COMPARISON OF THE VARIABLE POTASSIUM FERTILIZATION ON THE LIGHT AND HEAVY SOILS

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ABSTRACT

The present study aimed to characterize the effect of the annual potassium variable rates fertilization (VRF) on the content of the soluble K, with this being investigated in both light and heavy soils. The study was performed between 2007 and 2013 in two separate areas differentiating in the soil texture classes. The initial levels of potassium determined in both experimental areas were classified as very high. The data obtained confirmed positive effect of the variable fertilization techniques on the equalization of the K contents in the experimental fields, as determined by the decrease in the variance, standard deviation, and range of the elements content in both types of the soils studied. As assumed, the controlled withholding of fertilization applied in the early stages of the experiment resulted in decrease of K contents toward the preferred, medium to optimal, levels. In addition, we found that the progressive initiation of the potassium VRF on the experimental areas, to prevent an excessive decreases, resulted in earlier equalization of K contents in the light soils in contrast to the heavy ones, with the final spatial equalization being better in the latter, however.

Keywords:
Variable rate fertilization (VRF), potassium, spatial variation, light soils, heavy soils

INTRODUCTION

Potassium (K), apart from nitrogen, is another nutrient absorbed by plants in large amounts. Potassium plays a number of important metabolic functions, and both its deficiency and excess may significantly affect the crop yield and quality (Hawkesford, et al., 2012). K in the soil is mainly bind with the mineral fraction of the soils, and with various methods of chemical extraction applied to soil different forms of this element are isolated (Andrist-Rangel, et al., 2006, Fotyma, 2007). The potassium doses applied to plants strictly depend on the content of available K forms in the soil, which essentially depends on the soil texture (Blake, et al., 1999, Römheld and Kirkby, 2010). The finer-textured (heavy) soils have usually a higher potential K availability, on the other hand however, there is a higher risk of the nonexchangeable fixation of this element (Havlin, et al., Hawkesford, et al., 2012). In contrast, in the light soils there is a possibility of the potassium leaching due to lower content of the clay fraction, with this being intensified with increasing doses of K supplied (Alfaro, et al., 2004, Öborn, et al., 2005).

Although the role of the variable rate fertilization (VRF) on the equalization of potassium contents in the soils have been studied before, the extent to which variations in soil texture determine the overall effectiveness of this approach have not been widely investigated. In addition, the studies so far reported have rather focused on the shorter-term (2-3 years long) observations of the VRF results. The current study aims to address this gap. The specific objective of this investigation was to determine the impact of the long-term potassium variable fertilization on the content of the soluble K form studied in both light (< 20% clay) and heavy soils (> 35% clay). Here, we test the hypothesis that the potassium VRF applied results in a decrease in the variation of the K levels in both soil texture classes.

The initial levels of potassium determined in both experimental areas were classified as very high, therefore we assumed that controlled withholding of fertilization in the early stages of the experiment would result in decrease of potassium contents toward the preferred levels (medium to optimal). In addition, it was expected that the progressive initiation of the potassium VRF on the experimental areas studied, to prevent excessive decreases, would result in earlier equalization of K contents in the light soils in contrast to the heavy ones.

MATERIALS AND METHODS

The study was performed between 2007 and 2013 in two separate areas differentiating in the soil texture classes. The fields were localized in southwestern Poland (Fig. 1).

