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RECOGNITION OF SOIL HETEROGENEITY AS A BASE FOR THE STRATEGY OF SOIL SAMPLING

(Rozpoznanie zmienności przestrzennej gleby dla wyboru strategii pobierania próbek)

Introduction

Soil sampling is an important procedure to get information about the soil fertility status of agricultural fields to improve management operations and protect the environment from degradation or nutrient overload. Especially when these fields are large, different soil fertility situations may occur in reasonable spatial extents. The different soil fertility situations may be due to varying management operations, land use or ownership in the past, or a consequence of natural soil heterogeneity, or a combination of both. Soil fertility in production agriculture is mainly described by properties of soil nutrient status and soil reaction (pH value) of the topsoil, in relation to the soil texture assessment.

If plausible and reliable patterns in soil nutrient status occur and are of reasonable size, management operations could possibly be adjusted to them. Many farmers already do this by simply dividing the field according to the results of soil sampling, by treating specific areas with more care, or leaving out areas with high nutrient status from regular application. New technologies like site specific agriculture using DGPS[2] for localising the tractor on the field and computers controlling the fertilizer spreader may further facilitate this management approach in the future.

[1] The research was carried out while I was joining the PROLAND project from August 2004 till July 2005, in cooperation with dr. Tomasz Stuczyński and prof. dr. Mariusz Fotyma, both working at the IUNG, Puławy. One field on the farm of Mr. Święcicki's farm in Baborówko served as study area. The farm manager also supported the project financially by having the samples drawn and analysed in a commercial laboratory according to our plans, what is gratefully acknowledged. Further financial support by PROLAND project is gratefully acknowledged, also.

[2] DGPS is the acronym for differential global positioning system; 24 satellites in the earth's orbit are sending signals which a GPS receiver can receive and decode at nearly any place of the world. From signals of at least 3 satellites, a position can be calculated. However, the precision of the coordinates increases with number of satellites and their distribution at the sky. To further improve the localisation to reliable sub-meter precision, an independent differential signal is required.

However, to use the results of soil sampling and analysis, this sampling has to be based on an initial sampling strategy, that represents the spatial distribution of influencing factors for soil nutrient status. If areas, which are very different with respect to e.g. management history or soil quality, are mixed in one sample, the information obtained by analysing this sample is very difficult to interpret. Only if a sound approach of soil sampling is applied, the analysed values can be sensefully and reliably used for further management decisions.

Therefore, this paper will outline a theoretically based approach for improving the present system for decision about the initial locations for soil sampling. For this reason, soil fertility is understood as nutrient status and soil reaction of the top soil. I leave out further considerations regarding nutrient status of deeper soil horizons or water storage capacity in the rooting area. However, if factors important for the latter properties are known, the theoretical outline can be extended to this wider perception of soil fertility also.

This paper uses data from a field study, which was carried out on 80 ha with mainly sandy soils in Baborówko, near Poznań.

Present situation of soil sampling

At present, under Polish conditions soil samples on agricultural fields are taken in a more or less regular pattern, walking the field in the shape of a 'Z', 'W' or lying 'N', depending on the specific situation. If the field is larger than 4 ha, it is divided in smaller sub-areas, with the aim of having one soil sample for an area of at maximum 4 ha. The samples are then taken to a laboratory and analysed for soil texture, nutrient status and soil reaction. The results are assigned to the respective sub-areas of the field and used for documentation or further decisions. Although the spatial extent represented by one sample should not be larger than 4 ha, there is no regulation regarding the shape of the sub-area or the layout for walking to take samples on the field (Fig. 1).

The requirement to walk in certain patterns for actually taking the sample, as mentioned in the previous section, aims at getting a sample, that is representing the average situation. On the other hand, by requiring small sub-areas for large fields, it is obvious, that not the average situation of the whole field is the aim, but rather a spatially more refined result.

Because of this sampling approach, till now no explicit account is given for already known soil variability within a field. For nearly the whole Polish territory soil maps at a scale of 1 : 5 000 exist, showing soil suitability (kompleks), soil type (typ) and texture properties up to 1.5 m depth (podl1 - podl4). For the study area, a conventional sampling scheme would mix soil material from different soils in one bulk sample and therefore give a biased result (Fig. 2).

