



Greenhouse application of light-drone imaging technology for assessing weeds severity occurring on baby-leaf red lettuce beds approaching fresh-cutting

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Abstract

Aim of study: For baby-leaf lettuces greenhouse cultivations the absence of weeds is a mandatory quality requirement. One of the most promising and innovative technologies in weed research, is the use of Unmanned Aerial Vehicles (or drones) equipped with acquisition systems. The aim of this study was to provide an estimation of the exact weed amount on baby-sized red lettuce beds using a light drone equipped with an RGB microcamera.

Area of study: Trials were performed at specialized organic farm site in Eboli (Salerno, Italy), under polyethylene multi-tunnel greenhouse.

Material and methods: The RGB images acquired were processed with specific algorithms distinguishing weeds from crop yields, estimating the weeds covered surface and the severity of weed contamination in terms of biomass. A regression between the percentage of the surface covered by weed (with respect to the image total surface) and the weight of weed (with respect to the total harvested biomass) was calculated.

Main results: The regression between the total cover values of the 25 calibration images and the total weight measured report a significant linear correlation. Digital monitoring was able to capture with accuracy the highly variable weed coverage that, among the different grids positioned under real cultivation conditions, was in the range 0-16.4% of the total cultivated one.

Research highlights: In a precision weed management context, with the aim of improving management and decreasing the use of pesticides, this study provided an estimation of the exact weed amount on baby-sized red lettuce beds using a light drone.

Additional key words: decision support system; digital agriculture; high-throughput monitoring; precision farming; RGB imaging.

Abbreviations used: AGL (above ground level); ENAC (Italian Civil Aviation Authority); GPS (global positioning system); HSV (hue saturation value); k-NN (k-nearest neighbors); k-PE (k-patches extraction); LIDAR (laser imaging detection and ranging); PAR (photosynthetically active radiation); SFS (sustainable food security); TPS (thin plate spline); UAV (unmanned aerial vehicles); UNAPROA (Unione Nazionale tra le Organizzazioni dei Produttori Ortofrutticoli, Agrumari e di Frutta in Guscio)

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Introduction

Baby-leaf lettuces (*Lactuca sativa* L.) are required by the high-convenience food industry to be packaged, as single or mixed ingredient, in minimally processed salads (Martínez-Sánchez *et al.*, 2012). This crop is acquiring considerable economic relevance on the world market, in which Italy ranks among the majors' European producers [Nomisma/Unione Nazionale tra le Organizzazioni dei Produttori Ortofrutticoli, Agrumari e di Frutta in Guscio (Nomisma/UNAPROA, 2016)]. Due to the increasingly consumers' demand, totally organic produced ready-to-eat softer leaves are found appealing for healthy diets, rich in fibres and low in calories, and very convenient for daily quick and tasty meals (McMahon *et al.*, 2013). In this view, the renewed interest for food functional properties, associated to organoleptic and nutraceutical traits, is inciting the production of further new pigmented red type baby lettuce varieties, rich in anthocyanins and incremented in antioxidant activities (Mulabagal *et al.*, 2010; Kim *et al.*, 2018). Greenhouse cultivation systems calibrated on high-density precision sowing (over 1000 seeds m⁻²), combined to the specialized mechanization of the other phases and to the use of low-impacting agrotechniques, are crucial to harvest superior quality fresh-cut products with great shelf-life potential (Colelli & Elia, 2009). Baby lettuces are cut at very young stage in the range of 20–40 days after sowing, approximating commercial maturity with 8–12 cm-sized leaves, washed, packaged in plastic bags or trays and delivered to retail stores, keeping the cold chain unchanged from field to shelf. Currently, leaves are harvested mechanically by modern baby-leaf harvesters carrying height-adjustable cutter bars, so to preserve yields from wound damages that positively influences the postharvest quality (Martínez-Sánchez *et al.*, 2012; Saini *et al.*, 2017). It assures the uniformity of the leaves, allows to save time in the cool chain and results more remunerative than manual harvesting (Pimpini *et al.*, 2005). Generally, only a harvest per cycle is carried out for this species, contrarily to the fast regrow baby-leaf, such as rocket (Martínez-Sánchez *et al.*, 2008).