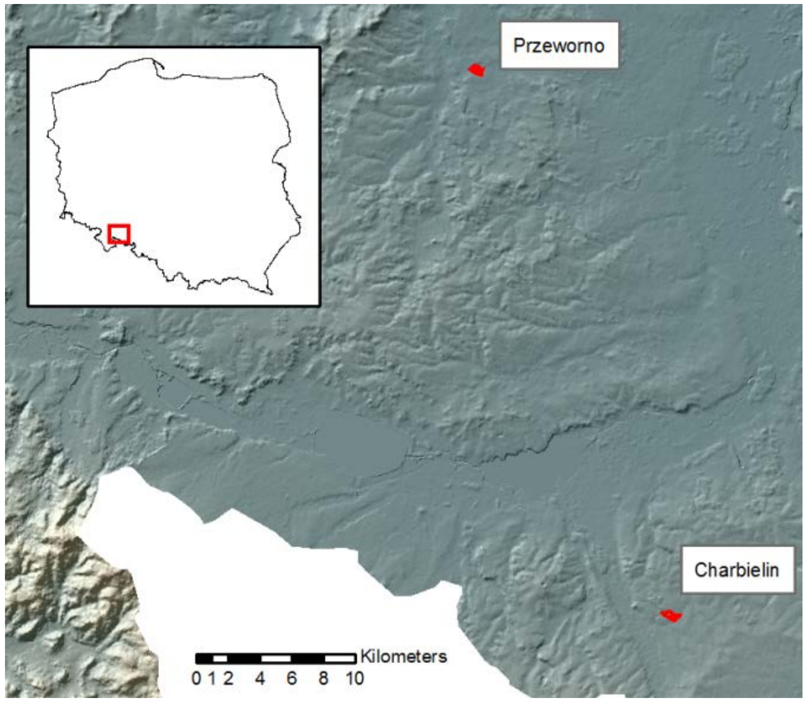


Fig. 1. Localization of the experimental fields (Produced using Copernicus data and information funded by the European Union - EU-DEM layers).

The field No. 1 representing the heavy soil class and localized in Charbielin (N: 50°22' E: 17°23'), incorporated a 61-ha experimental area. During each year of the experiment, 112 soil samples were collected, such that each sample location represented 0.54 ha (Fig. 1).

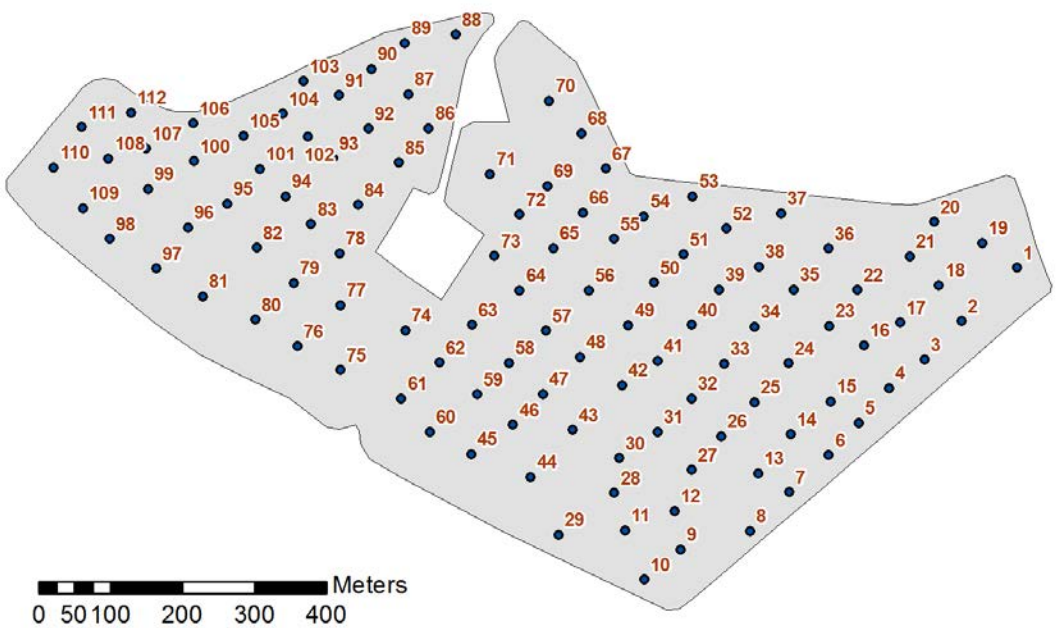


Fig. 2. Soil sampling scheme in a 61-ha experimental field in Charbielin (heavy soil)

The field No. 2, with an area of 56 ha and soil texture class categorized as light, was set up in Przeworno (N: 50°40' E: 17°12'). Similarly, in each year of the experiment, 120 soil samples were collected, with each sample location representing 0.47 ha (Fig. 2).

