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ANALYSIS OF GAME DAMAGE ESTIMATION METHODS IN WINTER WHEAT (*TRITICUM AESTIVUM*) THRUOGH GIS SIMULATIONS

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ABSTRACT

Wildlife damage to agriculture causes significant economic loss worldwide annually. Game managers or hunters are responsible for the financial compensation of the crop damage caused by game species in several countries, including Hungary. Accredited experts estimate the level of the damage; however, currently, there are no standardised methods that would be obligatory to apply. In order to obtain information on the accuracy and bias of the different sampling methods, we designed GIS simulations in winter wheat (*Triticum aestivum*), which covers a significant proportion of the arable land not only in Hungary, but also globally.

We tested two sampling methods with three sampling plot arrangements in a GIS environment. Our questions were the following: (1) How accurate and biased are the examined samplings? (2) Does the rate or the spatial distribution of the damage (or the interaction of these factors) affect the results of the investigated methods? We created 15 wheat field models with 1:2 side ratio, 12 cm row width and the area of 3 ha. We simulated 5 damage rates (10%, 30%, 50%, 70%, 90%) and 3 spatial damage patterns [random, aggregated in 1 and 2 field edges], of which the latter two follow the actual pattern of crop damage caused by big game species. V, W and X sampling tracks were allocated on each field model, and then they were sampled with square shaped, 1 m^2 quadrats and 1 m long row sections (with 5 repetitions). The sample size was 20 and 25 plots, respectively (determined by the original description of the methods). At the sample plots, the total number of plants and the number of damaged plants were counted. According to our results, the statistical parameters of the different samplings were similar; the difference between the best and the poorest values was low. The rate and spatial distribution of the damage, as well as their interaction, had a significant effect on the estimation of each quadrat sampling, while the row sections were significantly affected only by the damage distribution (V and W tracks) or the damage rate (X track). According to our findings however, the difference between the labour-intensity of the two approaches can be decisive. With the sample sizes in our study, remarkably lower number of plants had to be examined along the row sections, than in the quadrats. This suggests that the experts can obtain similar quality results with less effort, if they choose the row section sampling over the quadrats.

Keywords: Winter wheat, *Triticum aestivum*, game damage, sampling, damage estimation

INTRODUCTION

Wildlife damage to agriculture causes significant economic loss worldwide annually (CONOVER, 2002; CSÁNYI, 2018; MAILLARD *et al.,* 2010; PUTMAN, 2010). According to the legislation, the game managers or hunters are responsible for the financial compensation of the crop damage caused by game species in several countries (FINDO and SKUBAN, 2010; FRĄCKOWIAK *et al.,* 2013; MAILLARD *et al.,* 2010), including Hungary (BLEIER *et al.,* 2012a, 2012b). Accredited experts estimate the level of the damage (Act LV., 1996: Act on Game Conservation, Management and Hunting); however – currently – there are no standardised methods that would be obligatory to apply. Due to the lack of studies on the accuracy and bias of the different sampling methods, the experts are often not able to choose among them on a scientifically sound basis (BALÁZS, 2011; BLEIER, 2014). In order to support them with relevant results, we designed GIS simulations in winter wheat (*Triticum aestivum*), which covers a significant proportion of the arable land not only in

Hungary but also globally. As several game species [e.g. Wild boar (*Sus scrofa*), Red deer (*Cervus elaphus*) and Brown hare (*Lepus europaeus*)] cause damage to the wheat, it is an essential plant species regarding the game damage estimation.

In the present study, we tested two sampling methods with three sampling plot arrangements in a GIS environment. Our questions were the following: (1) How accurate and biased are the examined samplings? (2) Does the rate or the spatial distribution of the damage (or the interaction of these factors) affect the results of the investigated methods?

MATERIAL AND METHOD

For the GIS simulations we created 15 wheat field models with 1:2 side ratio and the area of 3 ha. The field models were based on a point grid with 12 cm row width and 5,000,000 wheat grains/ha (Varga and Kása, 2011), therefore the initial number of points was 14,976,028. In order to simulate the incomplete germination, we deleted a randomly selected 15% of the points (James and Lloyd, 1995), therefore the total number of points used in the actual work was 12,729,624.

