Preliminary study on the application of a commercial LAI ceptometer for estimation of leaf production on low vigour mulberry trees

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***Abstract*— In the last decades, the interest on instrumentation for fast plant canopy characterization has increased, in particular for the possibility of estimation of yield of cultivated plants. The present work investigates the suitability of a commercial LAI ceptometer (AccuPAR LP-80) for estimation of leaf yield of white mulberry (*Morus alba* L.) trees: focus of the present study is the evaluation of accuracy of LAI data collected with the ceptometer in comparison with the real total area of leaves and their weight for each plant. The evaluation has been carried on plants both cultivated in a controlled environment and in open field. Results from analyses show a relatively good grade of accuracy, affected by the geometry of the investigated crop.**

Keywords—mulberry cultivation, LP-80 LAI Ceptometer, LAI, plant canopy, agriculture

I. Introduction

Since the last decades of the past century, several research activities in agriculture have been dedicated to in-field application of sensors for the estimation of yield or quality of different crops through the characterization of plant canopy [1-6]. In this scenario, the collection of data related to the Leaf Area Index (LAI) has become a standard for the study of plant canopy [7-12]. Generally speaking, sensors could be divided into two classes: contact and non-contact instruments; this simple classification can be applied also to main LAI measuring devices. For in-field data surveys, the latter ones are the most interesting, since they allow collection of large amounts of data from investigated crops with no influence or induced disturb [13]. Thanks to fast data collection, non-contact devices can be applied for continuous monitoring of rapidly growing crops [14]. Both destructive and non-destructive methods have been proposed for canopy characterization, in particular to estimate the total photosynthetic area of a canopy. The most precise and accurate methodology for characterization of canopy LAI, relies on collection of all the leaves of a studied plant and on measurement of the extension of the total area of the same leaves taking advantage of dedicated scanning instrument. If by one hand this methodology for LAI extraction is accurate and repeatable, on the other hand it is time consuming and destructive for plant canopies.

Besides destructive methodologies, LIDAR (*Laser Imaging Detection and Ranging*) technology and photogrammetry represent reliable alternatives for fast and accurate in-field data collection related to plant canopies [2,15]; on the other hand, those technologies are time demanding in terms of data processing and elaboration [16-17]. An interesting alternative is given by ceptometer technology: many research papers have successfully implemented such technique for fast and precise characterization of plant canopy [18-19].

In the field of *sericulture*, the agricultural practice for silk production, the cultivation of mulberry trees (*Morus alba L.*) is a fundamental activity since mulberry leaves are the unique nourishment of reared silkworms (*Bombyx mori L.*) [20-21]. For this reason, the application of good agronomic practices to the cultivation of mulberry trees has to be focused on obtaining high yield in leaves. Furthermore, as leaves represent the principal economic product of mulberry cultivation, new technologies allowing a fast and precise characterization of the plant canopy are fundamental for the improvement of yield and quality of this crop. Such task is not trivial, since mulberry training systems often encompass relatively small plants characterized by low vigor complex shapes of the canopy.

II. MATHERIAL AND METHODS

The present paper aims to test the performances of a ceptometer-based technique for the estimation of the leaf production and LAI of young cultivated white mulberry (Morus alba L.) trees. For the scope, a commercial AccuPAR LP-80 LAI Ceptometer has been implemented; collected data have been analyzed against reference measures taken by means of a reference LAI scanner, the LI-COR LI3100. The authors analyzed LAI data collected by the ceptometer in terms of correlation with data collected with the LAI scanner and total weight of leaves taken from each plant. Analyses have been eventually used to define the best methodology for collection of LAI data with the ceptometer in the case of low vigor plants.

A. *Ceptometer working principle*

A ceptometer is defined as a non-contact passive sensor able to estimate the Leaf Area Index parameter of the canopy of a crop analyzing the information derived from the shadows produced by of the canopy of the crop itself.

