EFFECT OF SOIL PH ON REASONABLE TRAVEL SPEED OF MOBILE UNIT AND LIME APPLICATION

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Abstract. Precision agriculture, as a site-specific management concept, can increase profitability of crop production, improve the product quality and protect the environment. Applying the system of precision agriculture the soil, plant condition, fertilization demand, and fertility measures are taken into consideration. Using the data obtained, the technological parameters of agricultural machines are adjusted in a course of work. In such a way the consumption of fertilizers, lime, pesticides, fuel and time are optimised growing agricultural plants for food and feed. The soil pH value is a predictor of various chemical activities and a rough indicator of the plant availability of nutrients within the soil. Having the correct pH is crucial for the healthy plant growth as it will affect the amount of nutrients available to plants. The study was carried out using the mobile unit Veris 3150 MSP equipped with the Soil pH Manager system. After the assessment of accuracy of the pH maps formed, it can be stated that the reasonable travel speed of the mobile unit is 9 $km \cdot h^{-1}$. Increasing the speed, the unit records the measurement values in greater spaces, thus leaving small areas of field with different pH values unmarked. Traveling the unit at the speed of 3 $km \cdot h^{-1}$, it reached the work efficiency of 6.5 ± 0.5 $ha \cdot h^{-1}$ and at 12 $km \cdot h^{-1}$ – 26.5 ± 2.2 $ha \cdot h^{-1}$. The reliability of the soil acidity research conducted is proved by the linear correlation of soil pH identified using the Veris 3150 MSP and soil pH identified in the laboratory ($R^2 = 0.81$). Selecting the lime rates according to the maps created by using the data of the unit, lime savings are about 40 %, compared to the liming based on the maps created on pH values determined in the laboratory. When liming is done according to the average of the laboratory data (equal to 500 $kg \cdot h^{-1}$ rate), some field areas are under-limed or over-limed.

Keywords: soil pH, travel speed, lime, liming map, precision agriculture.

Introduction

As a measure of soil acidity or alkalinity, soil pH constitutes one of the most important chemical soil parameters and a good indicator of soil quality [1; 2]. To make strongly acid soils (pH less than or equal to 5.5) less acidic, the common practice is to apply a material that contains some form of lime. Liming improves plant nutrient availability and reduces toxicity problems in acid soils [3]. Different soils will require a different amount of lime to adjust the soil pH value.

The texture of the soil, organic matter content and the plants to be grown are all factors to consider in adjusting the pH value. In general, soil pH values outside the range of 5.5 to 6.5 are considered as non-optimum because they can have negative impacts on the above mentioned factors, and can make plants more sensitive to diseases [1; 4].

Soil liming is a long-term investment, and determination of lime requirement by different rate of lime within a large field is relatively sophisticated. The rates of lime required are based on soil analyses in order to accurately reflect the soil rocks, clay and organic matter, sum of exchangeable cations and soil pH. Soil pH values, and consequently liming requirements, can vary within an agricultural field. Thus, it may be profitable to apply lime according to the spatial variation of soil pH within the fields using precision agriculture technologies. Schirrmann et al. [1] report that the quality of pH maps is predominantly influenced by the sampling density, while other factors such as measurement errors are less important. Based on the soil sampling method and density, the lime application area and rate vary up to 4.9 times and 4.8 times, respectively [5].

In recent times, the demand for high-resolution soil maps becomes much more evident and spatially densed soil sampling becomes sensible [1]. Based on the newest cartographic technology, soil pH measurements can be performed on-the-go while traveling across the field [6]. During field operation, the accurate maps of soil pH are generated and they can be used as inputs. The on-the-go sensing system for soil pH has been developed by Adamchuk et al. [6; 7] and was combined with the Veris soil apparent electrical conductivity sensor. The pH Manager is marketed by Veris Technologies (Salina, USA) as a part of the mobile sensor platform Veris MSP. The travel speed clearly influences the number of the required samples, distance between sampling points, work efficiency. However, there is a lack of scientific information on the travel speed of a mobile unit Veris during on-the-go measurements. Several studies have shown that the scale of soil pH maps, developed using the on-the-go technology and obtained for eight production fields in six US states, were compared with the corresponding maps derived from grid sampling. The travel speed was maintained between 8 km·h^{-1} and 16 km·h^{-1} [7]. Setting reasonable travel speed allows accurate georeferenced on-the-go pH mapping and selecting the required lime rate for the field.

