European Geosciences Union General Assembly - Vienna | Austria | April 13 – 17, 2015 Session BG1.6 (G24)

# Accuracy of estimated geometric parameters of trees depending on the LiDAR data density


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## 1. Introduction

The estimation of dendrometric variables has become important for spatial planning and agriculture projects. Because classical field measurements are time consuming and inefficient, airborne LiDAR (Light Detection and Ranging) measurements are successfully used in this area. Point clouds acquired for relatively large areas allows to determine the structure of forestry and agriculture areas and geometrical parameters of individual trees. The aim of this study was to analyse the accuracy of automatically determined geometric parameters of trees depending on the density of LIDAR data. Consequently, the objective of this research was to investigate, if the low density LiDAR data can be used for reliable estimation of tree height, crown base height, average crown diameter and crown area. It was also investigated, whether the tree size had an impact on accuracy of estimated tree geometric parameters and if the analysis are sensitive to estimation strategy.

## 2. Data

The study area (5.92 ha) is located in the municipality of Viver (Central East of Spain). Two LiDAR datasets with different densities were used: sparse (average density of 0.5pt./m²) and the dense (4 pt./m²). The density of the second LiDAR dataset was not uniform - parts of study area covered by overlaying scans had an average density of 9 pt./m², while the remaining area had an average density of 3.5 pt./m². For 25 individual trees inside the study area the following parameters were measured using the traditional dendrology methods: tree height, crown base height, stem diameter, average diameter.

## 3. Methods

- **Digital Terrain Model and Canopy Height Model (CHM):** Using two LiDAR datasets two Digital Terrain Models (DTM) were created: using a window size of 5x5 m from sparse data and 4x4 m from dense data to select points with minimum elevations. The CHM was calculated by substracting the DTM from LiDAR point heights, so the point clouds were normalized from the DTM. CHM were created as a continuous grid surfaces that represented tree heights with maximum available resolution: 0.5x0.5 m from dense and 1x1 m from sparse data.
- **Crown shape and crown area:** Two different strategies were applied to identify crown shape: 1) raster data analysis - using the polygons derived from slicing a CHM raster at 0.5 m height, 2) raw data analysis -using the circular buffer zone around the tree centroid. In strategy 2) a radius of each buffer zone was defined as half of the distance to the nearest tree centre. In each buffer zone, using only LiDAR points with the height over 0.5 m, a minimum bounding polygons were created.
- **Tree height, crown base height and average crown diameter:** Some crown metrics were calculated for LiDAR points inside the crown shape polygons from both strategies to obtain tree height and crown base height. The average crown diameter was obtained as a mean of two diameters of crown shape polygon: the longest one and the perpendicular to this diameter.
- **Influence of tree size on the accuracy of results:** Measured stem diameter was considered as a tree size indicator to divide trees into two groups: medium (stem diameter smaller than 25 cm) and large (stem diameter larger than 40 cm). The Mann Whitney U test was performed, to test the similarity of results accuracy between both groups. A linear regression between the stem diameter and the accuracy of each parameter was also determined.

## 4.1 Results
### Crown shape and crown area

For majority of trees the crown contours obtained with different strategies are similar to each other. The dense LiDAR data allowed to determine more consistent crown shapes between the two strategies than the sparse dataset. Moreover with sparse dataset, for some trees it was impossible to obtained the reliable tree crown using strategy 2) (too few points detected).

The areas determined with both strategies for dense LiDAR dataset were close to each other – the standard deviation of differences was 1.7 m². However, there was a clear systematic error between the solutions – the mean difference between strategy 1) and 2) was -3.9 m², which means that areas determined with CHM raster slicing were larger than with minimum bounding polygon. The strategy 2) failed for sparse data analysis, because the areas were significantly underestimated comparing to other solutions. For sparse dataset much better results were obtained from raster analysis . When comparing the results of strategy 1) for sparse and dense data, a small bias was found (0.5 m²), but the standard deviation was relatively large (5.2 m²).

