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## Spatial variability of soil pH as influenced by different soil sampling methods and geostatistical techniques

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### Abstract

The aim of the current research was to assess the spatial variability of mapped soil pH data, obtained from soils of different types, as influenced by soil sampling methods and to evaluate the suitability of different geostatistical methods for the determination of acid areas.  $pH_{KCl}$  was measured in soil samples collected from three different sites, located in Elmininkai (155 ha), Daumanti kiai (55 ha) and Dapkūniškiai (73 ha). The following methods of soil sampling were tested: regular grid; soil sampling within the boundaries of prevailing soil group and texture; soil sampling within the boundaries of prevailing soil group and texture and in consideration of previous soil test results. Mapping of acid areas was conducted using *IDW*, *Simple Kriging* and *Simple Cokriging* interpolation methods. Soil samples were collected at 2 ha density.

Our research evidence suggests that the most accurate display of acid areas on the digital map can be obtained when soil sampling is conducted within the boundaries of prevailing soil group and texture and in consideration of previous soil test results. The less detailed display of acid areas was obtained when soil sampling was conducted within the boundaries of prevailing soil group and texture, and the least detailed display when soil samples were collected using the regular grid. As a result of interpolation of pH data using *IDW*, *Simple Kriging* and *Simple Cokriging* methods, the acid areas displayed on the digital maps were significantly smaller than those determined using the not interpolated pH data collected from the fields where acid soils comprised less than one fourth of the area dominated by slightly acid zones, and from the fields where not acid eroded soils intervene the acid zones.

We recommend collecting the soil samples for pH tests within the boundaries of prevailing soil group and texture and in consideration of previous soil test results. The pH data obtained using this soil sampling method may be interpolated employing *IDW*, *Simple Kriging* and *Simple Cokriging* methods only in the cases where acid soils account for more than 50% of the tested area – then the correctness of obtained interpolation results is satisfactory.

Key words: soil sampling, soil pH, interpolation methods.

### Introduction

The process of spatial mapping of soil pH is affected by several factors, the most important of them are soil sampling methods and mapping methods (Brodsky et al., 2004; Schirrmann et al., 2011). Soil samples can be collected from small plots selected in advance or using various transects; fields can be divided using regular grid, along the soil type boundaries and/or soil texture etc. (ISO 10384-1, 2002; Saladis, 2004; Flowers et al., 2005). As a rule, the soil sampling strategy is planned for the object to be tested before the soil sampling activities (ISO 10384-1, 2002; Paulauskas, Sabienė, 2009). Type of soil, relief, present and planned crops, results of previously con-

ducted soil tests etc. must be taken into consideration (Groenigen et al., 2000; Staugaitis et al., 2010). The areas to be limed are selected using the pH data maps, therefore acid areas should be displayed on the map precisely enough. If the pH data map is not accurate enough, some not acid areas could be limed, and some acid areas could be missed. On the long-run all this process might affect the plants as well as the further changes of soil pH (Franzen, Peck, 1995; Morales, Ferreira, 2009).

Spatial variability of soil pH displayed on the digital map depends on the way the pH data is calculated and presented (Flowers et al., 2005; Staugaitis

et al., 2010). Regular grid or soil type boundaries can be used as boundaries of pH group (Staugaitis et al., 2010). pH group boundaries can be successfully defined using the geostatistical interpolation methods – this approach has been popular for the last ten years (Brodsky et al., 2004; Webster, 2008). *Kriging* and *IDW* interpolation methods are widely used for interpolation of soil properties (Robinson, Metternicht, 2006; Webster, 2008; Krasilnikov, 2008; Wenjiao et al., 2009); *Cokriging* and some other methods are less popular (Kuzyakova et al., 2001). Geostatistical methods are very effective when soil samples for pH testing are collected using *on-the-go* technology. This automated system for *on-the-go* mapping of soil pH was developed and tested under field conditions by Adamchuk et al. (2007), Schirrmann et al. (2011). It involves automated soil sampling from the regular depth and uses the basic information on spatial variability of soil pH. In spite of the advantages, the geostatistical methods provide for mapping of such soil properties as pH and organic carbon, the variograms are not always suitable for analysis of specific data and first of all should be used for the development of hypothesis and for modelling (Krasilnikov, Sidorova, 2008).

The aim of the current research was to assess the effect of different soil sampling methods on the obtained estimates for spatial variability of pH in different

soils and to evaluate the suitability of different geostatistical methods for determination of acid areas. The following methods of soil sampling were compared: regular grid; soil sampling within the boundaries of prevailing soil group and texture; soil sampling within the boundaries of prevailing soil group and texture and in consideration of previous soil test results. Mapping of acid areas was conducted using *IDW*, *Simple Kriging* or *Simple Cokriging* interpolation methods.

## Research methods

Soil pH tests were conducted in areas with different relief and share of acid soils. Two sites – near Emininkai, Anykščiai distr., and Daumantiškiai, Ukmergė distr., represented rolling relief. Soil pH in these sites was tested in 2004. The share of acid soils in the sites was different: in Elmininkai approximately  $\frac{1}{4}$ , in Daumantiškiai more than  $\frac{3}{4}$  of the total area. The site near Dapkūniškiai, Molėtai distr., was selected as a representative of hilly relief; eroded and not eroded soils interspersed there. Soil pH in this site was tested in 2007.

Combination of three soil sampling methods with different mapping methods yielded 10 variants. The resulting experimental design is presented in Table 1.

