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Estimation of soil coverage of chopped pruning residues in olive orchards by image analysis

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Abstract

Residue chopping from orchard pruning is becoming a common practice in conservation agriculture after the establishment of eco-conditionality policies in the European Union. This type of residue is used to protect the soil from erosion and improve the water balance and fertility of soils by improving the organic matter content. However, no studies have evaluated the influence of pruning residues and size on soil coverage. This study examines the effect of different treatments on pruning residue soil coverage in an olive orchard (cv. Picual). Treatments consisted of two quantities of pruning residues, specifically, high (2.04 kg m^{-2}) and low (1.02 kg m^{-2}), and two chopping speeds, low (2.4 km h^{-1}) and high (3.2 km h^{-1}). The different treatments were evaluated by image analysis and pixel counting to determine the soil cover percentage, size, number and distribution of the pruning residues after chopping. After chopping, the soil cover percentage was 39% higher in the high quantity pruning residue treatments but was not significantly influenced by the chopping speed. The size and number of lignified residues was quantified via pixel counting. In the high quantity pruning residue treatments, the number of large lignified residues (> 6 cm^2) was higher, and the number of pruning residues smaller than 2 cm^2 was lower, when compared with low quantity pruning residue treatments. The high chopping speed treatments produced more smaller-sized pruning residues.

Additional key words: cover crop; soil management; spatial distribution; *Olea europaea* L.; blob analysis method.

Introduction

In Spain, approximately 2.5 Mha are dedicated to olive (*Olea europaea* L.) production, of which 75% are located in Andalusia, in southern Spain (MAGRAMA, 2013). As in other Mediterranean zones, the incidence of soil loss is notably high in southern Spain because approximately 1/3 of crops are grown on slopes with inclines greater than 15% (CAP, 2006). Olive growing, in particular, provides low soil coverage; approximately 75% of the soil surface is uncovered and exposed to erosion (Rodríguez-Lizana *et al*., 2008). Traditionally, olive growing has been characterized by high tillage, which increases erosion and soil loss through runoff. However, studies over the last decade have shown that these types of practices are unsustainable; in addition to reducing the soil fertility and productivity, these practices increase the level of atmospheric CO_2 and contribute to climate change (Hill *et al*., 1995; Schlesinger, 2000; Hervás-Martínez *et al*., 2010). In addition, the current reform by the European Community Agricultural Policy through Council Regulation 1782/2003 has decoupled subsidies from production and introduced the concept of eco-conditionality, which makes the receipt of subsidies contingent on compliance with a number of environmental standards (Cano-Montero *et al*., 2007). Thus, over the last few decades, many farmers have adopted the Conservation Agriculture and Good Farming Practices Codes to receive subsidies (Calatrava & Franco, 2011). For woody crops, such as olives, these codes recommend cultivation systems with uncovered soil and minimal or no tillage as an alternative to traditional tillage combined with living or inert plant coverage (Pastor, 2008). The use of inert coverage, *i.e.,* covering the soil with recycled crop residues or dead cover crops, is one of the most frequently used methods to help preserve organic matter in the soil and reduce erosion by rain and subsequent runoff (Ribeiro *et al*., 2011). In olive growing, the use of pruning residues as inert coverage is one of the most common practices

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used to protect against the negative environmental impacts caused by erosion (Pardini *et al*., 2002). It has also replaced the traditional practice of crop residue burning, which is now strictly controlled by authorities to avoid the high risk of fire and high quantities of CO_2 that are released into the atmosphere (Rodríguez-Lizana *et al*., 2008). Therefore, chopping residues provide additional field coverage while enabling pruning residues to be recycled in olive orchards. To do this, pruning residues are arranged in a line, bundled in the center of the rows, and chopped using a grinder coupled to a tractor (Velázquez-Martí *et al*., 2011).

Pruning residues are a valid resource for protecting soil from the impacts of erosion due to precipitation and subsequent runoff (Ribeiro *et al*., 2011). In addition, it has been shown that pruning residues are more efficient than spontaneous coverage in increasing the levels of organic material in the soil (Repullo *et al*., 2012). Depending on the technical criteria, pruning for olives can be performed annually or every two years (Velázquez-Martí *et al*., 2011). Thus, the amount of residues on the soil should be maintained during the second year. Soil coverage, a key factor in reducing erosion and improving the water balance, requires a sufficient amount of residues to be maintained and distributed adequately on the soil (Repullo *et al*., 2012).

