Analysis of the aerial application of fertilizer and dolomitic limestone

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ABSTRACT: The paper evaluates the quality of revitalization treatments (fertilization and liming) carried out in selected areas within Forests of the Slovakia (state enterprise) during the year 2008. Revitalization treatments were carried out in declining Norway spruce forest stands in different site conditions. Full-scale aerial technology (helicopter and crop duster) was applied. The aim of the study was to find out the total amount and its variability of both fertilizers and dolomitic limestone after their application. The analyses revealed significant differences between the amount of fertilizer and dolomitic limestone which was applied to selected areas and the required amount (norm). As for fertilization, the largest difference was found in magnesium (Mg) on Šaling area (the amount of magnesium reached only 7% ± 0.5 of the norm) and in zinc (Zn) on Ľadová area (only 8% ± 1 of the norm). The required amount according to the norm was approximately met in boron (B) on Ľadová area (65% ± 10 of the norm). Yet, a significantly lower amount of fertilizers than the required one was revealed on all selected areas. After the application of dolomitic limestone to Liptovská Teplička area the significantly lower amount than the required one was found out (72% ± 12 of the norm). On the other hand, the significantly higher amount of dolomitic limestone than the required one was determined on Smolník area (143% ± 27 of the norm). Results also show the huge spatial variability of both fertilizers and dolomitic limestone on all selected areas (from 40% up to 100% between collecting places, and up to almost 170% between collectors within the collecting places). Such high variability of applied fertilizers and dolomitic limestone and the lower total amount than the required one will influence the effect of revitalization treatments.

Keywords: fertilization; liming; revitalization; variability

In recent years there has been an actual problem with the health status of Norway spruce stands in Slovakia. One of the numerous reasons for the decline of these stands can be the lack of nutrients contained in soil environment as well as in needles. One of the possible ways of revitalization can be the compensation of deficient or insufficient nutrients through large-scale liming or fertilization. Aerial technologies seem to be efficient for such large-scale revitalization treatments. The main requirement should be the homogeneous distribution of active substance (fertilizer or dolomitic limestone) on the particular forest stand area. If there is a high variability in the amount of spread substance, different effect on forest stands has to be expected. Another requirement is the low variability of soil and needle characteristics. Factors like climate, site history, management, environmental conditions (e.g. actual and historical deposition rates), humus form, C/N ratio, nitrogen reserves, and the soil chemical properties (e.g. pH, base saturation, CEC) may strongly influence the effect of liming treatments (Schaaf, Hüttl 2006).

Materna (2001) emphasized that it is necessary to perform a detailed and objective analysis of the particular cases for the relevant estimation of treatment effectiveness. It mainly means to determine soil and site conditions and the nutrient status in needles before the application of fertilizer or dolomitic limestone, and to evaluate the total amount of substance (whether the amount of substance after application is the same as the required amount) and quality (homogeneity) of its application. Borgelt et al. (1994) used geostatistical techniques to analyze the variability of the soil acidity of samples and contributed to development of a map of liming application rates in the field. Soil pH, soil texture, and buffer pH variations showed spatial dependence. The application of the average recommended rate in the field could result in an overapplication of lime in 9% to 12% of the field and an underapplication on 37% to 41% of the field. When analyzing older cases, one of the main findings is that the variability of the spread amount of substance on the particular stand area is considerably different from the required amount, and in some cases it was a difference of one order (Materna 2001).

The aim of this paper is to evaluate total amount and variability of fertilizer as well as fine fractions of dolomitic limestone applied by aerial technologies.

MATERIAL AND METHODS

Five forest areas were selected for our experiment in which revitalization treatments (in the framework of the revitalization projects for the state enterprise Forests of the Slovakia, Banská Bystrica) were carried out (Pavlenda et al. 2008; Table 1). On the basis of soil and needle analyses, two of them were proposed for liming with fine-ground dolomitic limestone and three for fertilizing with multiple liquid foliar fertilizers. In Slovenská Ľupča, an experiment for verification of the methodology was established.

The following revitalization treatments were applied:

(A) Large-scale liming with fine-ground dolomitic limestone, amount of 4 $t.ha^{-1}$ in Smolník area and 2.5 $t.ha^{-1}$ in Liptovská Teplička area, helicopter technology;

(B) Large-scale fertilization with multiple liquid foliar fertilizers. The required amount of particular nutrients (chemical elements) was as follows: Mg 40 $kg.ha^{-1}$ = 4 $g.m^{-2}$, N should not be higher than 20 $kg.ha^{-1}$, Zn 1.2 $kg.ha^{-1}$, B 2 $kg.ha^{-1}$. The total amount of nutrients contained in the solution (suspension) must not exceed 20% (i.e. the dilution of the fertilizer has to be minimally at a ratio of 1:5), aircraft technology (crop duster).

Preparation of experiment

In addition, during fertilization in Slovenská Ľupča, the samples (100 ml) of pure substance from containers in which the solution was made were taken (during its preparation). On the basis of these samples, variability of the amount of chemical elements between particular preparations of the solution was analyzed. Thus, 38 samples were taken during the whole flight day (one sample per one container). A two-stage sampling method was used to survey the amount of fertilizer or dolomitic limestone during the field application. Collectors (saucers) and collecting places (satellite – a group of three collectors) were representatively distributed on revitalized areas according to the given methodology.

