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ARTICLE

Use of unmanned aerial system to assess wildlife (*Sus scrofa*) damage to crops (*Zea mays*)

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Abstract: Damage caused by ungulates to agricultural areas is difficult to evaluate because the real extent of the damage remains usually poorly described and potentially leads to conflicts. Recent advances in unmanned aerial systems (UAS) provide new versatile mapping and quantification possibilities in a wide range of applications. We used crop fields (*Zea mays*) damaged by wild boar (*Sus scrofa*) and compared the extent of the damage by means of three methods: (*i*) traditional ground-based assessment; (*ii*) UAS orthoimages with operator delineation; and (*iii*) UAS crop height model with automatic delineation based on height threshold. We showed for the first time that UAS can be applied for assessing damage of ungulates to agriculture. The two methods using UAS imagery provide coherent and satisfactory results and tend to underestimate the damage area when compared to in-use ground-based field expertise. However, we suggest that performance of UAS should further be tested in variable conditions to assess the broad application of this tool. Our study describes the potential of UAS as a tool for estimating more accurately the damage area and subsequently the compensation costs for wildlife damage. The proposed approach can be used in support of local and regional policies for the definitions of compensation for farmers.

Keywords: remote sensing, *Sus scrofa*, photogrammetry, wildlife damage, crop damage, UAV, UAS, drone.

Résumé : Les dommages que causent les ongulés aux zones agricoles sont difficiles à évaluer, car habituellement l'étendue réelle des dommages demeure mal décrite ainsi que les possibilités de conflits. Les progrès récents dans le domaine des systèmes aériens sans pilote (UAS) fournissent des nouvelles possibilités polyvalentes de cartographier et quantifier dans une vaste gamme d'applications. Nous avons utilisé les champs cultivés (*Zea mays*) endommagés par les sangliers (*Sus scrofa*) et comparé l'étendue du dommage au moyen de trois méthodes : (*i*) l'évaluation classique sur le terrain ; (*ii*) les ortho images à partir d'un UAS avec délimitation par l'opérateur et (*iii*) le modèle de la hauteur de la récolte par UAS avec délimitation automatique selon un seuil de hauteur. Nous avons montré pour la première fois qu'un UAS peut être utilisé pour évaluer les dommages causés par les ongulés à l'agriculture. Les deux méthodes utilisant l'imagerie UAS fournissent des résultats cohérents et satisfaisants et ont eu tendance à sous-estimer la zone endommagée lorsque comparés à l'expertise en usage sur le terrain. Cependant, nous suggérons que la performance du UAS soit mise à l'essai dans des conditions variables afin d'évaluer l'application générale de cet outil. Notre étude décrit les possibilités de l'UAS comme outil pour estimer plus précisément la zone endommagée et subséquemment les coûts de compensation pour les dommages

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causés par la faune. L'approche proposée peut venir appuyer les politiques locales ou régionales dans la détermination des compensations aux fermiers. [Traduit par la Rédaction.]

Mots-clés : télédétection, *Sus scrofa*, photogrammétrie, dommage à la faune, dommage aux récoltes, véhicule aérien sans pilote (UAV), système aérien sans pilote (UAS), drone.

Introduction

Global increase of ungulate populations

During the last decades, ungulate populations have increased and expanded, becoming overabundant in large parts of their range (Côté et al. 2004). The causes of this overabundance are multifactorial, involving simultaneously (*i*) higher food resource availability, naturally from the increase of mast production (Drobyshev et al. 2014) and artificially from agriculture and supplementary feeding (Milner et al. 2014), (*ii*) increased availability of suitable lands due to land abandonment (Navarro and Pereira 2012) and the net gain of forest cover in Eurasia (Hansen et al. 2013), climate change (Forchhammer et al. 1998), and its interaction with natural food resources availability (Bieber and Ruf 2005; Vetter et al. 2015). The expansion of ungulate populations leads to the increase of conflicting situations with humans' activities (e.g., forestry and agriculture or vehicle collisions). Although forest cover is globally increasing in Europe, forests are suffering from landscape fragmentation converting large forest areas into small patches embedded in agricultural matrix (Jongman 2002). Forest fragmentation increases the interface between forest and agricultural lands, and consequently enhances the risk of human–ungulates conflicts (Putman et al. 2011).