Looking on the results of different years, 4 of 17 sub-areas (i.e. 24% of the field) had changing texture results for different years. This is probably due to the way of soil

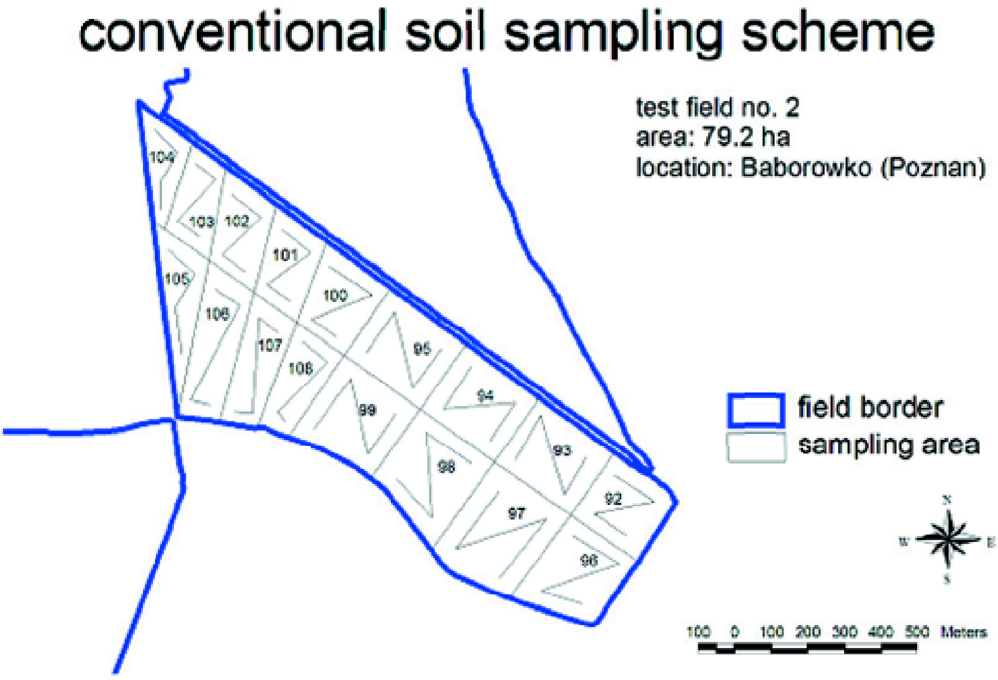

Fig. 1. Layout of standard soil sampling scheme for a 80 ha field near Baborówko, showing field borders, borders of subareas and possible walking transects for sampling (20-40 samples are taken on one transect and bulked)

sampling. As the walking transects are not defined spatially, every sampling period another transect might be walked. Resulting from this, other parts of the sub-area are sampled, and therefore the actual results are not comparable in the sense of changes of soil fertility status from period to period. Soil texture is an important parameter for arriving at the actual fertilising recommendation. Therefore, the sub-areas are treated differently from period to period because of sampling insufficiencies. Fig. 3 shows the Polish soil texture information for the study field, and the four sub-areas with changing results (red). Only one of the four cells shows reasonable variation regarding soil texture, therefore the reason for the changing results for the other three cells can not be answered by using this information. The figure shows additionally, that other sub-areas have reasonable differences in soil textures as well, and therefore represent different soil qualities, mixed within one sample.

Summing up this short overview of the recent situation of agricultural soil sampling and the results from our study field, the procedure applied at the moment is characterized by two uncertainties: (1) we do not know exactly, where a sample is drawn within each sub-area, and (2) we just can hope to get the main soil type within each