**Table 1.** Research scheme

| Variant No. | Soil sampling method  | Determination of boundaries of acid areas                      |
|-------------|---|--|
| 1           | Regular grid<br>(method 1)  | Boundaries of regular grid                                     |
| 2           |   | <i>IDW</i> method  |
| 3           |   | <i>Simple Kriging</i> method                                   |
| 4           | Soil sampling within the boundaries of prevailing<br>soil group and texture<br>(method 2)   | Boundaries of soil group                                       |
| 5           |   | <i>IDW</i> method  |
| 6           |   | <i>Simple Kriging</i> method                                   |
| 7           | Soil sampling within the boundaries of prevailing<br>soil group and texture and in consideration of previous<br>soil test results<br>(method 3) | Boundaries of soil group and<br>previously determined pH group |
| 8           |   | <i>IDW</i> method  |
| 9           |   | <i>Simple Kriging</i> method                                   |
| 10          |   | <i>Simple Cokriging</i> method                                 |

The field was divided into regular tetragonal plots in variants 1, 2 and 3. The composite soil sample was collected from each plot along diagonal transect. Soil group and texture were not taken into consideration during the soil sampling. Boundaries of the regular grid were used for the determination of acid areas ( $\text{pH} \leq 5.5$ ) boundaries in variant 1. Boundaries of acid areas in variants 2 and 3 were determined after processing the collected pH data using the *IDW* and *Simple Kriging* methods respectively.

Soil samples were collected within the boundaries of prevailing soil group and texture in variants 4, 5 and 6. The soil group boundaries available in the digital map of Lithuanian data base Dirv\_DB10LT were transferred on 1:10000 scale maps before the soil sampling. The aforementioned data base contains in-

formation on boundaries of different soil groups and texture corresponding to the FAO classification. Soil samples were collected along the diagonal transects. The boundaries of soil group were used for determination of acid areas boundaries in variant 4, and in variants 5 and 6 the boundaries of acid areas were determined after processing the collected pH data using the *IDW* and *Simple Kriging* methods respectively.

Variants 7, 8, 9 and 10: soil samples were collected within the boundaries of prevailing soil group and texture and in consideration of previous soil test results (i.e. the boundaries of particular pH group determined during previous soil tests were taken into account). The boundaries of soil groups and soil pH groups available on the digital maps of Lithuanian data bases Dirv\_DB10LT and DirvAgroch\_DB10LT

were transferred on 1:10000 scale maps before the soil sampling. Diagonal soil sampling transects were drawn in a way ensuring the collecting of soil samples within the boundaries of soil group as well as of particular pH group determined during previous soil tests. The boundaries of soil group and previously determined pH group were used for determination of acid areas boundaries in variant 7, while in variants 8 and 9 the boundaries of acid areas were determined after processing the collected pH data using the *IDW* and *Simple Kriging* methods respectively. *Cokriging* interpolation method was used in variant 10, but here the collected pH data were interconnected with the data of previous soil pH tests.

All variants were treated in the following way: the composite soil samples were collected at 2 ha density; data on the planned soil sampling transects boundaries of soil group and textures, agrochemical properties of soil were prepared and compiled in a computer before the field activities. Then the data was transferred into a GPS device *Mobile Mapper 6.52* used for precision marking of soil sampling position (LKS-94) and ensuring the correctness of actual soil sampling transect.

One composite soil sample was made of 25 sub-samples taken from 0–20 cm soil layer. The composite soil sample was collected from approximately 100 m long transect. The collected sample was thoroughly mixed and a sample of 300 g was taken for laboratory tests. Soil pH was determined in 1 M KCl extraction – 50 ml of 1 M KCl solution was added to 20 g of soil and stirred for 1 hour.

The following grouping of pH was used in our research:  $\text{pH} \leq 5.5$ ,  $\text{pH} \geq 5.6$ . Soils with  $\text{pH} \leq 5.5$  are denominated acid; these soils should be limed.

The testing of soil pH was carried out in three objects located in different regions of Lithuania: the majority of soils are not acid in the region where Elmininkai object is located, Daumantiškiai object is in the region where approximately half of the soils are acid, and the region of Dapkūniškiai object is characterized by highly irregular pattern of distribution of eroded and not eroded soils.

**Elmininkai (Object 1).** 154.6 ha object is located in Anykščiai district, Elmininkai cadastral area. Relief is typical of the rolling plateau of Western Aukštaitija. *Gleyic* and *Calc(ar)ic Luvisols* (*LVg* and *LVk*) prevail with some slightly eroded areas and intervening *Eutric Gleysols* (*GLe*). Prevailing soil texture in the arable horizon is sandy loam and silt loam, in the subsoil – sandy clay loam, sandy loam and clay. Soil samples were collected on 14 10 2004; the area was occupied with winter wheat.

**Daumantiškiai (Object 2).** 55.4 ha object is located in Ukmergė district, Daumantiškiai cadastral area. Relief is typical of the rolling plateau of Western Aukštaitija. *Eutric Gleysols* and *Gleyic Luvisols* (*GLe* and *LVg*) prevail. Silt loam and sandy loam prevail in the Ap horizon, and in the subsoil – clay and sandy clay loam. Soil samples were collected on 23 06 2004; the area was occupied with perennial grasses of the second year.

**Dapkūniškiai (Object 3).** 73.4 ha object is located in Molėtai district, Dapkūniškiai cadastral area. Relief is typical of the hilly Baltic uplands. *Eutric* and *Dystic Albeluvisols* (*Abe* and *ABd*) prevail with intervening *slightly and moderately eroded Eutric Albeluvisols* (*Abe-el* and *Abe-em*). Soil texture in the arable layer is sandy loam with sandy clay loam, in the subsoil – loam, sandy loam and silt loam. Soil samples were collected on 12 10 2007; the area was occupied with perennial grasses of the first year.

An exception was made for the object 3 – the hilly relief of this object caused a high soil group and pH variation level even in short distance. Soil samples in variants 4, 5, 6, 7, 8, 9 and 10 in this object were collected from  $10 \times 10$  m plots instead of transect method. There were several areas in this object where it was impossible to separate the not eroded and eroded zones. As a rule, eroded zones are not acid, therefore the spatial pH distribution was mapped using the black-and-white coloured complexes of acid and not acid areas expressed in percent.

In order to determine the soil pH values in areas between the actual measurement points, we used three most popular methods of spatial interpolation: *IDW* from the deterministic group, *Simple Kriging* and *Cokriging* – from the stochastic group. *IDW* is an inverse distance weighting interpolation method; here the data points that are closest to the considered point are more important. The bigger the distance from this point, the lesser the significance of the interpolated data point.