Two-stage sampling was applied in order to reduce the costs of the distribution and collection of collectors, while the required precision should have been maintained. The number of sampling units (collecting places) n was specified on the basis of variability (σ_M) of values x_{ij} (x – amount of the applied substance) between the collecting places, and difference $D = (\mu_x - X_{norm})/\sigma_M$, which we considered as acceptable. The difference means the difference between the assumed applied amount and the required amount of active substance per 1 m^2 in units of standard deviation. Computation of n is rather difficult (Bätz et al.1972; Šmelko 2008). To simplify this, the optimal number of collecting places was obtained from a nomogram (Bätz et al. 1972).

Number of collectors inside the collecting place was derived according to the following formula (Šmelko 1985):

$$k_{opt} = \frac{\sigma_A\%}{\sigma_B\%}\sqrt{\frac{c_1}{c_2}}$$

where:

$\sigma_A\%$ – variability inside the collecting place (between collectors j within the same place),

$\sigma_B\%$ – variability between the collecting places j,

c_1 – costs of transport (walk, selection and establishment of collecting place),

c_2 – costs of the establishment of one collector inside the collecting place.

These input values were unknown, and in the first phase, they were only estimated. The variability inside a collecting place was expected to be lower than the variability between collecting places (at a ratio of 1:2, maximum of 1:1). The ratio of costs from 10 up to 30 was also expected. On the basis of preliminary considerations, three collectors inside one collecting place were proposed. The distance between them varied from 15 m to 50 m.

The first selection of collecting places was done in the office in order to make it more efficient. The bases were following GIS layers: boundary of revitalized areas, orthophoto (resolution of 1 m and less) and the squared grid for sampling of collecting places. The grid was established as a tool for representative distribution of the proposed number of collecting places within the revitalized area (Fig. 1, on the left). The length of the square side is variable and it is to be calculated according to the following formula (Šmelko et al. 2003):

Table 1. Selected forest areas of revitalization and the number of established collecting places and collectors

Name of revitalized area	Area (ha)	Treatment	No. of collecting places (n)	No. of collectors	Representation of collecting places (ha.n^{-1})
Liptovská Teplička	665	(A) liming	25	75	26.6
Smolník	174		21	63	8.3
Šaling	637	(B) fertilization	22	66	29.0
Habovka	794		23	69	34.5
Ľadová	536		20	60	26.8
Total	2,806		111	333	25.3

$$s = 100\sqrt{\frac{P}{n}}$$

where:
s – length of the square side (m),
P – area of revitalized forest stands (ha),
n – number of sampling units.

A suitable place for establishing a group of collectors (satellite) was selected in the office within each square of the grid. Uncovered places (non-stocked area, forest gaps and young stands) were identified in order to capture the total amount of applied substance. The position of established collectors was adjusted in the field (the boundary of the square was not allowed to be crossed). Another requirement was to ensure the representativeness of surveying areas. The number of collecting places as well as of collectors is presented in Table 1.

Collectors were distributed 1–2 days before the application of the substance. They were collected as soon as the application to one revitalized area had been finished. Revitalization of one area took about 5–7 days according to weather conditions and total area as well. The collector was a saucer 48 cm in diameter (0.1809 m^2). In the field, they were placed as a group of three collectors – satellites (Fig. 1, on the right; Šebeň et al. 2008).

Field work

During the application of the substance, there were frequent situations when precipitation water appeared in collectors. It had an influence on the collection of samples. The first idea was to take the whole sample, but it appeared to be difficult as there were often 5 litres of water in a collec-