The aim of the present study was to determine the reasonable travel speed of the mobile unit Veris 3150 MSP and to obtain more accurate soil liming maps by analysing soil pH.

Materials and methods

The study site consisted of two fields (referred to as field A and field B) in Šilalė district, Lithuania. Fields A and B are approximately 6.65 ha and 2.45 ha in size, respectively. The experimental research was performed in the ploughed strips over entire length of the field at each 20 meters. Soil pH was determined by a mobile unit Veris 3150 MSP equipped with the Soil pH Manager (Veris Technogies Ltd, USA) system. The Soil pH Manager system is a real-time sensor for soil pH mapping. It automatically collects soil samples and measures soil pH from direct contact to the soil material on-the-go. The navigation system is equipped in the mobile unit. The Soil pH Manager consists of three main components: a hydraulic soil sampling system, a pH electrode measurement system, and a water wash system (Fig. 1). The soil pH measurements were performed as described in detail by Schirrmann et al. [1].

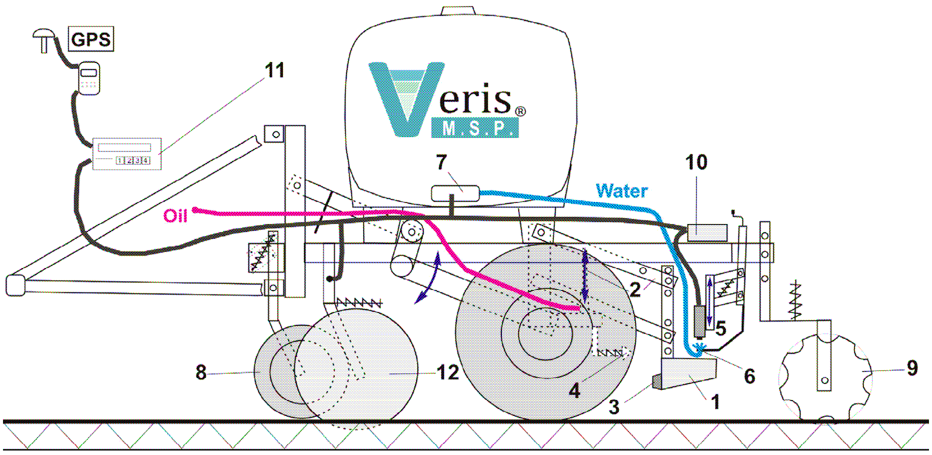


Fig. 1. **Schematic of the Veris MSP including the Soil pH Manager system [1]:** 1 – soil sampler shoe; 2 – parallel linkage; 3 – cone; 4 – scraper; 5 – antimony pH electrodes; 6 – wash nozzles; 7 –electric water pump; 8 – row cleaner; 9 –furrow closers; 10 – external controller; 11 – data input device; 12 – soil electrical conductivity device

Sampling the depth and time are adjustable but typically set to 0.01 m and 2 s. The obtained pH value is computed from the averaged voltage outputs of the two pH electrodes. Conversion of voltage to pH units is achieved by a calibration routine that involves measurement of two standard solutions with known pH values of 4 and 7. Measurement time depends on the antimony electrode response and ranges between 7 s and 25 s. During field operation, differential GPS coordinates are recorded at the moment the sampler shoe is pulled out of the soil [1].

The measurements were performed in a ploughed field by natural moist soil with the moisture content of 13.79 ± 0.65 % (% by weight). The soil samples for the laboratory analysis were collected on the second day after the field measurements. Subsequent sampling was done accurately from the furrows made by the soil sampler shoe. The sampling and measurement points were found by GPS. Furthermore, the additional reference samples were taken from the field for the transformed pH measurements data.

Soil mapping. Five data columns were obtained after the field measurements: the first two filled with the coordinates, the second two – with the pH values of two antimony pH electrodes, and the fifth column filled with the mean pH value of both antimony pH electrode records. The obtained findings were processed using the *SMS Advanced* software (AgLeader Ltd, USA) and, as a result, pH maps of the fields were computed. The subsequent transformation of pH values into the Veris 3150 MSP transformed pH values [8] was done by taking the reference samples from each individual field into account.

