YIELD ESTIMATION FOR AVOCADO USING SYSTEMATIC SAMPLING TECHNIQUES

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Abstract
Avocado is a high value crop ranking fourth among the planted fruit species in Chile with more than 32,000 ha.
Yield estimation is an important challenge in avocado due to its phenology, the size of the tree, and to the large variability usually observed within the orchards.
Due to the practical difficulties to sample the trees we use the following approach: 1) establish a systematic, non-aligned grid with > 20 sampling points (trees)/field, 2) previous to harvest, and once the fruit has reached the commercial size, all the fruits are removed from the tree, sorted and weighted, 3) maps are produced using kriging interpolation, 4) yield estimation is performed by field, 4) cross validation is performed by comparing real versus estimated yield. Extracted fruit weight are added to the total weight to calculate the “true” yield.
Results showed that the approach produced very close estimations of the actual yields with errors < 9%. The maps made it possible to identify the areas of lower yield, mainly at the border of the fields, caused in part “non agronomic” losses. With this information it is possible to focus management strategies to try to reduce fruit losses. Using high resolution satellite imagery to establish homogeneous vigor zones, “non agronomic” fruit losses were estimated to be as high as 30%.

Keywords: Avocado, yield estimation, mapping, fruit losses

1. INTRODUCTION

Avocado (*Persea americana Mill.*) orchards in Chile occupy approximately 32,636 hectares, where 3631 ha (11,1%) are cultivated in the O'Higgins region (Ciren, 2021). At the world level, the avocado production reaches ~ 5,5 million tons, where the main producers are Mexico, Perú, Colombia, and Dominican Republic (Odepa 2018). During the 2021/2022season, Chile exported near 10.6 million boxes of avocado (Chilean avocado committee, 2022). The main avocado variety is Hass, with approximately 29,300 ha. Avocado production requires a precise management in terms of irrigation, fertilization, pruning, and phytosanitary controls (Dejean, 2021). Yield estimation is a very relevant activity in the production and marketing of avocado. With the fruit production forecast it is possible to plan ahead the purchase of boxes and packing materials, make the reserves for shipping space; hire personnel and packing services, etc. For this, various estimates are made during the vegetative cycle, which are quite erratic, given the variability that exists between the trees. Yield components are number of trees per hectare, number of fruits per tree and fruit weight.

2. MATERIALS AND METHODS

2.1 Location

The study was performed at the Peumo commune (Rapel Valley, Chile) located at the coordinates 34º20'30.42'' South and 71º15'52.74'' West. The study area corresponds to a semi-arid, Mediterranean region, with a temperate climate with temperatures in the range of 5.5 to 27.6 ºC, while precipitation varies between 400 and 420 mm yr^{-1}. The soil belongs to the order Mollisol, which presents a silt loam texture, neutral pH, low organic matter content (~2%), and medium fertility.

2.2 Plant material and growth conditions

The four avocado orchard fields (*Persea americana mill.*), corresponded to the Hass variety (on mexicola rootstock) established in two densities: low density (473 plants ha^{-1}), fields 1 and 4, and high density (946 plants ha^{-1}), fields 2 and 3. The orchard was drip-irrigated with a double drip line with 6 drippers per plant (0. 8 mm ha^{-1} $hour^{-1}$). Wind machines are used as frost control, which turn on when the temperature reaches 2.5 Celsius degrees.

2.3 Experimental design

A systematic, non-aligned grid with ~ 20 sampling points (trees)/field was established at each field, before harvest, and once the fruit had reached its commercial size. All the fruits were removed from the tree, counted, and individually weighted. Fruits were sorted and classified into 9 size categories.

Yield was estimated, by field, using the yield component approach, as follows:

$$Yield\left(\frac{kg}{ha}\right) = \frac{trees}{ha} * \frac{n°fruits}{tree} * \frac{weight\ (g)}{fruit} * \frac{1kg}{1000g}$$

Number of fruits per tree and weight of fruits were obtained from the samples. Thus, 20 yield points were available at each studied field.
Cross validation was performed by comparing real versus estimated yield. Extracted fruit weight were added to the total weight to calculate the "true" yield.