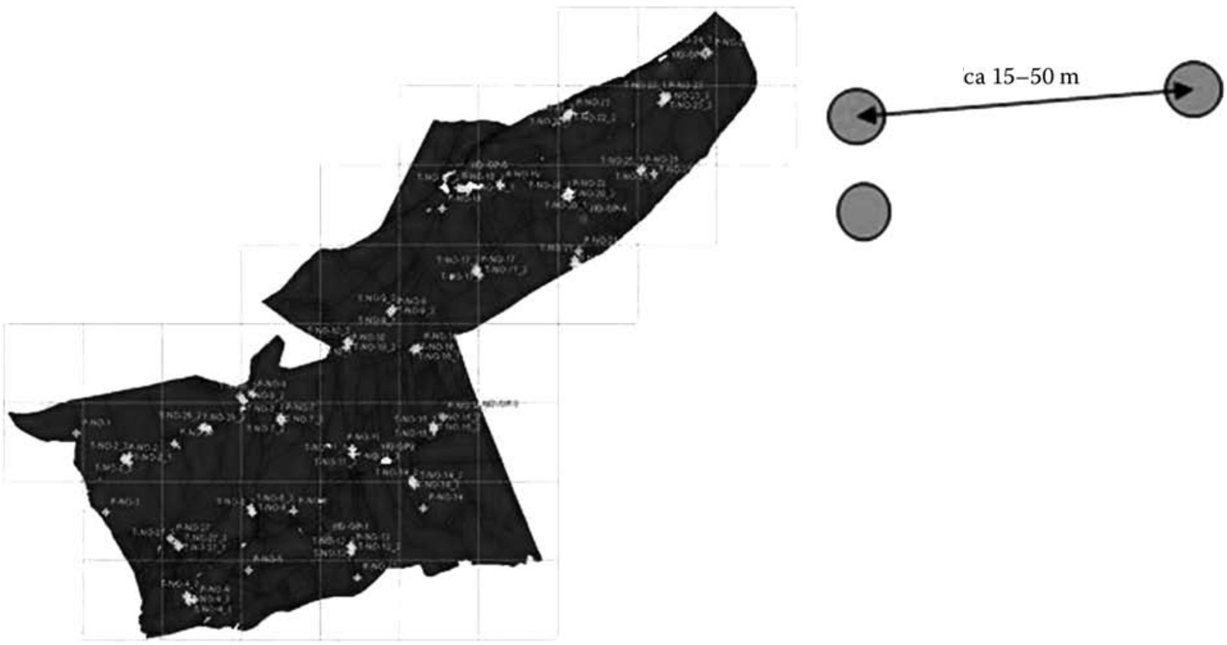

Fig. 1. Sampling design for collection of the substance in Habovka (left) and distribution of collectors within the collecting places (satellites)

tor. Hence, we used the two phases to take those samples:

(1) the samples of the solution (volume of 100 ml) were taken and the amount of precipitation was also measured (the content of chemical elements was subsequently converted to the whole volume),
(2) the solid substance (soluble after a long time) was often sunk at the bottom of the collector, therefore the water was carefully poured down so that the solid substance was kept in collectors.

These collectors as well as the collectors in which no precipitation appeared were taken to the Central Forest Laboratory of National Forest Centre in Zvolen to be analyzed. The same procedure was used during both applications – liming and fertilization.

Laboratory analyses

All laboratory analyses were carried out in the Central Forest Laboratory of National Forest Centre in Zvolen according to standard methods [AES-ICP+ aquaregy (AR), IC – ISO 10 3041, indofenol – ISO 7150, gravimetric analysis after sieve 1].

Statistical processing

The following method of statistical processing was applied:

– Mean, standard deviation and coefficient of variation within the collecting places (satellite) and between the collecting places were calculated. The standard error of total average was subsequently calculated.
– Student's t-test, whether the applied amount of the substance (limestone or fertilizer) met the required amount.
– The value t had to be more than $t_{0.05(f)}$ to be significant on the significance level $\alpha = 0.05$ for the number of degrees of freedom $f = k(n - 1)$.
– ArcMap 9.2 was used for visualization of the spatial variability of the applied substance amount.

RESULTS AND DISCUSSION

Results of analyses of samples from substances prepared at the airport

The well mixed substance solution is an essential assumption for an even supply of nutrients into soil or directly into needless (fertilization). In Table 2 we can see that even when the procedure of dilution of the substance is uniform, variability of the amount of chemical components between the containers is very high (from 30% in zinc to 46% in boron). Thus, we can state that this variability will have to be reflected in the analysis of the applied amount of the substance even when the aerial application is absolutely uniform. This leads to uneven fertilization of the revitalized area.

Results of analyses from fertilization

The final amount of the substance in a collector was calculated as the sum of the amount of chemical elements from 100 ml sample and of the rest of the solid substance from the collector. This amount was subsequently converted to units of $kg.ha^{-1}$ (fertilization) or $t.ha^{-1}$ (liming). When comparing the amount of chemical elements in 100 ml samples with the amount of the solid rest from a collector, the dissolved amount in samples is considerably higher (Table 3).

On the contrary, 100 ml samples of the solution after liming contained a minimum of the substance (from 0 to 2 $kg.ha^{-1}$) compared with the amount of dolomitic limestone in collectors (150 to 20,000 $kg.ha^{-1}$). It means that the limestone in the 100 ml sample does not have a significant influence on the total amount.

The required amount and evenness of the substance spraying have an influence on the final effect of fertilization or liming. Results from the analyses of the amount and variability of chemical elements contained in the solution of applied substance after fertilization are presented in Table 4.

Required amounts (norm) of particular chemical elements were as follows: boron 2 ± 0.2 $kg.ha^{-1}$, magnesium 40 ± 4 $kg.ha^{-1}$ and zinc 1.2 ± 0.1 $kg.ha^{-1}$. The average amount of boron, which was found out in particular revitalized areas, varied from 0.7 ± 0.1 to 1.3 ± 0.2 $kg.ha^{-1}$, magnesium from only 2.8 ± 0.2 to only 5.3 ± 0.4 $kg.ha^{-1}$. Statistical analysis showed that the amount of boron is significantly lower than the norm (Table 5).

High variability of element amounts was revealed in all surveyed areas (from 46% to 104%). Furthermore, the high variability within a satellite (group of three collectors) was surprising. It was from 33% up to 103%, and was almost the same as that between satellites. The highest variability was revealed in the amount of boron in Ľadová. The stands proposed to be revitalized were not in a compact area, which could influence the quality of aerial application. Different variability of particular elements within the respective areas, where boron achieved the highest, magnesium the mean, and zinc the lowest variability, is also noticeable.