Laboratory pH measurements. The soil pH analysis was carried out at the Agrochemical Research Laboratory of the Lithuanian Research Centre for Agriculture and Forestry following the ISO 10390:2005 standard protocol requirements.

Travel speed of the mobile unit. Impact of the working travel speed on the qualitative parameters of the mobile measurement unit Veris 3150 MSP was evaluated. For this purpose, the mobile unit aggregated with a New Holland T7060 tractor was trailed over the ploughed soil strips. The travel speed varied at intervals of 3 km·h^{-1} (from 3 km·h^{-1} to 12 km·h^{-1}).

Lime requirements. The rate of lime was calculated using the recommendation of German researchers [9]. The algorithm of lime rate requires pH ($CaCl_2$), the soil texture and the soil organic matter content as inputs. An economic estimation refers to the three liming systems. Liming was applied using the data measured with the Veris 3150 MSP (precision liming system I), the data obtained in the laboratory (precision liming system II), and the mean of the data obtained in the laboratory (conventional farming).

Statistical analysis. The investigation findings were assessed using the methods of dispersion and correlation-regression analysis [10]. The mean values, their standard deviations and confidence intervals under the 0.95 probability level were found.

Results and discussion

Variation of soil pH and determination of the reasonable travel speed. While increasing the travel speed of the measurement unit Veris 3150 MSP in steps of 3 km·h^{-1} (from 3 km·h^{-1} to 12 km·h^{-1}), it has been found that at the travel speed of 3 km·h^{-1} the sample number, the distance between the sampling points and the productivity of the unit were influenced. Using the Veris 3150 MSP, the soil pH was recorded each 10.67 ± 1.37 s. Consequently, when traveling at the speed of 3 km·h^{-1}, the distance between the sampling points amounted to 8.49 ± 2.34 m, whereas at the speed of 12 km·h^{-1} – 35.02 ± 3.14 m. The productivity of the unit was found to increase respectively: from 6.5 ± 0.5 ha·h^{-1} (working at the travel speed of 3 km·h^{-1}) to 26.5 ± 2.2 ha·h^{-1} (working at the travel speed of 12 km·h^{-1}).

The mean sample number per hectare (sampling density) was determined by the unit Veris 3150 MSP. It varied from 48.33 ± 1.28 samples (traveling at the speed of 3 km·h^{-1}) to 12.67 ± 1.74 samples (traveling at the speed of 12 km·h^{-1}). Similar experiences had been described by Adamchuk et al. [7]: the density of MSP pH data was between 8 and 26 measurements·ha^{-1} traveling at the speed between 8 km·h^{-1} and 16 km·h^{-1}.

Sampling density mainly depends on the travel speed and the distance between the soil strips (Table 1).

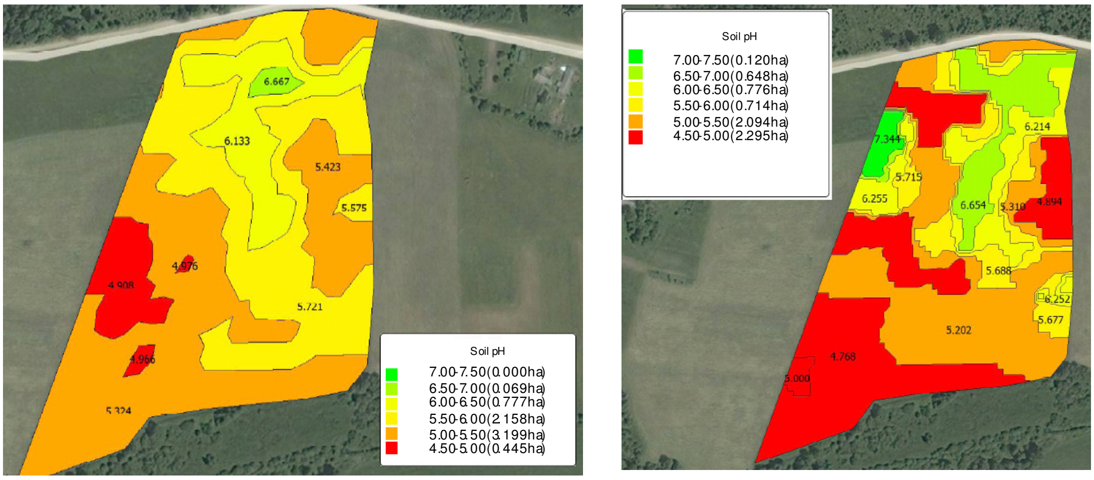
Table 1

The effect of the Veris 3150 MSP travel speed on the technological working parameters of the operation