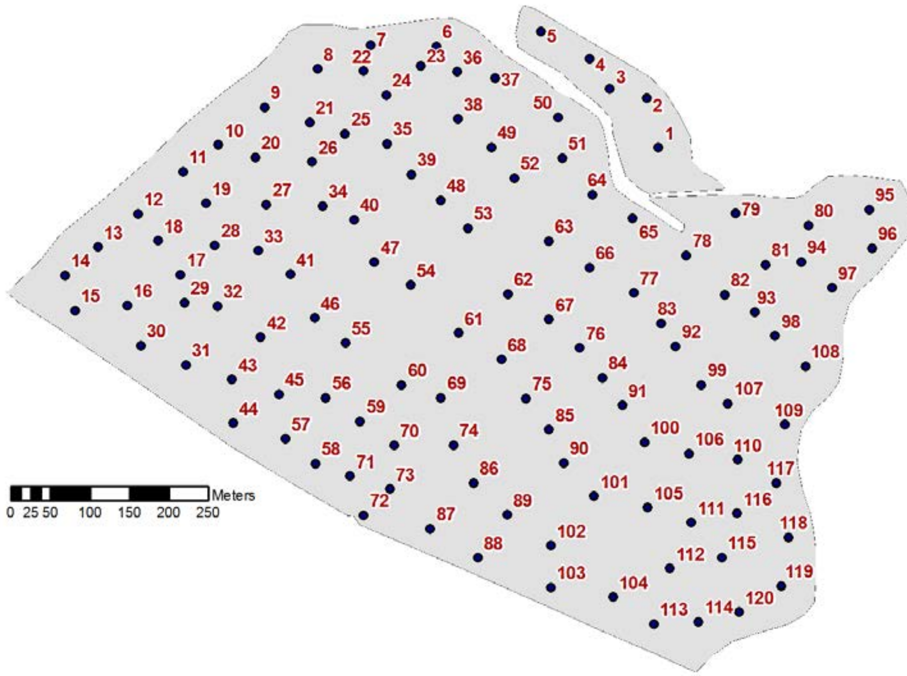


Fig. 3. Soil sampling scheme in a 56-ha experimental field in Przeworno (light soil)

Soil samples were collected in the period between harvest and fertilization of plants in each subsequent growing season. The soil sample locations were determined with GPS (with 0.5-m accuracy), and, an average sample test consisted of 10 individual samples. The content of the ‘available’ potassium was determined according to the Egner-Riehm DL method, being widely used in Poland (Egner and Riehm, 1955). Based on the determined amounts of potassium in the soil, the soil sample intervals were set to measure the fertility of the soil (Tables 1).

Table 1. The range of content of the available K form in soil and the corresponding defined doses of fertilizer

Range of soil fertility ($mg\ K \cdot kg^{-1}$ soil)	Soil-test level	Dose	
		K ($kg \cdot ha^{-1}$)	Potassium salt 60% K_2O ($kg \cdot ha^{-1}$)
< 104	very low	125	250
104 – 125	low	100	200
125 – 145	medium	75	150
145 – 166	optimal	50	100
166 – 178	high	25	50
> 178	very high	0	0

Subsequently, maps of the potassium soil fertility were created with the Agro-Map software (Agrocom GmbH, Germany). The variable fertilization doses were applied with fertilizer spreader linked to the Computer Terminals (ACT line; Agrocom GmbH, Germany) and a GPS antenna. The size of the potassium dose was adjusted by changing the operating speed of the spreader rollers.

The measure of the variability of K contents in the soil was implemented with classic descriptive statistics using the Statistica 10 software (StatSoft Inc., Tulsa, USA) and spatial statistics with ArcGIS (Esri Inc., Redlands, USA).

The study of spatial autocorrelation in spatial statistics was performed using Moran's I index (Wong and Lee, 2005).

$$I = \frac{n \sum \sum w_{ij}(x_i - \overline{x})(x_j - \overline{x})}{W \sum (x_i - \overline{x})^2} \qquad [1]$$

where x_i, x_j – values of the parameter in neighboring points, $\overline{x}$ – the average of the parameters values, w_{ij} – weighting matrix elements, n – number of features, W – sum of the weights.