*Simple Kriging* and *Simple Cokriging* methods are based on modelled semivariograms. *Simple Kriging* method uses one variable, and *Simple Cokriging* method uses two and more variables (Marcinkonis, Karmaza, 2008; Mozgeris, Dumbrasukas, 2008). We chose two variables for *Simple Cokriging* method in our research: soil pH values obtained from our research and soil pH values obtained from the previous soil tests. Application of *Simple Cokriging* method using the aforementioned two variables allows the spatial mapping of soil pH excluding the extreme pH values and improves coordination between the data obtained from the current and previous soil tests.

Spherical semivariogram was used in geo-statistical calculations carried out for evaluation of spatial autocorrelation (Vieira, Gonzalez, 2003). The following parameters were calculated:

nugget ( $C_0$ ) – semivariance when the distance between the points is vanishing and corresponds to the variability of values in the point that is not clarified by the spatial structure;

sill ( $C + C_0$ ) – indicates the maximum semivariance, this is the maximum height of semivariogram curve;

nugget and sill ratio ( $C_0 / C + C_0$ ) – indicates the spatial dependence of pH on the distance;

range (A) – distance between the points at which the spatial dependence occurs;

regression coefficient ( $r^2$ ) – indicates how well the model fits the semivariogram data. The re-

gression coefficient close to 1, the semivariogram model matches better;

residual sum of squares (RSS) – indicates how well the model fits the variogram data; the lower the residual sums of squares, the better the model fits.

*ERSI ArcView 9.3.1* programme with *Geostatistical Analyst* software package was used for interpolation and drawing the digital maps. Variograms were computed using *GS + 9.0* software programme (Longley et al., 2005; Robertson, 2008).

**Table 2.** Share of acid soils ( $\text{pH} \leq 5.5$ ) as affected by different methods of soil sampling and digital mapping of pH data

| Variant                         | Elmininkai      |        | Daumantiškiai   |        | Dapkūniškiai    |        |
|---------------------------------|-----------------|--------|-----------------|--------|-----------------|--------|
|                                 | % of total area | +/- ** | % of total area | +/- ** | % of total area | +/- ** |
| 1                               | 25.2            | –      | 50.5            | –      | 17.0            | –      |
| 2                               | 11.3            | –13.9  | 38.9            | –11.6  | 6.5             | –10.5  |
| 3                               | 7.9             | –17.3  | 31.7            | –18.8  | 1.5             | –15.5  |
| 4                               | 22.4            | –      | 79.3            | –      | 18.4            | –      |
| 5                               | 12.8            | –9.6   | 80.3            | +1.0   | 9.9             | –8.5   |
| 6                               | 8.8             | –13.6  | 100             | 19.7   | 9.5             | –8.9   |
| 7                               | 27.6            | –      | 78.7            | –      | 28.0            | –      |
| 8                               | 21.9            | –5.7   | 68.4            | –10.3  | 10.6            | –17.4  |
| 9                               | 16.7            | –10.9  | 78.7            | 0      | 3.6             | –24.4  |
| 10                              | 15.5            | –12.1  | 78.1            | –0.6   | 8.0             | –20.0  |
| $\bar{x}$                       | 17.0            | –      | 68.5            | –      | 12.6            | –      |
| Results of previous soil tests* | 20.0            | –      | 52.4            | –      | 28.2            | –      |

Notes. \* Elmininkai – data of 1993 was used, Daumantiškiai – 1992, Dapkūniškiai – 1991; \*\* +/- column indicates the respective increase/decrease of the share of acid soils.

from 7.9% to 27.6%. The largest share of acid soils (22.4–27.6%) was determined in the variants 1, 4 and 7. The difference between these three combinations of soil sampling and data mapping methods was small – 5.2 percentage units.

Spatial autocorrelation of pH data obtained from the Object 1 revealed the differences between the spherical semivariograms of actual pH values obtained using different soil sampling methods (Table 3, Fig. 1). pH values obtained from the neighbouring soil sampling spots varied more when soil sampling methods 2 and 3 were used, therefore the ranges here were similar – 2280 m and 2220 m. The calculated range for the method 1 (regular grid) was two times less. Values of semivariance, indicated by the range, were 0.592 and 0.564 for the methods 2 and 3 respectively and 0.290 for the regular grid method. Thus the variability of pH values obtained from the neighbouring soil sampling spots was less when the regular grid soil sampling method was used.

Share of acid soils was from 11.3% to 21.9% in variants 2, 5 and 8 (three soil sampling methods in combination with interpolation of data using *IDW* method). When soil samples were collected within the boundaries of prevailing soil group and of previously determined soil pH group the interpolated share of acid soils was 21.9% – that was similar to the result of not

## Results and discussion

Our research evidence suggests that spatial distribution of acid areas ( $\text{pH} \leq 5.5$ ) significantly depends on the methods of soil sampling and data mapping (Table 2).

**Elmininkai (Object 1).** According to the results of previous soil tests, approximately one fifth of total area was acid. Depending on the methods of soil sampling and data mapping used in the current research, the determined share of acid soils varied

interpolated data, only 5.7 percentage units difference. When soil samples were collected using regular grid or within the boundaries of prevailing soil group and the data was interpolated using *IDW* method, the share of acid soils was two times smaller. The spatial distribution of acid areas partially corresponds to the areas on the maps of not interpolated data, yet here the acid area boundaries coincide with the boundaries of regular grid or particular soil group, while interpolation using *IDW* method expresses the acid area as a dot in cases when there are not many enough  $\text{pH} \leq 5.5$  values in the array (Fig. 2). This is the reason why interpolation results in decreased areas of acid soils. Thus this interpolation method should not be used in the cases when the share of acid soils in the array is low.

