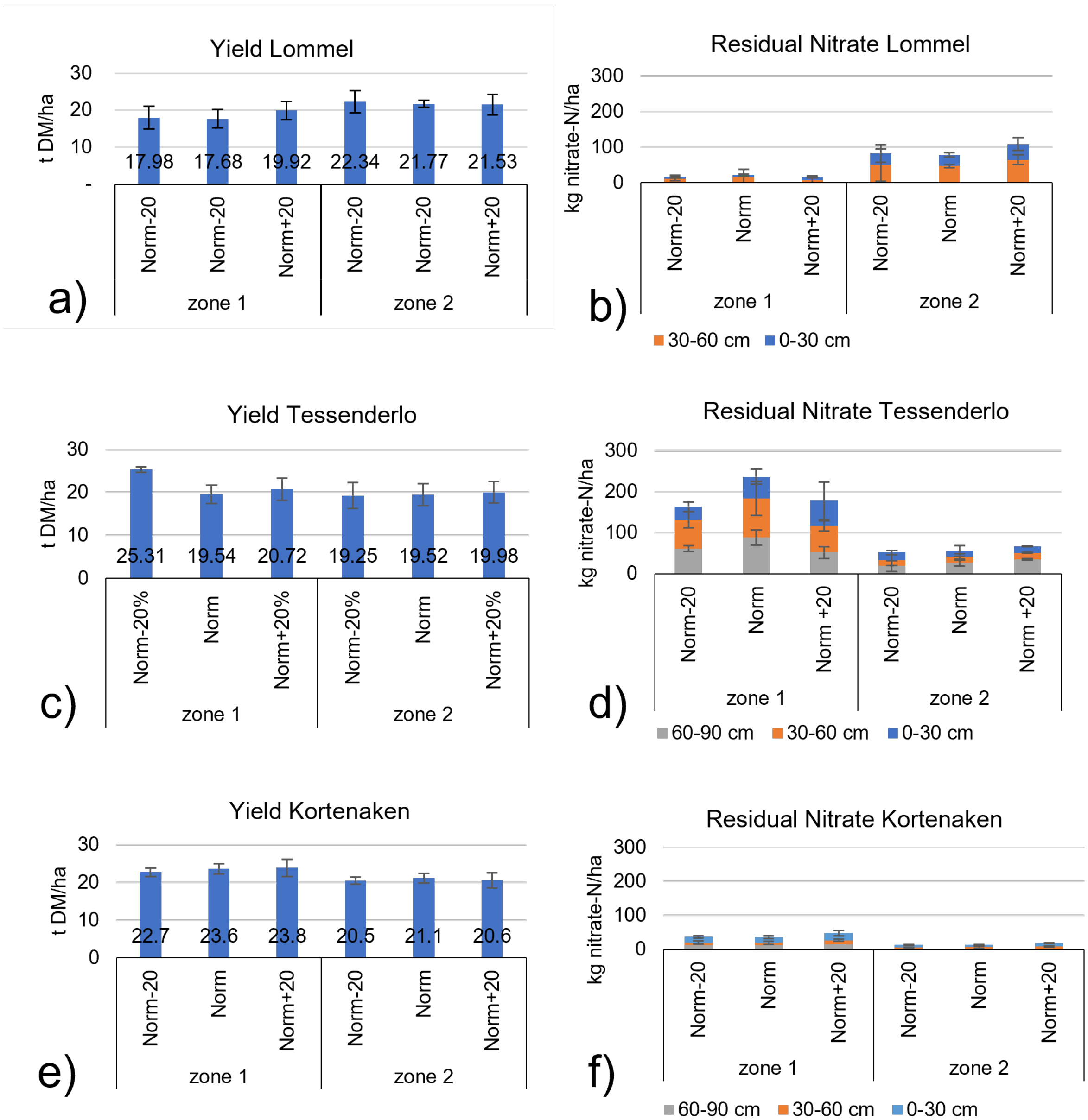

Fig 6. Yield and residual nitrate in the studied fields.