Parameter	Travel speed *v*, km·h^{-1} (m·s^{-1})			
	3 (0.83)	6 (1.67)	9 (2.50)	12 (3.33)
Sample number per ha	48.33 ± 1.28	28.67 ± 2.55	21.0 ± 0.84	12.67 ± 1.74
Average distance between sampling points, m	8.49 ± 2.34	19.25 ± 1.25	26.41 ± 0.25	35.02 ± 3.14
Productivity ha·h^{-1}	6.5 ± 0.5	12.8 ± 0.8	20.0 ± 1.5	26.5 ± 2.2

After processing the initial soil pH results from the unit Veris 3150 MSP, dot density maps were computed using the *SMS Advanced* software. Each recorded pH value was grouped by range and respective colour. Combining the measurement data of adjacent passes into the corresponding areas and marking them with different colours resulted in the pH maps. All the numerical values of pH were grouped into seven zones (from 4.53 to 6.93 of field A and from 4.45 to 6.64 of field B). Due to convenient application of the maps, the soil pH values were grouped into six equal range zones (from 4.50 to 7.50) (Fig. 2; 3).

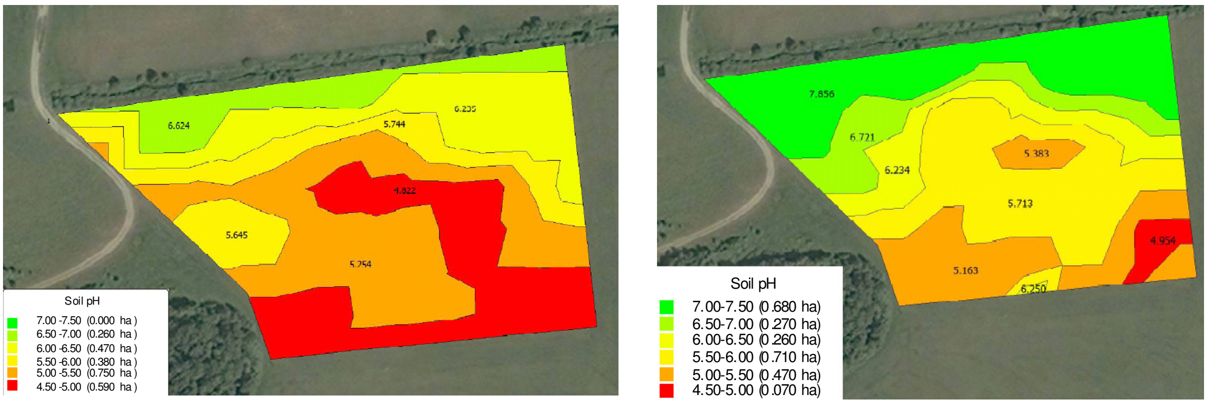
The soil pH analysis was carried out at the Agrochemical Research Laboratory. The results obtained in the laboratory were processed using the *SMS Advanced* software and respective pH maps were computed (Fig. 2, b; 3, b). The grouping scheme was done based on the above mentioned method.



a b

Fig. 2. Field A: **grouped pH maps computed by measuring with the Veris 3150 MSP (a) and compared with the laboratory analysis (b)**

The soil pH map analysis showed that they have similar zones with the low pH values. It is evident that the map computed by measuring with the Veris 3150 MSP is more detailed. More samples were analysed with pH electrodes of the unit in the same field than comparing the sample number of the laboratory analysis.