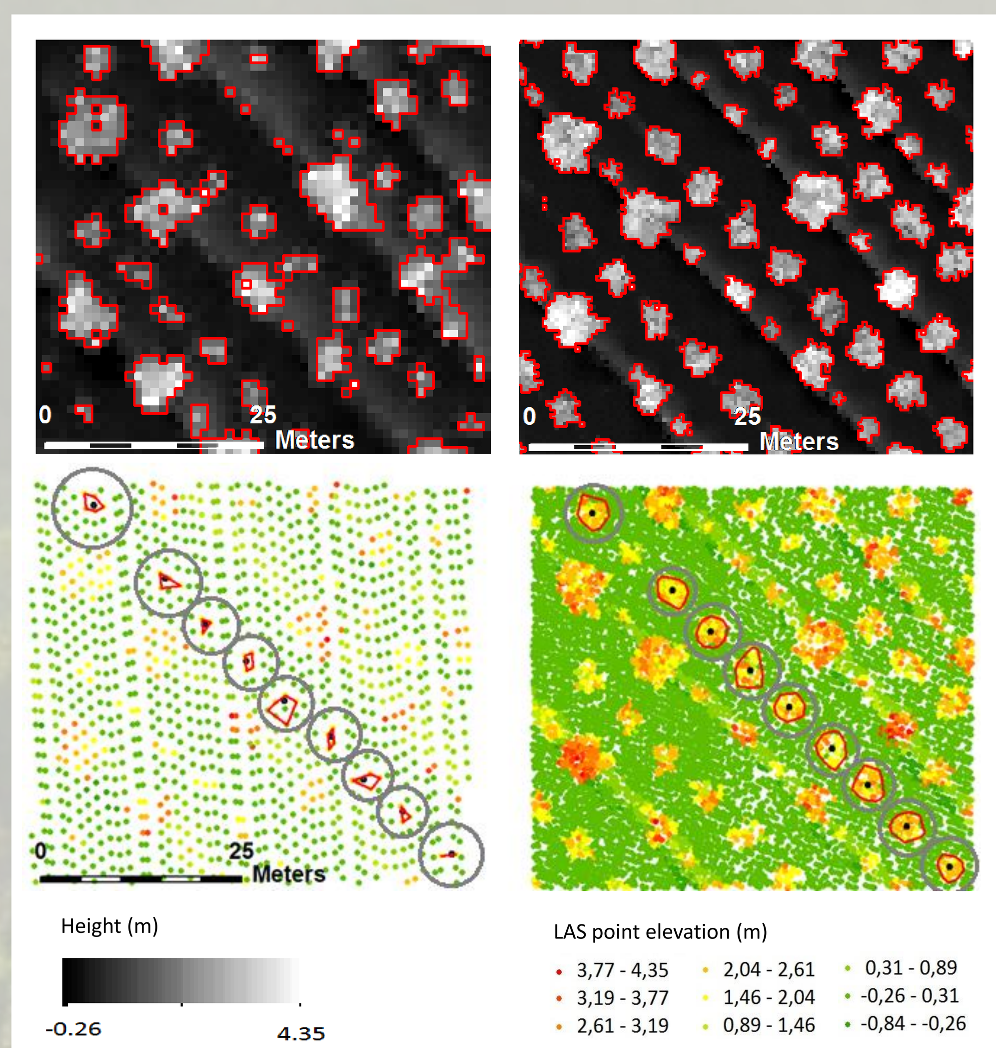


Figure 1. Strategy for determining tree crown: CHM sliced polygons (top) and minimum bounding polygons for sparse (left) and dense (right) dataset

The Mann Whitney U test showed that for raw data analysis the results are different between both datasets, but for strategy 1) the estimated crown area did not depend on dataset density.