Farmer–ungulate conflicts

Although most ungulates can be originally considered as forest-dwelling species, they have the inherent and adaptive ability to cope with open landscapes (Hewison et al. 2001; Keuling et al. 2009; Szemethy et al. 2003). The progressive adaptation of ungulate species to farmland landscapes even led, in the case of the European roe deer (*Capreolus capreolus*), to the description of two distinct (morphologically, behaviorally, and ecologically) ecotypes, the "forest" and the "field" roe deer (Fickel and Reinsch 2000). Owing to the large cover and abundance of food resources provided by agricultural lands, ungulates are seasonally attracted to croplands because of the high-energy food resources provided by agriculture, in a period when resources in forests are usually relatively low. These seasonal habitat shifts between forest and agricultural lands result in damage that affects crop harvest and income (Putman et al. 2011).

Wild boar

Among ungulates, wild boar (*Sus scrofa*) is probably the species raising the most concern in its native (Morelle et al. 2016; Putman and Apollonio 2014) and invasive ranges (Barrios-García and Ballari 2012). Although living under forest cover most of the year, during the growing season (June to September) wild boar may move their center of activity to agricultural lands to benefit from cover and food resources (Keuling et al. 2009; Morelle and Lejeune 2014). This seasonal movement results in damage to various crops (Herrero et al. 2006; Schley and Roper 2003).

Cost-compensation issue

In Europe, annual damage caused by wild boar to agriculture is evaluated at 80 million euros (Putman and Apollonio 2014). This cost is, however, based on a variety of different assessment methods, considering that there is currently no well-established and accepted method to accurately assess damage (i.e., every European country (and even regions within) uses its own method). Whatever the assessment method used, farmers suffering damage will usually be paid through a compensation system. The compensation system may be the responsibility of game management units at the local or regional scale (i.e., hunters owning hunting rights in the damaged area) or a public institution when damage is caused by species listed as protected (Apollonio et al. 2010). As the financial compensation is directly related to the damage, estimation methods are mandatory to ensure that compensation paid is accurate. Most of the time, damage is only assessed in the field through visual damage assessment in limited parts of the crop (Clark and Young 1986; DeHaven and Hothem 1979; Gabrey et al. 1993). Proposing new tools to improve traditional estimation methods of damaged areas poses a challenge in human–wildlife conflicts. The current challenge is to develop tools enabling relevant measurements of the damaged areas to ensure fair financial compensation for farmers.

Emergence of the unmanned aerial system (UAS) technology

UAS have recently emerged as an important support tool providing various environmental applications, such as forest biodiversity assessment (Getzin et al. 2012), precision farming (Bendig et al. 2013), wildlife census and monitoring (Linchant et al. 2015), and tree and forest characterization (Michez et al. 2016). The scientific community is more and more enthusiastic about the application of UAS in ecology, proclaiming the "dawn of drone ecology" (Koh and Wich 2012) or that the UAS "will revolutionize spatial ecology" (Anderson and Gaston 2013). The very high spatial and temporal resolutions are the two most important characteristics of UAS imagery. This allows the description of events occurring at a very local scale in a finite time window, such as ungulate damage.

UAS to estimate crop damage

In agriculture, UAS have already been developed for multiple uses (Huang et al. 2013) such as dispersing pesticides, mapping crop fields with remote sensing imaging, monitoring growth and response to different soil conditions, management and irrigation techniques. UAS can also support thermal imaging, allowing the detection of deer fawns in grasslands (Christiansen et al. 2014; Israel 2011) where they are at high risk of mortality during mowing operations (Jarnemo 2002). However, to our knowledge the use of UAS for the specific estimation of crop damage by ungulates has not been assessed.

The use of UAS to measure the height of crops is a regular application of UAS in precision agriculture (Bendig et al. 2013; Honkavaara et al. 2013). This task is regularly undertaken by terrestrial LiDAR (light detection and ranging) laser scanning (Zhang and Grift 2012) and UAS laser scanning (Anthony et al. 2014). Another solution, simultaneously cheaper and precise enough for this type of application, consists of generating crop surface model from photogrammetric point clouds (>10 points/m^2) derived from UAS-based RGB imaging, combined with LiDAR digital terrain model (Bendig et al. 2013, 2014).

Though wild boars consume a variety of agricultural crops (Schley and Roper 2003), they have a marked preference for corn (*Zea mays*), that can be 75% of its diet by volume (Herrero et al. 2006). We consequently focused our attention on damage caused by wild boar to corn fields. We evaluated the potential of UAS for detecting wild boar damage to corn fields by the use of UAS orthophoto and hybrid crop height models (CHM) (from photogrammetric surface model and LiDAR terrain model). More specifically, we investigated orthophoto and CHMs derived from low-cost UAS imagery as a tool to map and assess the damaged areas. This UAS approach was compared to the traditional ground-based damage assessment method.