The covering efficiency of living or inert plant coverings is generally evaluated by two parameters: the dry weight of the plant residues per unit of area and the percentage of soil covered by the residues, with the latter being more informative with regard to how effective the covering is at reducing erosion (Gilley *et al*., 1986). According to the CTIC (1990), at least 30% of the soil must be covered by pruning residues to effectively protect against erosion. However, there are other variables that influence chopping quality that have not yet been studied, such as the size and spatial distribution of the pruning residues. The size of the residues is notably important for coverage formation and to reduce the risk of diseases (Calatrava & Franco, 2011). In turn, the distribution of the residues after chopping should be homogeneous. Occasionally, the residues are not chopped homogeneously, which creates high spatial variation in coverage and areas that are not covered by pruning residues.

Traditionally, the percentage of soil covered by plant residues has been determined through traditional manual-visual methods, such as the visual estimate method, the transect line method, the point intercept method, etc. These methods require considerable time, and the results are usually inconsistent (Olmstead *et al*., 2004).

Thus, the determination of soil cover percentage by pruning residues requires more precise methods that enable the management and monitoring of efficiency in the use of plant coverings (Morrison *et al*., 1993). Among the most commonly used techniques are the use of spectral sensors (Hervás-Martínez *et al*., 2010) and hyperspectral sensors through automated classification systems (Huang *et al*., 2001). These techniques are based on differences in the spectral signature of various elements that can distinguish between cultivated plants, weeds, plant coverings, and soil.

Currently, the most reliable technique for determining soil coverage is image analysis. Among the different image analysis techniques, fractal image analysis (Velázquez-García *et al*., 2010), the use of fluorescent images (Daughtry *et al*., 1997), and computer-assisted analysis of images (Olmstead *et al*., 2004) are clear examples of the possibilities of image analysis. The last method is most commonly used for determining the percentage of soil covered by plant coverings (Reyniers *et al*., 2004; Geé *et al*., 2008) and detecting weeds within crop lines (Rasmussen *et al*., 2007). This technique is capable of identifying the proportion of the image occupied by green vegetation using the RGB values of the individual pixels (Meyer & Neto, 2008) and generates different color indices to distinguish between different elements (soil, vegetation, and crop residues) based on their chromatic coordinates (Woebbecke *et al*., 1995). This technique can also detect shapes through blob analysis, and quantifies the number of elements present in an image and on a surface. This process enables the size of pruning residues to be determined after chopping.

The size of the residues, along with other variables, such as type of residue and climate, has an important influence on the percentage of coverage by pruning residues and their decay over time (Thorburn *et al*., 2001). Improper chopping can result in a high quantity of poorly chopped lignified material, that is, pieces of wood and large splinters. This type of pruning residue presents high resistance to degradation and remains in the field for an extended period of time. In addition, these residues can serve as vectors for pathogens and favor the proliferation of various pests, such as the olive bark beetle, *Phloeotribus scarabaeoides* (Ruano *et al*., 2010). The residues also make tasks such as fruit collection from the soil and the use of meshes for collection difficult, and occasionally lead to blockage in the cleaning system when it collects fruit from the soil.

The objective of this study was to determine the soil coverage and size of pruning residues by image analysis, as a measure of the coverage efficiency of chopped pruning residues.

Material and methods

Field studies and experimental methods

This study was conducted at an experimental field site, property of the IFAPA (Andalusian government) in Cabra, Cordoba in southern Spain (latitude 37° 30' 17'' N; longitude 4° 26' 12'' W, referred to ellipsoid WGS84). The property is a 34 year old intensive olive orchard (7 m × 7 m) of the 'Picual' variety (*Olea europaea* L.), and the soil management is based on plant coverings. The soil is a calcixerept (Soil Survey Staff, 1999) with a sandy loam texture. The cover crop was complemented with chopped pruning residues; for the chopping, the residues were tied up in the center of the lane and chopped with a commercial chopper (TDR, Agarín, Spain), with steal rotational hammers located in a horizontal axis, attached to the tractor rear (6420, John Deere, USA).

