Journal für Kulturpflanzen, 73 (9-10). S. 324–329, 2021, ISSN 1867-0911, DOI: 10.5073/JfK.2021.09-10.03 Verlag Eugen Ulmer KG, Stuttgart



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# Estimating damage caused by wild animals to crops by comparing yields

Schätzung der von Wildtieren verursachten Schäden an Kulturen durch den Vergleich von Erträgen


## Abstract

Growing populations of large herbivores have caused significant damage to crops in recent years. The situation is exacerbated by the lack of reliable methods for determining the extent of the damage and for the subsequent calculation of the compensation for the destroyed crops. In this study, we defined the conditions and options for application of method for estimating damage caused by wild animals, which is based on comparison of yields in damaged and undamaged areas. This method is a good compromise between time consumption and accuracy of the damage determination. The proposed method also covers competition problems (undamaged plants with eliminated competition may have an increased yield) and growth compensation (for example when the plant is damaged at an early stage of growth) that the currently used methods could not objectively evaluate. This method is also suitable for determining the damage of a wide range of agricultural crops. The method described is a thought experiment and needs to be tested in practice to compare its accuracy and complexity with other methods.


**Key words:** Crop damage; browsing; wild herbivores; damage quantification


## Zusammenfassung

Wachsende Populationen großer Pflanzenfresser haben in den letzten Jahren erhebliche Schäden an Nutzpflanzen verursacht. Verschärft wird die Situation durch das Fehlen verlässlicher Methoden zur Bestimmung des Schadensausmaßes und zur anschließenden Berechnung der Entschädigung für die zerstörten Ernten. In dieser Studie haben wir die Bedingungen und Möglichkeiten für die Anwendung der Methode zur Abschätzung der durch Wildtiere verursachten Schäden definiert, die auf dem Vergleich der Erträge in geschädigten und nicht geschädigten Gebieten basiert. Diese Methode ist ein guter Kompromiss zwischen Zeitaufwand und Genauigkeit der Schadensermittlung. Die vorgeschlagene Methode deckt auch Wettbewerbsprobleme (unbeschädigte Pflanzen mit eliminierter Konkurrenz können einen erhöhten Ertrag haben) und Wachstumskompensation ab (z. B. wenn die Pflanze in einem frühen Wachstumsstadium beschädigt wird), die mit den derzeit verwendeten Methoden nicht objektiv bewertet werden können. Diese Methode ist auch für die Schadensbestimmung einer Vielzahl von landwirtschaftlichen Kulturen geeignet. Sie muss jedoch in Zukunft durch weitere Studien weiterentwickelt werden. Bei der beschriebenen Methode handelt es sich um ein Gedankenexperiment. Sie muss in


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**Submitted/Accepted**
11 July 2021/13 September 2021

der Praxis getestet werden, um ihre Genauigkeit und Komplexität mit anderen Methoden zu vergleichen.

**Stichwörter:** Ernteschäden, Verbiss, wilde Pflanzenfresser, Schadensquantifizierung

## Introduction

Wild herbivores, in accordance with the theory of optimal nutrition, are looking for food that will ensure optimal energy gain (Westoby, 1974; Bleier et al., 2017). Therefore, animals at certain times prefer agricultural crops for their high nutrients, and thus, cause a significant damage to the crops. The extent of the damage is the result of several factors. However, the extent of damage is most related to the number of large herbivores that caused significant increase in the amount and cost of environmental damage in recent decades. In extreme cases, the damage was so great that it limited the business management and did not allow cultivation of more attractive crops (Conover et al., 2018; Hohbein & Mengak, 2018). One of the reasons of these persistent problems is the complexity of determining the amount of damage. The affected enterprises are thus in a situation, where they are unable to quantify the damage, and thus, cannot request financial compensations.

In current practice, two methods are most used to determine the amount of damage to agricultural crops. The first is based on inspection of the observed area and estimating the damage extent in sub-areas. The second method uses aerial photography to estimate the damage. For both of these methods, the primary data source for subsequent damage calculations is the size of the damaged area expressed in absolute terms in $m^2$, or a in relative terms by proportion of the damage.

