Using smartphone leaf area index data acquired in a collaborative context within vineyards in southern France

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Using smartphone leaf area index data acquired in a collaborative context within vineyards in southern France

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ABSTRACT

Aim: The objective of this short communication is to study the opportunity of using a smartphone application for leaf area index (LAI) observations within vineyards in southern France in a farmsourcing context, i.e. when several operators make parallel acquisitions over the same area. In this context, several sources of variability are likely to affect measurement quality, such as the smartphone model or the operator. Understanding these sources of variability will enhance the ability to properly interpret LAI observations to produce relevant information for decision-making.
Methods and material: A study was specifically designed to evaluate the ability of a smartphone application to differentiate sites with different LAI and to determine the origin and the relative importance of different sources of variation in a context of farmsourcing data collection. This focused on the VitiCanopy application, which has been developed specifically for viticulture LAI measurements. Measurements were performed by 18 operators with 11 different smartphone models, on three different vines presenting controlled canopy size to evaluate the ability of the smartphone application to differentiate sites under varying acquisition conditions. Controlled repetitions over seven vines by seven operators with seven smartphone models were performed to further determine the sources of variation and their relative importance.
Results: LAI estimations made with VitiCanopy were consistent with the different levels of controlled vine size in the experiment. The operator and the smartphone model had a significant effect on the variance of the estimated LAI. The variance caused by the observation protocol was relatively low compared to the variability between plants within the observation site (seven vines).
Conclusions: This study showed that the VitiCanopy application was relevant for ordering or classifying vines according to LAI. In an operational context, the results of this study support the use of this smartphone application for relative measurements. However, the best results were achieved when smartphone model differences were minimised or avoided and with homogeneous acquisition conditions between operators. This last condition will require the organisation of group training sessions to minimise an observed operator effect on measurement variability.
Significance and impact of the study: This short communication demonstrated the potential of LAI observations collected with smartphones by several operators for decision-making in a context of farmsourcing. The results showed that this new source of observations, which is inexpensive to collect, made it possible to characterise vine size (LAI) differences in vineyards of southern France. This shows the potential of this app for large production areas such as cooperatives. Further investigations are needed to understand how different training systems may affect the measurement. This source of observations could be complementary to other information sources that are more precise or more accurate, but also more expensive (i.e. destructive methods).

KEYWORDS

precision viticulture, crowdsourcing, data quality, precision, accuracy

INTRODUCTION

Several smartphone applications have been developed for leaf area index (LAI) measurement, such as pocketLAI (Orlando *et al.*, 2016) and VitiCanopy (De Bei *et al.*, 2016). LAI assessment, which previously required specific and expensive sensors or destructive measurement, can now be performed with a smartphone. As the majority of technicians and farmers now have smartphones, such applications make it easier to measure LAI within crop production systems and more particularly in viticulture.

LAI is an integration of leaf canopy density, canopy architecture and biomass, and influences yield and grape quality (Smart, 1985; Dokoozlian and Kliewer, 1995; Johnson, 2008; De Bei *et al.*, 2016). LAI is therefore useful information for decision support for the wine industry, particularly to inform vineyard operations, such as fertilisation, leaf removal, etc. At a larger scale, such as the cooperative level, LAI can be used as a criterion for assessing the qualitative potential of a vineyard (and for field selection).

Going forward, smartphone applications for LAI estimation will likely be a relevant tool for a wide variety of stakeholders in viticulture, including advisers, technicians, vineyard managers, winemakers, etc. These smartphone applications pave the way for collaborative observation gathering by a large number of contributors, which Brabham (2008) defines as crowdsourcing. Minet *et al.* (2017) identifies several specificities in the application of this concept to agriculture: i) the observations collected are often temporal and generally related to a temporally evolving phenomenon (e.g. plant development); ii) observations are often acquired using a sensor or involve an expertise phase; and iii) observations are often collected by agricultural professionals. These specificities led Minet *et al.* (2017) to define collecting 'crowdsourced' data in this context as 'farmsourcing'. Farmsourcing should produce higher quality data as the collection is not performed by the general public, but rather by a cohort familiar with agricultural systems and have a better understanding of potential errors when collecting observations.