The experimental design consisted of random blocks of land with four repetitions. The experimental unit consisted of one block with an area of 73.5 m^2, corresponding to a 35 m long (5 lines of trees) and 2.1 m wide (working width of the chopper) area (Fig. 1).

For the study 20 trees were pruned and the residues were weighed. An average of 14.9 ± 10.9 kg of residues were obtained per tree. To evaluate two quantities of pruning residues, half of the blocks were covered with the given average quantity per tree, uniformly divided and aligned, *i.e.,* 75 kg per block. The remaining blocks were covered with double that amount, *i.e.,* 150 kg per block. This result in two quantity of pruning residues, low quantity of pruning residues (1.02 kg m^{-2}) and high quantity of pruning residues (2.04 kg m^{-2}) At the same time, two chopping speeds were evaluated: high speed (3.2 km h^{-1}) and low speed (2.4 km h^{-1}). The speed of advance during chopping was measured using a GPS (GM-48 UB Sanav). Thus, four treatments were evaluated corresponding to combination of two quantities of residues and two chopping speeds (see Table 1).

The variables used to estimate the chopping quality were: (i) soil cover percentage, average percentage of

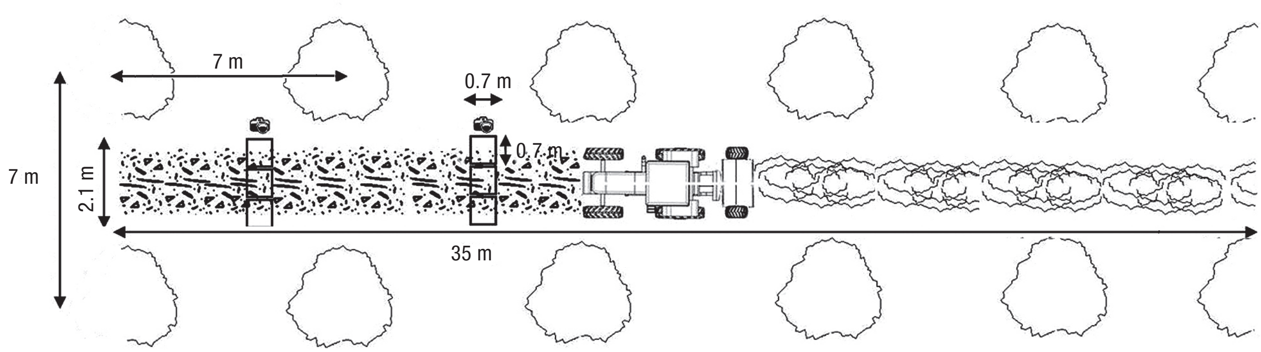

Figure 1. Block configuration for field image acquisition of the chopped pruning residues in an olive orchard.

Table 1. Soil cover percentage determined by image analysis and visual estimate

Treatment	Pruning residues quantity	Chopping speed	Soil cover percentage (%)	
			Digital image analysis	Visual estimation
I	Low (1.02 kg m^{-2})	Low (2.4 km h^{-1})	26.9 ± 3.4^{a}	44.9 ± 21.2^{ab}
II	Low (1.02 kg m^{-2})	High (3.2 km h^{-1})	25.8 ± 3.5^{a}	37.6 ± 8.0^{a}
III	High (2.04 kg m^{-2})	Low (2.4 km h^{-1})	37.4 ± 5.4^{b}	63.1 ± 9.8^{b}
IV	High (2.04 kg m^{-2})	High (3.2 km h^{-1})	36.1 ± 7.1^{b}	57.2 ± 18.3^{ab}

^{a,b,c} Same superscript letter in the same row shows no significant difference (Duncan's post-hoc, $p \leq 0.05$). Mean ± standard deviation values for the samples.

soil covered by the pruning residues in the sampled area, as determined by field-image analysis and spatial distribution of the residues sampled perpendicular to the path of the tractor; and (ii) size and number of pruning residues, elements contained in a sample and their unitary surface area, as determined by image analysis in laboratory.