We simulated 5 damage rates (10%, 30%, 50%, 70%, 90%) and 3 spatial damage patterns (random, aggregated in 1 and 2 field edges – *Figure 1*). The aggregated setup simulates the effect of a neighbouring forest on the actual pattern of crop damage caused by big game species based on previous field studies (Bleier *et al.,* 2006, Bleier *et al.,* 2017, Cai *et al.,* 2008, DeVault *et al.,* 2007, Hofman-Kamińska and Kowalczyk, 2012, Thurjfell *et al.,* 2009). In or study, we created 30 m wide buffer zones along 1 or 2 edges of the field, in which we allocated min. 80% of the damaged plants. Where the total number of plants in the buffer zone was less than the 80% of the damaged plants, the buffer zones were considered as entirely damaged areas.

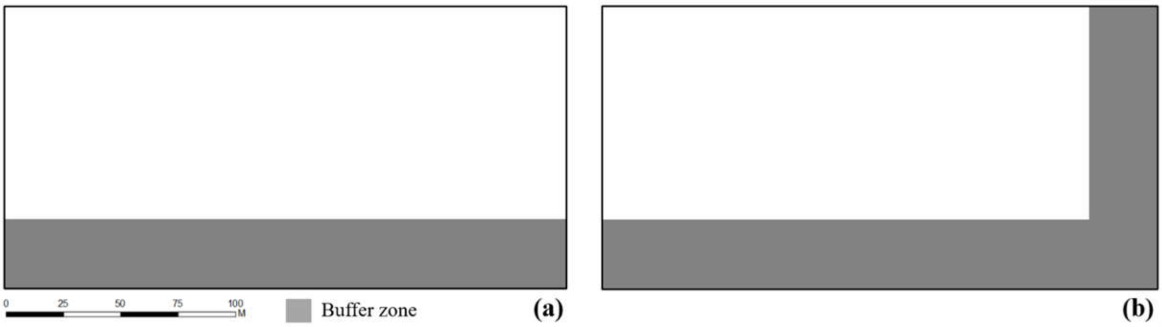

Figure 1. Simulated spatial patterns of damage distribution: aggregated in 1 (a) and 2 (b) field edges

V, W and X sampling tracks (*Figure 2*) were allocated on each field model, and then they were sampled with square shaped, 1 m^2 quadrats and 1 m long row sections. The sample size was 20 and 25 plots, respectively (determined by the original description of the methods: Klátyik, 2003, Király and Marosán, 2016). At the sample plots, the total number of plants and the number of damaged plants were counted. The damage rate was calculated as $(\sum DP / \sum TP)$ X 100, where DP was the number of recorded damaged plants and TP was the total number of wheat individuals observed.

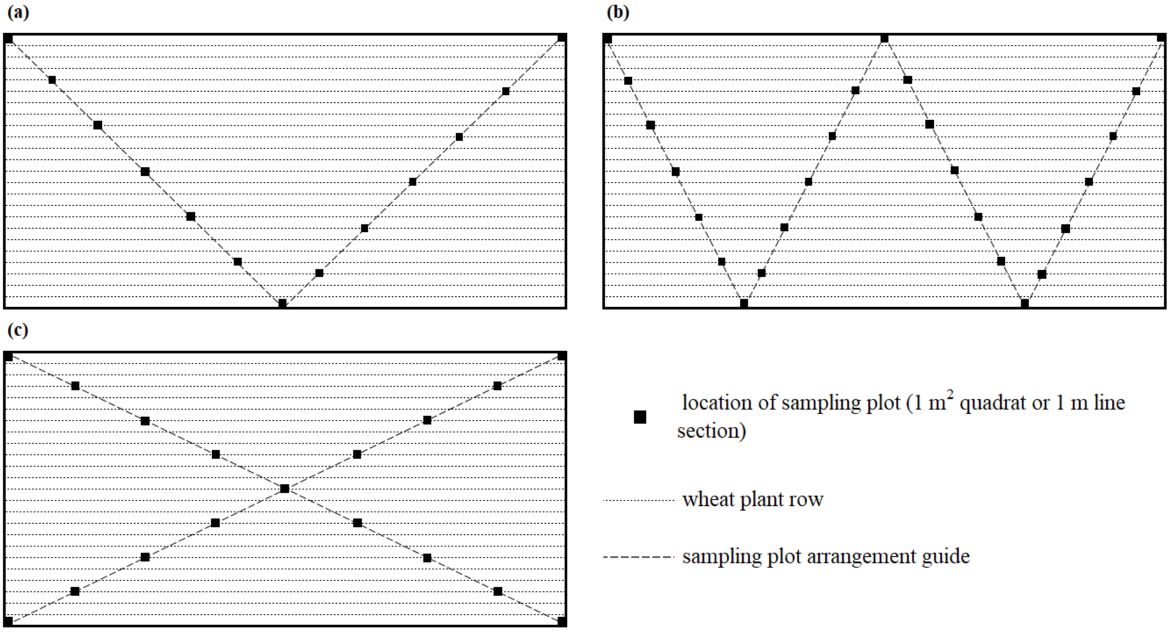

Figure 1. Arrangement patterns and schematic locations of the quadrats: V (a), W (b), X (c)

In order to simulate the differences in the samplings conducted by different experts in a real-life situation, we performed 5 repetitions of the samplings on each field model with each method. To repeat the samplings, we relocated the quadrats and line sections. This meant slipping each plot to the same distance and direction (e.g. with 1 m or 1 row upwards), which allowed us to keep the original spatial arrangement of the sampling.