However, operators may not necessarily be familiar with the local systems and will still exhibit individuality in collection and/or the available equipment. This raises questions about the quality of data collected from multiple operators equipped with different smartphones, which will have to be harmonised (compared, standardised, averaged, etc.) before being used. In this context, several sources of variability are likely to affect measurement quality and decision-making; some of these sources seem obvious, such as the operator and the smartphone model. The resolution of the smartphone sensor (camera), the operating system (OS), the focal length of the camera, or other smartphone characteristics may also be sources of variability.

The objective of this short communication is to study the relative importance of selected sources of variability in farmsourced LAI data, which will help to i) properly use the observations, and ii) make recommendations and develop protocols on data collection and/or interpretation.

The quality of LAI estimation by smartphone applications under controlled conditions (Orlando *et al.*, 2016; De Bei *et al.*, 2016) uses destructive LAI reference measurements. The objective of this short communication is not to question or to reproduce this work, but to study the behaviour of these applications in a farmsourcing context. The selected application is VitiCanopy (De Bei *et al.*, 2016), which was tested in a commercial vineyard in the south of France to i) validate its transferability into a different production and trellising systems, and, ii) determine the origin and the relative importance of different sources of variation in the farmsourced VitiCanopy dataset.

MATERIALS AND METHODS

1. Trial site

The study site was in Villeneuve lès Maguelone (latitude (WGS84): 43.531996 °; longitude: 3.867827 °) near Montpellier, southern France. It is part of the Languedocien viticulture plain and located in a Mediterranean climate. The cultivar was Grenache Noir (*Vitis vinifera L.*), planted in 2012 with a Cordon de Royat trellis system. This is a variant of vertical shoot positioning with the cordon trained along a wire approximatively 0.7 m above the ground and two lifting wires at 1.10 m and 1.50 m above the ground. The inter-row and inter-vine spaces were 2.50 m and 1.10 m, respectively.

2. Trial design

The sampling plan was designed to assess the ability of the VitiCanopy's LAI estimations (LAIvc) acquired by different operators and smartphones to differentiate sites with different

LAIs, and to understand the relative importance of sources of error by decomposing the variance.

2.1. Ability to differentiate sites

LAIvc observations were acquired on three sites in the vineyard along a single row and separated by 15 m (Figure 1). Each site comprised two vines, and two observations were made for each vine, 0.4 m before and after the vine trunk along the row direction. Each observation measured the whole canopy of the vine and was repeated twice in a short period of time. The value obtained for one site therefore corresponds to the average of these eight observations. All observations were acquired on the same day at the end of the 2017 season (stage 41; Coombe, 1995) when shoot growth had ceased and the canopy volume was maximal.

The leaf area differences between sites were artificially created by removing part of the canopy (Figure 1) to generate a wider range of LAI values. On the first (low LAI) and second (medium LAI) sites, all leaves were removed above the first lifting wire (Figure 1(1)) and the second lifting wire (Figure 1(2)) respectively. On the third site (high LAI), there was no leaf removal (Figure 1(3)).

Note that this defoliating method modified the LAI without modifying the canopy density, which was different from what would happen in a vineyard. The leaf removal also modified the light extinction coefficient of the canopy. This coefficient does influence the LAI prediction made by VitiCanopy. Here, a default constant value of 0.7 was used. It is likely that the chosen defoliation method, and expected variations in canopy size, shape and density, may result in the need for different light extinction coefficients. However, the likely default scenario is that users will not change the application's default values. Therefore, this value was not changed as it is expected to be the most often observed mode of operational, which is the context this study is aiming to investigate.

In order to verify that the three treatments generated three significant different LAI values, LAI observations at the three sites were acquired with a LAI-2200C plant canopy analyser (Welles and Norman, 1991) (LAIpca), using a white umbrella to avoid direct sunlight on the sensor while reducing blue light scattering (Dash *et al.*, 2010; Sun and Schulz, 2017). This sensor was chosen as it is a widely used and accepted system in southern France and it is known to be an estimator of the actual LAI (Ollat *et al.*, 1998). The objective of using this sensor was not to obtain reference data but to validate the actual differences in LAI between the three treatments. LAIpca observations were therefore carried out under controlled conditions. Three observations were collected on each vine and the resulting average value was used as the LAIpca. The LAIpca observations were made on the same day as the LAIvc observations.