Field image acquisition

For each block, two areas located transverse to the band of residues were randomly selected. Three images were taken of each area, corresponding to the three sampling surfaces for residues (central, lateral right, and left) located over the width of the band of residues (Fig. 2). In total, 24 images were recorded and analyzed for each treatment. The color images (RGB images) were taken with a Nikon D80 digital camera (Nikon Co., Tokyo, Japan) mounted on a frame, which placed the camera at a height of 1.5 m and had a square base with a sampling surface of 0.49 m^2, allowing for a constant perspective of the photographed area. Thus, each image sampled a surface of 1.47 m^2. The images were kept in JPEG format with an image size of 2,896 by 1,944 pixels. The camera settings included a shutter speed of 100 s^{-1}, an aperture of F5.0, a focal length of 18 mm and an ISO velocity index of 200. The field images were taken without flash and were artificially shaded to avoid any interference from sunlight.

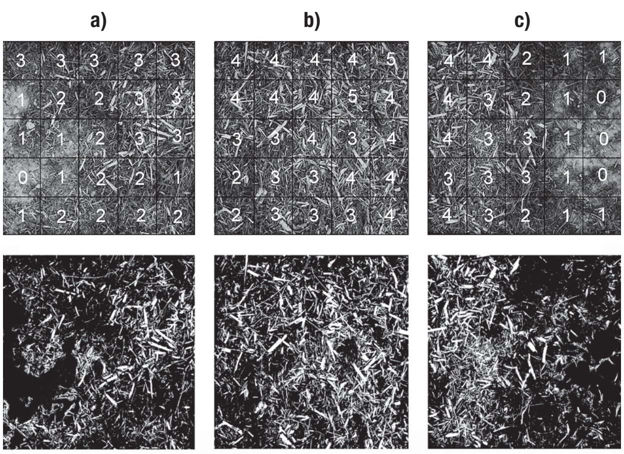

Figure 2. Examples of images taken under shielded conditions. Processing using the visual estimation method (top row) and digital image analyses (bottom row). a), b), and c) correspond to the left, central, and right surfaces of the sample area, respectively.

Determination of the coverage and distribution of the pruning residues

The soil coverage and spatial distribution of the pruning residues were determined both manually and by image analysis. Digital images were processed by an image-analysis program (Inspector 2.2, Matrox Imaging, USA). In the first stage, the original RGB values for the image were transformed into gray-scale to create a monochromatic image as is regularly done in digital image processing (Clement *et al*., 2012). The red band was used to perform segmentation of the various components (pruning residues, vegetation, and soil) because this approach allows for the best visualization of the residues and separation of the plant coverings and soil. The second stage determined the two thresholds in the gray-scale image that would allow the pruning residues to be distinguished from the vegetation and soil. In the resulting gray-scale image, the pruning residues appeared brighter when compared to the plant coverings; therefore, a lower threshold was selected. This separation threshold was manually established for each image by an expert trained for this purpose using R-values ranging from 0 to 255. The upper threshold used to distinguish the pruning residues and soil was determined in a similar manner. The percentage of soil covered by the pruning residues in each image was determined using this segmentation process for each image; the residues were separated from the rest of the image so that the pixels corresponding to the residues could be counted with respect to the other pixels from the image. To determine the distribution of the residues in the field, the images were divided into 25 units (5 × 5 matrix), and segmentation was performed in each of these surfaces. This way, the distribution of residues in the bandwidth (2.1 m) perpendicular to the direction of machine's path could be estimated. A total of three images were used, each divided into 25 units. Fifteen 14 cm wide bands were analyzed, with each band being the average of the other 5 bands in length.

In addition to image analysis, the soil cover percentage and spatial distribution of the pruning residues was also estimated using the visual estimation method developed by Agrela *et al*. (2003). The same expert evaluated the coverage of each unit, applying a scale of 0-5, comparing the images to templates with a known soil cover percentage. Each image was assigned a score as follows: 0 = 0-10%, 1 = 0-30%, 2 = 30-50%, 3 = 50-70%, 4 = 70-90%, 5 = 90-100% of soil coverage by pruning residues.

