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Optimization of Agricultural Fertilization Strategies based on Meteorological and Edaphic parameters: Analysis of Site-Specific Geoinformation to Support Decision Making

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Abstract. Within the framework of the project "StaPrax-Regio", Nitrogen-(N)-fertilization strategies will be developed aiming at the minimization of emissions of N into the environment (groundwater, air) due to non-availability for the crops. The consequence of such strategies is an improved absorption of N by the crops, instead of its loss. Meteorological and edaphic, as well as other factors play an important role to find out the optimal fertilization practice at a specific site. Most of the data to be considered is spatial which leads to the conclusion that GIS is an adequate means to support data analysis and, finally, decision making. Results can be visualized cartographically and maps can serve as means to support the finding of optimal practices for specific locations by farmers, agricultural consultants, scientists, and other stakeholders. The paper presents some first insights from project work in progress.

Keywords. Fertilization, Agriculture, GIS, decision making

1 Introduction

The project "StaPrax-Regio" started in 2021 and is aimed at the optimization of fertilization strategies in agriculture with a focus on Nitrogen (N-) fertilizers. Fertilizer nitrogen produced by the Haber-Bosch method using fossil fuels has played a key role in improving global food production, however, Nitrogen (N) in the form of nitrate is a common pollutant in both surface and ground waters [1, 3]. Unfortunately, less than half of the > 100 million tonnes of fertilizer N currently consumed by agriculture each year is assimilated into the aboveground biomass of crops [2]. While some fertilizer N will also be recovered by roots, much of the remainder is either leached or lost as environmentally harmful gas emissions [3]. The ultimate aim of the project is to achieve better plant availability of N-fertilizers on the one hand, and, as a consequence, to minimize harmful losses of N threating surface and groundwater, and the air, and in such a way, the climate. Nitrous oxide and ammonia are highly effective greenhouse gases which is part of the fact that agriculture accounts for 16 to 27 % of human-caused climate warming emissions [4,5]. Reduction of such emissions is one major topic concerning more efficient N-fertilization practices.

Within the project StaPrax-Regio highly efficient N-stabilized fertilization strategies will be identified under specific consideration of meteorological and edaphic parameters. The aim is to improve consultancy on fertilization strategies, thus using technologies such as Geographic Information Services (GIS) [1,6]. GIS can be applied to study the different statuses of nutrients in a field. This enables farmers to reach a specific requirement for the external application of nutrients, thus helping to combine computer software modelling analysis with site analysis for a conclusive interpretation of varying outputs and inputs [6]. If decision making concerning fertilization can be optimized because it is supported by more comprehensive spatial information compared with current practice, positive environmental outcomes are expected. Among other goals the minimization of N-losses that occur through gas emissions (nitrous oxide, ammonia) is primarily important. An optimization of N and an advancement of root development of crop plants is included here. If such a goal can be achieved, a significant larger amount of N-fertilizers can be absorbed by the crop plants instead of being leached into the environment without any positive effects for the crops, as it was mentioned before.

The research in StaPrax-Regio is primarily focused on the question of how short-term meteorological events, as well as the specific soil conditions in different regions have influence on the capability of crop plants to uptake N. However, new fertilization types include inhibitors that lead to longer availability of the fertilizer in the soil layers where roots of crops grow. In such a way they foster a better plant availability. But still the meteorological conditions, as well as soil properties and other factors play an important role and must be taken into account in particular. Due to the fact that the project has been started a year ago, the results so far are not the envisaged ultimate strategy recommendations. Hence, they represent some thoughts on approaches that will possibly support the achievement of the planned goals.

2 Spatial data to optimize fertilization strategies

2.1 Basic considerations

Considering the background introduced before, new strategies are investigated in StaPrax-Regio. They include the usage of spatial data, especially soil-, weather-, land cover-, and other spatial parameters aiming at achieving a comprehensive characterization of the local sites where crops are cultivated, thus considering these location specific parameters sophisticatedly in the fertilization strategy.

To achieve the mentioned goals, apart from a large producer of N-fertilizers (SKWP Piesteritz Ltd.), the German Weather Service is partner in the project. It carries out measurements at more than 60 different sites in all relevant landscape types of Germany. This leads to local data on precipitation, air and soil temperatures, soil humidity, and others.