The results showed that in none of the areas was the required amount met. In addition, high vari-

Table 2. The amount of chemical elements in the solution of the substance before application in Ľupa-Predajn (Jasenie airfield) – boron, magnesium, zinc

Statistical characteristic	Units	B	Mg	Zn
Mean	(kg.1,000 l)	5.5 ± 0.4	71.6 ± 4.4	1.5 ± 0.1
SD		2.6	26.5	0.5
CV	(%)	46	37	30
SE		**7.3**	**6.1**	**6.7**

SD – standard deviation, *CV* – coefficient of variation, SE – standard error

Table 3. The average ratio (%) of chemical elements contained in the rest from collectors and in 100 ml samples

Element	Average	Min.	Max.	SD	*CV*
B	1.4	0.2	10.3	1.6	114
Ca	8.1	2.5	16.9	3.6	44
Mg	5.3	0.7	27.4	4.8	90
K	3.6	0.4	11.7	3.2	89
Mn	24.4	1.9	217.4	32.7	134
Zn	7.5	1.0	28.7	6.5	87

SD – standard deviation, *CV* – coefficient of variation

ability of the applied amount of the substance was revealed (Fig. 2).

Results of analyses from liming

Results from the survey of the application of dolomitic limestone by helicopter are presented in Table 6. A considerably higher amount of applied dolomitic limestone than the required amount (40% ± 27%) was observed in Smolník area. In Liptovská Teplička area, the required amount of dolomitic limestone was not met. Furthermore, the enormous variability (from 97% to 103%) was revealed in both areas. These facts were a great surprise. The huge variability caused a great sampling error (20%) and significance was not proved (Table 7). To determine the statistical sig-

Table 4. Results from the sampling survey of the chemical element amounts and variability after fertilization

Fertilization	Units	Ľadová			Šaling			Habovka		
		B	Mg	Zn	B	Mg	Zn	B	Mg	Zn
No. of satellites			20			22			22	
Mean (total)	($kg.ha^{-1}$)	1.3 ± 0.2	3.9 ± 0.4	0.1 ± 0.0	0.7 ± 0.1	2.8 ± 0.2	0.4 ± 0.0	1.0 ± 0.1	5.3 ± 0.4	0.3 ± 0.0
SD (between)	($kg.ha^{-1}$)	1.4	3.1	0.1	0.7	2.0	0.3	0.9	3.2	0.1
CV (between)	(%)	104	79	57	91	71	67	93	60	46
SD (within)	($kg.ha^{-1}$)	1.4	3.0	0.1	0.7	1.7	0.3	1.0	3.1	0.1
CV (within)	(%)	103	75	44	91	60	65	106	59	33
SE (total)	(%)	13	10	6	11	7	8	13	7	4
Share from the norm	(%)	65 ± 10	10 ± 1	8 ± 1	35 ± 5	7 ± 0.5	33 ± 3	50 ± 5	13 ± 1	25 ± 1