2.2. Decomposition of variance

A fourth site of measurement was considered, performing a decomposition of variance that took into account inter-vines variability in addition to operators and smartphone model effects. LAIvc observations were made by different operators with different smartphones (see section *Description of smartphones and acquisition guidelines* for details) on seven vines, separated by a distance of 6 m between vines, within the same row.

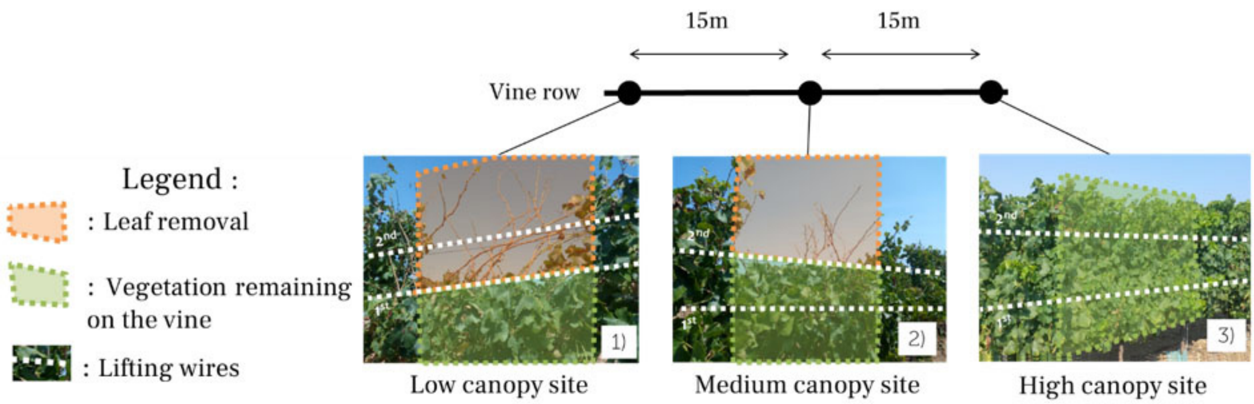

FIGURE 1. Trial design and treatments for evaluating the ability of LAIvc to differentiate sites.
Artificially generated range of leaf area by leaf removal at three sample sites: low canopy (1), medium canopy (2) and high canopy (3).

These seven vines were healthy plants with approximatively the same canopy size. All observations were acquired on the same day, around veraison (Coombe, 1995) in the 2018 growing season, using the same method described above: two images were taken at each site, respectively 0.4 m left and 0.4 m right of the trunk of the target vine and the LAIvc was considered as the average of these two values using the application's "effective LAI" output.

3. Description of smartphones and acquisition guidelines

LAIvc were acquired in conditions described as "Crowdsourcing of local visual observations" (Minet *et al.*, 2017). Operators were from the agricultural sector but were not familiar with the vineyard, and used their own personal smartphone with VitiCanopy installed. To evaluate the ability to differentiate sites, LAIvc was collected by 18 operators at the three sites following the acquisition methodology described above for each site. Each operator only collected data with their smartphone. Across the 18 operators there were 11 different smartphone models with camera resolution ranging from 1.2 to 5 megapixels (Table 1). The operating systems (OS) were Android (14/18 phones) and iOS (4/18 phones). For the decomposition of variance, LAIvc was collected by seven operators on each of the seven vines described above. Each operator collected data with their own smartphone as well as with all six other smartphones. The OS were Android (6/7 phones) and iOS (1/7 phones), the camera resolution ranged from 3.7 to 8 megapixels and focal length ranged from 1.9 to 2.2 (Table 1).

The camera's angular field of view (AFOV) may influence the VitiCanopy estimations (De Bei *et al.*, 2016). This characteristic is rarely indicated by manufacturers who prefer to indicate the focal length. The AFOV depends mainly on focal length but also on the size of the photographic sensor. For simplification purposes, in this study the effect of the resolution of the photographic sensor was considered as negligible and only the focal length was considered (Table 1).