We characterised the estimations by the Mean Squared Error (MSE), the Standard Error (SE) and the bias. Before calculating means for these statistical parameters, we tested the normality of the data of each 5 repetition groups with Kolmogorov-Smirnov test. Two-way ANOVA was conducted to identify the factors (true damage rate, spatial distribution of the damage or the interaction of these two values) that have a significant impact on the Percentage Relative Bias (PRB) of the estimations. Pairwise comparisons were performed with Tukey post-hoc test.

The GIS simulations were conducted in QGIS 2.18 Las Palmas (QGIS Development Team, Open Source Geospatial Foundation Project). In the statistical analysis we used R v2.15 (R Development Core Team) software.

RESULTS

Considering the single estimations, the difference from the true damage rate varied between -4.9% (1 m line sections with V arrangement, 30% true damage rate, damage aggregated 1 field edge) and 5.4% (1 m^2 quadrats with X arrangement, 30% true damage rate, damage aggregated 1 field edge).

In terms of the calculated parameters (*Table 1*), the quadrat sampling with W arrangement provided the majority of best values in the case of each parameter (expected value: 27% of the best values, MSE: 40%, SE: 47%, bias: 27). Overall, the quadrats with X arrangement provided most (60%) of the worst values in the case of the estimated damage rate and bias, while the majority of the poorest values of the SE (67%) and MSE (40%) were resulted by line section sampling with V arrangement.

It should be noted that since the bias and mean damage rate values are in direct connection, these two parameters always show the same method as best and as worst in case of each spatial damage pattern and damage rate combination.

It is interesting to mention that in the case of SE, only best or neutral values were obtained with the quadrat samplings, while the line section sampling resulted only the poorest or neutral values.

Table 1. Damage estimation, MSE, SE and bias of the investigated methods (black background: best values; gray background: poorest values)

