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Variability in Production of Avocado Trees in a Commercial Orchard in Southern Spain

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Abstract

The productions of 2603 avocado trees along ten years in an orchard of southern Spain have been analyzed. The trees were planted in terraces, with different altitudes, orientations and soil traits. Terrace position significantly affected tree production. Year effects were also statistically significant. The individual tree productions were corrected with both average effects (terrace and year), and ordered from high to low to detect the most productive trees. The irregularity production index, based in the standard deviations of corrected annual productions, which had previously been normalized, was also calculated.

A great variability in terms of production and irregularity in production index could be observed. There was a positive correlation between both indexes and 20 trees could be selected with a high normalized production index.

Introduction

The natural variability shown by seedling avocado rootstocks, due to the high degree of heterozygosis of this species is well documented (Ben-Ya'acov, 1976a; Olalla and Ruiz, 1992). This is particularly true in the case of Mexican rootstocks, whose origin seems to be quite disperse (Ben-Ya'acov 1976b). In practice, this natural variability is the main cause of differences in size and vigour of individual trees, flowering and fruit set capacity and hence, productivity. Most commercial orchards include highly productive trees with others showing either low or very low production capacity. In a commercial orchard of southern Spain, the production of individual trees has been controlled during the last ten years with the following objectives:

- To analyze natural variability in relation with soil traits, tree orientation, etc.
- To select elite trees, for further studies.
- To eliminate trees which have negative effects in orchard viability.

Material and Methods

Description of the orchard.

The orchard is located four kilometers north of the Mediterranean coast, over a series of low hills on the right side of the Vélez River (Málaga province). According to Elias (1977), the climate of this area is a warm-subtropical, and it can be considered as a

Mediterranean subtropical climate.

The different orientations and altitudes of each terrace give rise to different microclimates. The terraces and irrigation system were established during the years 1969-70. Original soils, before land movement, were made up of weathered slates. Following land movements, soils were very heterogeneous, with strong variations in depth and amount of coarse particles (greater than 2 mm). Currently, the combined action of irrigation, fertilization, avocado trees and time, have weathered an important part of these coarse elements. Drainage is generally good, although in specific areas there could be problems for water elimination, due to anomalous soil compaction, or the existence of original layers of clay or rock, near the radicular system. Topographically, the small hills and low areas of the orchard near the streams, arise from a main crest oriented approximately in the east-west direction.

The first area (A zone, table 1) is clearly oriented towards south and it is very well protected from winds due to the presence of two secondary crests in orientations southeast and south, respectively. The second area (B zone) is located between the two secondary crests cited above but clearly exposed to southeastern winds, generally coming from the Mediterranean Sea. The third area (zone C) is clearly exposed to east by southeast winds. The fourth area (zone D) is a relatively high slope exposed to northeastern and southeastern winds. Finally, zone E, is an isolated terrace, well kept from winds, except for the east side.

The establishment of the orchard took place in the period 1971-1975, with the Hass cultivar on seedling rootstocks of Mexican origin. Initially, trees were spaced at 4x4 m or 5x4 m, although currently distances among rows are 8-10 m and distances between trees of the same rows are in the range of 4-8 meters. Orchard management includes traditional practices, *e.g.,* absence of tillage, herbicide treatment when needed, fertilization with 75-100 Kg/ha N and K_2O respectively (irrigation water supplies nitrates) and application of zinc sulfate twice a year.

Flower pruning is carried out when flowering seems to be excessive. Originally, the irrigation system was designed using 12 drippers,(3 $l\ h^{-1}$) per 8 x 8 m tree, but eight years ago these drippers were changed for two microjets (20 l/h and 1.8 m of wet radius) per tree. Water is supplied as function of evaporation of a class A pan, using a 0.5 coefficient to establish the amount of water, although the water supply is modulated by reading of tensiometers located at 25 cm and 50 cm depth. The average daily consumption during the month of maximum water needs is 40-45 $m^3\ ha^{-1}$, with a year consumption of 9000 $m^3\ ha^{-1}$.

Data taken

During the period of 1989-1998, the individual production of 2603 trees were registered yearly. (Preliminary data of the first three years were published by Olalla and Rodríguez, 1992). These trees were distributed in 24 terraces with traits indicated in Table 1.

Analysis of data

In order to compare data of individual trees, the average effects of terrace and year were calculated. After being sure that they were statistically significant, individual tree productions, corrected from the cited effects, were obtained. Finally, productions were normalized (the difference with the average was calculated and it was divided for the standard deviation) for simplification.