The absence of weeds as well as other foreign bodies is a mandatory quality requirement for this particular type of vegetable product. Weeds are not easily removed by washing and some can be dangerous for consumers: consequently, tolerance levels are quite low. Their management is very challenging, in particular under organic or zero-residue farming, in which synthetic herbicides are banned (Boyd *et al.*, 2006). Thereby, it essentially relies on the preventive application of the pyroherbicide technique on false seedbed, and on the manual weeding as the cutting moment approaches (Grahn *et al.*, 2015). In post-harvesting, low levels of infestation may be further treated by optical sorter. However, all these solutions seriously affect production costs and still have high efficiency margins. All these strategies are based on the conti-

nuous visual monitoring of beds, that suffers difficulties due to the vastness of cultivated surfaces, variability in the lots and in the growth rate of the different weed species. Increase in monitoring capacity during farming is crucial for improving crop management. Nowadays, the European legislation on herbicide use (Horizon 2020, European Commission, Societal Challenge 2: Sustainable Food Security. SFS-3-2014: Practical solutions for native and alien pests –including weeds-affecting crops) and the relative restriction (Regulation EC No. 1107/2009 and Directive 2009/128/EC) require action to achieve the sustainable use of pesticides and to promote the use of the most advanced and latest technologies (Peña *et al.*, 2015).

The European legislation regarding the sustainable use of pesticides includes guidelines for their use reduction relying on the degree of weed infestation. This is part of the principles that represent the agronomic basis of precision agriculture. In this context, the recent development of precision application technology allowed for smaller treatment units by making applications according to site-specific demands, by decreasing the use, for example, of pesticides (Young *et al.*, 2014). Generally, this weed management strategy uses new remote sensing technologies to collect and process crop spatial information in field (Peña *et al.*, 2013) capturing images with aircraft and satellite platforms or vehicle-mounted Laser Imaging Detection and Ranging (LIDAR) technology (Andújar *et al.*, 2013) that allow to scan any type of object activating specific boom sections when weeds are detected.

One of the most promising and innovative advanced technologies in weed research today, but still in a limited manner in greenhouse, is the use of unmanned aerial vehicles (UAVs or drones) equipped with acquisition systems (for example RGB, spectral or thermal camera). UAVs can operate at low altitudes and capture images at very high spatial resolutions (cm or less), which is not feasible with conventional remote platforms (Peña *et al.*, 2013). The maps generated from these images could be used for appropriate site-specific management measures. In literature, few studies used light drones under greenhouses. For example, one of these uses this technology for providing biological and physical betokens to solve problems relative to several agricultural pests (El-Wahab, 2018).

In Italy, and practically everywhere else, light drones are not a reality yet for agricultural purposes unlikely their potential. Indeed, they strongly benefit of the possibility to fly without specific license, are extremely cheap, easy to transport and almost not dangerous at all. The advantages of this technology with respect to UAV of greater weight, includes the reduced cost, increased safety, popularity and increased adoptability for mapping relatively small distributed areas (Saadatseresht *et al.*, 2015). On the other side they have limited fly time and cannot carry more than an RGB camera already present onboard when the drone is

supplied by the producer. However, applications based on image analysis techniques within the RGB domain should be explored being potentially very interesting. Examples regards weed maps creation, biomass volume evaluation, species recognition, plant counting, etc.

In a precision weed management context, with the aim of improving management and decreasing the use of pesticides in the greenhouse, this study provided an estimation of the exact weed amount on baby-sized red lettuce beds using a light drone, usable with a certificate of competence and without a pilot license equipped with an RGB microcamera. The RGB images acquired by this UAV, were processed with specific algorithms, based on the Thin-Plate Spline interpolation procedure, distinguishing weeds from crop yields, estimating the weeds covered surface and the severity of weed contamination in terms of biomass.