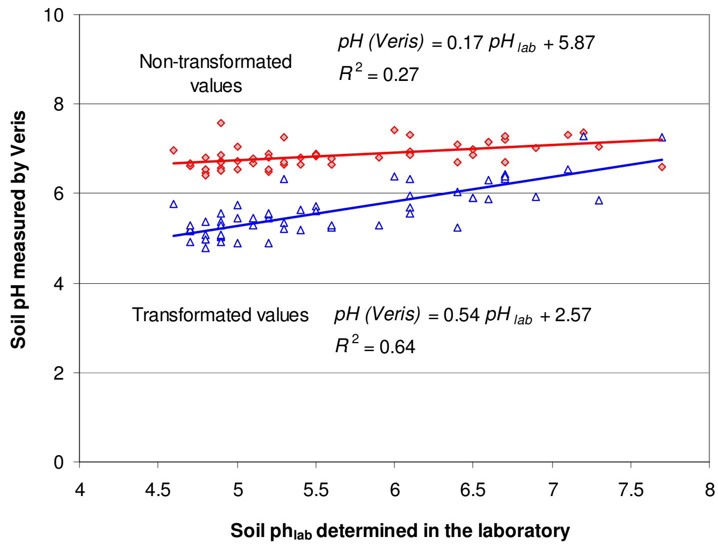
a b

Fig. 3. **Field B: grouped pH maps computed by measuring with the Veris 3150 MSP (a) and compared with the laboratory analysis (b)**

According to Olfs et al. [8], even at small-scale variation in soil pH is detectable providing evidence that a high sampling density is required to derive reliable lime application maps. The analysis of the data obtained while working by the unit Veris 3150 MSP revealed that the measurement values of pH electrodes varied between 6.54 and 7.36. Soil is alkaline in such a case and there is no need for liming. However, considering the obtained research findings, when compared with laboratory analysis, a significant discrepancy was determined. Consequently, it is important to transform [8] the obtained pH values according to the recommendations of the manufacturer.

The transformed pH values were correlated with the obtained in the laboratory. The reliability of the soil pH investigations is proved by the obtained close linear (R^2 = 0.64 and R^2 = 0.81) interrelation (Fig. 4). The linear interrelation (R^2 = 0.27 and R^2 = 0.40) of the non-transformed values obtained by the unit Veris 3150 MSP and compared with the laboratory analysis was weak.

a)



b)

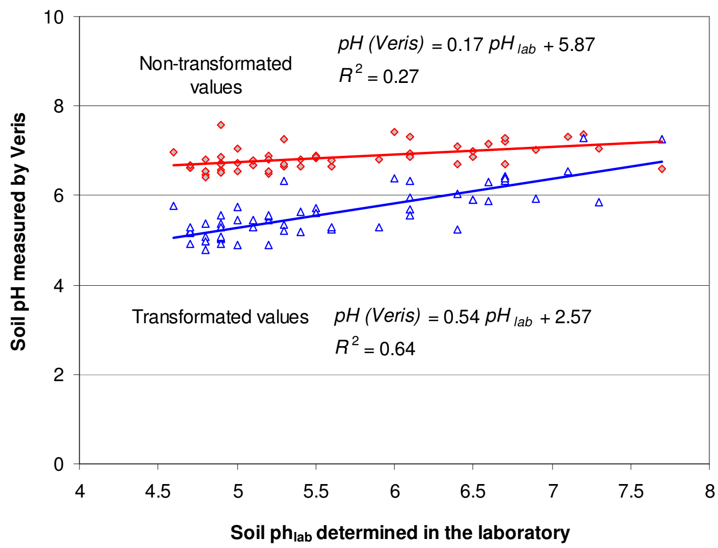


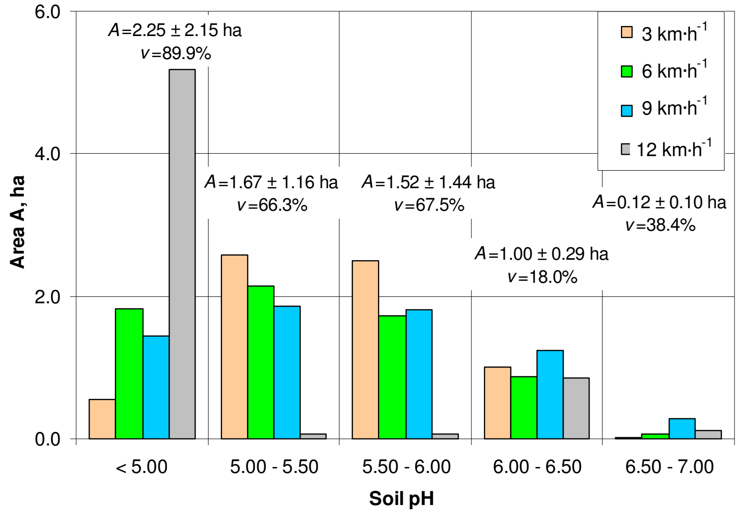
Fig. 4. **Correlation of the transformed and non-transformed pH values obtained by the Veris 3150 MSP and compared with the laboratory analysis pH_{lab} (fields A and B)**