The used ceptometer is the AccuPAR LP-80 LAI ceptometer, formed by a scanning bar equipped with 80 light sensors grouped in 8 sections for intercepting the amount of light under plant canopy; an additional external light sensor is used for collecting data about light level above the canopy.

For calculate the LAI parameter, the ceptometer uses the following equation number 1:

$$LAI = \frac{\left[\left(1-\frac{1}{2K}\right)f_b-1\right]\ln\tau}{A(1-0.47f_b)} \text{ (Eq. 1)}$$

The f_b parameter is defined as *fraction of beam radiation*, that is the ratio between the actual above canopy PAR measurement to the hypothetical one at the latitude and longitude of the site of data collection.
The parameter K is the *extinction coefficient for the canopy* and is computed using equation 2:

$$K = \frac{\sqrt{\chi^2+\tan\theta^2}}{\chi+1.744(\chi+1.182)^{-0.733}} \text{ (Eq. 2)}$$

Where θ is the *zenith angle*, derived by the ceptometer with the latitude, longitude, day and time data and χ is the *leaf angular distribution*, a value that the take in consideration how leaves are distributed in the canopy and the operator can set this parameter in function of the investigated crop according to a specific table provided by the user manual. For present tests, since no information are provided for mulberry trees, the value has been set to 1.0 as default.
The τ parameter (equation 3) is defined as the ratio between the belove canopy PAR (PAR_{bc}) measurement and the above canopy PAR (PAR_{ac}) measurement.

$$\tau = \frac{PAR_{bc}}{PAR_{ac}} \text{ (Eq. 3)}$$

The parameter A is calculated as reported in equation 4 by the implemented ceptometer from the *a* parameter, defined as the *leaf absorptivity in the PAR band*, set to 0.9 as default by AccuPAR

$$A = 0.283 + 0.785a - 0.159a^2 \text{ (Eq.4)}$$

B. *Leaf Area Scanner working principle*

The area scanner used for the present work is the LI COR LI3100. The LI3100 scanner allows fast measurements of total area of leaves. The instrument is composed by a transparent plastic belt, a solid-state camera, a fluorescence lightbulb at 15 Watt and a system of three mirrors.

The operator puts the analyzed leaves upon the transparent plastic belts, moved by several electric engines. Belts move the leaves under the fluorescent lightbulb and thanks to the system of three mirrors, light is reflected to the camera.

The width of scanned leaves is derived from the camera, while the length of each section of scanned leaves is calculated starting from the speed of the belt.

C. *Data collection and analysis*

The authors collected and analyzed two samples of LAI data:
- the first part of the research included 30 mulberry trees of about two-years cultivated in a protected environment, in pots;
- the second dataset refers to an orchard of about 150 plants cultivated in an open field in North-East of Italy (45.3588N, 11.756912E)

Analyzed trees belong to three different varieties, Florio, Restelli and Koukusò.

The objectives of the first test are testing the accuracy of the measurements taken by the ceptometer and, at the same time, to define a robust procedure for collecting data on low vigor mulberry trees using a LAI ceptometer. Thus, the authors collected two series of data, considering different distances and angles of the ceptometer relatively to the analyzed plant. For this first test, the authors divided the complete sample of mulberry trees into five sub-samples. Firstly, the authors randomly picked plants belonging to each sub-sample.