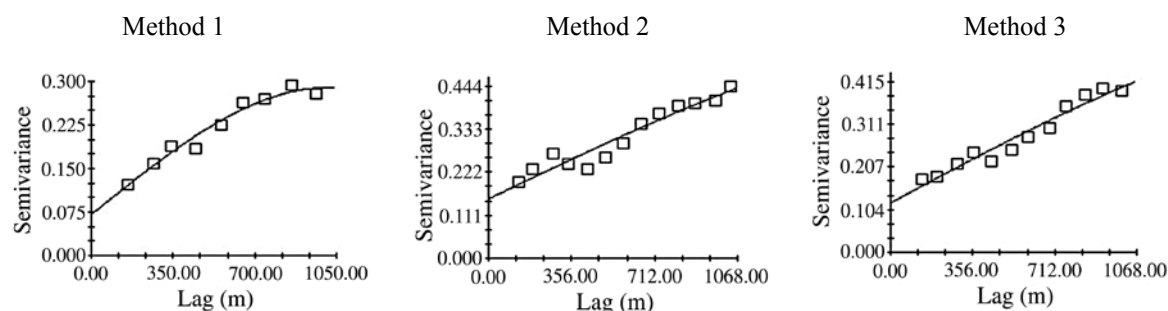
Share of acid soils was from 7.9% to 16.7% in variants 3, 6 and 9 (three soil sampling methods in combination with interpolation of data using *Simple Kriging* method). This percentage is significantly lower than the one obtained using not interpolated data, it is also significantly lower than the percentage obtained when the data was interpolated using *IDW* method. This difference was less when the soil samples were collected within the boundaries of prevailing soil group and of previously determined soil pH group – in this case the share of acid soils was 16.7%, the difference from not interpolated data – 10.9 per-

tage units. When the soil samples were collected using regular grid or within the boundaries of prevailing soil group, the calculated shares of acid soils were even more different from the ones obtained using not interpolated data – 17.3 and 13.9 percentage units, respectively. Thus interpolation using *Simple Kriging* method was not suitable for the Object 1. Similar opinions were expressed by Australian scientists Robinson and Metternicht (2006) considering different interpolation methods

(*Kriging*, *IDW* and *Spline*), who concluded that none of the interpolation methods gave reliable results necessary for soil pH mapping. But Chinese scientists compared the above mentioned classical interpolators to the new *HASM* (high accuracy surface modelling) method. *HASM* method evaluates sudden surface roughness, because it is more accurate than the classical methods (Yue, Song, 2008; Wenjiao et al., 2009).

**Table 3.** Parameters of spherical semivariograms of soil pH values obtained using different soil sampling methods

| Index                       | Elmininkai | Daumantiškiai | Dapkūniškiai |
|-----------------------------|------------|---------------|--------------|
| Method 1                    |            |               |              |
| Nugget $C_0$                | 0.071      | 0.031         | 0.016        |
| Sill $C_0 + C$              | 0.290      | 0.286         | 0.318        |
| Nugget/Sill $C_0/(C_0 + C)$ | 0.245      | 0.108         | 0.050        |
| Range ( $A$ )               | 1013       | 312           | 252          |
| $r^2$                       | 0.964      | 0.769         | 0.917        |
| RSS                         | 1.036E-03  | 6.031E-03     | 1.456E-03    |
| Method 2                    |            |               |              |
| Nugget $C_0$                | 0.153      | 0.016         | 0.065        |
| Sill $C_0 + C$              | 0.592      | 0.152         | 0.375        |
| Nugget/Sill $C_0/(C_0 + C)$ | 0.258      | 0.105         | 0.173        |
| Range ( $A$ )               | 2280       | 129           | 486          |
| $r^2$                       | 0.924      | 0.000         | 0.933        |
| RSS                         | 6.290E-03  | 6.402E-03     | 2.556E-03    |
| Method 3                    |            |               |              |
| Nugget $C_0$                | 0.120      | 0.070         | 0.190        |
| Sill $C_0 + C$              | 0.564      | 0.260         | 0.569        |
| Nugget/Sill $C_0/(C_0 + C)$ | 0.213      | 0.269         | 0.334        |
| Range ( $A$ )               | 2220       | 365           | 351          |
| $r^2$                       | 0.951      | 0.613         | 0.806        |
| RSS                         | 3.599E-03  | 5.327E-03     | 7.459E-03    |



**Figure 1.** Spherical semivariograms of soil pH values obtained using different soil sampling methods in Elmininkai (Object 1)

In order to mark the acid zone on the digital map, this method requires larger number of neighbouring  $\text{pH} \leq 5.5$  values. Single lower pH values surrounded by the higher ones are ignored by this method and regarded to be accidental, and actual pH values are modified.