SD – standard deviation, *CV* – coefficient of variation, SE – standard error

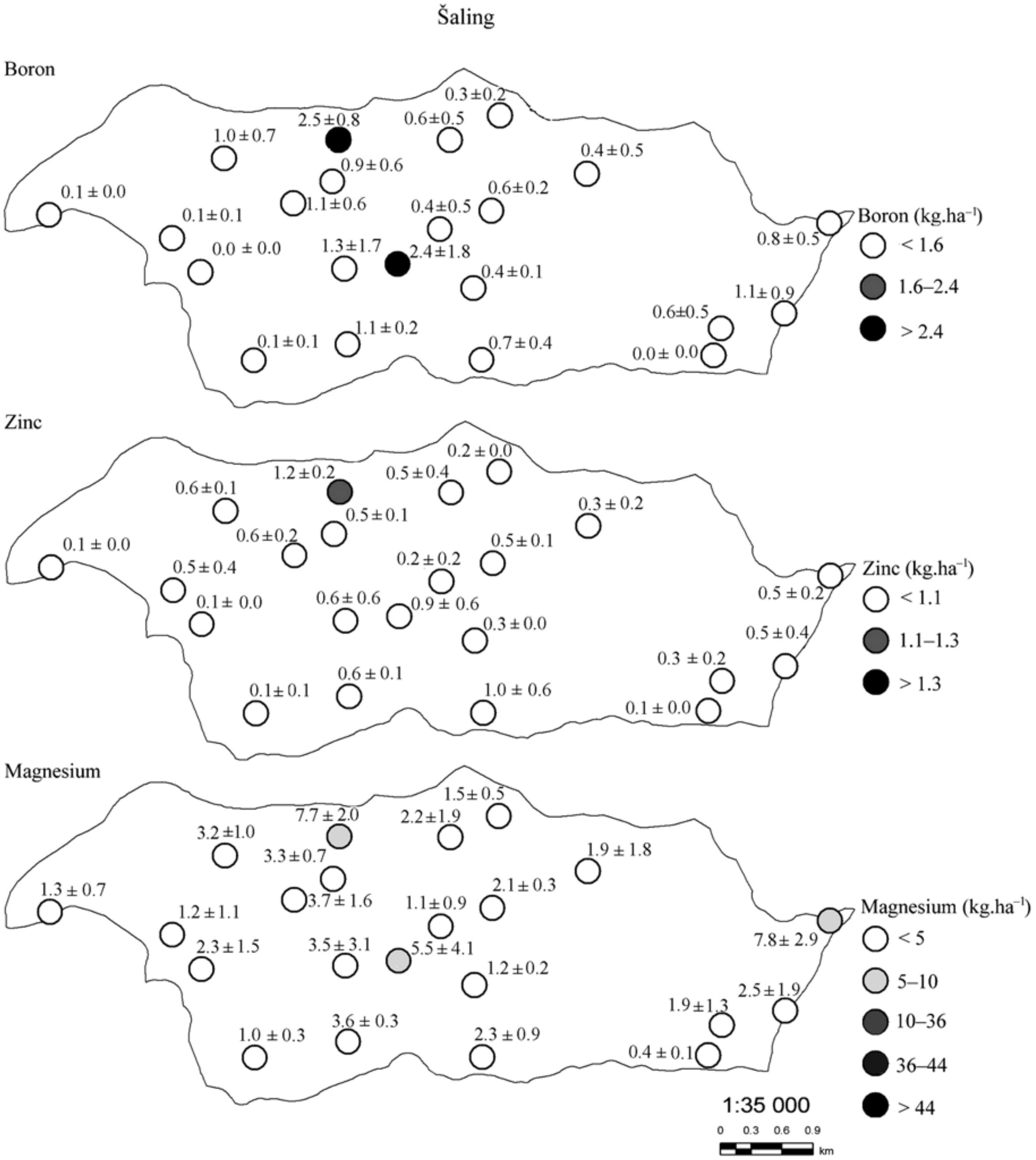

Fig. 2. Spatial variability of the applied amount of fertilizers (meeting the required amount in the particular parts of Šaling area)

nificance, it would be necessary to establish a higher number of collecting places (satellites).

To reach faster absorption and change of acidity, the higher ratio of fine-fractioned (< 1 mm) dolomitic limestone is essential (Musil, Pavlíček 2002). In Smolník area, the amount of this fraction from 2.9 to 4.2 t.ha^{-1} was found out. It means that even the amount of this fraction already met the required total amount. On the contrary, in Liptovská Teplička area the ratio of the total amount of dolomitic limestone and required amount (2.5 t.ha^{-1}) is 70%. The amount of the fine-fraction is 40% from the required amount. In Liptovská Teplička area the statistical *t*-test revealed a significant difference even though the variability was 100% (Table 7).

Fig. 3 shows the spatial variability of applied dolomitic limestone. In Liptovská Teplička the range of its amount was from 0.1 to 4.9 t.ha^{-1}. Some parts of the area were hardly treated at all. On the other hand, a higher amount than the required one was revealed in some parts. In Smolník area, the spatial variability is similar to that in Liptovská Teplička, but the difference

Table 5. The *t*-test of significance of differences between the applied amount and required amount of fertilizer

Area	B		Mg		Zn		*t*-test
	x	X_{norm}	x	X_{norm}	x	X_{norm}	
Ľadová	1.30	2.0	3.90	40	0.1	1.20	$X < X_{norm}$*
Šaling	0.7	2.0	2.80	40	0.4	1.20	$X < X_{norm}$*
Habovka	1	2.0	5.30	40	0.3	1.20	$X < X_{norm}$*

*Significance level α = 0.001

Table 6. Results from the sampling survey during liming

Liming	Units	Smolník			Liptovská Teplička		
		total	fraction > 1 mm	fraction < 1 mm	total	fraction > 1 mm	fraction < 1 mm
Number of collecting places			20			25	
Mean (total)	($t.ha^{-1}$)	5.7 ± 1.1	2.2 ± 0.5	3.5 ± 0.7	1.8 ± 0.3	0.8 ± 0.1	1.0 ± 0.2
SD (between)	($t.ha^{-1}$)	5.6	2.1	3.6	1.8	0.8	1.1
CV (between)	(%)	99	97	101	100	99	103
SD (within)	($t.ha^{-1}$)	8.7	3.5	5.2	2.4	1.0	1.4
CV (within)	($t.ha^{-1}$)	153	164	147	139	138	140
SE (total)	(%)	20	22	19	16	16	16
Share from the norm		**143 ± 27**			**72 ± 12**		

SD – standard deviation, *CV* – coefficient of variation, SE – standard error

Table 7. The *t*-test of significance of differences between the applied amount and required amount of dolomitic limestone

Area	x	X_{norm}	*t*-test
	($t.ha^{-1}$)		
Liptovská Teplička	1.8	2.5	$x < X_{norm}$*
Smolník	5.7	4.0	$x > X_{norm}$*

*Significance level α = 0.05

is the required total amount was met there. It was met in 3/4 of the area. What should be pointed out is the low amount of applied dolomitic limestone on the eastern part, where the required amount was not met at all.

The effect of aerial fertilization and liming depends on whether the required amount of the substance was really applied and on variability of its application. One of the ways how to manage this is to use modern technology. In 2003 the Polish State Forests bought the first aircraft for aerial spraying. It was the Ag-Nav 2 model, manufactured by the Canadian factory Picodas (Majewski 2005). This aircraft ensures precise spraying on small areas and excludes areas where no treatments are planned.