An estimate of production irregularity was also carried out, based on standard deviations of annual corrected productions for each tree; thus, these values could be normalized. Following these adjustments, trees could be ordered to select elite trees.

Results

Productions per terrace and years

Firstly, the average productions for the ten years period were calculated as well as the average per terrace. Data are shown in Table 2. This table also shows the terrace effects (average of each terrace minus the general average) and year effects (average of each year minus the general average). The global variance, within a terrace, was decomposed in its different components, *e.g.,* terrace, year and tree, and it was found that the effects of year and terrace were highly significant.

Production and soil surface available per tree

In Table 2, the productions per hectare and the effective planting density (available surface/ tree), per each terrace, is also shown. In Figure 1, the relationship between productions and planting density is shown. The production per tree, when other factors do not change, does not increase in proportion to the available surface, and there seems to be an optimum combination for maximum production (MT/ha) within the range 40-80 m^2 per tree; however, age of trees seems to have an effect (older trees increase their production at higher planting distances). However, global production (Kg/ha) shows a tendency to decrease above 80-90 m^2 per tree.

Production and soil and climate traits

A detailed examination of productions per terrace and year (Table 2) and traits of each terrace (Table 1) shows that higher productions are obtained in terraces with more age, although there are some exceptions. Generally, lower productions are obtained in terraces at higher altitude, although there are also some exceptions. For instance, 20 and 21 are two terraces of high altitude with very similar soil traits (originally it was a simple terrace that was split up in two) and they show an average production of 7 MT/ha, while terrace 9, also of high altitude, but with inferior soil traits, shows 10 MT/ha average production. However, it is necessary to take into account that terrace 9 has two rows of Bacon trees along the northern and southern boundaries (in parallel with the other rows), a circumstance not found in any other terrace, which could have had favorable effects as wind-break and as pollinating agent, explaining this increase in production.

The more productive terraces are generally grouped, although with exceptions, in the A zone (better orientation and protected from strong winds) and the less productive are generally located in areas more exposed to dominant winds, especially those coming from east by southeast (C and D zones).

Evolution of production with time

Another interesting aspect is the evolution of total production with time; it can be observed that there is a stronger tendency to biennial-bearing with age. (Figure 2).

Normalization and analysis of individual tree productions

The terrace and year effects were eliminated of the original data obtaining production data p_{ij} (i as tree subindex and j, year subindex). On this data the average production per tree, the standard deviation of these averages $s(p_i)$ as well as the standard deviation of data per each tree $s_i(p_{ij})$ were calculated. With these parameters, we could first undertake the normalization of p_i (average of each tree for the 10 years period) by obtaining the production of each tree as standard deviation units $s(p_i)$ - Normalised Corrected Production, NCP-, and secondly, assuming that $s_i(p_{ij})$ could be considered as irregularity production index -IPI-(higher interannual variations in production correspond to higher standard deviations), these values could also be normalized. The different normalization parameters were as follows:

- Standard deviation of corrected tree averages $s(p_i)$: 19
- Average of standard deviation values per tree $s_i(p_{ij})$: 18.65
- Standard deviation of values indicated above $s\{s_i(p_{ij})\}$: 40.22

NCP and IPI index have been ordered from high to low, to detect elite-trees. Data are shown for those trees showing production 2.5X standard-deviation values (Table 3), with those of very low production and a few selected intermediate production trees. There are clearly outstanding trees with average productions up to 6X the standard deviation above the general average. Distribution of these values is shown in Table 4. There are really only a few outstanding trees; moreover, there is a close association of higher production with higher IPI. A cross classification, through frequency intervals between both indexes are shown in Table 4. Most trees are in central intervals (1498 trees), and the distribution is clearly asymmetric, elongated towards the positive values. This could be a consequence of the continuous tree selection that has been carried out in this orchard with elimination of low production trees. Elite trees are not distributed at random, but in specific terraces, mainly those holding older trees. This suggests that due to the very different origins of seeds used those years (1970's) genetic variability was higher.

Conclusions

- It is clearly shown that single tree productivity as well as productivity referred to occupied surface, depends upon multiple factors, *e.g.:*
    - Rootstock traits, in terms of adaptation to soil conditions.
    - Orientation and exposure to dominant winds.
- There has been detected a great variability in production; moreover, average productions are mainly affected by wind exposure and factors related to inferior soil traits (low depth, stoniness, etc.). Under extreme circumstances, these factors reduce production to half of that obtained under good conditions.
- After correcting production for terrace effects (supposedly, including soil and environmental effects), a great concentration of average values is observed, while outstanding trees show a strong tendency for irregular production. There

are 20 trees with normalized yield greater than 2.9.