Material and methods

Baby-leaf lettuce growing conditions

Trials were performed at specialized organic farm site in Eboli (40°32'33"N, 14°59'32"E, 27 m asl; Salerno, Italy), under polyethylene multi-tunnel greenhouse [(with a thickness equal to 200 μm and a transmittance of about 90% of the photosynthetically active radiation (PAR) in the visible spectrum)] that was 3.5 and 2.4 m height at the ridge and the eaves, respectively, 7.2 m width and 50 m long. The soil was a Vertic Calcisols (FAO, 1998; Regione Campania, 2004) with clay texture, basic pH, low electrical conductivity, absent total carbonate and soil organic carbon content (10 g C kg⁻¹) and a high cation exchange capacity [28.9 cmol (+) kg⁻¹]. The main climatic data of the cultivation area recorded at meteorological station of Eboli (Regional Agro-meteorological Center of Campania Region, 2020), in the period December 2018-February 2019, were: solar radiation increasing from 69.5 to 129.2 w m⁻². Air minimum and maximum temperatures were, on average, in the ranges 1.8-3.7 °C and 11.3-14.3 °C, respectively. The average relative humidity of air ranged between 90 and 83.5%.

Red pigmented baby-leaf lettuce cv. 'Pamela' (Maraldi Sementi, Italy) was seeded at density of 1600 seeds m⁻² by a multi-row precision seeder (Ortomec) on 1.6 m width beds on December 2nd, 2018. Previous crop was equally baby lettuce. The crop was organically fertilized (Sublisan FR N1%, C10%, Agribios Italiana, Italy), irrigated with 390 m³ ha⁻¹, and insects were managed with pyrethrum extracts. No herbicides and solarisation were applied, but weeds were manually managed and, into soil out of production, currently cut up before flowering to avoid seed release. After image acquisitions, a qualitative floristic investigation by visual recognition was carried

out aimed at identifying weed species infesting baby-leaf lettuce crops.

Light drone and image acquisition

The greenhouse images were taken on January 11th, 2019, about five weeks after sowing, approaching the harvest took place on January 20th, 2019. To the scope a UAV DJI™ SPARK™, lightened to a weight <300 g for the Italian regulations [Art.12 paragraph 5 of the Italian Civil Aviation Authority (ENAC) regulation "Remotely piloted aircraft" Edition 2, Amendment 4 of 21 May 2018] on the use of drones without a pilot license, was used. Details of UAV specifications are described in Table 1. The UAV fly over manually the greenhouse field using a flight controller "DJI GO 4". The digital camera, included in the UAV, was used to collect still images of red cut lettuce every 2 seconds. Details of the camera technical specifications are described in Table 1.

Greenhouse baby leaf red lettuce images were collected using the UAV with the digital camera at 1 m/s at 2 m above ground level (AGL). The details of experimental flight are shown in Table 2. The images were acquired based on a time-lapse function of the RGB camera vertically oriented that took one image every one and half seconds ensuring around 75% overlapping ratio.

Images were acquired on two beds of red lettuce cultivated in a greenhouse. At the beginning of each flight on the bed an image including a color checker GretagMacbeth (24 patches) was acquired. Based on the *a priori* known color checker patches values all images were calibrated following the Thin-Plate Spline interpolation function (Bookstein, 1989) in the RGB space following the procedure of Menesatti *et al.* (2012) developed in MATLAB rel 7.1 (Mathworks, Natick, MA, USA). This procedure refers to a deflection in the z direction, orthogonal to the plane, of the coordinate transformation, as a displacement of the x or y coordinates within the plane. Summarily, the measured color checker sRGB coordinates within each image were warped (transformed) into the reference coordinates of the same color checker. This transformation was performed through the thin plate spline (TPS) interpolation function, modified for the three-dimensional space. The three-dimensional sRGB color space is an additive color model in which red, green, and blue light are added together in various ways to reproduce a broad array of colors. Figure 1 shows the original acquired image (Fig. 1A) and the resulting calibrated one (Fig. 1B).

To classify the infested lettuce images a k-nearest neighbors (k-NN) procedure was conducted providing the following phases: 1) transformation of the color coordinates from RGB into Hue Saturation Value (HSV), more efficient for the specific purpose; 2) extraction of the H and S channels; and 3) filtering for noise reduction (*e.g.*,

Table 1. Specifications of the unmanned aerial vehicle (UAV) DJI™ SPARK™.