Estimating the extent of damage by visual inspection method is the most used method, especially since no special equipment is needed to work in the field. The stands are inspected in a way that the inspected area is representative of the damage distribution. However, the method has several drawbacks. In particular: it is a time consuming method; there is a risk of secondary physical damage to the crops; there is a high risk of results being influenced by the evaluator; it is impossible to use in impenetrable crop areas; and there is also a risk of a significant underestimation of the damage in poorly visible parts (Bayani et al., 2016). On the other hand, Remote Survey Methods (Puri et al., 2017) are done by drone imaging. For this, the damage assessment is based either on a simple photograph viewing or on automated 3D-point analysis and subsequent identification of different crop height categories, or on recognition of crops colour changes caused by the herbivore's food behaviour. The advantage of remote survey is that there is no damage to crops during the damage assessment and data collection, and the damage evaluation is not time consuming due to the option of automatic categorisation. The disadvantage of aerial photography, in addition to the demands on technology, is that it can underestimate some types of damage even more than the visual inspection method. While drones would prevent increased damage made to crops by walking in it, there is a high risk of overlooking the cases where damage occurred in early stages of the growth and the damaged plants were able to regenerate and reached a similar height to the surrounding vegetation. However, the earlier damage is manifested by a decrease or complete absence of crops production (Kamler et al., 2009; Bayani et al., 2016). It is, therefore, common to have a significant difference between the estimated damage and the compensation received (Ogra & Badola, 2008; Haney & Conover, 2013). The cost of taking aerial pictures and partly the time spent for photo-processing also limits the usability of this method, although it is becoming more and more affordable.

Practical application of both above mentioned methods encounters some difficulties, and therefore, other methods are sought to estimate the amount of damage in a less demanding way while maintaining the necessary accuracy. Comparing yields could be one potentially good method, where the amount of damage could be estimated by comparing the yields in damaged and undamaged areas. The yield is either measured by weighing the crop, or directly during harvesting using sensors on the harvesting machines and GPS for monitoring the harvested area. This procedure is mainly used for machine-harvested crops, however, can also be applied to crops harvested by hand (Srivastava et al., 2018). One great advantage of this method is that it minimizes the demanding collection of damage data in the field and uses yield data that can only be obtained quite easily. At the same time, this Comparison Method also eliminates the usual underestimation of damage due to poor visibility. Under ideal conditions, the damage can be estimated with high accuracy and minimal difficulty. In practice, however, this method is dependent on correct selection of the reference area. It is best to use a damaged field, on which undamaged parts are selected for comparison as reference areas. Animal damage is usually unevenly distributed, where the damage is usually highest near the shelter from which the animals come to the field (Bleier et al., 2017). Therefore, it is often possible to find a continuous undamaged area of the field. At the same time, however, it is necessary to respect possible unevenness in the yield (for example due to shading, dampness, erosion or other influences) that could be significant in large fields. Therefore, the reference area must be of such a size and distribution as to represent the yield of the observed field with sufficient accuracy. Failure to respect this condition could result in errors and might even result in the damaged area having a higher yield than the undamaged reference area. Nevertheless, to have an ideal model for systematic distribution of reference areas throughout the field is practically impossible (Kovács et al., 2020) as damaged areas cannot be avoided and pure undamaged harvest would be technically too demanding. Thus, it is necessary to find a reasonable compromise, which would include a parameter of "reasonable labour" to determine the yield on the reference area, including consideration for the harvesting technique, in particular the width of the harvesting machine. The proposed method was created as a thought experiment based on the study of literature review and experience with other methods. For implementation it needs to be tested and statistically evaluated.

## Proposed Comparison method of Yields in One Area

The amount of damage is calculated from the difference between the yields of the damaged area and the undamaged reference area. Undamaged parts of the observed field are used as reference areas, but only if there is a comparable yield potential. To determine the similarity of yield potentials, it is recommended to use map data of average potential yields (Fig. 1). This data is becoming more available thanks to the growing precision agriculture and is mostly available online (for example for the Czech Republic they can be found at www.agrihub.cz). In the selected area, we use GIS to determine the standard deviation or a coefficient of variation, which determines the homogeneity degree of the particular field. Based on these quantities and the required accuracy, we then determine the size of the compared area. We placed the reference area in the field outside the damaged areas while taking into account the potential yield according to the yield map. This increased the accuracy of the damage quantification even further (Fig. 2).