2.4 Statistical analyses

Maps were produced using kriging interpolation. An omnidirectional linear variogram with all data was used in all cases.
Data were analyzed by descriptive statistics and regression analysis. Besides the observed and estimated fruit size distributions were compared by using the Chi-squared and Kolmogorov-Smirnov tests.
Accuracy of the estimation was calculated as follows:

$$accuracy\ (\%) = \frac{(estimated - observed)}{observed} * 100$$

Sampling efficiency was evaluated by the expected error from the mean:

$e = \sqrt{\frac{t^2 * s^2}{n}}$ and $\%e = \frac{e}{\bar{x}} * 100$

3. RESULTS AND DISCUSSION

Yield variability and estimation

A large spatial variability in terms of number of fruits per tree, fruit weight, and yield per tree was observed in the four studied avocado fields (Figure 1). Yield was estimated with an overall accuracy varying between 7-9% depending on the statistic used to estimate fruit weight (Table 1). Newer plantations and those with higher densities and more homogeneity had better accuracies. As expected, there was a strong relationship between avocado yields obtained by average and median fruit weight, however, on the average, median produced a yield almost 200 kg/ha higher than that produced by using the mean (Figure 2).

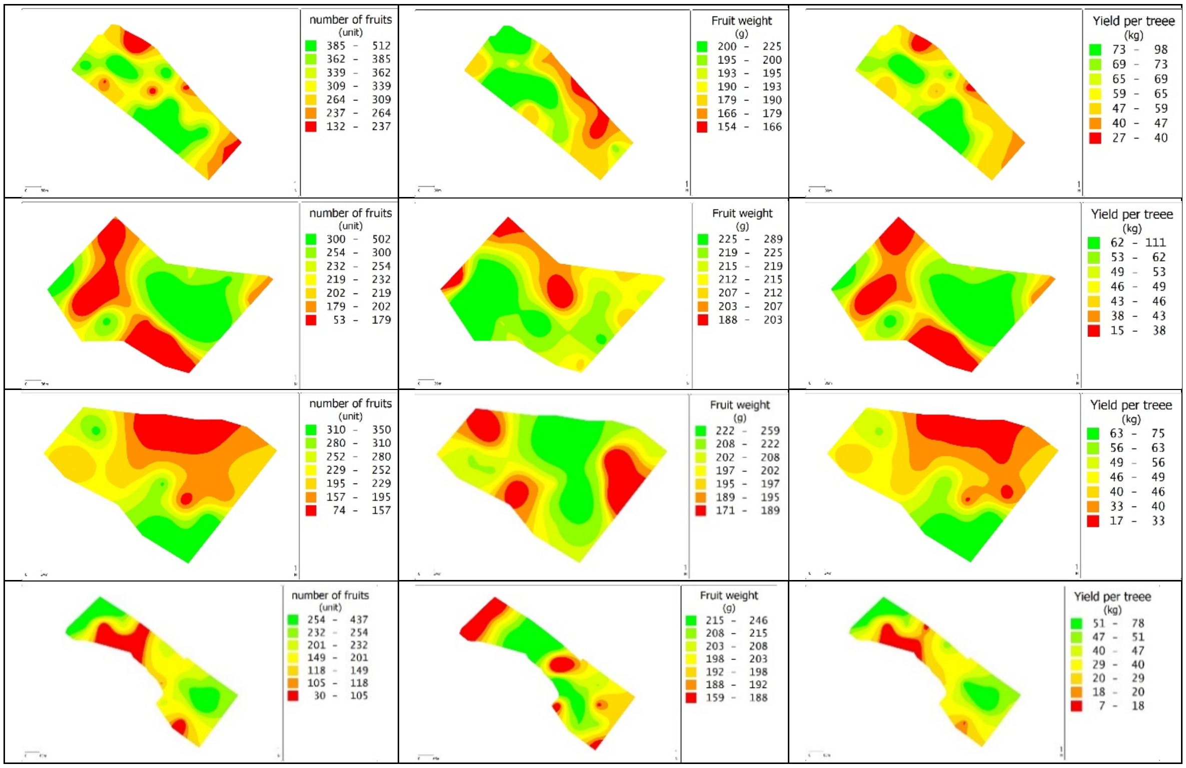

Figure 1. Spatial variability of number of fruits (left), fruit weight (center), and yield per tree (right) in avocado.

Table 1. Yield estimation in avocado considering average and median fruit weight, confidence intervals and accuracy of the estimation.