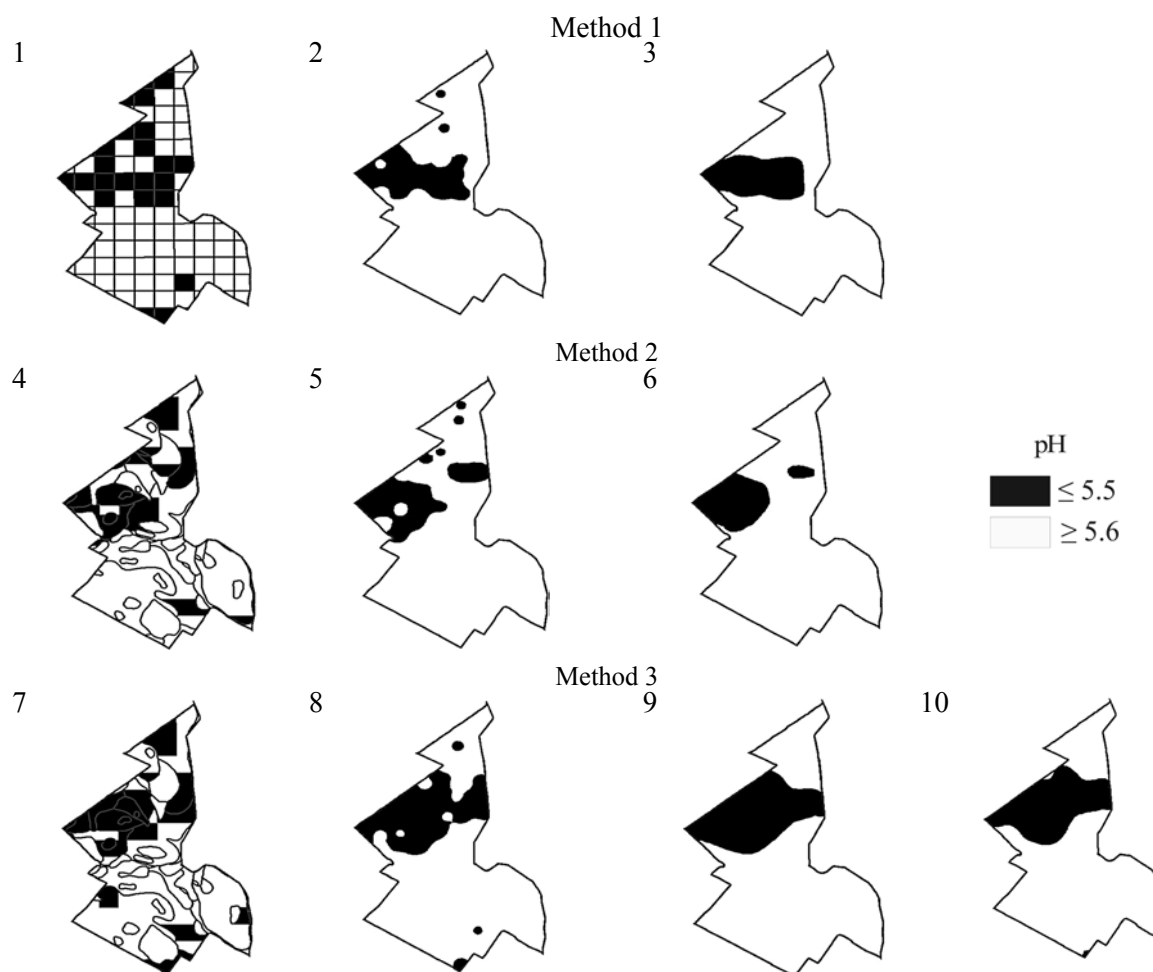
Share of acid soils was 15.5% in variant 10 (soil sampling method 3 in combination with interpolation of data using *Simple Cokriging* method); this is 12.1 percentage units less than the result obtained using the

not interpolated data. This method rejected the single lower pH values ( $\text{pH} \leq 5.5$ ). Interpolation using *Simple Cokriging* method was not suitable for the Object 1.

*Summing-up the research results for Object 1.* What were the reasons for the significant decrease of the share of acid areas observed in the cases when pH data were interpolated using *IDW*, *Simple Kriging* and *Simple Cokriging* methods? pH data matrix here was dominated by the pH values higher than 6.1, there were several values even higher than 6.5. pH values

indicating the acid soils were distributed within rather narrow range, from 5.1 to 5.5. This was the reason why the pH values calculated using the algorithms were higher, and because of that the share of acid areas was decreased. When the area of acid soils makes up to one

fourth of the array, the pH data interpolated using *IDW*, *Simple Kriging* or *Simple Cokriging* methods presents significantly smaller number of acid zones than the not interpolated data. This complicates the preparation of correct liming plan.



**Figure 2.** Spatial distribution of acid ( $\text{pH} \leq 5.5$ ) areas in Elmininkai (Object 1) as affected by different methods of soil sampling and digital mapping of pH data (1–10 – variant No.)

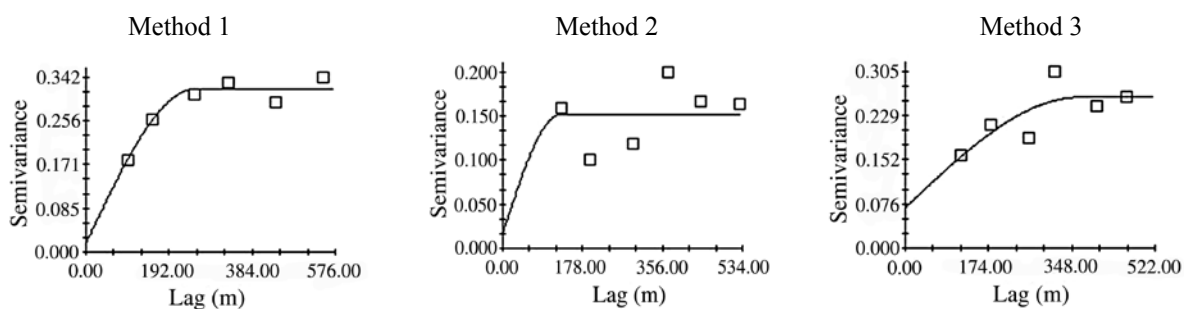
**Daumantiškiai (Object 2).** According to the results of previous soil tests, 52.4% of array was acid. On average for the methods used in the current research, the share of acid soils was 68.5% – the array became more acid. Depending on the methods of soil sampling and data mapping used the determined share of acid soils varied from 31.7% to 100% (Table 2, Fig. 4).

The share of acid soils ranged from 50.5% to 79.3% in variants 1, 4 and 7 (the data obtained was not interpolated). The smallest share (50.5%) of acid soils was determined when soil samples were collected using regular grid, 79.3% acid area share was determined when soil sampling was conducted within the boundaries of prevailing soil group and 78.7% – when soil sampling took place within the boundaries of prevailing soil group and of previously determined soil pH group. The difference between the latter two variants was only 0.6 percentage units; both variants presented the closest to reality display of acid areas in the Object 2.