For risk areas, where severe damage is very likely, an undamaged part can be fenced off in advance. At the same time, care should be taken to ensure that the crop yield conditions on the reference area are the same as on the damaged area and that the reference area is clearly defined in size and is easily harvestable, e.g. a multiple width of the harvesting machine. The yield of the reference area can also be determined manually from small experimental areas, which should be spaced with regard to field variability. These small areas should be checked in the reference area and also in the damaged areas and the aim is only to compare the yield potential. Thus, it is possible and preferable to present the result of such a comparison in relative values (%), rather than in absolute yield. This eliminates any possible errors in the yield estimation for the manual experimental method and also for the standard harvesting technique. If the yield and the damage are inhomogeneous in the observed field, then it would not be possible to set a sufficiently large reference area there, and thus, this method would be unsuitable.

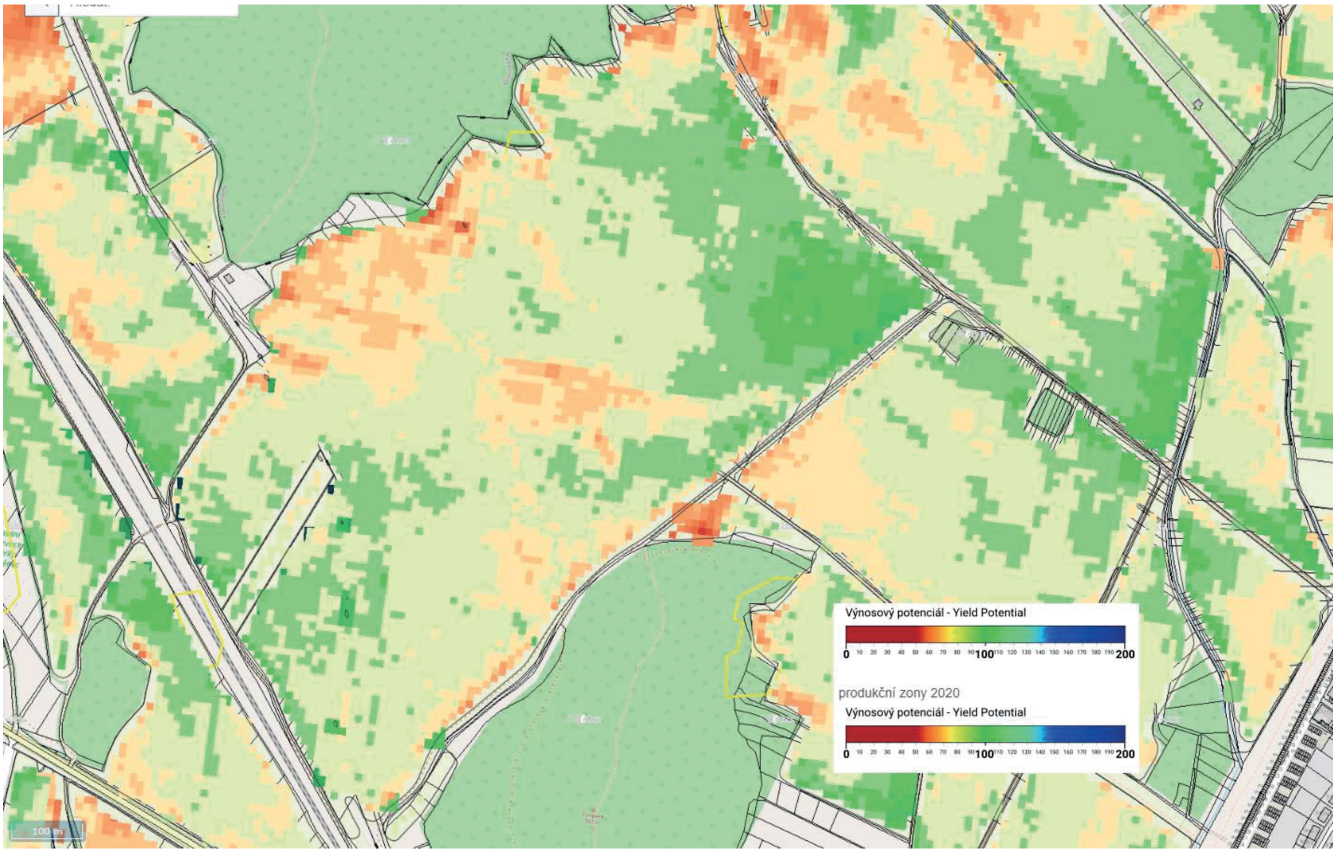


**Fig. 1.** Example of a yield potential map.

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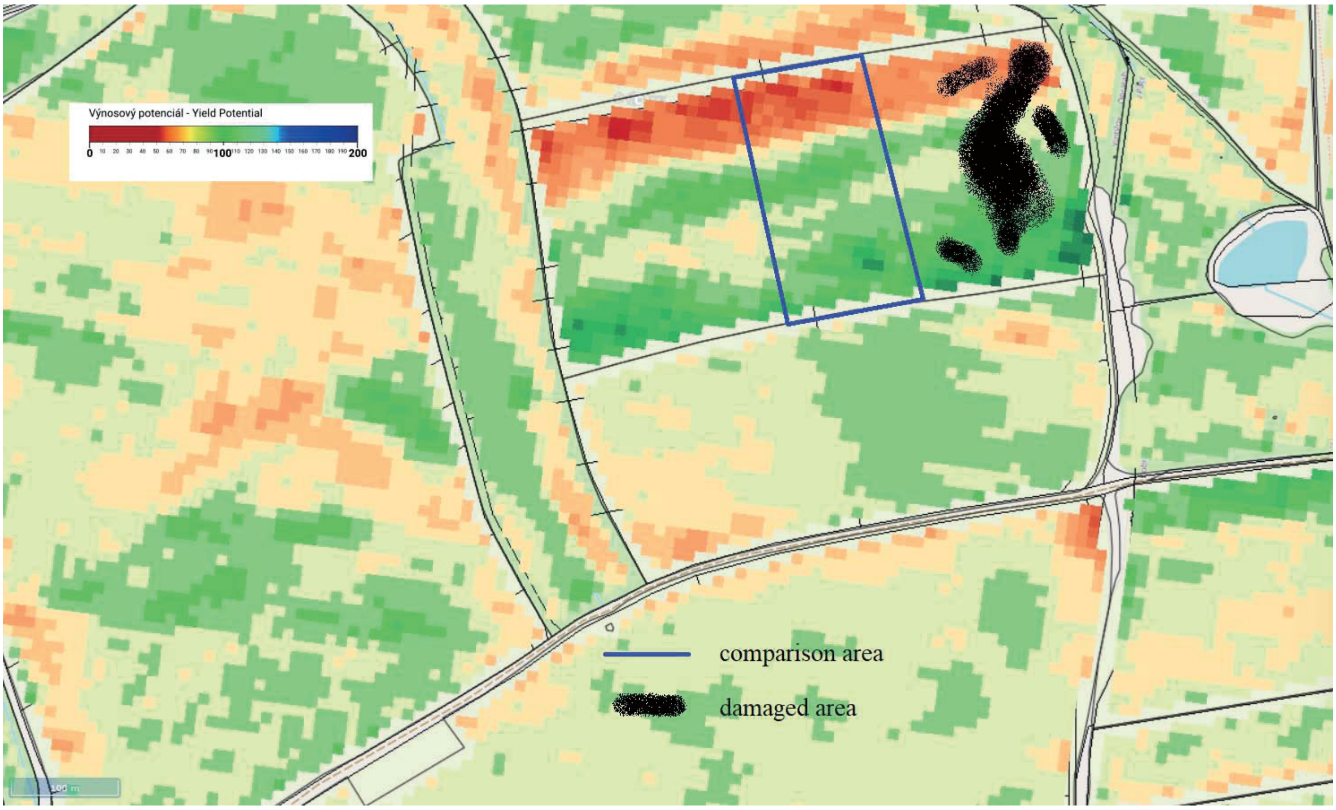


**Fig. 2.** Correct location of the compared area according to the yield map.

The damage can be calculated as follows:

$$N = \frac{Y_2 \times P_1}{P_2} - Y_1$$

$Y_1$ = yield achieved on the damaged area (t)
$Y_2$ = yield achieved on the undamaged area (t)
$P_1$ = area of damaged field (ha)
$P_2$ = area of undamaged field (ha)
N = loss of production (t)

## Discussion

Comparative methods for estimating damage caused by animals on agricultural crops have the potential to be effective methods of determining damage in practice. Nowadays, it is possible to use yield maps, compiled on the basis of multispectral satellite data from Sentinel-2A/B and Landsat 8 (Řezník et al., 2020), for the selection of reference areas, and thus avoid the time-consuming yield determination of the reference and damaged areas. These documents are currently available for a lot of agricultural lands. To eliminate the calculation error, it is advisable to use these maps only for comparison of the relative yield potentials in the monitored territories and not for accurate prediction of crop yields, although one study has conducted correlations between the predicted yield and the measured yield at a 95% accuracy level (Řezník et al., 2020). The difference between the predicted yield and the actual field yield is then called a yield gap (Lobell et al., 2009). The size of the comparison area can be determined by standard statistical methods for area size determination based on reliability interval.