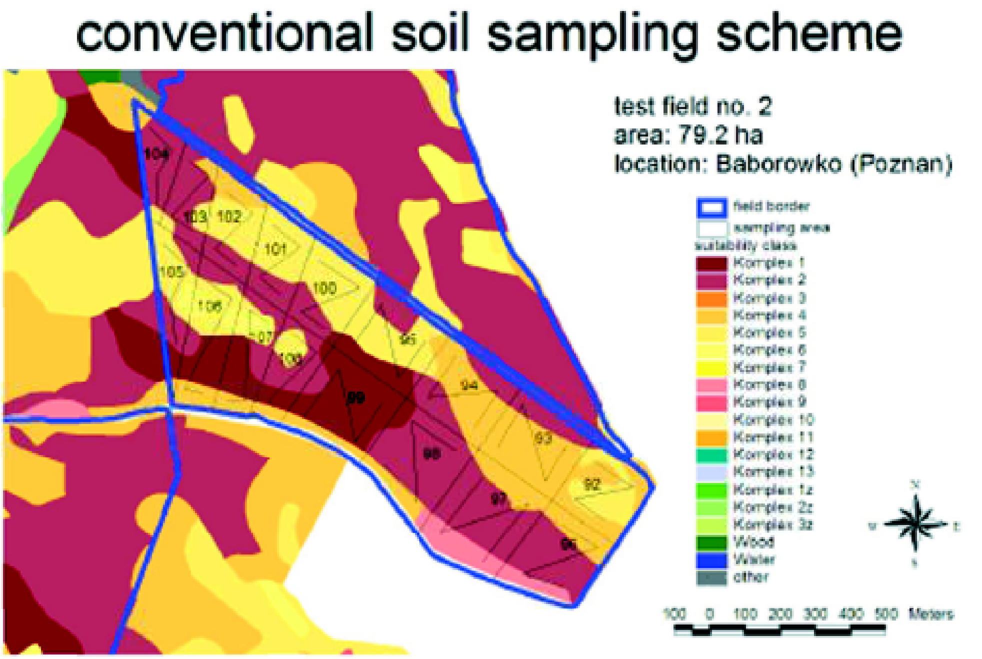

Fig. 2. Layout of standard soil sampling scheme for a 80 ha field near Baborówko, showing field borders, borders of subareas, possible walking transects for sampling, and soil suitability classes according to Polish soil map information

sub-area. However, it is highly questionable, whether an 'average' approach for categorical data like soil type or texture classes is reasonable at all.

Representativity

Because the purpose of soil sampling is to reflect or represent the specific situation on the field, the aspect of representativity is affected. When analysing the problem of representativity in relation to soil sampling of agricultural fields, it is helpful to theoretically differentiate between two of its components, the spatial component and the contextual component.

The spatial component answers the question „WHERE SHOULD WE TAKE THE SAMPLE?", and it takes responsibility for optimising the sampling in that way, that at 'every' location of the field a sample is taken. Because this is practically impossible, walking the field in a certain pattern while sampling should assure to get a spatially balanced sample, which is not affected by 'hot spots' or otherwise biased. The spatial component of representativity is assuring to have a reproducible average value for the sampled area.

The contextual part of representativity is not concerned with the spatial layout. The contextual part answers the question „WHAT SOIL SHOULD WE SAMPLE?",

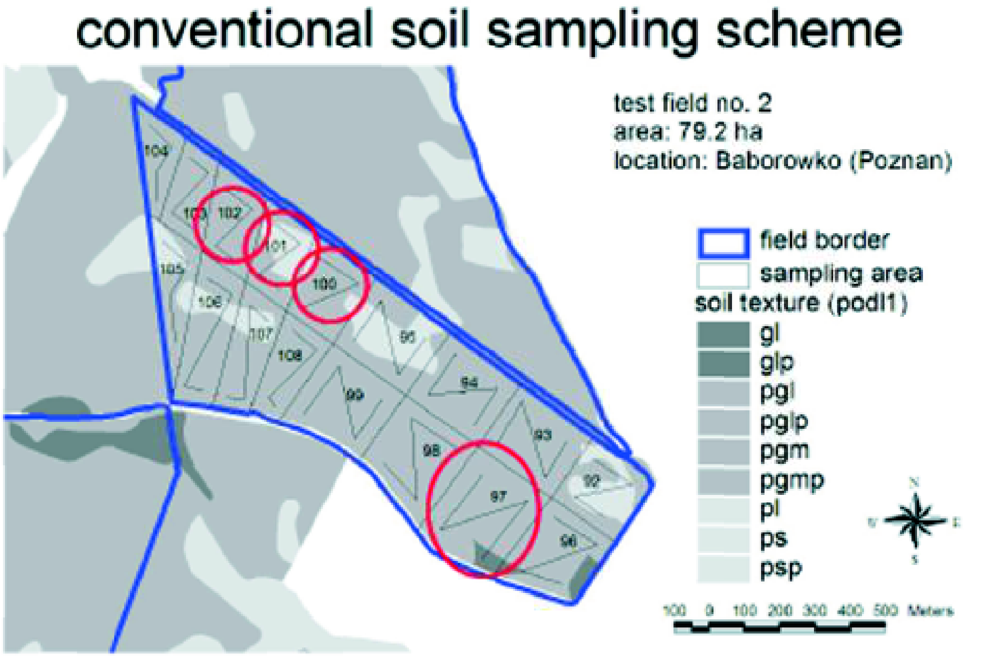

Fig. 3. Layout of standard soil sampling scheme for a 80 ha field near Baborówko, showing field borders, borders of subareas, possible walking transects for sampling, and soil texture classes according to Polish soil map information

and by this it assures that all relevant soil properties are sampled according to their spatial extent in the area. Therefore, the contextual component is assuring to have a senseful average value for the sampled area.