Evaluation of the spatial variability was calculated with the semivariance estimator (Zawadzki, 2011), as follows:

$$\gamma(\mathrm{h}) = \frac{1}{2N(h)} \sum_{(i,j)h_{ij}=h} [Z(x_i) - Z(x_i + h)]^2 \qquad [2]$$

where N – number of point pairs separated by h vector, $Z(x_i)$ – value of parameter in point i, $Z(x_i + h)$ - value of the parameter in point separated by vector h.

RESULTS

In the course of the experiment the average contents of the soluble potassium in the soil in Charbielin ranged from 243 to 182 mg K · kg^{-1} soil (Table 2), whereas in Przeworno 229 to 180 mg K · kg^{-1} soil (Table 3). The decrease in the content of the soluble K in the soil resulted from the suspension in fertilization of this element in the the early years of the experiment due to high initial values. In the first year the very high levels of potassium in the heavy (Charbielin) and light soils (Przeworno) were found on 93% and 86% of the total area, respectively (Fig. 4a and 4c).

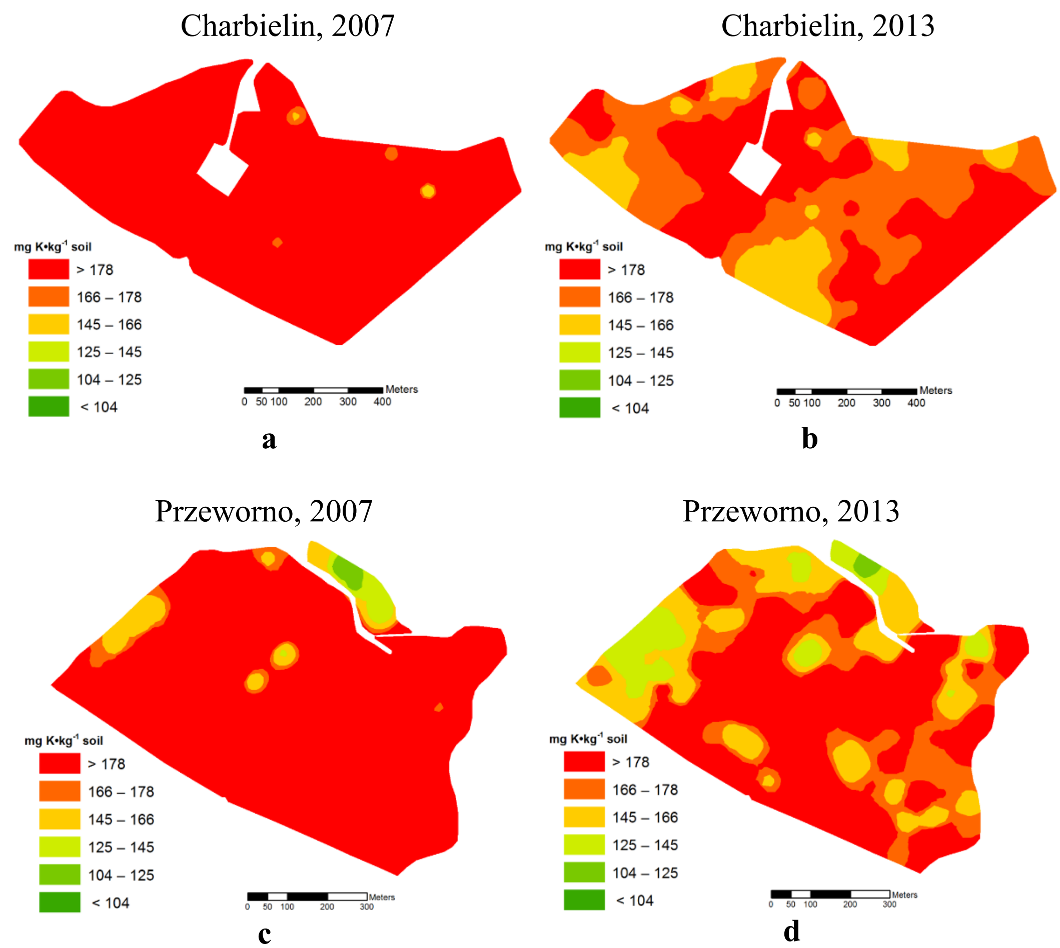


Fig. 4 Map of the K content according to the individual classes of fertility in Charbielin (heavy soils) and Przeworno (light soils) at the beginning (2007) and at the end of the experiment (2013).