The investigation has indicated that the variation coefficient of various soil pH zones was influenced by the travel speed of 12 km·h^{-1} both for field A (Fig. 5, a) and for field B (Fig. 5, b). While increasing the travel speed from 3 km·h^{-1} to 9 km·h^{-1}, it has been found that the measured areas with various soil pH zones were not differed, hence, the variation coefficients were significantly lower. For instance, a variation coefficient of 66.3 % (Fig. 5, a) in field A was detected in the area within the pH zone range 5.00-5.50 working at the travel speed from 3 km·h^{-1} to 12 km·h^{-1}, while a variation coefficient of 16.4 % was found at the travel speed from 3 km·h^{-1} to 9 km·h^{-1}. The variation coefficient in the other soil pH zones was decreased respectively.

In the summary of the soil pH investigation, it was observed that the reasonable travel speed by measuring pH with the mobile unit Veris 3150 MSP is 9 km·h^{-1}.

The comparative investigations on liming by three different systems were performed. According to the findings by the Veris 3150 MSP (precision liming system I), the liming area was amounted to 4.12 ha (approximately 62 % of total area) in field A and to 1.36 ha in field B (approximately 56 % of total area). According to the pH values obtained in the laboratory (precision liming system II), the liming area would be amounted to 4.86 ha (73 % of total area) in field A, and to 0.48 ha (approximately 20 % of total area).

a)



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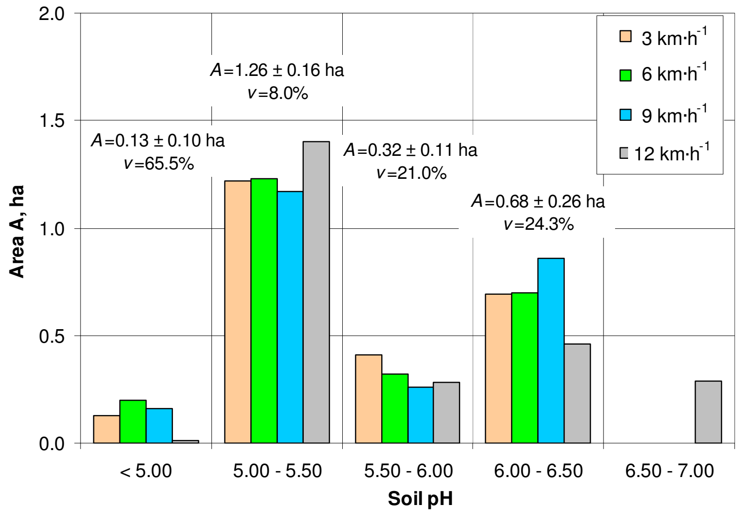

Fig. 5. **Dependence of soil pH of the upper layer and measured area working at different travel speed in ploughed fields A and B**

Applying a conventional farming system (lime rate of 500 kg·ha^{-1}), the total area requires lime application for fields A and B, respectively.

The cost of purchasing lime in Lithuania was found to be from 6 EUR to 30 EUR per ton. In an economic estimation of the present study, the cost of 17 EUR was taken per ton of lime. According to the market based data, the cost of lime transportation was found to amount up to 0.05 EUR·(t·km)$^{-1}$. A lime spreading machine will have to travel 400 km.

Applying the methods of precision agriculture, the lime rate for separate areas of fields was selected according to soil pH maps computed by the unite Veris 3150 MSP (Fig. 6, a) and obtained in the laboratory (map not presented). Consequently, 180 EUR and 304 EUR were spent by purchasing lime for field A (6.65 ha), while 77 EUR and 26 EUR for field B (2.45 ha, Fig. 6, b), respectively.