Integrating location and heterogeneity

The first above mentioned problem of uncertainty can be solved by using DGPS technology. If a DGPS receiver is used while sampling on the field, the exact walking transect is recorded and can be saved in a database, related to the specific farm. So, in every following sampling season for this field, the walking lines can be then loaded from the computer to a DGPS-device and used for navigating the sampling on the field. By doing so, every sampling period uses the same area of the field for creating a sample, which is analysed in the laboratory and used for further decision making on the farm. However, the inherent soil variability within one sample, and therefore the 'mixed' character of the sample   the second uncertainty mentioned above   is not avoided by this method.

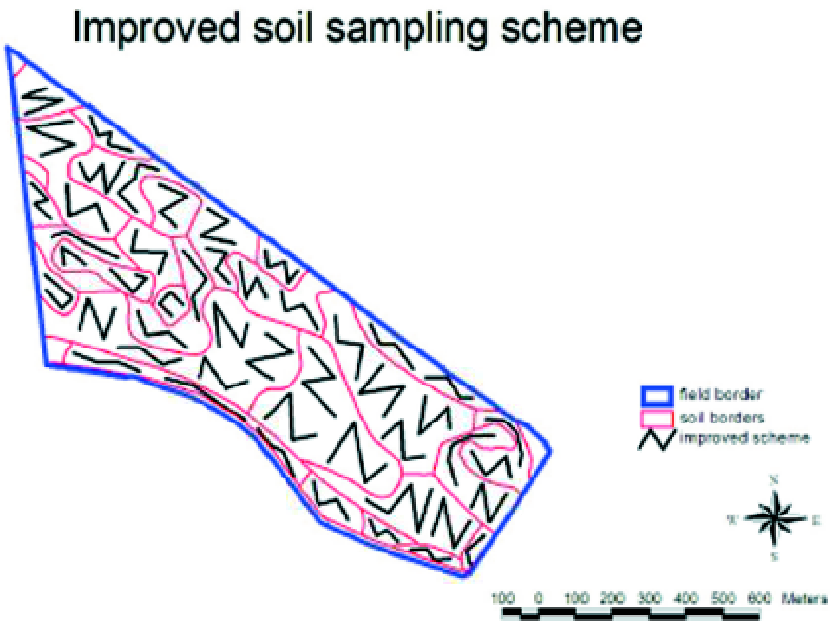

Fig. 4. Layout of improved soil sampling scheme for a 80 ha field near Baborówko, showing field borders, borders of soil polygons, and possible walking transects for sampling, applying a buffering operation of 15 m around all polygon borders (see text for details on the procedure; note that the number of samples is much higher than needed in routine sampling because of the research project)

To address this second aspect of optimised soil sampling, the Polish soil maps at a scale of 1 : 5 000 can be used to design a more specific sampling layout for the walking transects. Soil maps can be scanned and imported into a geographic information system (GIS)[3]. Using functions in the GIS, the soil boundary lines can be used to create better walking transects. First of all, the transects should be established in that way they do not cross any polygon border, because two different situations of soil quality would be mixed in one sample. Secondly, the polygon border lines can be used to create 'no go'-areas (buffer zones), regions of the field that should not be sampled, because they are close to the polygon borders. As every map has inherent uncertainties, the exact location of polygon boundary drawn on a map can vary within a scale dependent range. To my experience for soil maps in Poland at this scale, the buffer zones should be 15-20 to each side of the polygon border. The remaining area can be used to draw the sampling transects manually. The transects are then exported to a

[3] Geographic information systems are storing and managing spatial data like soil maps, field borders, topography, aerial photos or satellite images; using different layers of information offers many possibilities to analyse problems within a spatial context and get support for decision making.

portable DGPS receiver and can be used to navigate the sampling on the field. This procedure allows for much better certainty about the actually sampled soil type, using all knowledge, that is already available. Therefore, the mixing of two different texture types in one soil sample can be avoided to a large extent.