CONCLUSION

New information from a sampling survey of the amount and variability of fertilizer and dolomitic limestone large-scale application to forest stands has been acquired. The contents of chemical elements (boron, magnesium, zinc) in the fertilizer and dolomitic limestone were surveyed separately.

Many specialists studied fertilization and liming as possible revitalization treatments in declining Norway spruce forest stands (Badalík, Řezáč 2001; Musil, Pavlíček 2002; Podrázský et al. 2003; Schaaf, Hüttl 2006) or as measures to increase the volume increment (Derome et al. 1986; Materna

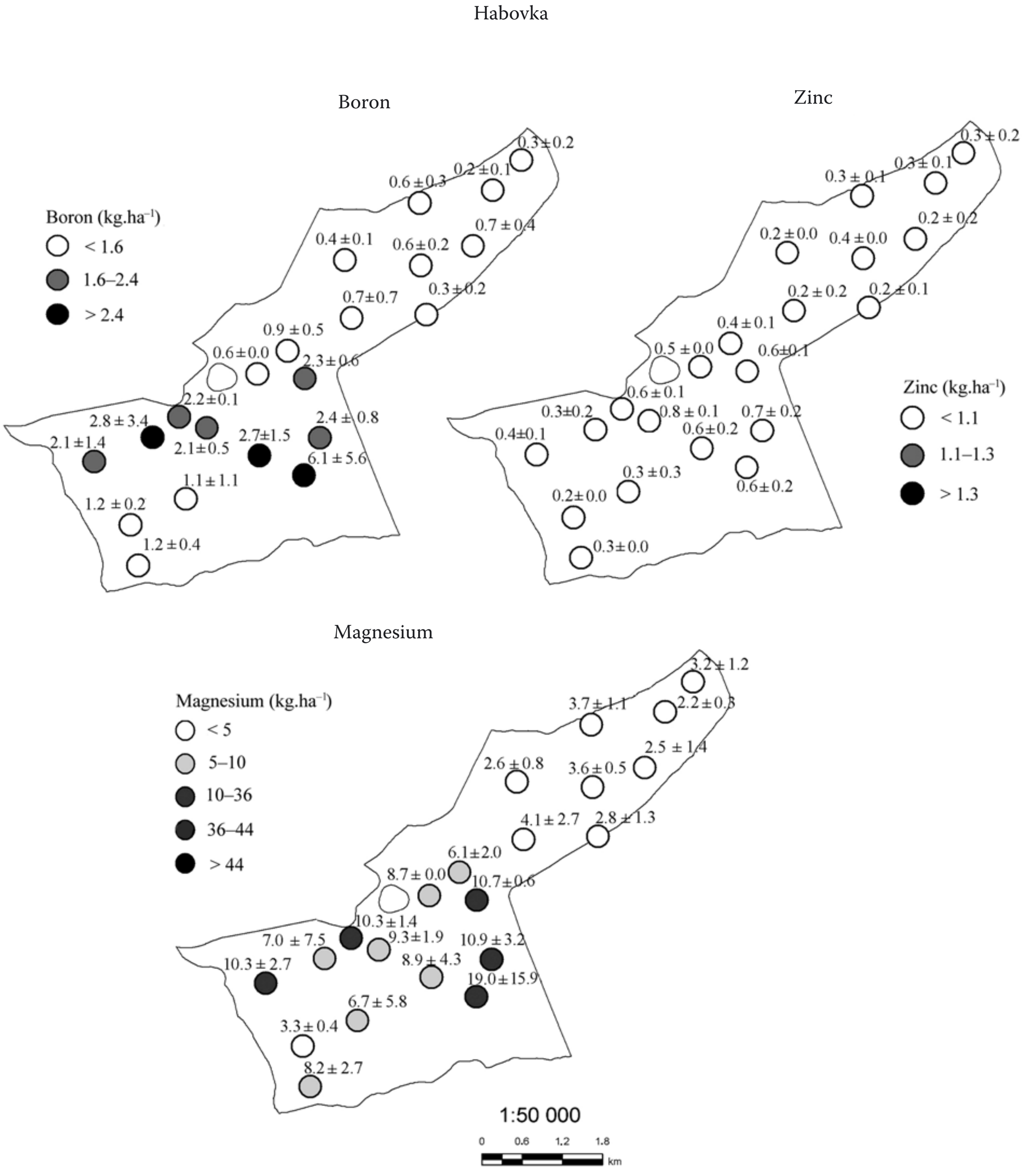

Fig. 3. Spatial variability of the applied amount of fertilizers (meeting the required amount in the particular parts of Habovka area)

2001). On the other hand, the complex analyses of aerial spraying and quality (variability) of aerial application of both fertilizer (using a crop duster) and dolomitic limestone (using a helicopter) have not been performed yet. Materna (2001) emphasized that an objective and detailed analysis of particular events are necessary for relevant quantification of the effect of revitalization treatments. It means to know particular conditions, to find out whether the amount of fertilizers or dolomitic limestone met the required amount and whether it is of required quality as well. He also reported older events when the variability of the amount of applied material was high and the total amount of fertilizers differed from the required amount. During our analyses, the insufficient amount of applied substance was revealed in all revitalized areas. The highest amount of boron (from 35% to 60% of the norm), medium amount of zinc (from 8% to 33% of the norm) and the lowest amount of magnesium (from 7% to 13% of the norm) were