Study area

The study area was located in Wallonia (southern Belgium, Fig. 1), in the Upper Ardenne ecoregion (5°56′3 E, 50°18′0 N, average altitude: 400 m). Corn cultivation had recently expanded in the region (Delcour et al. 2014), and forest cover together with high wild boar population densities resulted in regular damage to corn fields (Widar 2011).

Methods

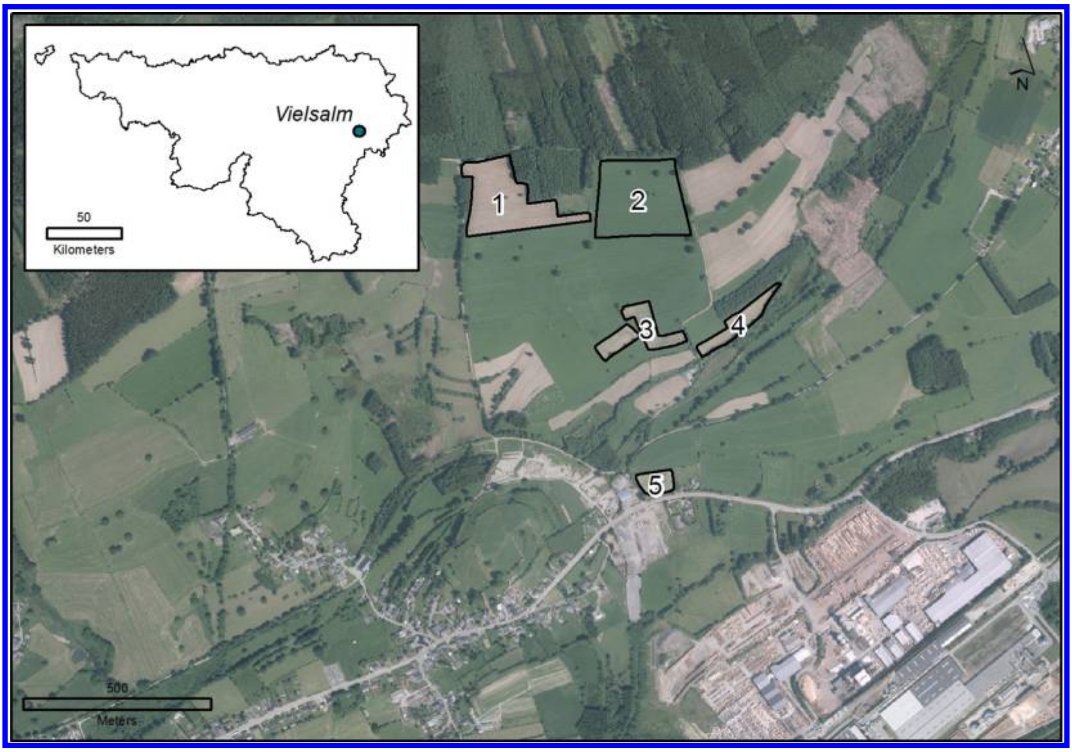
Acquisition of UAS imagery

To capture imagery, we used the UAS Gatewing X100 (wingspan, 100 cm; weight, 2 kg; cruise speed, 80 km/h; flight height, from 100 to 750 m; www.uas.trimble.com) equipped with a Ricoh GR3 (www.ricoh.com) camera (10 megapixel sensor, focal length 6 mm). We performed the aerial survey during the late growing season of corn because of the higher palatability of maize for wild boar at this period (Schley et al. 2008). The flight duration never exceeded 45 minutes, with a flight altitude of 200 m. The front and side overlaps between images were set to 80%. The UAS surveys were performed the 29th of September and the 27th of October 2014.

Photogrammetric processing and CHM computation

To perform photogrammetric survey, we used the Agisoft Photoscan 1.0 professional software (http://www.agisoft.com/) with the information from the inertial measurement unit and the GPS positions recorded by the UAS. These data are combined to a set of ground control points (GCP) to perform an initial aerotriangulation. The georeferencing process was based on a set of known points (road crossings, roofs, and pedestrian crossings) used as GCP in the Photoscan interface. The GCP planimetric and altimetric coordinates were defined using regional reference datasets (orthophoto coverage (0.25 m ground sampling distance, GSD) and LiDAR digital terrain model). The photogrammetric point cloud was computed at high resolution, using the "high accuracy" photoscan parameter. To ensure the altimetric accuracy of the generated digital surface model (DSM), we performed a registration process within CloudCompare software (http://www.danielgm.net/cc/), to match the photogrammetric model with the regional LiDAR coverage.