Number of soil samples

The former part of this paper dealt with the spatial optimisation of soil sampling. However, one might ask, how many samples are to be drawn with the proposed new method. In this part I want to propose a simple procedure for determining the necessary number of samples. These samples are then drawn manually into the map as outlined previously. I want to stress, that this proposition should be treated carefully, because only limited knowledge of standard soil variability could be included. Further research is necessary to improve the formula and make it applicable to a wider range of situations.

First of all, the number of samples depend on three different aspects: (1) the level of soil heterogeneity, (2) the legislation in the country, and (3) on the specific field history or the management concept, the farmer wants to apply. My proposition ad-

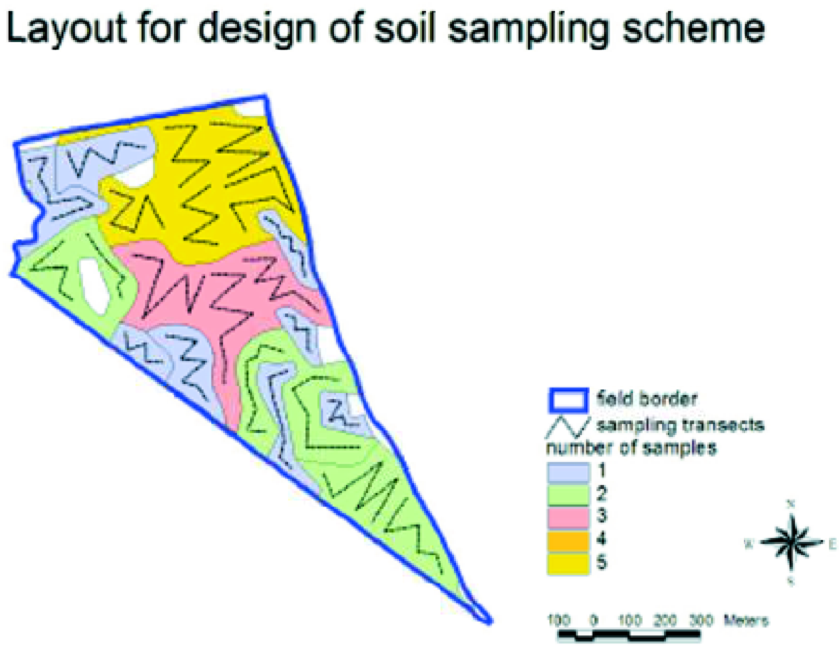

Fig. 5. Layout of improved soil sampling scheme for a 75 ha field near Baborówko, showing field borders, borders of soil polygons, and possible walking transects for sampling, applying a buffering operation of 15 m around all polygon borders and first and second rule for determining the numbers of samples in each polygon (see text for details on the procedure)

dresses only the first two aspects. The third aspect is too specific for each farm to be treated in a general way like in this paper.

Using the knowledge from the area near Poznań, the **first rule** for determining the number of samples is to take sample in every polygon, which is larger than one hectar. So at this stage, analysing the soil map with a GIS the operator can easily determine, which polygons of the field have to be sampled with at least one sample. This rule is taking into account the level of soil heterogeneity on the specific field.

The **second rule** says, that we should divide the polygon area of all polygons larger than four hectars by 4, and round the values to integers. This second number helps to determine, how many samples should be taken within each polygon. The value will be zero for polygons smaller than 2 hectars, and equal to or larger than 1 for the rest. As we have already given one sample to each polygon larger than one hectar by the first rule, we have to substract 1 from the result of the second rule. This second number is now the final result for each polygon at this step. The second rule is specific for the respective legal situation in the country.

If the farmer knows about specific problems in an area of the field or wants to have more samples to be drawn, than this knowledge has to be included separately and specifically for the situation (**third rule**).

Adding all three results gives the total number of samples for the whole field, and as well the number of samples for each specific polygon on the field. The following example will illustrate the idea of applying the first and second rule.