Table 1. The p-values of Mann-Whitney U test for similarity of results between datasets of different density

| Density of sample 1 [pt./m²] | Density of sample 2 [pt./m²] | Number of trees | p-value for raster data | p-value for raw data |
|---|---|---|---|---|
| 0.5 | 3.5 | 12 | 0.862 | 0.002 |
| 0.5 | 9 | 13 | 0.143 | 0.000 |
| 0.5 | 3.5 and 9.0 | 25 | 0.177 | 0.000 |

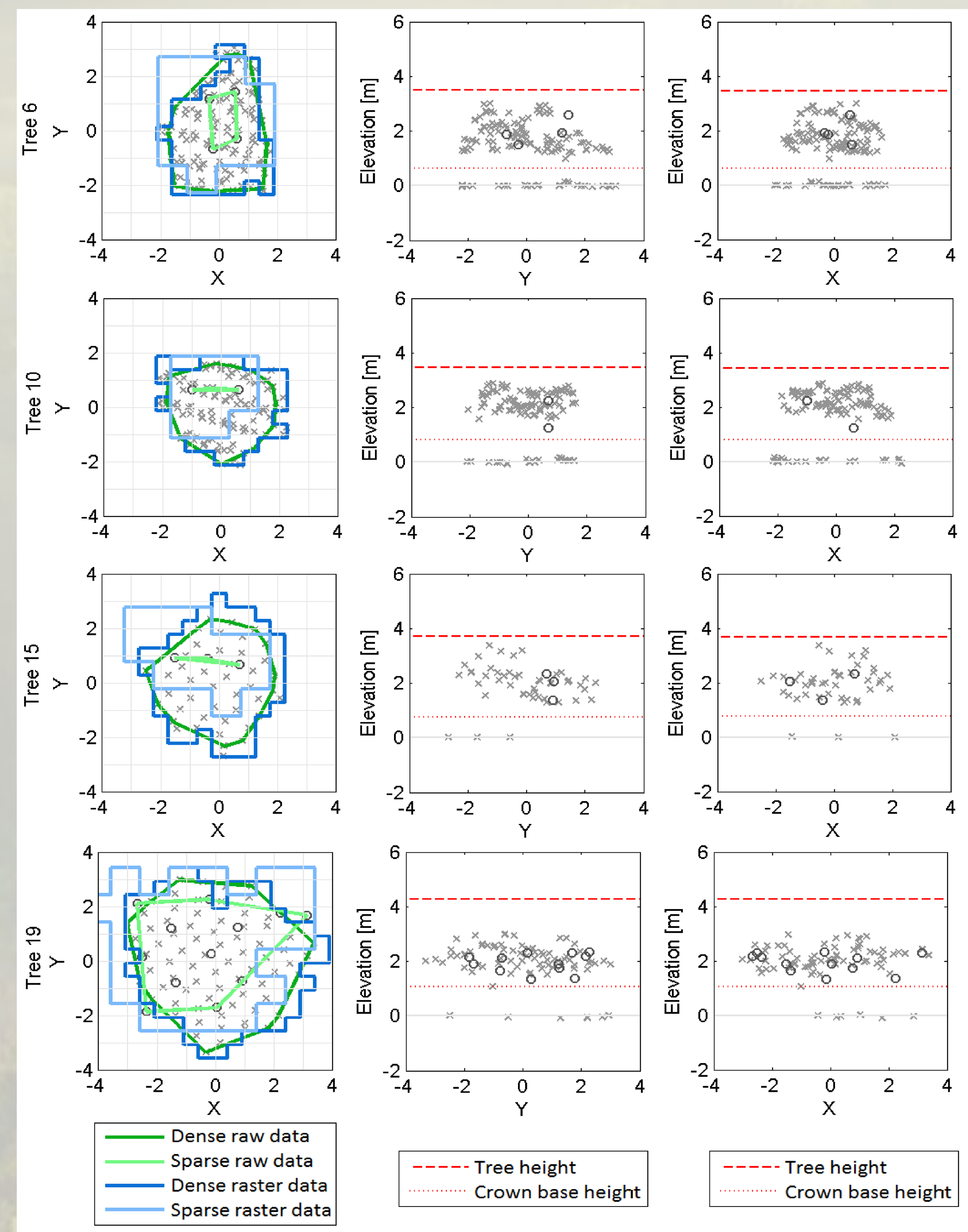


Figure 2. Projections of LiDAR points (grey circles for sparse dataset, grey crosses for dense dataset) within the area of a tree; crown shapes from various methods are presented on top view (left column); X=0 and Y=0 coordinates represents the location of a reference tree center