Fig. 1. Location of the five crop fields investigated between 29 September and 27 October 2014 for wild boar damage. The areas of the different fields were (1) 4.6 ha, (2) 3.6 ha, (3) 1.4 ha, (4) 1.0 and (5) 0.5 ha. Orthophoto layer from Public Service of Wallonia (2016).



The generated photogrammetric 3D model of the field crop allowed generating orthophotos for every flight dataset, resampled to 0.1 m GSD. The orthophoto generation process used the "mosaic" blending mode with the color correction option enabled in Photoscan 1.1.

For each site, we computed CHMs (0.1 m GSD) by subtracting the LiDAR digital terrain model from the photogrammetric DSM (Fig. 2). The orthophoto and the CHM were extracted as raster layers.

Wild boar damage assessment

We studied three assessment methods: one traditional ground-based method and two UAS-based methods, which were applied twice on the crops of the study area. The three damage assessment approaches were based on simultaneous observations (29 September and 27 October 2014). For each assessment method, we recorded the time required to perform the task and we compared each method in relation to the field size.

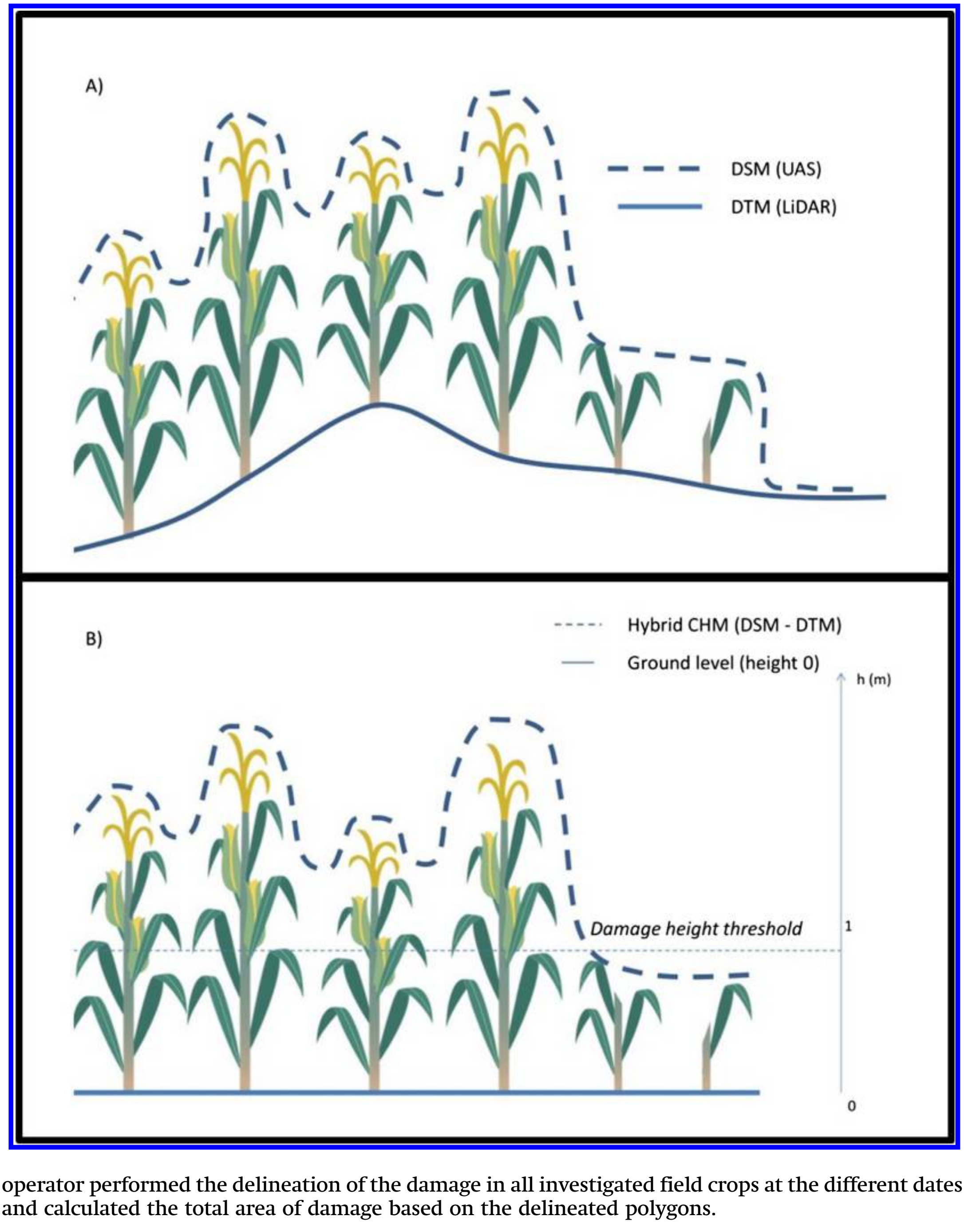
Ground-based assessment

We performed a complete survey of the crops to assess the extent of the damaged areas on the same days as the UAS surveys. A group of field workers progressed along the field and recorded the number of corn stalks lying down. Each field worker investigated three seeding lines on both sides. At the end of the line, the operators switched to the next six seeding lines of the field and repeated the same operation. The number of corn stalks damaged for a single field was then converted to a damaged area based on the density of sowing. The damaged area was then aggregated at the scale of an individual field. The damages caused by other species (e.g. badgers, *Meles meles*) found during the field operations were very rare. They have been consequently considered as negligible for the rest of the study. The ground-based method is representative of the traditional approach that is still in use in Wallonia (southern Belgium). It will be considered as the reference in our study.

UAS approach: operator delineation

Based on the aerial UAS orthophoto, an expert operator performed a manual delineation based on a photointerpretation of the damage area within a classical GIS environment (ESRI – Arcmap). The

Fig. 2. Hybrid CHM by combination of the photogrammetric DSM and LiDAR digital terrain model. The height threshold (1 m) allows identifying areas considered as damaged in field crops.