Assume, a field of 75 ha in the same region as our study field shall be sampled for soil analysis. The standard method would perform the operation 75 : 4 = 18,75, and therefore 19 samples should be taken from the field. However, the standard procedure does not give any idea concerning the location of the samples or the layout of the walking transects. Applying the proposed two rules leads the following way: the soil map analysis shows, that there are a total number of 22 polygons on the field and 13 of these are larger than 1 ha. Therefore, the first rule recommends to sample each of the 13 polygons at least once. Applying the second rule gives an extra of 9 samples because of some larger polygons in the field, that should have at least two samples one from rule one and a second from this rule. By this, we end up with 22 samples for the field, and a recommendation for the number of sampling transects within each polygon. The result for this field is shown in Fig. 5.

Although this number of samples might seem unfavourable, because 16% more samples mean increased costs for sampling and analysis, it should not be forgotten, that the standard sampling approach for the study field resulted in at least 24% uncertain results for the two compared years, what might be interpreted as 'useless' data. Keeping this result in mind, 16% increased sampling effort might worth to be accomplished, as the data has a higher level of certainty about really reflecting the situation on the field.

The proposed rules should be handled with care, especially regarding the first rule. More research is needed to analyse, whether there are landscape specific threshold values to determine the minimum polygon size to be included into soil sampling. As well, future research should concentrate on finding solutions and algorithms, that help determine the number of samples for specific agricultural management systems like e.g. site specific farming ('precision agriculture').

Conclusion

This paper describes the present situation of agricultural soil sampling in Poland and proposes some improvements for more reliable results. The idea is illustrated using data from a study field in Baborówko, near Poznań.

The present situation of soil sampling is insufficient and ineffective and may result in a high percentage of uncertain information. For the study field of 80 ha, 24% of the soil texture results between two sampling periods differed significantly.

The paper describes possible improvements in two steps:

1. using DGPS devices when walking on the sampling transects within the four hectar sub-areas,
2. integrating information about soil variability using the Polish soil maps at a scale of 1 : 5 000 in a GIS to derive at better locations for the sampling transects on the field.

The total number of samples can be calculated using two rules, that incorporate knowledge about soil heterogeneity and legislation. A third rule can adjust to the field specific situation. The resulting number of total samples per field may be higher than for the standard approach, but the information gained will be more reliable. Further research is needed regarding landscape specific threshold values for soil heterogeneity, and general approaches for new farm management systems like e.g. site specific agriculture.

Streszczenie

ROZPOZNANIE ZMIENNOŚCI PRZESTRZENNEJ GLEBY DLA WYBORU STRATEGII POBIERANIA PRÓBEK

Celem badania gleb jest pozyskiwanie informacji niezbędnych do określenia potrzeb nawożenia i wapnowania pól uprawnych. Trafność opracowywanych na tej podstawie zaleceń nawozowych zależy w dużym stopniu od tego na ile wyniki badania próbek odzwierciedlają rzeczywisty stan zasobności gleby, a więc od reprezentatywności próbek glebowych pobieranych do analiz. Na dużych polach próbki gleby pobiera się na ogół dzieląc badaną powierzchnię na części o podobnej wielkości i regularnych kształtach, najczęściej zbliżonych do kwadratu. Z każdej części pobierana jest jedna próbka, którą uważa się za reprezentatywną. Badania prowadzone na polu o powierzchni około 80 ha w okolicach Poznania pokazują jednak, że pobór próbek taką metodą, która nie uwzględnia naturalnej zmienności przestrzennej gleby może zniekształcać rzeczywisty obraz stanu agrochemicznego gleb. Przeprowadzone dwukrot-

nie analizy składu granulometrycznego gleby z tego samego pola dla 24% powierzchni dały różne wyniki. Wiarygodność wyników analizy można poprawić poprzez zastosowanie urządzeń do pozycjonowania satelitarnego (dGPS) w procesie pobierania próbek. Ułatwiają one bardziej precyzyjne wyznaczanie miejsc poboru próbek, co ma szczególne znaczenie w badaniach monitoringowych, tj. powtarzanych w czasie. Drugim sposobem zwiększenia rzetelności pozyskiwanych danych jest wykorzystywanie istniejących zasobów informacji o glebie do zaprojektowania schematu poboru próbek. Dla obszaru całej Polski informacja taka jest dostępna w postaci map glebowych sporządzonych w dużej skali.

W pracy zaproponowano stworzenie Systemu Informacji Geograficznej na bazie analogowej mapy glebowej i jego wykorzystanie do projektowania schematu poboru próbek, uwzględniającego przestrzenną zmienność gleb. Przedstawiono również procedury umożliwiające określenie koniecznej liczby próbek, którą należy pobrać z pola o określonej powierzchni.

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