Details	Items	Specifications
Light drone	Weight	297 g
	Dimensions	143 × 143 × 55 mm
	Max speed	50 km/h
	Satellite positioning systems	GPS/GLONASS
Digital camera	Camera	Included
	Sensor resolution	12 megapixels
	Image sensor type	CMOS
	Capture formats	MP4 (MPEG-4 AVC/H.264)
	Still image formats	JPEG
	Video recorder resolutions	1920 x 1080 (1080p)
	Frame rate	30 frames per second
	Still image resolutions	3968 × 2976
	GIMBAL	Control range inclination
Stabilization		Mechanical 2 axes (inclination, roll)
Obstacle detection distance		0.2-5 m
Operating environment		Surfaces with diffuse reflectivity (> 20%) and dimensions greater than 20×20 cm (walls, trees, people, etc.)
Remote Control	Operating frequency	5.8 GHz
	Max operating distance	1.6 km
Battery	Supported battery configurations	3S
	Rechargeable battery	Rechargeable
	Technology	Lithium polymer
	Voltage provided	11.4 V
	Capacity	1480 mAh
	Run time (Up To)	16 min
	Recharge time	52 min

Table 2. Experimental unmanned aerial vehicle (UAV) flight details

Flight date	Image number	Flight altitude (m)	Flight speed (m s ⁻¹)	Ground resolution (cm)	Illumination
Jan. 11, 2019	140	2	1	0.07	Natural light

low-band filter and morphological filters: erode and fill to avoid empty space within connected components) (Costa *et al.*, 2013). These operations were followed by three morphometric operations on the binarized images: 1) selection on the basis of image area and of shape factors, *i.e.* the relationship between the main axes calculated once the centroid is determined (*e.g.*, 0.75 = elliptic shape, 1 = perfect circle); 2) classification; 3) some additional operations may be required (the program automatically rejects the object only partially included in the image) depending on the images. The classification of objects was achieved by thresholding with a k-NN clustering algorithm (with k

= 7; for procedure see Pallottino *et al.*, 2018). The neighbors were taken from a set of pixels (one per class) for which the correct classification was known (training set). The minimum area for consideration of an object was established at 1000 px. The training set was built by averaging the values of each color channel of representative patches extracted from the original images (54 for both red lettuce and soil and 50 for weed). The software utility k-Patches Extraction-k-NN (k-PE-k-NN) was used to facilitate the training operations. The software acquires square patches of a chosen size and assigns them to clustering classes (Pallottino *et al.*, 2018).



Figure 1. Original acquired image from light drone DJI™ SPARK™ of the very low infested red lettuce bed with the color checker GretagMacbeth (24 patches) (A) and the resulting calibrated one (B).

3D ortho image reconstruction

After the acquisition of aerial greenhouse images, the collected pictures were analyzed to reconstruct the ortho images with the software “3DF Zephyr” (Anwar *et al.*, 2018) through the following steps: project creation selecting the pictures needed; camera orientation and sparse point cloud generation set at high accuracy; dense point cloud generation; mesh extraction; textured mesh generation; and export outcome files including orthoimage (Fig. 2). Not all the images could be used by the software to reconstruct the orthoimage. For this reason, images were processed separately.

Regression (surface/weight)

A regression analysis between the percentage of the surface covered by weed (with respect to the image total surface) and the weight of the weed (with respect to the total harvested biomass) was performed. Twenty-five



Figure 2. A portion of the reconstructed orthoimage showing the infested red lettuce bed.

squared parcels (30 cm side) with different weed cover degrees were photographed and then, the fresh and dry biomass of the weed and the red lettuces were weighted. A linear regression and a linear correlation coefficient r together with the probability (H_0 null hypothesis of uncorrelation) were extracted. Considering the regression formula extracted, it was applied to the mean weed cover percentages, extracted by light drone images, from both infested and not infested rows.

Results

Weeds floristic composition

A total of 15 species belonging to 11 plant families were recorded from the investigated area. The major contributors of alien species included: *Asteraceae* (*Cirsium arvense* (L.) Scop., *Taraxum officinale* Web., *Senecio vulgaris* L.), followed by *Brassicaceae* (*Capsella bursa-pastoris* (L.) Medik., *Raphanus raphanistrum* L.), *Poaceae* (*Alopecurus myosuroides* Huds., *Poa* spp.), *Amaranthaceae* (*Amaranthus retroflexus* L.), *Caryophyllaceae* (*Stellaria media* (L.) Vill.), *Fabaceae* (*Trifolium* spp.), *Plantaginaceae* (*Veronica persica* Poir.), *Ranunculaceae* (*Ranunculus repens* L.), *Fumariaceae* (*Fumaria officinalis* L.), *Urticaceae* (*Urtica dioica* L.) and *Lamiaceae* (*Lamium purpureum* L.).