Comparing yields of the damaged crops shows the rate of production loss even for hard-to-control crops. The indisputable advantage is that it evaluates even minor damage. The visual inspection method or the drone survey are not able to detect damage by browsing that is spread over large area and is mainly caused by deer walking through the crops. It is said that visual damage evaluation usually estimates significantly lower loss compared to other methods as the damage is not always noticeable. Visual evaluations also show an inconsistent deviation compared to harvest-based methods. This means that even the visual inspection conversion correction for more accurate damage determination cannot be used, and thus, visual estimation is unreliable (Bayani et al., 2016).

Unlike visual inspection methods, comparative methods are also suitable for large and complicated areas. In addition, they are in many cases also more suitable than remote survey methods that are so far used for large continuous areas damaged by intensive grazing, trampling or rolling, and for monitoring pasture damage caused by wild boars (Rutten et al., 2018). In particular, comparative methods eliminate the inability of other methods to

**Table 1. Assumed suitability of methods for estimating damage to field crops by wild animals.**

| Type of Vegetation | Visual Inspection Method | Remote Survey Method | Yield Comparison |
|---|---|---|---|
| Large Areas | – | + | + |
| Small Areas | + | – | + |
| Low Vegetation | + | + | + |
| High Vegetation | – | + | + |
| Scattered Damage by Browsing | 0 | – | + |
| Area-concentrated Damage | + | + | + |
| Damage-sensitive Crops by visual inspection | 0 | + | + |
| Damage at an Early Stage of Growth | 0 | – | + |
| Cost of Damage Estimation | 0 | – | + |
| Time-consumption | – | 0 | + |

Comment: – problematic, 0 usable under certain conditions, + suitable

accurately quantify the regeneration and compensatory growth of the damaged plants (Thomson et al., 2003; Scholes & Paige, 2014). For example, in plants damaged in the early stage of growth, the damage may not result in a decrease in yield (Poveda et al., 2018). In some cases, slight damage can even increase crop production. However, the exact effects of damage on yield depend on a number of factors (growing phase, damage intensity, weather pattern). Thus, the same intensity of damage to the vegetative parts of plants may have different effects on the yield depending on the current conditions (Petkov et al., 2017). While it would be possible to determine the intensity of damage to the crop in the individual growing stages and model the relevant yield on the basis of it, this procedure would be very time-consuming and also with a significant risk of error, as each plant is damaged differently and the damage occurs continuously over a long period of time. As the quantification of crop damage by comparative methods occurs only at the time of harvest, the problem of crop production compensation after damage at an early stage of growth, as well as an increase in yields of undamaged plants due to lower crop density, are fully taken into account. Similarly, these methods also take into consideration secondary damage caused by climatic conditions, after primary damage by animals.

Other advantages of the proposed method are their low demand on time, personnel and costs. Based on our own knowledge and information from publications, we propose this method, which is suitable for different types of crops (Table 1). When using the proposed methodology, it is advisable to support the damage type by photodocumentation. It is also useful to use the tools of the developing precision agriculture, such as yield maps, showing the distribution of crop damage, or drone footage that determines the amount of biomass in the area (Gil-Docampo et al., 2020).

## Conclusion

We propose a method for assessing damage caused by wild animals on agricultural crops. It is based on the calculation of damage using comparison of the actual yield on the damaged area with the yield expected on a similar undamaged area.

By comparing production on damaged and undamaged areas, all the production losses are captured – taking into account the ability of plants, damaged at an early stage of growth, to compensate for the damage, as well as the ability of undamaged plants to increase their production due to the density decrease in the vegetation.

This method is cheaper and less time consuming than the existing methods for determining production losses. However, this method needs to be extended by further studies and can be further modified.

## Conflicts of interest statement

The authors declare no conflicts of interest.

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