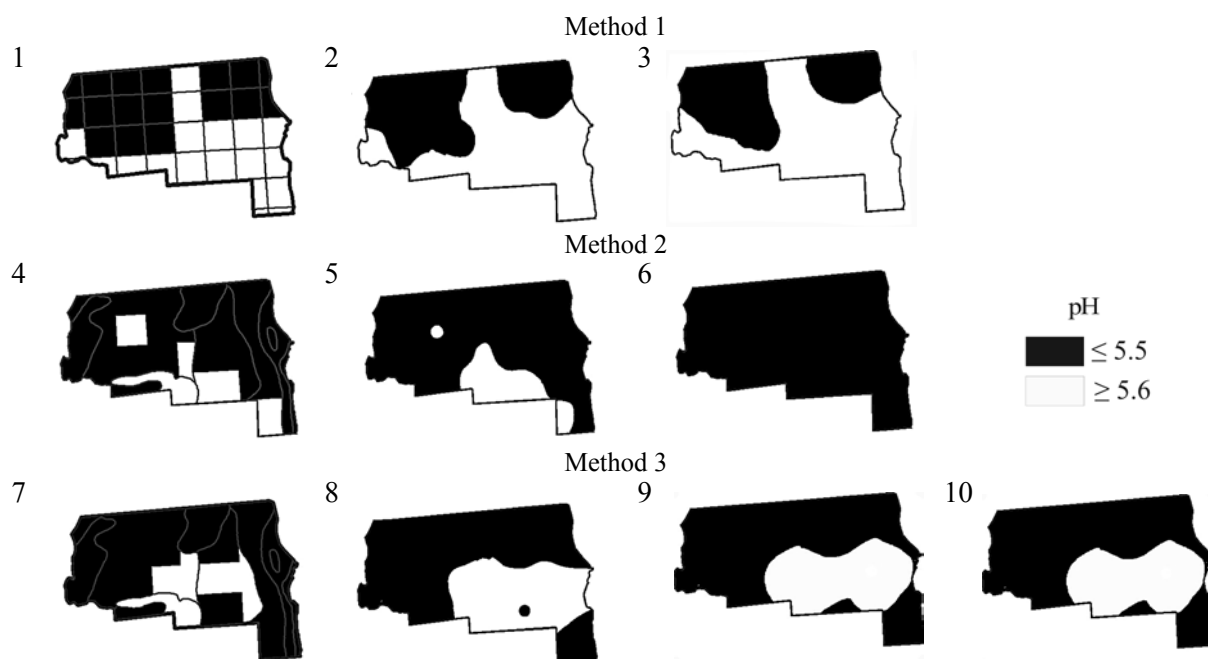
During the evaluation of spherical semivariograms (Table 3, Fig. 3) the spatial autocorrelation was not determined for the soil sampling method 2, because the calculated range was less than the distances between the points (lag, m). Due to this fact the interpolation of pH data using *Simple Kriging* method (variant 6) resulted in 100% share of acid area (Fig. 4).

Greater variation of pH data was obtained when soil sampling method 3 was used – the nugget and range ratio was larger than the one obtained when the soil samples were collected using regular grid. Thus the largest variation of pH data was determined when the soil samples were collected within the boundaries of prevailing soil group and of previously determined soil pH group.

Acid area share of 38.9% was determined in variant 2 (regular grid, data interpolation using *IDW* method). This share is almost two times less than the average for all variants. pH data matrix here was dominated by the pH values higher than 6.1, there were



**Figure 3.** Spherical semivariograms of soil pH values obtained using different soil sampling methods in Daumantiškiai (Object 2)



**Figure 4.** Spatial distribution of acid ( $\text{pH} \leq 5.5$ ) areas in Daumantiškiai (Object 2) as affected by different methods of soil sampling and digital mapping of pH data (1–10 – variant No.)

several values even higher than 6.5. pH values calculated using the algorithms were higher, and because of that the share of acid areas was decreased. When soil samples were collected within the boundaries of prevailing soil group or within the boundaries of prevailing soil group and of previously determined soil pH group (variants 5 and 8), the data interpolated using *IDW* method were similar to the not interpolated ones. Calculated acid area difference was only 1.0 percentage unit, when soil samples were collected within the boundaries of prevailing soil group, and 10.3 – when soil samples were collected within the boundaries of prevailing soil group and of previously determined soil pH group. Spatial distribution of acid areas on the digital maps of these two variants was quite similar to the one on the digital maps of not interpolated data, yet the acid areas were presented more compactly (Fig. 4).

Results of data interpolation using *Simple Kriging* method strongly depended on the soil sampling method. In the case of regular grid soil sampling method, the calculated share of acid soils was 31.7%. When soil samples were collected within the boundaries of prevailing soil group, this share was 100%, and soil sampling within the boundaries of prevailing soil

group and of previously determined soil pH group resulted in share of 78.7%. In this case it is obvious that *Simple Kriging* method should not be combined with regular grid soil sampling method and with soil sampling within the boundaries of prevailing soil group. The spatial distribution of acid areas on the digital maps supports this conclusion. The calculated pH values were significantly higher in one case and lower in another. When soil samples were collected within the boundaries of prevailing soil group and of previously determined soil pH group, the results of data interpolation using *Simple Kriging* method were similar to the ones obtained using the not interpolated data, and the presentation of acid areas on the digital map corresponded to the results of the data interpolation using *IDW* and *Simple Cokriging* methods.

*Summing-up the research results for Object 2.* When the area of acid soils makes 50–70% of the array, the most suitable method for soil sampling and presentation of acid areas on the digital maps is to follow the boundaries of prevailing soil group or the boundaries of prevailing soil group and of previously determined soil pH group. Presentation of data using *IDW*, *Simple Kriging* and *Simple Cokriging* methods gives similar results

as regards the acid areas on condition that soil sampling was conducted within the boundaries of prevailing soil group and of previously determined soil pH group.

**Dapkūniškiai (Object 3).** The array is characterised by irregular, slightly rolling relief, eroded zones intervene the not eroded ones. This situation makes this array a complicated task for soil sampling as well as for presentation of acid areas on the map. Soil on the tops of the hills is acid and on the eroded slopes – mostly not acid, in some locations pH 6.6 and even above 7.0. Downhill soils are slightly acid or close to neutral. It was difficult to separate the small eroded areas on the map, therefore on the maps of variants where soil samples were collected within the boundaries of prevailing soil group or within the boundaries of prevailing soil group and of previously determined soil pH group (variants 4 and 7) the complexes of acid and not acid soils were presented.