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Table 1. Some characteristics of the terraces

Nr	Zone	Orien-tation	Exposure to winds (High-average-low)	Altitude (meters above sea level)	Plantation date	Soil Characteristics
1	A	SE	l	40	1985	standard(1)
2	A	SE	l	45	1975	standard
3	A	S	l	50	1975	standard
4	A	S	l	52	1975	depth <60 cm
5	A	S	h	70	1975	depth <60 cm
6	A	S	a	65	1975	depth <60 cm
7	A	S	l	60	1975	standard
8	A	S	l	55	1975	standard
9	A	all	h	77	1978	stony
10	B	SO	h	60	1978	standard
11	B	S	l	62	1975	standard
12	B	O	a	67	1975	depth <60 cm
13	B	all	h	68	1975	depth <60 cm
14	B	SO	a	65	1975	depth <60 cm
15	B	O-S-E	l	72	1975	standard
16	C	E	a	68	1978	standard
17	C	O-S-E	l	65	1978	standard
18	C	O-S-E	a	70	1978	standard
19	C	O-S	h	75	1978	standard
20	C	all	h	72	1980	standard
21	C	T	h	72	1980	standard
22	D	NO	h	83	1980	standard
23	D	O	a	80	1980	depth <60 cm stony
24	E	E	l	75	1985	standar

(1)depth>60cm, % (particles>2 mm)<20

TABLE 2. AVERAGE TERRACE AND YEAR PRODUCTIONS

	Nr of	MEAN Kg/TREE											Terrace	Surf.		
Terr.	trees	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	Averg.	effects	(Ha)	T/Ha	m2/tree
1	181	8.8	20.5	36.1	20.7	13.8	0.0	0.0	38.4	53.4	101.8	**29.3**	-17.70	0.73	7.28	40
2	218	28.9	31.4	69.0	56.6	87.8	88.9	48.1	149.3	32.3	201.8	**79.4**	32.36	1.64	10.56	75
3	88	29.0	21.0	56.8	47.6	67.9	22.6	31.9	88.1	25.5	90.3	**48.1**	1.03	0.61	6.94	69
4	41	14.8	61.9	38.6	104.7	75.3	11.0	59.0	129.8	29.2	204.7	**72.9**	25.83	0.38	7.86	93
5	51	26.9	43.3	52.2	83.2	66.1	52.3	19.1	98.3	38.6	142.1	**62.2**	15.17	0.43	7.38	84
6	62	13.9	45.3	53.0	78.7	38.7	34.3	30.8	136.1	15.5	205.2	**65.2**	18.10	0.51	7.92	82
7	64	19.5	40.3	33.2	84.3	37.7	35.3	22.8	100.8	23.8	101.1	**49.9**	2.81	0.51	6.26	80
8	61	25.3	57.2	51.8	94.2	60.4	40.5	29.1	94.1	27.3	147.4	**62.7**	15.69	0.41	9.33	67
9	165	42.8	66.7	42.7	91.9	99.1	92.3	49.1	102.9	31.4	105.3	**72.4**	25.39	1.18	10.13	72
10	17	10.9	21.5	86.8	35.9	105.3	113.1	16.1	22.3	80.4	194.3	**68.7**	21.61	0.07	16.67	41
11	75	17.2	46.8	29.7	55.3	55.9	56.7	28.0	76.0	14.7	50.6	**43.1**	-3.96	0.49	6.60	65
12	103	20.0	31.4	48.1	50.3	44.4	43.3	14.2	57.6	17.4	60.0	**38.7**	-8.37	0.45	8.85	44
13	6	29.8	23.2	74.7	98.7	52.0	55.7	55.2	222.7	25.3	197.0	**83.4**	36.37	0.05	10.01	83
14	29	17.9	28.6	53.6	43.2	73.3	49.5	15.9	19.1	33.8	55.1	**39.0**	-8.06	0.15	7.54	52
15	163	14.7	15.3	48.1	56.7	54.0	33.3	29.0	71.4	8.6	82.4	**41.3**	-5.70	1.06	6.36	65
16	91	13.8	27.5	50.8	57.1	85.7	65.9	36.6	111.5	43.9	122.5	**61.5**	14.48	0.82	6.83	90
17	86	15.7	37.4	48.1	46.4	75.1	60.2	24.4	92.5	10.3	157.5	**56.8**	9.71	0.87	5.61	101
18	91	21.2	13.1	77.0	48.9	79.8	41.3	18.8	93.6	22.7	108.8	**52.5**	5.48	0.68	7.03	75
19	131	9.9	15.4	60.6	59.1	67.9	42.6	13.3	72.7	18.8	100.1	**46.0**	-1.01	0.74	8.15	56
20	184	9.8	12.7	14.5	30.4	60.8	17.1	13.1	27.1	16.6	60.1	**26.2**	-20.82	0.70	6.90	38
21	239	18.2	23.2	16.3	22.3	72.8	28.1	23.9	49.9	15.9	54.6	**32.5**	-14.54	1.10	7.06	46
22	113	6.8	10.1	21.5	17.0	36.2	19.4	3.4	19.8	25.0	22.3	**18.2**	-28.89	0.50	4.10	44
23	63	7.4	7.1	45.5	25.2	40.5	19.8	5.8	33.7	33.5	53.4	**27.2**	-19.86	0.13	13.18	21
24	281	8.5	34.0	62.1	9.8	47.2	31.4	33.3	74.3	14.4	113.7	**42.9**	-4.19	1.12	10.75	40
Means	2603	**17.4**	**29.0**	**45.3**	**45.9**	**61.3**	**41.2**	**25.5**	**76.5**	**24.4**	**104.0**	47.1	(*)0.00	**15.33**	**7.99**	**59**
Year effects		**-29.65**	**-18.05**	**-1.75**	**-1.15**	**14.25**	**-5.85**	**-21.55**	**29.45**	**-22.65**	**56.95**	0.00				