The recommendations for VitiCanopy made by De Bei *et al.* (2016) were presented to all operators before data collection to standardise the collection

TABLE 1. Technical characteristics of smartphones used in the study for the evaluation of the accuracy (18 operators) and the precision (seven operators) of VitiCanopy's LAI estimations.

	Operator	Device brand	Device model	Operating system (OS)	OS version	Front camera resolution (megapixel)	Camera focal length (mm)
Differentiation of sites	1	Huawei	P10	Android	7.0	2	1.9
	2	Samsung	Galaxy S6	Android	7.0	5	1.9
	3	Apple	iPhone SE	iOS	10.3.3	1.2	2.4
	4	Samsung	Galaxy A5	Android	7.0	5	2.2
	5	Samsung	Galaxy J5	Android	5.1.1	5	2.2
	6	Apple	iPhone 6	iOS	10.3.3	1.2	2.2
	7	Samsung	Galaxy S4	Android	5.0.1	2	2.4
	8	BQ	Aquarius M5	Android	6.0.1	5	2.0
	9	Sony	Z3 Compact	Android	6.0.1	2	2.8
	10	Kazam	Tornado 348	Android	4.4.2	5	-
	11	Samsung	Galaxy S5	Android	6.0.1	2	2.4
	12	Samsung	Galaxy A5 2016	Android	7.0	5	1.9
	13	Sony	Xpéria Z3 C	Android	6.0.1	2	2.8
	14	Samsung	Galaxy S4	Android	5.0.1	2	2.4
	15	Samsung	Galaxy S6	Android	7.0	5	1.9
	16	Apple	iPhone 5	iOS	10.3.3	1.2	2.4
	17	LG	G3 Beat	Android	4.4.2	1	2.0
	18	Apple	iPhone 6S+	iOS	10.3.3	5	2.2
Decomposition of variance	1	Huawei	P8 Lite	Android	7.0	8	2.0
	2	Huawei	P9 pro	Android	6.0	8	1.9
	3	Huawei	P8 Lite	Android	7.0	8	2.0
	4	Apple	iPhone 6S	iOS	11.4	5	2.2
	5	Nexus	5X	Android	8.1.0	5	2.0
	6	Samsung	Galaxy J7	Android	7.0	5	2.2
	7	Samsung	Galaxy Note 4	Android	6.0.1	3.7	1.9

method as much as possible. Images were taken using the front camera of the smartphones and upward looking to the grapevine canopy. The approximated distance between the smartphone and the cordon was 0.7 m. The parameters of all devices were set to default values, i.e. 0.7 for the light extinction coefficient and 0.75 for the gap fraction threshold (De Bei *et al.*, 2016) to reflect the expected norm of operation, i.e. operators accept default values.

4. Data analysis

All calculations and statistical analyses were performed in R (R Core Team, 2019). A Student's test was used on the LAIvc and LAIpca observations to verify that the three treatments (low, medium and high canopy size) generated significantly different LAI values.

The decomposition of the LAIvc variance was performed using analysis of variance (ANOVA). Initially, the ANOVA was carried out on the scale of the vine plant. Factors in the ANOVA were operators, smartphone model, camera resolution, camera focal length and OS type. The OS version was recorded (Table 1) but not used. This analysis made it possible to understand the contribution of each of these effects to the observed variance. In a second step, the ANOVA was repeated for data acquired on the fourth site composed of seven vines. The individual vine factor was added to the analysis. This analysis made it possible to understand the importance of the different factors in comparison with the variance between vines that compose the same observation site.

RESULTS AND DISCUSSION

1. Ability to differentiate sites

LAIpca observations acquired under controlled conditions confirm that the three treatments (low, medium and high canopy size) did generate three significantly different LAI values (Student's test, $p > 0.1$) (Figure 2a). LAIvc observations acquired by 18 different operators with 11 different smartphones also captured these differences (Figure 2b). Differences in LAIvc values were significant, with a *p*-value of 0.1 (Student's test) for low vs high and medium vs high treatments, and significant with a *p*-value of 0.2 (Student's test) for low vs. medium treatment.