Using the conventional farming system, the lime rate was chosen to be equal for the entire field. Accordingly, the cost of purchasing lime was amounted to 127 EUR per 6.65 ha (Field A). Field B (2.45 ha) was not recommended to require lime application.

The difference between the first and the second liming methods was amounted to 124 EUR, whereas 53 EUR – between the first and the third methods for field A. Meanwhile, the difference between the first and the second liming methods was 51 EUR, whereas 26 EUR – between the first and the third methods for field B.

a) b)

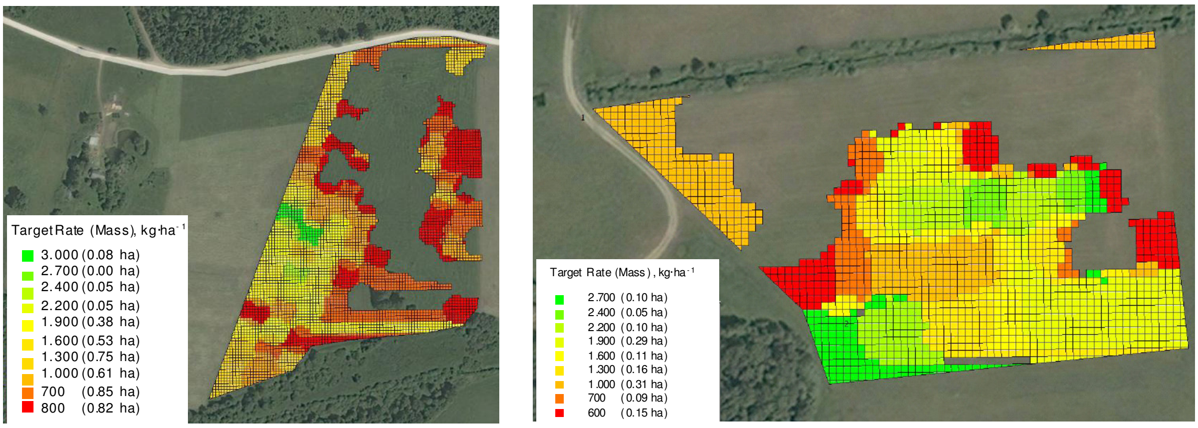

Fig. 6. **Soil liming maps computed by the unite Veris 3150 MSP (fields A and B)**

The investigation has shown that when using a conventional liming method, fields A and B would be limed not enough. As a result, liming maps computed by the Veris 3150 MSP are assumed to be more precise, as 140 and 51 measurements were performed per hectare in fields A and B, respectively. The density of the samples taken for the laboratory amounted to 58 (field A) and 33 (field B). It can be stated that when liming by the second method, unreasonable costs will be arisen, while a reasonable yield would not be reached by using the third (conventional) method in both fields.

Selecting the lime rates according to the maps created by using the data of the unit, lime savings are about 40 %, compared to the liming based on the maps created on pH values determined in the laboratory. When liming is done according to the average of the laboratory data, some field areas are under-limed or over-limed.

Conclusions

1. After the assessment of accuracy of the pH maps formed, it can be stated that the reasonable travel speed of the mobile unit Veris 3150 MSP is 9 km·h^{-1}. Increasing the speed, the unit records the measurement values in greater spaces, thus leaving small areas of field with different pH values unmarked.
2. Traveling the unit at the speed of 3 km·h^{-1}, the distance between the sampling points amounted to 8.49 ± 2.34 m, whereas at the speed of 12 km·h^{-1} – 35.02 ± 3.14 m. The work efficiency was increased accordingly: from 6.5 ± 0.5 ha·h^{-1} (3 km·h^{-1}) and 26.5 ± 2.2 ha·h^{-1} (12 km·h^{-1}).
3. The reliability of the soil pH investigations carried out by the unit Veris 3150 MSP and compared with the laboratory analysis is proved by the obtained close linear interrelation ($R^2 = 0.64$ and $R^2 = 0.81$).
4. Selecting the lime rates according to the maps created by using the data of the unit, lime savings are about 40 %, compared to the liming based on the maps created on pH values determined in the laboratory. When liming is done according to the average of the laboratory data, some field areas are under-limed or over-limed.

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