On the both, the heavy and light soils a decrease in the variance and standard deviation of the K content was observed through the subsequent years, with this being particularly evident after the fourth year of fertilization (Table 2, 3).

Table 2. The impact of variable fertilization on changes in the content of the available form of potassium in the heavy soil - Charbielin (mg K · kg^{-1} soil)

The statistical parameters (n=119)	Year of research						
	2007	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
The arithmetic mean	243	229	216	204	193	185	182
Range	217	206	181	200	144	135	129
Variance	1 772	1 656	1 425	1 237	875	773	588
Standard deviation	42.1	40.7	37.7	35.2	29.6	27.8	24.2
Variation Coefficient (CV)%	17.3	17.8	17.5	17.3	15.3	15.0	13.3

Table 3. The impact of variable fertilization on changes in the content of the available form of potassium in the light soil - Przeworno (mg K · kg^{-1} soil)

The statistical parameters (n=119)	Year of research						
	2007	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
The arithmetic mean	229	214	200	189	184	179	180
Range	223	209	193	151	158	155	115
Variance	1 987	1 808	1 595	1 155	973	921	665
Standard deviation	44.6	42.5	39.9	34	31.2	30.3	25.8
Variation Coefficient (CV)%	19.5	19.9	20.0	18.0	17.0	16.9	14.3

The content of potassium in the soil during the years of VRF was examined with Fisher's test of variance analysis. An analysis of the average content of potassium in the soil (Fig. 3) showed significant decrease of potassium in the initial four years of the study in heavy soil (Charbielin), and the three years in light soil (Przeworno). In the following years of the experiment, the continued decline in K content in the soils was observed, with the averages for these years not being significantly different however (Fig. 3)

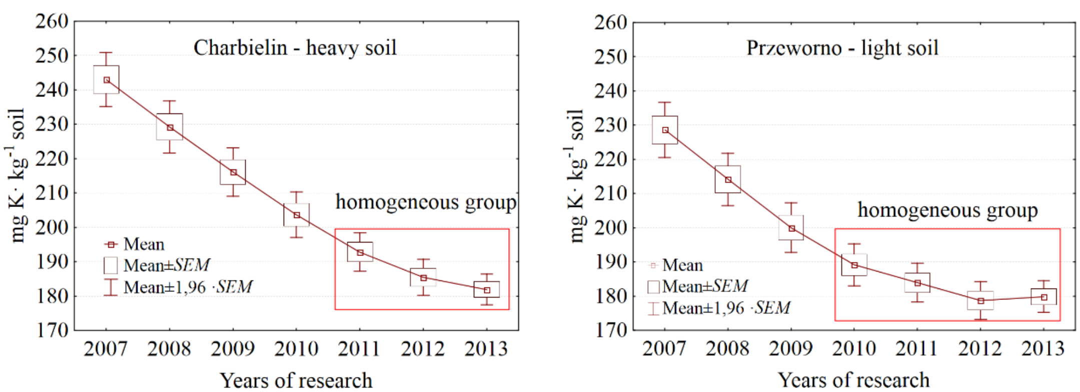


Fig. 5 Analysis of the K soil levels in test F for the model one-way ANOVA

Two separate approaches were employed for analysis of the spatial differentiation of potassium contents in the soils – Moran's I index and semivariograms.

The values of the index ranged from -1 to 1. The closer the index is to -1, the more the values of the neighboring points differ from each other. In contrast, the closer it is to 1, the higher the similarity in values is. For the expected values, close to zero ($E = -1 / (n-1)$), the distribution of the characteristic is random. Index uses the average value of the data distribution must therefore be as close to normal in all the cases studied occurred. Due to the fact that the value of the index I is sensitive to the weight applied, it was calculated using divert weighting methods: by the inverse distance, the inverse distance squared, and the neighborhood Voronoi polygons. Table 4 provides an index I for the Charbielin and Przeworno experimental fields.