These results showed that the VitiCanopy application was transferable to a vineyard systems that was different from the one in which it was developed and validated (De Bei *et al.*, 2016) in terms of region (South Australia vs South of France), cultivar (Shiraz (*Vitis vinifera* L.) vs Grenache Noir (*Vitis vinifera* L.) and trellising systems (both vertical shoot positioned but with a cordon height of 1 m vs 0.7 m). Note that the trellising systems were relatively similar.

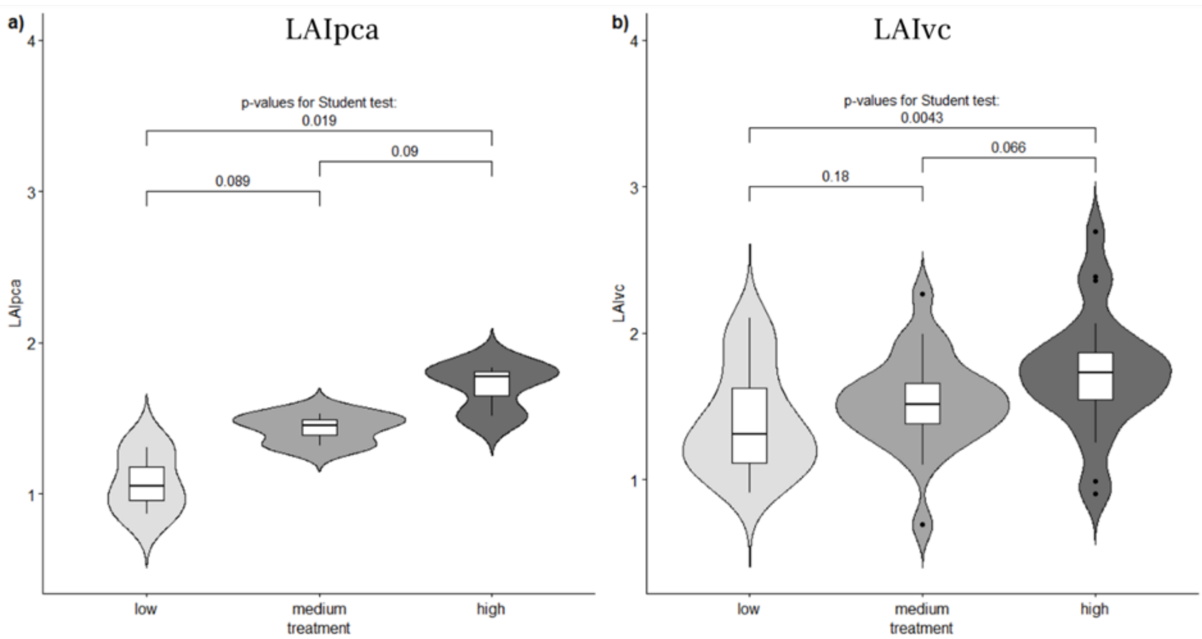

FIGURE 2. (a) Violinplot of LAIpca collected in controlled conditions for three different treatments (low, medium and high canopy size), with respective p-values for a Student's test. (b) Violinplot of LAIvc collected by 18 operators with 11 different smartphone models for the same three treatments, with respective p-values for a Student's test.

In an operational context, the observations of LAIpca are generally used to order or classify sites in the south of France (not for providing definitive LAI values). The ability of the LAIvc observations to differentiate sites was similar (Figure 2a,b) to the ability of the industry-used LAIpca observations. Therefore, LAIvc observations collected in a farmsourcing context seemed to be a relevant information source for ordering or classifying sites (vineyards). The use of VitiCanopy in this farmsourcing context would be of interest for a cooperative winery or a large wine-growing estate in southern France to identify and rank blocks based on average LAI and to use the variance in LAI to perform site or field selection.