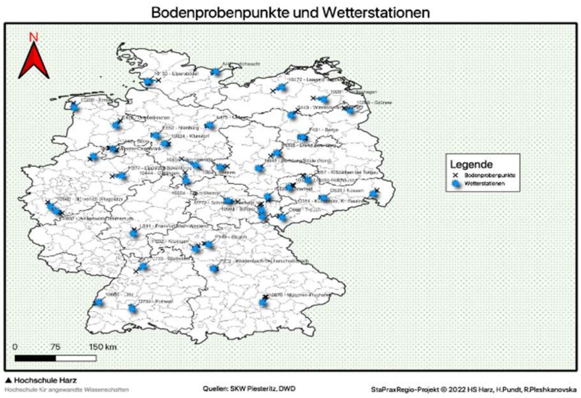

Figure 1: Weather stations with relevance for soil data sampling sites in StaPrax-Regio

This information is complemented by phenological data because phenology plays an important role concerning the growing stage of crops. Furthermore, soil data is provided digitally by a state's agency, the Geological Service of Saxony, who is also partner in the project consortium, and similar agencies in the other federal states of the country.

Weather-, phenological-, soil-, and other information will be collected and presented using the StaPrax-Regio Mapserver. First maps have been produced using QGIS, aiming at integrating different data types from the different sources that are relevant for the project. Such basic maps that result from various overlays of different data layers lead to insights into local conditions and therefore they serve as input for decisions on adequate fertilization strategies. Figure 1 represents weather stations and soil sampling sites with relevance to the StaPraxRegio-project.

The inclusion of GIS analysis and cartographic representation of results is seen as a probate means to provide a comprehensive and integrated view of local, site specific conditions of various parameters in view of the optimal fertilization practice. Maps should support farmers and consultants by representing the status quo, potential developments, the limitations and challenges that are given in a specific location. This should be done in different time periods and on the basis of daily, weekly, monthly, and yearly periods. It is required to consider properly the dependences of the mentioned parameters and the varying fertilization strategies. The comprehensive perspective on all relevant parameters is expected to contribute significantly to the optimisation of fertilization practices. Figure 2 gives an example of the StaPrax-Regio Mapserver which has just been implemented to provide relevant data to project partners.

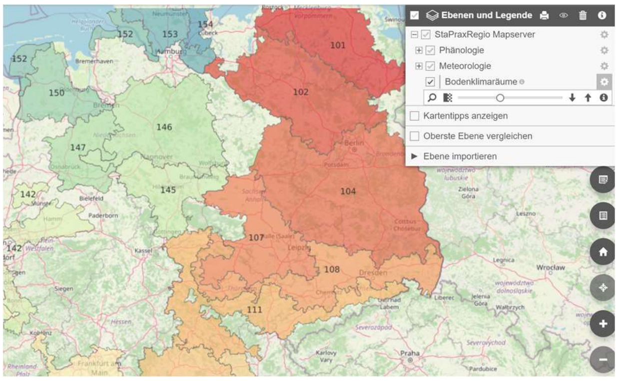

Figure 2: First version of the StaPrax-Regio Mapserver

2.2 Methods to support decision making

The GIS-based approach followed in StaPrax-Regio is based on the capabilities of GIS to support decision making. In such a sense a GIS can become a Spatial Decision Support System (SDSS) as it has been already discussed and described by, among others, Densham et al. [7]. These authors stated that SDSS have been developed to address ill-structured problems with spatial query, modelling, analysis, and display capabilities. Densham et al. explain a mismatch between the widespread single-user model of GIS and SDSS use and the group-based approach to decision-making that is often adopted when semi-structured problem-settings are addressed. This kind of problem is addressed to a certain extent within the StaPrax-Regio project. It is well known that meteorological and edaphic, as well as other factors, play an important role for the correct application of fertilizers on the one hand, but the detailed consideration of each parameter and its exact and balanced effectiveness is often not totally clear on the other hand. Within the framework of SDSS this can be interpreted in the sense that the group-based approach relates to the need of considering different contexts for spatial decision making. In other words: there is no one and single "correct" fertilization strategy for a specific crop due to the varying spatial contexts that have to be taken into account. It has to be analysed in detail during the project, if a concept such as "agricultural response units (ARUs)" could be established in analogy of "hydrological response units". Such ARUs would deliver possibly equal or similar responses to the fertilization strategy that was decided to be adequate in a specific region or at a specific site. But this is still an open issue. Concerning the decision-making process, Densham et al. came to the conclusion that SDSS-based spatial analysis and display methods must be used to generate, evaluate, and illustrate the strong and weak points of alternative scenarios and come to a consensus about how to proceed toward a decision. This means that an SDSS can occur in various forms, aiming at helping decision makers in developing improved decisions [8]. These authors found even more reasons for the necessity of such "group-based" approaches toward SDSS, e. g. the fact that complex spatial problems often have multiple, conflicting objectives for their solutions and that a solution, to be acceptable by all actors, must reconcile these conflicting goals. This is also a reason to strengthen the issue of multi-contextual views of one and the same problem setting. Many problems occurring in practice are still solved in a one-dimensional ("single-user") manner and they tend to solve them in a piecemeal way, instead of using an integrated approach. Such an integrated approach requires strongly the usage of timely-based meteorological data, as well as soil data such as type, humidity, soil texture, pH, cation exchange capacity, and others, and information on the fertilizer itself that is potentially used.