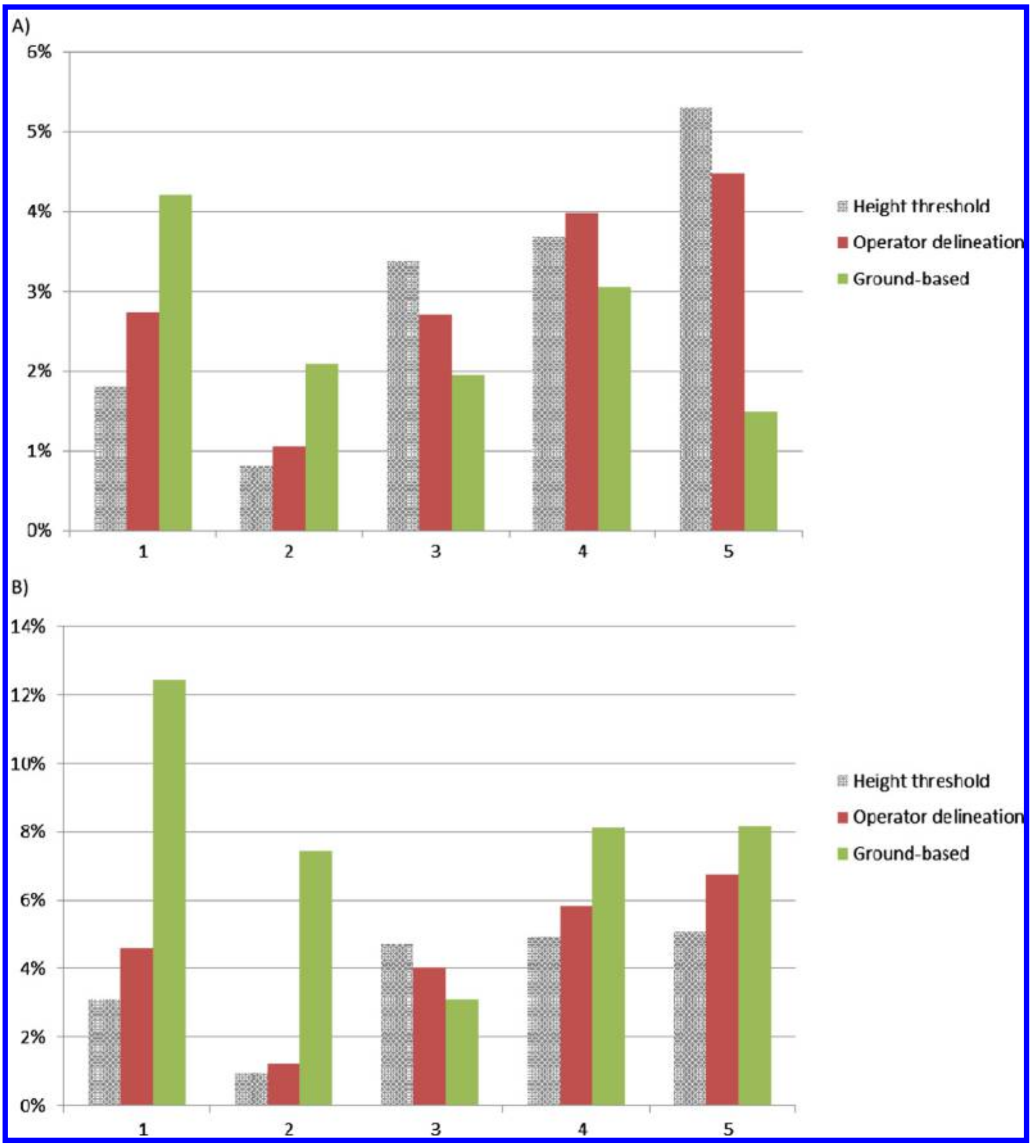


operator performed the delineation of the damage in all investigated field crops at the different dates, and calculated the total area of damage based on the delineated polygons.

UAS approach: height threshold

We developed and tested an automatic approach based on hybrid CHMs (Fig. 2). We used a single threshold height of 1 m to discriminate between damaged (<1 m) and undamaged areas (>1 m), considering that beneath this threshold, the maize plants can no longer be considered as productive. The threshold was based on the mean height of undamaged field crops (ca. 2 m). This method was completely

Fig. 3. Standardized damaged area (% of field area) estimated with the three methods (height threshold UAS, operator delineation UAS, and ground-based assessment) and the five fields: (A) 29 September and (B) 27 October 2014.



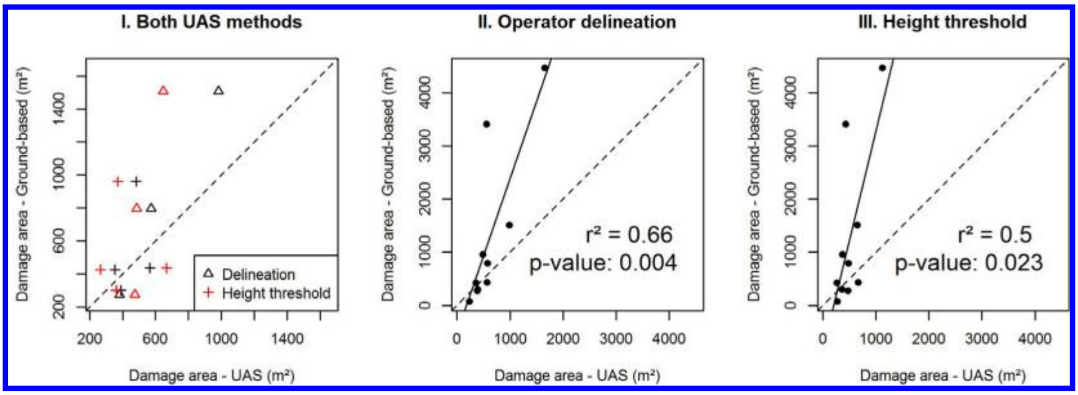
computer based and did not require any field information. The number of pixels below the height threshold were converted to a damage area and aggregated at the scale of an individual field.

Results

Among the methods used to estimate the damaged area, we found marked differences (Fig. 3) between the estimations based on the UAS imagery methods and the ground-based approach. A Student's paired t-test was run to compare the standardized UAS and ground-based damage estimates (damage area/field area). The result of the t-tests highlighted no significant differences in means between the UAS and the ground-based approaches, with *p*-values of 0.199 and 0.180, mean of differences of −14% and −18% for the operator delineation and height threshold methods, respectively.

The trend to underestimate wild boar damage by using the UAS approach is also noticeable in Fig. 4I. The linear models fitted between the ground-based damage assessment and the two UAS methods on the individual field crop scale (Fig. 4II and 4III) highlight a significant relationship,

Fig. 4. Comparing the UAS assessment of wild boar damage with the traditional ground-based approach (individual field crop scale). The dashed line is 1:1 line. The solid lines represent the linear models fitted for the two UAS methods.



with p-values reaching 0.004 and 0.023 for operator delineation and height threshold. The operator delineation of the damage assessment was the best predictor of the ground-based estimate ($r^2 = 0.66$) while the height threshold approach provided lower quality but still satisfactory results ($r^2 = 0.5$).