The variances of the LAIpca observations (0.049 (low), 0.011 (medium), and 0.029 (high) treatments) were lower than those of the LAIvc observations (0.125(low), 0.102(medium), 0.167 (high)). Considering that the performance of VitiCanopy in estimating LAI was close to that of the Plant Canopy Analyser (De Bei *et al.*, 2016), it is likely that this difference in variance was induced by the large number of operators and the smartphone models aiming at simulate a farmsourcing context. The objective of the following section is to focus on the decomposition of this variance in order to understand the respective contribution of the different factors.

2. Decomposition of variance

The ANOVA (Table 2) shows that the operator, the smartphone model and the focal length (an indication of AFOV) have a significant effect on the observed variance. The smartphone effect is stronger (higher sum of squares) than the operator effect. There is no significant interaction between these three factors, and they are considered to be independent.

The front camera image resolution range (3-8 megapixels) corresponds to current standards in the smartphone market in Europe. There is no effect of the camera resolution or the OS (iOS vs. Android) on the LAIvc variance (p > 0.05, results not shown). The presence of a smartphone effect (Table 2) is likely to be a combined effect associated with the diversity of smartphone characteristics (OS type, OS version, camera resolution) and their interactions (Table 1) in the study. Understanding these individual smartphone effects would require a larger study. The effect of focal length (and AFOV) can be explained by the amount of vegetation actually observed by the different smartphones placed at the same distance from the canopy. The results did not allow for precise recommendations on the characteristics of preferred smartphones or camera for LAIvc. However, given the effect of the smartphone model and the focal length on measurement variance, it seems prudent to recommend that smartphone characteristics are as homogeneous as possible (or even restricted to the same smartphone model) when several operators are required to perform measurements in parallel.

The operator effect can be explained by operator differences in protocol interpretation and execution. These differences have not been quantified in this study but it is likely that they can be explained by the positioning of the smartphone during acquisition, the vertical distance from the canopy, the horizontal distance from the trellis or the inclination angle of the smartphone during acquisition. Further study would be required to clarify the respective contributions of each of these potential sources of variation.

The presence of an operator effect when standard smartphones were used highlighted the need to organise collective training sessions for all operators in order to harmonise their practices

TABLE 2. Results of the ANOVA performed on VitiCanopy's LAI estimations with three factors (operator, smartphone model and focal length).

	DF	Sum Sq	Mean Sq	F value	Pr (>F)	
Focal length	1	0.330	0.3302	22.457	3.356e-06	***
Operator	6	2.047	0.3411	23.197	< 2.2e-16	***
Smartphone	5	4.175	0.8350	56.787	< 2.2e-16	***
Focal length : operator	6	0.061	0.0102	0.693	0.656	
Operator : phone	30	0.298	0.0099	0.675	0.903	
Residuals	293	4.308	0.0147			

before data collection and ensure the rigorous application of the acquisition protocol in farmsourcing contexts.

3. Decomposition of variance in an operational context

In an operational context, LAI observations are often made on vines considered homogeneous and representative of the field. In this context, VitiCanopy would be used to characterise the average LAI of a block, not of individual vines. Therefore, the variability of LAIvc values will depend on both smartphone and operator effects and on the actual inter-vine LAI variability.

When vine effects were included in the ANOVA, the majority (60 %) of the observed variance was explained by inter-vine variability at a site. The proportion of variance explained by the operator, the smartphone and the focal length represented only 29.7 % of the total variance (6.8 %, 16.7 % and 6.2 %, respectively). Approximatively 10 % of the variance was unexplained by the factors studied. The variability due to error in data collection (operator, smartphone and focal length) was therefore relatively low compared to the variability in LAI across the seven studied vines. From an operational point of view, this puts in context the effect of vine variability relative to acquisition error (smartphone, operator, focal length) and the importance of correct sampling procedures to respond to the intrinsic variability in the system when determining mean LAI over an area. This does not negate the relevance of previous conclusions that addressed the 29.7 % of variance associated with data acquisition. However, in order to limit the sensitivity of the LAIvc measurement to inter-vine variability in commercial applications, it is advisable to determine minimum (random) sampling sizes for fields based on known or expected variability and sampling theory (Taylor and Bates, 2012). Sampling should also pay particular attention to the choice of vines so that they are as representative as possible of the target area. In this study, the selected vines were visually considered to be homogeneous and chosen to be representative of the field average. Consequently, the site (inter-vine) variability was almost certainly underestimated compared to what would be expected in a commercial system.