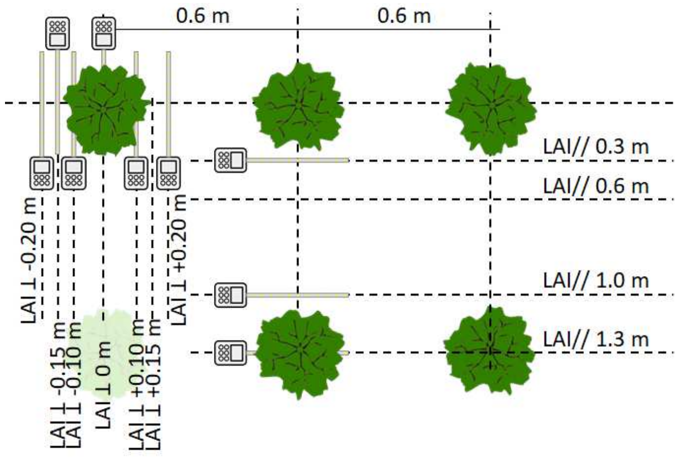

Fig. 1. Schematic view of the sampling procedure for data collection

This preliminary operation has been done in order to obtain a dataset with a larger range in terms of leaf growth and development: as discussed in the following, data collection involved the total defoliations of mulberry plants. For each data collection operation, plants of the designed sub-sample were identified in an open field on a row at the typical on-the-row distance of 0.60m. Then taking this simulated row as a reference, two series of data has been collected, with the ceptometer held respectively parallel and perpendicular to the row of mulberry trees. Measurements with the ceptometer positioned parallel to the simulated row were taken at 0.3-0.6-1.0-1.3 m from the basis of the plants. The maximum distance (1.3 m) corresponds to the typical interrow distance for open field cultivated mulberry plants: such value was thus chosen as the upper bound to verify the theoretical performance of the instrument in an ideal controlled condition. For measurements taken with the ceptometer orthogonal to the simulated row, the ceptometer was positioned at 0, 0.10, 0.15 and 0.20m from the center of the principal branch, on both sides of the plant. Figure 1 provides a schematic view of the adopted sampling scheme. For the first sample, the authors collected LAI data once a week for two months, to allow mulberry trees of the last sub-samples to grow and develop a complete canopy. In order to increase repeatability of collected data, all the measurements were taken between 10 AM to 1 PM (local time) [18]. In addition, a set of ancillary data about plant structure, as total height, and number of branches, was concurrently collected. To have a better understanding of the results of the test on the first sample of plants, the authors analyzed the ancillary data through ANOVA tests; when statistically significant differences were found, Tukey HSD tests for mean separation was carried out.

The objective of the second test was to validate the procedure defined with the first test, in an actual open field condition. For this test, a sample of three varieties (the same of the first test) of about 150 mulberry trees, homogeneous in terms of planting year, was chosen. In this case, the ceptometer data sampling procedure considered only three different measurements, defined on the basis of the results from the first test: one parallel to the row at about 0.50m and two orthogonal to the row at about 0.20m from the center of trees. In addition, a set of measurements taken with an approximate angle of 45° from the row was also collected. For the second test, LAI data from the ceptometer were compared to fresh weight data measured in field after LAI data collection. In addition, a subsample of leaves from 50 mulberry trees was frozen and later used in order to estimate the total area, taking advantage of the LAI scanner used also for the preliminary test.

For data analysis of both the two tests, data from different angulation have been averaged and different combinations of data were tested in order to define the best correlation with LAI data from the scanner. For data analysis, the statistical software R was used. For outlier research and treatment, the Cook's Distance [22] approach was considered.

III. Results and discussion

A. Preliminary test

The first analysis of the preliminary test was aimed at verifying the importance of leaf area data collection from the plant, by testing the correlation between leaf area data and the total leaf production by the same plant. Indeed, the focus for sericulture practices is the estimation of the total leaf production of mulberry trees, needed in order to allow estimation of the optimal number of silkworms to be reared during the rearing season. In Figure 2, a graph with the correlation between the fresh weight of mulberry leaves per plant and the total area of leaves per plant is reported. The correlation in this case is high, with an adjusted determination coefficient $R^2=0.91$, the correlation between these two parameters is also highly significant ($p<0.01$). The authors then analyzed the ancillary data about plant heights and number of lateral branches, since those are the plant morphological characteristics that can affect the leaves distribution on the whole volume of the canopy and, consequently, LAI measurements by means of the ceptometer. As reported by the graphs in Figure 3, the whole sample of thirty plants are homogeneous for the total height of the main branches ($p=0.01$), but Restelli variety gave evidence of a higher number of lateral branches ($p=0.01$). During the first experiment on the performance of the ceptometer, the authors studied the correlation between LAI data from different positions and leaf production. This analysis showed how best results could be obtained by positioning the ceptometer perpendicular to the row and, in particular, at a distance of about 0.15 to 0.20m left and right from the main branch both for the total area of leaves ($R^2=0.31$) and for the total weight of leaves ($R^2=0.25$). Testing the correlations between ceptometer data and total area from scanner within each variety, in this preliminary test Florio variety gave evidence of the highest correlation: this is most probably due to the fact that the interval of LAI data for plants of Florio variety was wider than for the other varieties (Figure 4), eventually producing higher correlation. As previously mentioned, different combinations of LAI parameters from various positions were studied. Best correlation eventually uses useful in order to determine the best methodology for collecting data. Best results were achieved by averaging measurements collected with the ceptometer positioned parallel to the simulated row of mulberry plants, with measurements taken orthogonally to the row.