The multi-contextual view of fertilization problems leads to what is called an approach to "holistic problem-solving". It represents the result of inter- and/or transdisciplinary cooperation of relevant actors [9, 10]. "Holistic decision-making" also means to consider as much relevant, and multi-perspective, information as possible during all steps of the decision-making process, aiming at achieving sound decisions. Sound is meant in the "tangible sense of honoring the whole situation, minimizing unintended negative consequences" [11]. From a GIS perspective, holistic means that as many relevant datasets, and considerations of different actors, as possible are taken into account [12].

2.3 Decision trees as first step towards multi-contextual decision making

During project meetings different approaches for modelling adequately the integration of the mentioned data were discussed. As one approach decision trees have been identified. Decision trees are structured approaches to the decision making process. They help to form a balanced picture of the risks and rewards associated with an event [13].

Furthermore, tree based models split the data multiple times, mostly according to certain cutoff values in the features. Through splitting, different subsets of original datasets are created, with each instance belonging to one subset. Such trees can be used, e. g., for classification and regression [14].

Decision trees have been used in agricultural decision making and concerning fertilization strategies in the past with success. To give only one example, Chogoule et al [15] describe the usage of decision trees to support nutrition management of grapes. From such a decision tree, the corresponding algorithms can be deviated. The authors try even to set up an ontology based on the decision tree. The next figure shows exemplary a decision tree, as presented in [15].

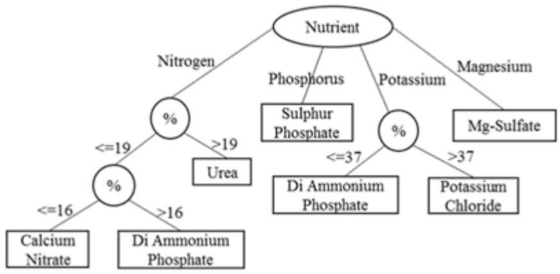

Figure 3: Example of a decision tree for nutrition of grapes [15]

It is expected that decision trees can help within StaPrax-Regio to understand and structure different alternative decisions that could be followed under consideration of varying meteorological and edaphic input parameters. According algorithms can be used as input for a GIS-based approach, thus integrating the different datasets and producing results that can be presented by maps. Map-based visualisations of alternative fertilization scenarios, however, can help to discuss and finally decide on the most adequate fertilization strategy at a specific site.

3 Third mission approach on new agricultural practices

The partners within the project, especially the experts of the company that produce N-fertilizers including the above mentioned inhibitors, the weather service, the geological survey and the GI-scientists from university work closely together aiming at achieving the mentioned goals. New fertilization strategies identified in the project under usage of GIS-produced maps will be evaluated and possibly tested not only by the project partners, but together with practitioners such as farmers and agricultural consultants.

The next figure shows the agricultural test areas relevant to the project, overlaid by the official digital soil map [16] out of which the relevant areas were cut beforehand on the basis of the coordinates of soil sampling points.

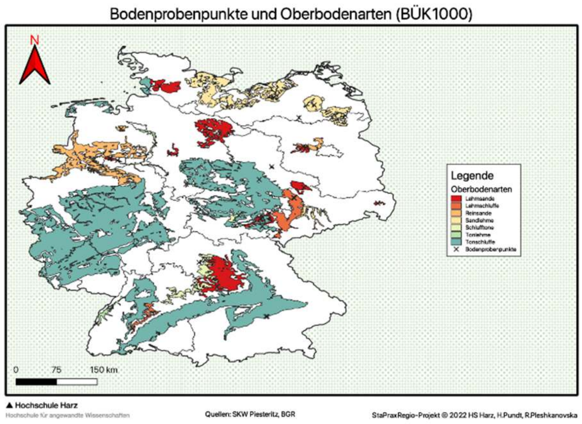

Figure 4: Test sites where weather stations, soil sampling sites are situated on specific soil type

The current project year is dedicated to collaboratively develop decision trees that integrate the different data types in a way that lead to alternative solutions on fertilization practices. The decision trees will serve at least as a model to understand and analyse the data. The analysis results, however, are envisaged to be visualized cartographically as a means to support final decision making.

The paper will give an overview of the project StaPrax-Regio. It will foremost focus not on the biochemical, but on the data integration part, the analysis of the underlying spatial datasets and their visualisation aiming at supporting decision making to achieve highly efficient N-fertilization practices in order to support more sustainable and environmentally friendly agricultural practices.

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