(*) Weightered mean with number of the trees

Table 3. Some examples of normalized corrected productions (NCP high, intermediate, low) and irregularity production index (IPI)

Terr.	Tree	NCP	IPI	Terr.	Tree	NCP	IPI	Terr.	Tree	NCP	IPI
2	210	6,0	5,7	15	54	0,1	-0,5	2	201	-2,5	0,0
2	20	5,5	7,1	22	52	0,1	-0,4	9	36	-2,5	-0,3
6	14	4,9	2,7	14	24	0,1	-0,1	9	58	-2,5	-0,4
9	14	4,4	5,0	20	109	0,1	-1,3	2	137	-2,5	-1,0
2	211	4,4	3,4	1	179	0,0	0,0	5	3	-2,5	-1,0
5	17	4,2	2,1	24	20	0,0	-0,4	6	54	-2,5	-1,3
14	12	4,2	2,1	22	73	0,0	-0,2	5	2	-2,5	-1,3
2	50	4,1	2,7	12	47	0,0	0,3	9	154	-2,6	-0,1
12	46	4,0	5,1	3	2	0,0	0,3	9	68	-2,6	-0,3
6	12	3,8	3,8	11	19	0,0	-0,2	2	86	-2,6	-0,2
12	53	3,8	2,0	23	33	0,0	-1,5	2	102	-2,6	-0,8
19	45	3,7	1,9	2	181	0,0	2,1	2	131	-2,6	-0,7
9	83	3,6	2,3	....	....	....	....	5	1	-2,6	-0,9
8	36	3,6	4,1	24	105	0,0	-1,0	8	3	-2,7	-1,0
17	3	3,6	4,5	3	27	0,0	-0,6	9	18	-2,7	-0,3
15	148	3,5	2,6	21	214	0,0	-1,4	2	82	-2,7	1,4
15	82	3,4	1,7	21	48	0,0	-0,4	9	3	-2,7	0,1
8	38	3,4	2,6	5	11	0,0	0,4	2	6	-2,7	-0,5
2	24	3,2	2,9	8	20	0,0	0,0	9	142	-2,8	0,0
2	59	3,1	4	15	57	0,0	-0,6	4	23	-2,9	0,1
9	65	3,1	3,9	24	214	0,0	-1,1	9	50	-2,9	-0,2
2	117	3,0	2,6	11	26	0,0	0,3	6	62	-3,0	-1,1
9	160	3,0	1,9	19	115	-0,1	0,0	9	95	-3,1	0,1
9	127	3,0	2,2	9	34	-0,1	1,2	9	15	-3,2	-0,3

Table 4. Cross tabulation of number of trees, by Normalized Corrected Production (NCP) and Irregularity Production Index (IPI)

	IPI							
NPC	-1	0	1	2	3	4	5	7
-3	1	2						
-2	5	39	2					
-1	38	28 4	11	1				
0	21 4	14 98	14 9	33	5	1		
1		13 1	66	31	10	2		
2			13	15	20	9		
3			3	5	2	3	1	
4				4	1		1	
5							1	1