In the Tessenderlo field, no contrast in yield between the two zones was observed (Fig. 6, c). In zone 1 with hypothesized higher productivity potential, the yield was 19.54 t/ha, and in zone 2 the yield was 19.52 t/ha. A 20% increase in fertilization dosage in both zones did not cause the yield to increase, and the difference between treatments remained unpronounced. The 20% reduction in fertilization dosage combined a similar yield with a decrease in N-residue from 237 to 163.5 kg nitrate-N/ha, which is still well above the limit of 90 kg N/ha (Fig. 6, d).

In the Kortenaken field, the observed yield differences were in agreement with the historical NDVI data: zone 1, historically having higher productivity, had a higher yield of 23.6 t DM/ha in comparison to zone 2, where the yield was around 21.1 t DM/ha (Fig. 6, e). In zone 1, 20% higher N fertilization increased both the yield and the nitrate residue in the soil to a limited extent (Fig. 6, f). In zone 2, no significant effect of the fertilizer dosages on the nitrate residue was detected. A 20% reduction of the N dosage did not affect the yield in both zones, but resulted in a lower nitrate residue in the soil of the zone with lower crop productivity.

Discussion

All three fields had zones which were identified to have higher and lower crop productivity potentials based on the soil maps, the EC maps and the historical NDVI data. However, the reasons for the low historical productivity in these zones were different.

For the field located in Lommel, the trends observed in wet years were not in line with the NDVI observations for the dry year 2018. Due to reduced drainage, zone 1, which had better performance during more dry years, had a reverse effect of remaining too wet for better crop development in the wet growing season of 2021. As the fertilizer dosage has to be decided before the weather in the actual season is known, fields with such reverse effects in different zones have the risk of selecting the wrong fertilization strategy. So, in this case precision fertilization may not be recommended.

The presence of clay particles in the Tessenderlo field was the main reason for the low historical crop performance in zone 2. In the wet growing season of 2021, no effect of precision fertilization and no significant differences between the zones were detected. According to the NDVI time series, the difference between the zones was not pronounced as well in the dry growing season of 2018, despite the observed differences in electrical conductivity. In this case, precision fertilization is also not recommended, as neither a yield increase, nor environmental benefits were achieved.

The presence of stones and a lower water holding capacity in zone 2 of the Kortenaken field made it more susceptible to drought stress. The location of this zone was consistent over the dry and wet growing seasons. The compensation strategy of applying more nitrogen to the zone with lower crop productivity did not cause an improvement in crop performance, as the amount of nitrogen was not the main limiting factor in that zone. On the other hand, addition of 20% N in the zone with a higher crop productivity potential resulted in unfavorable higher nitrate residues. Therefore, it is recommended to only lower the fertilization in the less productive zone to reduce the nitrate residue after harvest without affecting the yield.

These findings are in line with the conclusions of Basso et al. (2013), who observed the influence of the amount and distribution of rainfall on fertilization recommendation. In addition, Robertson et al. (2007) concluded from their study on grain production in Western Australia that variable rate fertilization is only beneficial if the field zones are temporally consistent in their performance, which in this study was only the case for the Kortenaken field.

Some researchers try to link the yield uncertainty and fertilizer recommendation to the inter-annual climate variability. For instance, crop models (e.g. STICS) help to address climatic uncertainty, as they allow to include the influence of a climatic variables on the cropping system (Dumont, 2015). This approach is quite complex and requires a lot of data for calibrating and validating the model, limiting its adoption. Therefore, NDVI series of previous growing seasons could be a good alternative for identifying the fields with stable management zones. In such fields, precision fertilization could allow to reduce the environmental impact of crop production without compromising the yield.

Conclusion

Management zones were identified in three Flemish fields based on soil maps and historical NDVI profiles. In these zones, the effects on the yield and nitrate residue of increasing or decreasing the N fertilizer dose was investigated with field trials. The field trial results indicate that precision fertilization outperforms the conventional practice in the fields with temporally stable management zones. In the fields having differences in the physical soil properties (e.g. presence of stones or clay particles etc.), which affect water availability, lower fertilization in zones with poor soil productivity potential could be recommended. In the fields where the performance of the managements zones changes between seasons, there is a risk of incorrect implementation of the precision fertilization concept and the conventional practice of homogeneous fertilization remains the recommended approach.

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