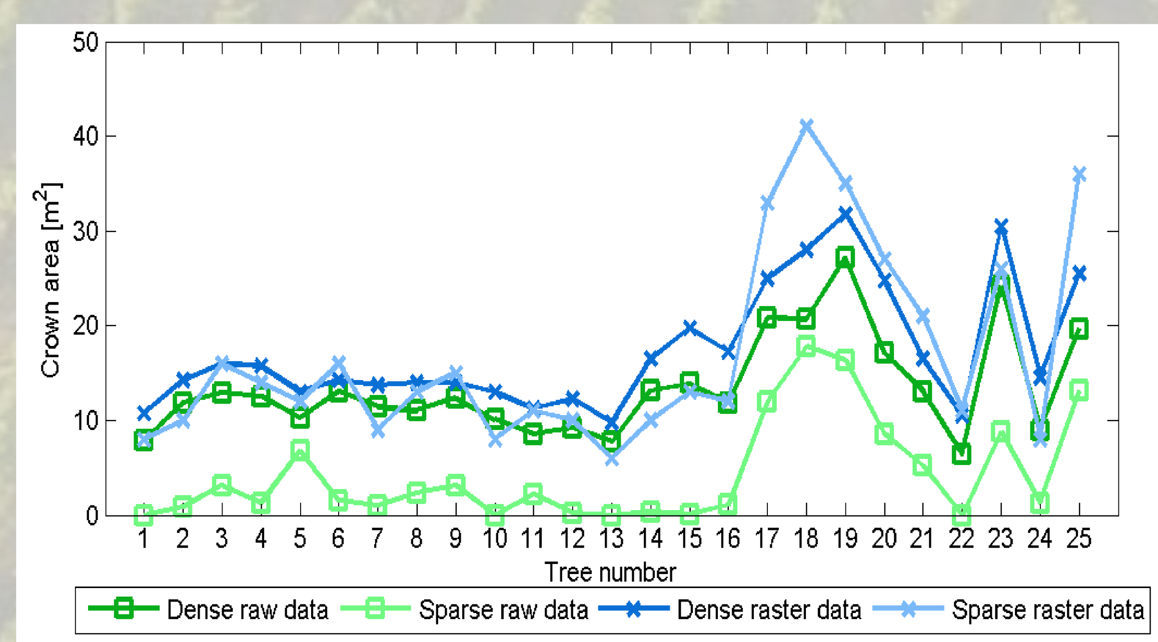


Figure 3. Estimated tree crown area

## 4.2 Results
### Tree height, crown base height, average diameter

Both strategies returns very similar tree heights and crown base heights. Tree heights were underestimated with respect to field measurements and the errors were larger for sparse dataset than for dense dataset. Crown base heights were usually overestimated and the errors were larger for sparse dataset too.