Table 4. Spatial autocorrelation - Moran's I index

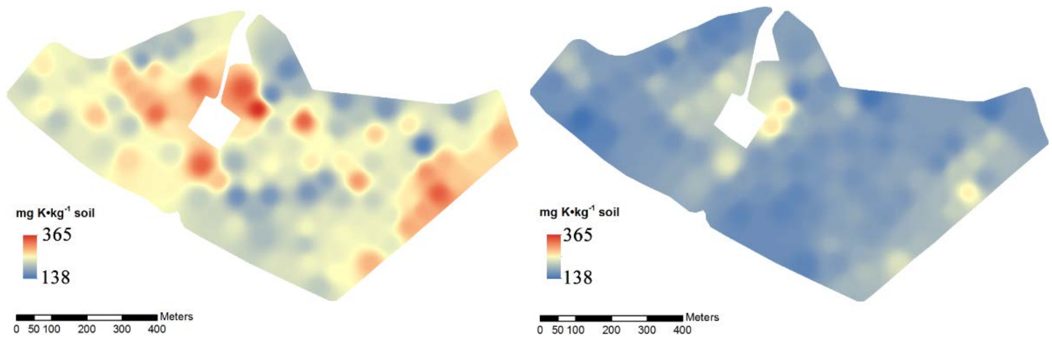
Year	Charbielin			Przeworno		
	Weighting method					
	Inverse distance	Inverse distance squared	Voronoi adjacency	Inverse distance	Inverse distance squared	Voronoi adjacency
2007	0.09	0.12	0.16	0.57	0.60	0.43
2008	0.16	0.20	0.31	0.55	0.57	0.38
2009	0.18	0.21	0.32	0.40	0.40	0.25
2010	0.16	0.20	0.28	0.33	0.34	0.16
2011	0.17	0.21	0.31	0.20	0.19	0.12
2012	0.11	0.13	0.25	0.35	0.36	0.17
2013	0.17	0.20	0.36	0.31	0.31	0.13

Regardless of the weighting method an increase in the spatial autocorrelation was observed in Charbielin (Table 4.). As presented in the maps (Fig. 5) there was a decrease in potassium content between 2007 and 2013 with well-defined equalization. Only a few small areas represented distinctly different values.

In contrast, in second area studied (Przeworno) a gradual decrease in the Moran's I index values (with one exception) was observed, implying reduction in the spatial autocorrelation of the neighbouring observation points in the course of the experiment (Table 4).

Two distinctive areas can be distinguished on the map of potassium content in 2007 (Fig. 5c) - an area with lower values in the western and central part of the field, and, second area with higher values being localized in the south and east of the field. The both were internally relatively uniform in term of potassium contents, with only four "enclaves" with lower values in the eastern margin. There was a general reduction in potassium content throughout the area as compared to 2007 (Fig. 5d), however due to the various rates of decrease a chessboard pattern developed.

Charbielin, 2007 | Charbielin, 2013



a | b

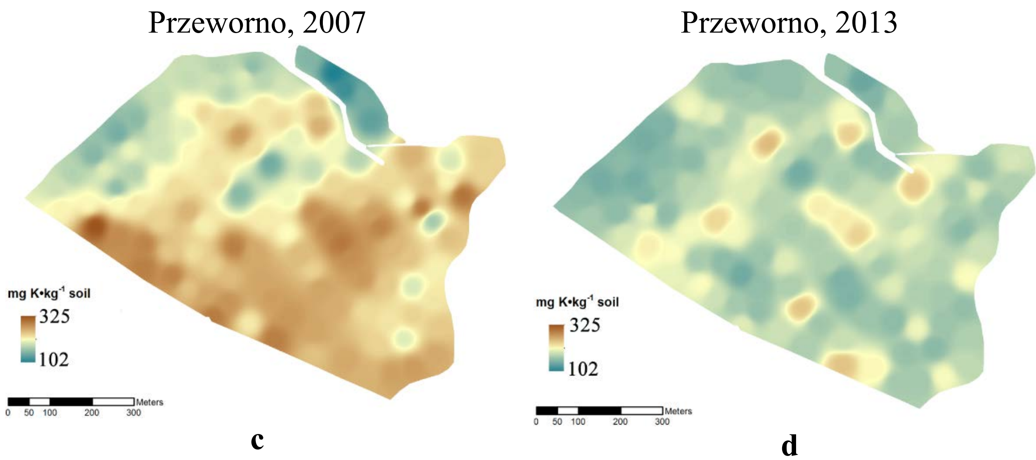


Fig. 6. Map of the interpolated (IDW – inverse distance weighting method) K contents determined in Charbielin (heavy soils) and Przeworno (light soils) at the beginning (2007) and at the end of the experiment (2013).