Laboratory determination of pruning residue size

The size, number, and unitary surface area of the pruning residues were also determined by image analysis. Two samples per block (8 repetitions) were selected after chopping, corresponding to the area sampled, and transported to the laboratory. The residues were processed in the laboratory to separate the leaves from the lignified material (wood) since the latter produces a risk of disease. From the wood samples, a subsample of approximately 200 g was selected for analysis. To facilitate the identification of the residues, the subsamples were spread over a white background (36 cmM × 55 cm). Images of the residues were captured under controlled lighting in the laboratory. The camera settings included a shutter speed of 32 s^{-1}, aperture of F7.1, focal length of 18 mm, and an ISO velocity index of 200. The images were processed with Adobe Photoshop® to obtain a homogeneous image size (1,276M × 1,949 pixels) and enable measurements on the image through pixel counting functions. The threshold segmentation tool in RGB was used to separate the pruning residues from the rest of the image. The size of the residues was determined using the particle analysis tool, also referred to as the blob analysis tool (Fig. 3). The number of elements and their surface area were determined using this tool and pixel counting to identify blobs at the coordinates of the image. The size of the residues was determined using the standard relationship between the area in pixels of the image and the real area of the sampling surface.

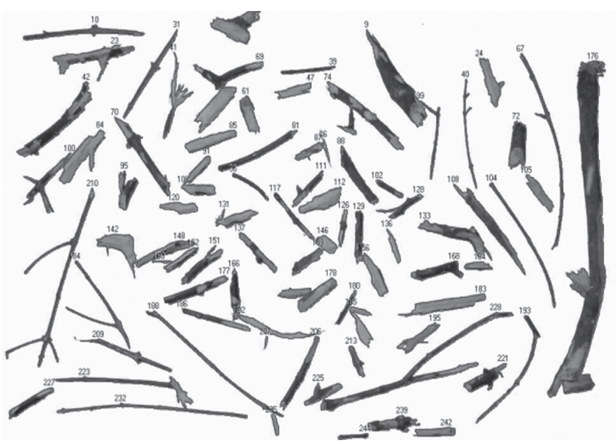

Figure 3. Identification of size, number and distribution of pruning residues through digital image analysis in laboratory conditions.

Statistical analyses

Data were subjected to statistical analysis using the analysis of variance (ANOVA) test. Variance analysis was performed using a random block design; the dependent variables were the number of residues on the sample surface and the soil cover percentage by the pruning residues. The subsequent comparison of mean values was performed using the Duncan multiple range test ($p \leq 0.05$).

Results and discussion

The following results correspond to the analysis of the field images. Table 1 shows the soil coverage values of the pruning residues after chopping for an evaluated surface of 1.47 m^2 with respect to the work speed, quantity of residues, and analysis method. The soil cover percentage determined by image analysis depended primarily on the quantity of residues and showed no significant differences ($p \leq 0.05$) in soil coverage between the low and high chopping speeds. Higher soil coverage values were obtained for treatments III and IV, which correspond to the chopping of a high quantity of pruning residues (2.04 kg m^{-2}) at low and high speeds, respectively. For both chopping speeds, a 39% greater soil cover percentage was recorded when the quantity of pruning residues was doubled after chopping. The soil cover percentage by pruning residues was also determined by the visual estimation technique. Similar to image analysis, the soil cover percentage was greater at a higher quantity of separated biomass; however, this difference was not significant. The two types of analysis resulted in significantly different values for all treatments ($p \leq 0.05$). These differences are due to the greater error that occurs in visual estimation. The visual method presents a greater dispersion in the results because it does not allow for differences between groups and overestimates the soil cover percentage by pruning residues. Despite the overestimation error, a Pearson correlation of 0.622 ($p \leq 0.01$) was obtained between the soil cover percentage estimated visually and the image analysis estimate. These results are consistent with Olmstead *et al.* (2004), who showed a lineal overestimation of the percentage of soil covered by plant residues through visual determination; correlation coefficients (R^2) of 0.297 and 0.684 were obtained in two different seasons. Pforte *et al*. (2012) compared various manual methods and image analysis methods, and obtained higher Pearson correlation coefficients of between 0.86 and 0.92. Image analysis has demonstrated its usefulness in determining the soil cover percentage by pruning residues in comparison with visual estimation. However, the method proposed in this study requires a manual, not an automated, threshold. It is difficult to automatically establish thresholds because the threshold value depends on the lighting conditions, which determine the brightness of the image, as a result, causing the gray-scale intensity values to vary. Other authors were able to automatically determine the threshold in the case of plant coverings. In this case, the plant coloring is notably different from that of the soil, and a color index that accentuates the green (excess green color index) in the image enables automatic separation of the plant and soil components (Rasmussen *et al.*, 2007). Furthermore, the robustness of the segmentation depends on the conditions of the image capture, which can vary significantly in the field.

