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# The Maps for Precision Fertilization, Manuring and Liming - Requirements for their Preparation. A Case of Poland

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*Abstract-* Fast development of precision agriculture in last years requires detailed maps for precise application of lime, manure and mineral fertilizers. Two kinds of maps are required: a general, base map, and application maps of a particular inputs. The general base map should contain management zones, resuming all factors affecting field management and fertilization, such as the water bodies, trees and windbreaks in direct neighborhood of the field, field topography, soil texture to a depth of about 1m, organic matter content, overall assessment of moisture/drainage conditions on the field and other factors, which may affect field management in long-term period. The application maps regarding a particular applications of lime, manure and mineral fertilizers should be prepared using the current results of soil analyses and the base map before each input application. Variable N application during crop vegetation should take into account also the weather conditions in a period preceding the application and current canopy N status or yield predicted in a particular vegetation period. The scale/resolution of the maps for precision agriculture should be concordant with the technical possibilities of the equipment used for application of various materials on a particular farm.

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## I. Introduction

During last few years fast development of precision agriculture has been observed. It results from the interest of farmers to optimize their production, new farm equipment and software available and online services dedicated to precision agriculture.

The main purpose of a precise field and crop management is an optimal utilization of inputs in particular parts of the field. These inputs comprise not only different substances applied to soil (fertilizers, manures, amendments, some pesticides) or over crop canopy (pesticides) but also amount of seeds or other sowing material and fuel, which use is affected for example by a tillage depth and other inputs. This paper is focused on variable lime, manures and fertilizer application using precision agriculture techniques. For example, fertilizers should be applied in greater doses in field zones with higher yielding potential and in smaller doses in field zones without potential to obtain high yields, if both zones have the same status of nutrients availability. However, sometimes the same soils may have high yielding potential in wet years and low yielding potential in dry and vice versa (Delin and Berglund 2005). A proper establishment of variable doses of fertilizers and similar materials within a field combine two aspects: economic and environmental. The optimal use of production means – only dose and time, when they are actually to reduce crop production costs. The application of inputs at right dose and at the right time also results in avoidance of excessive use of the inputs, which could contribute to soil degradation or soil, air and water pollution (Anonymous 1991, Duer et al. 2004).

A great variability of crop yields and soil properties, even within one field and at small distances is frequently found in Poland (Koćmit and Podlasiński 2002, Podlasinski 2013, Usowicz et al. 2004) and other countries (Lucas et al. 2009, Czech Republic). For this reason preparation of large scale, detailed soil maps is needed for precision field and crop management purposes.

The present paper has the aim to discuss requirements, which should be fulfilled by detailed soil maps and about the possible sources of data for these maps preparation and which are available in Poland.

## II. Requirements, which should be Met by Maps for a Precision Fertilization

*a) Map content*

The content of a map depends on the purposes of the creation of a such map. The maps used for precise manuring or liming in a particular year or even at a date, should contain, above all, the doses of material to be applied in particular place. However, depends on many factors (Table 1). A field topography is one of the factors affecting fertilization indirectly, because it influences movement of water – not only on a field surface, but also a subsurface run of water in soils with a finer subsoil. Such water movements cause also translocation of nutrients applied with fertilizers, mainly nitrogen (N) and potassium (K), but also others. For this reason it should be considered to increase doses of fertilizers in higher parts of the field and reduce these doses in lower parts. The field surroundings also certain importance in the application of fertilizers and manures. First, the open water bodies adjacent to the field limit

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manuring and fertilizers applications (DEFRA 2009, Duer 2004). Trees close to the field borders in a form of windbreaks or forest cause reductions of yield in their nearest proximity, within a distance approximately equal to the half of their general effect on crops grown at quite greater distance is positive (David et al. 1994, Jakubczak i Wołk 1977). Doses of fertilizers should be reduced in the nearest vicinity of forest or windbreak.

The dose of lime is determined by soil pH and buffer properties, which are determined mainly by soil texture and soil organic matter (DEFRA 2010). Common recommendations of lime doses in Poland take into account pH values and simplified classification of soil texture according to the content of soil particles finer than 0.02mm (IUNG 1990, Jadczyszyn et al. 2010).

The manure, as conventional fertilizers, if applied in excess, may be a source of pollution of surface water and groundwater (Moshia et al. 2014). On the other hand farmyard manure and other organic materials may consist an effective amendment to improve majority of properties and productivity of degraded soils (Mercik et al. 2004a, b). They slightly increase pH of acid soils (Mokolobate and Haynes 2002, Narambuye et al. 2008, Stępień et al. 2004a, Whalen et al. 2000), organic matter content and availability of nutrients (Mokolobate and Haynes 2002, Stępień et al. 2004a, Whalen et al. 2000). As consequence, the places and doses of manure application should consider the risk on environmental pollution, i. e. the distance to surface of water bodies, soil drainage capacity, groundwater level, and potential yields, to avoid excessive nutrient application. On the other hand, the applications of maximum manure doses admitted by the law or more frequent applications should be considered in places without a risk of environmental pollution and with different constraints for crop production, which may by amended or alleviated by addition of organic matter. These constraints comprise low organic matter content, extreme acidity, places susceptible to shortage of water (e. g. sandy field areas) and/or susceptible to waterlogging (fine soils). Also a depth of manure application may depend on local soil conditions, for example it should be deeper in more sandy soils.