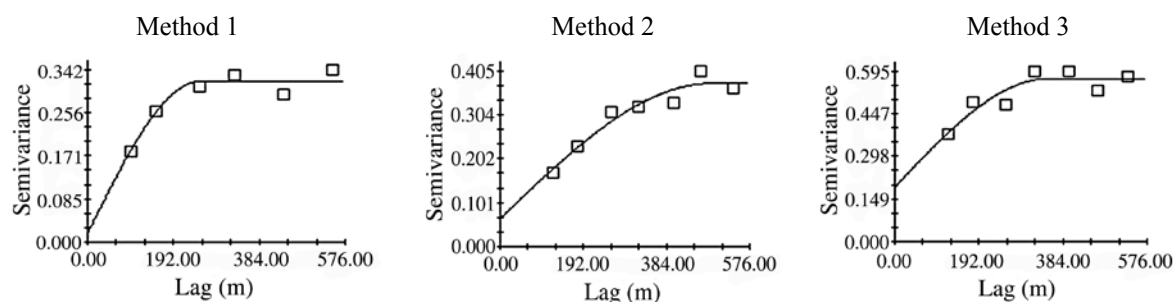
According to the results of previous soil tests, 28.2% of array was acid. On average for the methods used in the current research, the share of acid soils was 12.6% – the array became less acid. Depending on the methods of soil sampling and data mapping used the determined share of acid soils varied from 1.5% to 28.0% (Table 2, Fig. 6).

The share of acid soils was 17.0% and 18.4% in variants 1 and 4 respectively. When soil samples were collected within the boundaries of prevailing soil group and of previously determined soil pH group

(variant 7), the calculated share of acid soils was 28.0%, 11 percentage units more than in the case of regular grid soil sampling.

The semivariance calculated for the soil sampling method 3 was 0.569 (the largest one), nugget and sill ratio was the largest as well – 0.334 (Table 3, Fig. 5). This means that application of the soil sampling method 3 resulted in the highest variability of pH between the neighbouring soil sampling locations.

Share of acid soils was from 6.5% to 10.6% in variants 2, 5 and 8 (three soil sampling methods in combination with interpolation of data using *IDW* method). These results are substantially less than the ones of not interpolated data. When soil samples were collected within the boundaries of prevailing soil group and of previously determined soil pH group the interpolated share of acid soils was 10.6%. When soil samples were collected using regular grid or within the boundaries of prevailing soil group and the data was interpolated using *IDW* method, the share of acid soils was 6.5% and 9.9% respectively. The spatial distribution of acid areas corresponds to the areas on the maps of not interpolated data, yet the acid area on interpolated data maps is significantly smaller. Thus this interpolation method should not be used in the cases when the share of acid soils in the array is not more than one fourth of the total area, the relief is hilly/rolling with eroded zones intervening the not eroded ones, and the range of determined pH values is very wide – from 4.6 to 7.4.



**Figure 5.** Spherical semivariograms of soil pH values obtained using different soil sampling methods in Dapkūniškiai (Object 3)

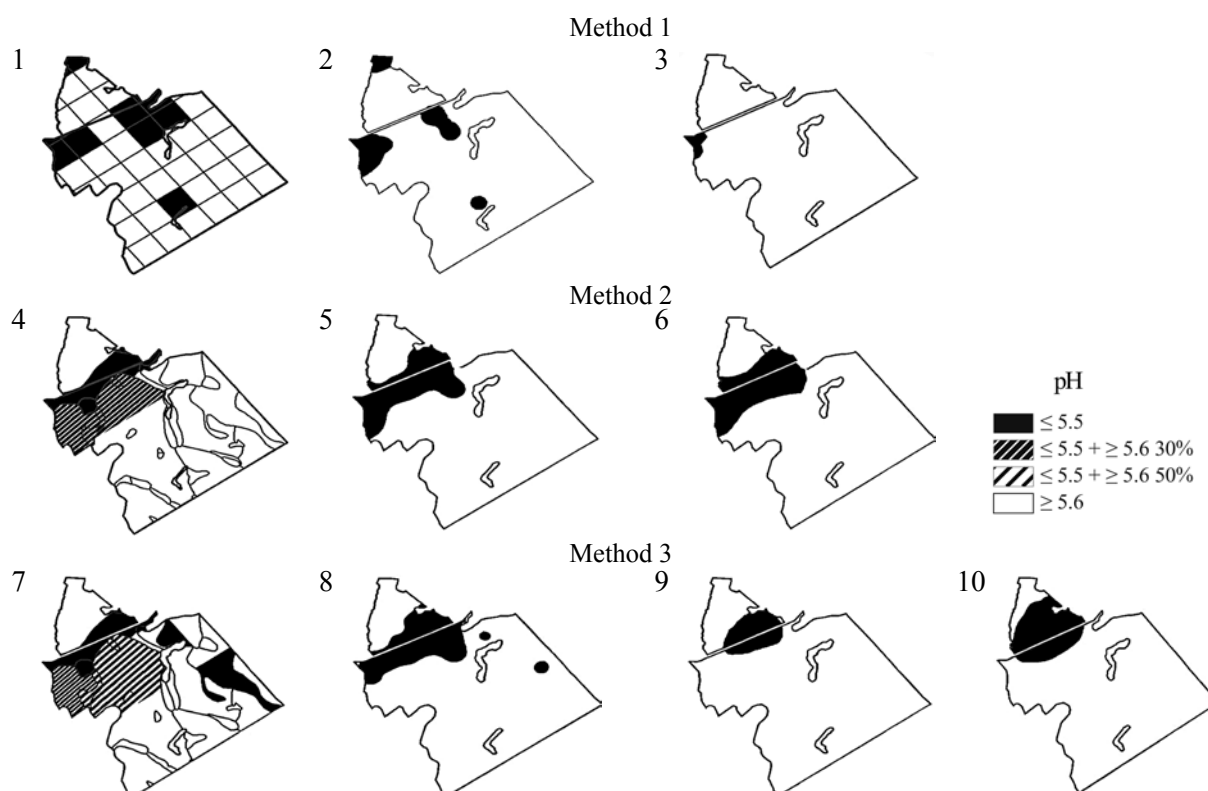
*Simple Kriging* method was not suitable for presentation of acid areas in Object 3 either. Share of acid soils was from 1.5% to 9.5% in variants 3, 6 and 9 (three soil sampling methods in combination with interpolation of data using *Simple Kriging* method). This percentage is significantly lower than that obtained using not interpolated data, it is also significantly lower than the percentage obtained when the data was interpolated using *IDW* method. The biggest discrepancy was recorded when soil samples were collected using the regular grid. 17.0% share of acid areas was obtained when not interpolated data was used, and 1.5% – when data was interpolated using *Simple Kriging* method, difference of 15.5 percentage units. When soil samples were collected within the boundaries of prevailing soil group and of previously determined soil pH group, the share of acid areas was 28.0% and 3.6% respectively, difference of 24.4 percentage units.