The spherical model were used for generation of semivariograms as described previously (Krivoruchko, 2011). The semivariograms made for lags corresponding to the average distances in the sampling gridding are presented in Fig. 6 and 7 Charbielin and Przeworno, respectively.

In both cases, there was slight decrease in semivariance sill. In Charbielin it decreased from 1.22 to 1.13 (Fig. 6), while for the second experimental field in Przeworno there was decline from 1.30 to 1.10 (Fig. 7). In additional, there was a significant decrease in semivariance range in the latter.

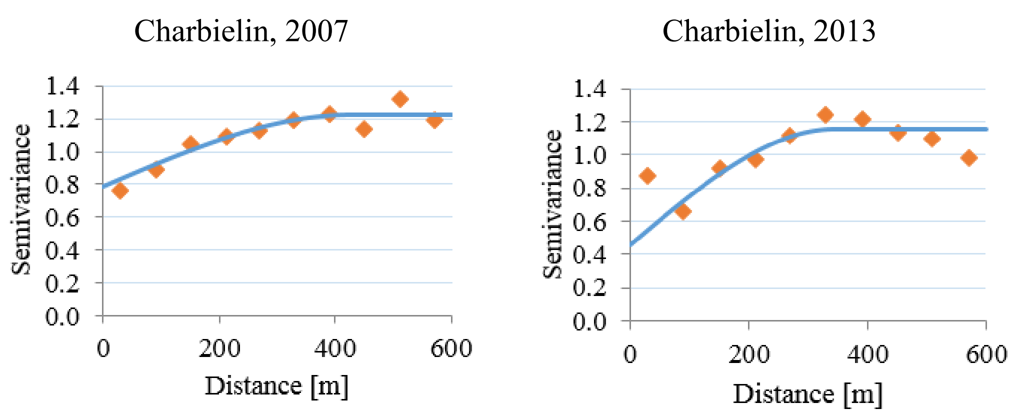


Fig. 7 Semivariogram of the K contents in Charbielin (heavy soils) at the beginning (2007) and at the end of the experiment (2013).

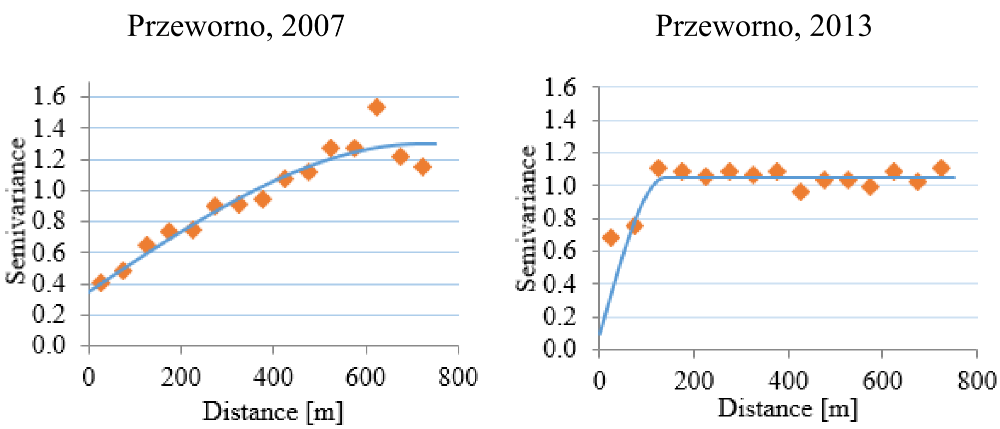


Fig. 8 Semivariogram of the K contents in Przeworno (light soils) at the beginning (2007) and at the end of the experiment (2013).