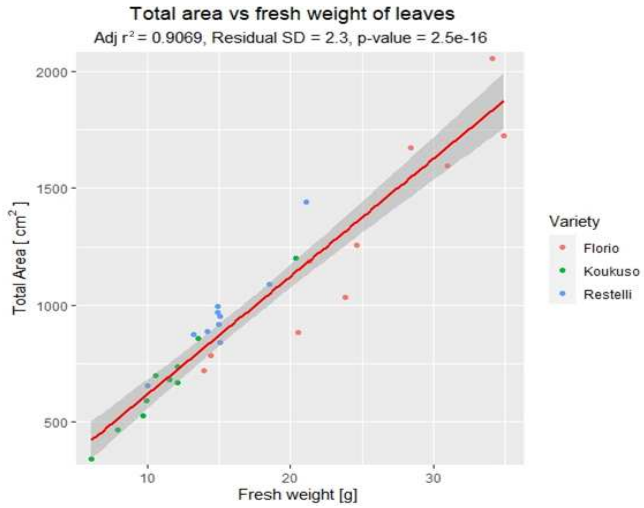

Fig. 2. Regression analysis between fresh weight and total area of leaves. The grey area represent the fiducial interval of the regression line

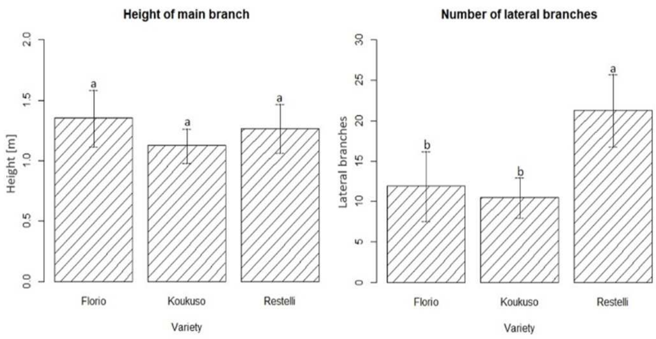

Fig. 3. Height of main branch and number of lateral branches. Letters from Tukey HSD test, p=0.01. Error bars represents standard deviation

In particular, the highest correlation with LAI scanner data was achieved by averaging measurements taken at 1.30m from the row and those taken at 0 and 0.20 m from the plant center, with the ceptometer orthogonal to the row (R^2=0.38), as shown in Figure 5. The correlation is not very high, but statistically significant ($p<0.01$). From the correlation analysis, Restelli variety showed a high correlation (R^2=0.73), most probably due to a number of lateral branches higher than for other varieties, and for this reason orthogonal measuremnts could better estimate the total leaf production in terms of total leaf area.

In conclusion, from this preliminary test, the ceptometer represents a useful instrument for fast collection of data about the canopy development in mulberry orchard, even in the case of low vigor plants. It is remarkable to note that from preliminary test the accuracy of the measurements with the ceptometer is influenced by morphological characteristics of the plants themselves. Such problem is not limiting, and could be mitigated by a precise management of pruning of mulberry plants.