The results of application of *Simple Cokriging* method were not satisfactory. When soil samples

were collected within the boundaries of prevailing soil group and of previously determined soil pH group, the share of acid areas was 28.0% for not interpolated data and 8.0% for interpolated data, difference was 20.0 percentage units.

*Summing-up the research results for Object 3.* When the array relief is hilly/rolling, eroded zones intervene the not eroded ones and the range of determined pH values is very wide, the soil samples should be collected within the boundaries of prevailing soil group and of previously determined soil pH group. Yet it must be noted, that application of this method results in increase of share of acid areas by 65% and 52% if compared to the regular grid and soil sampling within the boundaries of prevailing soil group methods respectively. Digital mapping using *IDW*, *Simple Kriging* and *Simple Cokriging* methods is not suitable for this type of field, because the share of acid areas was decreased substantially.





**Figure 6.** Spatial distribution of acid ( $\text{pH} \leq 5.5$ ) areas in Dapkūniškiai (Object 3) as affected by different methods of soil sampling and digital mapping of pH data (1–10 – variant No.)

## Conclusions

1. The most accurate presentation of acid soils on the digital map was obtained when soil samples were collected within the boundaries of prevailing soil group and of previously determined soil pH group. Soil sampling within the boundaries of prevailing soil group resulted in less detailed maps of acid areas, and the most inaccurate results of mapping were obtained when regular grid soil sampling method was used.

2. The evidence of spatial autocorrelation of actual pH data suggests that the obtained pH data values were changing most when soil samples were collected within the boundaries of prevailing soil group and of previously determined soil pH group. Nugget and sill, indicating the biggest semivariance, were the largest when the soils samples collected using the regular grid were compared.

3. If the area of acid soils makes up to one fourth of the array and slightly acid areas prevail, or if the eroded zones intervene the not eroded ones, the pH data interpolated using *IDW*, *Simple Kriging* or *Simple Cokriging* methods present significantly smaller number of acid zones than the not interpolated data.

4. When the area of acid soils makes up 50% and larger share of the array, *IDW*, *Simple Kriging* and *Simple Cokriging* methods can be used for correct mapping of acid areas on condition that soil sampling is conducted within the boundaries of prevailing soil group and of previously determined soil pH group.

5. Soil sampling for pH tests should be conducted within the boundaries of prevailing soil group and of previously determined soil pH group. If this soil sampling method is applied, the interpolation

of pH data using *IDW*, *Simple Kriging* or *Simple Cokriging* methods is possible on condition that acid areas make not less than 50% of tested field. In this case the aforementioned interpolation methods produce similar displays of acid areas.

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## Dirvožemio pH erdvinis pasiskirstymas, taikant skirtingus ėminių atrinkimo būdus ir geostatistinius metodus

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### Santrauka

Lietuvoje įvairios dangos dirvožemių pH<sub>KCl</sub> tyrimai atlikti 2004 m. Anykščių r. Elmininkų (155 ha), Ukmergės r. Daumantiškių (55 ha), 2007 m. – Molėtų r. Dapkūniškių (73 ha) vietovėse. Tikslas – įvairios dangos dirvožemiuose, ėminius imant skirtingais būdais, įvertinti erdvinį pH pasiskirstymą ir geostatistinių metodų taikymą. Siekta įvertinti ėminių paėmimo tinklelio būdą ir būdus, kai naudojamos dirvožemių grupės bei granulimetrinės sudėties kontūrų ir ankstesnio tyrimo pH kontūrų duomenų bazės. Skaitmeniniame žemėlapyje rūgšties plotams atvaizduoti taikyti *IDW*, *Simple Kriging* ir *Simple Cokriging* interpoliavimo metodai. Dirvožemio ėminiai tyrimams imti 2 ha tankumu.

Tyrimų rezultatai parodė, kad skaitmeniniame žemėlapyje rūgštūs plotai laukuose tiksliausiai atvaizduojami, kai ėminiai atrenkami ir žemėlapyje pateikiami pagal vyraujančio dirvožemio kontūro bei ankstesnio tyrimo rūgščių plotų ribas. Kiek mažiau detalieji rūgštūs plotai atvaizduojami, kai ėminiai imami pagal dirvožemių kontūrų ribas, mažiausiai – taisyklingo tinklelio būdu. Masyvuose, kur rūgštūs plotai sudarė nedidelę dalį (iki ketvirtadalio) viso ploto ir vyravo daugiausia silpnai rūgštaus pH plotai arba kur tarp neeroduotų plotų buvo įsimaišę eroduoti, *IDW*, *Simple Kriging* ar *Simple Cokriging* metodais interpoluoti pH duomenys pateikė gerokai mažesnę kiekį rūgščių plotų nei neinterpoluoti.

Rekomenduojama pH tyrimams dirvožemio ėminius imti pagal vyraujančio dirvožemio kontūro ir ankstesnio tyrimo rūgščių plotų ribas. Ėminius imant šiuo būdu, pH duomenų interpoliavimas *IDW*, *Simple Kriging* ar *Simple Cokriging* metodais galimas tik tuomet, kai rūgštūs plotai sudaro daugiau nei 50 % tiriamo ploto. Tokiuose plotuose taikant šiuos interpoliavimo metodus, gaunami panašūs rūgščių plotų rezultatai.

Reikšminiai žodžiai: dirvožemio ėminio ėmimas, dirvožemio pH, interpoliavimo metodai.