Field	Statistic	Yield	Lower	Upper	Accuracy
		------------------kg/ha------------			%
1	Average	25729	22219	29239	16
	Median	26120	22591	29649	18
	Real	22145			
2	Average	34684	28714	40653	19
	Median	35102	29059	41145	20
	Real	29252			
3	Average	30121	23315	36927	-4
	Median	30481	23639	37323	-3
	Real	31513			
4	Average	21722	17349	26096	0
	Median	22135	17698	26571	2
	Real	21652			
Overall	Average	28064	25354	30774	7
	Median	28459	25729	31189	9
	Real	26141			

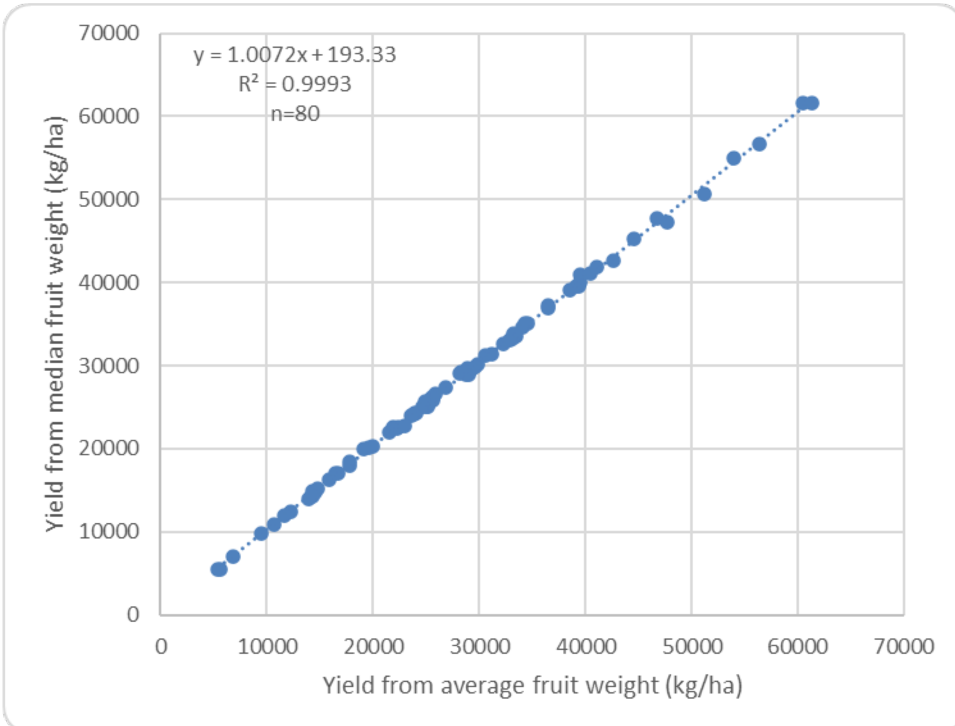

Figure 2. Relationship between estimated avocado yield by fruit average and median weight.

Yield estimation was sensitive only to the variation in the number of fruits per tree but not to the fruit weight (Figure 3). This means that yield could be a function only of the number of fruits per tree, which could be counted by using manual and automatic techniques such as image analysis.

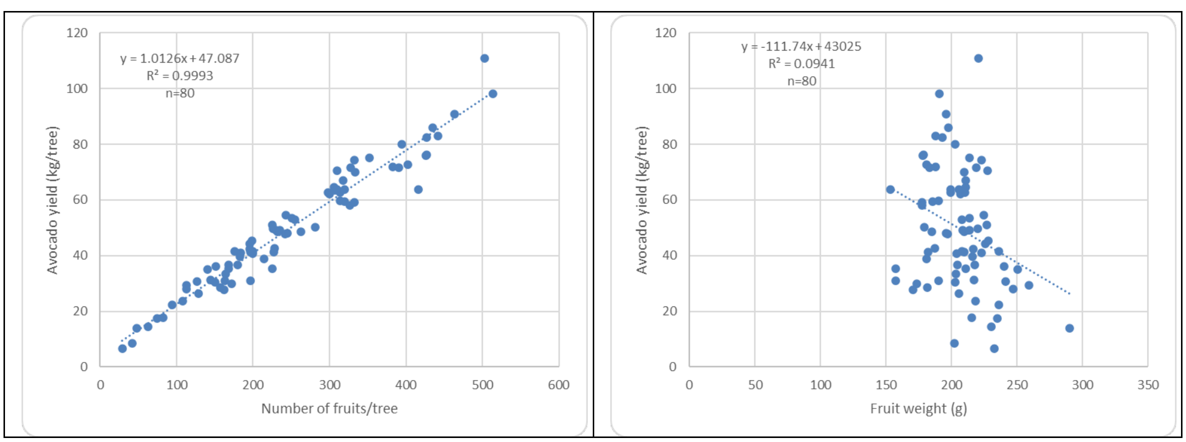

Figure 3. Relationships between number of fruits per tree (left) and fruit weight (right) on avocado yield.

Fruit size distribution

Observed and estimated fruit size distributions were similar (P>0.9) according to the Chi-Squared and Kolmogorov-Smirnov test for equality of distribution functions (Figure 4).