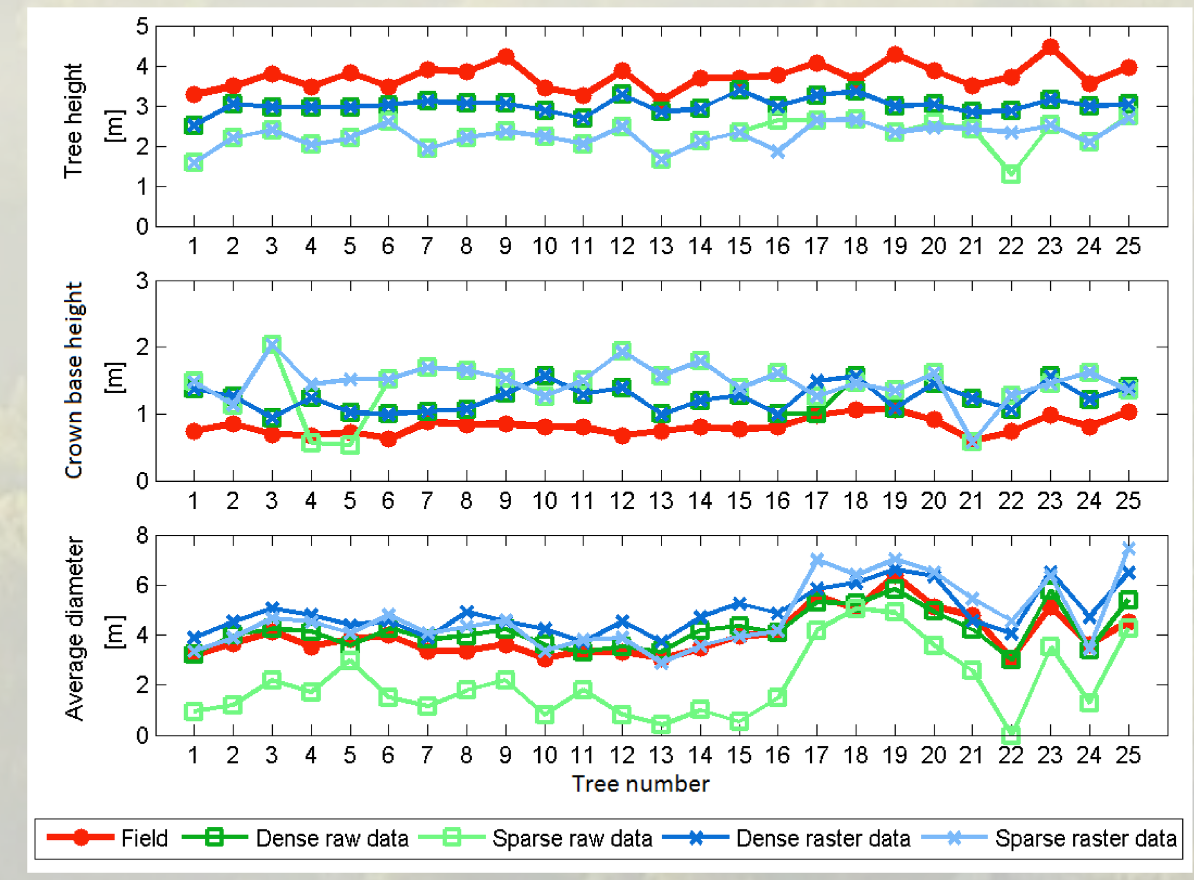


Figure 4. Values of tree height, crown base height and average crown diameter obtained from field measurements and estimated from LiDAR data