B. Open-field test

During open field tests, a regression analysis for the total fresh weight of the leaves per plant and the total leaf area has been initially carried out, as done for the preliminary test. Results gave evidence of some difference from the previous ones, probably due to the larger range of data and higher

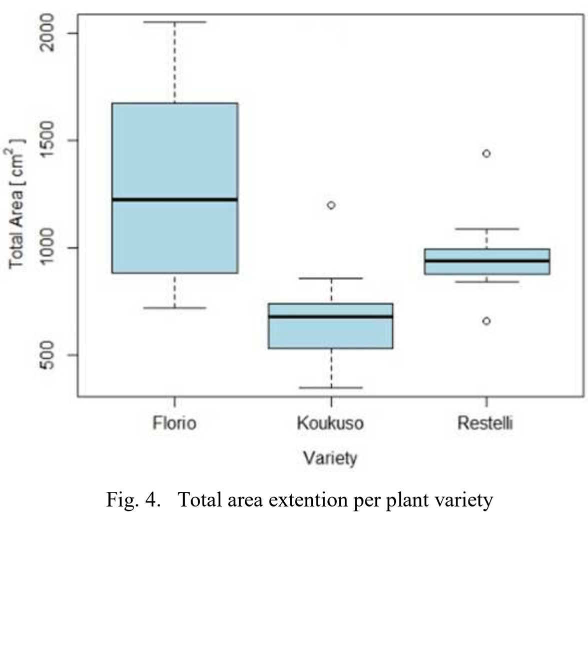

Fig. 4. Total area extention per plant variety

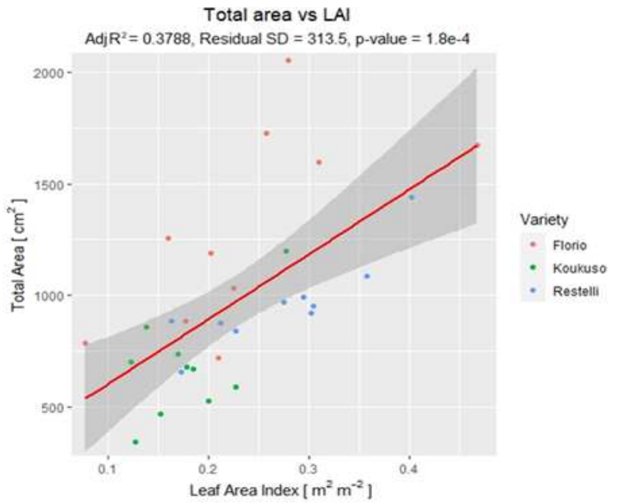

Fig. 5. Regression analysis on LAI data from LP-80 Ceptometer and LAI scanner. The grey area represent the fiducial interval of the regression line

number of leaf samples. In this case, the adjusted determination coefficient was significantly higher (R^2=0.98), while the regression was still highly statistically significant (Figure 6). In comparison to the test which considered plants from a controlled environment, in the open field test Florio variety highlighted lower yield values, while Restelli and Koukuso varieties showed a wider range of values, with Restelli variety characterized by a huge number of high values for both fresh weight and total area of leaves.

The authors then analyzed ancillary data, as height of the main branch and number of lateral branches per plant. The results of such analyses are graphically reported in Figure 7. According to ANOVA results, plants resulted inhomogeneous considering both the height of the mail branch (p=0.01), with the Restelli variety taller than the others (from Tukey HSD test at p=0.01) and the number of secondary branches (p=0.01). High variability is typical of field tests, but still, it is useful to test the proposed methodology under different conditions which characterize real applications.