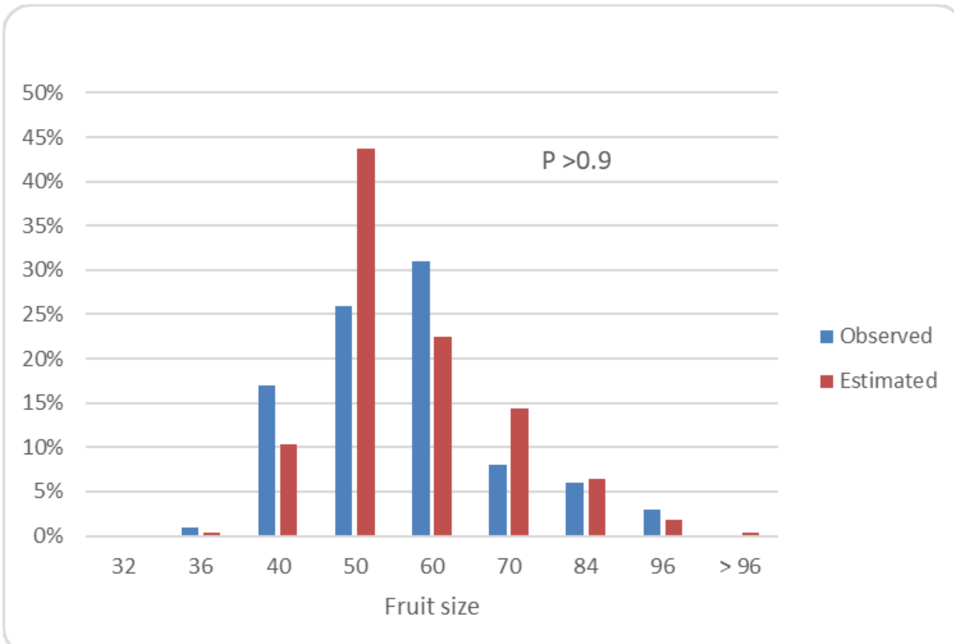

Figure 4. Observed and estimated fruit size distribution in avocado.

Systematic sampling efficiency

Sampling efficiency estimated by calculated error (e) varied with the field and variable measured (Table 2). Overall efficiency was about 3% error for fruit weight and 10% error for number of fruits and yield, respectively. Results indicate that the use of the sampling scheme and the number of samples per field were enough to obtain < 10% error on the average. For fields, given their elevated coefficients of variation, more samples would be needed or else some stratification approach should be used.

Table 2. Sampling efficiency as measured by the estimation error.

Field	Statistic	number of fruits (n°)	Fruit weight (g)	Yield (kg/ha)
1	Variance	10329	328	56242808
(n=20)	Average	336	193	25729
	CV(%)	30	9	29
	t	2.1	2.1	2.1
	e	48	8	3510
	e (%)	14	4	14
2	Variance	6594	590	162683775
(n=20)	Average	211	209	34684
	CV (%)	39	12	37
	t	2.1	2.1	2.1
	e	38	11	5969
	e (%)	18	5	17
3	Variance	9828	568	211503829
(n=20)	Average	188	205	30121
	CV (%)	53	12	48
	t	2.09	2.09	2.09
	e	46	11	6806
	e (%)	25	5	23
4	Variance	13346	455	87331800
(n=20)	Mean	253	219	21722
	CV (%)	46	10	43
	t	2.1	2.1	2.1
	e	54	10	4374
	e (%)	21	5	20
Overall	Variance	12841	558	148252661
(n=80)	Mean	247	206	28064
	CV (%)	46	11	43
	t	1.99	1.99	1.99
	e	25	5	2710
	e (%)	10	3	10

4. Preliminary conclusions

- Systematic sampling with a minimum of twenty samples per field allowed a good estimation for avocado yields.
- Predictions were within 95% confidence intervals in all studied fields.
- Avocado yields are a function mainly of the number of fruits, therefore the task is to find simpler ways of counting them.

5. References

Chilean Avocado Committee (2022). Statistical information on avocado.

Dejean G. et al. (2021). Integración del Procesamiento Imágenes e Internet de las Cosas en la estimación temprana del rendimiento de cultivos frutales. RedUNCI - UNdeC. ISBN: 978-987-24611-3-3 2021

Oficina de Estudios y Políticas Agrarias - Centro de Información de Recursos Naturales (ODEPA-CIREN). (2021). Catastro Frutícola / Principales resultados / Región de O'Higgins.