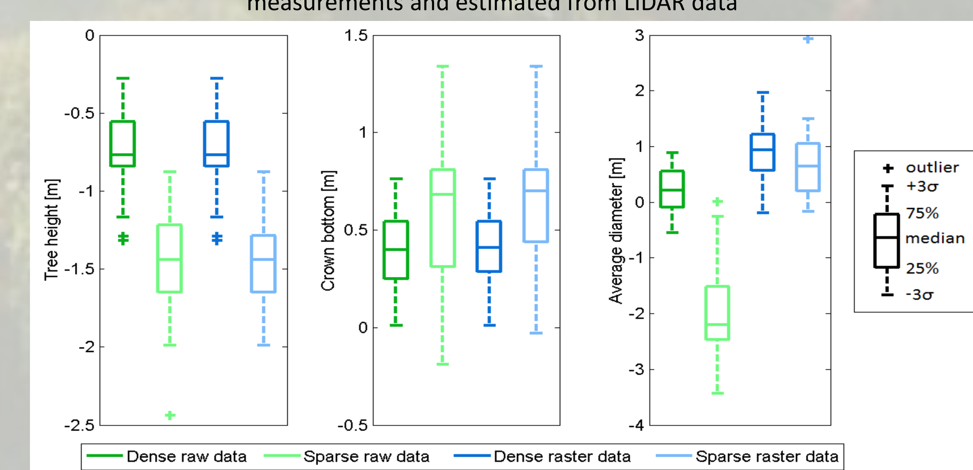


Figure 5. Boxplots of differences between estimated and field measurement heights, crown base heights and average crown diameter

Table 2. The p-values of t-test for the similarity of results between dense and spars datasets

| Tree parameter | Raster data | Raw data |
|---|---|---|
| Tree height | 0.000 | 0.000 |
| Crown base height | 0.000 | 0.003 |
| Average crown diameter | 0.240 | 0.000 |

The estimated length of average crown diameter varies between the strategies and datasets. Poor results were obtained with strategy 2) and sparse dataset, that corresponds to the poor results in crown area estimation. In contrast, strategy 2) provided the most accurate results for dense dataset. Strategy 1) provided more similar results for both datasets.

A paired sample t-test showed, that the values of estimated tree heights, crown base heights and average crown diameters were different between strategies, except the results for average crown diameter in strategy 1). This exception corresponds to the result obtained for crown shape area determination, where it was shown, that for raster analysis, the estimated crown area did not depend on dataset density.

## 4.3. Results
### Influence of tree size on the accuracy of results

Table 3. The p-values of Mann-Whitney U test and determinations coefficients $R^2$ for the relation between stem diameter and the accuracy of estimated parameter

| Parameter | dataset | Raster data | | Raw data | |
|---|---|---|---|---|---|
| | | p-value | $R^2$ | p-value | $R^2$ |
| Tree height | dense | 0.08 | 0.13 | 0.080 | 0.13 |
| | sparse | 0.977 | 0.00 | 0.190 | 0.03 |
| Crown base height | dense | 0.748 | 0.00 | 0.683 | 0.10 |
| | sparse | 0.005 | 0.35 | 0.044 | 0.11 |
| Average crown diameter | dense | 0.683 | 0.07 | 0.190 | 0.15 |
| | sparse | 0.023 | 0.18 | 0.290 | 0.19 |

In both strategies the crown base height accuracy was dependent on tree size (for larger trees the crown base heights were more accurate). A significant dependency was also noticed for the relation between tree size and average crown diameter accuracy for sparse data analysis using strategy 1). However, this was not confirmed by determination coefficient. In every other case, the accuracy of estimated parameter occurred not to be related with the size of a tree.