The distribution of residues in the direction transverse to the bundle for chopping as determined by image analysis is shown in Fig. 4 for 14 cm wide bands. No significant differences were observed among the distributions of residues as a function of chopping speed. However, there was significantly greater coverage for the whole band width for treatments III and IV with a greater quantity of residues (2.04 kg m^{-2}) when compared to treatments I and II ($p \leq 0.05$). These data are consistent with the notion that the width of distribution of residues with a higher soil cover percentage is higher for a high volume than for a low volume of pruning residues.

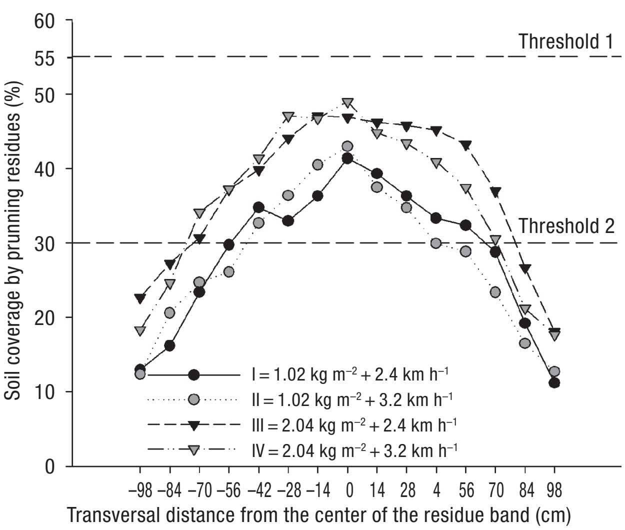

Figure 4. Transverse distribution of the mean values of the soil cover percentage as a function of the distance from the center of the chopping band for different pruning residue quantities (kg m^{-2}) and chopping speeds (km h^{-1}) as determined by image analysis.

The width of effective distribution of pruning residues was estimated. That is, the width of soil covered by more than 30% of pruning residues (CTIC, 1990). For a high quantity of residues (treatments III and IV), the effective width of the average residue after chopping was 1.51 and 1.54 m, while for the residues with lower volumes, it was significantly less (1.13 and 0.84 m for treatments I and II, respectively). Other authors have suggested that this threshold is higher, stating that soil coverage values below 55% enable erosion under simulated rain conditions (Snelder & Bryan, 1995). In this study, the soil cover percentage was below this level in all cases.

Image analysis using block analysis enables us to determine the number of residues and unitary surface of each of the lignified pruning residues contained in homogeneous samples of residues with an average approximate weight of 200 g. Fig. 5 shows the number of residues contained in a 200 g sample as a function of the work speed and residue quantity. The average values for the number of residues for treatments I, II, III, and IV were 199, 286, 147, and 184, respectively. Better chopping was achieved for the lower volume residues, resulting in a larger number of residues. The chopping speed also exerted an important effect on the quality of the chopping, with a high speed being more effective. For the low volume residues chopped at the high speed, the number of residues was 60% higher than when chopped at the low speed. This effect, even

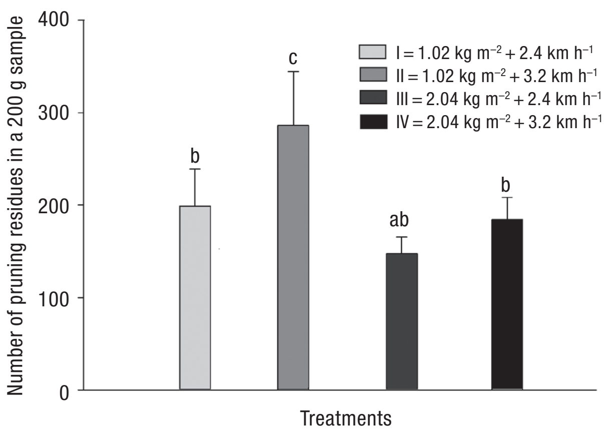

Figure 5. Mean number of lignified pruning residues and standard deviation for different quantities of pruning residues (kg m^{-2}) and chopping speeds (km h^{-1}) determined by image analysis. Different letters indicate significant differences ($p \leq 0.05$), as determined by the Duncan test.