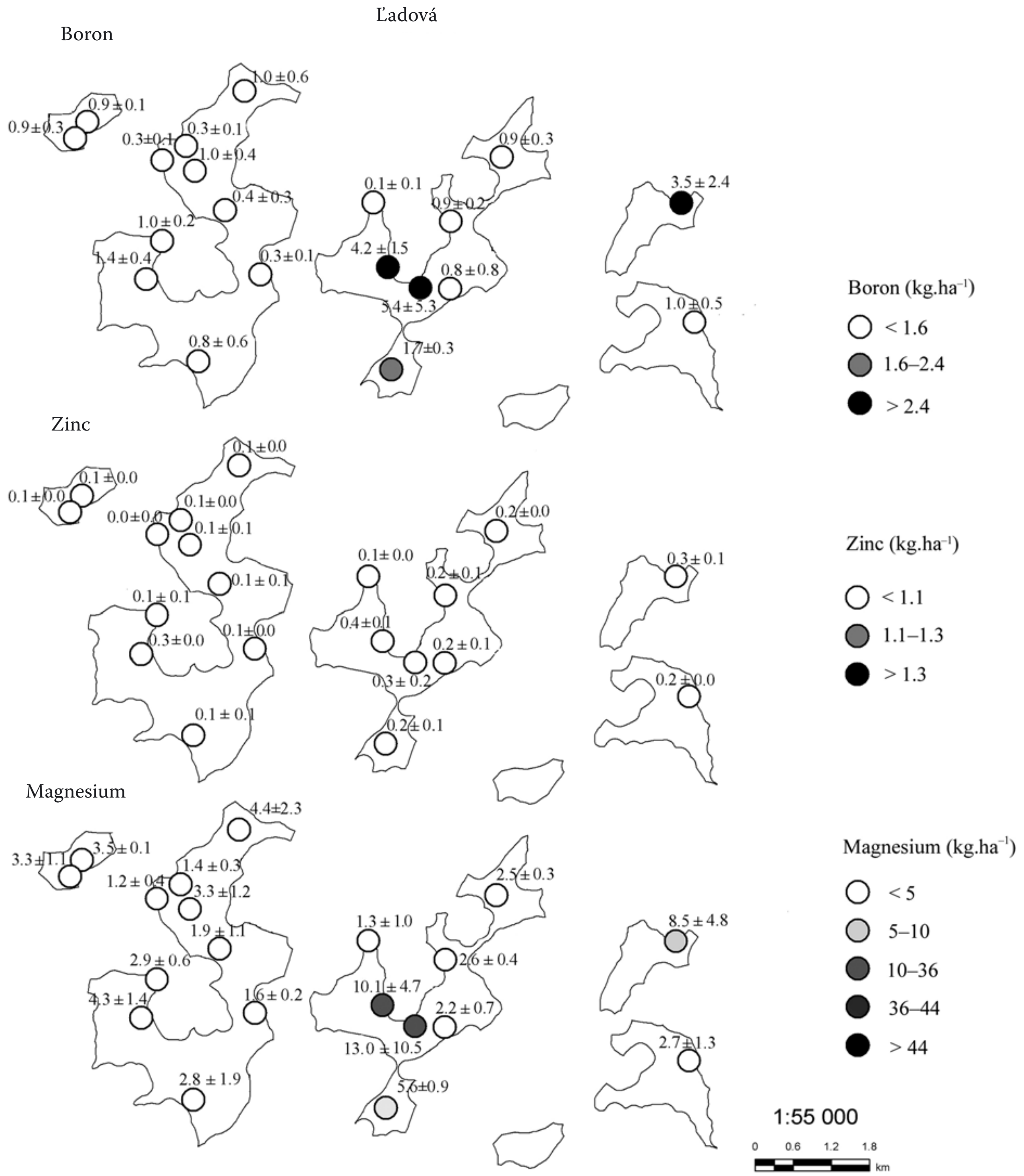

Fig. 4. Spatial variability of the applied amount of fertilizers (meeting the required amount in the particular parts of Ľadová area)

observed. The high variability within the groups of three collectors as well as between them (coefficient of variance from 40% to 100%) was also discovered. At the majority of the collecting places (satellites) a lower amount of the substance than the required one was observed. The required amount (in some parts even a higher amount) was approximately met in boron in the southern part of Habovka.