Damage distribution			Random					Aggregated in 1 field edge					Aggregated in 2 field edges				
True damage rate (%)			10	30	50	70	90	10	30	50	70	90	10	30	50	70	90
Estimated damage (expected value)	1 m^2 quadrats	V	10.11	30.16	50.15	69.76	90.14	8.87	25.65	47.31	68.28	89.38	10.32	31.05	50.99	70.38	90.22
		W	10.01	29.84	50.06	69.93	89.82	8.73	25.79	46.82	68.49	89.16	10.14	30.91	51.02	70.79	90.10
		X	10.14	30.23	50.34	70.17	89.99	11.78	34.78	53.22	71.97	90.47	11.17	33.82	54.16	72.52	90.67
	1 m line sections	V	10.11	29.98	49.87	70.63	89.64	8.67	25.74	47.16	68.23	89.00	9.43	29.54	48.90	68.76	90.22
		W	9.37	29.38	49.66	70.12	90.16	9.47	29.91	49.44	70.28	90.44	10.70	31.74	51.35	71.54	90.61
		X	9.81	29.06	50.43	69.65	89.66	9.19	29.39	49.34	70.11	89.61	9.78	29.46	48.96	70.43	90.03
MSE	1 m^2 quadrats	V	0.10	0.29	0.52	0.25	0.03	1.33	19.24	7.45	3.75	0.48	0.13	1.26	1.09	0.34	0.11
		W	0.08	0.18	0.05	0.03	0.07	1.66	17.83	10.29	2.69	0.72	0.05	0.98	1.21	0.81	0.04
		X	0.06	0.49	0.30	0.19	0.21	3.35	22.93	10.65	4.17	0.23	1.48	14.65	17.43	6.40	0.52
	1 m line sections	V	0.60	2.94	1.57	3.38	0.64	3.94	18.40	9.00	5.21	2.50	2.24	1.43	2.10	4.62	0.16
		W	0.94	2.00	1.68	0.42	0.38	0.91	0.42	2.13	1.72	0.50	2.14	3.30	2.77	2.91	0.98
		X	0.54	2.95	1.08	1.25	0.29	1.15	0.97	1.28	0.77	0.47	0.27	1.50	1.43	0.50	0.42
SE	1 m^2 quadrats	V	0.34	0.57	0.79	0.49	0.09	0.28	0.60	0.52	0.99	0.35	0.17	0.45	0.38	0.49	0.28
		W	0.31	0.43	0.24	0.18	0.21	0.24	0.40	0.44	0.73	0.13	0.18	0.43	0.48	0.48	0.21
		X	0.22	0.74	0.48	0.45	0.51	0.49	0.39	0.58	0.61	0.13	0.37	0.25	0.34	0.30	0.31
	1 m line sections	V	0.86	1.92	1.39	1.93	0.79	1.64	0.59	1.08	1.62	1.37	1.54	1.24	1.05	1.97	0.38
		W	0.82	1.42	1.40	0.72	0.67	0.89	0.72	1.50	1.43	0.62	1.43	0.59	1.09	0.82	0.88
		X	0.80	1.61	1.06	1.18	0.47	0.78	0.87	1.03	0.98	0.63	0.53	1.23	0.66	0.63	0.72
bias	1 m^2 quadrats	V	0.11	0.16	0.15	-0.24	0.14	-1.13	-4.35	-2.69	-1.72	-0.62	0.32	1.05	0.99	0.38	0.22
		W	0.01	-0.16	0.06	-0.07	-0.18	-1.27	-4.21	-3.18	-1.51	-0.84	0.14	0.91	1.02	0.79	0.10
		X	0.14	0.23	0.34	0.17	-0.01	1.78	4.78	3.22	1.97	0.47	1.17	3.82	4.16	2.52	0.67
	1 m line sections	V	0.11	-0.02	-0.13	0.63	-0.36	-1.33	-4.26	-2.84	-1.77	-1.00	-0.57	-0.46	-1.10	-1.24	0.22
		W	-0.63	-0.62	-0.34	0.12	0.16	-0.53	-0.09	-0.56	0.28	0.44	0.70	1.74	1.35	1.54	0.61
		X	-0.19	-0.94	0.43	-0.35	-0.34	-0.81	-0.61	-0.66	0.11	-0.39	-0.22	-0.54	-1.04	0.43	0.03

According to the two-way ANOVA, the rate and the spatial distribution of the damage, as well as the interaction of these factors had a significant effect on the PRB of the quadrat samplings with each spatial arrangements. The PRB of the line section samplings was affected only by the spatial damage distribution (V and W arrangement) or the true damage rate (X arrangement) (*Table 2*). The Tukey post-hoc test did not reveal any patterns, the significant differences distributed variably among the pairwise comparisons.

Table 2. Estimation affecting factors based on two-way ANOVA (*p<0.001; **p<0.01; *p<0.05)**

Sampling method		Damage rate	Spatial damage distribution	Rate-distribution interaction
1 m^2 quadrats	V	**F4=10.511*****	**F2=206.120*****	**F8=29.592*****
	W	**F4=23.654*****	**F2=284.021*****	**F8=36.216*****
	X	**F4=79.576*****	**F2=128.189*****	**F8=19.432*****
1 m line sections	V	**NS**	**F2=8.3238*****	**NS**
	W	**NS**	**F2=8.0766*****	**NS**
	X	**F4=2.9341***	**NS**	**NS**

CONCLUSIONS

Based on our results, we cannot conclude that any of the examined samplings would be able to provide remarkably better quality results in general. Consistent under- or overestimations (when each 5 repetitions shows difference from the true damage rate in the same direction) were also present in the case of both approaches. After analysing multiple different statistical parameters, we found that it is variable that which sampling results the best and the poorest values in the different damage rate and spatial distribution scenarios. For example, based on the calculated parameters (expected value, SE, MSE, bias), the 1 m^2 quadrats provided the best values more often than the 1 m line sections, but on the other hand, the absolute difference (without ranking) between the performance of the samplings was often low. Moreover, the PRB of the line section samplings proved to be affected by less factors than the same parameter of the quadrat estimations.

In summary, we found the applicability of the two estimation principles (quadrats and line sections) and the three sampling plot arrangements generally similar, which means that one should look for further aspects to support the selection among the available sampling approaches. The experts have to consider the sampling efforts (ENGEMAN and STERNER, 2002), therefore the difference between the labour-intensity of the two approaches can be decisive. In the present study, remarkably lower number of plants (approx. 15% with the current exact simulated field area and sample sizes) had to be examined along the row sections, than in the quadrats. This suggests that the experts can obtain similar quality results with less effort, if they choose the row section sampling over the quadrats.

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