DISCUSSION

An application of the GPS technologies facilitated a fast and reliable determination of the punctual positions in cultivated lands, allowing collection of a multiple data on the spatial distribution of the physical and chemical properties of the soils (Franzen, 2011, McBratney and Pringle, 1999). Diagnosis of the spatial nutrients variability in the soils is essential for rational (i.e. adjusted to the current content) use of the mineral fertilizers. The variable rate fertilization can significantly reduce the expenses associated with the fuel and fertilizers consumption in the areas with the soluble forms of nutrients being sufficient for the optimal crop production (Havlin and Heiniger, 2009, Korsaeth and Riley, 2006, Meyer-Aurich, et al., 2008 , Robertson, et al., 2012). Another important aspect offered by the VRF technology is an essential reduction of the environmental burden resulting from an extensive use of the mineral fertilizers (Mc Lean and Watson, 1985, Sawyer, 1994, Stafford, 2000).

There are several common approaches used for determination of the fertilizer recommendations (Eckert, 1987, Havlin, et al.). The sufficiency concept of the soil testing is a major diagnostic tool used for potassium (Havlin, et al., Hergert, et al., 1997). This philosophy is based on the soil test calibrations that show no yield response to an applied nutrient when the soil tests are above a certain level. Although sometimes the sufficiency concept, used in our present study, has been criticized as being too conservative, it offers the greatest potential for most economic yield production in harmony with the concepts of nutrient management planning (Hodges, 2008). An application of the accurate values for the soil-test levels and setting of the appropriate fertilizer doses for the variable fertilization should be confirmed by the positive equalization of the content of elements in the soil. The role of the variable rate fertilization (VRF) on the equalization of potassium contents in the soils have been studied before, however the extent to which variations in soil texture determine the overall effectiveness of this approach have not been widely investigated. In addition, the studies so far reported have rather focused on the shorter-term (2-3 years long) observations of the VRF results. In our experiment, the 7-year cycle of the potassium VRF resulted in a successful decrease in the variability of the K content in both the heavy and light soils, as verified statistically. Previously, Mallarino and Wittry (2006) reported similar results in the small-scale experiment comparing both traditional potassium applications and the precision fertilization approach, in which there was lower variance in the available K forms resulting from the precision fertilization.

The variability in the level of available potassium forms in the soil is defined as high with a high coefficient of variation (CV) ranging from 39 to 157% (Mulla and McBratney, 2002). During present experiment, the highest coefficients of variation were found in the early years of the study. In 2007, the potassium CV was higher in the light soil 19.3% then in the heavy soil 17.5%; after seven years of variable fertilization, it dropped to 14.3 and 13.3%, respectively. Similar resulting CVs for potassium, achieved with the VRF techniques, were also reported before (Kulczycki and Grocholski, 2013). For large-scale fields, where an areas with differential characteristics are expected, an application of the geostatistical methods for analysis of the soils is particularly recommended (Scott and Janikas, 2010, Yost, et al., 1982). Two separate geostatistical approaches were employed for analysis of the spatial differentiation of potassium contents in our experiment – Moran's I index and semivariograms. As revealed with the Moran’s I index approach an increase in the spatial autocorrelation was observed in the heavy soils with well-defined equalization, by contrast to the light soils studied, where the observed reduction in the spatial autocorrelation was probably attributed to the more divers soil pattern. The semivariogram approach, allowing more global evaluation of the spatial variability, confirmed the results from the classic statistic methods. In both of the experimental areas studied there was a slight decrease in semivariance, implying general spatial equalization of the K contents.

CONCLUSIONS

There was a positive effect of the VRF techniques used in this experiment on the equalization of the K contents in the experimental fields, in both types of the soils studied.

The controlled suspension of the fertilization applied in the early stages of the experiment resulted in decrease of K contents toward the preferred levels.

The potassium VRF being successively employed in the experimental areas resulted in an earlier equalization of K contents in the light soils in contrast to the heavy ones.

The final spatial distribution of the potassium content was more effectively equalized in the heavy soils, with this probably resulting from the higher sorption-desorption stability.

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