The UAS methods allowed us to map and visualize the spatial pattern of the damage (Fig. 5). From the UAS orthophoto, damage area was distinguishable from standing crops (Fig. 5A). The two UAS approaches revealed similar damage patterns (Fig. 5B and C). The damage pattern in the considered field presented in Fig. 5 (field 1, see location in study area in Fig. 1) highlights the higher density of wild boar damage in the parts of the field located close to woodlands. The core area of the field also seems to present higher damage densities.

In terms of implementation time, the ground-based estimation was the most time-consuming approach (5.1 man-hours/ha). Including UAS field operations, the manual delineation by the operator on UAS orthophoto represents a mean labor time of 1.3 man-hours/ha while the height threshold approach needed 0.5 man-hours/ha.

Discussion

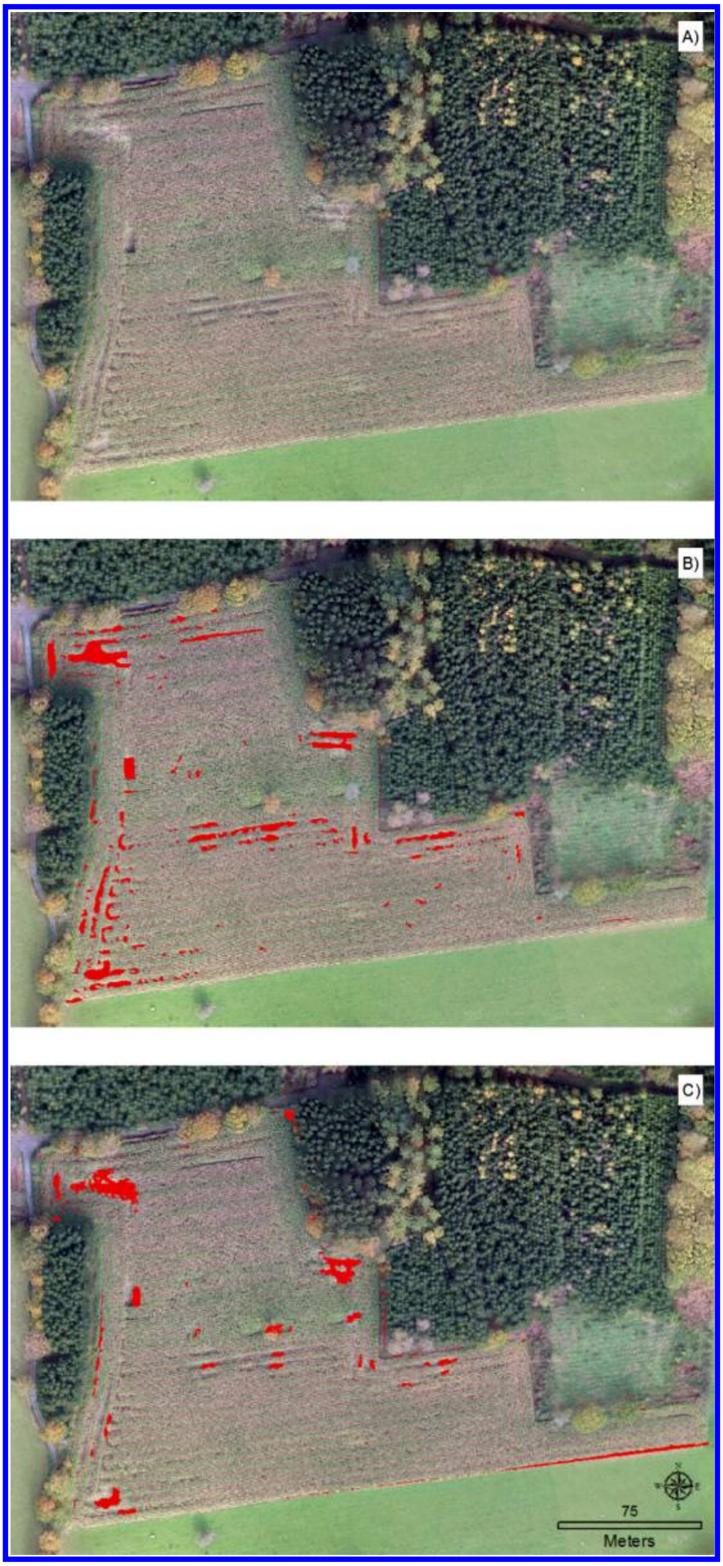
Comparison of the methods

Compared to traditional ground-based method, we found that UAS-imagery-based methods tend to underestimate ungulate damage area. Even if the traditional ground-based approach was considered as the reference in this study, inaccuracies in damage area estimates with this method are likely. These inaccuracies are related to the inherent difficulty of simultaneously navigating, detecting, and assessing through the dense habitat of the corn field. As data collection is based on the count of damaged corn stalks, the task becomes more difficult when the size of the damage patches increases, leading to poor visibility of the seeding lines.