Weeds RGB imaging

Figure 3 shows the image processing flow for two different conditions of weed coverage (A high infested and B very low infested). In particular: 1) original acquired images; 2) segmentation (binarization) of the image by k-NN with consequent reduction of the chromatic dynamics from RGB to two classes (background and object)

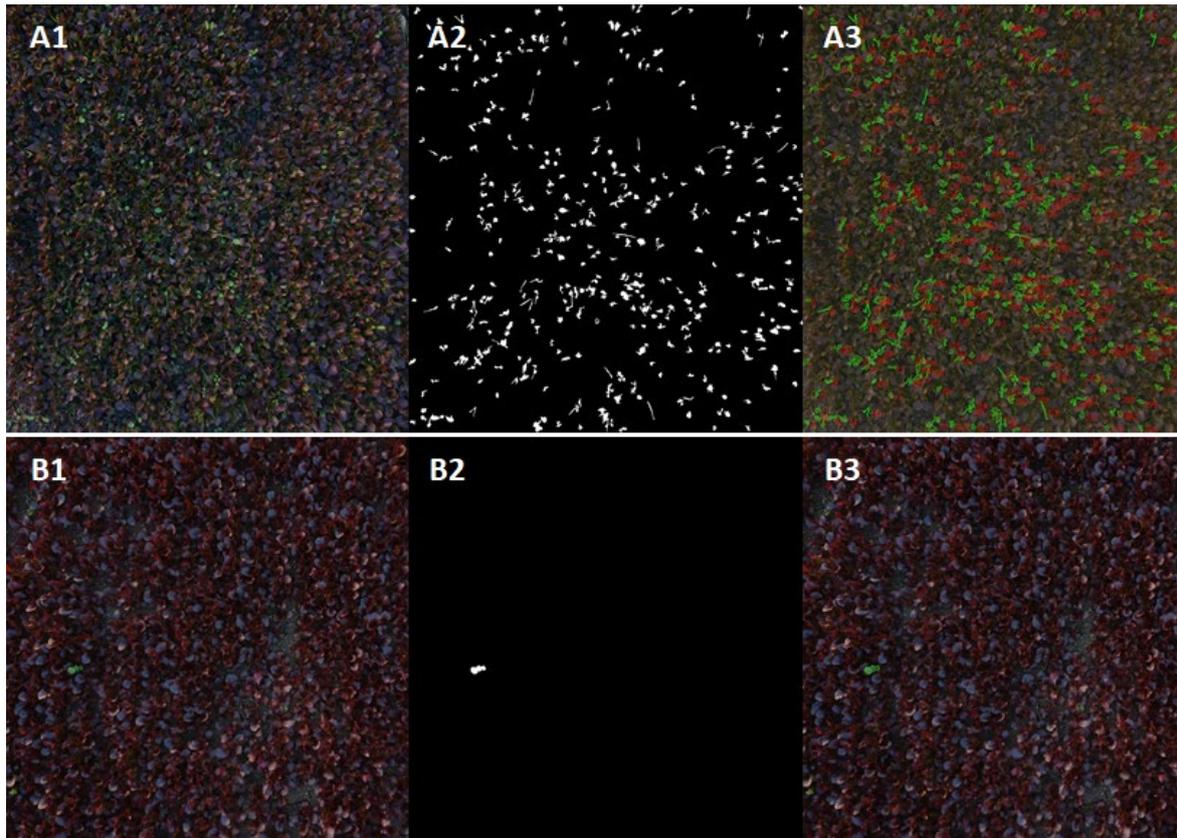


Figure 3. Acquired images from light drone DJI™ SPARK™ of the high infested (A) and very low infested red lettuce bed (B): 1) original acquired images; 2) segmentation (binarization) of the image by k-NN with consequent reduction of the chromatic dynamics from RGB to two classes (background and object) and 3) composition of the original image (A1-B1) with the selected crop object contour (A2-B2).

and 3) composition of the original image with the selected crop object contour from Figure 3.