CONCLUSIONS

This study showed that a farmsourced use of the VitiCanopy application provided relevant information for ordering or classifying vines or vineyards based on their LAI (canopy size). In a farmsourced context, variance associated with the type of smartphone used was greater than the variance associated with operators. To achieve the best data, it is important to standardize smartphones characteristics as much as possible and to organise group training sessions for all operators (and regularly validate operators). These encouraging results with the use of VitiCanopy in a farmsourcing context open the way for future research, especially in the use of these observations in conjunction with other existing LAI/canopy measurements. The importance of adjusting the light extinction coefficient according to the actual characteristics of the canopy needs to be explored in further detailed studies. Finally, the larger amount of inter-vine LAI variability relative to the variability associated with operator and smartphone effects is a key issue. This raises an important question, common in viticulture, of the number of measurements to be made and the choice of sampling vines to produce a reliable estimate with a smartphone application.

REFERENCES

Brabham D.C., 2008.Crowdsourcing as a Model for Problem Solving: An Introduction and Cases. *Convergence* 14(1), 75–90. doi:10.1177/135485650 7084420

Dash J., Curran P.J., Tallis M.J., Llewellyn G.M., Taylor G. and Snoeijf P., 2010. Validating the MERIS terrestrial chlorophyll index (MTCI) with ground chlorophyll content data at MERIS spatial resolution. *International Journal of Remote Sensing* 31(20), 5513–5532. doi:10.1080/01431160903376340

De Bei R., Fuentes S., Gilliham M., Tyerman S., Edwards E., Bianchini N., Smith,J. and Collins C., 2016. VitiCanopy: A free computer app to estimate canopy vigor and porosity for grapevine. *Sensors* 16(4), 585. doi:10.3390/s16040585

Dokoozlian N.K. and Kliewer W.M., 1995. The light environment within grapevine canopies. II. Influence of leaf area density on fruit zone light environment and some canopy assessment parameters. *American Journal of Enology and Viticulture* 46(2), 219–226.

Johnson L.F., 2008. Temporal stability of an NDVI-LAI relationship in a Napa Valley vineyard. *Australian Journal of Grape and Wine Research* 9(2), 96–101. doi:10.1111/j.1755-0238.2003.tb00258.x

Minet J., Curnel Y., Gobin A., Goffart J.P., Mélard F., Tychon B., Wellens J. and Defourny P., 2017. Crowdsourcing for agricultural applications: A review of uses and opportunities for a farmsourcing approach. *Computers and Electronics in Agriculture*, 142, 126–138. doi:10.1016/j.compag.2017.08.026

Ollat N., Fermaud M., Tandonnet J.P. and Neveux M., 1998. Evaluation of an indirect method for leaf area index determination in the vineyard: Combined effects of cultivar, year and training system. *Vitis*, 37(2), 73-78.

Orlando F., Movedi E., Coduto D., Parisi S., Brancadoro L., Pagani V. and Confalonieri R., 2016. Estimating leaf area index (LAI) in vineyards using the PocketLAI smart-app. *Sensors*, 16(12), E2004. Available at: doi:10.3390/s16122004

R Core Team, 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org

Smart R.E., 1985. Principles of grapevine canopy microclimate manipulation with implications for yield and quality. A review. *American Journal of Enology and Viticulture* 36, 230–239.

Sun L. and Schulz K., 2017. Spatio-temporal LAI modelling by integrating climate and MODIS LAI data in a mesoscale catchment. *Remote Sensing* 9(2). doi:10.3390/rs9020144

Taylor J.A. and Bates T.R., 2012. Sampling and Estimating Average Pruning Weights in Concord Grapes. *American Journal of Enology and Viticulture* 63(4), p.559 LP-563. doi:10.5344/ajev.2012.12069

Welles J.M. and Norman J.M., 1991. Instrument for Indirect Measurement of Canopy Architecture. *Agronomy Journal*, 83(5), 818-825. doi:10.2134/agronj1991.00021962008300050009x