The amount of dolomitic limestone dissolved in precipitation water (in a collector) was not significant. To find out the total amount of limestone in a collector we need just to take insoluble limestone sunk to the bottom of a collector. Fractions below 1 mm were recognized as well. In Smolník area, the considerably higher amount of applied limestone (5.7 ± 1.1 t.ha^{-1}) than the norm (4 t.ha^{-1}) was found out. The required amount was met even in fractions below 1 mm (3.5 ± 0.7 t.ha^{-1}). In Liptovská Teplička area, the total amount of applied dolomitic limestone (1.8 ± 0.3 t.ha^{-1}) was significantly lower than the

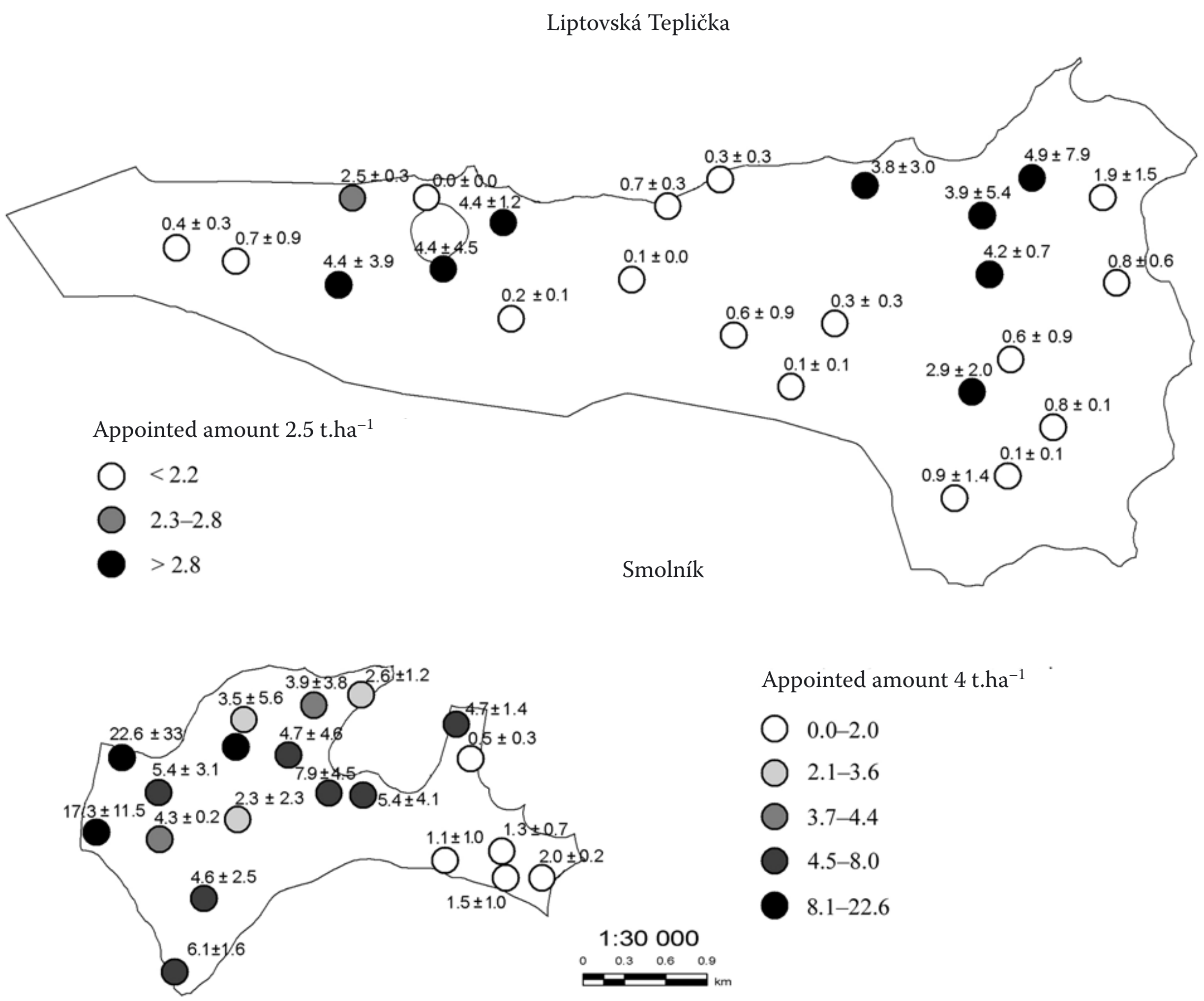

Fig. 5. Spatial variability of the applied amount of dolomitic limestone (meeting the required amount in the particular parts of the area)

norm (2.5 t.ha^{-1}) and the amount of fractions below 1 mm was only 1.0 ± 0.2 t.ha^{-1}. The high variability within collecting places as well as between collecting places was revealed. The largest difference in the amount of dolomitic limestone within the collecting places (satellites) was from 0.2 to 10 t.ha^{-1}, between satellites it was from 0.2 to 60 t.ha^{-1}.

Presented results showed very high variability of the aerial application and lower amounts than the norm. This must have a negative influence on the effectiveness of such treatments. Therefore, it is possible to judge such treatments as less effective, even though the relevant arguments can be obtained only by monitoring after several years.

There will be a space for research which could bring more relevant information on the effect of large-scale fertilization or liming with respect to stand age, growth stage, representation of Norway spruce, regeneration, nature of stands, height structure, soil status, tree damage and other factors that could influence the effect of such treatments. The problem is that the study of their effect needs a long time of investigations to be recognized. Controversial liming of forest stands represents very complicated problems. Their complexity is given particularly by high variability of the complex of factors that jointly affect the results of liming itself (Musil, Pavlíček 2002).

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