Figure 4 represents three different infestation degrees: A) no weed (0.2% of total coverage and 0% of total weight); B) intermediate infestation (7.2% of total coverage and 6.4% of total weight) and C) high infestation (16.4% of total coverage and 9.4% of total weight). The regression between the total cover values of the 25 calibration images and the total weight measured report a significant linear correlation ($p < 0.01$).

The drone flight on the entire beds verified the feasibility of the experimented image technology. The very low infested light drone images presented a coverage of 0.24 ± 0.47 % corresponding to an estimated weight of 0.14 ± 0.27 %, while the higher infested one showed a coverage of 2.22 ± 2.40 % corresponding to an estimated weight of 1.28 ± 1.39 %.

Discussion

Generally, in vegetable production systems, weeds must be urgently managed since alien species compete with plants for water, nutrients and other resources.

In this context, nonconventional and nonchemical weed management strategies, crucial points among precision agriculture practices, could include tillage improving, crop nutrient management, herbicide-tolerant crops, bio-herbicides, thermal techniques, and among all precision weed management (Bajwa *et al.*, 2015).

Weeds impact yields and quality more severely with increasing crop density, their competitiveness, emergence rate, proximity to the cultivated plants, and duration of the co-presence (Pike *et al.*, 1990; Slaughter *et al.*, 2008). Lettuce, in particular, has been found to be very sensitive to weeds, which may reduce yields by over 50%, and may be vector of diseases and pests (Lanini & Le Strange, 1991; Ljevnaić-Mašić *et al.*, 2011). In baby-leaf lettuces, weeds are very feared even more by growers for all the additional negative implications that the presence of these type of contaminants have in determining the qualitative range in the post-harvest phases of high-convenience chain (Colelli & Elia, 2009). Moreover, the very limited availability of herbicidal options to be applied during the fast growth stage and in the proximity of the fresh-cutting, as just in the proper case of baby-leaf lettuce, compels farmers to operate in emergency relying on their timely and efficient monitoring ability (Grahn *et al.*, 2015). Floristic

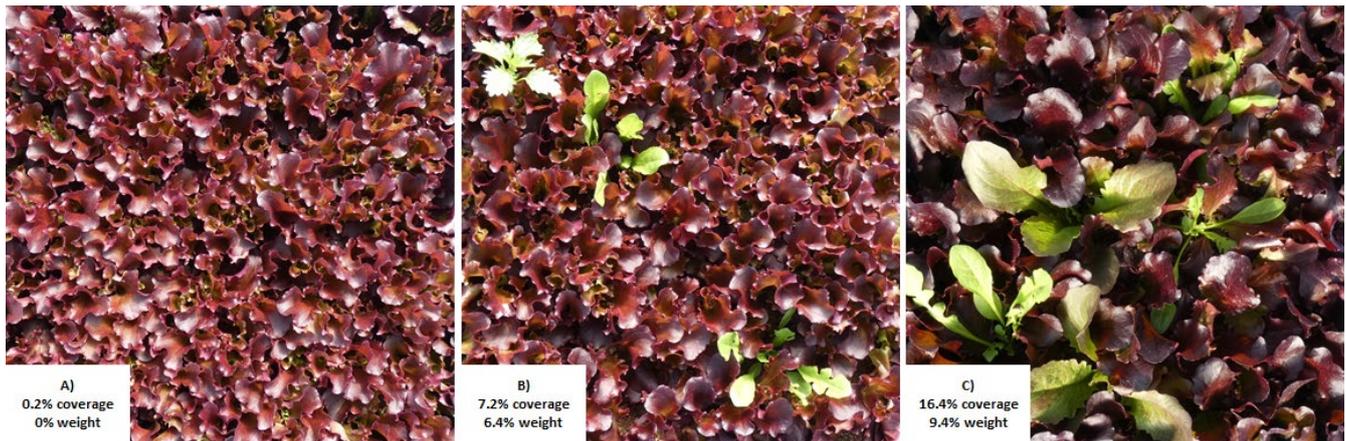


Figure 4. Original acquired images from light drone DJI™ SPARK™ with (A) no weed (0.2% of total coverage and 0% of total weight); (B) intermediate infestation (7.2% of total coverage and 6.4% of total weight) and (C) high infestation (16.4% of total coverage and 9.4% of total weight).

composition suggests a prevalence of members belonging to the same families of the most cultivated baby leaf, such as *Asteraceae* and *Brassicaceae*. In this view, precision technologies may be opportunities to be seized to meet requirements for reducing chemical pesticides in agriculture and optimize the application of sustainable solutions.