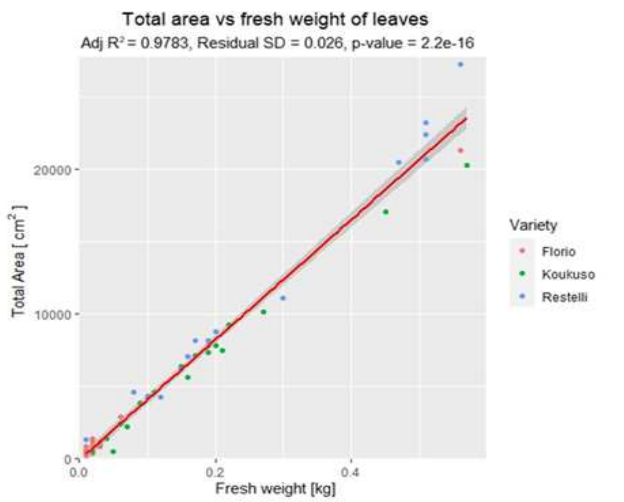

Fig. 6. Regression analysis between fresh weight and total area of leaves. Data from open field test

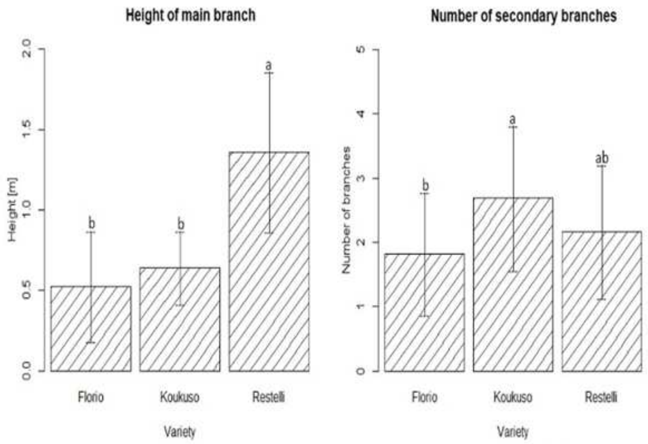

Fig. 7. Height of main branch and number of lateral branches. Letters from Tukey HSD test, p=0.01. Error bars represents standard deviation

The authors then tested the correlation between total fresh weight of leaves per plant and ceptometer measurements taken at different angles from the rows.

Then, different correlation and regression analyses between total fresh weight of leaves per plant and LAI data were calculated. From data analysis, best regressions have been found in second grade polynomial forms. Best fitting regression has been identified between fresh weight data of leaves and the average LAI values from all different measurements, i.e., perpendicular, orthogonal, and 45° angulated referring to the row (Figure 8). The adjusted R^2 value is equal to 0.751 and the regression is statistically significant ($p<0.01$), as achieved through an ANOVA test analysis. In this case, differences between varieties are clearly visible in the graphs, with Florio variety characterized by lower values.

The authors tested also other transformation models, such as higher degree polynomials, exponential or logarithmic equations, in order to find better regression on collected data. The authors achieved best results by logarithmic

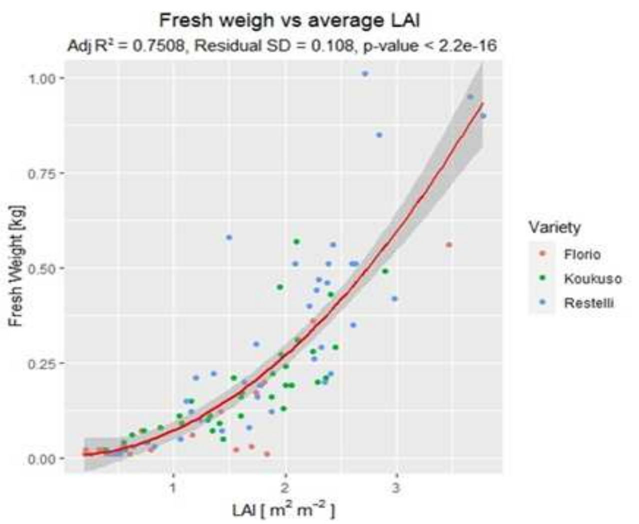

Fig. 8. Regression analysis between fresh weight and LAI data (average from parallel, orthogonal and 45° angulated). Data from open field test