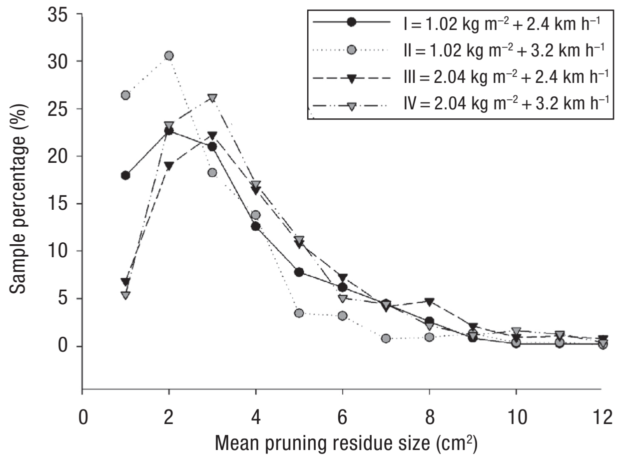

Figure 6. Distribution of the mean values for size of pruning residues for different quantities of pruning residues (kg m^{-2}) and chopping speeds (km h^{-1}) determined by image analysis.

for a smaller quantity, was also observed for the high volume residues, confirming the importance of controlling the chopping speed to obtain a high number of small residues.

The chopping quality can be observed not only by looking at the number of residues contained in a fixed volume but also by their unitary surface area. Through digital image analysis, it was possible to determine the size distribution, which is measured as the unitary surface area (Fig. 6). The size of the residues was strongly related to the number of residues contained in a fixed volume ($R^2 = 0.70$-0.80). A sample with a high number of residues is formed by a high percentage of small residues (< 2 cm^2) and a low percentage of large residues (> 6 cm^2) (data not shown).

The geometrical characteristics of the pruning residues after chopping are also influenced by the quantity of residues and chopping speed. For the high quantity residues (treatments III and IV), the average percentage of residues smaller than 2 cm^2 was 19.1% and 23.3%, respectively, while for the low volume residues (treatments I and II), it was significantly higher (22.7% and 30.6%, respectively). At the higher speed, we obtained lower percentages of residues greater than 6 cm^2, with the percentage being 3.2% and 5.1% (treatments II and IV) for the high speed and 6.2% and 7.3% (treatments I and II) for the low speed. To compare the distribution of this variable, we calculated the mean area of the chopping residues for each treatment: 2.4, 1.7, 3.1, and 2.8 cm^2 for treatments I, II, III, and IV, respectively. These results show that image analysis using the threshold segmentation tool in RGB and

Table 2. Evaluation of the quality of the soil cover by pruning residues as a function of soil cover percentage and pruning residue size

Soil coverage by pruning residues	Size of the pruning residues		
	> 6 cm²	2-6 cm²	< 2 cm²
> 55%	3	4	5
30-55%	2	3	4
< 30%	1	2	3

Different values represent different level of quality of cover soil after chopping [very poor (1), poor (2), regular (3), good (4), and very good (5)].

block analysis tool provides an effective method for estimating soil coverage by pruning residues and residue size. The quality of the chopping can thereby be determined by taking into account these two parameters. Evaluation consists of assigning a rating to the various types of chopping within a range of 1 to 5 depending on the combination between the soil coverage, which is understood as the average percentage of coverage, and the size of the residues as the mean of the distribution on the surfaces of the residues. Table 2 shows a scheme for evaluating the coverage quality of pruning residues as a function of its effectiveness in combating erosive processes and typical diseases. According to this classification, the quality of the soil coverage by treatment I (low quantity residues and low speed) was poor (2) and regular (3) for the other three treatments, *i.e.,* II, III, and IV.

As final conclusions, this study developed a methodology for estimating the quality of soil coverage by pruning residues by determining the soil cover percentage, distribution and size of the pruning residues in olive orchards by image analysis using the threshold segmentation tool in RGB and the block analysis tool. The percentage of soil coverage after chopping was 39% higher in the high quantity pruning residue treatment (2.04 kg m^{-2}) but was not significantly influenced by the chopping speed (2.4 to 3.1 km h^{-1}).

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