The doses of P and K, but also N fertilizers, if applied before sowing or planting should be based on crop nutrient demand, which depends mainly on crop potential productivity in particular site and current soil fertility status – i.e. the content of available forms of particular nutrient in soil. Crop productivity worldwide is limited mainly by supply of water (Mueller et al. 2010), especially in rainfed agriculture. The main factors affecting plant water supply at field scale is surface and subsurface soil texture to a depth of about 100cm, field topography and organic matter content.

The doses of N applied during crop growth are also determined by crop demand, depending mainly on soil productivity in particular sites. However, the soil productivity is frequently not the same across years (Delin and Berglund 2005, Singh 2016). Some sites, especially with coarse (sandy or gravelly) soils have generally low productivity, but in some years with exceptionally favourable distribution of precipitation may be very productive. As opposite to this, some sites with fine soil or with strong increase of clay in subsoil, located especially in flat and low parts of the field have drainage problems. Such sites are characterized by low or even null productivity in wet years, but might be the most productive in dry years. For this reason, the N doses should be modified according to weather conditions in a particular year. For example, during the wet years, the N-doses should be increased in the places with good drainage and reduced in places of being in danger of water logging. Opposite modifications of N doses should be performed during dry years. Currently, the main factor modifying N doses, within fields, during crop growth is canopy N status, assessed by the use of various optical sensors. The current crop N status is determined by both soil properties and weather conditions in the time preceding N applications. However, the prescription of a variable N-rate based only on crop status, expressed by NDVI (Normalized Difference Vegetation Index) reading and without a direct consideration of soil variability did not produce consistent, positive and strong effects on grain yields (6-8.5t/ha) of intensively managed winter wheat in northern Poland (Samborski et al. 2016). It indicates, that the N-prescriptions during vegetation must be based on combination of various criteria such as canopy status, soil maps indicating areas with problems with both excessive and poor drainage, yield limiting factors and estimated yield potential in a particular year due to weather condition in the period preceding N application.

The analysis of the Table 1 and above considerations allow to draw a conclusion, that precise applications of lime, manure and N, P and K fertilizers require maps with doses prescribed for each of the inputs separately. However, precise base maps of so-called management zones (MZs) are even more important than application maps. The delineation of these MZs should not be based only on potential yields (Blackmore 2000, Diker et al. 2004, Moshia et al. 2014), but on all important factors affecting crop productivity, directly interacting with materials applied to soil and the environmental risk of excessive input applications. These factors include presence of open waters in areas adjacent to a field, groundwater level, field topography, and soil properties relatively stable in time, such as texture of topsoil and subsoil, drainage conditions (actually – determined by topography, soil texture and groundwater level) and organic matter content. It might be noted, that almost all these factors can be derived from agricultural soil maps at a scale of 1:5000 and

1:25000, comprising the whole agricultural area of Poland (Terelak and Witek 1995, Bednarek et al. 2011). These maps were made about 40 years ago and their content not always reflects the current status of the fields (Koćmit and Podlasiński 2002, Podlasinski 2013, Stępień et al. 2016, Świtoniak et al. 2016), but may be a useful source of information about the field at the beginning of introduction of precision agriculture, before preparation of better maps with modern techniques. The detailed base maps might be prepared once for a longer time period comprising 10-30 years, if there is no any natural or anthropogenic change regarding field conditions during this time, such as flood, artificial draining, surface levelling, etc. Such maps should be considered, together with results of soil chemical analyses and used for preparation of detailed maps for precise application of lime, manure and mineral fertilizers.

*Table 1:* Main factors to be considered in precise application of lime, manure and N, P and K fertilizers

| Material applied | | Surroundings of field | Topography | Yield potential | Current crop status | Topsoil texture | Subsoil texture | Drainage conditions | pH | Organic matter content | Available (mineral) N | Available P | Available K |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lime | | - | + | - | - | + | ? | - | + | + | - | - | - |
| Manure | | + | + | + | - | + | + | + | + | - | + | + | + |
| Fertilizers applied before sowing or planting | N | + | + | + | - | + | + | + | - | + | + | - | - |
| | P | + | + | + | - | + | + | - | - | + | - | + | - |
| | K | - | + | + | - | + | + | - | - | - | - | - | + |
| N after planting or sowing | | + | + | + | + | + | + | + | - | + | + | - | - |

*+ factor is or should be considered in precision agriculture*

*- factor does not have to be considered*

*b) Map resolution/scale and quality (precision)*

Nowadays, the map resolution is of greater importance than the scale. This statement results from the fact, that current computer software permits to zoom in any existing image to the scale desired by the user. For this reason it is much more important to consider, what is a minimum field area to be shown on the map or simply map resolution. This field area should depend on: 1) variability of the mapped feature (recommended dose of lime, manure or mineral fertilizer) on the particular field and 2) resolution of the farm equipment and 3) resolution of methods used for mapping.