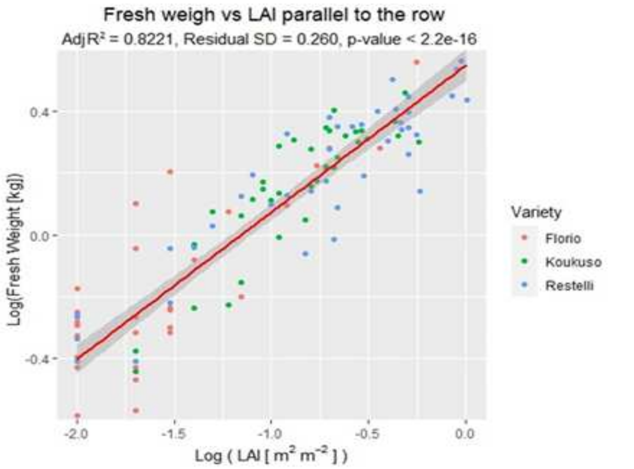

Fig. 9. Regression analysis between fresh weight and LAI data collected parallel to the row. Data from open field test

transformations of both total fresh weight of leaves and of different combination of LAI data. Best results in terms of regression have been achieved with only LAI data collected parallel to the row (Figure 9) and with averaged LAI data collected parallel and orthogonal to the row (Figure 10). As shown by the graphs in Figure 9 and Figure 10, the best fitting regression between total fresh weight of leaves data and LAI data is the one that considers both parallel and othogonal LAI data. In terms of determination coefficient, the model considering both the measurements provided an adjusted R^2 value of 0.833, slightly higher than the value achieved just through parallel data (adjusted R^2=0.822). Furthermore, the AIC values (20.527 vs 13.879 for rispectively the simpler and the more complex one) as well as the BIC values (28.709 vs 22.062 for rispectively the simpler and the more complex one) highlighted a better performances in the case of the second model.

However, even if the second bilogarithmic model provides better results, the increase in estimations is low and,

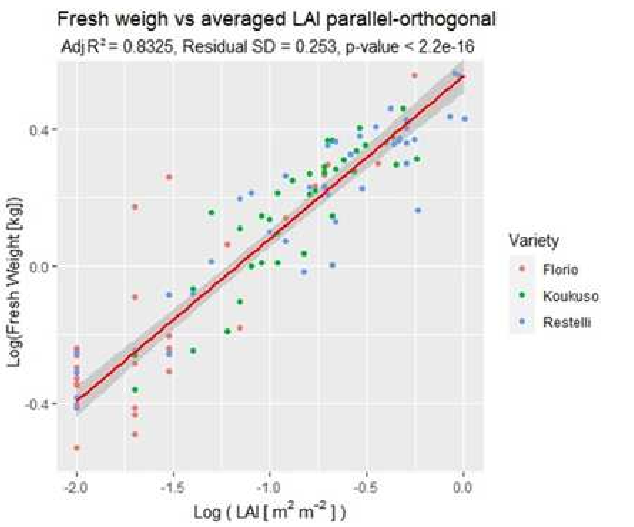

Fig. 10. Regression analysis between fresh weight and LAI data collected parallel to the row. Data from open field test

on the other hand, it requires a higher amount of data since two sets of measuremnts are needed. For this reason, the authors consider the simpler model to be still the most suited for field applications.

IV. Conclusions

The aim of the present work was to identify a suitable instrument for fast data collection of mulberry leaf yield data. For this aim, the authors tested a commercial ceptometer.

Proposed experiments gave evidence that such sensing technology can be usefully implemented in an efficient way for investigating yield characteristics of low vigor mulberry orchards.

The research work also focused on the definition of the best measuring condition, for collection of LAI data in mulberry orchards. The two reported experiments showed how the best setup for collection of LAI data, is with the ceptometer positioned parallel to the row, at about 0.50m: in this case a high correlation with mulberry leaf yield data was achieved (R^2=0.822).

Further developments of this work can include the application of this methodologies for early leaf yield data prediction or analysis of spatial variability characterization.

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