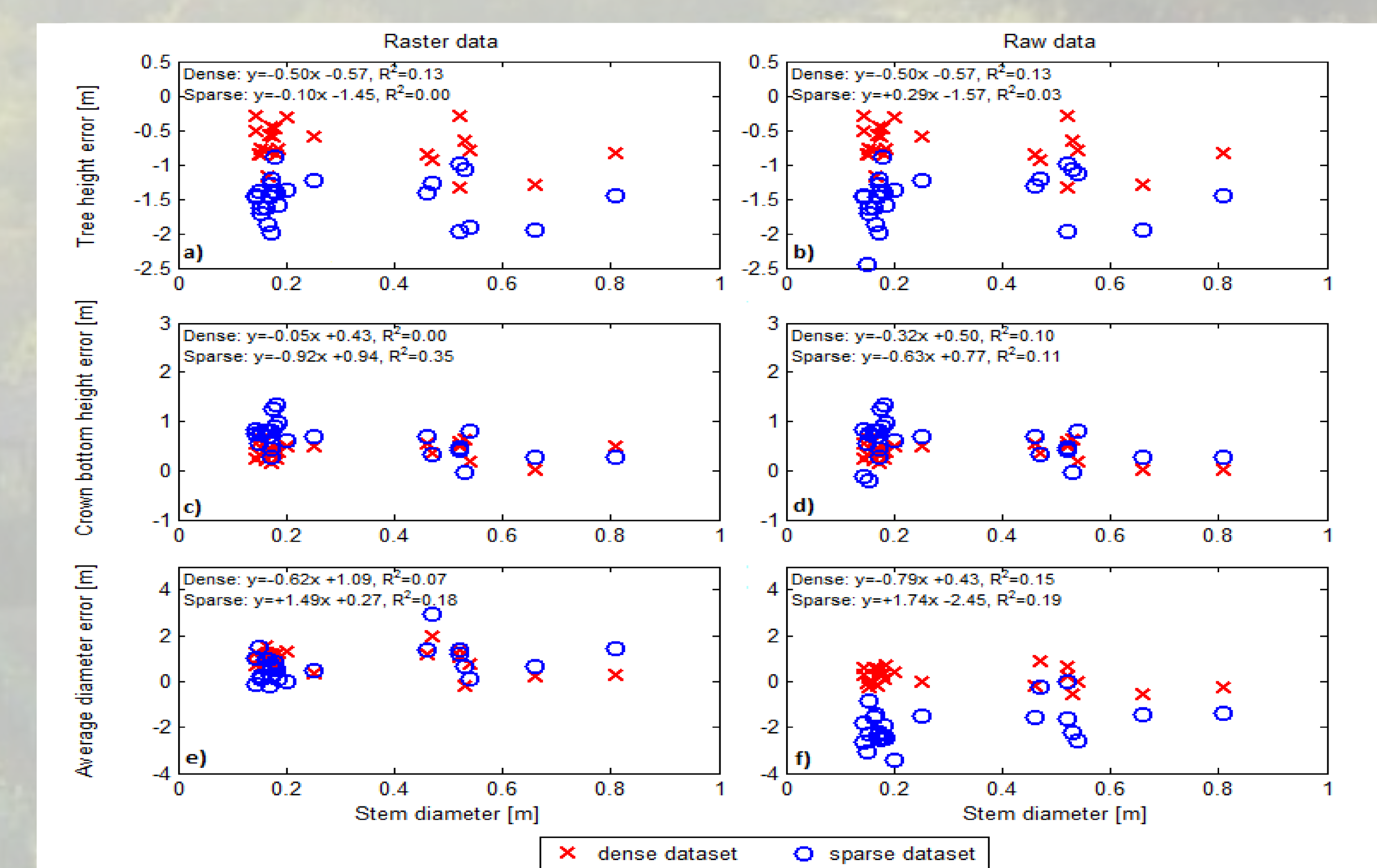


Figure 6. Relation between measured stem diameter and error of estimated tree parameters for two strategies and two LiDAR datasets; a linear regression model and $R^2$ are presented in top left of each plot

## 5. Conclusions

The parameters estimated from dense LiDAR data were more accurate than the ones obtained from sparse LiDAR data analysis. These differences were especially noticed for tree height and crown base height estimation. For crown shape area and average crown diameter the choice of a strategy was important. When processing dense dataset, the raw data analysis provided the most accurate results. The results from raster analysis strategy were slightly biased (the average crown diameters were overestimated) and slightly less accurate. However, the raw data analysis resulted in a very poor determination of crown shape area and average crown diameters for sparse data. This effect was overcome with raster data analysis strategy, by which the results from sparse and dense dataset do not differ statistically. This is an important finding, showing that low density LiDAR data may be useful for some agricultural management purposes.

It was shown that the accuracy of estimated parameters do not depend on tree size. The only exception was found for crown base heights obtained from sparse dataset. In this case the results were slightly more accurate for large trees, but it should be reminded here that the accuracy of these results was very poor anyway.


**ACKNOWLEDGEMENTS:** The authors appreciate the financial support provided by the Vice-Rectorate for Research of the Universitat Politècnica de València [Grant PAID-06-12-3297; SP20120534].