The changes of soil properties within one field may occur at very small distances, even of several meters (Koćmit and Podlasiński 2002, Lucas et al. 2009, Podlasiński 2013, Usowicz et al. 2004), and these could create a need of preparation of very detailed maps. However, the technical possibilities of variable application of particular input are more likely to determine the required resolution of application maps, than the variability of a particular soil property within the field. It would be rather unreasonable to prepare maps of greater resolution, than the working width of the input application equipment currently used or supposed to be used within next years on farm. Consequently, the required map resolution depends on a particular farm – mainly production scale and the area of fields to be fertilized. The working width of farm equipment depends on production scale and destination of machinery. For example, the working width of a tractor sprayer usually ranges between 6 and 50 meters and the working width of spreader used for lime, or mineral fertilizer application generally varies between about 4 to 40 meters. The applications of solid manures are generally performed by spreaders with working width of 2-20m. Except the working width of the input application equipment, it is important, how fluently and quickly the equipment may change the application dose. In case of spreaders and sprayers it does not occur immediately, but requires a distance of several meters. Probably, this distance is rather not significantly greater, than the working width of equipment. The technological progress in agriculture makes possible to design of machines applying different doses of inputs by different sections of a pneumatic spreader or sprayer at the same time. However, for now it can be assumed, that the required resolution of the maps prepared for precision agriculture purposes should be of a half to a full working width of machines used on a particular farm for spreading fertilizers. In other words, this resolution should be of about 5-30m

It is important to ask a question, if currently existing technologies make possible to create of field maps at this resolution. Certainly yes, however the technical possibilities of mapping soil properties may be limited mainly by costs. It is unreasonable to sample or analyse soil at dense grids, as mentioned above 5 or 15 meters, but currently existing technologies for proximal and remote soil sensing permit to map the fields with a higher resolution and at relatively low costs and to locate the places on the fields, which should be sampled more densely or more sparsely, depending on local soil heterogeneity. The main technologies, which may be helpful in a preparation of detailed maps for precision agriculture purposes, comprise mapping of yield, vegetation indices such as NDVI, and EC/ECa (electrical conductivity/apparent electrical conductivity on the farm Stępień et al. 2016). There are also many external sources of data, which may be available for farmers. The most important sources of such data may be images obtained from airplanes, drones and satellites. All these sources of images may provide useful data concerning field topography – derived from LIDAR and spectral data, which may be used for the calculation of vegetation indices. Some satellite data are freely available at the resolution which may be useful for precision agriculture, e. g. 30m in case of Landsat 8 satellite or 10m for Sentinel 2 satellites (Turner et al. 2015).

The last issue to be considered is the required quality of maps prepared for precision agriculture purposes. This should be understood rather in terms of a correct delineation of particular areas (MZs) on the map and internal uniformity of these delineations than obtaining of smooth map contours. Correct delineation of MZs, means, that their placement and extent on the map should be as close as possible to the field's reality, to assure adequate and precise application of fertilizers. In the author's opinion, the agreement between map and field should be greater than 90%. Although it may be very difficult to achieve on very variable fields and at low cost. However, only such maps will be a good base for a precise fertilization. On the other hand, if soil texture is considered as an example, it is not necessary to delineate each soil texture group on the map, as they are presented on a agricultural soil map (Stępień et al. 2016). It is rather recommended to map, in case of Poland, soil texture groupings based on the content of particles smaller than 0.02mm, and called "agronomical categories" ("kategorie agronomiczne" in Polish, IUNG 1990), because these groupings are considered in liming and K and Mg fertilizer recommendations (IUNG 1990, Jadczyszyn et al. 2010). As the fertilization/liming/manuring is supposed to be uniform within a particular MZ, this MZs should also be as uniform as possible, with minimum internal variability. In other words, the generalization of these maps should be strictly related to the possibilities – resolution of application – of the equipment used on a particular farm. The delineations present on the application map may include generalized spots of different soil, if their dimensions are smaller than the working width of machines used in the map.

## III. Summary

In author's opinion, precision applications of lime, manure and mineral fertilizers require 2 kinds of maps: a general base map, and an application map of a particular input. The general base map should contain so called management zones, resuming all factors affecting field management and fertilization. These factors should include water bodies, forests and windbreaks in direct neighborhood of the field, field topography, soil texture to a depth of about 1m, organic matter content, overall assessment of moisture/drainage conditions of the field and other relatively stable factors, which may affect field management in a long-term period. The maps regarding application of a particular input: lime, manure and mineral fertilizers should be prepared on the base of actual results of soil analyses and on the base map before each application. Variable N application during crop vegetation should take into account also weather conditions in the period preceding the application and current canopy N status, soil moisture yield predicted in a particular vegetation period.

The scale/resolution of application maps should be concordant with the technical possibilities of the equipment used for application of various inputs on a particular farm.

## IV. Acnknowledgments

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