Our study examined a greenhouse application of a light-drone imaging technology for the high throughput screening of weeds coverage on baby-leaf red lettuce beds. Generally, the use of drones in the greenhouse does not represent a common practice. Much of these previous criticisms has focused on safety issues, on the collection of the flights Global Positioning System (GPS) coordinates, on the data transmission, etc.

The experimental flight allowed to capture time-laps images with suitable resolution to reach, after their bioinformatic processing, an accurate assessment of the infestation severity degree. The effective detection of weeds may be facilitated by the clear differentiation of alien species from the red coloured crops (Drysdale & Metternicht, 2003). Digital monitoring was able to capture with accuracy the highly variable weed coverage that, among the different grids positioned under real cultivation conditions, was in the range 0-16.4% of the total cultivated one.

Airborne imagery has been just proposed to successfully detect and/or map weeds in many crops in order to address site-specific operational actions and improve effectiveness of the available control methods, including chemicals (Lamb & Brown, 2001; Peña *et al.*, 2013). While, UAV-based technology has been recently applied for monitoring the physiological status and biometric parameters of crops (Rueda-Ayala *et al.*, 2019; Yao *et al.*, 2019). Yu *et al.* (2019) conjugated the remote imaging with artificial neural network technology for the smart weed management by precision herbicide spray of turfgrasses: a growing system that shares the high sowing density and the low size with the greenhouse baby-leaf

lettuce cultivations. In other cases, modelling-based decision support systems, aimed at enhancing sustainability of weeds control, have been designed to identify the dosage of the active ingredients and the timing of herbicidal interventions (Macé *et al.*, 2007).

The system thus set up here, further implemented to infer the relative weeds contamination of the harvested biomass by comparing remotely sensed crop-weed plots, at scalar superficial coverage, with the corresponding cut-fresh weight, aspires to function as a digital support to the farmer's technical choices regarding the management of production lots. So, accounting the precise degree and variability of infestation among lots, growers may plan site-specific management strategies choosing on the basis of the economic convenience. Here, the UAV camera was applied on two contiguous experimental beds, which were preliminarily individuated, according to the operator's empiric scale, respectively, as very low (weeds almost absent) and severely infested. In this last, weed covering percentage assessed by imaging amounted to 2.22% of the total cultivated surface, on average, which precisely predicts intolerable levels of weed contamination in the fresh-cut lettuces equal to 1.28% of total weight. Since weeds similarly to crop are "baby" their systematic characteristics seem do not impact the assessed severity. The information provided by image analysis has an operational value helping to map the quality of products in pre-harvesting. Thereby, farmer may decide to keep the cultivation scheduling targeted cost-effective manual weeding on the mapped surfaces (Grahn *et al.*, 2015). Distinction of lots into different qualitative classes may help to preserve quality of the non-infested fresh-cuttings by avoiding the further useless handling of the product that would reduce its conservation potential (Ariffin *et al.*, 2017). In very serious cases, contaminations forecast greater than an economic threshold of convenience may lead until the drastic decision to interrupt the cultivation

cycle and reseed, disrupting weed niches (Liebman and Davis, 2000).

In summary, UAV-borne RGB sensing may provide effective technical support to the real-time estimation of infestation degree of baby leaf lettuce beds allowing to save time and money in weed contamination management improving quality of the fresh-cut product. In addition, floristic investigation indicated that most of the detected alien species preferentially disseminate their seeds by wind. In agreement, a previous study identified an association between wind-dispersed weeds and tilled systems (Derksen *et al.*, 1993). Therewith, weeds monitoring always remains an indispensable strategy even in the presence of stringent treatments (*i.e.*, soil solarisation, biofumigation, etc.) aimed at reducing the weed seed-bank size.

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