Estimations obtained with the two UAS-based approaches were similar, yet when the size of the field increased, we also observed that operator delineation provided higher damaged area estimates (see Figs. 3 and 4I). This may be due to operator errors when delineating the damage area or a trend to approximate and overestimate damage area in the case of small patches. The delineation process is indeed easier in the case of large damaged patches. When the size of the patch decreases it becomes more complicated for the operator to determine whether a gap in the field is real damage or an artifact due to trails of the tractor wheels or a failure in seed germination. The distinction between such artifacts and effective wild boar damages cannot be drawn based on the sole basis of an orthophoto.

However, damage area identified by the height threshold UAS method can in reality be undamaged corn stems, lying flat due to the wind. This misclassification is limited with the two other methods, as they involved human interpretation. Wind speed appeared to be exceptionally high during the monitoring period and caused damaged that could not be related to ungulates. This issue should not be too problematic for corn, but could have a higher impact if the method were to be applied to other crops, such as wheat, that are more sensitive to wind conditions. Further improvement in image classification tools could also potentially allow overcoming this issue by using object-based image analysis. Meanwhile, to account for this issue, we suggest that UAS monitoring should be applied with a limited number of ground-based control plots for cross-validation purpose.

Fig. 5. From top to down, the UAS orthoimage (A) and the results of the operator delineation (B) and height threshold (C) approach for the assessment of wild boar damage.



An unequivocal, spatialized, ground-based damage sensing method would have improved the comparisons between the ground-based method and the UAS methods, notably through the evaluation of commission and omission errors. Nevertheless this protocol would require a much greater workforce than the ground-based damage assessment method used for this study.

Mapping of ungulate damage with UAS imagery

Compared to the traditional ground-based approach, the UAS methods allow visualizing and mapping the damage area. The use of "damage maps" can be overlapped in GIS environment with other geographic information in GIS environments. This represents a concrete added value in term of support to operational management of the problematic areas.

The spatial information provided by the UAS approach also provides additional proof of ungulate damage, which can leverage mediation processes between stakeholders.

Will UAS expertise overcome the classical field approach?

Our results demonstrate the applicability of UAS technology to map and assess damage caused by wild boar to maize crops. The methods based on UAS imagery allow substantial reduction in time and effort required for field work. The time needed to perform the entire UAS damage assessment represents 25% and 10% of the time needed for the traditional ground-based expertise for the operator delineation and the height threshold UAS methods, respectively. Moreover, the UAS methods are more objective and avoid double counting, which is common in intensively damaged field crops, especially when the ground expertise is performed with multiple field operators. However, we recommend the use of combined approaches, using UAS imagery as a support to the field estimation. UAS imagery is an objective tool to assess the damage extent, but can hardly be used to characterize the type of crop damage itself. UAS imagery can also help experts to document their assessments. UAS images, processed in an orthophoto or not, can be used to locate damaged areas and reduce the time spent by the field operator. Nevertheless, the field expertise remains mandatory to identify or clarify the causes of the identified damage.

Operational recommendation for potential users

UAS platform

We used a fixed-wing UAS solution to perform the flight surveys. This commercial solution is relatively expensive (>40 000 €) and is not totally suited for the scale of analysis (field crop <1 km^2). Moreover, the take-off and landing patterns require wide area (ca. 300 m × 60 m), which can induce operational issues in steep or forested landscapes. We recommend the use of a low-cost multicopter platform, which can fly at lower altitude (<100 m) and take off close to the field, even within the field.

Choice of UAS method and application to other crop types

The height threshold method provides good results in less time. However, it requires advanced knowledge in photogrammetry and a high-quality digital terrain model (e.g., LiDAR). It would likely be less accurate when tested with other crop types. Maize fields present a relatively high mean height compared to other crop types in Western Europe. This leads to higher contrast between the damaged and the undamaged areas within the fields. We therefore advise the use of the method relying on operator delineation with UAS orthophoto for its better transferability in terms of crop types and in terms of specific skills needed. This allows building strictly UAS-based approaches that can be adapted to a wider range of local conditions without the need for a reference (LiDAR) terrain model.

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